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XMUT204 Electronic Design

Demo 3b - Voltage Regulator Simulation in LTspice

1. Introduction

In this tutorial, we will see about one of the most commonly used regulator IC's, the 7805 voltage regulator IC. A regulated power supply is very much essential for several electronic devices due to the semiconductor material employed in them have a fixed rate of current as well as voltage. The device may get damaged if there is any deviation from the fixed rate.

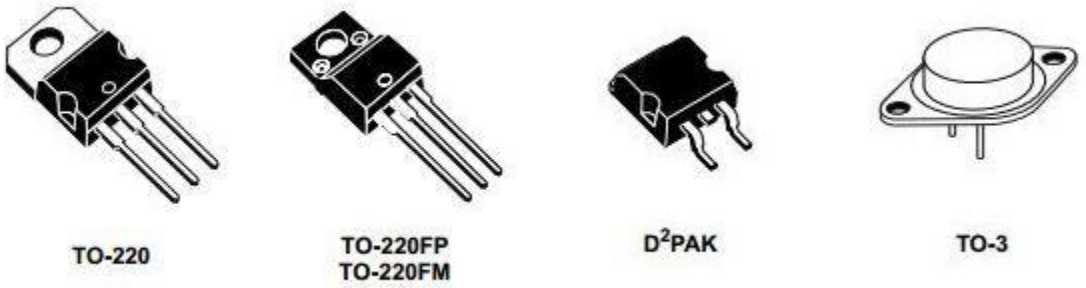
One of the important sources of DC Supply are batteries. But, using batteries in sensitive electronic circuits is not a good idea as batteries eventually drain out and deviate from their normal over time.

Also, the voltage provided by batteries are typically 1.2 V, 3.7 V, 9 V and 12 V. This is good for circuits whose voltage requirements are in that range. But, most of the TTL IC's work on 5 V logic and hence we need a mechanism to provide a consistent 5 V Supply.

Then, we have 7805 voltage regulator IC to the rescue. It is an IC in the 78XX family of linear voltage regulators that produce a regulated 5 V as output.

2. A Brief Note on 7805 Voltage Regulator

7805 is a three terminal linear voltage regulator IC with a fixed output voltage of 5 V which is useful in a wide range of applications. Currently, the 7805 voltage regulator IC is manufactured by Texas Instruments, ON Semiconductor, ST Microelectronics, Diodes incorporated, Infineon Technologies, etc.



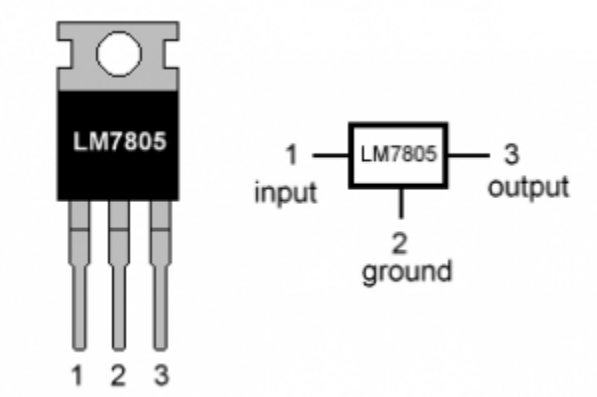
They are available in several IC packages like TO-220, SOT-223, TO-263 and TO-3. Out of these, the TO-220 package is the most commonly used one (it is the one shown in the above image).

Some of the important features of the 7805 IC are as follows:

- It can deliver up to 1.5 A of current (with heat sink).
- Has both internal current limiting and thermal shutdown features.
- Requires very minimum external components to fully function.

The 7805 Voltage Regulator IC

As mentioned earlier, 7805 is a three terminal device with the three pins being: 1. INPUT, 2. GROUND and 3. OUTPUT. The following image shows the pins on a typical 7805 IC in TO-220 Package.



Design Rating of 7805 IC

- Input voltage range: 7 V – 35 V
- Current rating: Ic = 1 A
- Output voltage range: VMax = 5.2 V and VMin = 4.8 V

Pin Details of 7805 IC

The pin description of the 7805 is described in the following table:

Pin No.	Pin	Function	Description
1	INPUT	Input voltage (7 V – 35 V)	This pin of the IC positive unregulated voltage is given in regulation.
2	GROUND	Ground (0 V)	This is the pin where the ground is given. This pin is neutral for equally the input and output.
3	OUTPUT	Regulated output; 5 V (4.8 V-5.2 V)	The output of the regulated 5 V volt is taken out at this pin of the IC regulator.

Application Areas for 7805 IC

7805 IC is used in a wide range of circuits. The major ones being:

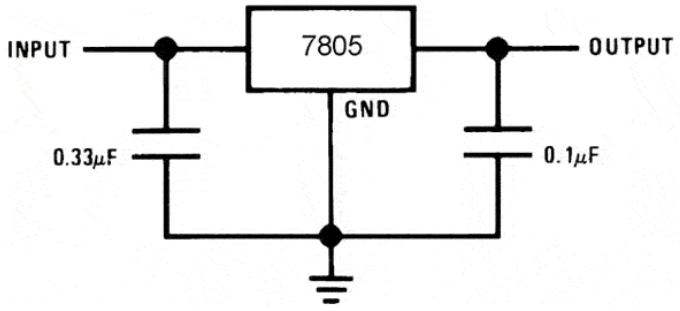
- Fixed-Output Regulator
- Positive Regulator in Negative Configuration
- Adjustable Output Regulator
- Current Regulator
- Adjustable DC Voltage Regulator
- Regulated Dual-Supply
- Output Polarity-Reversal-Protection Circuit
- Reverse bias projection Circuit

The 7805 IC also finds usage in building circuits for: inductance meter, phone charger, portable CD player, infrared remote control extension and UPS power supply circuits. More detailed information about 7805 IC can be found in the datasheet.

3. Basic Circuit of 7805

As we have previously talked about regulated power supply as a device that works on DC voltages and it can uphold its output accurately at a fixed voltage all the time even if there is a significant alteration in the DC input voltage.

As per the datasheets of 7805 IC, the basic circuit required for 7805 to work as a complete regulator is very simple. In fact, if the input supply is an unregulated DC voltage, then all you need are two capacitor (even those are not mandatory depending on the implementation).



The above circuit shows all the components required for a 7805 IC to work properly. The 0.33 µF capacitor near the input is required only if the distance between the regulator IC and the power supply filter is high. Also, the 0.1 µF capacitor near the output is optional and if used, it helps in the transient response.

In this circuit, VIN is the input voltage to the 7805 IC and the source can be from either a battery of an unregulated DC. VOUT is the output of the 7805 IC, which is a regulated 5 V.

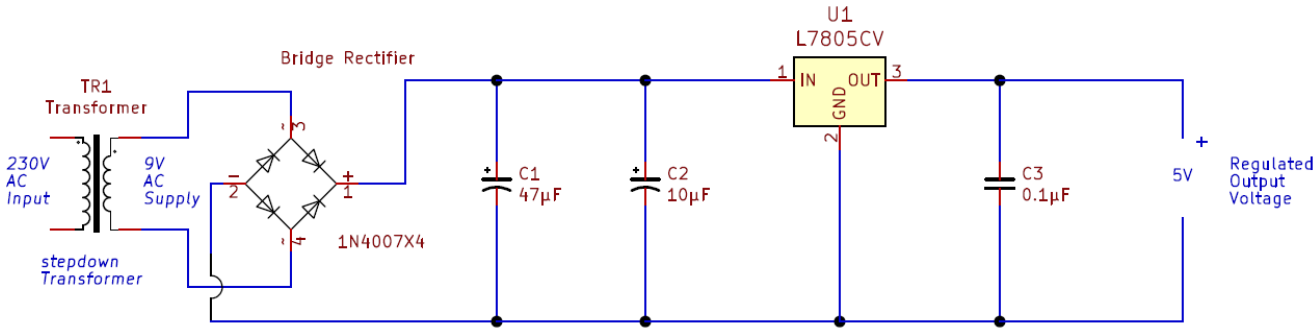
How to Get Constant DC Power Supply from AC?

Although batteries can be used as input to the 7805 voltage regulator IC, we face certain bumps like frequent discharge of batteries and reduction of battery voltage levels over a period of time.

The best alternative to using Batteries is to provide an unregulated but rectified DC voltage from an AC Source. Since AC Source is easily available as mains supply, we can design a circuit to convert AC Mains to DC and provide it as input to the 7805 voltage regulator IC.

Circuit Diagram

The following image shows the circuit diagram of producing a regulated 5 V from AC Mains supply.



Components Required

- 230 V-12 V Step Down Transformer
- Bridge Rectifier (or 4 PN Diodes – 1N4007)
- 1A Fuse
- 1000 µF Capacitor
- 7805 Voltage Regulator IC
- 0.22 µF Capacitor
- 0.1 µF Capacitor
- 1N4007 Diode

Voltage sources in a circuit may have fluctuations resulting in not providing fixed voltage outputs. A voltage regulator IC maintains the output voltage at a constant value. 7805 IC, a member of 78xx series of fixed linear voltage regulators used to maintain such fluctuations, is a popular voltage regulator integrated circuit (IC). The xx in 78xx indicates the output voltage it provides. 7805 IC provides +5 Volts regulated power supply with provisions to add a heat sink.

Device Heat Management

As you may have noticed, there is a significant difference between the input voltage & the output voltage of the voltage regulator. This difference between the input and output voltage is released as heat. The greater the difference between the input and output voltage, more the heat generated. If the regulator does not have a heat sink to dissipate this heat, it can get destroyed and malfunction.

Hence, it is advisable to limit the voltage to a maximum of 2-3 Volts above the output voltage. So, we now have two options. Either design your circuit so that the input voltage going into the regulator is limited to 2-3 Volts above the output regulated voltage or place an appropriate heatsink, that can efficiently dissipate heat.

What to do with all the heat?

7805 is not very efficient and has drop-out voltage problems. A lot of energy is wasted in the form of heat. If you are going to be using a heatsink, better calculate the heatsink size properly. The below formula should help in determining appropriate heatsink size for such applications.

Heat generated = (input voltage – 5) x output current. If we have a system with input 15 volts and output current required is 0.5 amperes, we have: (15 – 5) x 0.5 = 10 × 0.5 = 5 W. This 5 W energy is being wasted as heat, hence an appropriate heatsink is required to disperse this heat. On the other hand, energy actually being used is (5 x 0.5 Amp) = 2.5 W. So twice the energy, that is actually utilized is wasted.

On the other hand, if 9 V is given as input at the same amount of load: (9-5) x 0.5 = 2 W. This 2 W energy will be wasted as heat.

What we learn: Higher the input voltage, less efficient your 7805 will be. What about an estimated efficient input voltage would be at about 7.5 V?

Other circuit components?

If your voltage regulator is situated more than 25 cm (10 inches) from the power supply, capacitors are needed to filter residual AC noise. Voltage regulators work efficiently on a clean DC signal being fed. The bypass capacitors help reduce AC ripple. Essentially, they short AC noise from the voltage signal and allow only DC voltage into the regulator. The two capacitors are not necessarily required and can be omitted if you are not concerned about line noise.

However, for a mobile phone charger or logic assessment, you require a nice clean DC line. Capacitors will be beneficial in this case as they are good at maximizing voltage regulation. The values of capacitors can also be changed slightly.

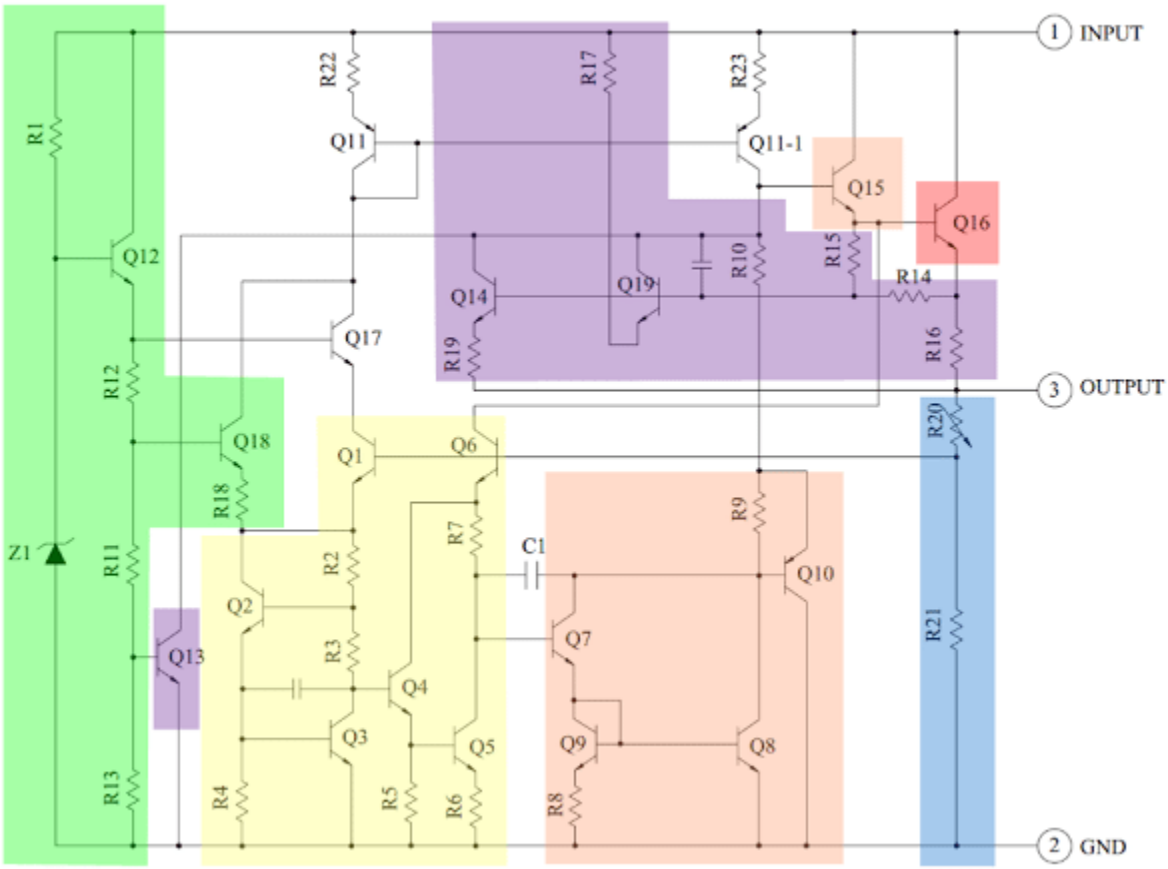
Manufacturer Datasheet of 7805

The datasheet of 7805 IC gives the complete information about it including its operating conditions, different types of packages, configurations and recommended operating conditions etc. The datasheet tells us that:

- The IC comes in different packages like TO 220, TO 3, SOT 223, TO 92 and TO 252 out of which SOT 223 and TO 252 are SMD and the others are through-hole type with long leads.
- Recommended input voltage (Vi) range is from 7 V DC to 25 V DC.
- It can provide output current up to 1.5 Amperes.
- It has three pins/leads input voltage (Vi), Ground/common and the output voltage (Vo). The common pin is the middle one which should be connected to the ground for both the input and the output.
- And the very important thing from the datasheet is that about the external components, the input, and the output capacitors. We should connect, as per the datasheet, a filter capacitor at the input and a filter capacitor and a low pass filter at the output.
- Since it is a linear regulator (the one which drops the unwanted power across its junction as heat), the package usually contains a portion for attaching a heat sink to the heat transfer.

4. Schematic of 7805 IC

An internal diagram that shows the internal parts and components of 7805 IC is given below.



Note:

- Voltage control (red).
- Bandgap reference (yellow).
- Error amplifier (orange).
- Start-up circuit (green).
- Protection (purple)*.
- Voltage divider (blue).

* Protection: overheating, excessive input voltage and excessive output current.

Voltage Control

The heart of the 7805 IC is a transistor (Q16) that controls the current between the input and output and thus controlling the output voltage.

Bandgap Reference

The bandgap reference (yellow) keeps the voltage stable. It takes the scaled output voltage as input (Q1 and Q6) and provides an error signal (to Q7) for indication if the voltage is too high or low. The key task of the bandgap is to provide a stable and accurate reference, even as the chip's temperature changes.

Error Amplifier

The error signal from the bandgap reference is amplified by the error amplifier (orange). This amplified signal controls the output transistor through Q15. This closes the negative feedback loop controlling the output voltage.

Start-up Circuit

The start-up circuit (green) provides initial current to the bandgap circuit, so it does not get stuck in an "off" state.

Protection

The circuit in (purple) provides protection against overheating (Q13), excessive input voltage (Q19) and excessive output current (Q14). These circuits reduce the output current or shutdown the regulator, protecting it from damage in case of a fault.

Voltage Divider

The voltage divider (blue) scales down the voltage on the output pin for use by the bandgap reference.

The 7805's scaled output provides the input voltage (Vin) to the bandgap reference and the bandgap provides an error signal as the output. The 7805's bandgap circuit removes the feedback loop that exists inside a traditional bandgap reference. Instead, the entire chip becomes the feedback loop.

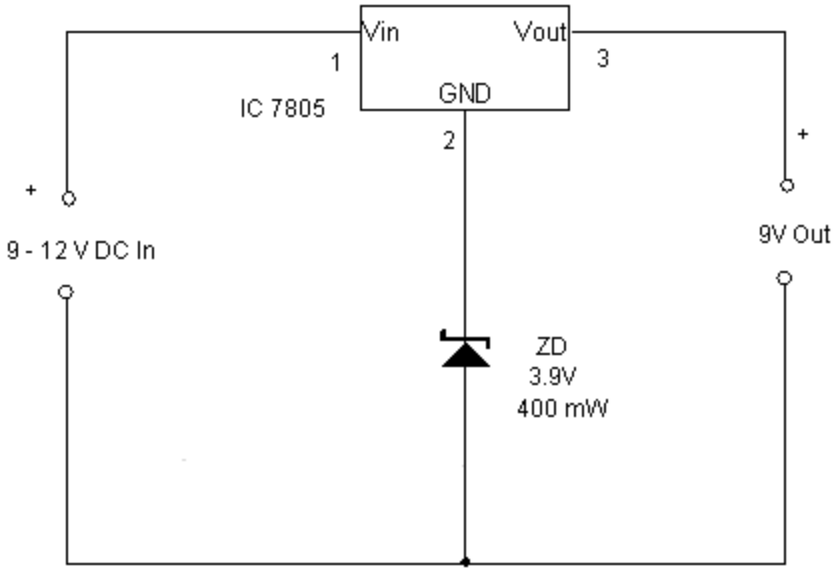
If the output voltage is correct (5 V), then the voltage divider provides 3.75 V at Vin. Any change in output voltage propagates through Q6 and R7, causing the voltage at the base of Q7 to rise or fall accordingly. This change is amplified by Q7 and Q8, generating the error output. The error output, in turn, decreases or increases the current through the output transistor. The negative feedback loop adjusts the output voltage until it is correct.

5. Typical 7805 Circuit Configurations

Fixed voltage Positive and Negative regulator ICs are used in circuits to give precise regulated voltage. 78XX series regulator IC can handle maximum 1 Ampere current. The Regulator ICs require minimum 1.5 higher input voltage than their voltage rating. For example, 7805 IC requires minimum 6.5 Volts to give 5 Volt output. Here are some circuit designs of IC 7805 to monitor the output voltage.

Circuit 1 – Zener Diode

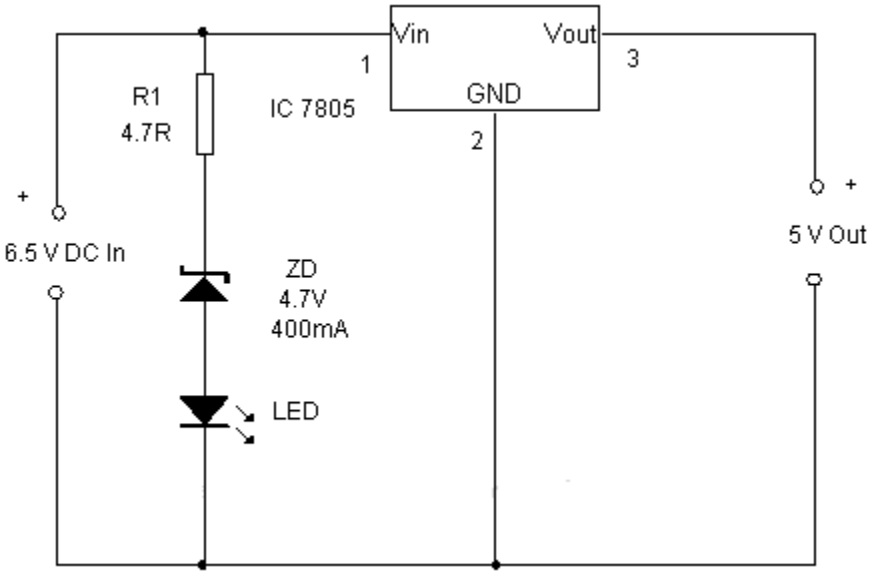
This is the manipulation of the Regulator IC 7805 to give 9 Volt regulated output. Normally the pin 2 of the regulator IC is connected to the ground. Here it is connected to a 3.9 Volt Zener diode. So, the output from the Regulator IC will be 9 Volts.



Circuit 2 – Zener Diode with Indicator

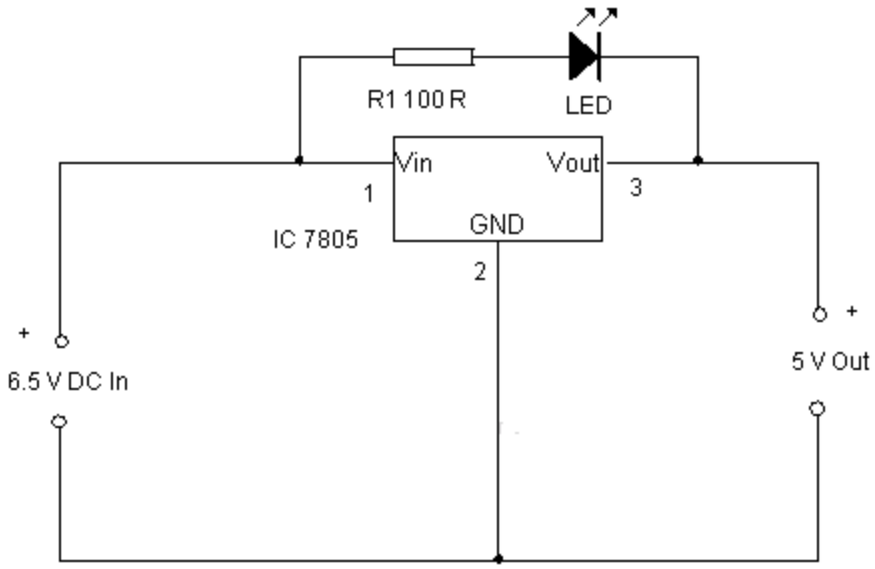
This circuit can tell whether the IC 7805 is giving output or not. IC 7805 requires minimum 6.5 Volt input to give 5 Volt regulated output. When the input voltage is above 6.5 Volts, Zener conducts and LED turns on indicating sufficient input voltage. Diffuse type Red LED requires 1.8 Volts and Zener 4.7 Volts.

So, to activate both these, input voltage should be minimum 6.5 Volts. If the input voltage drops below 6.5 Volts, Zener cut off and LED turns off. This indicates the zero output from the regulator IC.



Circuit 3 – Indicator Only

This is a simple LED monitor to tell the output voltage from 7805. If the input voltage is above 6.5 Volts, LED shows full brightness. When the input voltage reduces below 6.5 Volts, brightness of LED decreases.



6. Simulating 7805 in LTspice

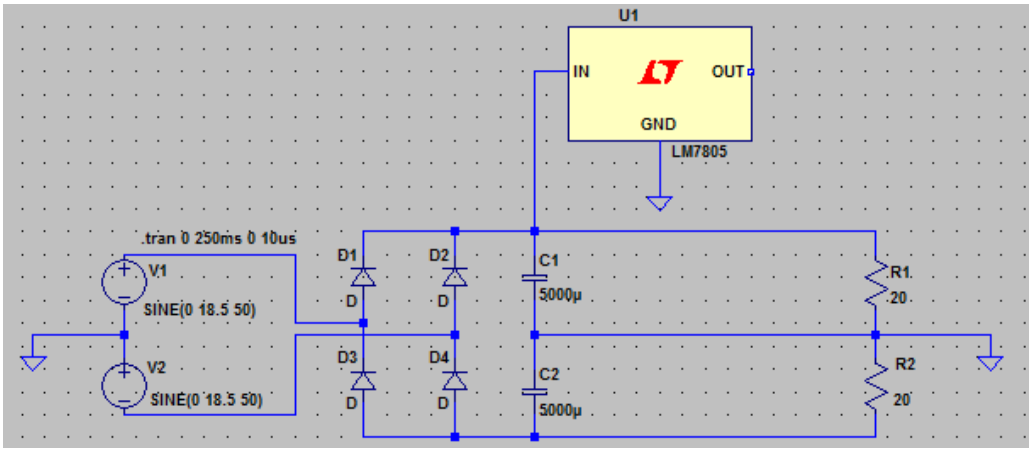
7805 voltage regulator can be implemented through several approaches in LTspice. We can use the equivalent built-in 7805 devices in the library of the LTspice, create a model of 7805 using existing similar device, or create 7805 from its internal parts and components.

Use 7805 Equivalent Model in LTspice

Using the equivalent 7805 IC in the library of LTspice. The equivalent models are labelled as:

- LT1085-3.3 for 3.3 V,
- LT1085-3.6 for 3.6 V,
- LT1085-5 for 5 V, and
- LT1085-12 for 12 V.

These are available in the Power Supply folder in the LTspice component library.



7805 Internal Model in LTSpice

You can opt also for creating the 7805 model in LTspice from scratch i.e. creating the model from 7805 internal parts and components. As you are aware the integrated circuit of 7805 consists of a number active (e.g. transistors i.e. NPN and PNP types and diode i.e. a zener diode) and passive components (e.g. resistors and capacitors).

Notice that the model given above consists of parts and components of the 7805 following the details given in the datasheet from Texas Instrument. The internal components of the 7805 are based on several predetermined device models:

- The model for 6.3 zener diode is based on. The characteristic of this zener diode is its BV = 6.3 V.
- The model for 3.5 zener diode is based on. The characteristic of this zener diode is its BV = 3.5 V
- The model for NPN transistor is based on. The SPICE characteristics of the NPN model is based on BF=125, Cje=0.5pF, Cjc=0.5pF, and Rb = 500 Ω.
- The model for PNP transistor is based on. The SPICE characteristics of the PNP model is based on BF=25, Cje=0.3pF, Cjc=1.5pF, and Rb = 250 Ω.

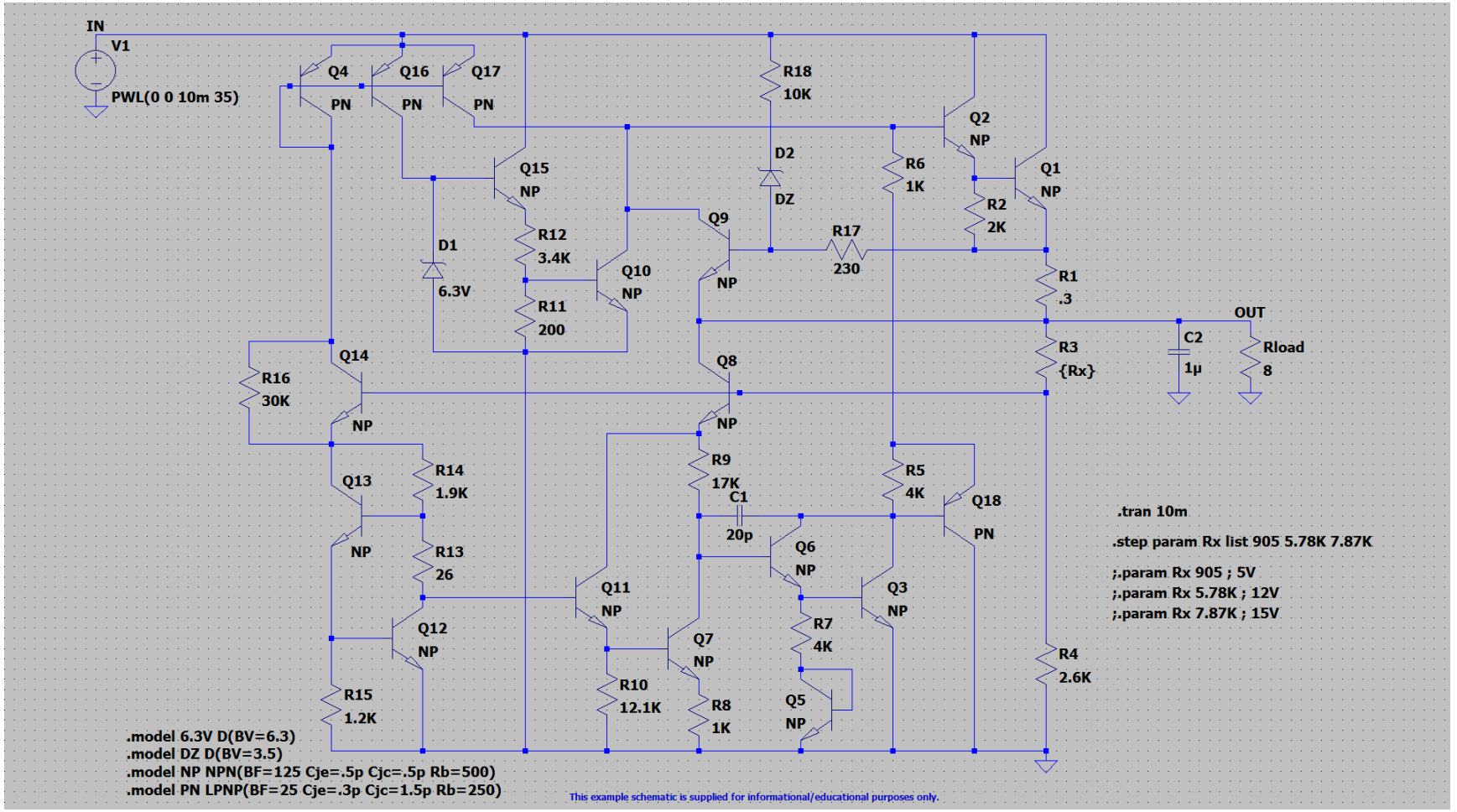
The simulation of 7805 integrated circuit in LTspice is performed using the following testing components:

- The voltage regulator is connected with voltage source configured as a PWL pulse generator with 10 millisecond duration and amplitude of 35 V.
- The load consists of 8 Ω resistor in parallel with a capacitor of value 1uF.

And the setup and conditions of simulation are:

- The transient simulation is carried out up to 10 m second period and the plots are based on step increments of resistance values of adjustable voltage divider resistor (Rx).
- The adjustable voltage divider resistor (Rx) is chosen either from 905 Ω for 5 V output, 5.78k Ω for 12 V output, and 7.87k Ω for 15 V output.

The following diagram shows the 7805 IC model based on the internal contents of 7805 voltage regulator IC.


IN
V1
PWL(0 0 10m 35)
Q4
Q16
Q17
PN
PN
PN
R18
10K
Q2
NP
D2
DZ
R6
1K
Q1
NP
R2
2K
Q15
NP
R12
3.4K
D1
6.3V
R11
200
Q10
NP
Q9
NP
R17
230
R1
.3
OUT
C2
1µ
Rload
8
R3
{Rx}
Q14
R16
30K
NP
Q8
NP
R9
17K
C1
20p
R14
1.9K
Q13
NP
R13
26
Q12
NP
R15
1.2K
Q11
NP
Q7
NP
R10
12.1K
R8
1K
R5
4K
Q18
PN
Q6
NP
Q3
NP
R7
4K
Q5
NP
R4
2.6K
.tran 10m
.step param Rx list 905 5.78K 7.87K
;.param Rx 905 ; 5V
;.param Rx 5.78K ; 12V
;.param Rx 7.87K ; 15V
.model 6.3V D(BV=6.3)
.model DZ D(BV=3.5)
.model NP NPN(BF=125 Cje=.5p Cjc=.5p Rb=500)
.model PN LPNP(BF=25 Cje=.3p Cjc=1.5p Rb=250)
This example schematic is supplied for informational/educational purposes only.