

AN100

The Elusive Tapped Output Inductor

By
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Designers of forward voltage-fed dc/dc converters are always facing the possibility of transformer core saturation and the resultant current and voltage spikes that put undue stress on the switching transistors, which can lead to premature failure. There is a simple modification of the output filter that can eliminate or greatly reduce core saturation caused by asymmetrical currents on the secondary.

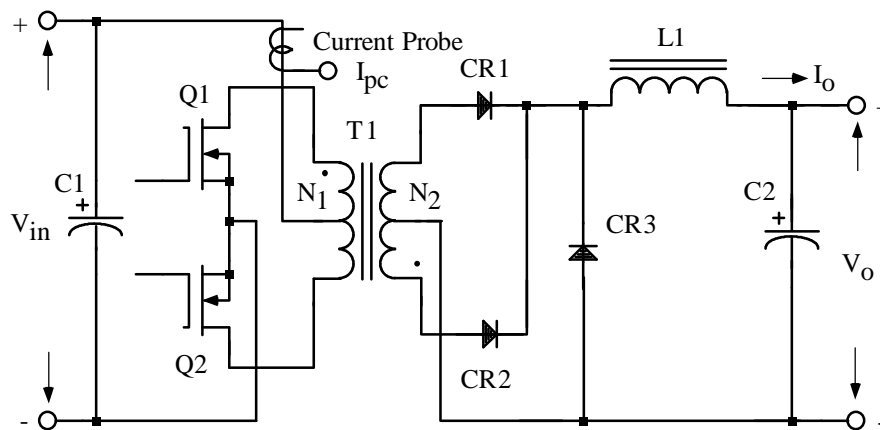


Figure 1. A typical push-pull primary, with a center-tapped secondary converter.

A conventional push-pull voltage-fed dc/dc converter, with a center-tapped secondary and a LC output filter, is shown in Figure 1. The ideal current waveforms are shown in Figure 2, without parasitic influence. It is assumed the time intervals are the same.

$$Q1_{on} = Q2_{on}$$

$$Q1_{off} = Q2_{off}$$

The performance description of the push-pull converter in Figure 1 will be discussed using the waveforms in Figure 2. When transistor Q1 is turned on, (See Figure 2A), diode CR1 is forward-biased and delivers current to the load through L1. (See Figure 2D and 2E.) In the same time interval, CR2 is back-biased and turned off. Now, when Q1 is turned off, diode CR1 is still conducting, providing the commutating current I_{LX1} for the inductor. This same thing is repeated on the next half cycle. When transistor Q2 is turned on, (See Figure 2B.) diode CR2 is forward-biased and delivers current to the load through L1. (See Figure 2C and 2E.) In the same time interval, CR1 is back-biased and turned off. Now, when Q2 is turned off, diode CR2 is still conducting, providing the commutating current I_{LX2} for the inductor. There are many designs that show a diode, like CR3, in Figure 1, as an alternate path for the commutating current for L1. This diode, CR3, does not conduct, nor does it prevent the commutating current from flowing in diodes, CR1 and CR2. It will be noted that currents I_{LX1} and I_{LX2} are flowing at the same time. This is the result of transformer T1 trying to balance the ampere-turns, due to the commutating current I_{LX1} flowing in CR1. The currents I_{LX1} and I_{LX2} are not always balanced.

The B-H loop, in Figure 3, shows how the unbalanced current will cause the core to ratchet to one end or the other of the B-H loop and saturate the core.

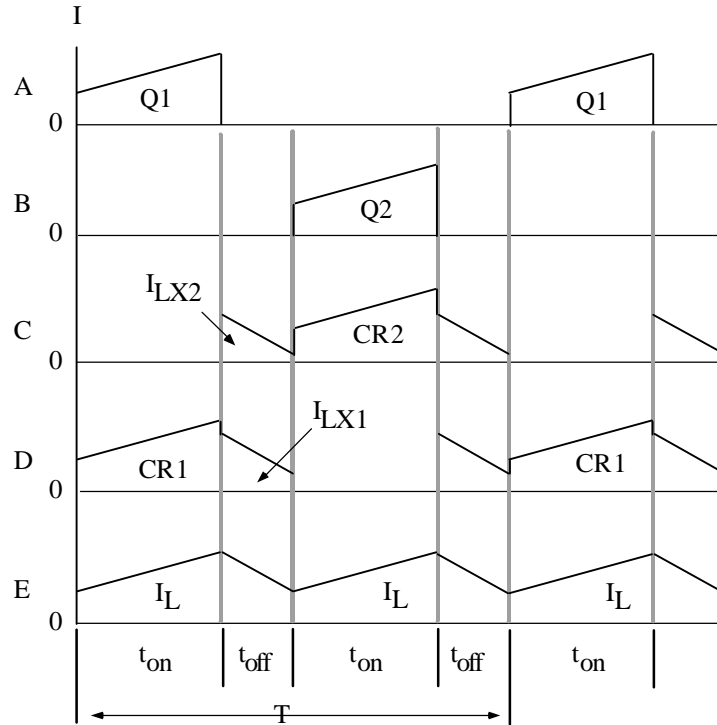


Figure 2. Typical currents waveforms of a push-pull converter.

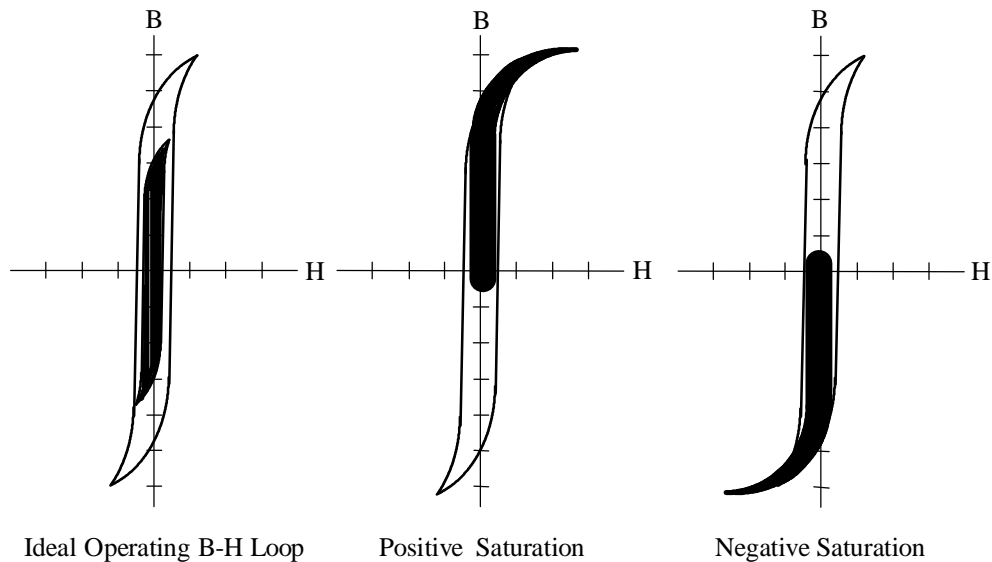


Figure 3. Typical B-H loop driven into saturation.

The commutating current flowing through diodes CR1 and CR2 is from a current source. Engineers have tried to balance this current through the diodes by screening and matching components, but this is both costly and limited in effectiveness because it is difficult to match

components over a wide temperature range. The transformer should have tightly coupled, secondary windings for current sharing. The result of this unbalanced current can be seen in Figure 4, using the current probe in Figure 1. The waveforms in Figure 4 have been viewed many times. The waveform A, in Figure 4, shows the primary current, I_{pc} , when the commutating current, I_{LX1} , and I_{LX2} , has only a small imbalance. The waveform B, in Figure 4, shows the primary current, I_{pc} , when the commutating current, I_{LX1} and I_{LX2} , has a large imbalance forcing the transformer core into saturation.

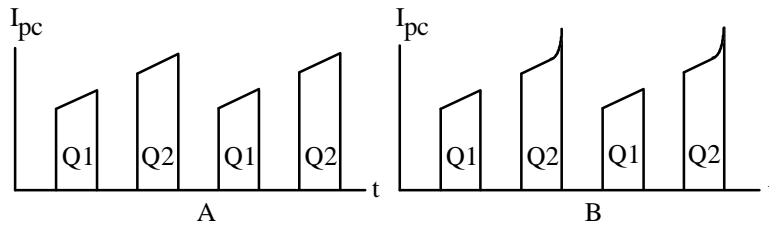


Figure 4. Primary center-tapped current.

Tapped Inductor Description

If the diode, CR3, were forced to conduct and provide an alternate path for the commutating current, while at the same time back-biasing diodes CR1 and CR2, this commutating problem could be solved. The need is for a small bias voltage that could turn on CR3, while at the same time Q1 or Q2 is turned off. The standard output filter inductor and the tapped inductor are shown in Figure 5. When either transistor, Q1 or Q2, is on, the current in the inductor L1 is increasing, with the polarity, as shown in Figure 5, as Charge. Now, when either transistor, Q1 or Q2, is turned off, the current in the inductor L1 will start to decrease, with the polarity, as shown in Figure 5, as Discharge.

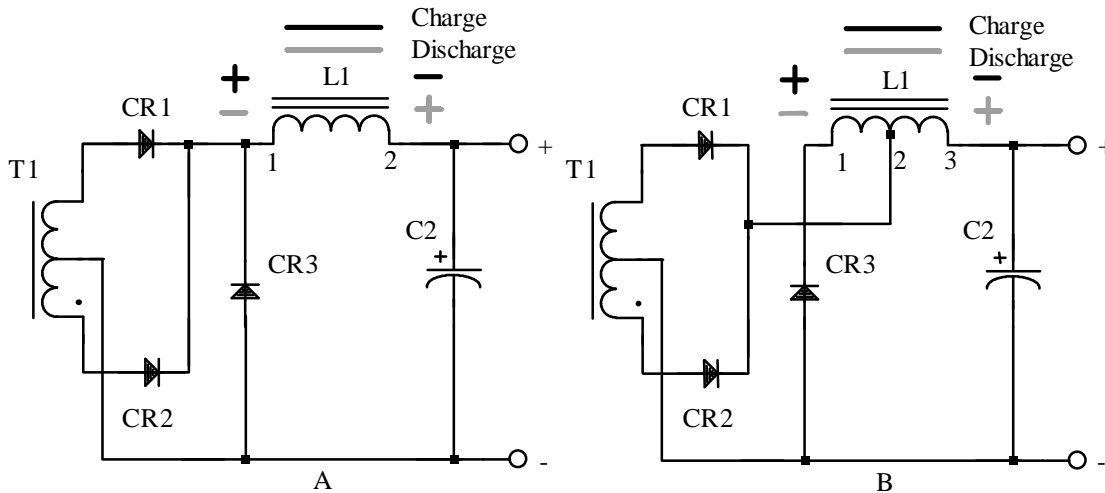


Figure 5. Comparing the standard output inductor with the tapped inductor.

Such a bias voltage source is readily available right on the inductor L1. This can be done by adding just a few turns to the output inductor L1 as shown in Figure 5B. The selection of the tap ratio is greatly dependent on the transformer T1 secondary leakage inductance and the output voltage V_o [See Reference 1]. Normally, it requires only a few turns.

Another benefit in using the tapped inductor is when the commutating current is flowing through CR3, diodes, CR1 and CR2, is that it has plenty of time to recover. The anodes for both diodes CR1 and CR2 are tied to the tap (#2) on L1. When Q1 and Q2 are turned off, the inductor L1 becomes a voltage divider and back-biases CR1 and CR2. This prevents the currents I_{LX1} and I_{LX2} from L1 from flowing through the secondary of the transformer T1 and biasing the transformer core. This full recovery of both diodes CR1 and CR2 reduces the stress on the switching transistors Q1 and Q2 requiring the transistors to turn-on into a diode, recovery short. The new waveforms, using the tapped inductor, are shown in Figure 6. Again, these are idealized waveforms without parasitic influence. The number of turns required on the over wind (#1-2) should be minimized in order to keep the current step, I_{step} , to a minimum (See Figure 6F). With the tapped inductor L1 installed, the primary center tap current is returned to normal, as shown in Figure 7.

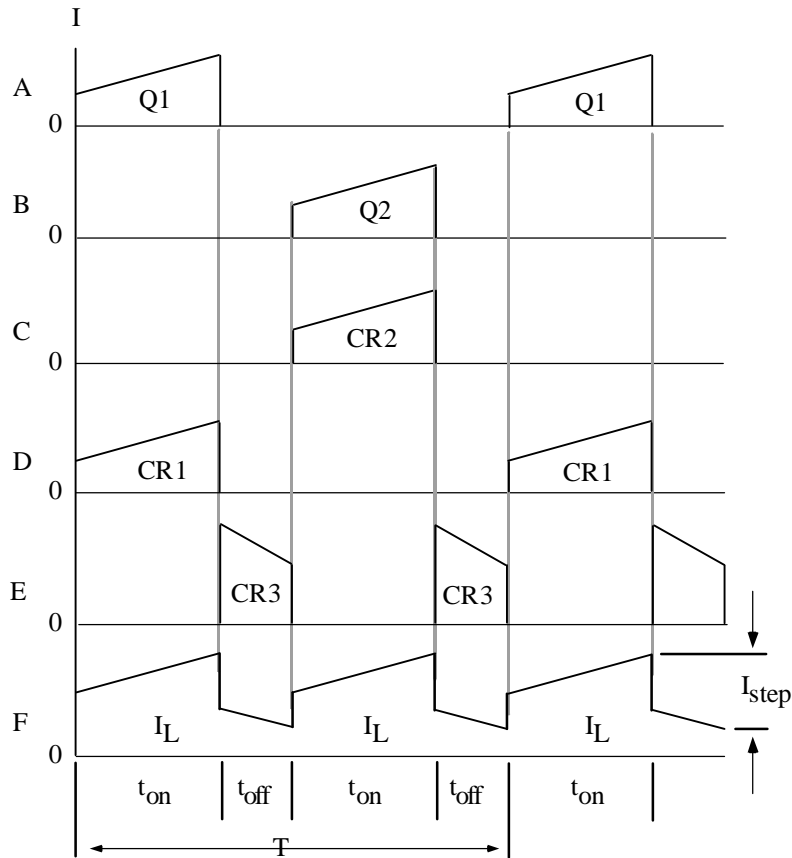


Figure 6. Push-Pull converter current waveforms using the tapped inductor.

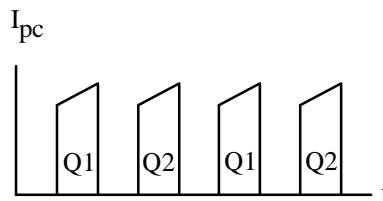


Figure 7. Primary, center tapped current, using the tapped inductor.

Single Forward Converter

The tapped inductor is also beneficial to the single-ended, forward converter. A conventional, single-ended forward dc/dc converter and a LC filter are shown in Figure 8. The ideal current waveforms are shown in Figure 9, without parasitic influence. The single-ended forward converter has the same commutating problem as the push-pull converter. The performance description of the forward converter, in Figure 8, will be discussed, using the current waveforms in Figure 9. Under ideal conditions, when transistor Q1 in Figure 9A is turned on, diode CR2 in Figure 9C is forward-biased and delivers current to the load through the inductor L1. When Q1 is turned off, diode CR2 will cease to conduct, and CR3, in Figure 9D, will then conduct the commutating current in inductor L1. At the same time, when Q1 is turned off, diode CR1 in Figure 9B is conducting the demagnetizing current to reset the core. In actuality, when looking at the diode recovery and forward conduction, along with the transformer's many parasitics, the true waveforms found on the actual converter are far from ideal. There are times when CR2 and CR3 are sharing the commutating, as shown in Figure 10, using the current probe in Figure 8. There are two demagnetizing currents, shown in Figure 10. The current waveform, in Figure 10A, is the normal, reverse, saw tooth waveform. The current waveform, in Figure 10B, is a current that would be expected if some of the commutating current were flowing through CR2 and CR3 at the same time.

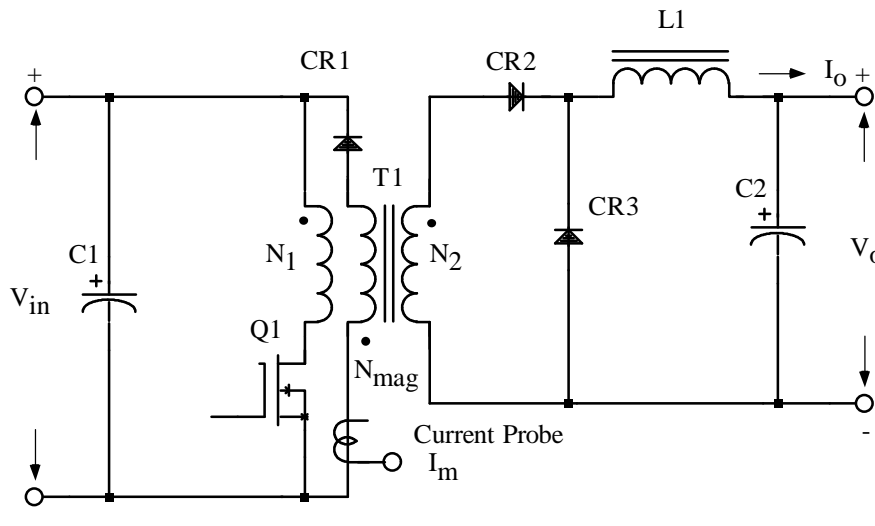


Figure 8. A typical single-ended, forward converter.

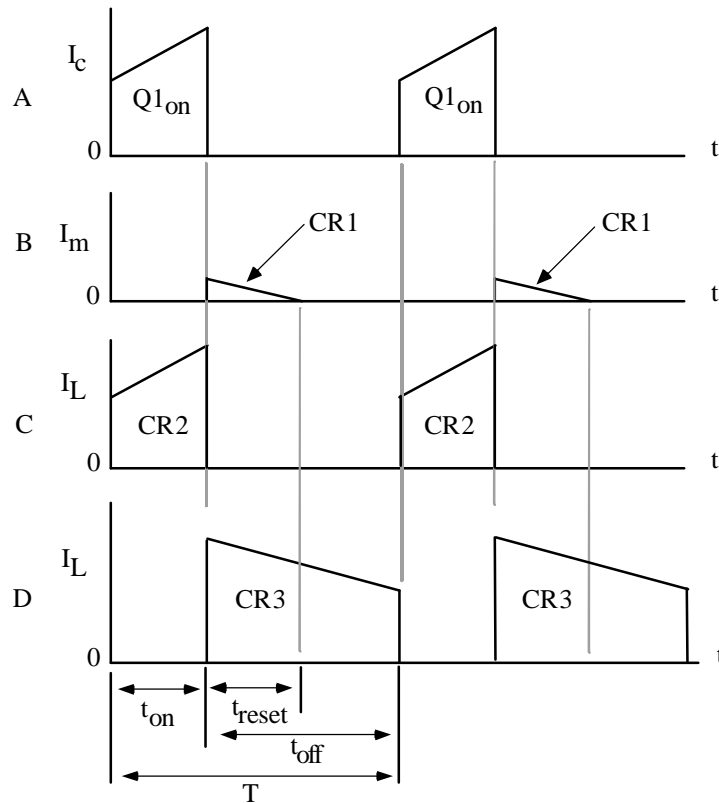


Figure 9. Idealized currents for a single-ended, forward converter.

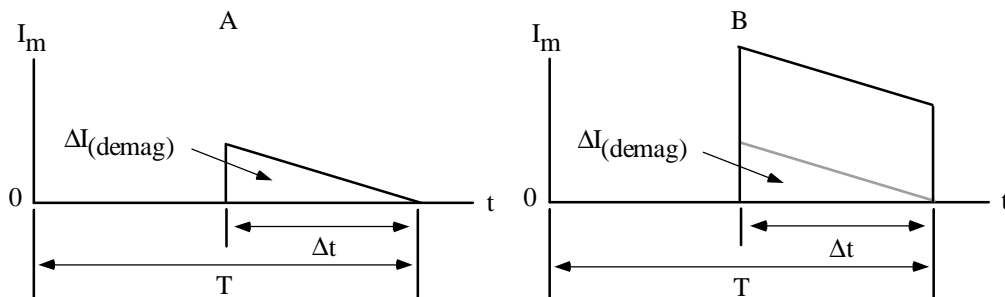


Figure 10. Examples of the demagnetizing current through the demag winding.

This extra current flowing in demag winding can only come from the secondary winding, being energized by the commutating current. When there is current flowing in the secondary winding during the off time, the transformer T1 will try to balance the ampere-turns by adding current to the demag winding, as shown in Figure 10B. This can really cut into the overall converter efficiency. The same tapped inductor approach, used on the push-pull, can be used on either the single-ended forward converter, or the two series transistor forward converter. The tapped inductor for the single-ended forward converter is shown in Figure 11. The same design guidelines for the tapped inductor can be used for both the single-ended forward converter and the push-pull converter.

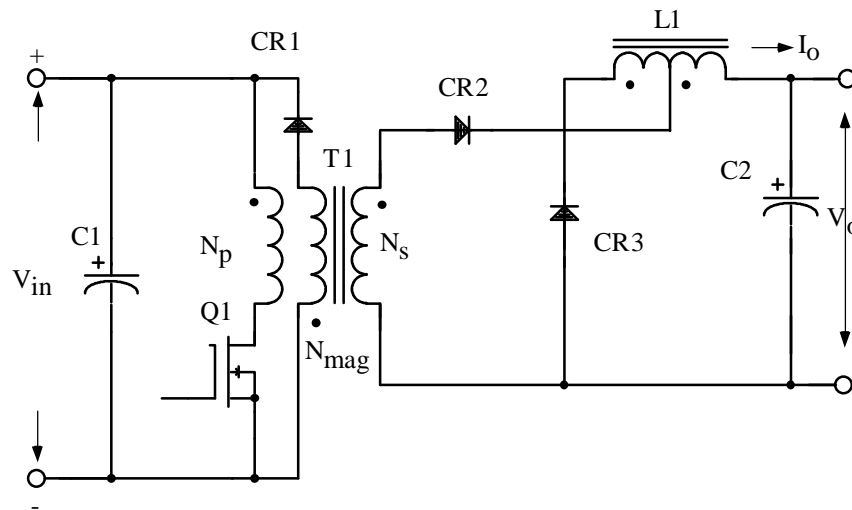


Figure 11. A single-ended, forward converter using the tapped, output inductor.

The tapped inductor can be used to improve the performance, in designs that incorporate the magnetic amplifiers. A push-pull converter incorporating a magnetic amplifier design and a tapped inductor is shown in Figure 12. . A single-ended forward converter incorporating a magnetic amplifier design and a tapped inductor is shown in Figure 13.

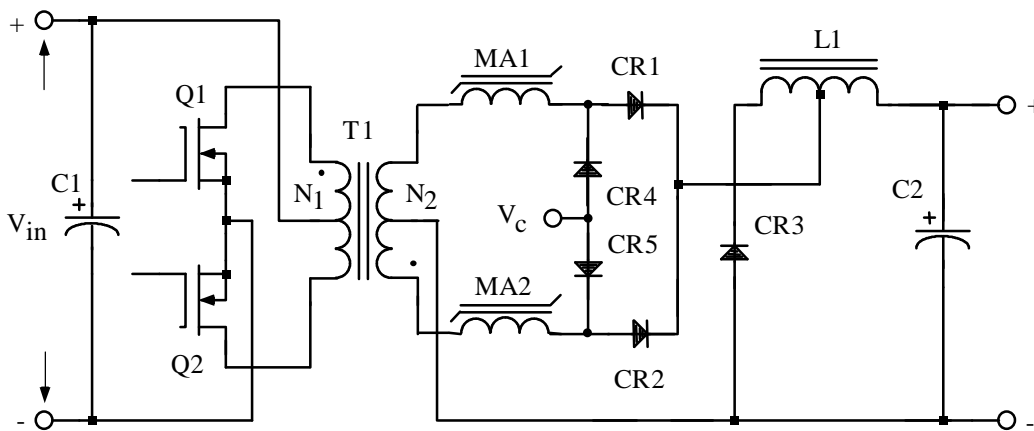


Figure 12. A push-pull magnetic amplifier design using the tapped, output inductor.

Conclusion:

The use of the tapped, output inductor and its benefits have been shown for both the push-pull converter and the single-ended, forward converter. There is very little to add to get exceptional circuit performance. The author incorporates the tapped inductor in all designs, when feasible. The performance of a converter, using the single or push-pull magnetic amplifiers, can also be improved with the tapped inductor.

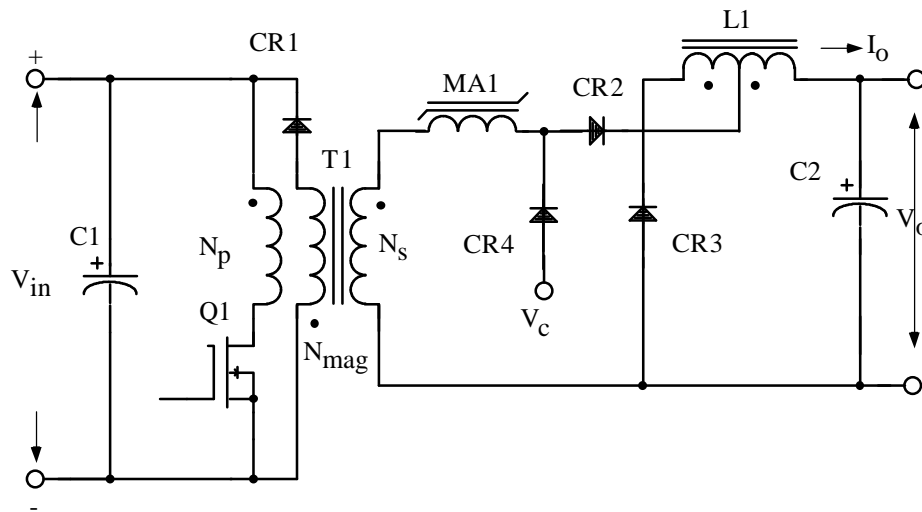


Figure 13. A forward converter magnetic amplifier design using the tapped, output inductor.

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