Choosing a DC/DC Converting Circuit
by Brenton Sirowatka

Abstract:

An incomprehensive overview of techniques for converting DC voltages are introduced including basic theoretical concepts, design considerations and limitations. Resistive voltage dividers, linear regulators, and switching regulators are covered.

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Keywords:
DC/DC, Voltage divider, Linear Regulator, Switching Regulator, Buck, Boost,
Introduction:

DC/DC converters allow DC voltages to be converted to different DC voltages. This allows for multiple components operating at multiple voltages to be powered by a single power source with a constant voltage, such as a battery. Often times a sensor or actuator, like a microphone or motor respectively, does not work at the same voltage as an instrument, like a microcontroller. These components often work at a different voltage as the supply voltage as well, for example a microcontroller may work at 3.3V, but a wall wart outputs 5V. Choosing an efficient power converter is an important circuit design consideration, and each circuit comes in a variety of flavors, offering various advantages and disadvantages. Table 1 lists the main characteristics of the circuits described below.

Table 1. Overview of Voltage Converter’s Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Resistive Divider</th>
<th>Linear Regulator</th>
<th>Switching Regulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Voltage</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Decrease Voltage</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Power Efficient</td>
<td>X</td>
<td>X</td>
<td>✓</td>
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<tr>
<td>Simple</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>EMC Friendly</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Stable Output Voltage</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>High Power</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Low Cost</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

Resistive Voltage Divider:

The simplest technique to step a voltage down, DC or AC, is to implement a resistive divider. This consists of two resistive components in series, and applying a voltage across resistors allows a voltage to be present between the resistors. The resistor values can be changed to produce a voltage anywhere between the input voltage. The equation for the voltage out is \( V_o = V_{in} \times \frac{R_2}{R_1+R_2} \), where R2 is the resistor the output voltage is across.
While this circuit is simple and cheap, it is of the least efficient and is subject to being loaded down. This means that a load attached across Vo will draw current, causing Vo to change. Any current not going to the load, is wasted as heat by the resistors and will constantly draw power from the source regardless of whether the load is drawing power. Increasing R1 and R2 will decrease the power consumed, but will also limit the current to the load.

Another disadvantage of this circuit is that the output voltage is dependent upon the input voltage. If the input voltage changes, the resistive divider will also need to change to maintain the output voltage. Batteries decrease their voltage as they are drained, so the voltage output will also decrease with the battery. A resistive divider can only step a voltage down, which requires the source to always be higher than any required output voltage. An example of a constant voltage source is a wall wart, where the voltage does not change with time.

Linear Regulators:

A linear regulator are similar to resistive voltage dividers, but offer a few more advantages. It can be thought of as a variable resistive divider that dynamically changes its resistance as a load changes. This is accomplished by making a transistor act like a resistor. The power loss of the linear regulator is equal to the voltage drop across the regulator multiplied by the current through it. This means that if the current being drawn
is large, the power wasted will be large. In contrast, a circuit which only draws a small amount of current is a candidate because the overall power lost is usually small compared to the rest of the circuit. This equation is shown in Figure B below. Figure B: Efficiency of a linear regulator (2)

\[ \eta_{LR} = \frac{P_{\text{OUTPUT}}}{P_{\text{OUTPUT}} + P_{\text{LOSS}}} = \frac{V_0 \cdot I_0}{V_0 \cdot I_0 + (V_{\text{IN}} - V_0) \cdot I_0} = \frac{V_0}{V_{\text{IN}}} \]

Figure C shows a simple series regulator schematic. Vs is the voltage source, Q is a bipolar transistor, R1 & R2 are resistors, and DZ is a zener diode. The zener diode had a bandgap, which forces the voltage across itself. It only breaks down when there is sufficient current, causing current to flow. Figure C: Simple Series Regulator (3)

Market linear regulators are more complex and offer the ability to drop wider voltage ranges and are available in a variety of packages. Linear regulators outputs can either be fixed or adjustable. Adjustable regulators have an adjust, usually called Adj, that can be connected to a potentiometer.

Another advantage of linear regulators is that they are affordable, usually a couple dollars and cheaper in bulk, and they do not provide much noise or electromagnetic interference. A disadvantage is that like resistive dividers, they can only step down a voltage.

There exists five basic linear regulators to choose from (10).
1. Positive: A positive regulator regulates positive voltages.
2. Negative: A negative regulator regulates negative voltages.
3. Fixed Output: A fixed output regulator will take in a range of voltages, but will only output a single voltage. The voltage can not be precisely adjusted.

4. Tracking: The tracking regulator can track a reference input allowing the output voltage to be adjusted.

5. Floating: A floating regulator allows the use of a floating input, like a battery, giving several advantages such as high efficiency negative voltage regulation (11).

When implementing a linear regulator, the datasheet will provide you with how the pins are connected as well as providing characteristics of the regulator. Below is an pinout of a positive fixed regulator, the LT1083 by Linear Technologies. This particular regulator will take in a voltage greater than 6.5 Volts and output a voltage of 5V. To add stability to the circuit, they recommend adding tantalum capacitors.

LT1083 by Linear Technologies

Switching Regulators:

Switching regulators are of the most power efficient strategies to convert a voltage. They work by storing energy temporarily in a storage element like a capacitor or inductor, and then releasing that energy. Another huge advantage of switching regulators is that they can either step down or step up a voltage or even do both. Disadvantages of switching regulators are that they are space consuming, costly, and complex. Figure D and Figure E show a buck and boost converter respectively.

The buck converter allows voltages to be stepped down. When the switch is closed, the inductor is charging. When there is energy stored in the inductor, current can flow through the load. The diode prevents the inductor from discharging current back to ground, forcing it to go through the load. No current flows when the switch is
closed. When the switch is open, the inductor is no longer being charged, and the inductor is just discharging. Current is flowing through the diode in a clockwise manner. When the switch closes again, the voltage polarity is reversed, forcing the voltage drop across the load to drop. The load voltage would be the supply voltage minus the voltage across the inductor.

Figure D: Simple Ideal Buck Converter (4)

The boost converter is similar to the buck converter in every aspect, but for the fact that the inductor’s voltage polarity is opposite, causing the load’s voltage to be pushed high. The load voltage would be the supply voltage plus the voltage across the inductor.

Figure E: Simple Idea Boost Converter (5)

Switching converters are much more complex than linear regulators. When building a switching regulator, components must meet design specifications. Knowing several parameters is required to output the correct voltage and ensure high efficiency. These include knowing the Input Voltage Range, nominal output voltage, the maximum current that will be present in the system, and the integrated circuit parameters in the circuit (6). See “Basic Calculation of a Boost Converter’s Power Stage” by Brigitte Hauke for more information on calculating these values.

Capacitors can be placed between the input and output voltages to reduce the voltage ripple caused by the switching. Switching frequency can also reduce the ripple.
Due to FCC and CISPR 22 and other governmental regulations, circuits must be below a certain dB threshold at a given frequency. Often times switching circuits must be mitigated to abide by the law. Figure F gives a quick reference for FCC radiated emission limits for class A and B devices.

Figure F: FCC Radiated Emission Limits (7)

After the component values are calculated for, consideration must be made in selecting components. Low equivalent series resistance capacitors should be used to minimize losses. Capacitors should meet RMS current and voltage ratings to ensure safe operation (8). A safety factor should be used in selecting values in case of a malfunction. A voltage rating of 1.5 times more than the maximum current is recommended (8).

Inductors can be either bought or hand wound. Using a magnetic core can increase the inductance of the circuit. Finding a balance between these values is also crucial, because a larger inductor means an increased wire resistance, decreasing efficiency. Ensuring the inductor’s saturation current is below the maximum current that will be present will ensure the inductance doesn’t decrease (8). The inductor’s rated current should be taken into consideration to prevent the inductor from overheating (9).
Another design consideration is the switching device. MOSFETs are often used and allow for high switching efficiency, but often require extra peripheral, like a gate driver, to be controlled, such as from a microcontroller.

Conclusion:

Choosing which circuit technique to select for powering devices can be difficult because of the numerous variables to be accounted for. Knowing the limitations, costs, and design implementation difficulty can be necessary for an informed choice. Any of these constraints can limit the design to a single circuit, limiting other constraints. Being able to implement these designs correctly can mean a reliable and competitive product.

Bibliography:

