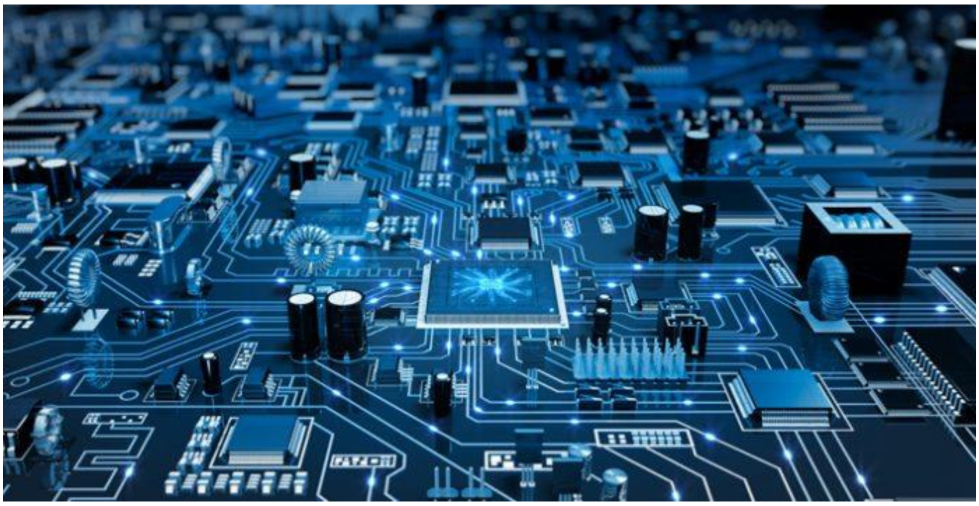
Ministry of high Education and Scientific Research
Middle Technical University
Electrical Engineering Technical College
Medical Instrumentation Techniques Engineering

Module 4

Regulated Power Supplies (Part 3)

For
Students of the Third Stage
Department of Medical Instrumentation Techniques Engineering



By

Ali Abdulelah Al-Naji
Dep. Medical Instrumentation
Techniques Engineering

2024

1. Overview

a. Target population:

This educational module is intended for third-class students enrolled in the Department of Medical Instrumentation Techniques Engineering at the Electrical Engineering Technical College, Middle Technical University in Baghdad, Iraq.

b. Rationale:

The module aims to provide an in-depth understanding of Zener diodes and IC regulators as voltage regulators, a critical topic in the field of electrical engineering and medical instrumentation.

c. Objectives:

Upon completion of the lecture, students will achieve the following learning outcomes:

- Explain the applications and significance of Zener diodes and IC regulator in medical instrumentation.
- Demonstrate the ability to calculate and select appropriate Zener diodes for specific voltage regulation tasks.

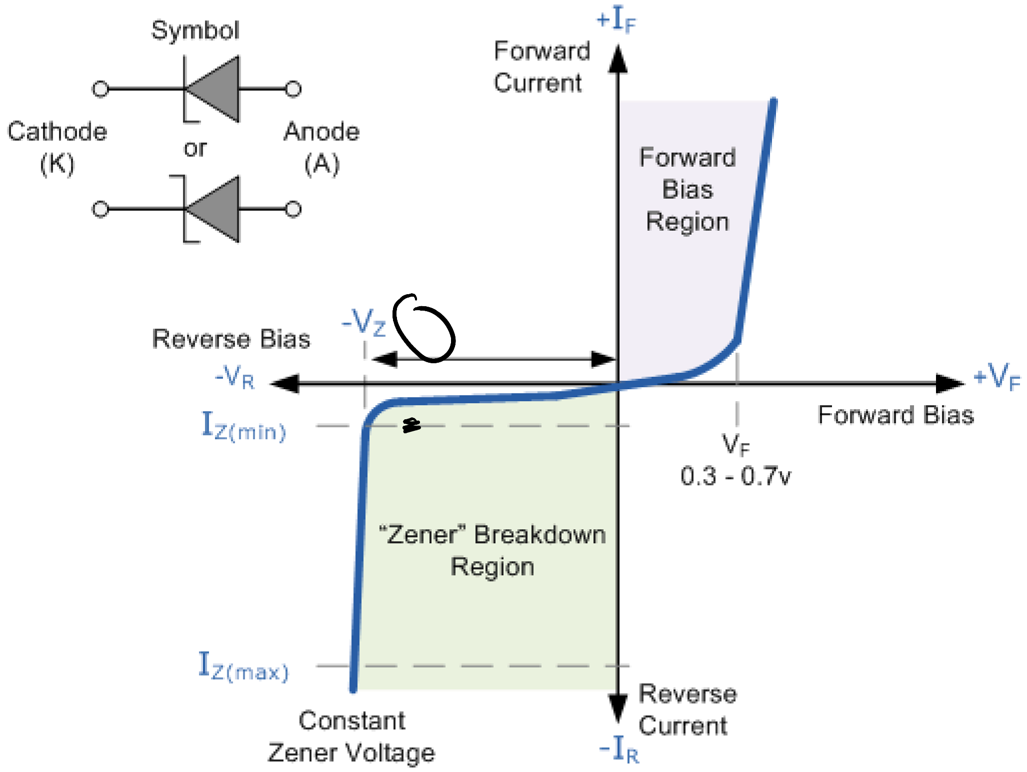
2. Introduction:

A **regulated power supply** converts unregulated AC (Alternating Current) to a constant DC (Direct Current). A regulated power supply is used to ensure that the output remains constant even if the input changes. The basic building blocks of a regulated DC power supply are as follows:

1. A step-down transformer.
2. A rectifier.
3. A DC filter.
4. A regulator.

Zener Diode Regulator

A **Zener diode** is a special type of diode designed to reliably allow current to flow "backwards" when a certain set reverse voltage, known as the Zener voltage, is reached.

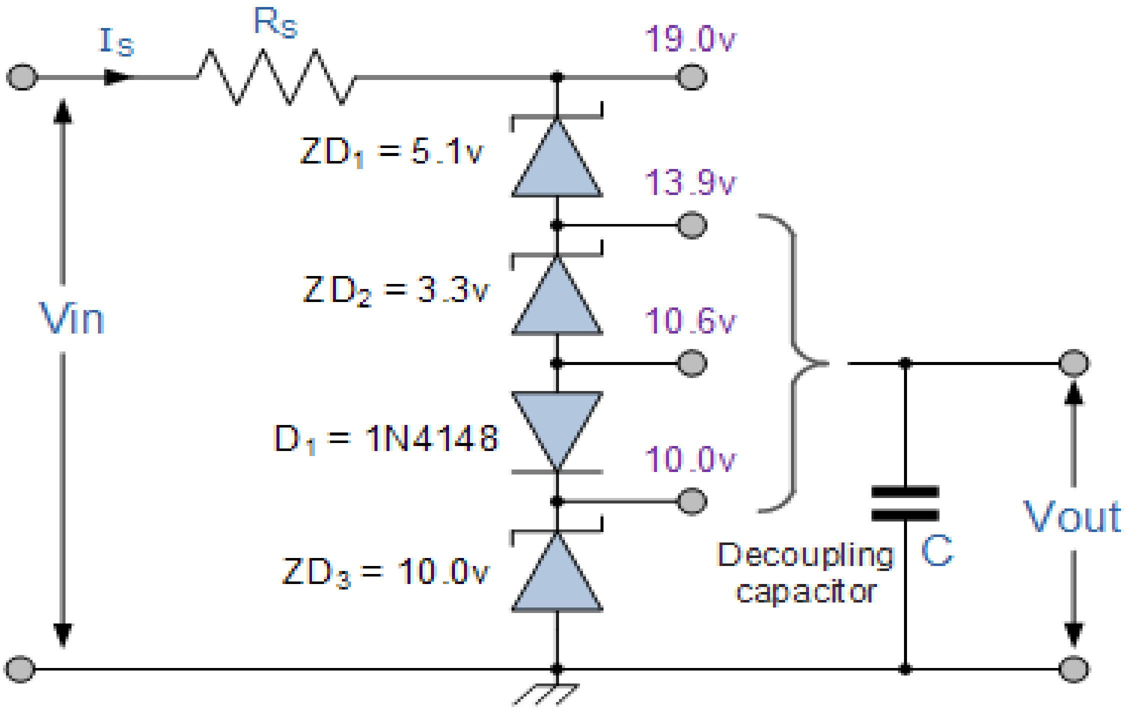


The values of the individual Zener diodes can be chosen to suit the application while the silicon diode will always drop about 0.6 – 0.7V in the forward bias condition. The supply voltage, Vin must of course be higher than the largest output reference voltage and in our example above this is 19v.

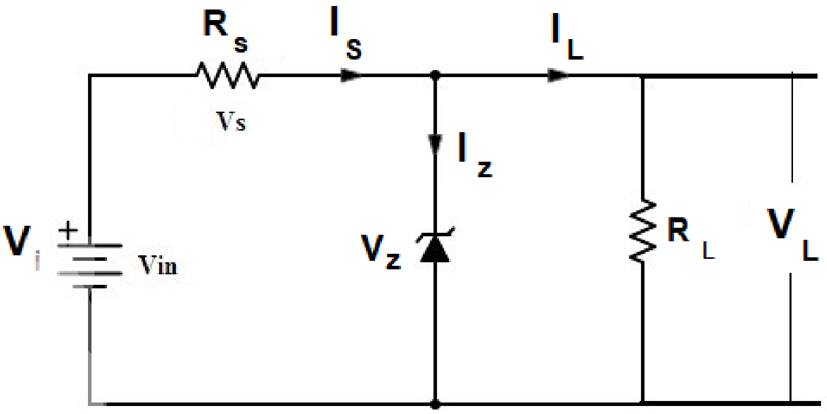
A typical **Zener diode** for general electronic circuits is the 500mW, *BZX55* series or the larger 1.3W, *BZX85* series were the Zener voltage is given as, for example, *C7V5* for a 7.5V diode giving a diode reference number of *BZX55C7V5*.

As well as producing a single stabilized voltage output, Zener diodes can also be connected together in series along with normal silicon signal diodes to produce a variety of different reference voltage output values as shown below.

Zener Diodes Connected in Series



Stage 1: Fixed V_i and Fixed R_L



When $V_z > V_L$ Zener is off

$$V_L = \frac{R_L}{R_L + R_s} V_i$$

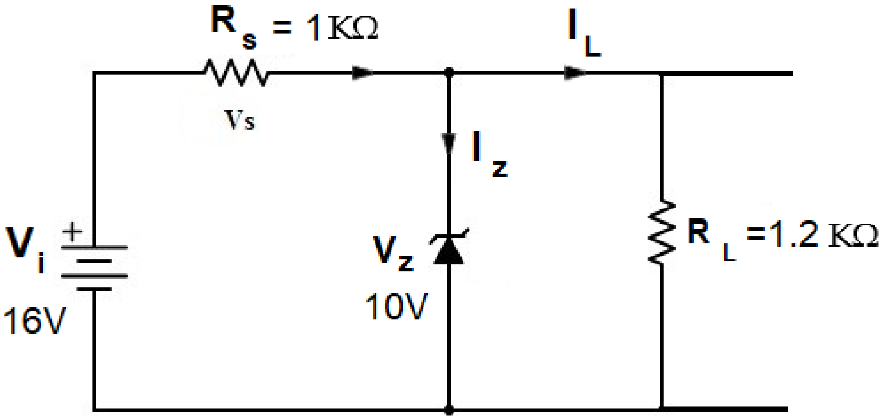
$$I_L = \frac{V_L}{R_L}$$

$$V_i - V_s - V_L = 0$$

$$I_s = \frac{V_s}{R_s}$$

$$I_z = 0$$

Ex1: For the Zener circuit below, determine V_L, I_L, V_s, I_s and I_z



Ans:

$$V_L = \frac{R_L}{R_L + R_s} V_i = \frac{1.2}{1.2 + 1} \times 16 = 8.72\ V$$

$$\because \boldsymbol{V_z\ (10\ V) > V_L\ (8.72\ V)} \quad \therefore \ \textbf{Zener is off}$$

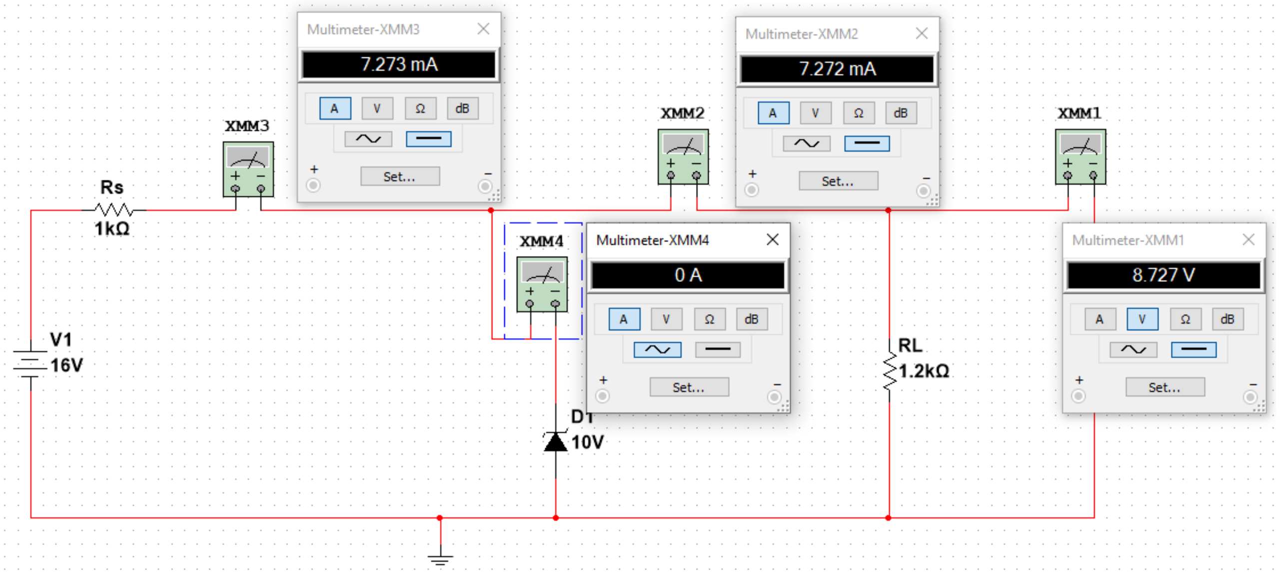
$$I_L = \frac{V_L}{R_L} = \frac{8.72}{1.2 \times 10^3} = 7.27\ mA$$

$$V_i - V_s - V_L = 0$$
$$16 - V_s - 8.72 = 0$$
$$V_s = 7.27\ V$$

$$I_s = \frac{V_s}{R_s} = \frac{7.27}{1K} = 7.27\ mA$$

$$I_z = 0$$

Answer with MULTISIM



Multimeter-XMM3

7.273 mA

Multimeter-XMM2

7.272 mA

Multimeter-XMM4

0 A

Multimeter-XMM1

8.727 V

Repeat Ex.1 with $R_L = 3\ K\Omega$

Ans:

$$V_L = \frac{R_L}{R_L + R_s} V_i = \frac{3}{3+1} \times 16 = 12\ V$$

$$\because \boldsymbol{V_z\ (10\ V) < V_L\ (12\ V)} \quad \therefore\ \textbf{Zener is on}$$

$$\therefore V_L = V_z = 10\ V$$

$$I_L = \frac{V_L}{R_L} = \frac{10}{3 \times 10^3} = 3.33\ mA$$

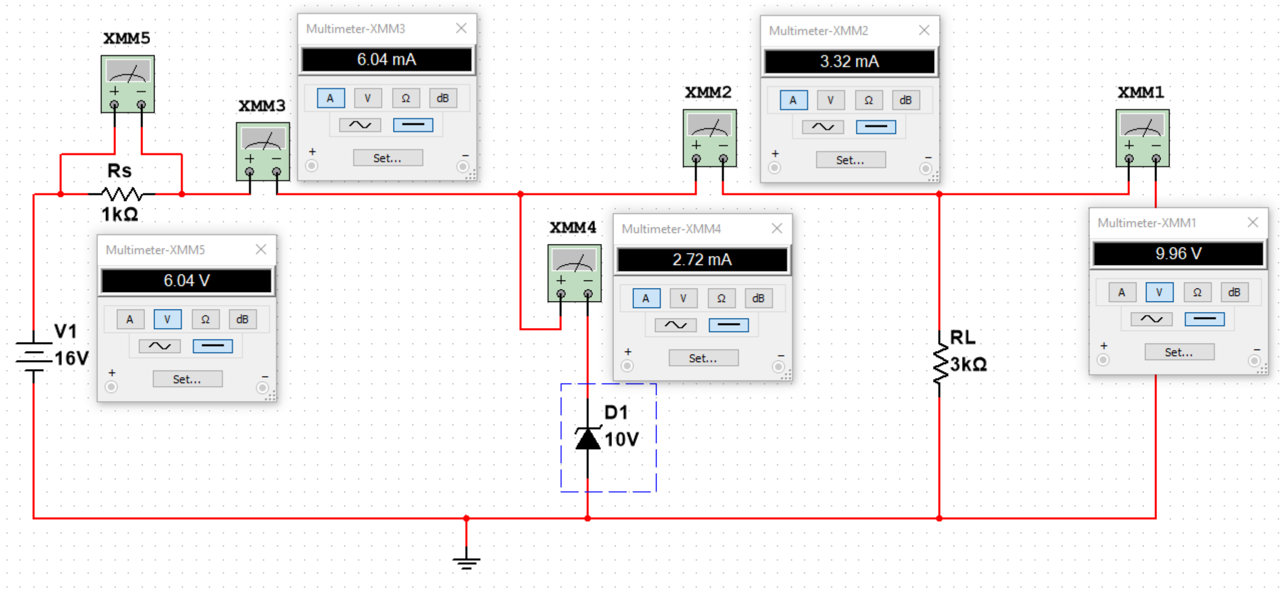
$$V_i - V_s - V_z = 0$$
$$16 - V_s - 10 = 0$$
$$V_s = 6\ V$$

$$I_s = \frac{V_s}{R_s} = \frac{6}{1K} = 6\ mA$$

$$I_s = I_z + I_L$$

$$\therefore I_z = I_s - I_L = 6 - 3.33 = 2.67\ mA$$

Answer with MULTISIM



Ex2: A 5.0V stabilized power supply is required to be produced from a 12V DC power supply input source. The maximum power rating Pz of the Zener diode is 2W. Using the Zener regulator circuit above calculate:

a). The maximum current flowing through the Zener diode.

$$\text{Maximum Current} = \frac{\text{Watts}}{\text{Voltage}} = \frac{2\text{w}}{5\text{v}} = 400\text{mA}$$

b). The minimum value of the series resistor, Rs

$$R_S = \frac{V_S - V_Z}{I_Z} = \frac{12-5}{400\text{mA}} = 17.5\Omega$$

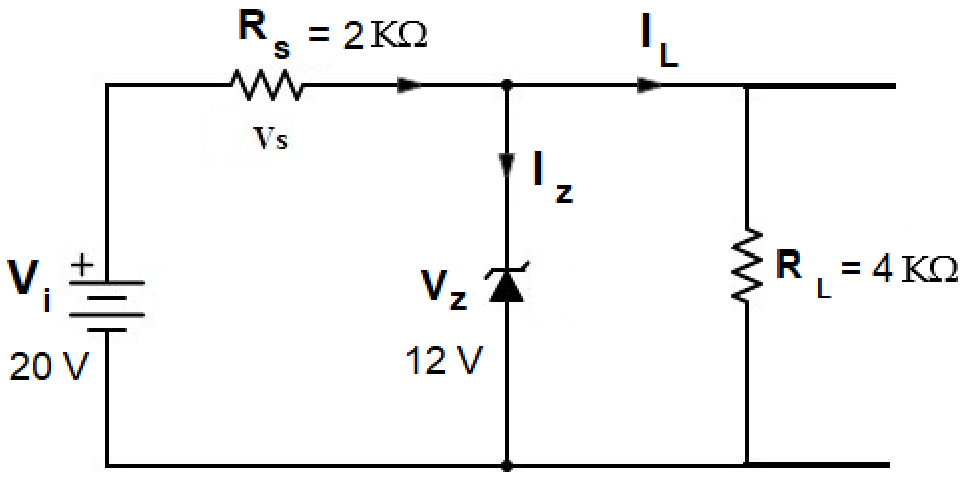
c). The load current IL if a load resistor of 1kΩ is connected across the Zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5\text{v}}{1000\Omega} = 5\text{mA}$$

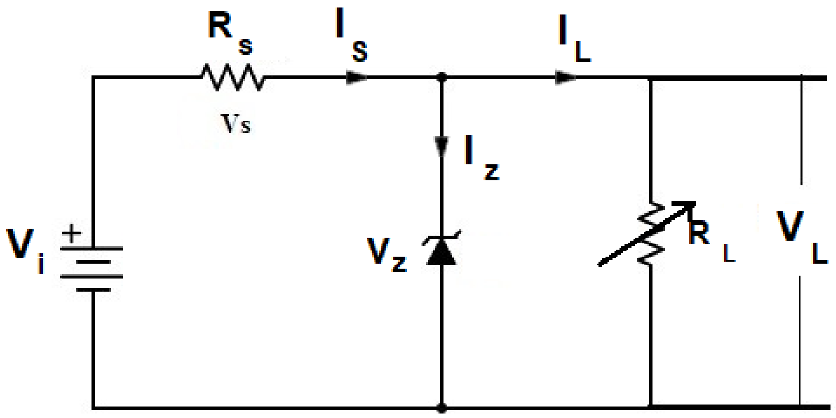
d). The Zener current Iz at full load.

$$I_Z = I_S - I_L = 400\text{mA} - 5\text{mA} = 395\text{mA}$$

Ex3 (H.W): For the Zener circuit below, determine V_L, I_L, V_S, I_S and I_Z



Stage 2: Fixed V_i and Variable R_L



$$R_{Lmin} = \frac{V_z}{V_i - V_z} R_s$$

$$V_L = V_z$$

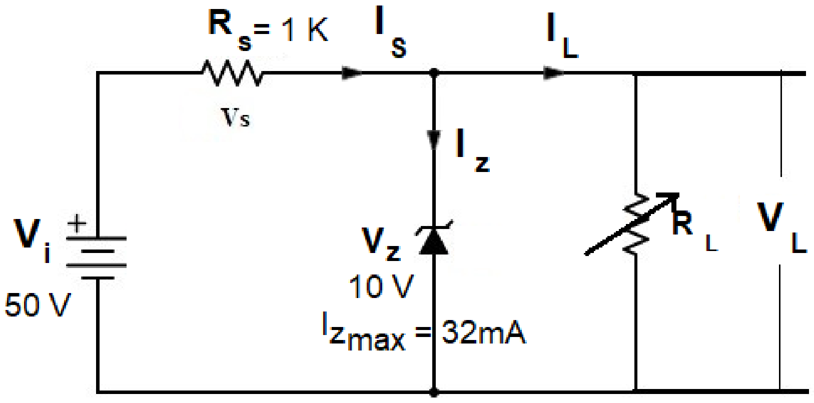
$$I_{Lmax} = \frac{V_z}{R_{Lmin}}$$

$$I_z = I_s - I_L$$

$$I_{Lmin} = I_s - I_{zmax}$$

$$I_{Lmin} = \frac{V_z}{R_{Lmax}}$$

Ex4: For the Zener circuit below, determine the range of R_L and I_L



Ans:

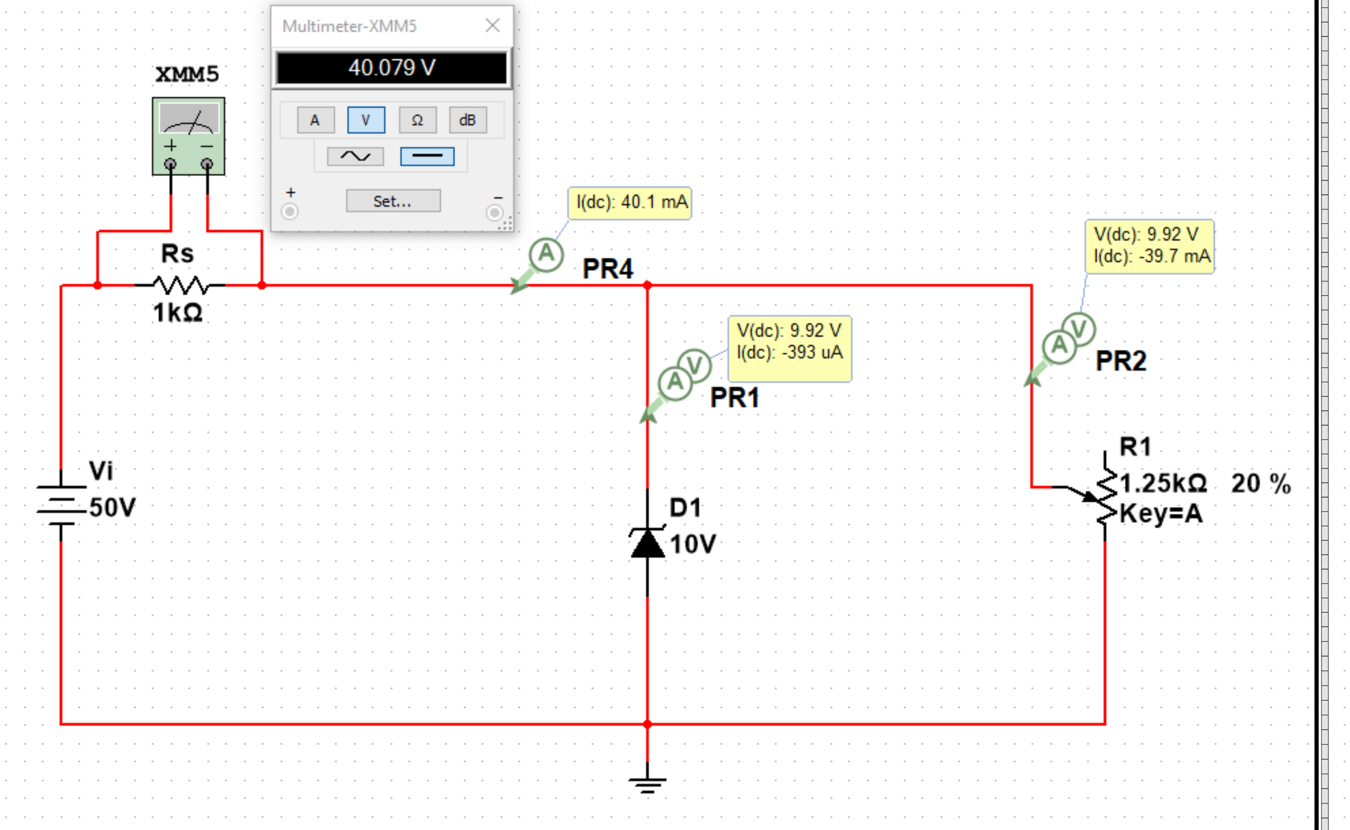
$$R_{Lmin} = \frac{V_z}{V_i - V_z} R_s = \frac{10}{50 - 10} \times 1000 = 0.25\ K\Omega$$

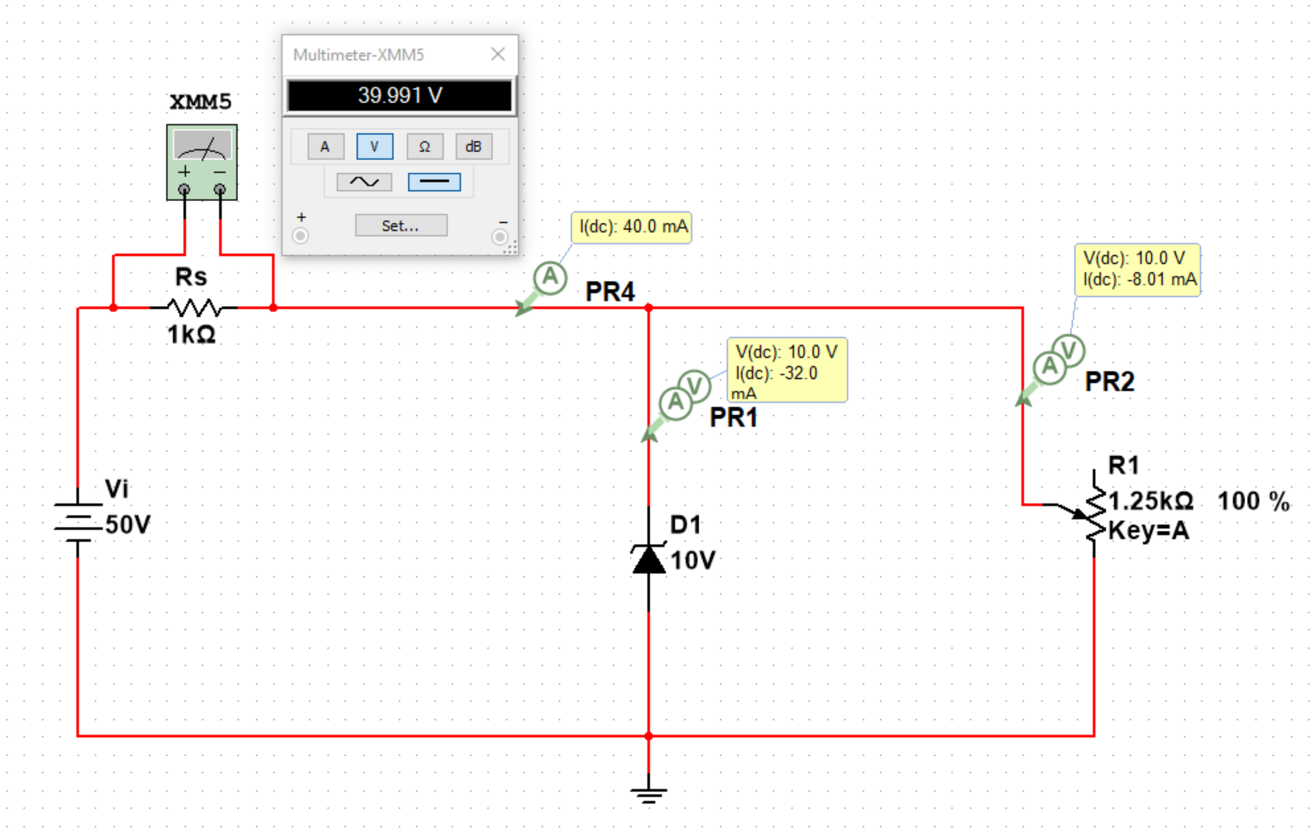
$$V_i - V_s - V_z = 0$$
$$50 - V_s - 10 = 0$$
$$V_s = 40\ V$$

$$I_s = \frac{V_s}{R_s} = \frac{40}{1K} = 40\ mA$$
$$I_{Lmin} = I_s - I_{zmax} = 40 - 32 = 8\ mA$$

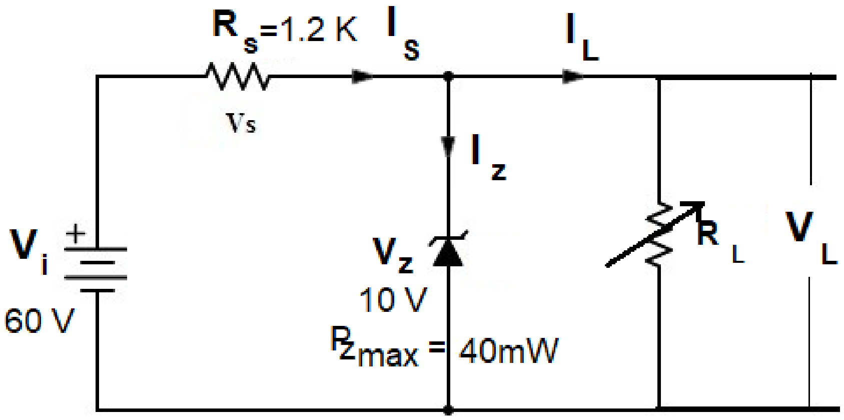
$$R_{Lmin} = \frac{V_z}{I_{Lmax}} = \frac{10}{8m} = 1.25\ K\Omega$$
$$I_{Lmax} = \frac{V_z}{R_{Lmin}} = \frac{10}{0.25K} = 40\ mA$$

Answer with MULTISIM

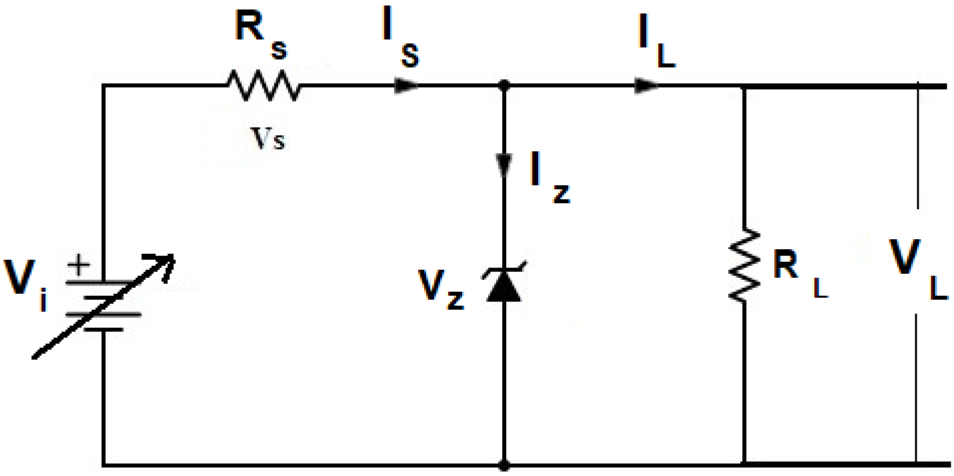




Ex5 (H.W): For the Zener circuit below, determine the range of R_L and I_L



Stage 3: Variable V_i and Fixed R_L



$$V_{i\,min} = \frac{R_L + R_s}{R_L} V_z$$

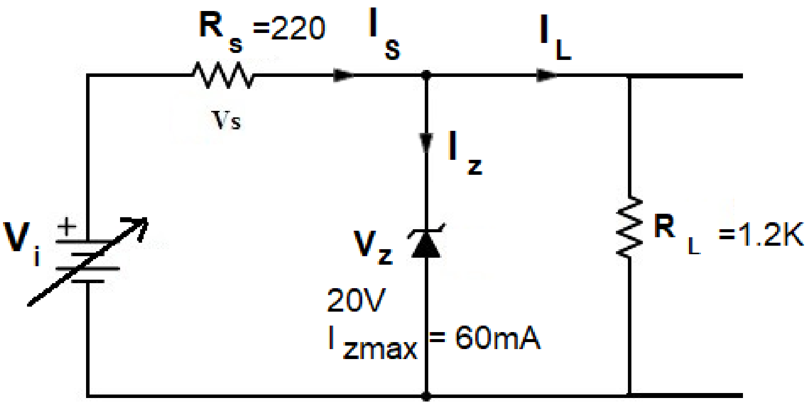
$$I_{S\,max} = I_{z\,max} + I_L$$

$$V_{i\,max} = I_{s\,max} . R_s + V_z$$

$$V_{s\,max} = I_{s\,max} R_s$$

$$V_{s\,min} = I_{s\,min} R_s$$

Ex6: For the Following circuit, determine the range of the input voltage and V_{s.}



Answer:

$$V_{i\,min} = \frac{R_L + R_s}{R_L} V_z = \frac{1200 + 220}{1200} \times 20 = 23.67\ V$$

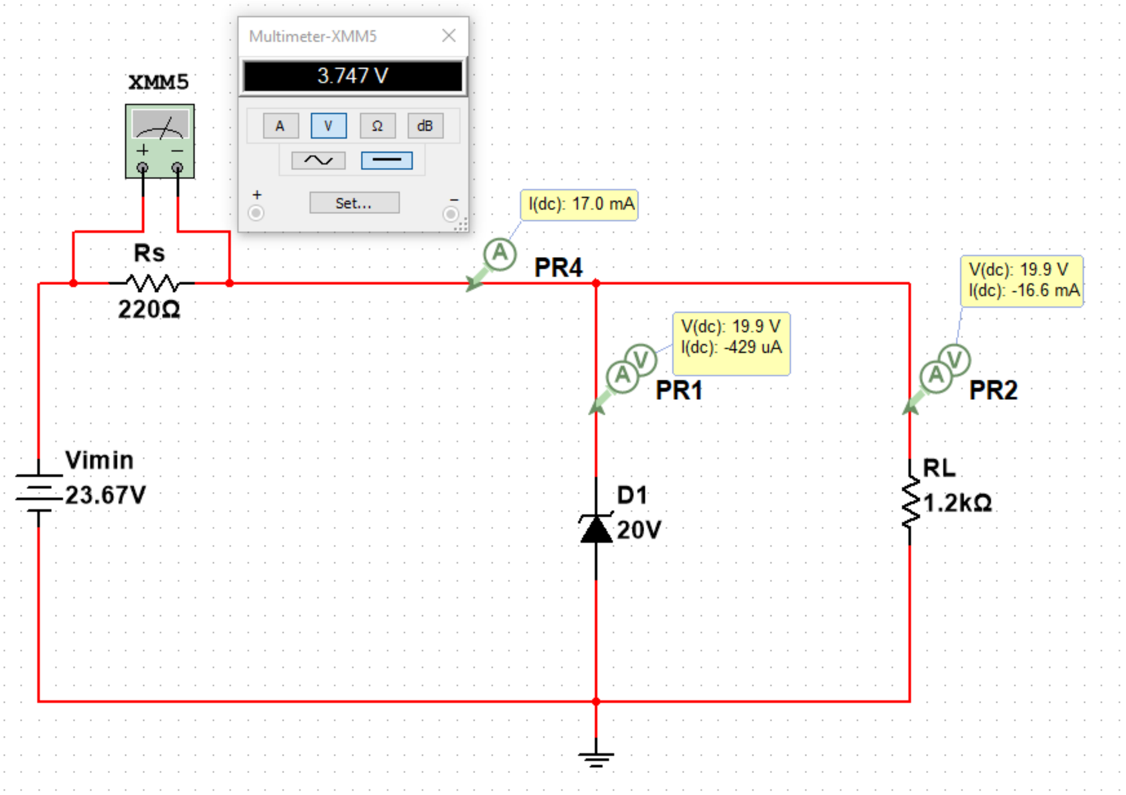
$$I_L = \frac{V_L}{R_L} = \frac{20}{1.2 \times 10^3} = 16.6\ mA$$

$$I_{S\,max} = I_{z\,max} + I_L = 60 + 16.6 = 76.6\ mA$$

$$V_{i\,max} = I_{s\,max}.R_s + V_z = 76.6m \times 220 + 20 = 36.86\ V$$

$$V_{s\,max} = I_{s\,max}\,R_s = 76.6 \times 220 = 16.852V$$

$$V_{s\,min} = I_{s\,min}\,R_s == 17.032 \times 220 = 3.747V$$



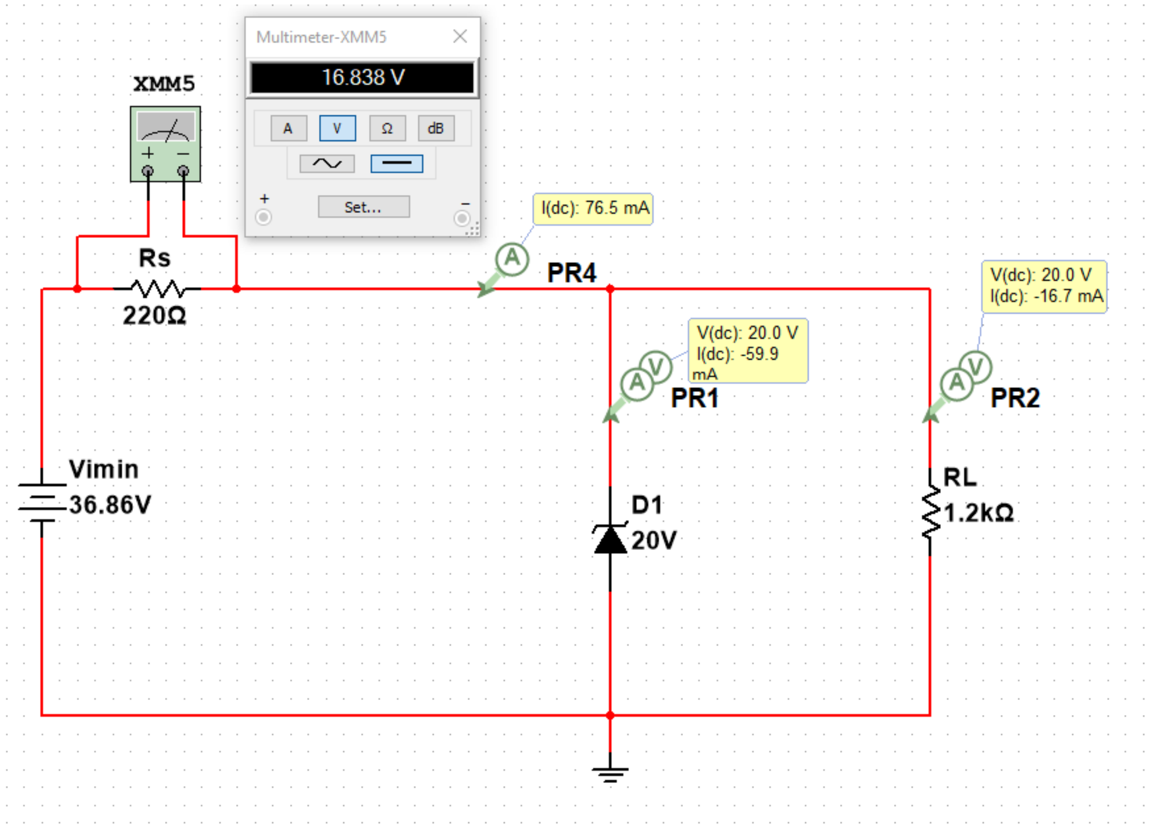
Multimeter-XMM5

3.747 V

I(dc): 17.0 mA

V(dc): 19.9 V
I(dc): -429 uA

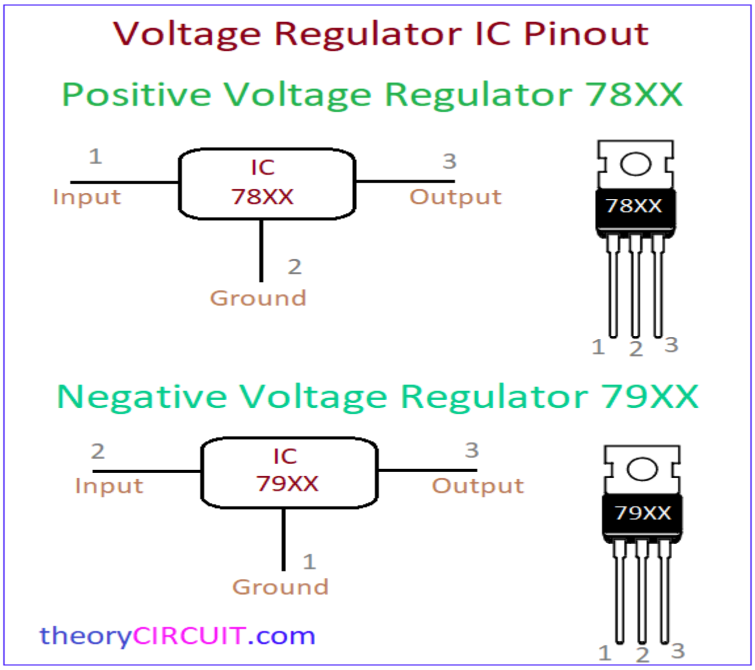
V(dc): 19.9 V
I(dc): -16.6 mA



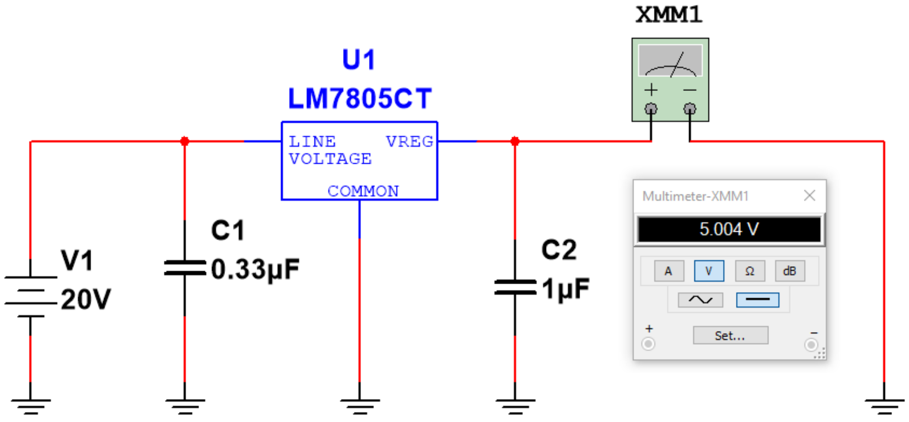
Ex7 (H.W): Repeat with $R_s = 330$ and $R_L = 2$ K and $V_z = 22$ V

IC Regulator

IC's like LM78XX and 79XX (such as the IC 7805) are used to obtained fixed values of voltages at the output.

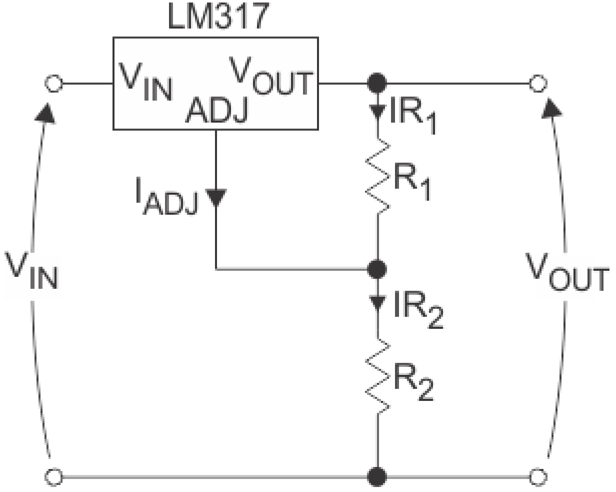


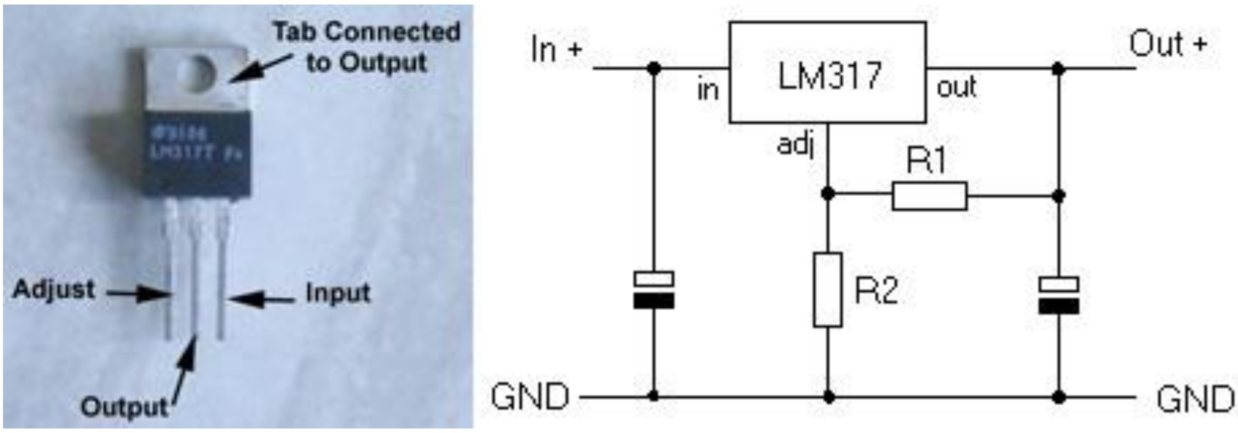
An example for LM7805 in Multisim



The adjustment of the output voltage to a required constant value can be achieved using ICs such as LM 317 and 723. The LM317 voltage regulator is depicted in the figure below. The adjustment of output voltage can be accomplished by modifying the resistances R1 and R2. Typically, coupling capacitors with values ranging from 0.01μF to 10μF should be connected at both the output and input terminals to mitigate input noise and output transients. Ideally, the output voltage is determined by the following equation.

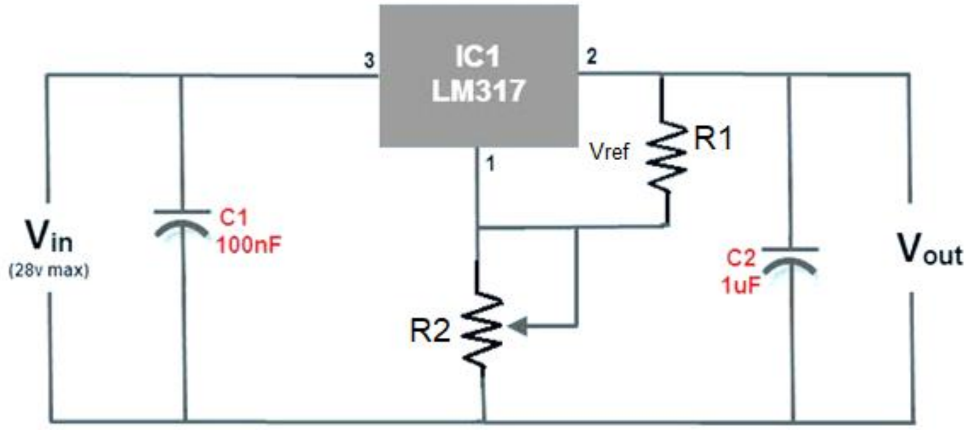
$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$





LM317 Voltage Regulator Circuit

The LM317 features three terminals: an input pin, an output pin, and an adjustment pin. The circuit diagram for the LM317 voltage regulator, as illustrated in the figure below, represents a standard configuration, complete with decoupling capacitors. This LM317 circuit is capable of delivering a variable DC power supply with a maximum output of 1A, adjustable up to 30V. It includes a low-side resistor and a high-side resistor connected in series, forming a resistive voltage divider. This passive linear circuit generates an output voltage that is a fraction of its input voltage. Decoupling capacitors are implemented to prevent undesired coupling or interference between different sections of an electrical circuit. They serve to mitigate input noise and output transients, minimizing the impact of noise from specific circuit elements on the overall performance. Furthermore, to prevent excessive heat generation and component overheating resulting from high power dissipation, a heat sink is utilized in conjunction with the circuit.



LM317 Voltage Regulator Circuit

C_1=C_{in} needed if regulator is located far from power supply filter. C_2=C_{out} improves transient response.

Features of LM317 Voltage Regulator

There are some special features of LM317 regulator and a few are as follows:

- It is capable of providing excess current of 1.5A, hence it is conceptually considered as operational amplifier with an output voltage ranging from 1.2V to 37V.
- The LM317 voltage regulator circuit internally consists of thermal overload protection and short circuit current limiting constant with temperature.
- It is available in two packages as 3-Lead Transistor Package and surface mount D2PAK-3.
- Stocking of many fixed voltages can be eliminated.

Working of Voltage Regulator LM317 Circuit (Adjustable Voltage Regulator)

The LM317 regulator can provide excess output current and hence with this capacity, it is conceptually considered as an operational amplifier. The adjustment pin is the inverting input of the amplifier and to produce a stable reference voltage of 1.25V, an internal bandgap reference voltage is used to set the non-inverting input.
The output pin voltage can be continuously adjusted to a fixed amount using a resistive-voltage divider between the output and ground, which will configure the operational amplifier as a non-inverting amplifier.

A bandgap reference voltage is used to produce constant output voltage irrespective of the changes in supply power. It is also called as temperature independent reference voltage frequently used in integrated circuits.

The output voltage (ideally) of the LM317 voltage regulator circuit

$$V_{out} = V_{ref} * (1 + (R_2/R_1))$$

Where V_{ref} **is 1.25V**, an error term is added because some quiescent current flows from the adjustment pin of the device.

$$V_{out} = V_{ref} * (1+(R_2/R_1)) + I_{adj} R_2$$

For achieving more stable output, the LM317 voltage regulator circuit diagram is designed such that to make the quiescent current less than or equal to 100 micro Amp. Thus, in all practical cases the error can be ignored.

If we replace the low-side resistor of the divider from the LM317 voltage regulator circuit diagram with the load, then the resulting configuration of the LM317 regulator will regulate the current to a load. Hence, this LM317 circuit can be treated as LM317 Current Regulator Circuit.

The output current is the voltage drop of reference voltage across the resistance RH and is given as

Output current in ideal case is

$$I_{out} = V_{ref}/R_1$$

Considering the quiescent current, the output current is given as

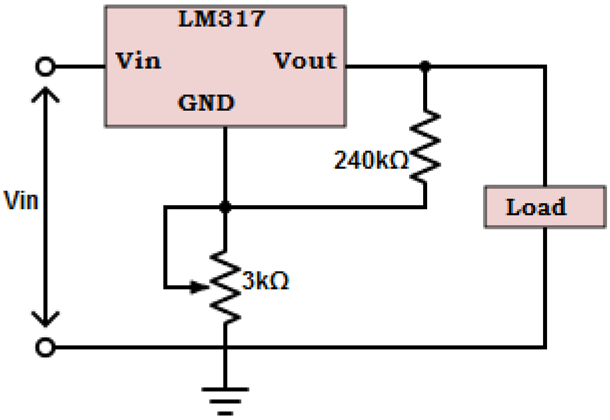
$$I_{out} = (V_{ref}/R_1) + I_{adj}$$

These linear voltage regulators LM317 and LM337 are frequently used in DC-DC converter applications. Linear regulators naturally draw much current as they supply. The power produced due to the multiplication of this current with the voltage difference between the input and output will be dissipated and wasted as heat.

Due to this, a heat is required to be considered for significant design and leads to inefficiency. If the voltage difference increases, then the power wasted will increase and sometimes this dissipated waste power will be more than the supplied power.

Even though this is insignificant, but as the linear voltage regulators with a few additional components is a simple way to obtain stable voltage, so, we must accept this trade-off. The switching voltage regulators are alternative for these linear regulators as these switching regulators are generally more efficient, but they require more number of components to design and thus need more space.

Ex 8: Calculate the output voltage for LM317 regulator. The current I_{ADJ} is very small in the order of 100μA. (Assume V_{REF}=1.25v)



Answer:

Explanation: The output voltage, $V_{Out}=V_{REF}[1+(R_2/R_1)]+(I_{ADJ}\times R_2)=1.25V\times [1+(3k\Omega/240\Omega)]+(100\mu A\times 3k\Omega)=16.875+0.3$.

=> $V_{Out}=17.17v$.

Ex9 (H.W): Calculate the output voltage for an LM317 voltage regulator with $R_2=1k\Omega$ and $R_1=240\Omega$, given a reference voltage V_{REF} of 1.25V and an adjustment pin current I_{ADJ} of 100μA.

Answer: $V_{Out}\approx 6.4585V$

H.W: Drive the following questions

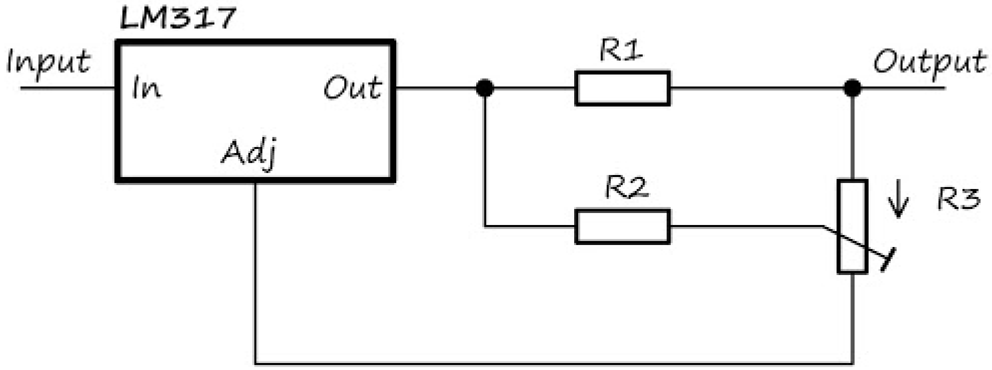
$$V_{out}=V_{ref}(1+\frac{R_2}{R_1})$$

$$R_1=R_2\frac{1.25}{V_o-1.25}$$

$$R_2=R_1\frac{V_o-1.25}{1.25}$$

Ex10 (H.W): You are designing a power supply circuit using an LM317 voltage regulator. You have a reference voltage (V_{REF}) of 1.25V and a resistor (R_1) of 240Ω. The adjustment pin current (I_{ADJ}) is 100μA. If you desire an output voltage (V_{out}) of 9V, what value of $R2$ should you choose to achieve this output voltage?

Adjustable Current Regulator


LM317 (adjustable current source)

$$V_{R1} = 1.25\left(1 + \frac{xR_3}{R_2}\right)$$

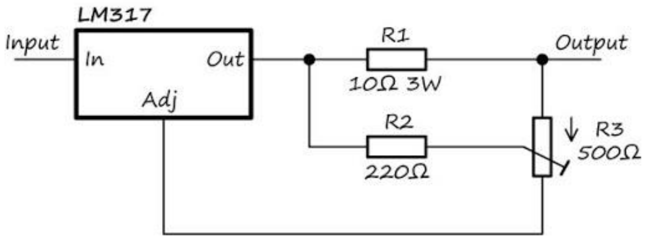
x= 0 to 1

$$I_{R1} = \frac{V_{R1}}{R_1}$$

$$I_{min} = \frac{1.25}{R_1}$$

$$I_{max} = \frac{1.25}{R_1}\left(1 + \frac{R_3}{R_2}\right)$$

Ex10 (H.W): Determine I_{min} and I_{max} of the following circuit.


LM317 adjustable current source
approx. 125-400mA range

Full Regulated Power Supply Using Multisim