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Why Phase-Shift Converters Are More Accurate Than PWM Converters

by Gregory Mirsky, Design Engineer, Deer Park, Ill.

PWM and phase-shift power converters are being widely used for medium- and high-power applications at power levels from a few hundred watts through a few kilowatts. The dc output of these converters is obtained from a filtered rectangular pulse train. Ideally, the converter feedback control system that regulates the output voltage derives the average value of the pulse train and keeps it proportional to the internal or external reference voltage. Typically the converter output should follow the reference voltage very accurately over a wide range of the duty-cycle to achieve high stability over a wide voltage range, requiring strict proportionality of the output voltage to the duty-cycle.

However, this tight relationship between duty cycle and output voltage is not maintained if —in addition to the pulse train—there is some extra voltage filling the gap between pulses. Such is the case with PWM converters. And analyzing and simulating the PWM and phase-shift converters' operation, one can notice that their performance differs accuracy-wise. As we'll see in the simulations presented in this article, the output voltage of PWM converters is not always proportional to the rectified pulse-train duty-cycle, while in the phase-shift converters it is.

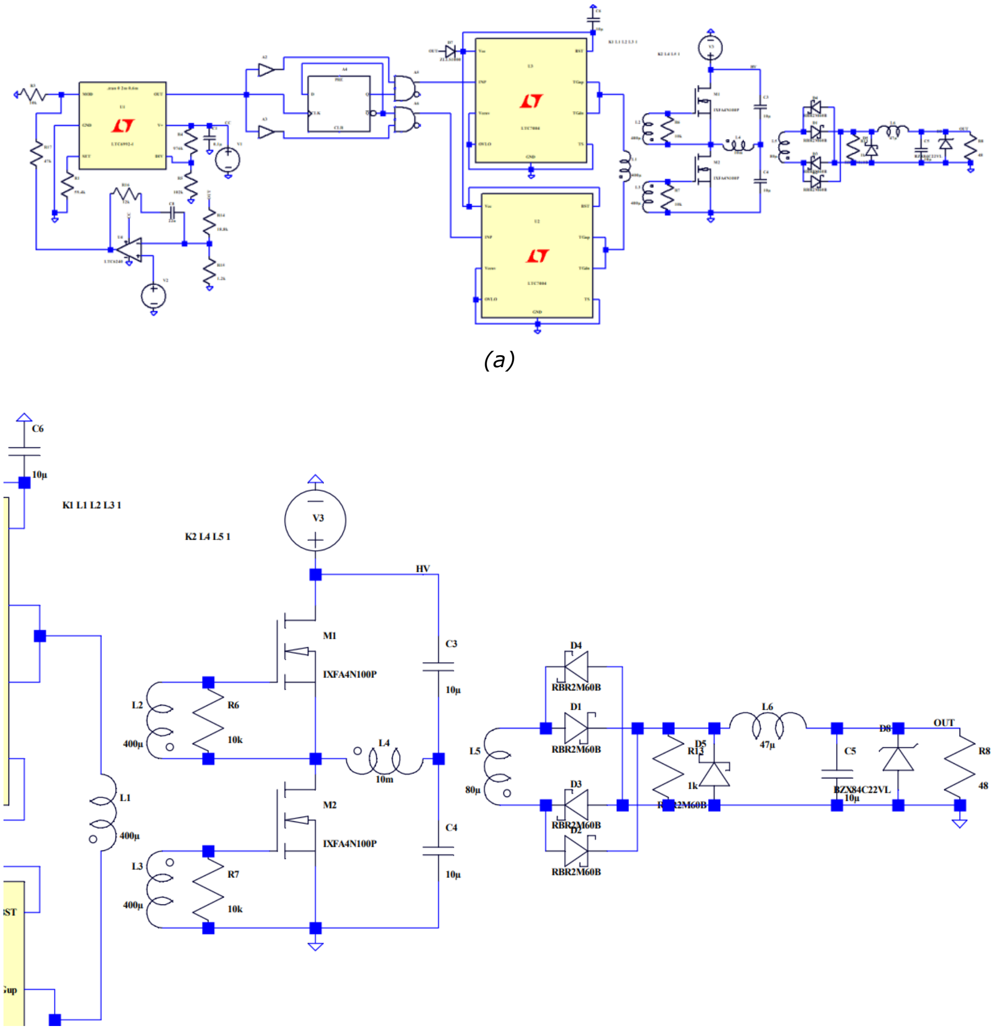
The Impact Of A Floating Primary Winding

Let's consider the LTSpice schematic layout of a PWM converter presented in Fig. 1. It is important to know for this schematic layout that when the duty-cycle is controlled there are gaps between pulses, and both terminals of the winding L1 see the same voltage (as soon as its value is zero), and therefore the MOSFETs' gates see zero voltage with respect to their sources, and M1 and M2 are off.

When that occurs, the primary winding L4 of the power transformer is *floating*, which is very important to note, and does not affect the resonant process on the secondary side of this transformer. So what happens on the secondary side of the power transformer?

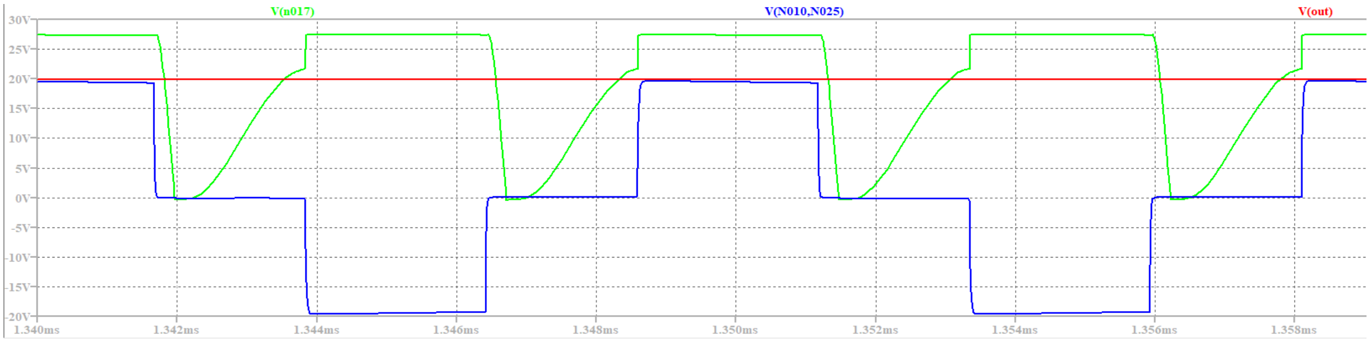
To answer that question, we must consider what was happening in the circuit before the dead-time across L4 was created. At that time, a load dc+ac current would have been flowing through the filter inductor L6 as well as the filter capacitor C5. So when the voltage across L5 was interrupted due to the duty-cycle control, the current that was then flowing in L6 current would start circulating in L5, L6, and C5, and then would reflect to L4, C3 and C4 under resonant conditions with high quality factor since L4 would be free-wheeling.

This resonating current on the secondary side creates a sine wave voltage across D5, which adds voltage to the node where C5 and L6 are connected, i.e. the filter input sees not just the rectangular voltage across D5 but some extra sinewave voltage in the gap between adjacent pulses. This resonant voltage is trying to increase the output dc voltage, but the output dc voltage is held steady by the feedback loop, reducing the duty-cycle. Therefore this extra sinewave reduces the actual duty-cycle and regulation range. The resulting waveforms are depicted on Fig. 2.



(a)

Fig. 1. Schematic of a half-bridge PWM converter (a). The output voltage is regulated by controlling the duty-cycle of the pulses applied to the gate-drive transformer primary winding L1, which is more easily seen in the enlarged version of the output stage (b).

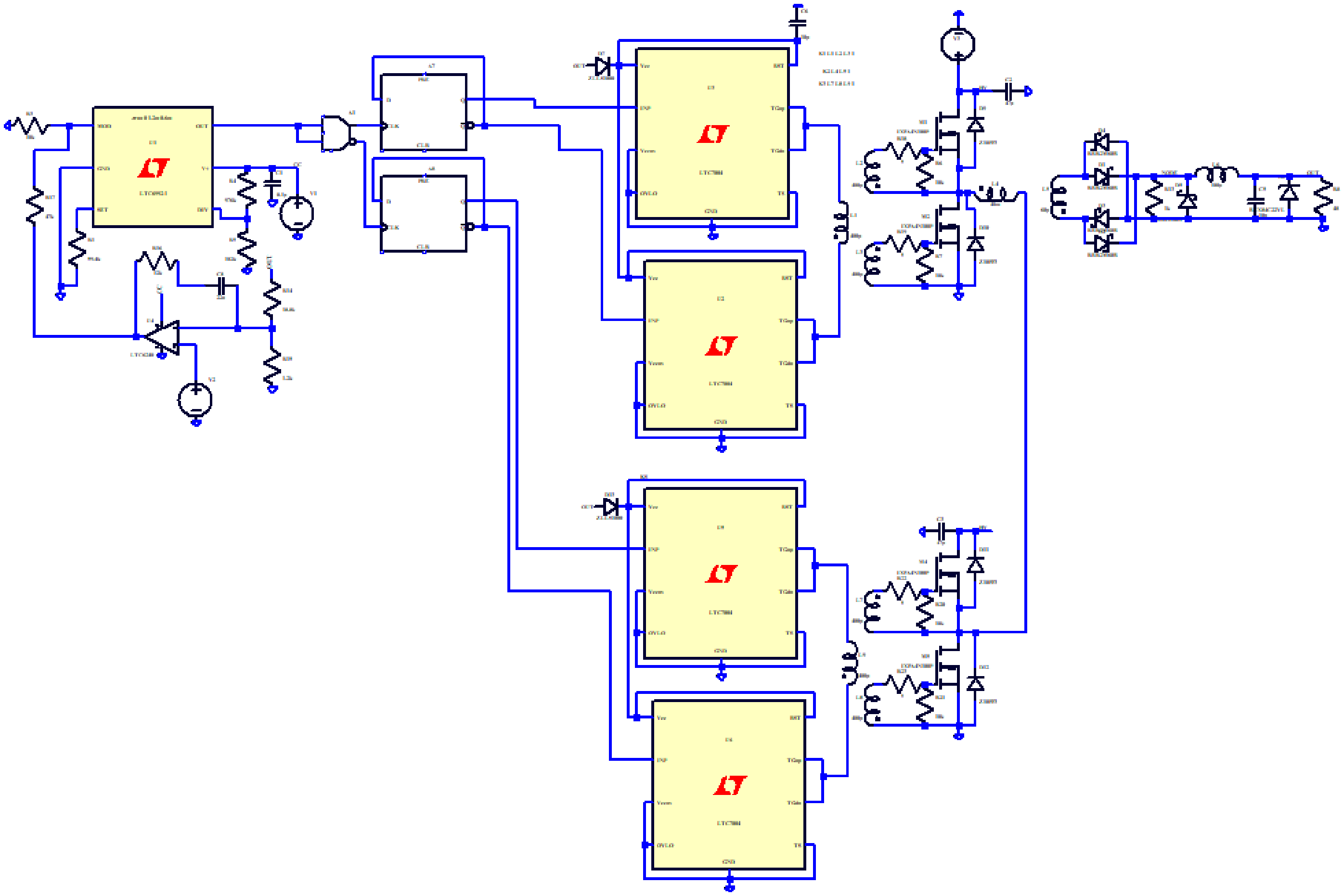


Vampl = 27.4 V   D = 0.571   Vout.calculated = 15.7 V   Vout.measured = 20 V

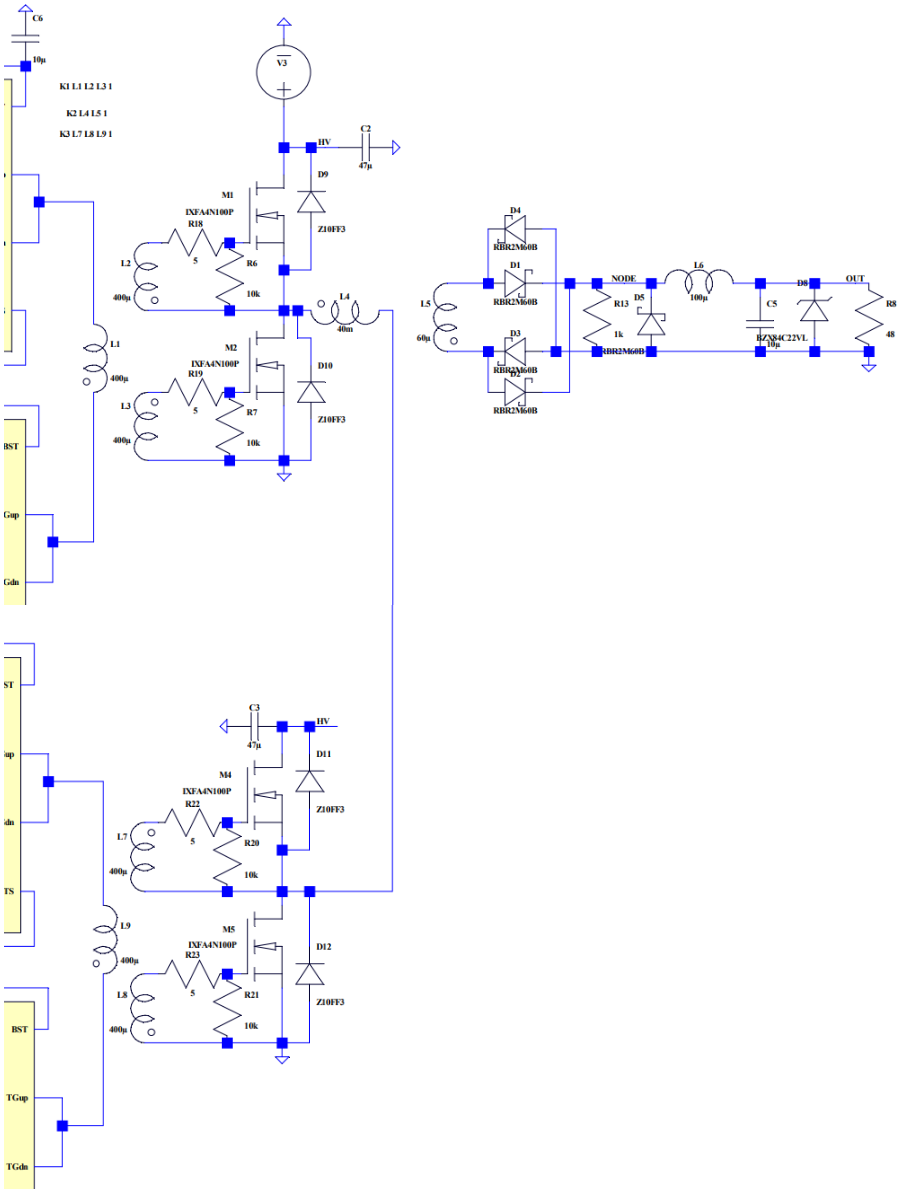
Fig. 2. Resonating voltage fills the gaps between the rectangular pulses thus trying to add up to the output average voltage. But this process actually reduces the duty-cycle.

Fig. 3 shows a schematic of the phase-shifting bridge, which is free of the duty-cycle reduction effect thanks to the continuous connection of L4 to a short circuit created by the upper or lower MOSFETs (seen more clearly in Fig. 3 part b), which are both on during the off times of the switching-node waveform. This shorts out the possibly resonating components on the secondary side of the power transformer and thus kills the extra voltage in the gap between the pulses. This is clearly shown in Fig. 4.

Therefore, the phase-shift converter configuration allows for a wider input voltage range and much better accuracy since it ensures a continuous duty-cycle control. This improved duty cycle control may increase the converter input voltage range by 20%.

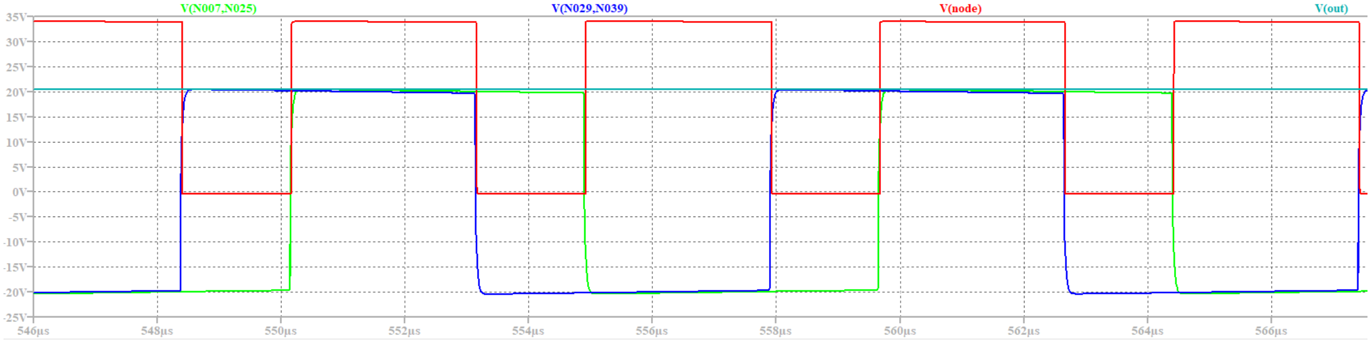


(a)



(b)

Fig. 3 Phase-shift converter (a). Output voltage is regulated by controlling the phase shift between 50% duty cycle pulse trains coming to the L4 terminals, which are more easily seen in the enlarged view of the output stage (b). Thus, L4 is never floating.



Vampl = 34 V   D = 0.38   Vout.calculated = 21.3 V   Vout.measured = 20.6 V

Fig. 4. The gaps between the pulses (Vnode) are clear of extra voltage. The duty-cycle corresponds to the output voltage. The difference between Vout.measured and Vout.calculated is the voltage drop across inductor L6.

About The Author

Gregory Mirsky is a design engineer working in Deer Park, Ill. He currently performs design verification on various projects, designs and implements new methods of electronic circuit analysis, and runs workshops on MathCAD 15 usage for circuit design and verification. He obtained a Ph.D. degree in physics and mathematics from the Moscow State Pedagogical University, Russia. During his graduate work, Gregory designed hardware for the high-resolution spectrometer for research of highly compensated semiconductors and high-temperature superconductors. He also holds an MS degree from the Baltic State Technical University, St. Petersburg, Russia where he majored in missile and aircraft electronic systems.

Gregory holds numerous patents and publications in technical and scientific magazines in Great Britain, Russia and the United States. Outside of work, Gregory's hobby is traveling, which is associated with his wife's business as a tour operator, and he publishes movies and pictures about his travels online.