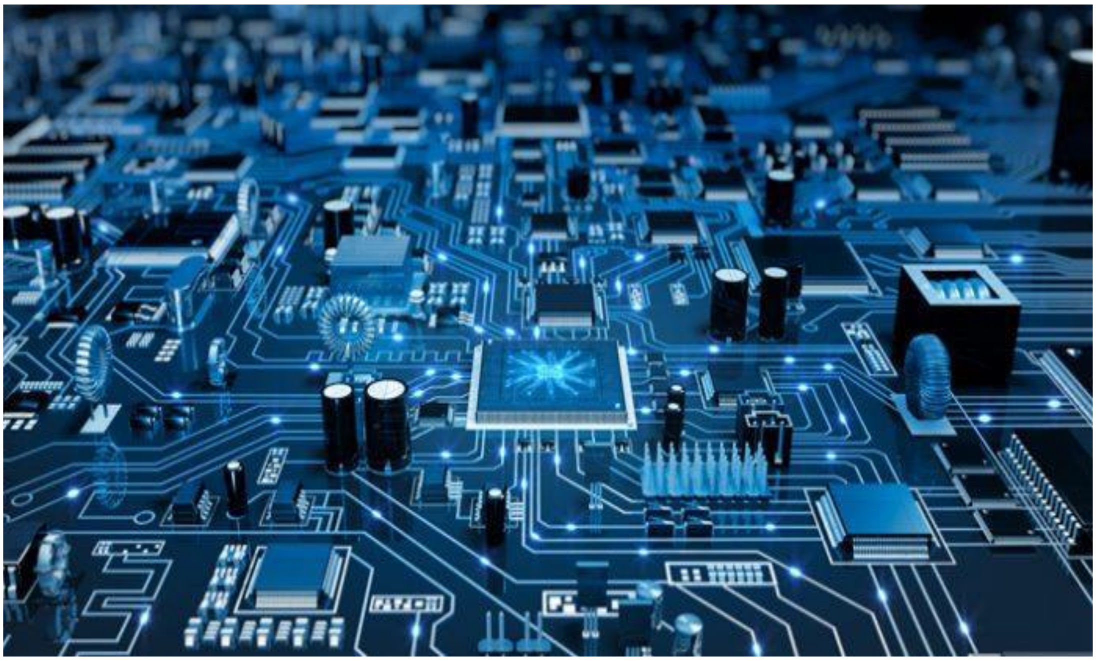
Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Adnan Ali
Lecture:5&6

Mode Unit 5

Regulated Power Supplies (Part 3)

For
Students of Third Stage
Department of Medical Instrumentation Techniques Engineering



By

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Dep. Medical Instrumentation
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2025

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1. Overview

a. Target population:

For students of third class of Department of Medical Instrumentation Techniques Engineering, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.

b. Rationale:

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.

c. Objectives:

The student will be able after finishing lecture on:

- Identify the main components of regulated power supply.

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.
A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks.

The regulated power supply will accept an AC input and give a constant DC output. The figure below shows the block diagram of a typical regulated DC power supply.

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

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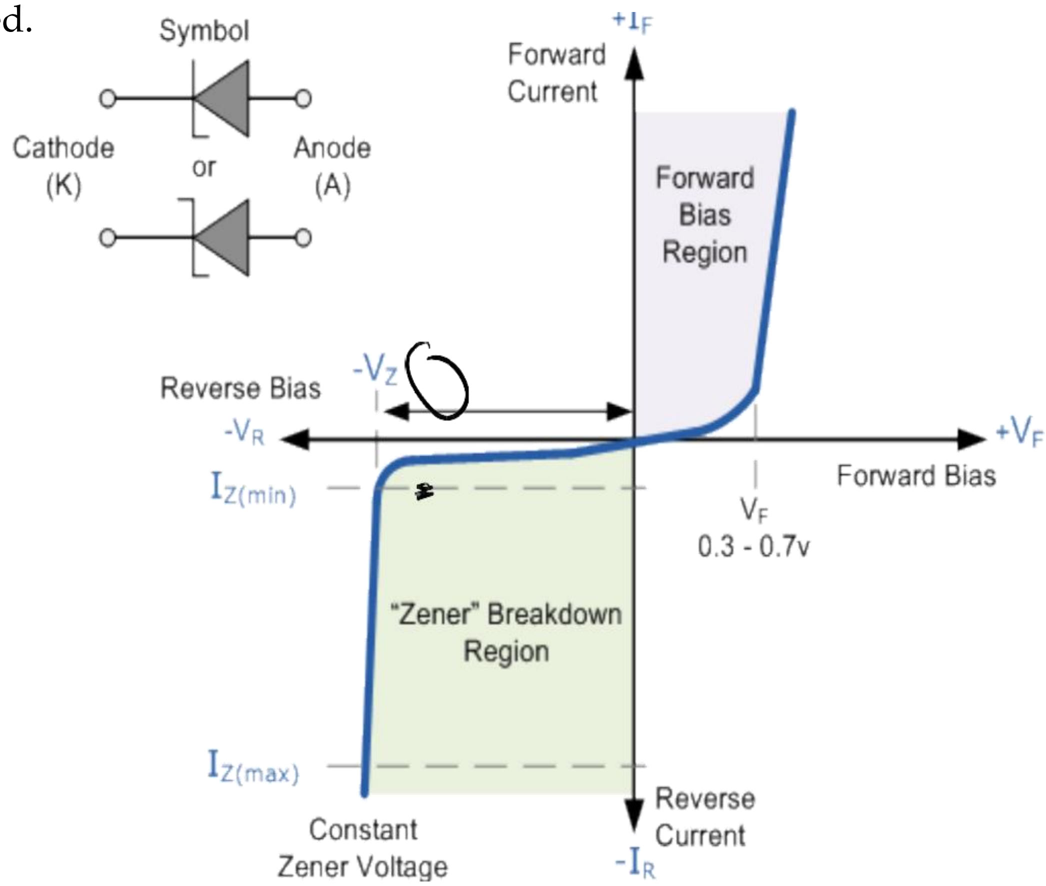
Zener Diode Regulator

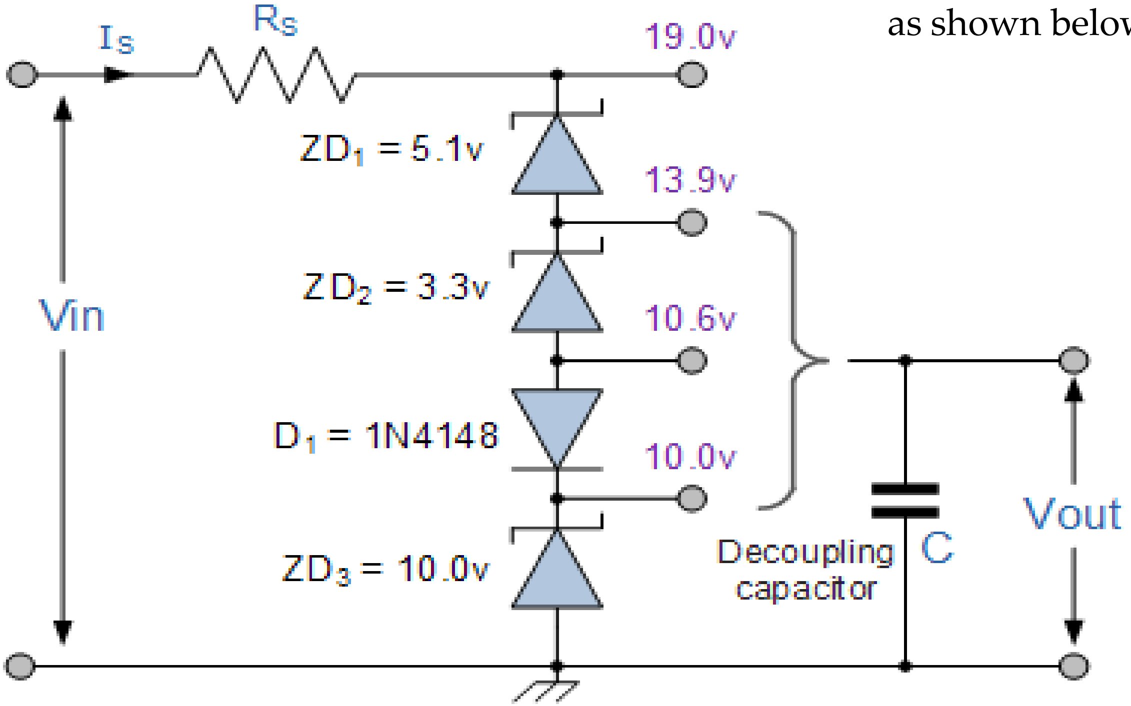
A **Zener diode** is a special type of diode designed to reliably allow current to flow "backwards" when a certain set reverse voltage, known as the Zener voltage, is reached.



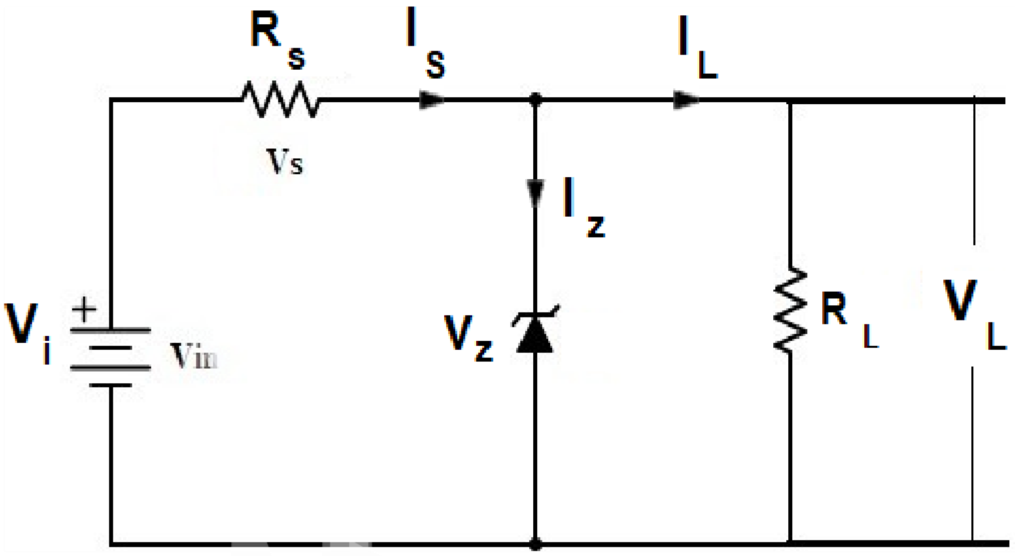
The values of the individual Zener diodes can be chosen to suit the application while the silicon diode will always drop about 0.6 – 0.7V in the forward bias condition. The supply voltage, Vin must of course be higher than the largest output reference voltage and in our example above this is 19v.

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



When $V_z > V_L$ Zener is off

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

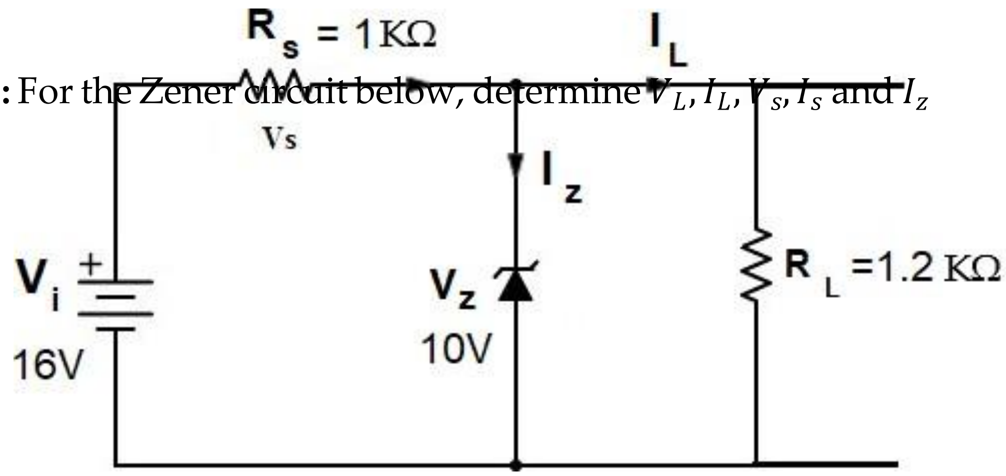
$$I_L = \frac{V_L}{R_L}$$

$$V_i - V_s - V_L = 0$$

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

$$I_z = 0$$

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



Ans:

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

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

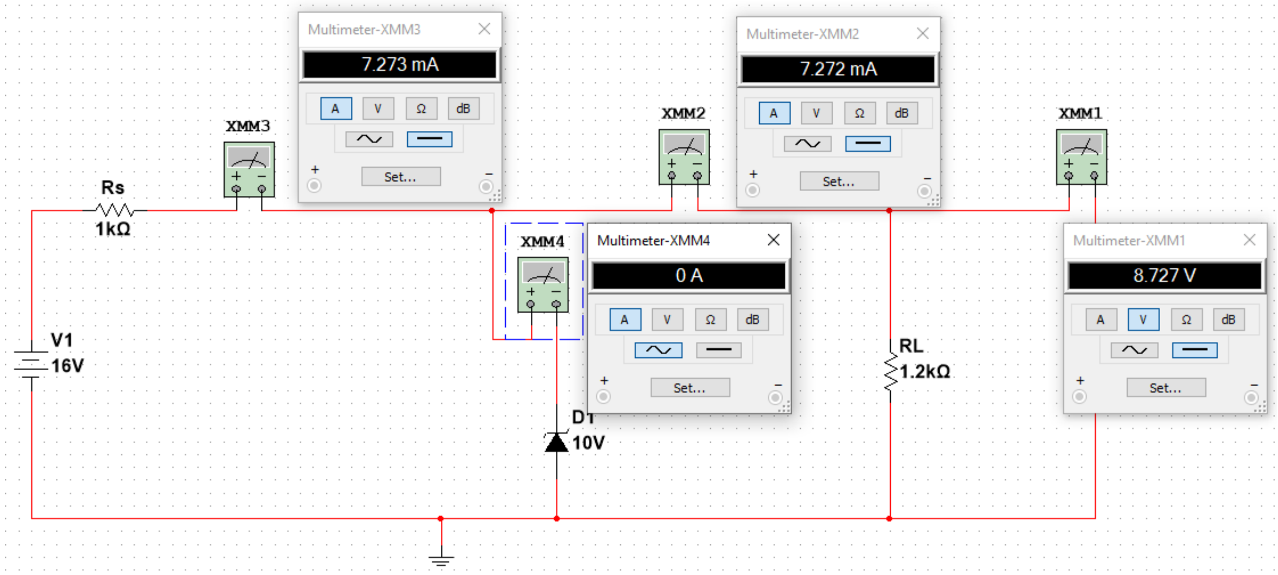
$$I_L = \frac{V_L}{R_L} = \frac{8.72}{1.2 \times 10^3} = 7.27\,mA$$

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

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

$I_z = 0$

Answer with MULTISIM



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

Ans:

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

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

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

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

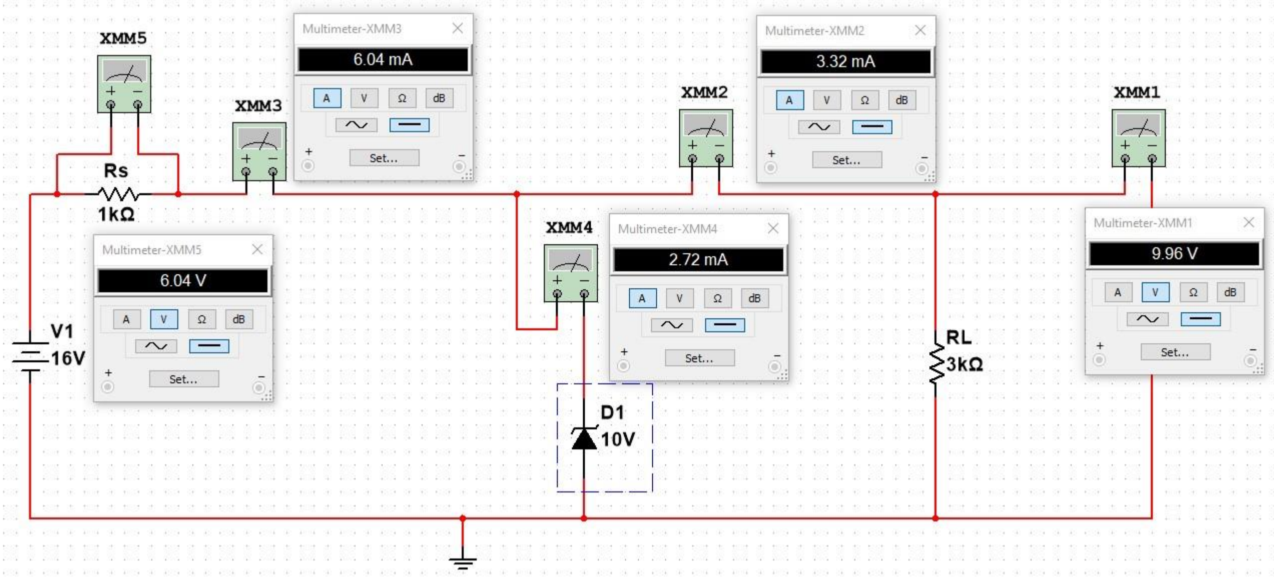
$$V_i - V_s - V_z = 0$$
$$16 - V_s - 10 = 0$$
$$V_s = 6\ V$$

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

$$I_s = I_z + I_L$$

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

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.

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

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

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

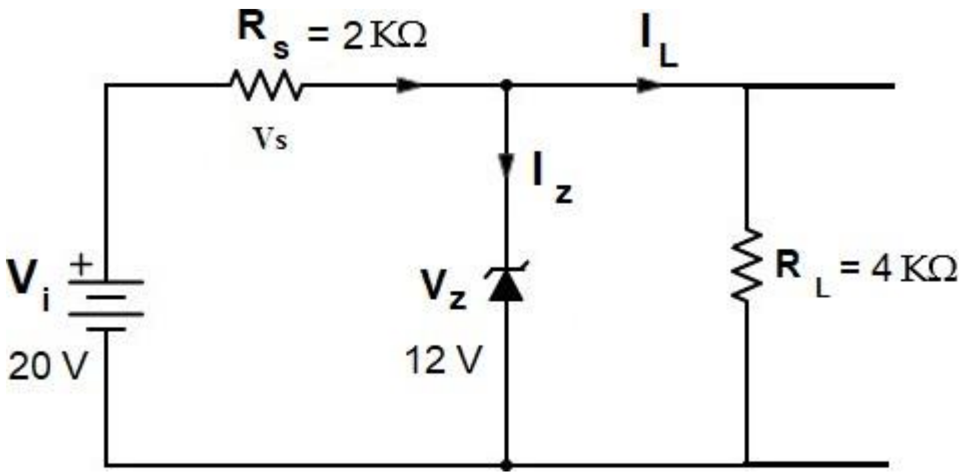
c). The load current IL if a load resistor of 1kΩ is connected across the Zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5v}{1k\Omega} = 5mA$$

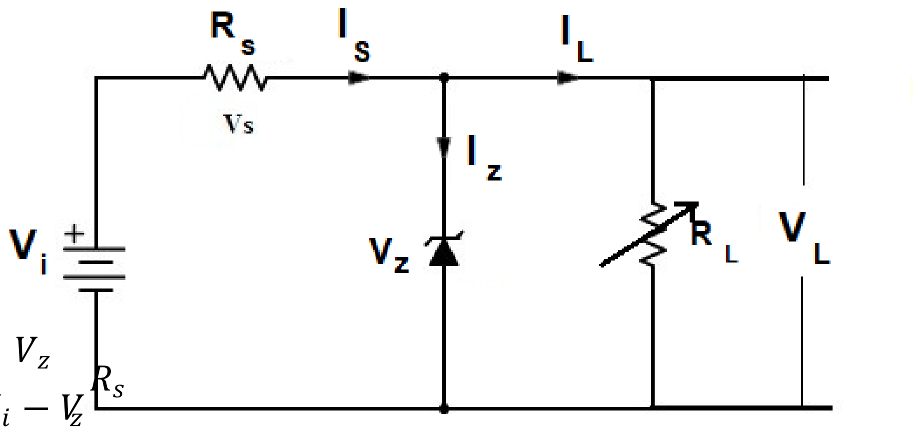
d). The Zener current Iz at full load.

$$I_Z = I_S - I_L = 400mA - 5mA = 395mA$$

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



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

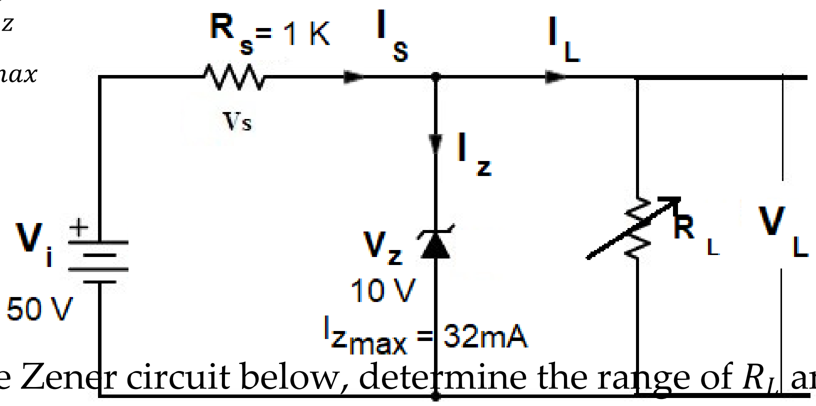
$V_L = V_z$

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

$$I_z = I_s - I_L$$

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

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



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

Ans:

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

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

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

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

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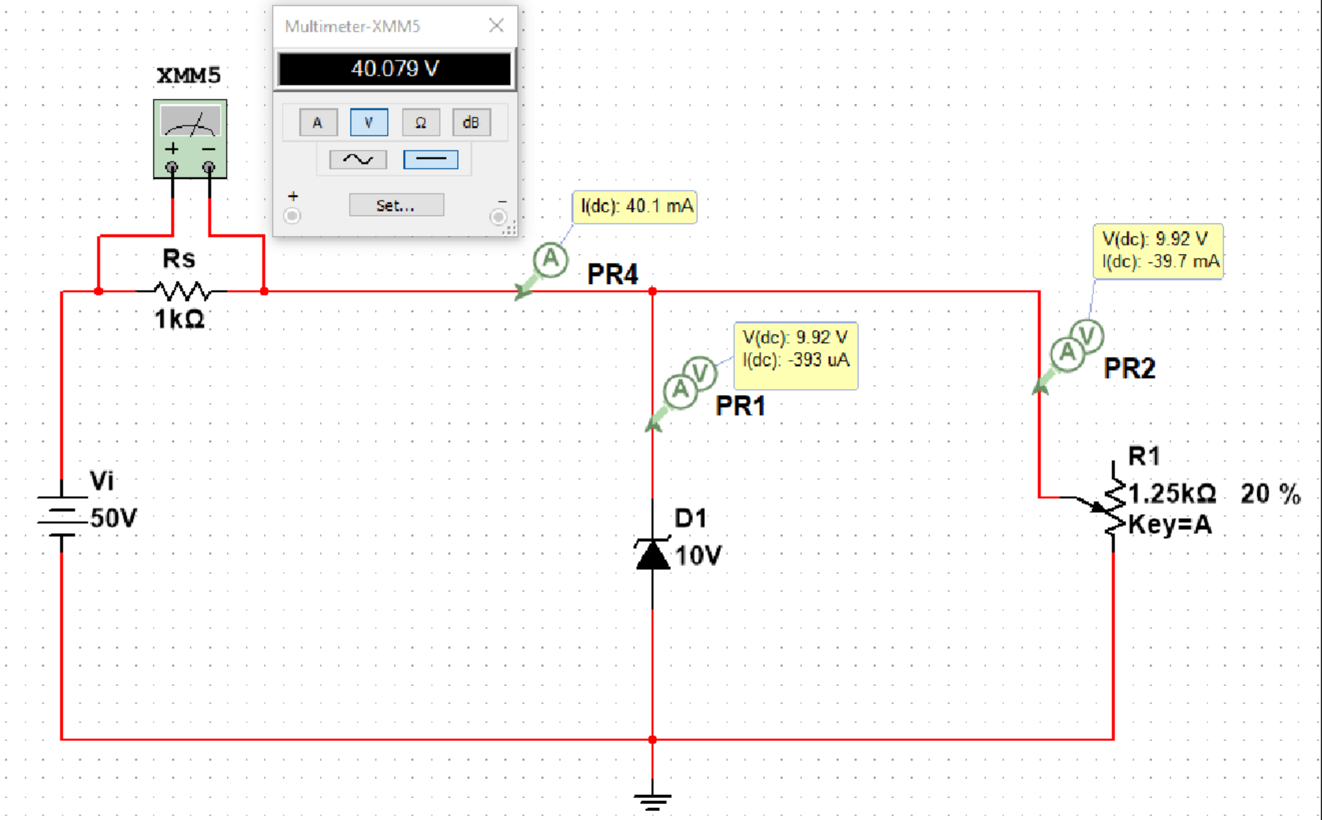
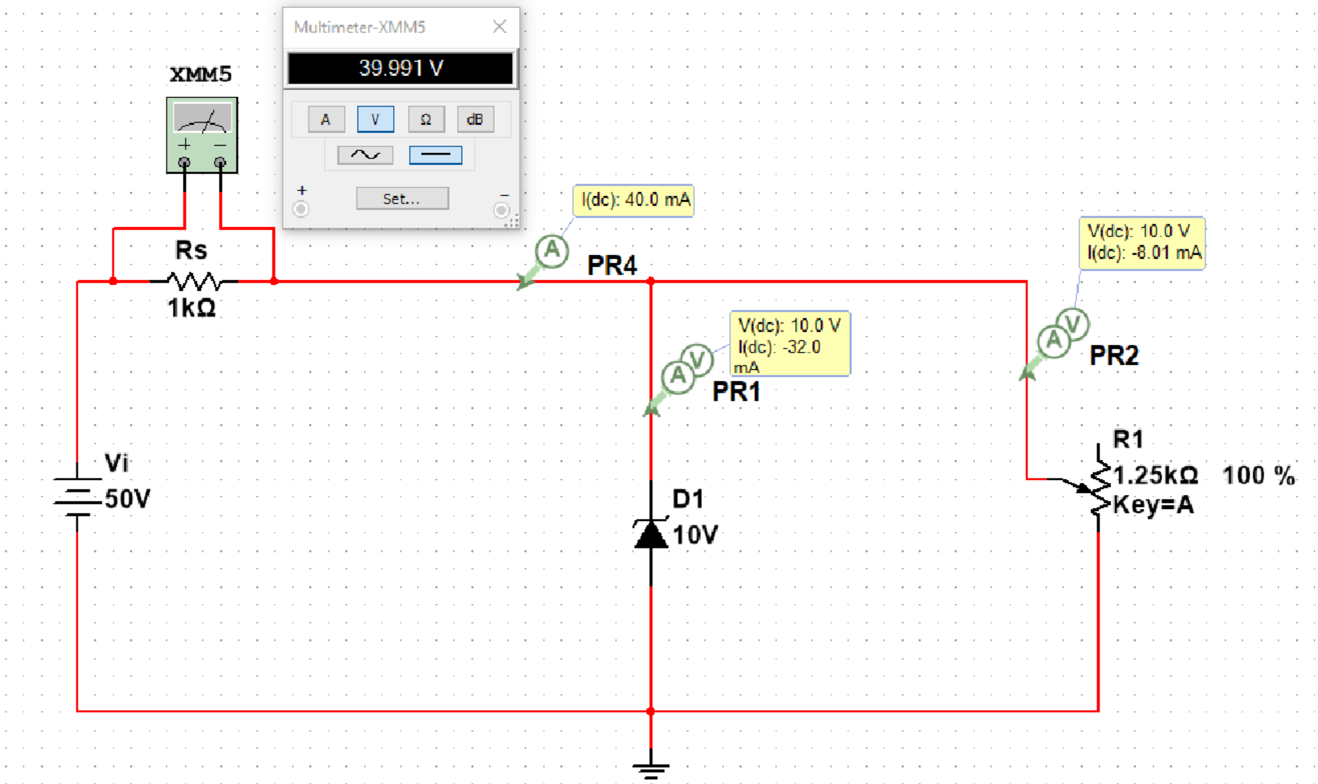
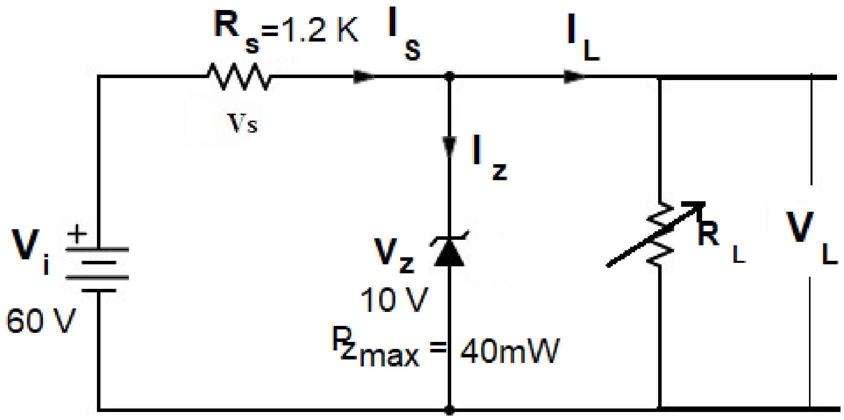
Answer with MULTISIM

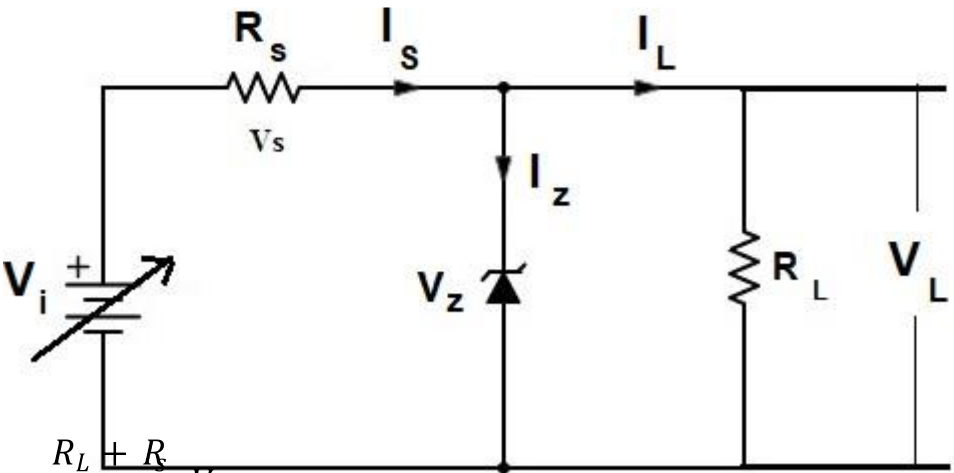




Ex5 (H.W): For the Zener circuit below, determine the range of R_L and I_L



Stage 3: Variable V_i and Fixed R_L



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

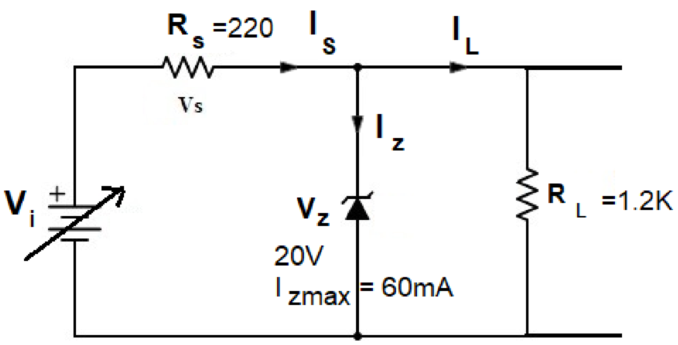
$$I_{S\,max} = I_{z\,max} + I_L$$

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

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

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

Ex6: For the Following circuit, determine the range of the input voltage and V_s



Answer:

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

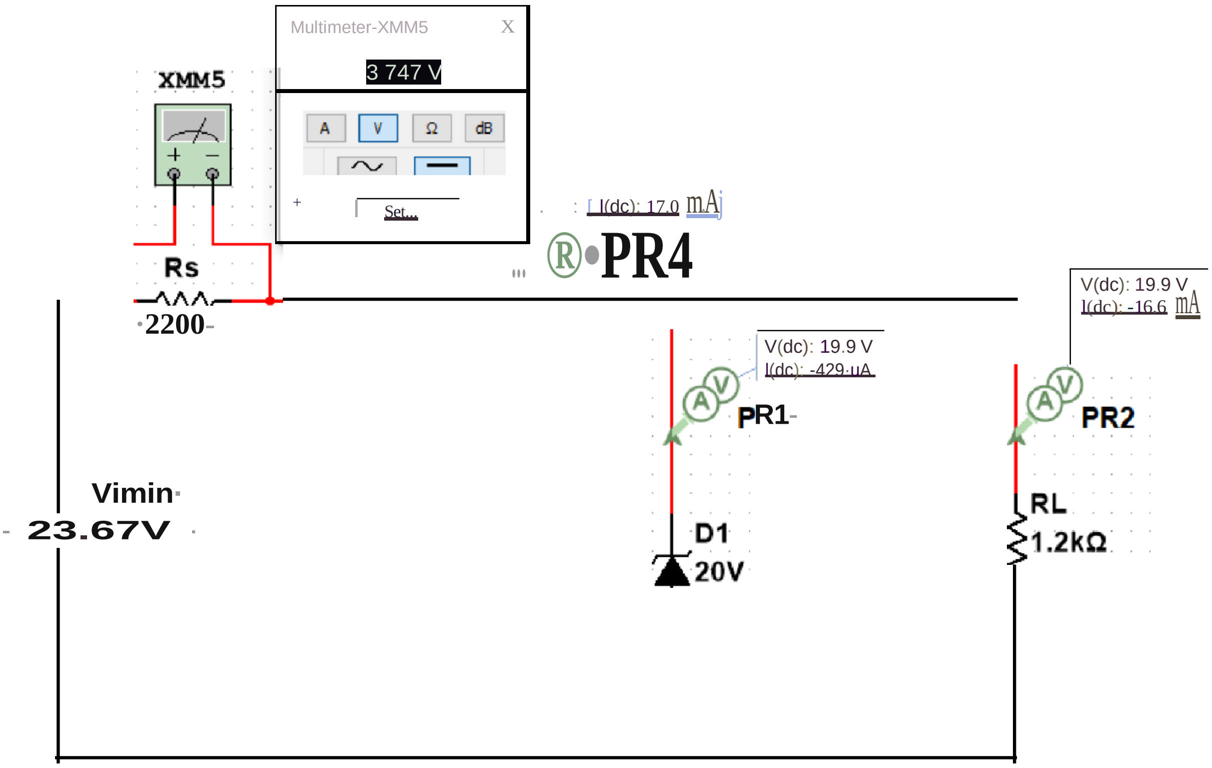
$$I_L = \frac{V_L}{R_L} = \frac{20}{1.2 \times 10^3} = 16.6\,mA$$

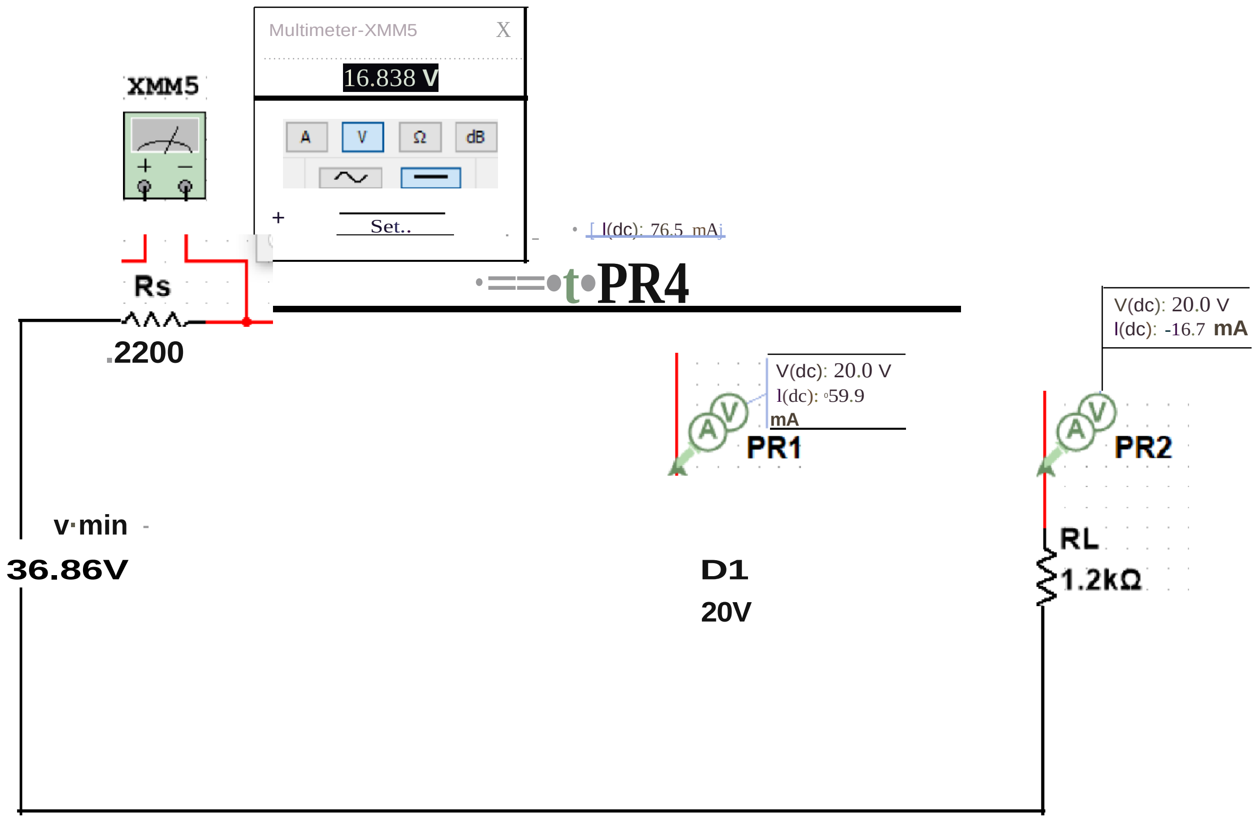
$$I_{S\,max} = I_{z\,max} + I_L = 60 + 16.6 = 76.6\,mA$$

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

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

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


Multimeter-XMM5
3 747 V
A
V
Ω
dB
Set...
XMM5
Rs
2200
I(dc): 17.0 mA
PR4
V(dc): 19.9 V
I(dc): -16.6 mA
V(dc): 19.9 V
I(dc): -429 uA
PR1
PR2
Vimin
23.67V
D1
20V
RL
1.2kΩ


Multimeter-XMM5
16.838 V
A
V
Ω
dB
Set..
XMM5
Rs
2200
I(dc): 76.5 mA
PR4
V(dc): 20.0 V
I(dc): -16.7 mA
V(dc): 20.0 V
I(dc): 59.9 mA
PR1
PR2
v min
36.86V
D1
20V
RL
1.2kΩ

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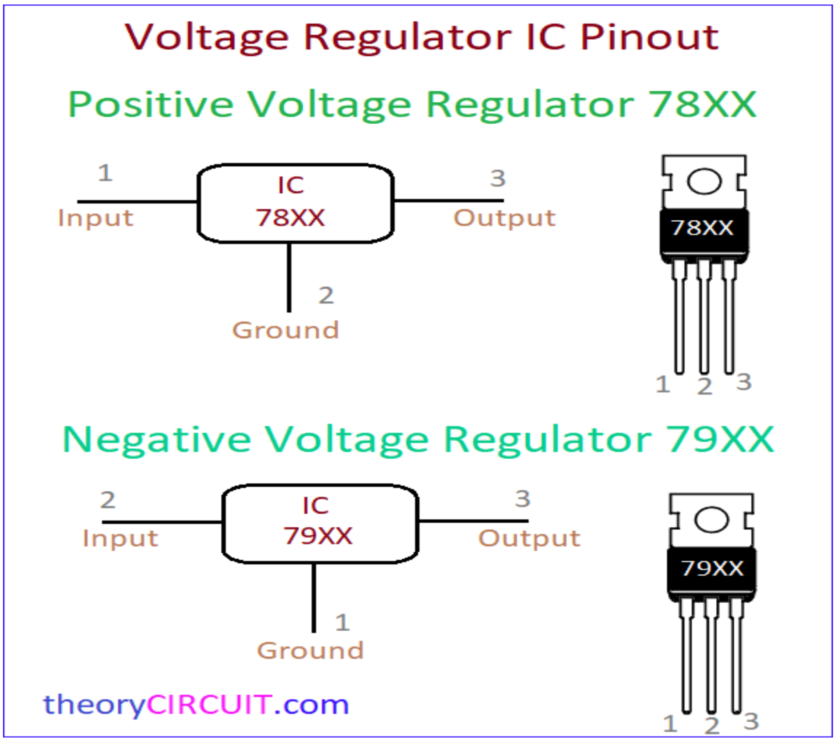
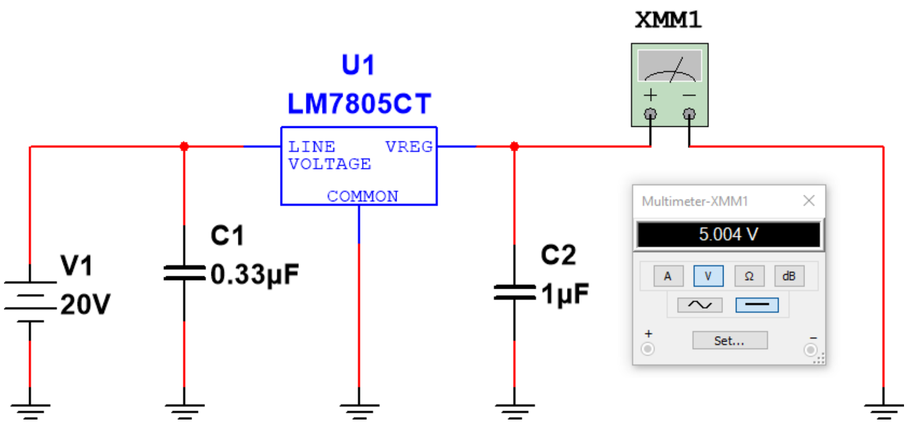
IC Regulator

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

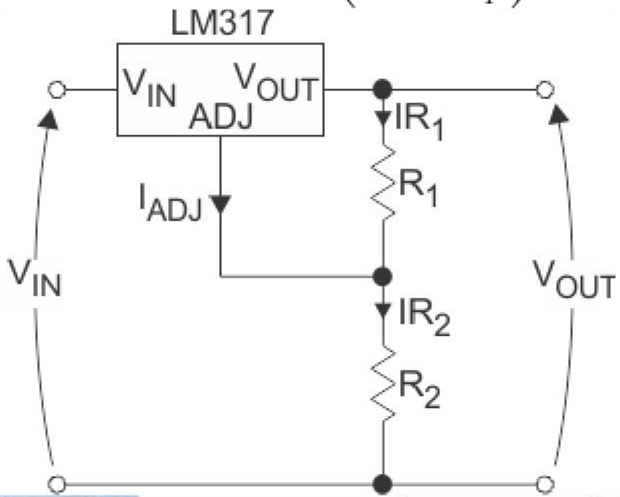
An example for LM7805 in Multisim

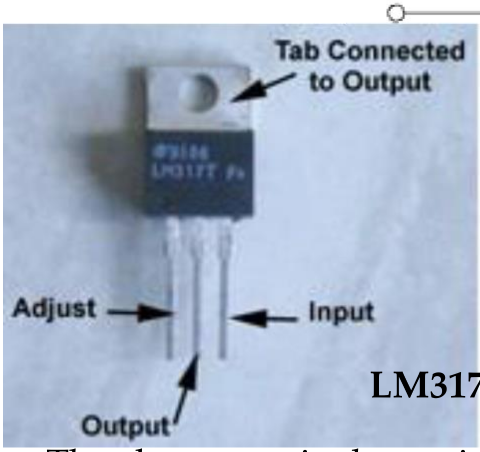


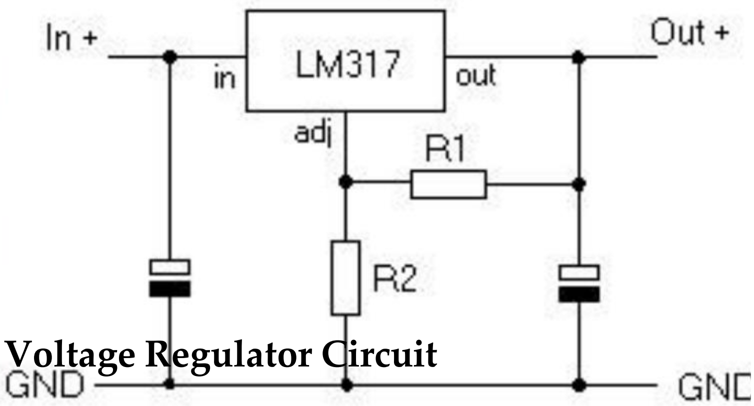


With IC's like LM 317 and 723, we can adjust the output voltage to a required constant value. The figure below shows the LM317 voltage regulator. The output voltage can be adjusted by adjusting the values of resistances R_1 and R_2. Usually, coupling capacitors of values about 0.01µF to 10µF need to be connected at the output and input to address input noise and output transients. Ideally, the output voltage is given by

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

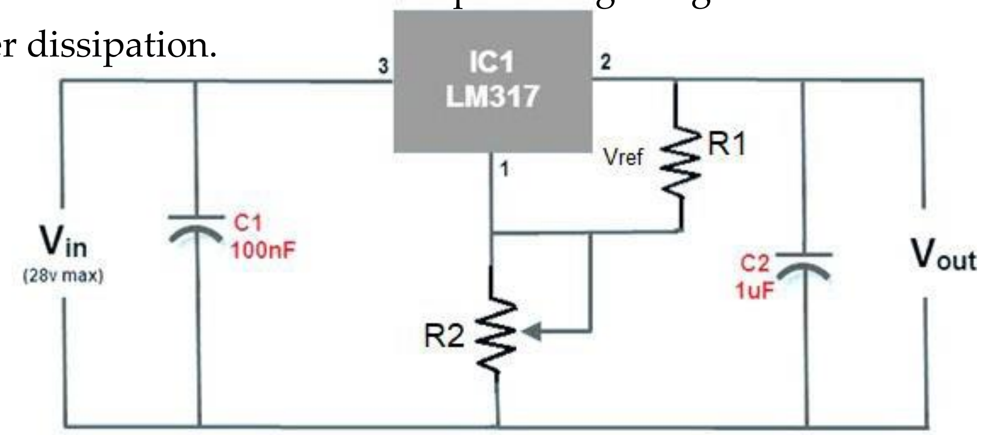






LM317 Voltage Regulator Circuit

The three terminals are input pin, output pin and adjustment pin. The LM317 circuit is shown in the below figure is a typical configuration of the LM317 voltage regulator circuit diagram including the decoupling capacitors. This LM317 circuit is capable to provide variable DC power supply with output of 1A and can be adjusted up to 30V. The circuit consists of a low-side resistor and high-side resistor connected in series forming a resistive voltage divider which is a passive linear circuit used to produce an output voltage which is a fraction of its input voltage. Decoupling capacitors are used for decoupling or to prevent undesired coupling of one part of an electrical circuit from another part. To avoid the effect of noise caused by some circuit elements over the remaining elements of the circuit, the decoupling capacitors in the circuit are used for addressing the input noise and output transients. A heat sink is used with the circuit to avoid the components getting overheated due to more power dissipation.



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

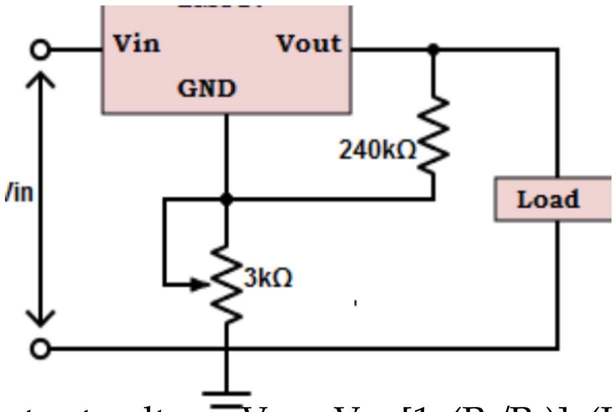
$$I_{out} = (V_{ref}/R_1) + I_{adj}$$

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, $V_{Out} = V_{REF}[1=(R_2/R_1)]+(I_{ADJ}\times R_2)=1.25V_{in}\times$ $[1+(3k\Omega/240\Omega)] +(100\mu A\times 3k\Omega)= 16.875 +0.3$.
=> V_{Out}=17.17v.

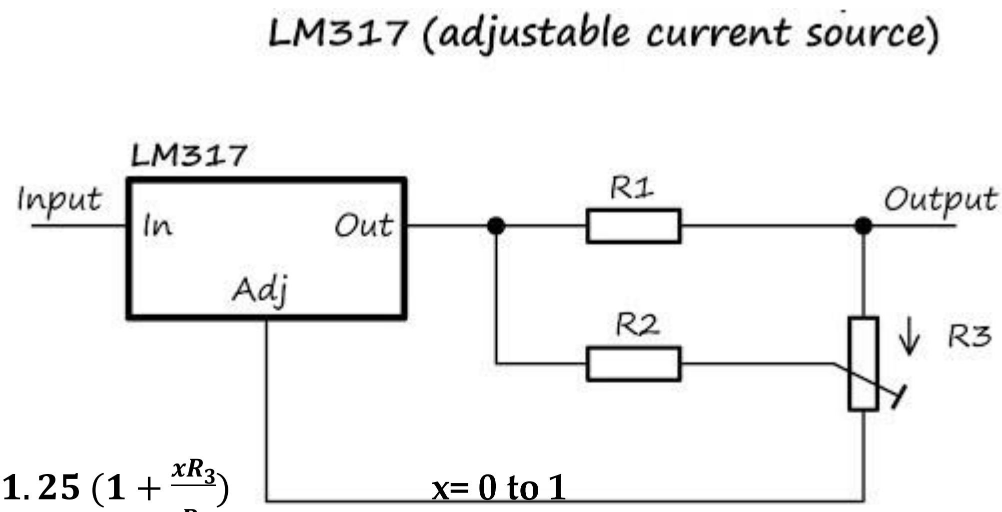
Ex9: Drive the following questions

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

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

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

Adjustable Current Regulator



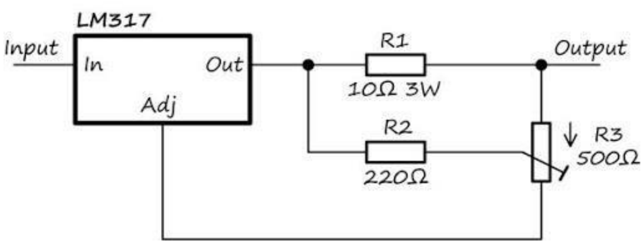
$$V_{R1} = 1.25\left(1 + \frac{xR_3}{R_2}\right)$$

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

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

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

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



LM317 adjustable current source
approx. 125-400mA range

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Full Regulated Power Supply Using Multisim