Controlling a Voltage Regulator by a Reference Voltage

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A voltage regulator performs the function of stabilizing its output voltage to a certain potential difference relative to its ground pin. The regulator's supply voltage provides it with output power, while the voltage at the ground pin (V_{GND}) acts as a reference for the device to regulate its output voltage above. Under normal circumstances, V_{GND} would be tied to the ground potential of the circuit, so if it was a 5 volt regulator, the output voltage would be 5 volts above ground. However, since the reference at V_{GND} is required to sink only a few milliamps from the ground pin, this potential can theoretically be supplied by the output of an operational amplifier.

The circuit in figure 1 can test this concept using a 7805 positive 5 volt regulator. The potential at V_{GND} is supplied by the output of a difference amplifier circuit built around the OPA277. It functions like a non-inverting unity-gain DC amplifier that regulates its output (V_{GND}) according to the voltage at the wiper of the 10k potentiometer. As V_{GND} increases, V_{OUT} should increase at an equal rate.

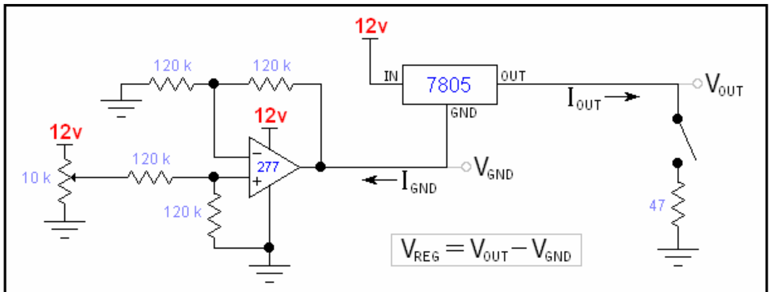

Figure 1 7805 Fixed Voltage Regulator

The table below compares the data of the unloaded circuit to the data obtained when V_{OUT} was loaded with a 47Ω resistor. As V_{GND} was adjusted from about 2 volts to 5 volts, the regulated potential difference (V_{REG}) stayed reasonably consistent at about 4.93 volts, and was not affected by loading. However, the data suggests that when the regulator was loaded with 47Ω, the op-amp's output voltage (V_{GND}) was slightly weakened by an average of 52mV, causing V_{OUT} to decrease along with it.

The drop in V_{GND} was also accompanied by a slight decrease in I_{GND} by an average of about 40nA, when the regulator was loaded. The 7805 regulator has a minimum 2 volt drop from the input to output. As expected, when V_{OUT} got to within 2 volts of the supply voltage, the loading of the regulator began to have an increasing affect on I_{GND}, causing it to decrease dramatically. Overall, the 5mA of current flowing out of the regulator's ground pin had little effect on the op-amp's output voltage (V_{GND}). For most applications, the slight 50mV fluctuations in V_{OUT} due to loading would be insignificant.

7805 with NO LOAD					7805 with LOAD=(47Ω)					7805 change due to LOAD		
V_{OUT}	I_{OUT} (mA)	V_{GND}	I_{GND} (mA)	V_{REG}	V_{OUT}	I_{OUT} (mA)	V_{GND}	I_{GND} (mA)	V_{REG}	ΔV_{OUT}	ΔV_{GND}	ΔI_{GND} (mA)
7.11	0.00	2.18	5.23	4.93	7.09	150.85	2.16	5.20	4.93	-0.02	-0.02	-0.03
7.58	0.00	2.65	5.22	4.93	7.55	160.64	2.62	5.20	4.93	-0.03	-0.03	-0.02
8.40	0.00	3.47	5.20	4.93	8.36	177.87	3.43	5.17	4.93	-0.04	-0.04	-0.03
9.13	0.00	4.20	5.17	4.93	9.07	192.98	4.14	5.12	4.93	-0.06	-0.06	-0.05
9.67	0.00	4.75	5.12	4.92	9.60	204.26	4.68	5.07	4.92	-0.07	-0.07	-0.05
10.06	0.00	5.14	5.09	4.92	9.97	212.13	5.05	4.75	4.92	-0.09	-0.09	-0.34

The circuit in Figure 1 showed that the op-amp's output voltage remained relatively stable when used as the ground reference of a fixed voltage regulator. Figure 2 illustrates a similar design, using the LM350 adjustable voltage regulator in place of the 7805 fixed regulator. The V_{REG} of the LM350 is determined by the two resistors R_1 and R_2, and the current flowing out of the devices adjustment pin (I_{ADG}). This circuit is supplied with 20 volts to provide a larger range of adjustment.

The regulated potential difference (V_{REG}) of the LM350 regulator in Figure 1 has been programmed to 2.80 volts. As seen in the data from the unloaded LM350, the current flowing into the op-amp's output is 10mA, twice the current of the 7805 circuit. Despite the increased sinking current at the op-amp's output, the voltage V_{GND} was not weakened by the loading of the regulator. In fact, V_{GND} actually increased in response to the regulators load current, by about 55mV on average, causing V_{OUT} to do the same.

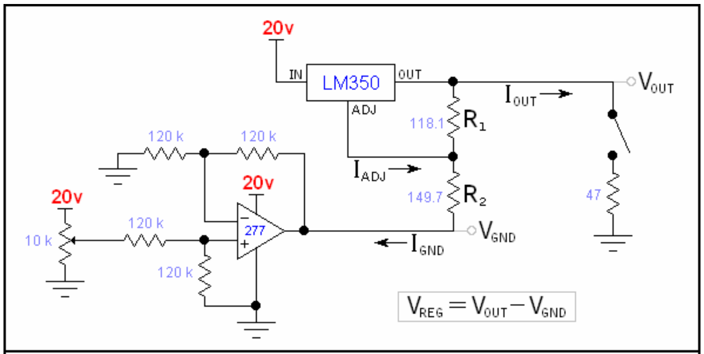

Figure 2 LM350 Adjustable Voltage Regulator

LM350 with NO LOAD			
V_{OUT} (volts)	V_{GND} (volts)	V_{REG} (volts)	I_{GND} (mA)
4.87	2.05	2.83	10.44
5.72	2.91	2.80	10.44
6.89	4.09	2.80	10.43
7.81	5.01	2.80	10.43
8.67	5.87	2.80	10.43
9.84	7.04	2.80	10.43
10.92	8.12	2.80	10.43
11.88	9.08	2.80	10.43
13.12	10.33	2.79	10.43
14.18	11.38	2.80	10.43
15.66	12.86	2.80	10.43
16.48	13.68	2.80	10.44
17.02	14.21	2.81	10.44
	Averages	2.8023	10.4331

As previously stated, the regulated potential difference V_{REG} is determined not only by the two resistors R_1 and R_2, but also by the current flowing out of the adjustment pin (I_{ADG}). Ohm's law can be used to derive an equation for I_{ADG} in terms of V_{REG}, I_{GND}, R_1 and R_2. However, ohm's law cannot predict how the V_{IN}-V_{OUT} voltage difference will affect the adjustment current. With R1=120Ω as recommended by the datasheet, the change in I_{ADJ} due to the V_{IN}-V_{OUT} potential is negligible, so the output voltage is not affected by the regulators input supply voltage.

For other resistor combinations, such as R_1=2kΩ and R_2=820Ω, I_{ADJ} is dramatically affected by the regulators V_{IN}-V_{OUT} potential difference. In this case, as V_{GND} changes, so does the V_{IN}-V_{OUT} potential, causing I_{ADJ} and thus V_{REG} to change as well. At the lower end of the range, V_{REG} was 3 volts, and by the upper end of the range, V_{REG} had dropped to 2 volts.

In conclusion, a voltage regulator can be safely adjusted via the ground reference V_{GND}, while maintaining reasonably high V_{OUT} stability relative to the current load (I_{OUT}).

LM350 change due to LOAD=(47Ω)					
V_{GND}	V_{GND} (load)	ΔV_{GND}	V_{OUT}	V_{OUT} (load)	ΔV_{OUT}
1.96	1.97	0.01	4.82	4.82	0.00
2.01	2.01	0.00	5.04	5.07	0.03
2.29	2.34	0.05	5.28	5.33	0.05
3.00	3.05	0.05	5.57	5.61	0.04
3.25	3.30	0.05	6.04	6.09	0.05
3.77	3.83	0.06	6.51	6.58	0.07
4.55	4.62	0.07	7.02	7.09	0.07
5.30	5.38	0.08	7.49	7.56	0.07
6.45	6.53	0.08	8.00	8.07	0.07
7.41	7.51	0.10	9.11	9.20	0.09
9.39	9.47	0.08	11.00	11.09	0.09
10.54	10.61	0.07	11.84	11.92	0.08
11.07	11.15	0.08	12.66	12.75	0.09
12.23	12.31	0.08	13.66	13.73	0.07
13.08	13.09	0.01	15.69	15.72	0.03
14.13	14.14	0.01	16.83	16.85	0.02
	Average ΔV_{GND}	0.0543		Average ΔV_{OUT}	0.0578