Power Supplies

Contents

1 Introduction

Almost all electronic circuits need a DC power supply. DC is needed to give the circuit enoug energy to work properly, give power to the charge and compensate inevitable losses (i.e. Joule effect). It is needed also to allow components in conditions where they can surely works. In this last case we talk about polarisation.

We can recognize three different sources of power supplies:

- Electronic power supplies
- Batteries
- Solar cells

Obviously there are much more different power supplies, but usually they are not used in electronics or can be reduced to one of them. A typical example is a car, where is produced the DC current needed for the nowadays sophisticated cars?

Independently of the origin of the DC, the final user requirements are quite clear, for a proper work it is needed a stable DC. In order to assure this an extra stage is need to be added to the generators, this stage is called stabilazer or regulator.

2 Electronic Power Supplies

2.1 Transformers

2.1.1 Ideal transformer

2.1.2 Real transformer

2.2 Rectifiers

2.2.1 Half-wave rectifier

2.2.2 Full-wave rectifier

2.2.3 Capacitive filters

3 Batteries

A battery is an electrochemical device that converts chemical energy into electricity, by use of a galvanic cell. A galvanic cell is a fairly simple device sonsiting in two electrodes and an electrolyte solution. Batteries consists of one or more galvanic cells.

Let's see in detail how a galvanic cell works. In figure 1 is shown schematically a galvanic cell. Electrodes, made with different metals or alloys are in a electrolyte solution. Electrical wires connect the electrodes to an electrical load. The metal in the anode (negative) oxidizes, releasing electrons and postive charged metal ions. The electrons travels through the wire to the cathode were recombines with the material therein. This combination is called reduction and releases a negatively charged metal-oxide ion, that in contact with the electrolyte causes a water molecule to split in an hydrogen ion and an hydroxide ion. The positive hydrogen ion combines with the charged metal-oxide that become inert. The hydroxide ions flows through the electrolyte to the anode where combiens with the metal ion, forming water and a metal-oxide molecule. In other words, the anode disolve in the electrolyte and while hydrogen frome the electrolyte is deposited onto the cathode.

When the anode is fully oxidized or the cathode fully reduced, the chemical reaction will stop and the battery is considered discharged.

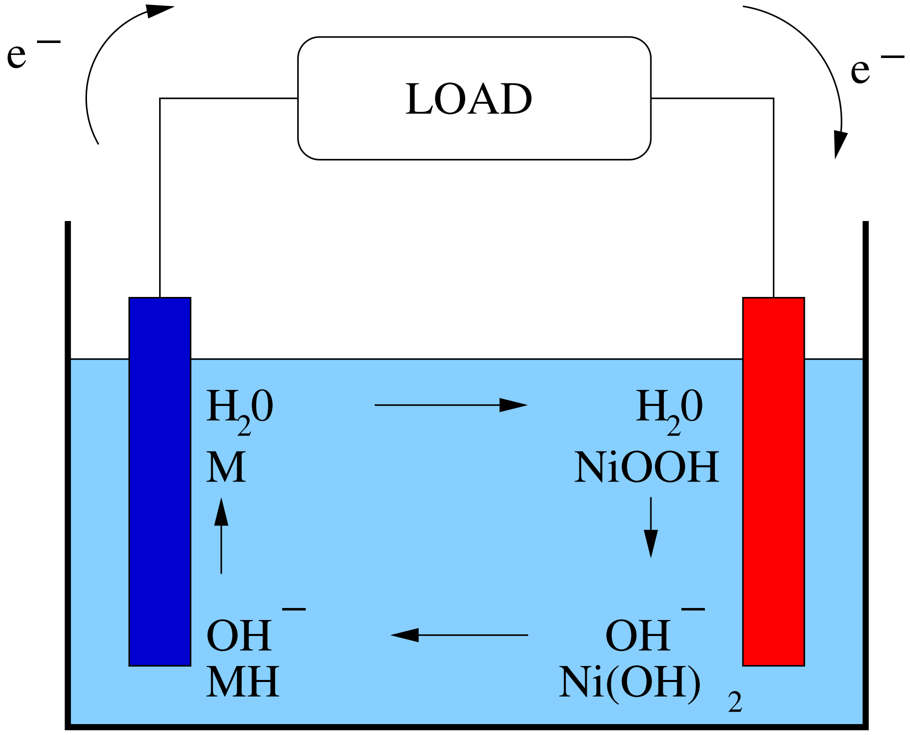


Figure 1: Galvanic cell. In this example the reactions correspond to a $Ni - MH$ one.

As an example let's see what happens in a $Ni - MH$ battery, this is the one that most portable phones and computer use. The anode is composed by two kind of alloys AB_2 ($TiMn_2$, $ZnMn_2$) or AB_5 ($LaNi_5$), so the metal M is one of these alloys. In the cathode is usedd Nicke oxyhydroxide ($NiOOH$). The electrolyte is an aqueous solution of potassium hydroxide. The reactions that take place is:

Anode $MH + OH^- \rightarrow M + H_2O^-_e$

Cathode $NiOOH + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$

Overall $MH + NiOOH \rightarrow M + Ni(OH)_2$

Recharging a battery will consist in apply an external voltage across the electrodes to reverse the chemical process. This process evidently is not possible for all chemical process. Batteries with irreversible reactions are known as primary batteries, while the ones with reversible reactions are known as secondary cells.

A primary battery is a battery dessigned to be cycled (fully discharged) only once. It is highly recommended not to try to recharge them.

A secondary battery is designed to be cycled between 100 and 1000 times. Usually are made from the same materials as the primary batteries, but with different design and manufacturing.

The voltage and current supplied depend on the types of materials used. The duration of the cell is related directly with the amount of active material in the cell.

The materials in the anode should have a great electroaffinity. On the other hand, materials in the cathode should have a great electropositivity.

3.1 Energy Densities

The energy density of a battery is a measure of how much energye the battery can supply relative to its weight or voulume. The energy densities are given in $W-h/kg$ and $W-h/L$.

3.2 Voltage Profiles

An ideal battery will mantain a voltage V_B across its terminals even when short circuited and during all his lifetime. As the power is $P=V^2/R$ if $R \to 0$ then $P \to \infty$, thats we call them ideal. In this picture it is infered that thi internal resistance of the battery is zero, but this is not true, because, even if it is small (0.005 - 0.15 Ω) this resistance is not zero, which limits the maximum output.

Looking the voltage profile of a battery (the relationship of its voltage to the time it has been discharging (or charging)) as shown in fig **??** some batteries drops its voltage steadily as the chemical reactions are diminished. This leads to an almost linear drop in voltage called sloping profile. On the other hand other batteries porvide a relatively flat voltage profile. At some point at the end of the cycle the voltage drops sharply to nearly zero volts. This profile is known as flat discahrge. Depending on the use this voltage profiles can be important.

We can represent a battery then as an ideal battery in series with a resistor. When connected to a load, we will have that:

$$V_B = iR_i + iR_L$$

where R_L is the load. So the output voltage of the battery is

$$V_L = V_B - iR_i = V_B \frac{R_L}{R_L + R_i}$$

We can see then the discharge process as an increase of the battery internal resistance.

To measure the voltage of a battery we can open-circuit the battery (or R_L great), as in this case $i=0$, then $V_L = V_B$.

To measure the internal resistance we should short-circuit (dangerous) or we can see the voltage profile.

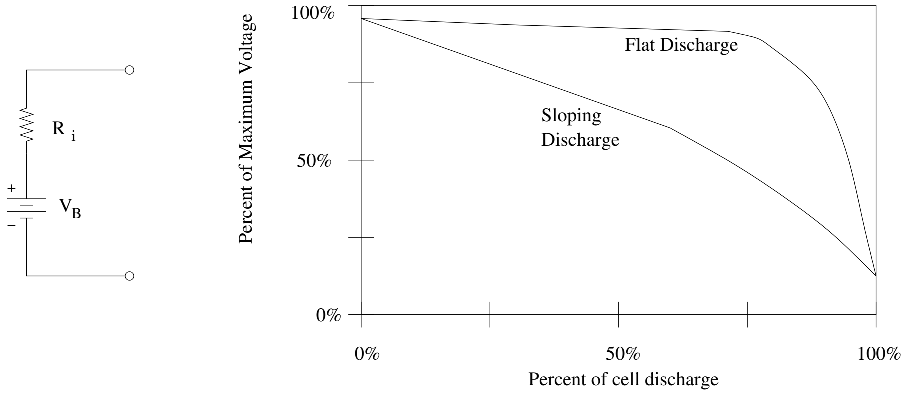


Figure 2: Flat discharge curve vs. sloping discharge curve

3.3 Self-discharge Rates

All charged batteries will slowly lose their charge over time, even if they are not connected (through the moisture in the air or the slight conductivity of the housing. The rate at which a battery loses power in this way is called the self-discharge rate. This rate can be from few percents per day till 5% to 10% per year.

3.4 Operating temperatures

Battery performance deteriorates gradually above 25^oC and deteriorates rapidly above 55^oC. At very low temperatures -20^oC the performance is only a fraction of the performace at 25^oC.

At low temperatures, the loss of energy capacity is due to the reduced rate of chemical reactions and the increase of electrolyte resistivity. At high temperatures, the loss of energy is due to the increase of unwanted, parasitic chemical reactions.

3.5 Capacicty

Capacity of a battery is measured in ampere-hours (voltage is fix). We can distinguish between initial capacity, that is the electrical output that the fully charge battery can provide and the rated capacity, that is the total electrical output at typical discarge rates (i.e. a device can be on only 6 seconds per minute and standby the rest of the time)

3.6 Types of Batteries

3.6.1 Lead-Acid batteries

First commercial available batteries. Widely used as car batteries. Battery manufacturing is the single largest use for lead in the world.

Anode	Pb
Cathode	PbO_2 Lead dioxide
Electrolyte	H_2SO_4 Sulfuric acid
Energy density	–
Rechargable	Yes - A lot
Voltage profile	–
Self-Discharge Rate	–

Deep cycled batteries are built in a configuration similar to normal batteries, except that they are specifically designed for prolonged use rather thar for short bursts. This term is used almost specifically in lead-acid batteries.

3.6.2 Zinc-Carbon batteries

Also known as Leclanché cells. Very low production cost.

Anode	Zn
Cathode	$MnO_2 + C$
Electrolyte	$ZnCl$ Zinc chloride or ammonium chloride
Energy density	
Rechargable	No
Voltage profile	Sloping Discharge
Self-Discharge Rate	–

Used in small devices. Drawback: Case is also the electrode (Zn), if the anode does not oxide evenly can develop holes and the acid electrolyte can damage the device.

3.6.3 Alkaline batteries

Is a zinc-carbon with an alkalyne electrolyte. They have a useful life 5 or 6 times greater of a zinc-carbon battery.

Anode	Zn
Cathode	MnO_2
Electrolyte	Alkaline
Energy density	
Rechargable	Yes
Voltage profile	
Self-Discharge Rate	–

3.6.4 Ni-Cd batteries

Anode	Cd
Cathode	$NiOOH$ nickel hydroxide
Electrolyte	Alkalyne
Energy density	
Rechargable	Yes. Most used rechargable batteries
Voltage profile	
Self-Discharge Rate	

Quite expeansive because of cadmium. On the other hand they are easily recycle.

3.6.5 Ni-MH batteries

Can last 40% longer than the same size $Ni - Cd$.

Anode	MH ($TiMn_2$, $ZnMn_2$ or $LaNi_5$)
Cathode	$NiOOH$ nickel hydroxide
Electrolyte	Potassium hydroxide solution
Energy density	
Rechargable	Yes. >600 cycles.
Voltage profile	
Self-Discharge Rate	High

Used extensively in laptops, cellular phones, camcorders.

3.6.6 Ni-Iron batteries

Anode	Fe
Cathode	
Electrolyte	
Energy density	
Rechargable	Yes. Do not recharge very efficiently
Voltage profile	
Self-Discharge Rate	

3.6.7 Ni-Zn batteries

Anode	Zn
Cathode	
Electrolyte	
Energy density	
Rechargable	Yes. <200
Voltage profile	
Self-Discharge Rate	

When recharging, Zn do not deposit on the sam holes but randomly, that l eads to a weakening and eventual failure of the electrode.

3.6.8 Lithium batteries

Based on high electropositivity of Lithium. Energy density three times greater than alkalyne batteries. Also provides a minimum of 3.0 V per cell.

Anode	C
Cathode	$LiMnO_2$ or $LiCoO_2$
Electrolyte	organique with Li salt
Energy density	
Rechargable	Yes.
Voltage profile	
Self-Discharge Rate	

Lithium is highly reactive, so case can be destroyed, and in contact with water lithium explodes. Lithium has low melting temperature (180^oC) and in direct contactc with the cathode this will ignite.

3.6.9 Metal-air batteries

High density cell where oxigen in air is use as cathode. This allows to reduce the size.The oxygen is reduced in a portion of the cell that is isolated from the anode and electrolyte.

Anode	Zn or Al
Cathode	Oxigen in air
Electrolyte	
Energy density	
Rechargable	Yes.
Voltage profile	
Self-Discharge Rate	

Used in hearing aids, watches adn clandestine devices. Quite difficult to build and mantain the oxigen cathode isolated, (lifetime from 1 to 3 months)

3.6.10 Silver-Oxide batteries

Reduced size

Anode	Zn
Cathode	Silver Oxide
Electrolyte	potassium hydroxide
Energy density	Relatively high
Rechargable	No
Voltage profile	Flat voltage
Self-Discharge Rate	

Quite expensives.

3.6.11 Mercury Oxide batteries

Reduced size

Anode	Zn
Cathode	Mercury Oxide
Electrolyte	potassium hydroxide
Energy density	high
Rechargable	Yes.
Voltage profile	Flat voltage
Self-Discharge Rate	

Quite expensives and have environmental problems.

3.6.12 Ni-H batteries

Developed by the US space program. Under certain conditions of preassure and temperature hydrogen can be used as an actiove electrode

Anode	Ni
Cathode	Hydrogen
Electrolyte	
Energy density	
Rechargable	
Voltage profile	
Self-Discharge Rate	

Quite expensives and have environmental problems.

3.6.13 Thermal batteries

High temperature, molten salt primary battery. At ambient temperatures, the electrolyte is a solid, non-conducting salt. When power is required from the battery, an internal pyrotechnic heat source is ignited, melting the electrolyte and aloowing the generation of electricity (1.5V-3.3V) from few seconds to one hour.

Anode	Ni
Cathode	Hydrogen
Electrolyte	Salt
Energy density	
Rechargable	No
Voltage profile	
Self-Discharge Rate	

They are inert at normal temperatures, having an excellent shelf life, requiring no maintenance. Basically used in military applications and emergency-power situations in aircrafts or submarines.

3.6.14 Super Capacitor

3.6.15 Lemon battery

3.7 Battery Chargers

4 Solar cells

Full sunlight delivers about $1kW/m^2$ after traversing the atmosphere.

Solar cells or photovoltaic cells are based on semiconductors and in the PN junction propierties. Basically it uses the energy left in the junction by the incident light, that creates electron-holes pairs allowing the creation of a current.

Sun light is an almost perfect blackbody around 6000^oC, and only those wavelengts with an energy greater that the bandgap (1.1 eV in case of the Si) can produce electron-holes pairs. This means that between 75% and 85% of the incident sunlight is lost, either because the photon is not energetic enough or beacause in the compton effect some of the energy is lost.

The internal structure of a solar cell is composed by a minimum of six layers:

- Cover glass
- Antireflective coating
- Contact grid
- N-type Si
- P-type Si
- Back contact

5 Regulators and stabilazers

The aim of both devices is exactly the same, maintain the voltage between two points conected to a load. The way they do is different, stabilizers use the non linear behaviour of some components as the zener diodes, and regulators are feedback systems that use reference.

In order to define the quality of these components let's define some parameters. In general the output voltage (v_o) will depend on the input voltage (v_i), the output current (i_o) and the temperature (T),

$$dv_o = \frac{\partial v_o}{\partial v_i} dv_i + \frac{\partial v_o}{\partial i_o} di_o + \frac{\partial v_o}{\partial T} dT$$

So assuming that small variations are equal to differentials ($d = \delta$) we have:

$$\delta v_o = K \delta v_i + r_s \delta i_o + \lambda \delta T$$

where the stabilization factor K is defined as:

$$K = \frac{\partial v_o}{\partial v_i} = \frac{\delta v_o}{\delta v_i}$$

the stabilization coefficient is:

$$r_s = \frac{\partial v_o}{\partial i_o} = \frac{\delta v_o}{\delta i_o}$$

and the temperature coefficient is

$$\lambda = \frac{\partial v_o}{\partial T} = \frac{\delta v_o}{\delta T}$$

The devices are the best the lower are the parameters. This parameters also can depend on the temperature.

Another important parameter is the ripple rejection rate, defined as:

$$k = 20 \log \frac{\Delta v_i}{\Delta v_o}$$

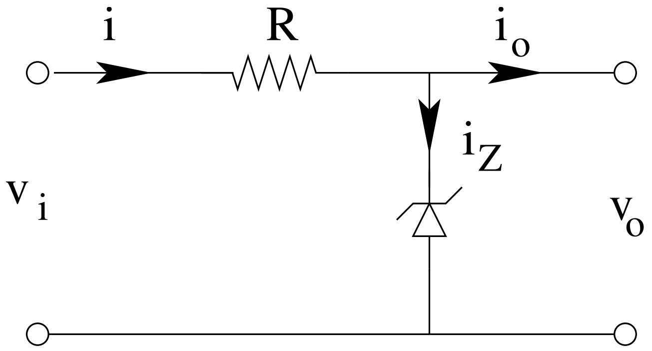
A good value of k is between 60 and 100 dB

5.1 Stabilizers

Almost all stabilizers are based on the propiertes of the Zener diode. So all propiertes of this component have to be taken into account, basically the zener resistance r_Z, the temperature dependence and the noise introduced by the device, basically when it is operated at low intensities and the diode is working around the zener knee.

We are going to modelize the diode as an ideal voltage source and a resistor in series. Usually this resistor is between some dizaines and few hundreds ohms.

5.1.1 Stabilizer with a parallel diode Zener



$$R \leq \frac{v_i^{min} - V_Z}{i_o^{max} + i_Z^{min}}$$

$$P_R = \frac{(v_i^{max} - V_Z)^2}{R} \leq P_R^{max}$$

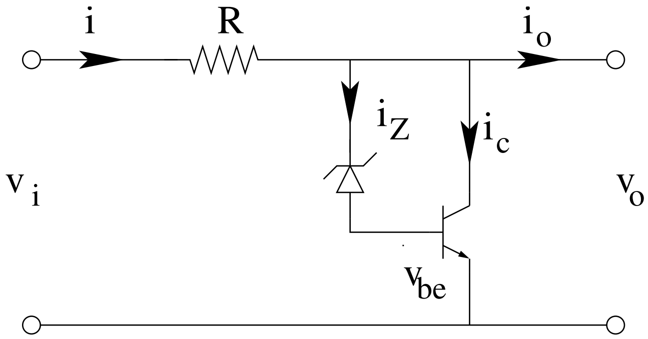
$$P_Z = V_Z \frac{v_i^{max} - V_Z}{R} \leq P_Z^{max}$$

$$v_o = \frac{R}{R + r_Z} V_Z + \frac{r_Z}{R + r_Z} v_i - \frac{R r_Z}{R + r_Z} i_o$$

The temperature coefficient is almost equal to the Zener temperature coefficient:

$$\lambda = \alpha_Z$$

5.1.2 Stabilizer with a parallel diode Zener and transistor



$$v_o = V_Z + V_{BE}$$

$$R \leq \frac{v_i^{min} - v_o}{i_o^{max} + (\beta + 1) i_Z^{min}}$$

$$P_R = \frac{(v_i^{max} - v_o)^2}{R} \leq P_R^{max}$$

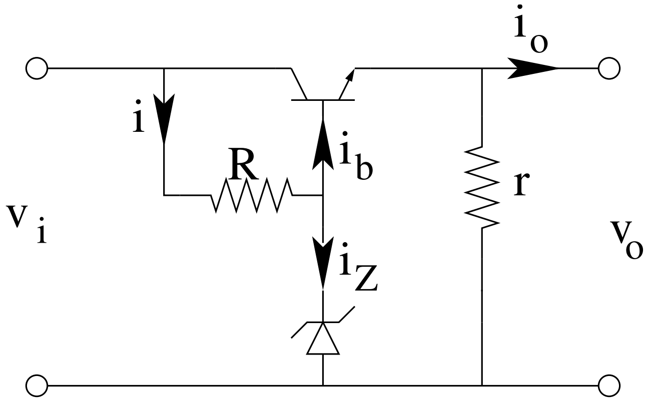
$$P_Z = V_Z \frac{v_i^{max} - v_o)^2}{\beta R} \leq P_Z^{max}$$

$$P_T = v_o \frac{v_i^{max} - v_o}{R}$$

$$K = \frac{1}{1+(\beta+1)\frac{R}{r_Z+r}} \simeq \frac{r}{\beta R}$$

$$r_s = \frac{R}{1+(\beta+1)\frac{R}{r_Z+r}} \simeq \frac{r}{\beta}$$

5.1.3 Serial stabilizer with a diode Zener and transistor



$$v_o = V_Z - V_{BE}$$

$$R \leq \frac{v_i^{min} - V_Z}{i_Z^{min} + i_b^{max}} \quad , \quad i_b^{max} = \frac{i_o^{max}}{\beta_{min}+1}$$

$$P_R = \frac{(v_i^{max} - V_Z)^2}{R} \leq P_R^{max}$$

$$P_Z = V_Z \frac{v_i^{max} - V_Z}{V_R} \leq P_Z^{max}$$

$$P_T = (v_i^{max} - v_o) i_o^{max}$$

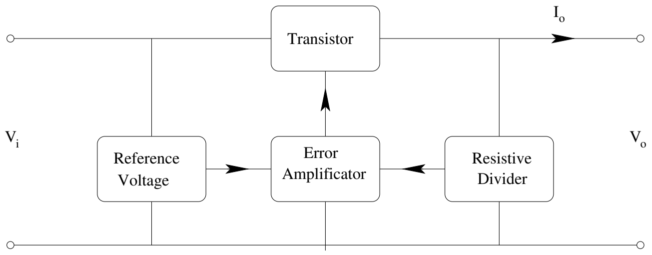
$$K = \frac{r_Z}{R + r_Z} \simeq \frac{r_Z}{R}$$

$$r_s = \frac{1}{\beta+1}\left(r + \frac{R r_Z}{R + r_Z}\right) \simeq \frac{r}{\beta}$$

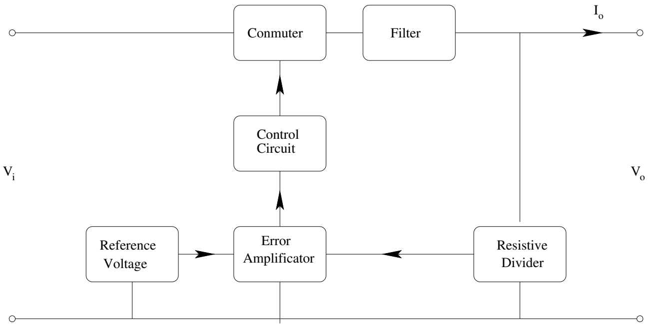
5.2 Regulators

Between the regulators we can distinguish two different kinds:

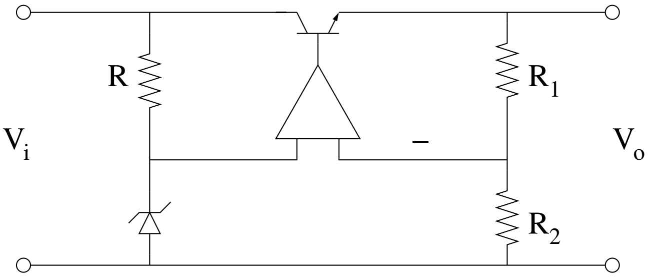
- Linear regulators. They use a transistor as an amplifier to modify the output tension depending on the variotions detected.



- Switch regulators. The input DC is cutted by a electronic conmuter and later filtered by a inductive-capacitive filter. Varying the on-off states the output voltage can be controled.



5.2.1 Linear Regulators



$$v_o = \left(1 + \frac{R_2}{R_1}\right) V_Z$$

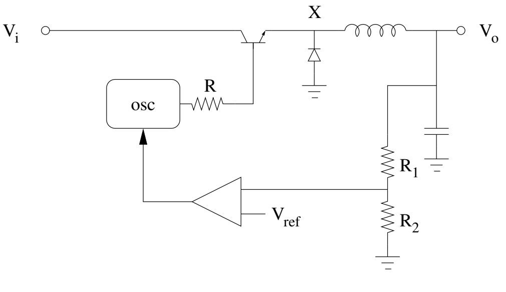
$$K = \frac{A\frac{r_Z}{R+r_Z}}{1 + A\frac{R_1}{R_1+R_2}} \simeq \frac{r_Z}{R+r_Z}\frac{R_1+R_2}{R_1}$$

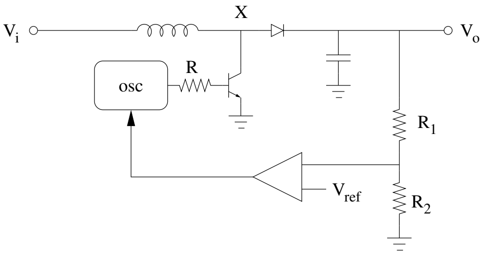
$$r_s = \frac{r}{(\beta+1)(1 + A\frac{R_1}{R_1+R_2})}$$

There are numerous integrated circuits that contain this montage, the best is to used them. Historical component 723, nowadays component 78xx for positive values and 79xx for negative values, xx=output voltage.

5.2.2 Switch Regulators

Use directly integrated circuits. Based on the so called step-down and step-up circuits





6 Grounding

7 Biliography

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