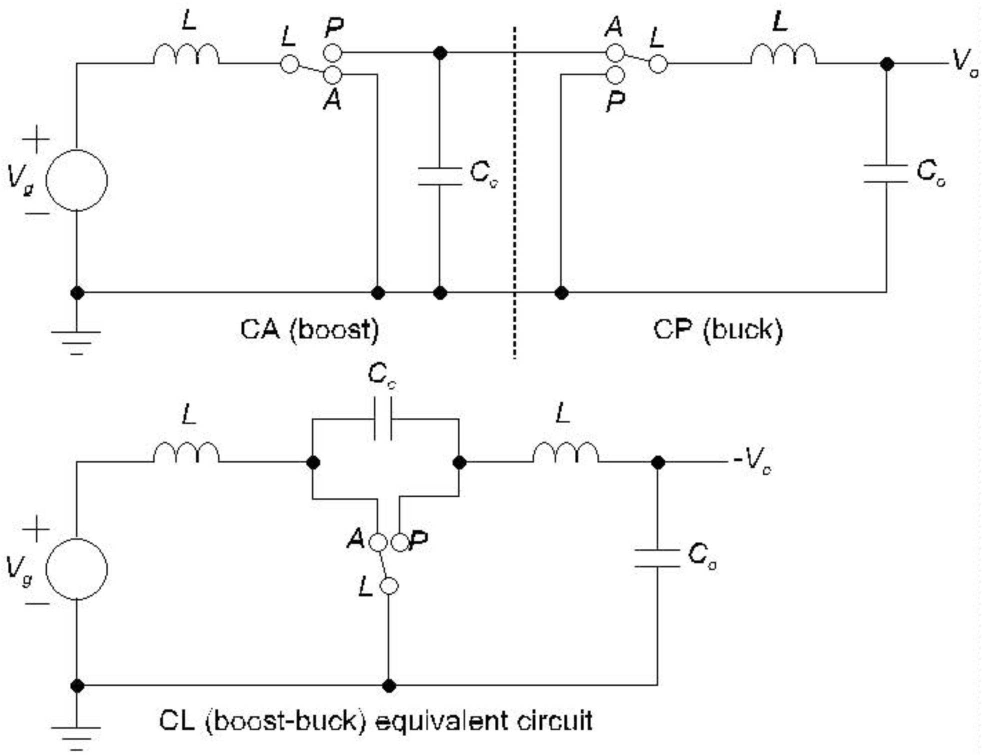
Cuk-Based Converter Concepts

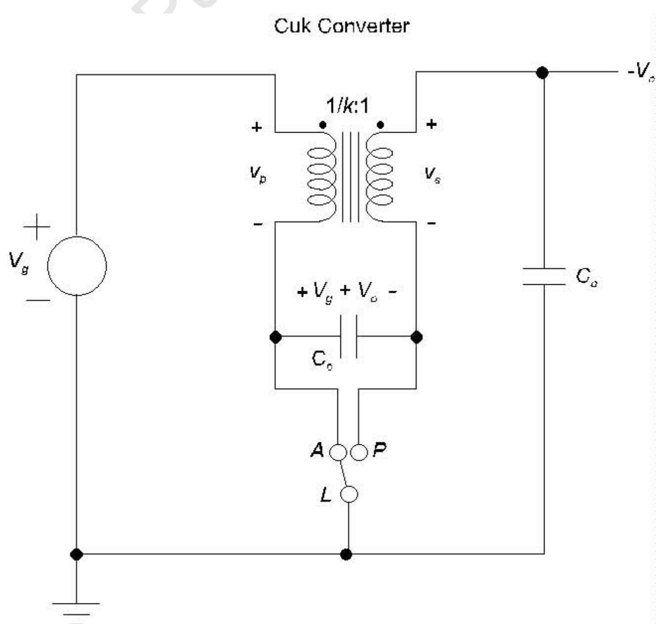
Part 2: Cuk-Cell Converters

by Dennis L Feucht

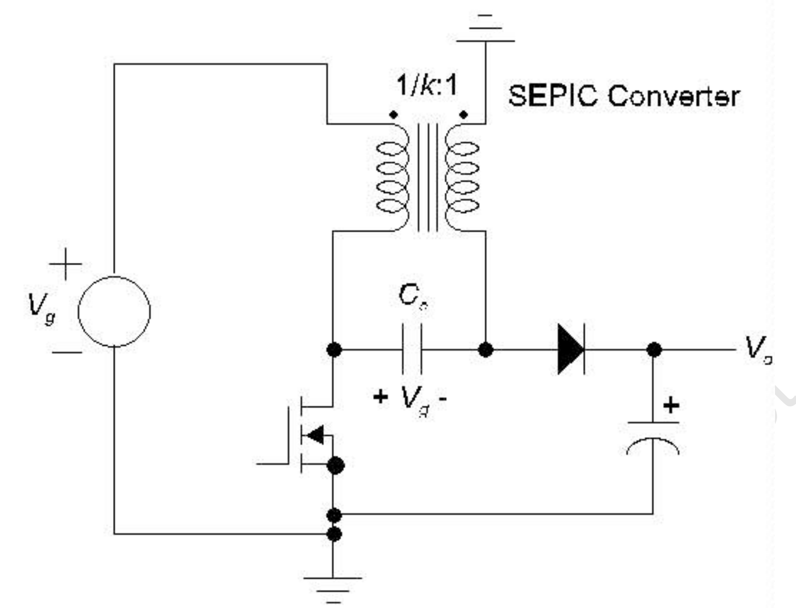
In Part 1, the advantages of ripple steering for the three basic switch-cell converter configurations was presented. The basic Cuk converter evolved from cascading CA (boost) and CP (buck) converter stages and replacing the interface with an equivalent capacitor circuit, as shown below.



The switch terminals are labeled according to switch-cell labeling, though now an inductor is no longer in series with the common (*L*) terminal. The final step was to couple the two inductors, to result in the Cuk converter, shown below.



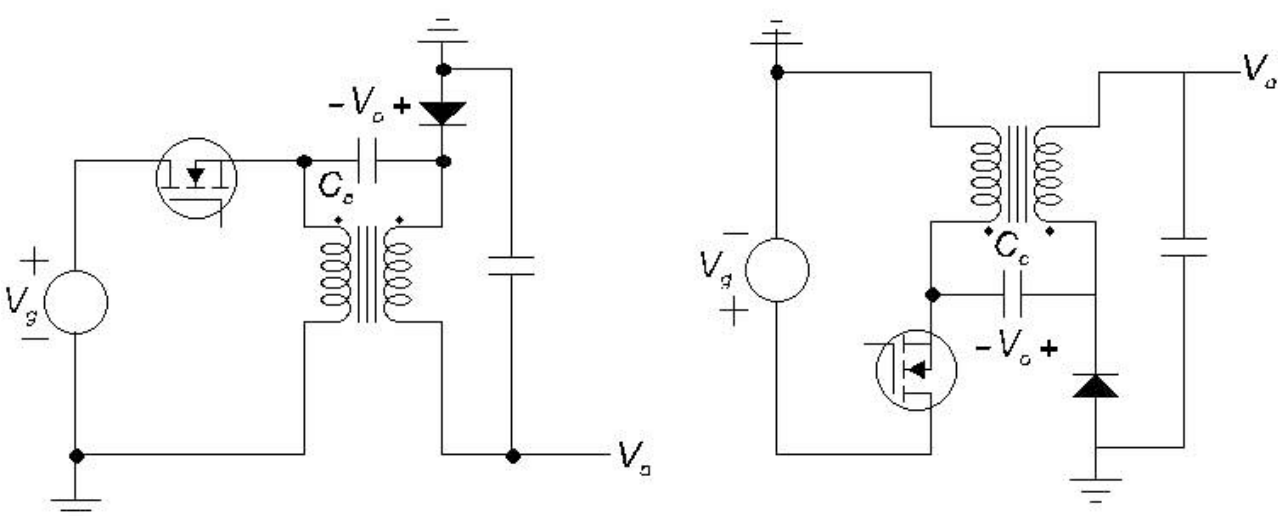
Soon it was discovered that variations on this converter also shared some of its advantages. One variation is the SEPIC topology. (SEPIC stands conventionally for *single-ended primary inductance converter* but I prefer to think of it as a *SEcondary Polarity-Inverted Cuk* instead.) The difference between Cuk and SEPIC topologies is where ground is connected. Because the SEPIC does not invert, it tends to be the most popularly used. The basic SEPIC converter topology is shown below.



At turn-on, C_c will charge to V_g. When power-switch S turns on, the left end of C_c is zero volts. Its right-plate voltage, $-V_c = -V_g$, is applied to the undotted end of the secondary winding, and with the same polarity that the V_g source (at the converter input) is applied to the primary. Each winding attempts to induce the same voltage into the other. During the off time of the MOSFET, the diode conducts, applying the output voltage (plus diode drop) to the primary winding through the secondary. This voltage induced across the primary winding is set to be the same voltage applied to it by the algebraic addition of the input source and V_c in series with $V_o + V_D$. The SEPIC has a discontinuous output current waveform and a continuous and nearly ripple-free input current waveform.

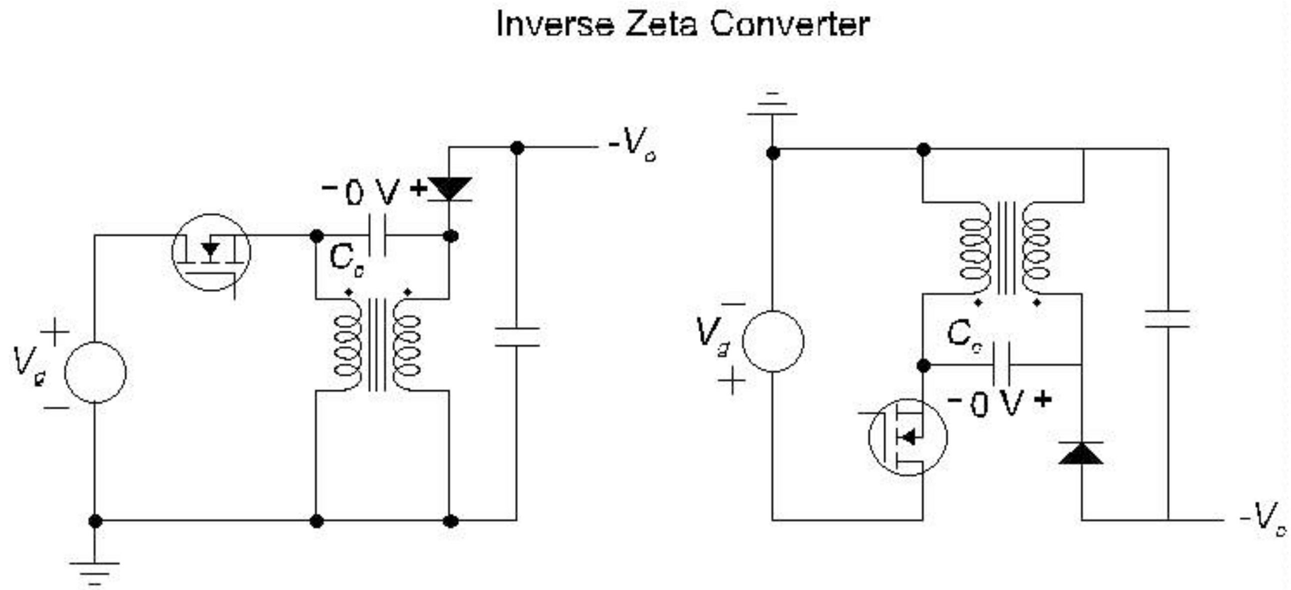
Beyond the Cuk and SEPIC, another Cuk-derived variation is the Zeta converter, shown below.

Zeta Converter

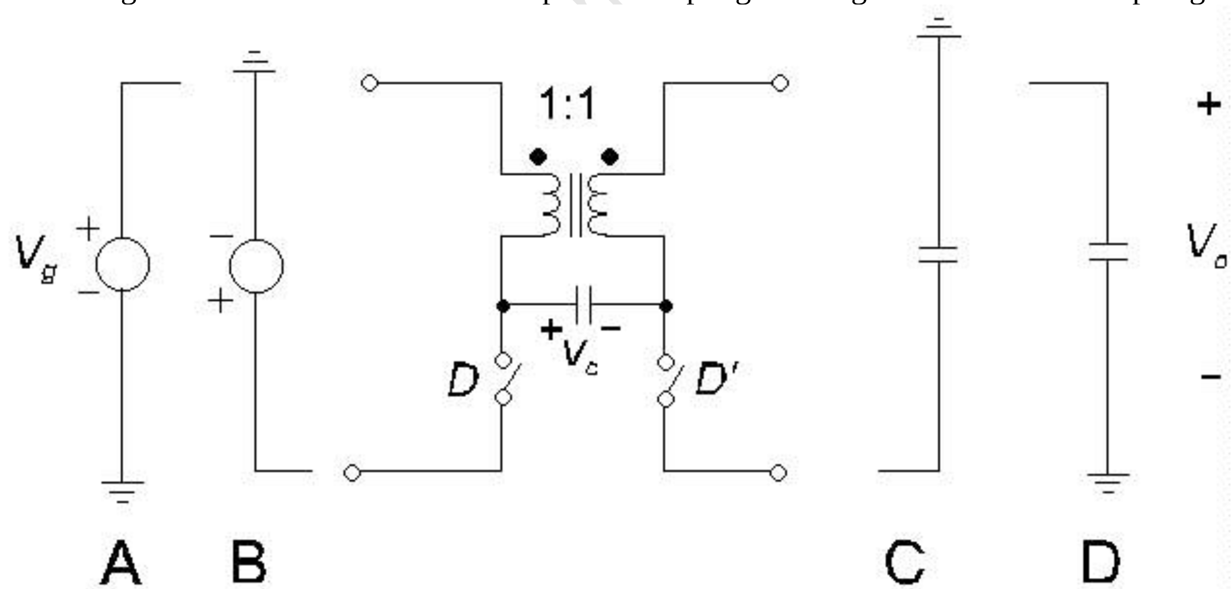


The zeta converter has a discontinuous input current and continuous output current. Its C_c voltage is V_o.

A fourth topology, possibly novel, which I call the *inverse Zeta*, is shown below. It is like the ripple-steered CL in that coupling capacitor C_c has a steady-state 0 V across it.



These four Cuk-derived topologies all have a steady-state voltage transfer function or voltage gain of $V_o/V_g = D/(1 - D)$. They can be categorized by where input and output ground is attached. The following diagram shows the four circuits in a single-converter depiction. The four-terminal circuit in the middle remains unchanged. The four combinations of input and output grounding results in the four topologies.

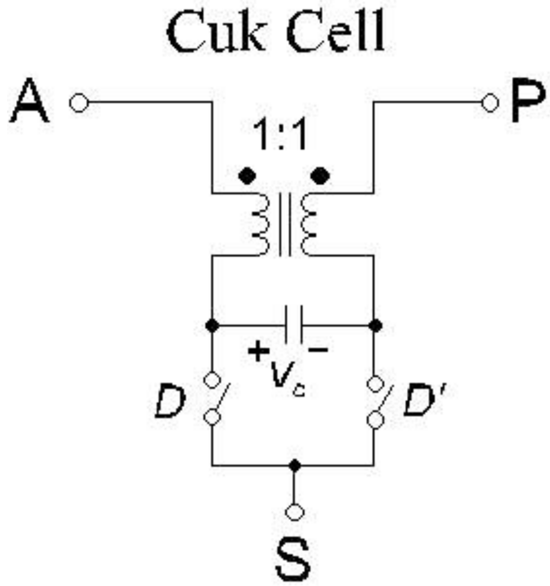


Topology	Designation	V_c	V_o	V_Q	i_g	i_o
Cuk	AD	$V_g + V_o$	−	$V_g + V_o$	CC	CC
SEPIC	AC	V_g	+	$V_g + V_o$	CC	DC
Zeta	BD	V_o	+	$V_g + V_o$	DC	CC
Inverse Zeta	BC	0 V	−	$V_g + V_o$	DC	DC

CC = continuous current; DC = discontinuous current. B has DC in; C has DC out. A has CC in and B has CC out.

The Cuk Cell

The Cuk-based derivations, plus the desirability of a modular device such as the switch cell, leads to formulation of another three-terminal device which might be called the *Cuk cell,* shown below.



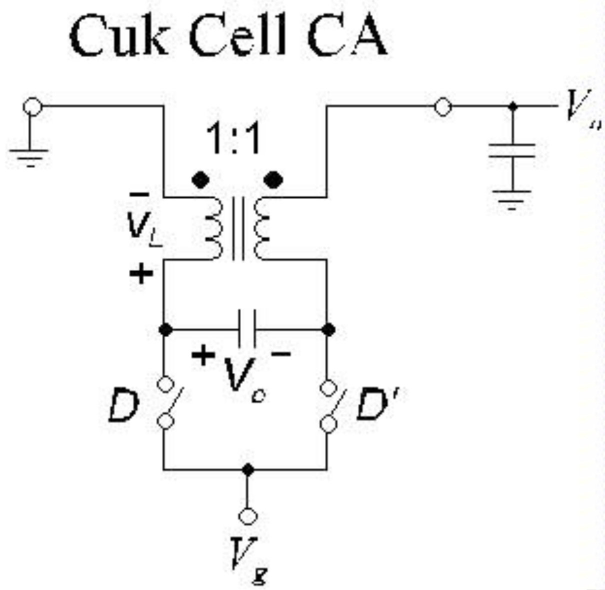
The Cuk cell is the basic Cuk circuit with the bottom terminals of the switches connected to a common terminal, S. This device also has three converter configurations, all of which have continuous input and output currents and ripple steering (with the approximate turns ratio of one). Referring to the three device terminals as active (A), passive (P), and switch (S), the active terminal of the transductor is on the same side as the on-time switch. The three resulting configurations are the CS or Cuk converter, the CA, and the CP, which might be novel.

The three Cuk-cell configurations have properties summarized in the following table and correspond to the three switch-cell configurations according to transfer function.

Configuration	**A**	**P**	**S**	V_o/V_g	V_c
CS (Cuk)	V_g	$-V_o$	GND	D/D'	$V_g + V_o$
CA	GND	$+V_o$	V_g	$1/D'$	$+V_o$
CP	V_g	GND	$+V_o$	D	V_g
CS^{-1}	$-V_o$	V_g	GND	D'/D	$-(V_g + V_o)$
CP^{-1}	GND	V_g	$+V_o$	D'	$-V_g$
CA^{-1}	$+V_o$	GND	V_g	$1/D$	$-V_o$

The last three entries are simply the first three with D and D' exchanged. This is significant in that these converters are bidirectional in function. This property leads to the development of switching amplifiers and regenerative motor-drive supplies based on them.

The CA is shown below.

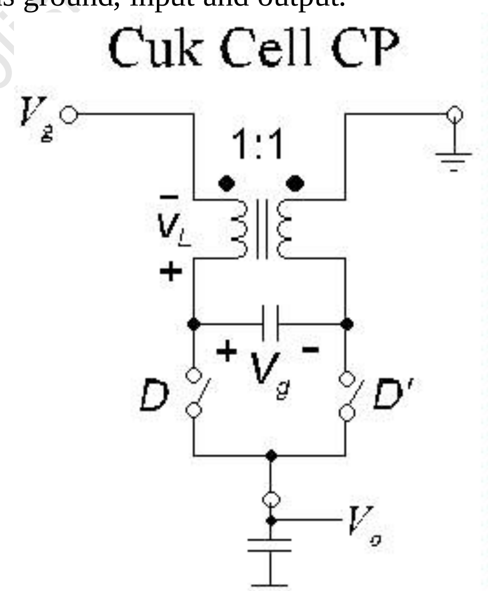


During the on-time, $v_L = V_g$ and during the off-time, $v_L = V_g - V_o$. The Cuk-cell CA draws continuous current from the supply and outputs continuous current to the load. The Cuk-cell CA has the voltage gain like that of a switch-cell CL (boost-buck) except that it does not invert with respect to ground:

$$\frac{V_o}{V_g} = \frac{1}{D'}$$

Over the range of D' from zero to one, the gain varies from infinity to one. Thus, the Cuk-cell CA is applicable whenever $V_o > V_g$. I discovered this circuit in the late 1980s and recorded it in my notebook, considering it obvious to anyone skilled in the art, only to find years later that it had subsequently been patented (US 6,252,383 B1).

The Cuk-cell CP is shown below, drawn in the same orientation as the Cuk-cell CA above to emphasize that only the terminals are reconfigured as ground, input and output.



The voltage gain of this topology is:

$$\frac{V_o}{V_g} = D$$

This is the same as the switch-cell CA (buck) converter and is applicable whenever $V_o < V_g$. This circuit I also deem obvious to anyone skilled in the art, yet I am not aware of its use in industry. Having constant-current input, and with a topology essentially the same as power-line input EMI filters, it serves as both the filter and the converter with a minimized parts count. The output current is also continuous, which reduces the capacitance and ripple current rating of the output capacitor -- another benefit of this desirable converter scheme. The input capacitor ratings are also reduced, of course, by the constant input current.

Multi-Stage Cuk-Cell Circuits

In a previous TechNote, Transistor and Inductive-Switch Analogs, a correspondence was identified between the three terminal configurations of transistors with those of the switch-cell, also a three-terminal nonlinear *device*. The Cuk-cell is another. Transistor configurations are combined into multistage circuits, some having a modular or *cell* quality such as the cascode (CE, CB) and Darlington (CC, CC) circuits.

It is possible to combine Cuk-cell converters as circuit stages, just as the CA and CP switch-cell stages were combined to result in the Cuk converter. Some guidance on how to construct new combinations can be taken by analogy with multi-transistor circuits such as the cascode, Darlington, and diff-amp. The correspondences between BJT, switch-cell, and Cuk-cell configurations lead to interesting and useful new schemes.