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RAQ Issue 183: Voltage Conversion in Four Quadrants

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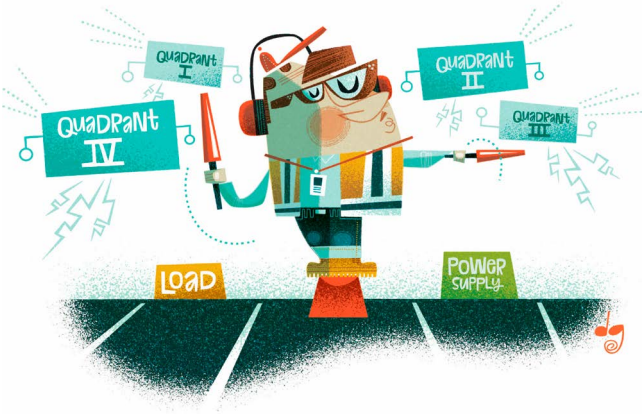
Question:

What is a four-quadrant power supply?



Answer:

A power supply that can sink and source on positive and negative currents and voltages.

While simple voltage converters can generate a fixed output voltage from an input voltage, there are applications for which this behavior is not sufficient. An example is the control of a voltage node to which capacitors are connected These capacitors may be charged to any voltage. If they need to be brought to a lower voltage, they have to be partially discharged. Thus, in such an application, a power supply has to be able to source or sink current as required. Such a converter is called a four-quadrant dc-to-dc converter. For applications such as this, a power supply can be used with an output discharge function. It can discharge output capacitors quickly. Figure 1 shows such a function for a step-down switching regulator. Here, switch S2 is switched on for a lengthy period after the switching action of the buck converter is switched off and the output capacitor is discharged.

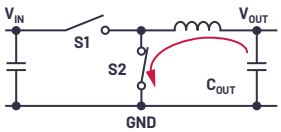


Figure 1. Discharge of an output capacitor via a simple output discharge function.

An elegant way of controlling currents and voltages is with a four-quadrant dc-to-dc converter. A typical buck converter only operates in one quadrant. It can generate a positive voltage with a positive current flow; that is, current flowing from the dc-to-dc converter to the load. With a four-quadrant converter, not only can the output capacitors be discharged, but voltage can also be generated. This is possible because current can flow in the direction of the load or taken away from the load. That is the case in the previous example about quickly discharging output capacitors. A four-quadrant dc-to-dc converter can do even more than that. Besides generating voltages, it can also set the current to any level. This current can be positive or negative. Such four-quadrant converters are frequently used in universal lab power supplies. The user can, for example, test an LED using a fixed current setting. A solar cell can also be operated, with the four-quadrant converter acting as a load that sinks a predetermined current.

Another interesting application is tinting window panes with LCD technology. This often requires a precisely set voltage in the positive and in the negative range to yield a suitable tint level depending on the available light and the desired brightness in the room.

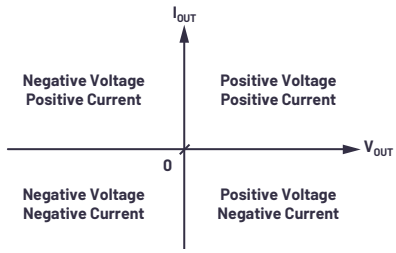


Figure 2. Four-quadrant voltage converter.

Figure 2 shows what four quadrant means in relation to a power supply. The quadrants of a coordinate system are shown with voltage on the x-axis and current on the y-axis. Current and voltage can be either positive or negative.

The dc-to-dc converter can thus be used as an energy source and as an energy sink. In other words, the converter can function as a power supply or an electric load.

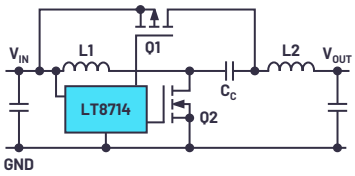


Figure 3. Simplified circuit diagram showing the topology of a four-quadrant voltage converter.

The LT8714 from Analog Devices is a controller for a four-quadrant regulator. It has all the functions required for this type of regulation. For example, with this IC, a voltage of 0 V can be precisely maintained. Figure 3 shows a simplified circuit diagram with the controller IC and the power stage. The latter consists of the two inductors L1 and L2, the two switches Q1 and Q2, and the coupling capacitor C_C. Explanations on the respective operation in each of the quadrants as well as on the behavior at the transitions from one quadrant to another can be found in the LT8714 data sheet.

In some applications, a power supply operating in four quadrants is required. This can easily be built with an optimized controller such as the LT8714. The circuit design is very simple and its operation, especially around the frequently critical 0 V crossover point, is clean and reliable.

There are alternatives to using a four-quadrant regulator, such as switching regulator topologies that have to be connected in parallel to enable multiple quadrant functionality. However, these are often more cost intensive when compared to using a dedicated four-quadrant solution.

About the Author

Frederik Dostal studied microelectronics at the University of Erlangen in Germany. Starting work in the power management business in 2001, he has been active in various applications positions including four years in Phoenix, Arizona, where he worked on switch-mode power supplies. He joined Analog Devices in 2009 and works as a field applications engineer for power management at Analog Devices in München. He can be reached at frederick.dostal@analog.com.