

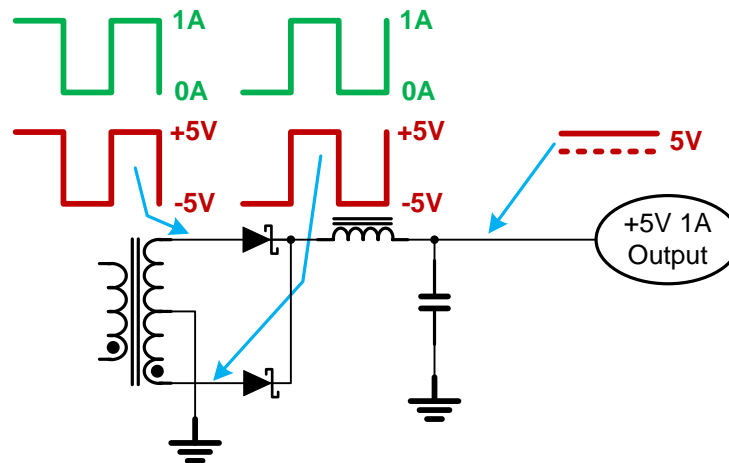
## How It Works: The Current Doubler Demystified

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The current doubler is a particularly useful rectifier configuration for low-voltage or high-current outputs. It combines two advantages—efficient usage of the transformer secondary winding (like a bridge rectifier) and easy self-drive of two n-channel MOSFET synchronous rectifiers (like a full-wave center tap). It has the disadvantage of needing two inductors, but because the transformer is usually more critical, I believe that this tradeoff is usually favorable.

By comparison, a full-wave center-tapped secondary winding output is less efficient because no more than half of the secondary winding is conducting at any moment (Fig. 1.) The result is a ratio of RMS winding current to dc output current that is less favorable. This inefficient usage increases the minimum total wire mass that is needed to achieve a given performance level.

Increased wire mass increases the winding "build" dimensions and places "idle" wire (that is the wire which is not conducting at a given moment) between the primary winding and the conducting secondary half during at least one half cycle. (The precise analysis depends on how the windings are layered.) This idle space tends to increase leakage inductance between the transformer primary and secondary windings. Increased leakage inductance will often degrade the efficiency and/or voltage regulation of the transformer.



*Fig. 1. The current in either half of the full-wave center-tapped rectifier output winding is zero for at least half the time, so the wire is used inefficiently. Direction of positive current flow is implied by the schottky diode orientation.*

In contrast, the two inductors that are required by the current doubler may increase the total size and mass of the magnetic components. However, there are few adverse side effects. If you focus on the ripple current seen by the transistors driving the transformer, the size of the inductors may need to be larger than the one inductor needed for a bridge rectifier output. That is because the current doubler inductors operate at half the frequency and will typically operate at twice the input voltage from the transformer. Of course, the current is half. This is an argument that is subject to some strong opinions, but larger inductors are not likely to adversely affect performance in the way that inefficient transformer use does.

One other advantage of the current doubler is its output ripple cancellation. When one end of the transformer output is driven high, the current flowing out of the connected inductor ramps up while the other (freewheeling) inductor output current ramps down. If the total duty cycle is close to 100% (meaning that one end of the transformer secondary or the other is almost always high) then these two inductor current slopes will cancel well and the combined output ripple current will be a small fraction of that in either inductor.

The bridge rectifier configuration similarly makes efficient use of the transformer secondary winding, but it requires four rectifiers instead of two. More rectifiers imply increased cost and/or losses. Using diode rectifiers will usually result in higher loss and inferior load regulation as compared to synchronous rectifiers. If the four rectifiers are synchronous, two of them will probably be p-channel MOSFETs (which are less efficient than n-channel) unless the designer uses a more-complicated drive scheme.

Some engineers may be confused as to how the current doubler works. In fact, I was puzzled when I first encountered it. But then I discovered the similarities between the current doubler and the dual-phase buck converter. In this article, I use this analogy with the dual-phase buck converter to explain how the current doubler operates.

### The Simple Buck Converter

In a basic buck regulator, the inductor averages the input voltage waveform and it is smoothed by the LC filter. The average dc voltage is the same on both ends of the inductor, but the LC filter removes most of the ac component. In the example pictured in Fig. 2, the 0-V to 10-V 50% duty cycle square wave has an average dc value of 5 V, so 5 V is the value of the dc output. Output voltage can be regulated by varying the duty cycle.

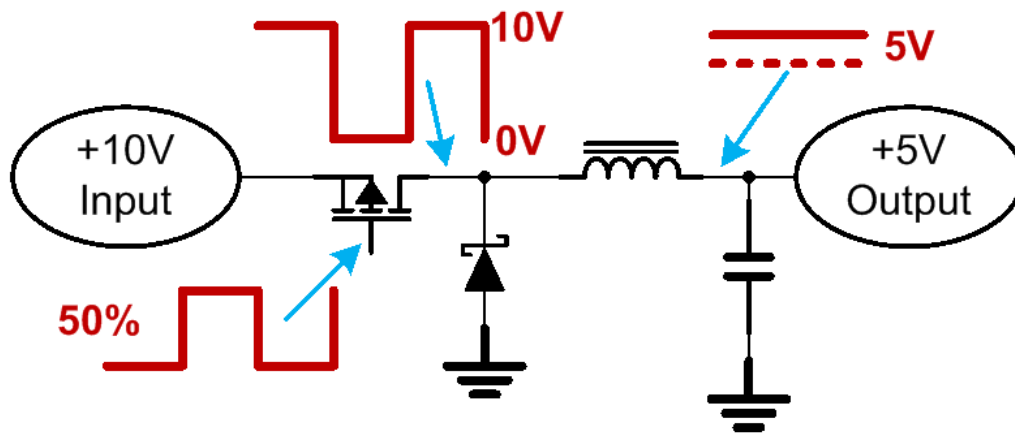


Fig. 2. The switch in this buck regulator produces a 0-V to 10-V 50% duty cycle square wave, which has an average dc value of 5 V. The output LC filter removes most of the ac component.

In a two-phase buck regulator, you have two sets of FET switches, diode or synchronous FET rectifiers, and inductors both operating with the same input voltage and duty cycle. They will produce the same output voltage so the outputs can be tied together to double the output current.

In this example, shown in Fig. 3, the two FET switches are operating "interleaved" or out of phase. That is the best and most relevant example because it gives us the desired ripple cancellation, and because our current doubler below must work similarly.

Note that this circuit in Fig. 3 could also work with the switches operating in phase. That would not normally be done due to the greatly increased input and output ripple. Output voltage can be regulated by varying the duty cycle.

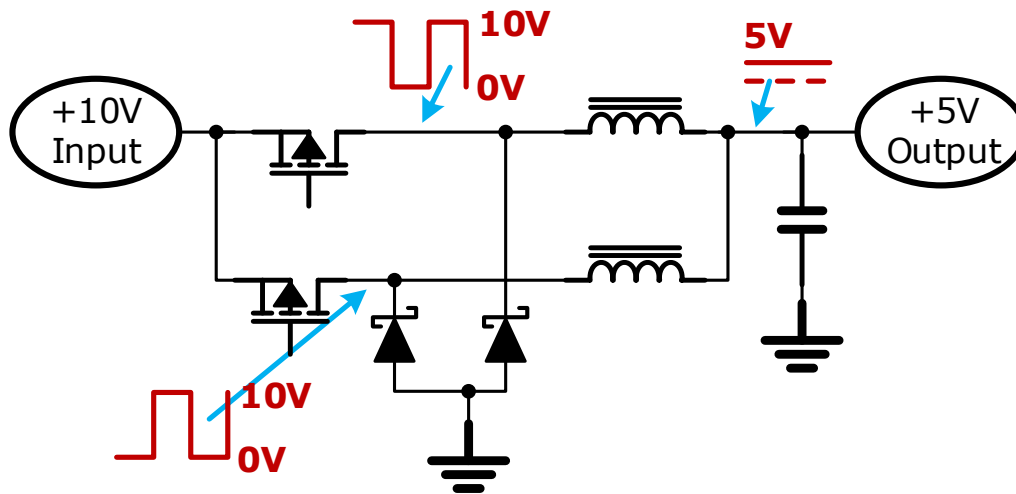


Fig. 3. Going from the single-phase buck converter shown in Fig. 2 to the dual-phase buck shown here produces the same output voltage but doubles the output current. The two FET switches are usually operated out of phase so that the ripple currents in the two inductors tend to cancel.

The current doubler, which is shown in Fig. 4, operates very much like the two-phase buck regulator above, with interleaved phasing and cancellation of output ripple. In our current doubler example, the transformer is producing the same 10-V peak that was previously produced by the MOSFET switches. Meanwhile, the rectifiers prevent either end of the transformer secondary winding from traversing below ground, so when one rectifier is conducting we have +10 V at the opposite end of the winding. As was true for the buck converters, the current doubler's output voltage can be regulated by varying the duty cycle.

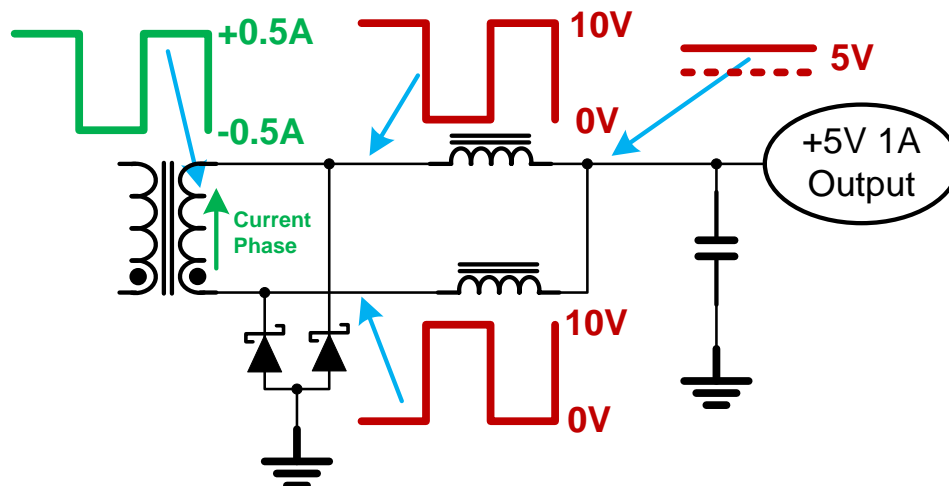


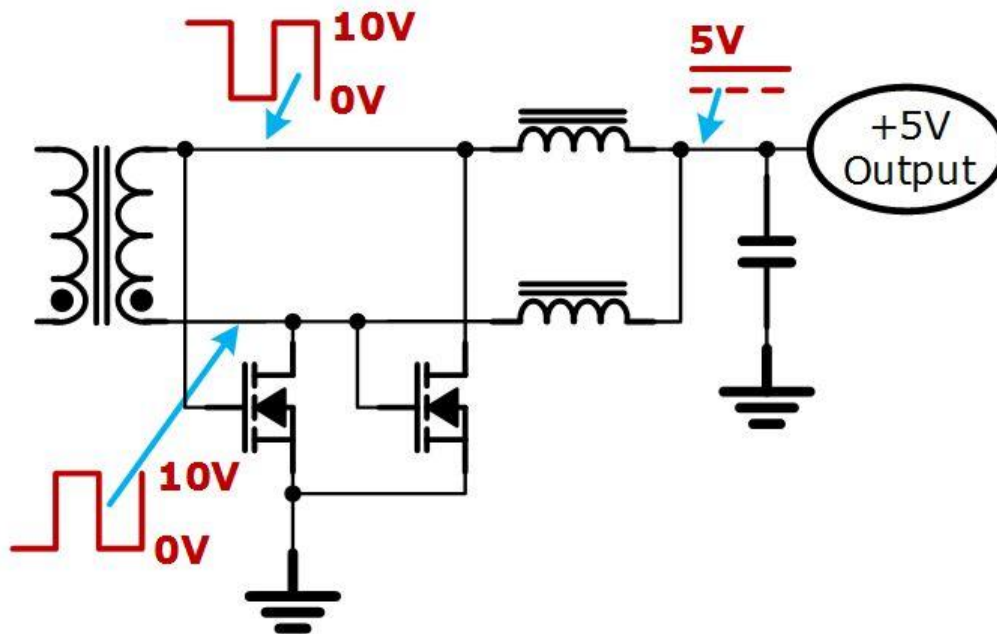
Fig. 4. The current doubler operates like the dual-phase buck converter including use of interleaving and cancellation of output ripple. But instead of being directly fed by MOSFETs, the transformer is producing the 10-V peaks while the rectifiers prevent either end of the transformer from going below ground. The output winding has only two end terminations so the current in it is defined by only one waveform.

In the case where the transformer is almost always driving the output (that is, the total duty cycle is nearly 100%) as in our example, the current doubler lends itself very nicely to self-driven synchronous rectification (Fig. 5.) When either end of the transformer secondary is high, it drives one inductor and the gate of the

synchronous rectifier MOSFET whose drain is connected to the other side. Unlike self-driven synchronous rectifiers in some other schemes, there should be little or no shoot-through.

Synchronous rectification improves both full load efficiency and load regulation. The efficiency improvement is caused by lower forward voltage drop. The load regulation improvement is caused by the fact that synchronous rectification forces "continuous conduction mode," which allows the ripple current to traverse negative and prevents peak rectification during light load conditions.

Note that the schematic diagram in Fig. 5 is simplified in the area of the synchronous rectifier gate drive. So as to protect the synchronous rectifier gates against backfeed from residual dc output voltage, the gate drive should normally be ac coupled and should include level protection and dc restoration with resistors and zener diode clamps.



*Fig. 5. When duty cycle is close to 100%, the current doubler is well suited to use of self-driven synchronous rectifiers, exhibiting little or no shoot through. Synchronous rectifiers can work very well regardless of duty cycle. But with low duty cycle, self drive is likely to cause a large conduction angle through the MOSFET drain-body diode, which is inefficient. For this reason, active gate-drive circuitry may be better for low duty cycles.*

## About The Author



*Bob Zwicker received a BSEE in 1974 from North Carolina State University and began designing switching power supplies in 1980. He has one patented invention for a method of secondary-side control of synchronous rectifiers. Bob became an applications engineer in 2002 and now does consulting out of his home in Olympia, Wash. For more on Bob's experience, see his listing in [How2Power's Consultants Corner](#).*