ECEN 438/738 – Power Electronics Spring 2025

Lab 8: AC-DC Rectification: Single Phase

Lab 8: AC-DC Rectification: Single Phase

The goal of this lab is to investigate the behavior of a diode-bridge AC-DC rectifier, which is used in all power supplies taking energy from AC sources, like grid utility. First, we review the principle of operation of a diode-bridge AC-DC rectifier. Next, we simulate the rectifier to analyze the effects of its parameters on voltage and current waveforms. Finally, we perform lab experiments to observe the voltages and currents of a real AC-DC rectifier under different operating conditions.

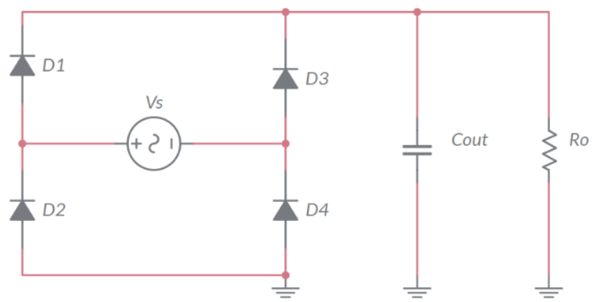


Figure 1-1. Diode-bridge AC-DC Rectifier

Learning Objectives

After completing this lab, you should be able to complete the following activities.

1. Given an AC-DC diode rectifier with specified parameters and an AC source, you will estimate the amplitude of its average DC output voltage and peak-peak AC ripple, with specified units and accuracy, under different output capacitor configurations.
2. Given an AC-DC diode rectifier with specified parameters and an AC source, you will simulate its operation under different output capacitor and AC source inductance, to analyze the effect of system parameters on voltage and current waveforms.
3. Given a real AC-DC diode rectifier with specified parameters and an AC source, you will observe the rectifier voltage and current waveforms and measure the amplitudes of their DC and AC components, with specified units and accuracy, to verify the consistency with simulation results and estimate the system parameters.

Required Tools and Technology

Platform: NI ELVIS III Instruments used in this lab: • Function generator • Digital multimeter • Oscilloscope • Power Supply **Note**: The NI ELVIS III Cables and Accessories Kit (purchased separately) is required for using the instruments.	✓ Access Instruments https://measurementslive.ni.com/ ✓ View User Manual http://www.ni.com/en-us/support/model.ni-elvis-iii.html ✓ View Tutorials https://www.youtube.com/watch?v=TwvbRUpEpJU&list=PLvcPIuVaUMIWm8ziaSxv0gwtshBA2dh_M
Hardware: TI Power Electronics Board	✓ View User Manual http://www.ni.com/en-us/support/model.ti-power-electronics-board-for-ni-elvis-iii.html
Software: NI Multisim Live	✓ Access https://www.multisim.com/ ✓ View Tutorial https://www.multisim.com/get-started/
Software: TI Power Electronics Configuration Utility	✓ Download (Windows OS Only) http://download.ni.com/support/acadcw/PowerElectronics/TIPowerElectronicsBoardUtility-Windows.zip Note: Mac Version will be available soon

Expected Deliverables

In this lab, you will collect the following deliverables:

- ✓ Calculations based on equations provided in the Theory and Background Section
- ✓ Results of circuit simulations performed by NI Multisim Live
- ✓ Results of experiments performed by means of TI Power Electronics Board for NI ELVIS III
- ✓ Observations and comparisons on simulations and experimental results
- ✓ Questions Answers

Your instructor may expect you to complete a lab report. Refer to your instructor for specific requirements or templates.

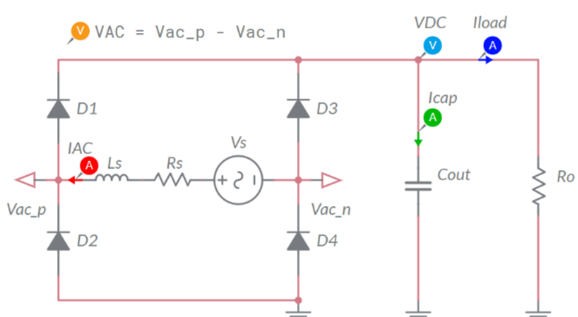
1 Theory and Background

1-1 Introduction

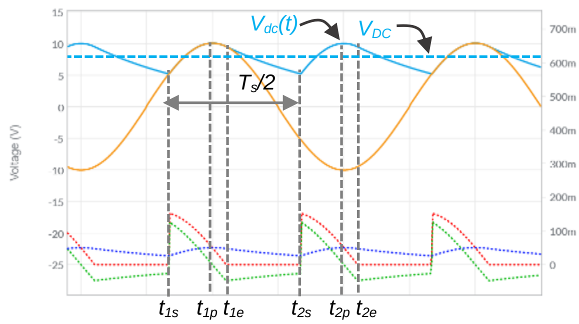
In this section, we review the fundamental concepts relevant to the operation of an AC-DC diode-bridge rectifier. First, we analyze the principle of operation and the resulting voltage and current waveforms. Next, we discuss the effect of AC source parameters and of DC output capacitance.

1-2 Ideal Diode-Bridge Rectifier

Figure 1-2(a) shows the typical configuration of an AC-DC diode-bridge rectifier, taking energy from an AC voltage source $V_s(t) = V_s\sin(2\pi f_s t)$ and supplying a DC load resistor R_o.



(a) AC-DC Diode-Bridge Rectifier



(b) AC-DC rectifier voltage and current waveforms: R_S=400mΩ, L_s=1nH, R_o=200Ω, C_{out}=47nF, f_s=50kHz, V_s=10V, V_F=0V.

Figure 1-2. AC-DC Rectifier.

In this case, the AC voltage $V_{AC}(t)$ applied between the input nodes V_{ac_p} and V_{ac_n} of the diode-bridge, shown as a yellow trace in Figure 1-2(b), is equal to the source voltage $V_s(t)$. When the voltage $V_s(t)$ is positive, diodes D_1 and D_4 may conduct, thus applying the positive voltage $V_s(t)$ to the output capacitor C_{out}, whereas when the sinusoidal voltage $V_s(t)$ is negative, diodes D_2 and D_3 may conduct, thus inverting the voltage $V_s(t)$ and applying the positive voltage $-V_s(t)$ to the output capacitor C_{out}. In this way, the voltage $V_s(t)$ is *rectified,* namely it is converted into a voltage $V_{dc}(t)$ having a major DC component V_{DC} (dashed cyan line in Figure 1-2(b)) and a minor AC ripple component $\Delta V_{AC}(t) = V_{dc}(t) - V_{DC}$, whose fundamental frequency is twice the frequency f_s of the AC source voltage $V_s(t)$. The diodes D_1 and D_4 conduct during the interval $[t_{1s},t_{1e}]$, and stop conducting when the sinusoidal voltage $V_s(t)$ is smaller than the voltage $V_{dc}(t)$ of the output capacitor C_{out}, which is also the voltage of the DC load resistor R_o. Similarly, the diodes D_2 and D_3 conduct during the interval $[t_{2s},t_{2e}]$ and stop conducting when the inverted sinusoidal voltage $-V_s(t)$ becomes smaller than the voltage $V_{dc}(t)$. Over the period $T_s/2$, the output capacitor C_{out} is charged during the interval $[t_{1s},t_{1p}]$, t_{1p} being the instant $V_s(t)$ where the voltage reaches the peak, and discharged in the time interval $[t_{1p},t_{2s}]$. The same happens in the next period $T_s/2$, and so on. The dashed green trace in Figure 1-2(b) shows the capacitor current $I_{cap}(t)$, which is positive during [t_{1s},t_{1p}] and negative during [t_{1p},t_{2s}]. The dashed red trace shows the current of the AC source voltage, which is positive during [t_{1s},t_{1e}] and negative during [t_{1e},t_{2s}]. The dashed blue trace shows the current of the DC load resistor R_o, which is always positive, like the voltage $V_{dc}(t)$. The output capacitance C_{out} determines the DC component V_{DC}. If C_{out} is very small, we have $t_{1s} \cong 0$ and $t_{1e} \cong T_s/2$, and V_{DC} is given by Equation 1-1:

Equation 1-1

$$V_{DC} = V_s \frac{2}{\pi}$$

The non-linear circuit equations of the rectifier do not allow easily determining an exact analytical expression of the DC component V_{DC} and of the amplitude ΔV_{ACpp} of the AC ripple component as a function of system parameters. Nevertheless, simplified equations to estimate the expected values of V_{DC} and ΔV_{ACpp} can be derived as follows. The voltage of the output capacitor is equal to $V_{AC}(t)$ in the interval [t_{1s},t_{1e}]. The sinusoidal AC voltage $V_{AC}(t)$ can be well approximated within the half-wave time interval [0,$T_s/2$] by means of the parabolic function given in Equation 1-2:

Equation 1-2

$$V_{dc}^{(1)}(t) = V_{AC}(t) \cong 8V_s f_s t(1-2f_s t)$$

In the interval [t_{1e},t_{2s}], the voltage of the output capacitor is an exponential function, starting from the value $V_{AC}(t_{1e})=8V_s f_s t_{1e}(1-2f_s t_{1e})$ and decaying with a time constant $\tau = C_{out}R_o$. This exponential function can be well approximated by means of the linear function given in Equation 1-3:

Equation 1-3

$$V_{dc}^{(2)}(t) \cong V_{dc}^{(1)}(t_{1e})(1-(t-t_{1e})/\tau)$$

The two functions given in Equations 1-2 and 1-3 are tangent in the instant t_{1e}, which is given by Equation 1-4

Equation 1-4

$$t_{1e} = \frac{1}{4}\left[T_s - 4\tau + \sqrt{T_s^2 + 16\tau^2}\right]$$

The instant t_{2s} can be determined as the intersection of function given by Equation 1-4 with the function given by Equation 1-2 shifted horizontally right side of $T_s/2$. The resulting expression of the instant t_{2s} is given by Equation 1-5:

Equation 1-5

$$t_{2s} = \frac{T_s}{2} + \frac{-B + \sqrt{B^2 - 4A \cdot C}}{2A}$$

$$A = -16V_s f_s^2 \qquad B = 8V_s f_s + \frac{8V_s f_s^2 t_{1e}(T_s - 2t_{1e})}{\tau} \qquad C = -\frac{4V_s f_s^2 t_{1e}(T_s - 2t_{1e})(2t_{1e} - T_s + 2\tau)}{\tau}$$

The approximated values of DC component V_{DC} and amplitude ΔV_{ACpp} of the AC ripple component are given by the simplified Equations 1-6:

Equations 1-6

$$V_{DC} \cong \frac{V_s + V_{dc}^{(2)}(t_{2s})}{2} \qquad \Delta V_{ACpp} \cong V_s - V_{dc}^{(2)}(t_{2s})$$

The real value of V_{DC} will be higher while the real value of ΔV_{ACpp} will be lower than the the result predicted by Equations 1-6.

1-3 Impact of Diodes Voltage Drop

Figure 1-3 shows the effect of the diodes forward voltage drop V_F on voltage and current waveforms of the AC-DC rectifier. It can be observed that the diodes conduct during the interval $[t_{1s},t_{1e}]$ where $|V_s(t)|>V_{dc}(t)+2V_F$. The diodes voltage drop causes a reduction of $2V_F$ Volts in the DC component of the output voltage.

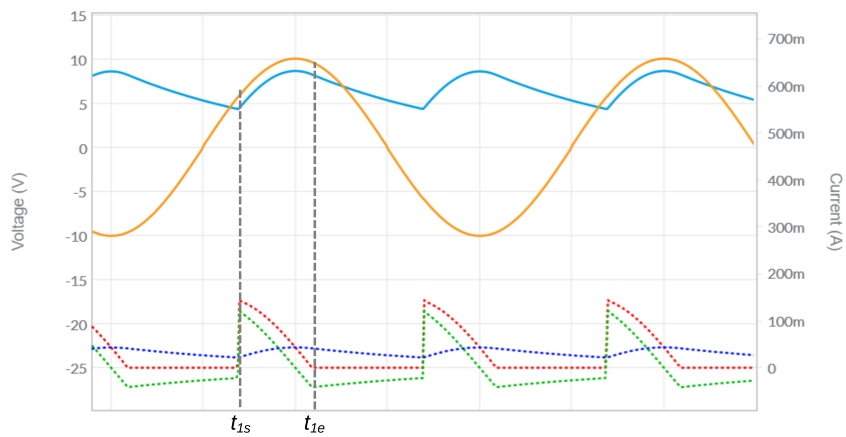


Figure 1-3. Effect of Diodes Voltage Drop on AC-DC Rectifier Waveforms: R_s=400mΩ, L_s=1nH, R_o=200Ω, C_{out}=47nF, f_s=50kHz, V_s=10V, V_F=0.7V.

1-4 Impact of Output Capacitor

Figure 1-4 shows the results obtained by increasing the output capacitance C_{out}. The plots highlight that, as C_{out} increases, the DC component V_{DC} increases, the amplitude ΔV_{ACpp} of the AC ripple component $\Delta V_{AC}(t)$ decreases, the interval $[t_{1s},t_{1e}]$ shortens, and the peak of the AC voltage source increases. If C_{out} gets very big, the DC component V_{DC} is almost equal to the V_s -2V_F and the amplitude ΔV_{ACpp} of the AC ripple component is almost equal to zero. In real applications, the capacitance C_{out} is limited to a value allowing to have an amplitude ΔV_{ACpp} of the AC ripple component about 5% to 15% of the DC component V_{DC}. A DC-DC post-regulator is normally connected to the output of diode-bridge AC-DC rectifiers, to filter the AC ripple $\Delta V_{AC}(t)$ and regulate the DC output voltage suitable for the DC load (see **Lab12**).

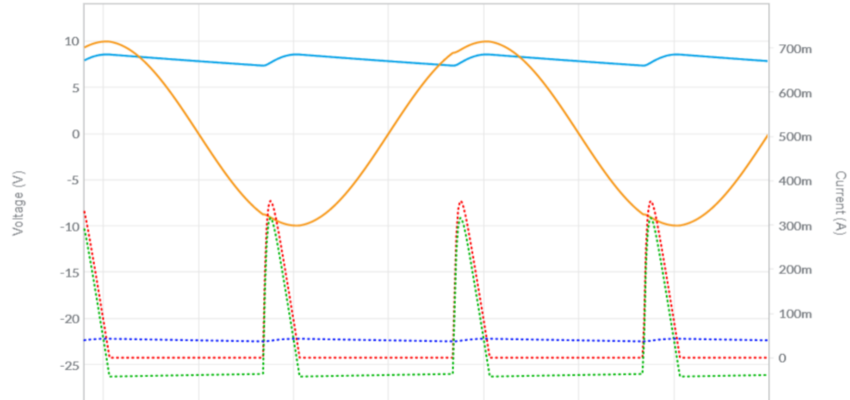


Figure 1-4. Effect of Output Capacitor on AC-DC Rectifier Waveforms: R_s=400mΩ, L_s=1nH, R_o=200Ω, C_{out}=47nF+220nF, f_s=50kHz, V_s=10V, V_F=0.7V.

1-5 Impact of Voltage Source Inductance

Figure 1-5 shows the effect of the source inductance L_s on the voltage and current waveforms of the AC-DC rectifier. Comparing Figure 1-5 with Figure 1-3 allows to observe that, during the interval [t_{1s},t_{1e}], wherein diodes are conducting, the inductance L_s causes a distortion of the AC voltage $V_{AC}(t)$, while smoothing the AC current $I_{AC}(t)$ and the capacitor current $I_{cap}(t)$.

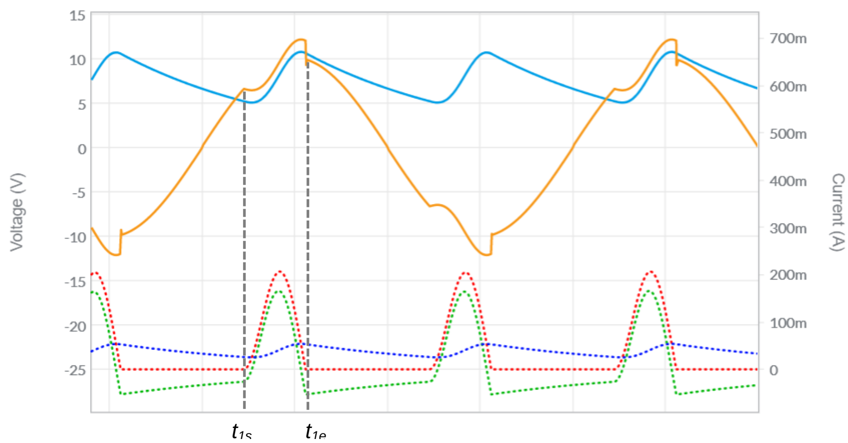


Figure 1-5. Effect of Source Inductance on AC-DC Rectifier Waveforms: R_s=400mΩ, L_s=10µH, R_o=200Ω, C_{out}=47nF, f_s=50kHz, V_s=10V, V_F=0.7V.

The AC voltage $V_{AC}(t)$ during the interval [t_{1s},t_{1e}] is given by Equation 1-2:

Equation 1-2

$$V_{AC}(t) = V_s(t) - 2V_F - R_s\left(C_{out}\frac{dV_{dc(t)}}{dt} + \frac{V_{dc}(t)}{R_o}\right) - L_s\frac{d}{dt}\left(C_{out}\frac{dV_{dc(t)}}{dt} + \frac{V_{dc}(t)}{R_o}\right)$$

Equation 1-2 highlights that increasing the capacitance C_{out} increases the distortion effect of the source inductance L_s, as shown in Figure 1-6.

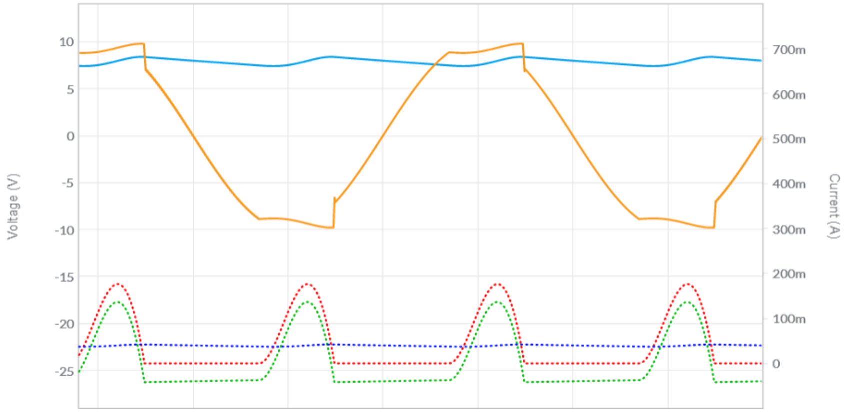


Figure 1-6. Combined Effect of Source Inductance and Output Capacitance on AC-DC Rectifier Waveforms: R_S=400mΩ, L_S=10µH, R_O=200Ω, C_{out}=47nF+220nF, f_S=50kHz, V_S=10V, V_F=0.7V.

Check Your Understanding

Note: The following questions are meant to help you self-assess your understanding so far. You can view the answer key for all "Check your Understanding" questions at the end of the lab.

1-1 What is the function of an AC-DC rectifier?

A. to convert an input voltage into a proportional output voltage
B. to convert a sinusoidal AC voltage into a DC voltage
C. to convert a voltage source into a current source

1-2 What are the factors majorly affecting the DC component and the amplitude of the AC ripple component of the rectifier output voltage?

A. the output capacitance and load resistance
B. the phase of the AC source voltage
C. the frequency of the AC voltage source

1-3 How does the forward voltage drop of diodes impact the rectifier output voltage?

A. it is not influential
B. it causes a decrease of the DC component
C. it causes an increase of the DC component

1-4 What is the effect of AC source inductance on the rectifier operation?

A. a distortion in the output voltage
B. an increase of the DC component of the output voltage
C. a decrease of the amplitude of the AC ripple component of the output voltage

1-5 How does an increase of output capacitance affect the peak current of the AC source?

A. the peak current decreases
B. it is not influential
C. the peak current increases

1-6 How does an increase of the output capacitance affect the DC component and the amplitude of AC ripple of the output voltage?

A. the DC component and the amplitude of AC ripple decrease
B. the DC component increases and the amplitude of AC ripple decreases
C. the DC component decreases and the amplitude of AC ripple increases

2 Exercise

The AC-DC Rectifier Section of the TI Power Electronics Board for NI ELVIS III is characterized by the following nominal parameters:

- V_F = 0.3V@300mA
- R_o = 200Ω
- L_s = 3µH
- R_s = 6Ω

Two connection options are available for output capacitor #1 and #2:

- option (a): C_{out} = 47nF
- option (b): C_{out} = 47nF+220nF

2-1 Assuming the AC source provides a 50kHz-5Vp sinusoidal voltage, use the equations provided in the **Theory and Background** section to evaluate:

- the DC component of the rectifier output voltage, in Volt with two decimal digits of accuracy:

option (a): V_{DC} [V] = _____ **option (b)**: V_{DC} [mA] = _____

- the amplitude of the AC ripple voltage of the rectifier, in Volt with two decimal digits of accuracy:

option (a): ΔV_{ACpp} [V] = _____ **option (b)**: ΔV_{ACpp} [V] = _____

3 Simulate

The goal of the simulations you will perform in this section is to analyze the operation of an AC-DC rectifier. You will observe the AC voltage and current waveforms under different output capacitor setup, to verify the impact of the capacitance on DC and ripple components on the rectifier output voltage, and the consistency of the theoretical model.

3-1 Instructions

1. Open *Lab11 – AC-DC Rectifier Operation* from this file path: https://www.multisim.com/content/BCzmqYVZWKkxG8u23Niho2/lab-11-ac-dc-rectifier-operation/open/
   The circuit schematic for the analysis of the AC-DC rectifier operation is shown in Figure 3-1. The AC voltage is generated by a 50kHz/5V sinusoidal voltage source, with output impedance comprised of 6Ω resistance R_s and 3µH inductance L_s. The switch *SL* allows to add 10µH in series to inductance L_s. The switch *J2* allows to add 220nF in parallel to capacitance C_{out1}, thus enabling options (a) and (b) of the **Exercise** Section. A voltage-controlled source is used to allow AC differential voltage measurement with a single voltage probe.

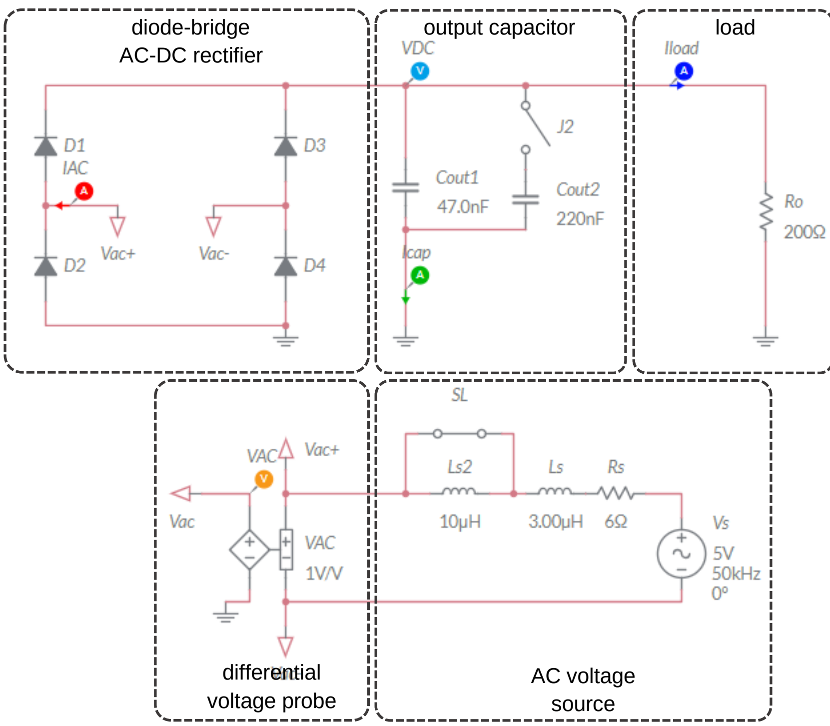


Figure 3-1. Multisim Live Circuit Schematic for the Analysis of the Diode-Bridge AC-DC Rectifier Operation.

3-2 Simulation 1 – AC-DC Rectifier Operation with low source inductance.

1. Set the switch *J2* open and the switch *SL* closed.

2. Set V_S AC voltage source parameters as follows:
   - *VA* = 5.0V, *Freq*= 50k, *VO* = 0, *Phase* = 0, *TD* = 0, *DF* = 0;
3. Set *Interactive* simulation and *Split* visualization options.
4. Double click on probes *VAC*, *IAC, VDC*, *Icap,* and *Iload*, check the *Show plot* option box, and check the *Periodic* option box for *Interactive simulation*.
5. Run the simulation and wait until it stops.
6. In the voltage probe *VDC* measurement box, read the average value V_{AV} and peak-peak value V_{PP}, in Volt with two decimal digits, which provide the DC component V_{DC} and the peak-peak amplitude of the AC ripple component ΔV_{ACpp} of the rectifier output voltage respectively, and report the results in Table 3-1-1 (you may also use Y-axis cursors on trace VDC in the *Grapher* to measure the average value V_{AV} and peak-peak value V_{PP}).
7. In the current probe *IAC* measurement box, read the peak-peak value I_{PP}, in milli Ampère with one decimal digit, which provides the peak I_{ACpeak} of the AC source current, and report the results in Table 3-1-1 (you may also use Y-axis cursors on trace IAC in the *Grapher* to measure the peak value I_{ACpeak}).
8. In the current probe *Icap* measurement box, read the average value I_{AV}, in micro Ampère with one decimal digit, which provides the average capacitor current I_{capDC}, and report the results in Table 3-1-1.
9. In the current probe *Iload* measurement box, read the average value I_{AV}, in milli Ampère with one decimal digit, which provides the average load current I_{outDC}, and report the results in Table 3-1-1.
10. In the current probe *IAC* measurement box, read the average value I_{AV}, in milli Ampère with one decimal digit, which provides the average source current I_{ACDC}, and report the results in Table 3-1-1.
11. Set the switch *J2* closed, and repeat steps 5-10.
12. Import in Table 3-1-1 the values of V_{DC}, ΔV_{ACpp} calculated in the *Exercise* Section for options (a) and (b).

Table 3-1-1 AC-DC Rectifier Operation with 3µH AC source inductance.

	V_{DC} [V] sim.	V_{DC} [V] calc.	ΔV_{Acpp} [V] sim.	ΔV_{Acpp} [V] calc.	I_{Acpeak} [mA] sim.	I_{capDC} [µA] sim.	I_{outDC} [mA] sim.	I_{ACDC} [mA] sim.
option (a) C_{out} = 47nF								
option (b) C_{out} = 47nF+220nF								

3-2-1 Are the results of simulations and calculations consistent?

A. yes

B. no

Please provide your comments: ____

____

3-2-2 Under what condition is the peak of AC source current maximum?

A. option (a)
B. option (b)
Please provide your comments: ____

____

3-2-3 Is the DC load current equal to the DC current of the AC source?

A. yes
B. no
Please provide your comments: ____

____

3-2 Simulation 2 – AC-DC Rectifier Operation with high source inductance.

1. Set the switch *J2* open and the switch *SL* open.
2. Set V_s AC voltage source parameters as follows:
   - *VA* = 5.0V, *Freq*= 50k, *VO* = 0, *Phase* = 0, *TD* = 0, *DF* = 0;
3. Set *Interactive* simulation and *Split* visualization options.
4. Double click on probes *VAC*, *IAC, VDC*, *Icap,* and *Iload*, check the *Show plot* option box, and check the *Periodic* option box for *Interactive simulation*.
5. Run the simulation and wait until it stops.
6. In the voltage probe *VDC* measurement box, read the average value V_{AV} and peak-peak value V_{PP}, in Volt with two decimal digits, which provide the DC component V_{DC} and the peak-peak amplitude of the AC ripple component ΔV_{ACpp} of the rectifier output voltage respectively, and report the results in Table 3-2-1 (you may also use Y-axis cursors on trace VDC in the *Grapher* to measure the average value V_{AV} and peak-peak value V_{PP}).
7. In the current probe *IAC* measurement box, read the peak-peak value I_{PP}, in milli Ampère with one decimal digit, which provides the peak I_{ACpeak} of the AC source current, and report the results in Table 3-2-1 (you may also use Y-axis cursors on trace IAC in the *Grapher* to measure the peak value I_{ACpeak}).
8. In the current probe *Icap* measurement box, read the average value I_{AV}, in micro Ampère with one decimal digit, which provides the average capacitor current I_{capDC}, and report the results in Table 3-2-1.

9. In the current probe *Iload* measurement box, read the average value I_{AV}, in milli Ampère with one decimal digit, which provides the average load current I_{outDC}, and report the results in Table 3-2-1.
10. In the current probe *IAC* measurement box, read the average value I_{AV}, in milli Ampère with one decimal digit, which provides the average source current I_{ACDC}, and report the results in Table 3-2-1.
11. Set the switch *J2* closed, and repeat steps 5-10.
12. Import in Table 3-2-1 the values of V_{DC}, ΔV_{Acpp}, I_{Acpeak}, I_{capDC}, I_{outDC}, I_{ACDC} obtained in the *Simulation 1*.

Table 3-2-1 AC-DC Rectifier Operation with 13µH AC source inductance..

	V_{DC} [V]		ΔV_{Acpp} [V]		I_{Acpeak} [mA]		I_{capDC} [µA]		I_{outDC} [mA]		I_{ACDC} [mA]	
	sim 1	sim 2	sim1	sim2	sim1	sim2	sim1	sim2	sim1	sim2	sim1	sim2
option (a) C_{out} = 47nF												
option (b) C_{out} = 47nF+220nF												

3-2-1 What is the effect of the increase of source inductance on distortion of AC and output voltage waveform?

A. the distortion increases

B. the distortion decreases

C. no effect

Please provide your comments: ____

____

3-2-2 What is the effect of the source inductance increase on output voltage DC component?

A. the DC voltage increases
B. the DC voltage decreases
C. other: ____

____

Please provide your comments: ______________________________

____

3-2-3 What is the effect of the increase of source inductance on the amplitude of the AC ripple component of output voltage?

A. the amplitude of AC ripple voltage increases
B. the amplitude of AC ripple voltage decreases
C. other: ____

____

Please provide your comments: ______________________________

____

Troubleshooting tips:

If the simulation does not converge and you get some error message, reload *Lab11 – AC-DC Rectifier Operation* from this file path https://www.multisim.com/content/BCzmqYVZWKkxG8u23Niho2/lab-11-ac-dc-rectifier-operation/open/ and restart the simulation following the instructions.

4 Implement

The experiments you perform in this section allow you to observe the voltage and current waveforms of a real AC_DC diode-bridge rectifier operation, under different output capacitance configuration. The **AC-DC Section** of the TI Power Electronics Board for NI ELVIS III shown in Figure 4-1 will be used to perform the experiments.

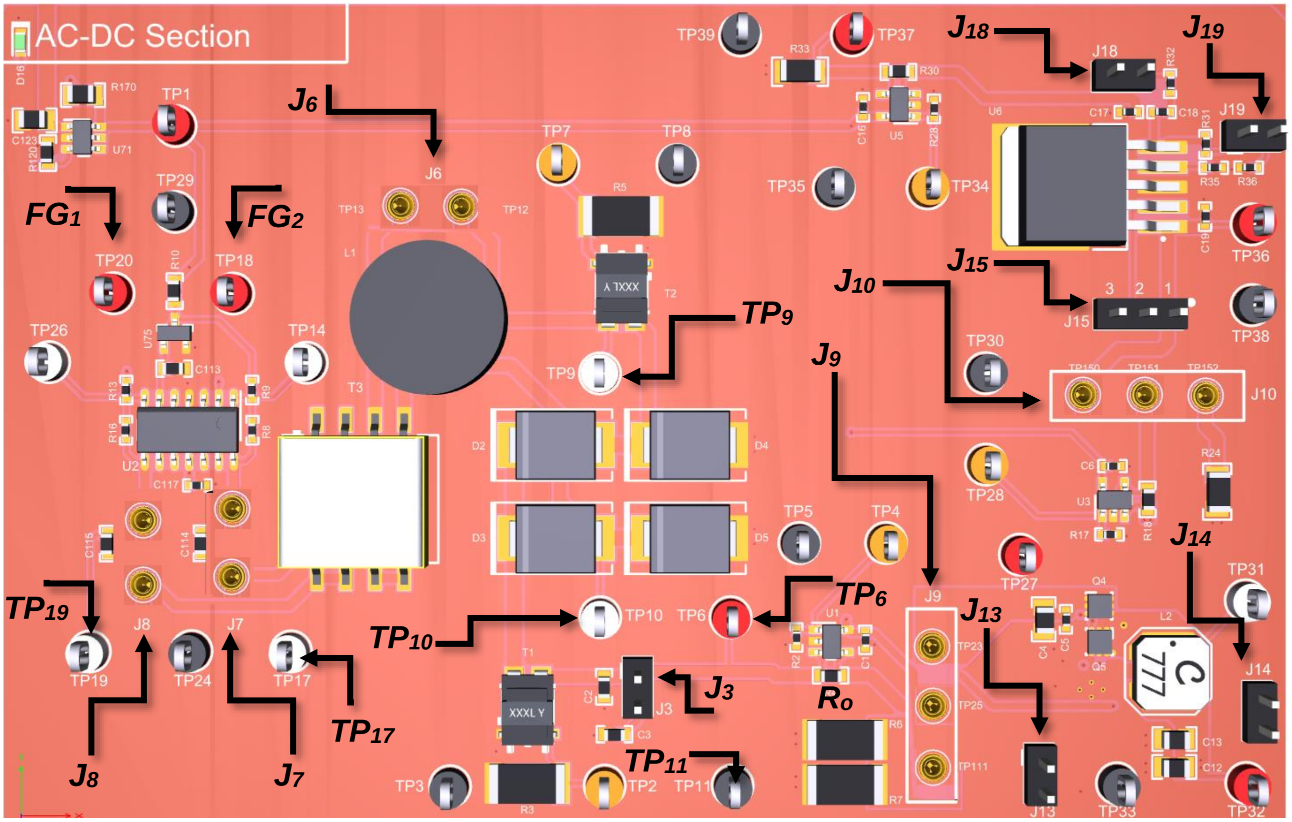


Figure 4-1. TI Power Electronics Board for NI ELVIS III – AC-DC Section Used for the Analysis of Diode-Bridge Rectifier Operation.

The AC source voltage is generated by a circuit comprised of a non-inverting amplifier and an inverting amplifier, using TI's OPA2674I OP-AMP. A TI's LM4040C25I voltage reference provides a common 2.5V bias voltage to the amplifiers. Two synchronized sinusoidal signals (FG_1,FG_2) are injected in the amplifiers to generate two output sinusoids 180° shifted each other. The outputs of the two amplifiers (TP_{17},TP_{19}) are connected in differential mode to the secondary coil of a Wurth 750311308 1:1 transformer, through jumpers J7 and J8. The primary coil of the transformer (TP_9,TP_{10}) is connected to the input of the diode full-bridge, using four B550C-13-FAC Diodes Incorporated 50V/5A Schottky diodes. The output of the diode bridge (TP_6,TP_{11}) can be connected to a 200Ω fixed load resistor R_o or to the input of a 1.2MHz TI's TPS40305 integrated buck converter, whose output can be connected to a 100Ω fixed load resistor R_{o1}, or to the input of a TI's TPS7A6201-Q1 integrated linear regulator with 100Ω load resistor R_{o2}. The OPAMPs have about 6Ω output resistance. The transformer is characterized by the following parameters:

- Turns ratio: 1:1 ±1%
- Primary coil resistance: R_p = 325mΩ ±10%
- Secondary coil resistance: R_s = 480mΩ ±10%
- Magnetizing inductance: L_m = 100µH±10%
- Primary side leakage inductance: L_p = 3.0µH max.

The jumper J6 allows to connect, or bypass, a 10µH inductor in series to the transformer primary coil. Two Coilcraft CST7030-150LC 150:1 current sensing transformers allow sensing the diode bridge input and output currents at test points TP7 and TP2, respectively, by means of two voltage probes. As the voltage-to-current transconductance of the two sensing transformers is 10, multiplying the voltages measured at test points TP7 and TP2 by 10 provides the diode bridge input and output currents respectively. A TI's INA139NA current shunt monitor allows measuring the DC component of diode bridge output current at test point TP4 by means of a voltage probe. The datasheets of components are available at these links:

- OPA2674I-14DR OPAMP: http://www.ti.com/lit/ds/symlink/opa2674.pdf
- LM4040C25IDBZR voltage reference: http://www.ti.com/lit/ds/symlink/lm4040.pdf
- 750311308 transformer: https://katalog.we-online.com/pbs/datasheet/750311308.pdf
- B550C-13-FAC diode: https://www.diodes.com/assets/Datasheets/ds13012.pdf
- TPS40305 buck regulator: http://www.ti.com/lit/ds/symlink/tps40303.pdf
- TPS7A6201-Q1 linear regulator: http://www.ti.com/lit/ds/symlink/tps7a6201-q1.pdf
- CST7030-150LC sensing transformer: https://www.coilcraft.com/pdfs/cst7030.pdf
- INA139NA/3K current monitor: http://www.ti.com/lit/ds/symlink/ina139.pdf

[**Note:** the parameters provided in the following instructions for instruments setup may require some adjustment due to thermal effects and tolerances of TI Power Electronics Board components]

4-1 Instructions

1. Open *Power Supply*, *Function Generator*, *Pattern Generator*, *Digital Multimeter* and *Oscilloscope* using Measurements Live. For help on launching instruments, refer to this help document: http://www.ni.com/documentation/en/ni-elvis-iii/latest/getting-started/launching-soft-front-panels/
2. Open the *User Manual* of TI Power Electronics Board for NI ELVIS III from this file path: http://www.ni.com/en-us/support/model.ti-power-electronics-board-for-ni-elvis-iii.html
3. Read the *User Manual* sections *Description*, *Warnings* and *Recommendations* regarding *Discrete Buck Section*.

4. Open the *TI Top Board RT Configuration Utility* of TI Power Electronics Board for NI ELVIS III (See Required Tools and Technology section for download instructions), and select *Lab11 – AC-DC Rectifier Operation*.
5. Connect and configure the instruments as indicated in Tables 4-1 and 4-2. [**Note:** the AC input voltage of diode bridge can be observed on the *Oscilloscope* Math channel]
6. Configure the jumpers of the board as indicated in Table 4-3.

Table 4-1 Instruments Connections

Power Supply	connect to red and black banana connectors
Oscilloscope	connect CH-1 to TP9 (V_{AC+}), connect CH-2 to TP10 (V_{AC-}) connect CH-3 to TP7 (I_{AC}), connect CH-4 to TP6 (V_{DC})
Function Generator	connect CH-1 to FGEN1 BNC connector (→TP18 = *FG1*) connect CH-2 to FGEN2 BNC connector (→TP20 = *FG2*)
Pattern Generator	connect TRIG to DIO 0 (red) and GND (black) using a BNC-to-Alligator Cable
Digital Multimeter	connect to TP4 (average I_{load})

Table 4-2 Instruments Configuration and setup

<table>
<tr><td>Power Supply</td><td colspan="5">Channel “+”: Static, 10.00V, Channel “-“: Inactive</td></tr>
<tr><td rowspan="2">Oscilloscope</td><td>Trigger:
Analog Edge,
CH-1, set to 50%</td><td>Horizontal:
5µs/div</td><td>Acquisition:
average</td><td colspan="2">Measurements:
show</td></tr>
<tr><td>CH-1: OFF
• DC coupling
• 1V/div
• offset 0V</td><td>CH-2: OFF
• DC coupling
• 1V/div
• offset 0V</td><td>CH-3: ON
• DC coupling
• 20mV/div
• offset 0V</td><td>CH-4: ON
• DC coupling
• 1V/div
• offset 0V</td><td>Math: ON
• CH1-CH2
• 1V/div
• offset 0V</td></tr>
<tr><td>Function Generator</td><td colspan="5">follow instructions provided below</td></tr>
<tr><td>Pattern Generator</td><td colspan="5">follow instructions provided below</td></tr>
<tr><td>Digital Multimeter</td><td colspan="5">Measurement mode: DC voltage; Range: Automatic</td></tr>
</table>

Table 4-3 Jumpers Setup

<table>
<tr><th>J6</th><th>J7</th><th>J8</th><th colspan="2">J9</th><th>J3</th></tr>
<tr><td>shorted</td><td>shorted</td><td>shorted</td><td colspan="2">short TP25-TP111</td><td>open</td></tr>
<tr><th>J18</th><th>J15</th><th>J19</th><th>J10</th><th>J13</th><th>J14</th></tr>
<tr><td>shorted</td><td>short 2-3</td><td>open</td><td>open</td><td>open</td><td>shorted</td></tr>
</table>

7. On *Channel 1* of the *Function Generator*, select *Custom*, use the file selector to select the TDMS waveform *Lab11_FG1.tdms*, set *Trigger source* to *TRIG*, set *Gain* to 1, set *Update rate* to 100MS/s,set *Generation mode* to *Loop*.

8. On *Channel 2* of the *Function Generator* select *Custom*, use the file selector to select the TDMS waveform *Lab11_FG2.tdms*, set *Trigger source* to *TRIG*, set *Gain* to 1, set *Update rate* to 100MS/s, set *Generation mode* to *Loop*.
9. On *Logic Analyzer and Pattern Generator*, click on *"+"* in the *Pattern Generator* section, click on *Signal* to add a new signal to the *Pattern Generator*, check the box next to *Logic 0* to add the line and click on the whitespace in the instrument, set *Status* to *On*, set *Mode* to *Clock*, set *Frequency* to 1Hz, set *Duty cycle* to 50%.
10. Run *Oscilloscope*, *Digital Multimeter, Power Supply, Pattern Generator* and *Function Generator*.
11. Measure the DC component of the output voltage V_{DC} on *Oscilloscope* CH-4, in Volt with two decimal digits of accuracy, and report the result in Table 4-4. [**Note:** the measurement of the average value of Channel 4 can performed by means of cursors. The measurement of the RMS value provides an approximated value of the average value]
12. Measure the amplitude of peak-peak output voltage ripple ΔV_{Acpp} on *Oscilloscope* CH-4, in Volt with two decimal digits of accuracy, and report the result in Table 4-4.
13. Measure the average DC load current I_{load} on *Digital Multimeter*, in milli Ampère, with one decimal digit of accuracy: I_{load} [V] = _____ (21.1mA); [**Note:** there can be up to about 15mA DC bias in the measurement. Check the value of the load current with the ratio between the DC output voltage V_{DC} and the load resistance R_o=200Ω]
14. Measure the peak amplitude of diode-bridge AC current I_{AC} on *Oscilloscope* CH-3, in milli Ampère with one decimal digits of accuracy, and report the result in Table 4-4.
15. Stop *Oscilloscope*, *Digital Multimeter, Power Supply*, *Function Generator* and *Pattern Generator*, set jumper J3 to be shorted and repeat steps 10 to 14.
16. Import in Table 4-4 the results of *Simulation 1* relevant to V_{DC}, ΔV_{Acpp} and I_{Acpeak}.

Table 4-4 AC-DC Rectifier Operation with different output capacitance.

	V_{DC} [V]		ΔV_{Acpp} [V]		I_{ACpeak} [mA]	
	sim 1	exp	sim 1	exp	sim 1	exp
C_{out} = 47nF						
C_{out} = 47nF+220nF						

4-2-1 Are the simulation values of output voltage DC component and peak-peak AC ripple consistent with experimental measurements?

A. yes

B. no

Please provide your comments: ____________________________________

____

____

4-2-2 Are the simulation values of peak AC diode bridge current consistent with experimental measurements?

A. yes

B. no

Please provide your comments: ______________________________________

____

____

Troubleshooting tips:

- If the AC-DC rectifier does not work, or its waveforms look much different with respect to simulations, verify the correct setup and connections of jumpers and instruments, following the directions provided in Tables 4-1, 4-2 and 4-3, and restart the experiments.

5 Analyze

5-1 Comparing the simulated and experimental values of the DC output voltage average and peak-peak ripple values, identify the parameters of the simulation model to change in order to achieve a better agreement, based on concepts discussed in the ***Theory and Background*** section:

____

____

____

6 Conclusion

6-1 Summary

Write a summary of what you observed and learned about the operation of an AC-DC diode bridge rectifier, and discuss the impact of the output capacitor on the resulting voltage and current waveforms.

6-2 Expansion Activities

6-2-1. Measure diodes voltage drop

a. Repeat the experiment following the instructions of Section 4-1.
b. Set the *Oscilloscope* cursors in *Track* mode, associate Cursor 1 to Math CH and Cursor 2 to CH-4
c. Align the cursors horizontally in a time instant where Math CH trace is higher than CH-4 trace and read the difference between the two traces measured by the *Oscilloscope*

Divide the measured voltage by two to obtain the forward voltage drop of each diode.

6-2-2. No load operating condition

a. Repeat the experiment following the instructions of Section 4-1 with jumper J9 open, which allows to disconnect the load resistor from the output of the rectifier.
b. Analyze the waveforms of input and output voltages of diode bridge rectifier, to verify that the input voltage is an ideal sine wave without distortion and the output voltage is a constant without AC ripple.

6-4 Resources for learning more

- This book provides the fundamentals of AC-DC diode bridge rectifiers:
  N. Mohan, T.M. Undeland, W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc.