UNITRODE

Design Note

DN-63

The Current-Doubler Rectifier: An Alternative Rectification Technique For Push-Pull And Bridge Converters

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This design note describes an alternative rectification method which offers simpler structure and better utilization of the isolation transformers in push-pull, half-bridge and bridge power stages where usually full-wave rectification is required on the secondary side of the transformers. Converters using the current-doubler rectifier can achieve lower and better distributed power dissipation and smaller size in the magnetic components.

The common property of the push-pull, half-bridge and bridge topologies which makes the full-wave rectification necessary is that they utilize bipolar voltage across the secondary side of the transformer.

Figure 1 illustrates the commonly used circuit arrangement for full-wave rectification. For proper operation the secondary winding has to be center-tapped with one terminal connected to the reference potential (ground) of the circuit. The center-tapping splits the secondary winding into two inductors which are coupled strongly but not perfectly within one magnetic structure.

This design note assumes a full-bridge power converter using the phase-shifted control method. Consequently, the primary of the isolation transformer is short circuited in the free-wheeling mode which has a profound effect on the current distribution in the secondary windings during that period. In all other aspects, the operation of the push-pull, half-bridge and the conventional full-bridge converters are identical to the description below.

Based on the polarities and signal names of Figure 1, operation is as follows:

During the first active period when energy is transferred from the primary to the secondary side, the voltage across TR1 is positive. D1 is forward biased while the negative voltage appearing across TR2 keeps D2 reverse biased. The current of the output inductor, LO, is forced to flow through TR1 while TR2 carries no current. During the free-wheeling period, the voltages across TR1 and TR2 become zero. In theory the output current is evenly distributed between the secondary windings TR1 and TR2. In practice, because of leakage inductance associated with real magnetic structures, the output current is not shared evenly. TR1 still conducts most of the output inductor current while the current slowly builds up in TR2 depending on the value of the leakage inductance and the available voltage across it. In the next active interval, V2 is positive, in which case TR2 and D2 carries all the current of LO while D1 is reverse biased by TR1 having no current through them. In the next period V1 and V2 are zero again and similarly to the previous free-wheeling period the output inductor current will keep flowing in TR2.

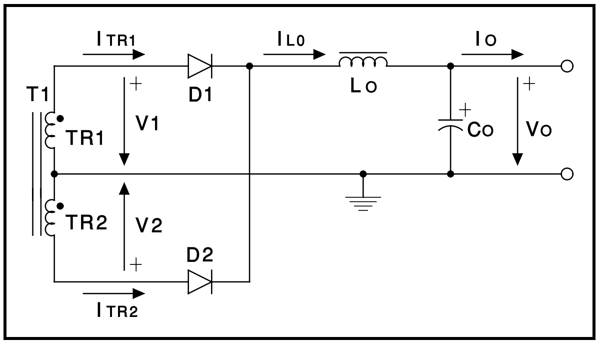

Figure 1. Full-Wave Rectifier

Figure 2 shows the most important waveforms of operation.

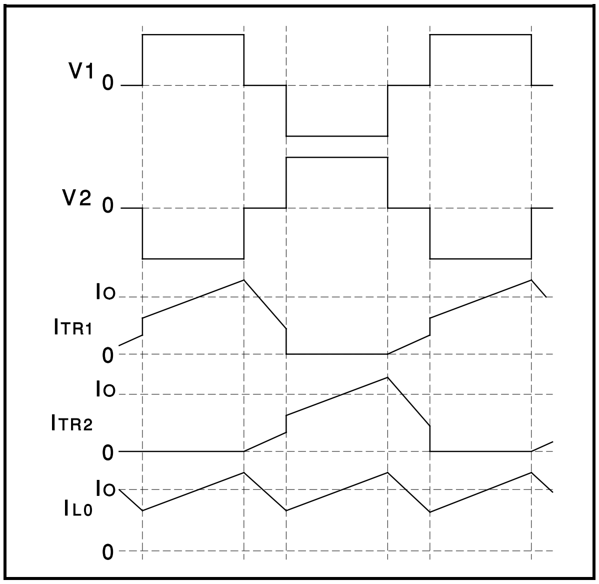

Figure 2. Waveforms of the Full-Wave Rectifier

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The proposed current-doubler rectifier is presented in Figure 3. It is composed of the secondary winding of the isolation transformer which is not center-tapped now, the same two rectifier diodes, two individual but identical filter inductors and an equal output capacitor to the one of the full-wave rectifier circuit.

Using the symbols and signal polarities introduced in Figure 3 the operation of the rectifier is described below:

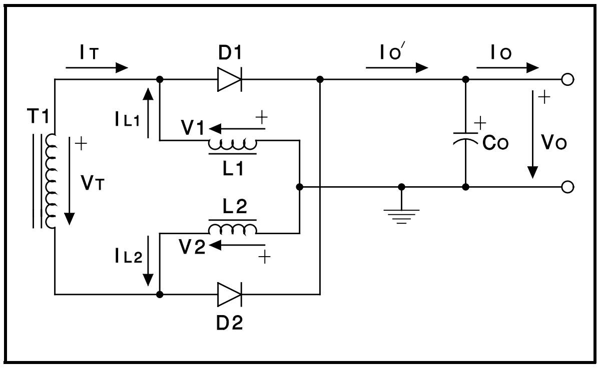

Figure 3. Current-Doubler Rectifier

Starting at the first active period the voltage across the secondary winding of the transformer, V_T is positive. Current flows in positive direction in both filter inductors, L1 and L2. During this period D1 is forward biased while D2 is kept off by V_T. It means that the current path for L1 runs through D1 and the output capacitor, basically kept away from the secondary winding of the transformer. The current of the second filter inductor L2 flows through the transformer winding and D1, closing the loop through the output capacitor. Hence the output current is the sum of the DC components of the two filter inductor currents, the transformer sees only half of the load current during the active time interval. During this time, the voltage across L1 is negative and equals the output voltage causing the current in L1 to decrease. On the other hand, V2 across L2 is positive, causing the current in L2 to increase. The active period is followed by a free-wheeling interval. V_T is not forced across the secondary winding of the transformer any longer. The voltage across L2 becomes negative, and equal to the output voltage amplitude, producing a negative slope in the current through L2. As in the full-wave case, theory would suggest that the current of L2 goes through D2 instead of the transformer winding, but in practice this current will continue, due to flow in the transformers secondary. The conditions for L1 do not change. At the beginning of the consecutive active interval, a negative voltage appears on the output of the transformer. D1 turns off while D2 is forward biased. The current rapidly changes direction in the transformer winding, and is equal to the current of L1. The current of L2 is not flowing through the transformer any longer and keeps decreasing by the rate determined by the inductance value and the output voltage. Having a positive voltage across L1, the current starts building up in the inductor. The full operating cycle is completed by another free-wheeling period when V_T becomes zero, $-V_O$ appears on L1 causing its current to decrease and there is no change in the condition of L2.

The essential waveforms of the current-doubler rectifier are indicated in Figure 4.

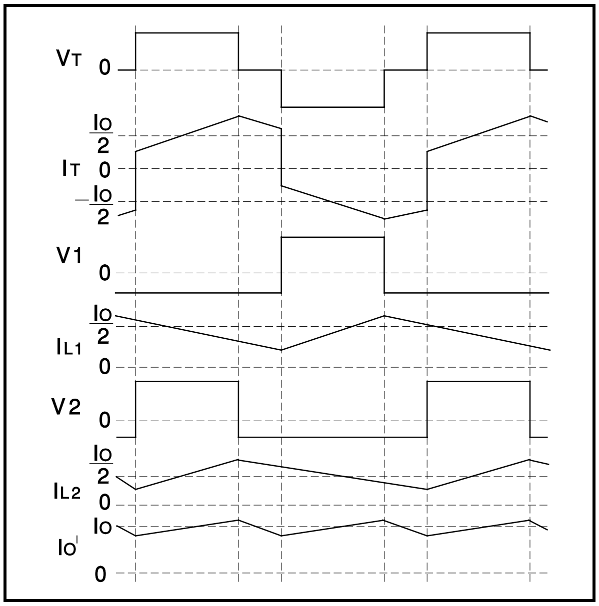

Figure 4. Waveforms of the Current Doubler Rectifier

Summarizing the most important properties of the current-doubler rectifier as revealed by the circuit diagram, the description of operation and the different waveforms, the following conclusions can be drawn:

- there is no need for center-tapping
- finer steps in turns ratio are possible
- transformer structure is simpler
- transformer carries approximately half of the output current (only the secondary winding)
- operation on the primary side, including duty-cycle is unchanged

- diode and output capacitor stresses are identical to the full-wave technique
- additional filter inductor required
- each filter inductor carries only half of the DC output current
- ripple currents cancel on common output capacitor
- requires current-mode control to ensure equal currents in the filter inductors

In order to correctly judge the merit of this rectification technique for practical applications, a quantitative comparison is presented. Assume, that two converters operate with a clock frequency of fs, have the same input and output voltages, equal load currents and equal ripple currents in the output capacitors. For these cases, the most important design parameters are given in an easy to use form in Table 1. For simplicity, the current values are not reflecting the effect of the AC components of the inductor currents.

Table 1. Comparison of Full-Wave and Current-Doubler Rectifiers

Technique >	**Full-Wave**			**Current-Doubler**		
Magnetics>	**TR1**	**TR2**	**Lo**	**Tr**	**L1**	**L2**
Transformer Operating Frequency	$\frac{fs}{2}$			$\frac{fs}{2}$		
Transformer Primary Number of Turns	N			N		
Transformer Secondary Number of Turns	1	1	-	2	-	-
Transformer Secondary Current (DC average; multiplier is the duty-cycle of the secondaries)	$I_O \bullet 0.5$	$I_O \bullet 0.5$	-	$\frac{I_O}{2} \bullet 1$	-	-
Secondary current reflected to the primary (DC average)	$I_O \bullet \frac{1}{N} \bullet D$			$\frac{I_O}{2} \bullet \frac{2}{N} \bullet D$		
D1; D2 Breakdown Voltage (minimum)	$V_{IN} \bullet \frac{1+1}{N}$			$V_{IN} \bullet \frac{2}{N}$		
Output Inductor Operating Frequency	-	-	fs	-	$\frac{fs}{2}$	$\frac{fs}{2}$
Output Inductor Current (DC Average)	-	-	I_O	-	$\frac{I_O}{2}$	$\frac{I_O}{2}$
Output Inductance (minimum) ** function of duty-cycle*	-	-	L_O	-	$\leq L_O$*	$\leq L_O$*

Summary: the presented current-doubler rectifier provides an alternative rectification technique for converters employing push-pull, half-bridge or bridge topologies. The method simplifies the power transformer and adds one more filter inductor to the circuit. Depending on the particular application, the total volume of the two filter inductors might be equal or smaller than the choke of the full-wave rectifier due to their lower operating frequency and lower current rating.

Further trade-offs can be made in order to reduce inductor sizes by lowering the inductance value and relying more strongly on the ripple current cancellation of the two inductors. Additionally, the current-doubler rectifier offers the potential benefit of better distributed power dissipation which might become a vital benefit in densely packed power supplies. Because of its added circuit complexity, this solution could probably be justified in medium to higher power and/or high output current applications.