Demo 3b - Voltage Regulator Simulation in LTspice

XMUT204 Electronic Design

Overview*

1. The 7805 IC.
2. Basic circuit of 7805 based voltage regulator.
3. Internals of 7805 IC.
4. Typical circuit configuration.
5. Simulating 7805 in LTspice.

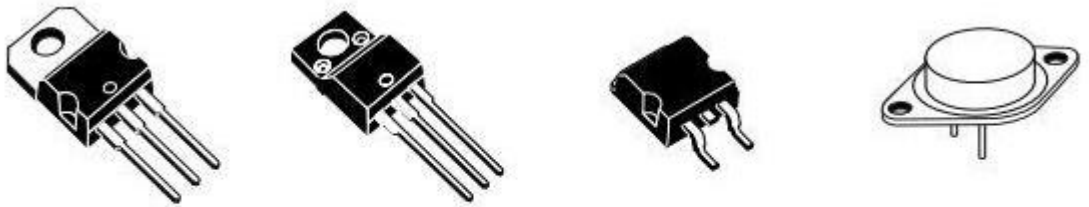
* Related to Design Project 1 – Power Supply (7805 Voltage Regulator)

The 7805 IC

- It 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.
- Manufactured by Texas Instruments, ON Semiconductor, ST Microelectronics, Diodes incorporated, Infineon Technologies, etc.

The 7805 IC

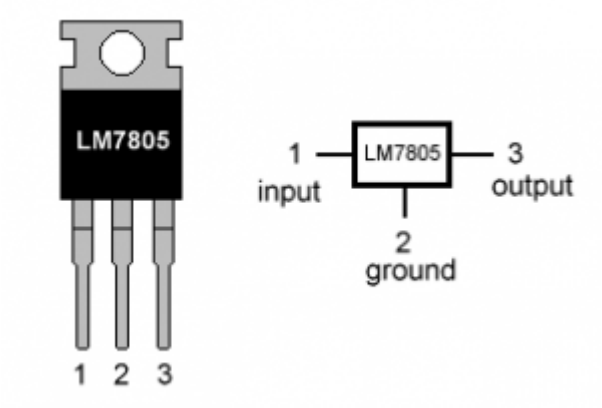
- Available in several IC Packages like TO-220, SOT-223, TO-263 and TO-3. Out of these, the TO-220 is most common.
- Some of the important features of the 7805 IC are as follows:
  - It can deliver up to 1.5 A of current (with heat sink) of voltage regulation.
  - Has both internal current limiting and thermal shutdown features.
  - Requires very minimum external components to fully function.



The 7805 IC

Design Rating:

- Input voltage range: 7 V – 35 V
- Current rating: Ic = 1 A
- Output voltage range: V_{Max} = 5.2 V and V_{Min} = 4.8 V



Pin Details:

Pin No.	Pin	Function	Description
1	INPUT	Input voltage (7 V – 35 V)	In this pin of the IC positive unregulated voltage is given in regulation.
2	GROUND	Ground (0V)	In this 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.

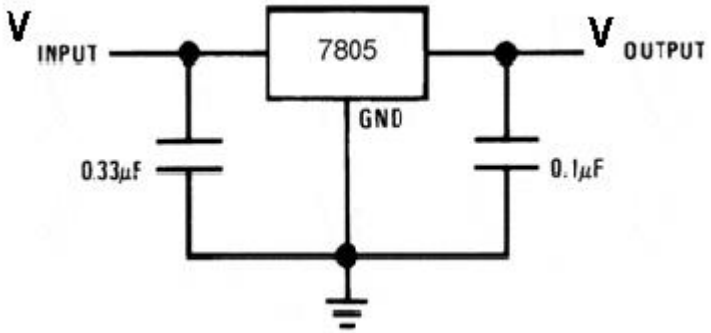
The 7805 IC

Applications of 7805 voltage regulator integrated circuit:

- 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

It is also used for: inductance meter, phone charger, portable CD player, infrared remote control extension and UPS power supply circuits.

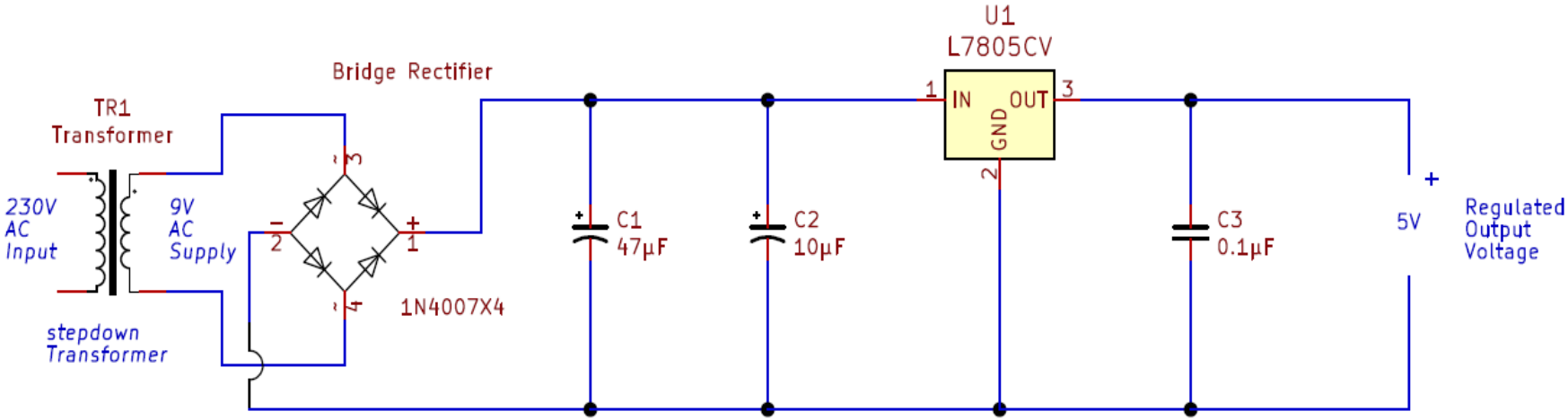
Basic Circuit of 7805 based Voltage Regulator



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, V_{IN} is the input voltage to the 7805 IC and the source can be from either a battery of an unregulated DC.
- V_{OUT} is the output of the 7805 IC, which is a regulated 5 V

Basic Circuit of 7805 based Voltage Regulator



Components required:

- 230 V - 9 V step down transformer.
- Bridge rectifier (or 4 PN diodes – 1N4007).
- 47 µF capacitor.
- 7805 voltage regulator IC.
- 10 µF capacitor.
- 0.1 µF capacitor.

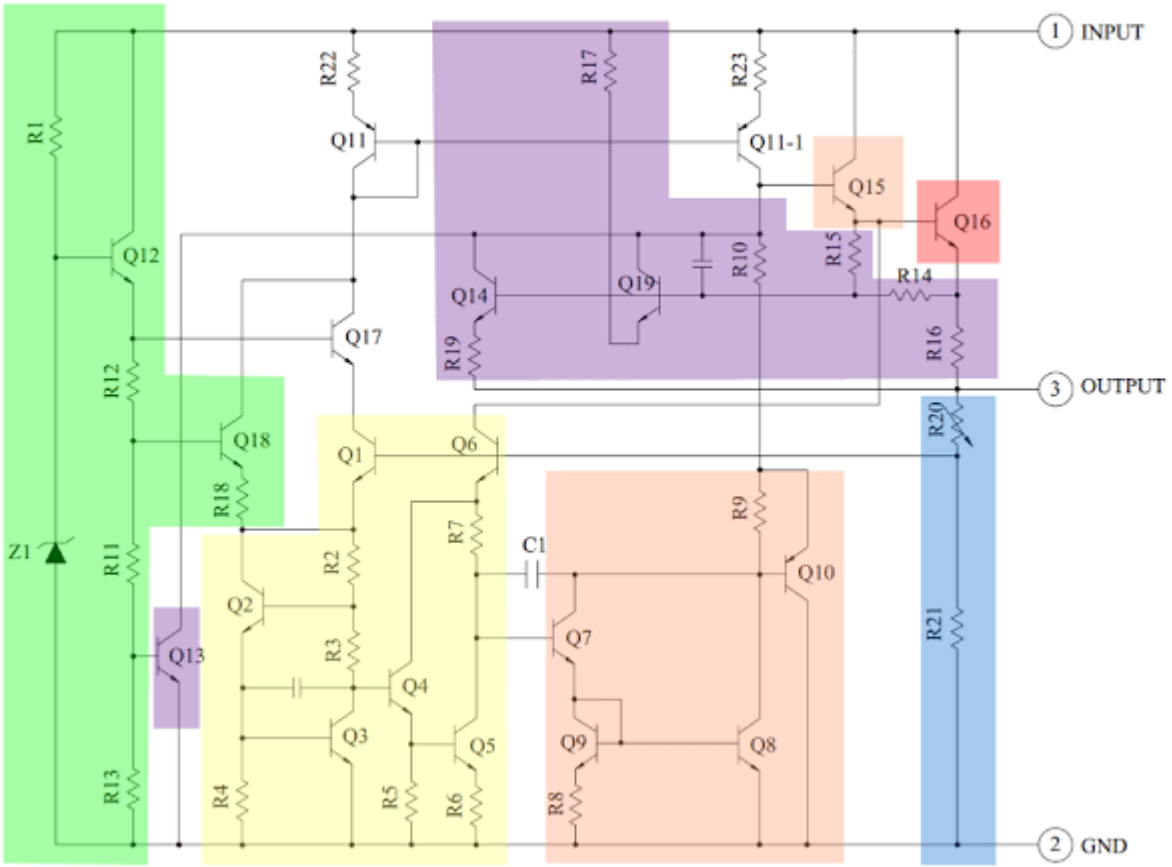
Basic Circuit of 7805 based Voltage Regulator

7805 is not very efficient and has drop-out voltage problems. A lot of energy is wasted in the form of heat.

- 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.

Internals of 7805 IC

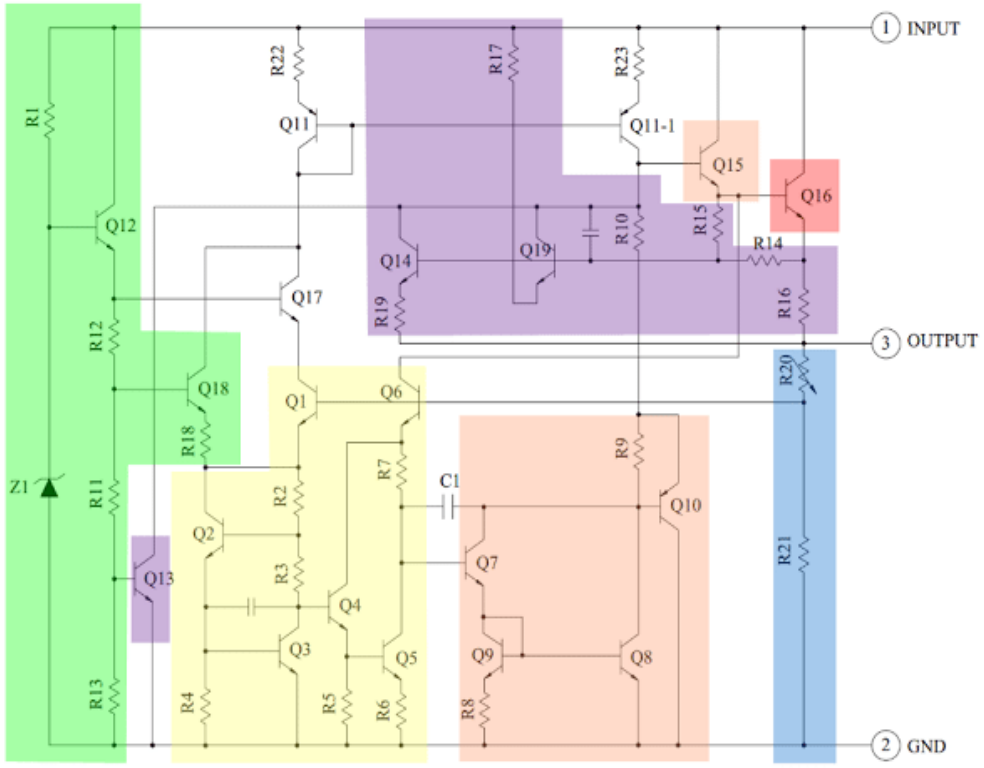
- The following diagram shows schematic of internal parts and components that make up 7805 regulator IC.



Internals of 7805 IC

The internal parts and components that make up 7805 regulator IC:

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

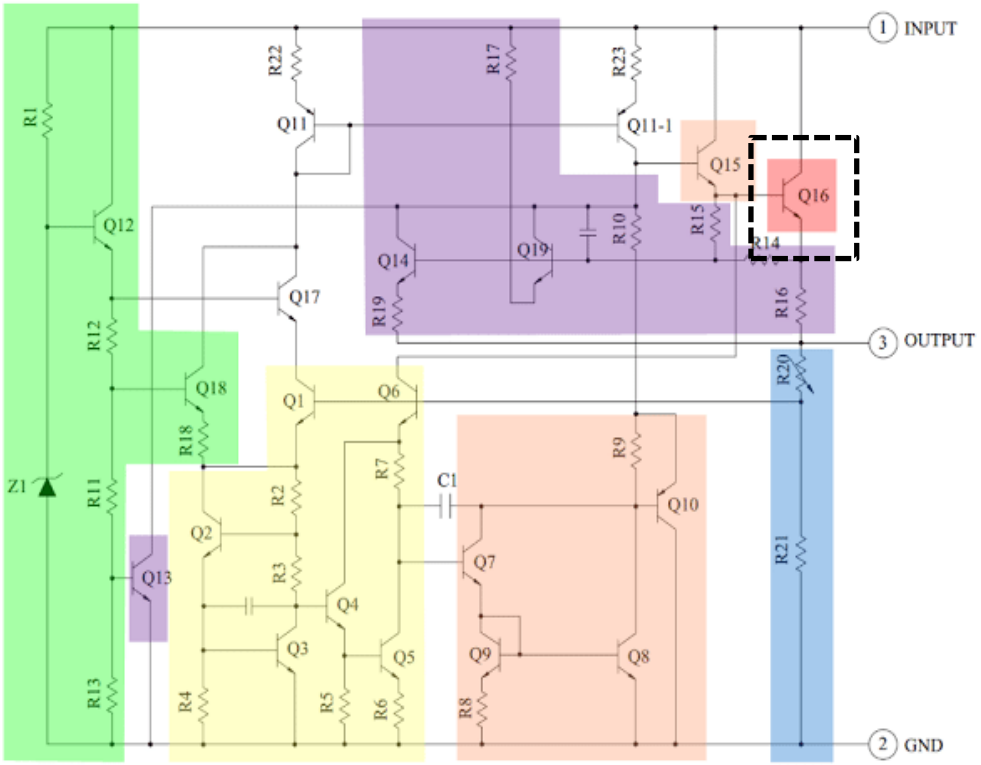


* protection: overheating, excessive input voltage and excessive output current.

Internals of 7805 IC

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.



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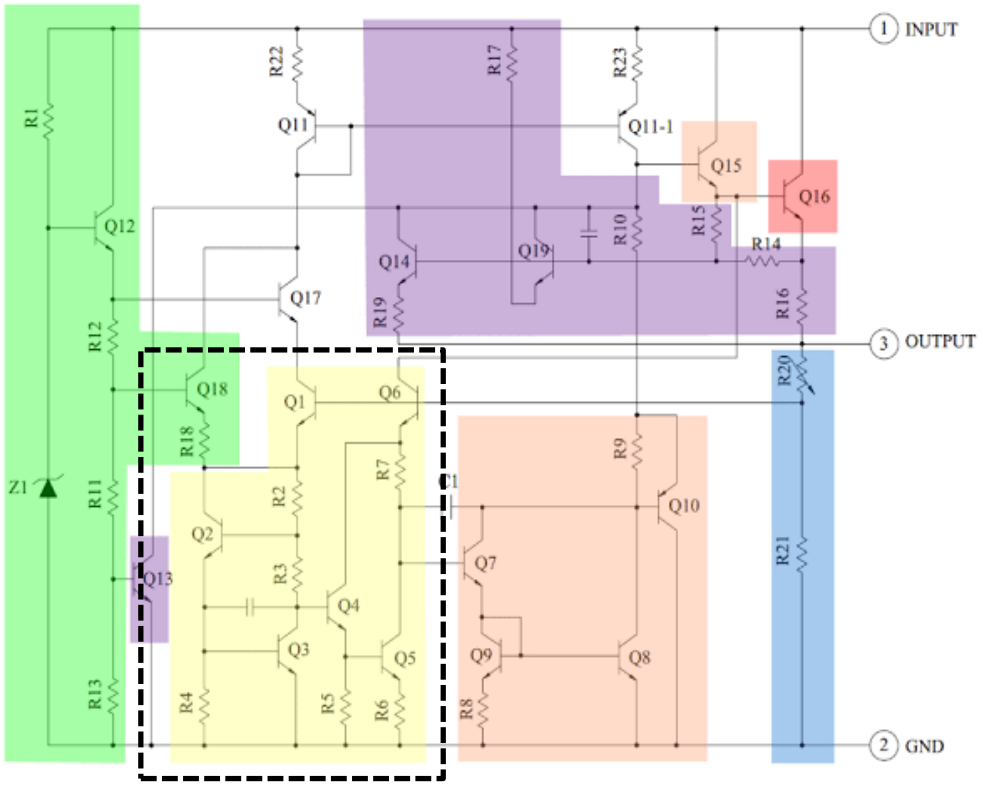
Internals of 7805 IC

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.



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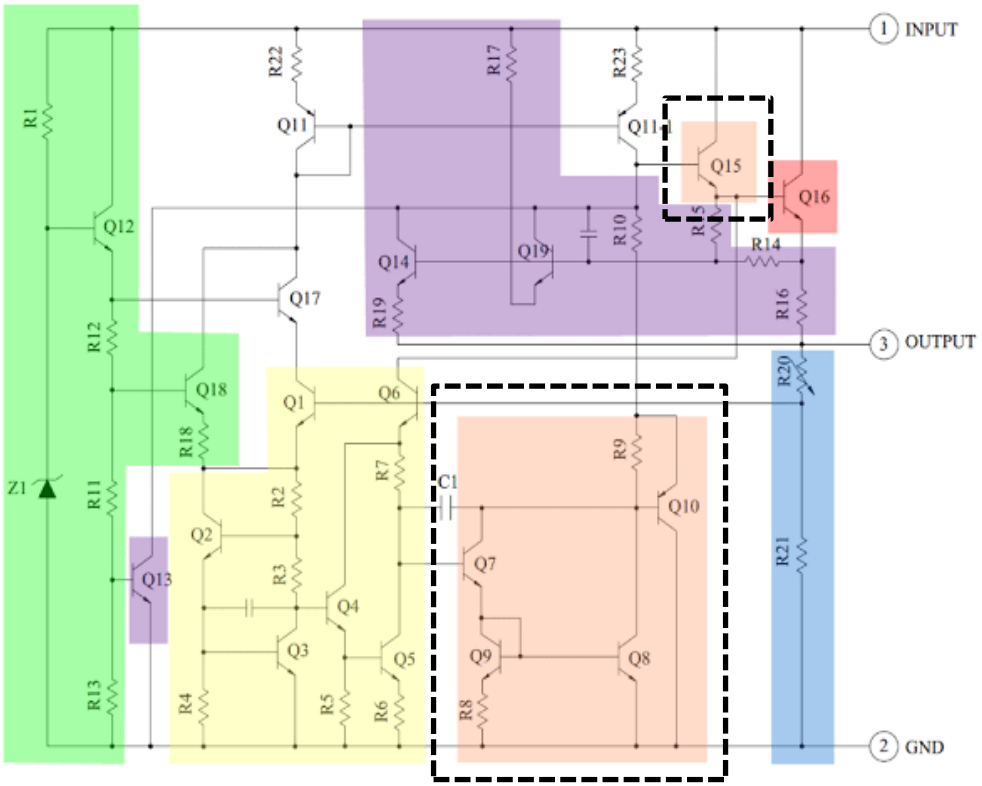
Internals of 7805 IC

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.



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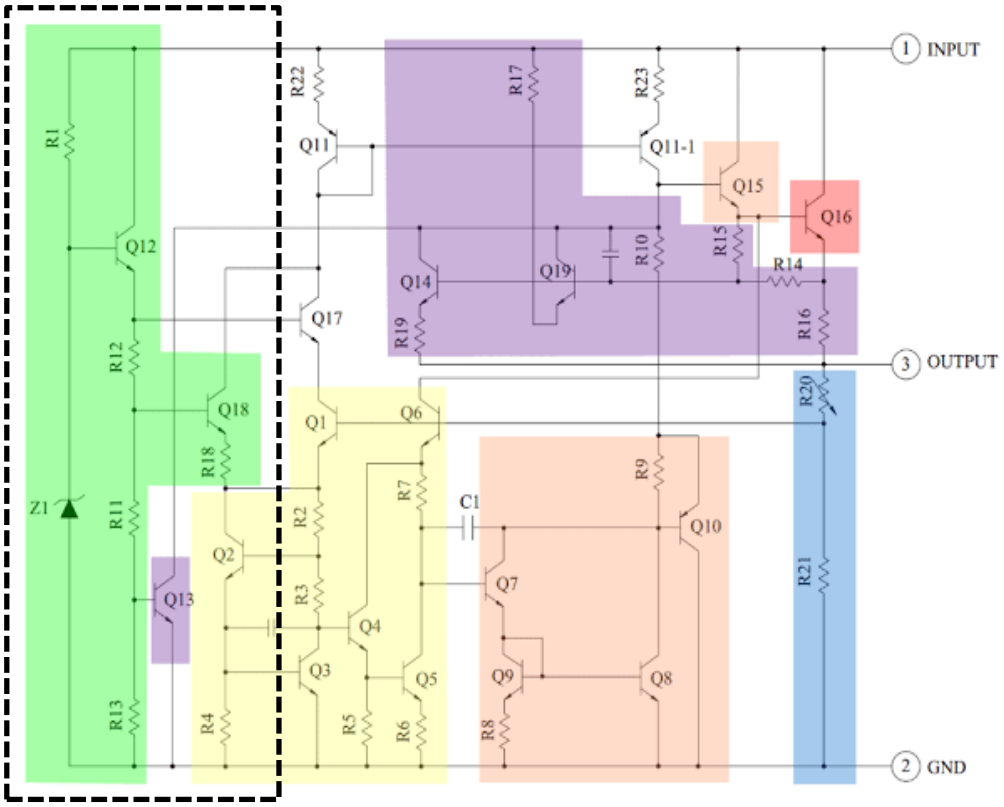
Internals of 7805 IC

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.



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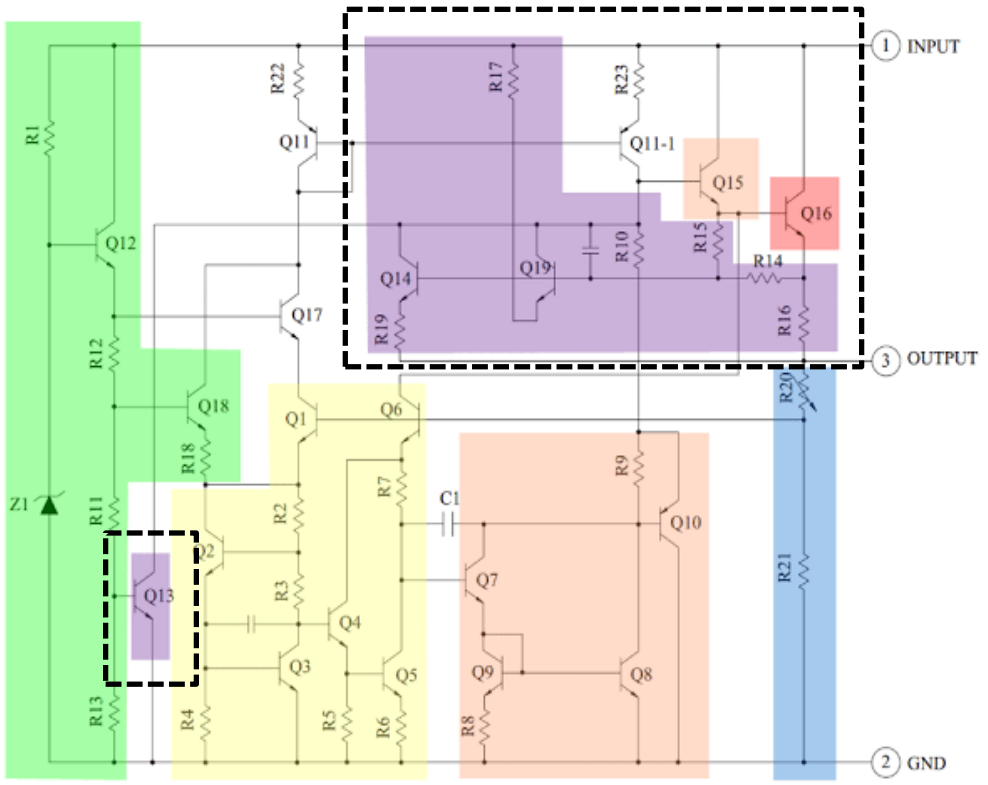
Internals of 7805 IC

Protection

- The circuit in (purple) circuit 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.



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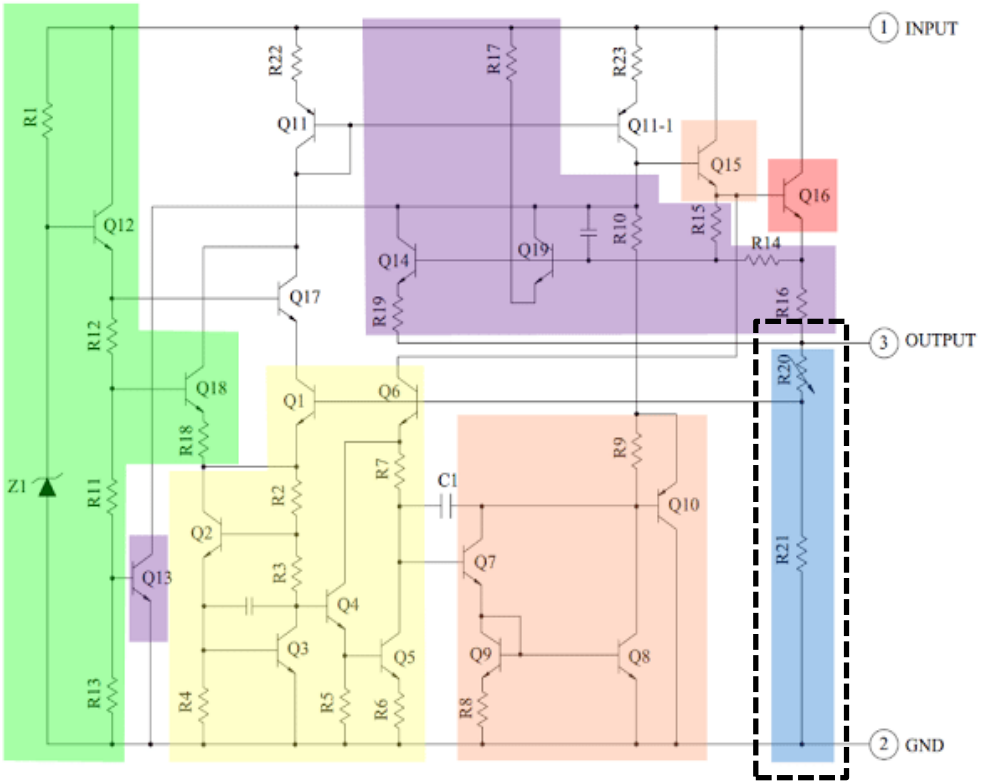
Internals of 7805 IC

Voltage Divider

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



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Internals of 7805 IC

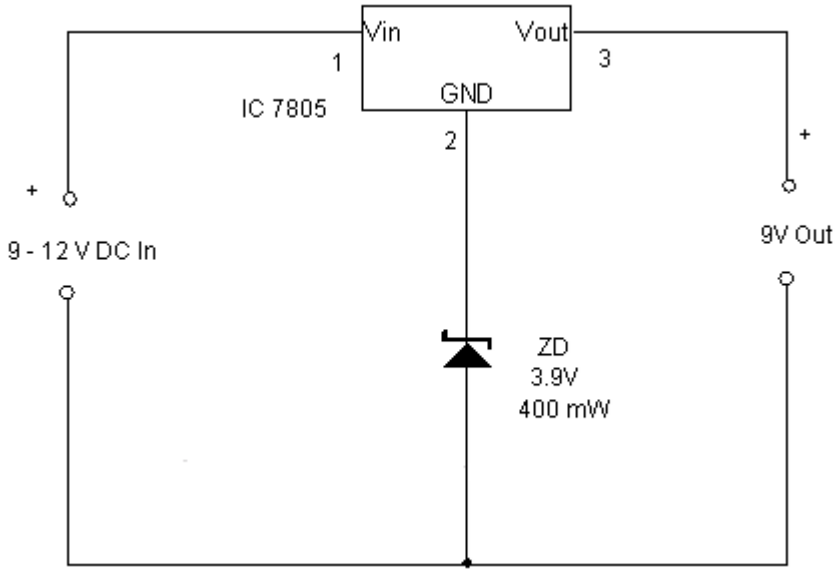
Scaling the Output

- 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.

Typical Circuit Configuration

Circuit 1

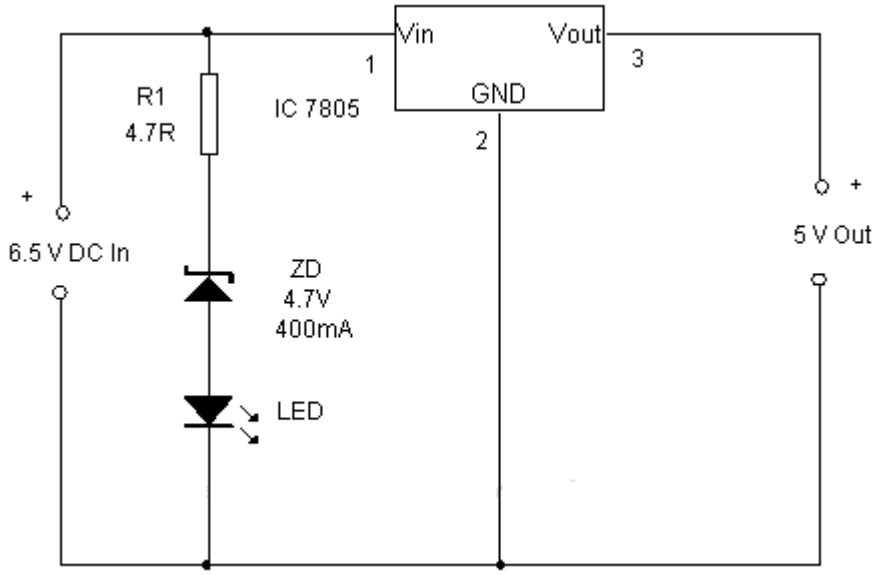
- This is the manipulation of the regulator IC 7805 to give 9 Volt regulated output.
- Normally the pin 2 of the regulator IC is connected to the ground.
- Here it is connected to a 3.9 Volt Zener diode. So the output from the regulator IC will be 9 Volts.



Typical Circuit Configuration

Circuit 2

- 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.

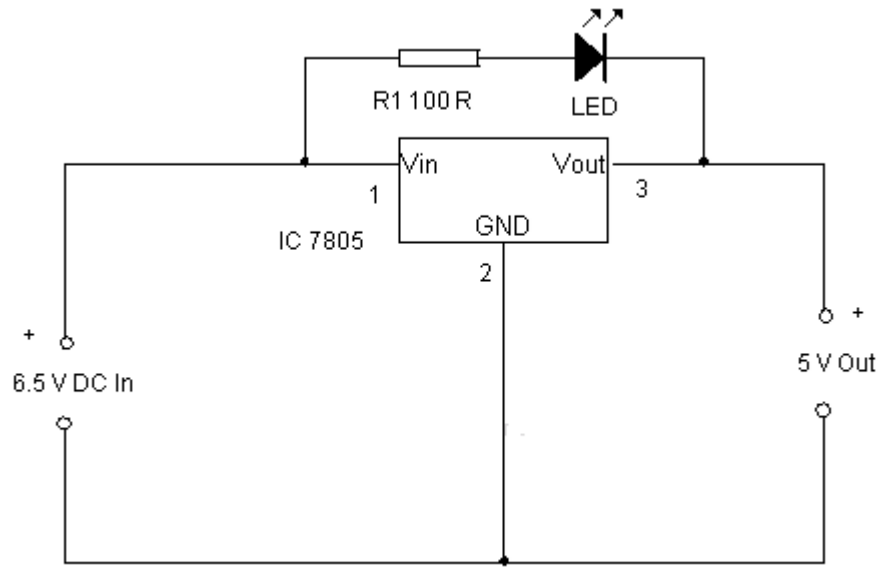


- Diffuse type Red LED requires 1.8 Volts and Zener 4.7 Volts .So to activate both these, input voltage should be minimum 6.5 Volts.
- If the input voltage drops below 6.5 Volts, Zener cut off and LED turns off. This indicates the zero output from the regulator IC.

Typical Circuit Configuration

Circuit 3

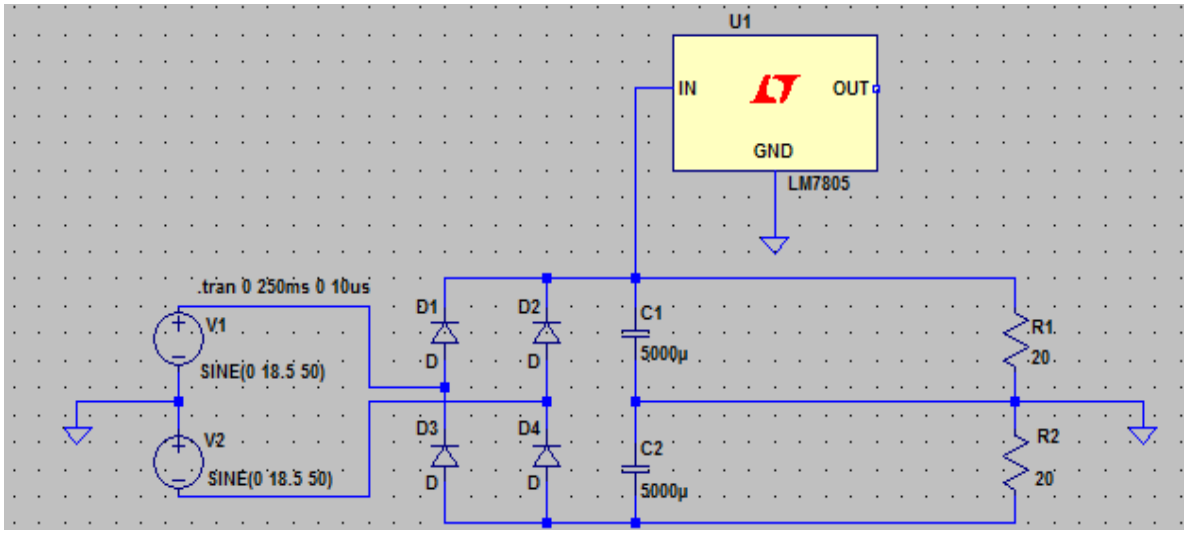
- This is a simple LED monitor to tell the output voltage from 7805.
- If the input voltage is above 6.5 Volts, LED shows full brightness.
- When the input voltage reduces below 6.5 Volts, brightness of LED decreases.



Simulating 7805 in LTspice (Built-in Model)

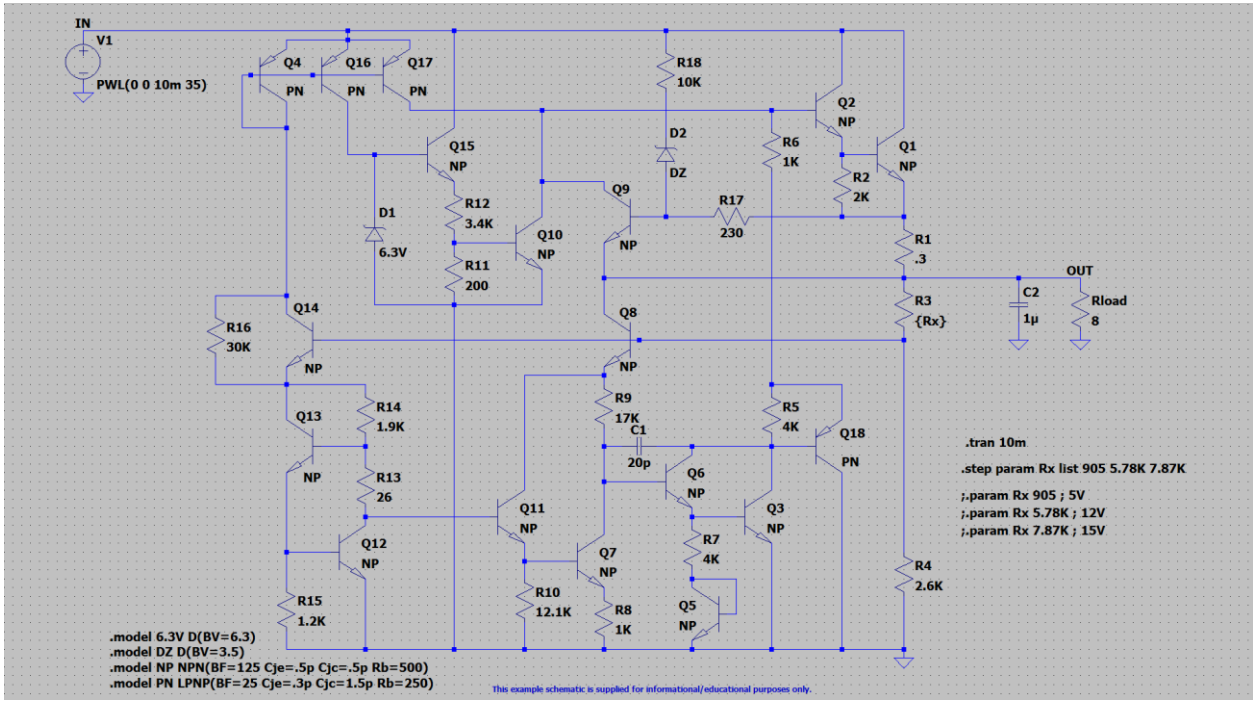
Using the equivalent 7805 IC in the library of LTspice. The equivalent models in LTspice are labelled as:

- 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.



Simulating 7805 in LTspice (Internal Device Model)

- You can opt also for creating the 7805 model in LTspice from scratch i.e. creating the model from 7805 internal parts and components.



- Internal parts: voltage control, bandgap reference, error amplifier, start up circuit, protection (overheating, excessive input voltage and excessive output current), and voltage divider.

Simulating 7805 in LTspice (Internal Device Model)

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.

Simulating 7805 in LTspice (Internal Device Model)

The simulation of 7805 integrated circuit in LTspice is performed under the respective component setup and condition:

Testing components:

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

Testing setup conditions:

- 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.