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BASICS OF DESIGN ENGINEERING

ELECTRONICS

Switching power supplies, small motors, polymer fuses, alarm ICs, circuit protectors, and sensors are among the topics covered in this electronics reference issue.

Switching power supply design rules

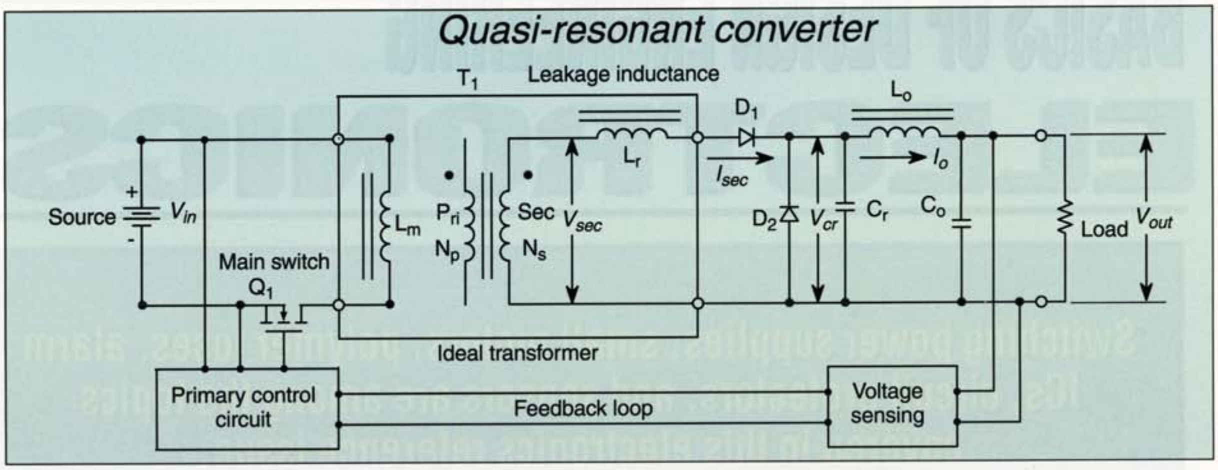
Resonant and quasi-resonant dc/dc converters are becoming more widely used because they are less expensive and more efficient than equivalent linear supplies. Not long ago, efficiency hinged on the converter's switching devices that wasted most of the power budget during relatively low-frequency transitions — typically 20 to 30 kHz — between on and off states. Improving efficiency by increasing the speed of these converters while using the same type of switching devices, however, peaked out at about 66 kHz. But because newer high-speed switching devices operate at 100 kHz and more while dissipating much less power during transitions, converter efficiency has increased dramatically.

High-density dc/dc converters come in numerous combinations of input voltage, output voltage, and power level. Modules such as these small PC-board-mounted packages provide output power to 150 W.

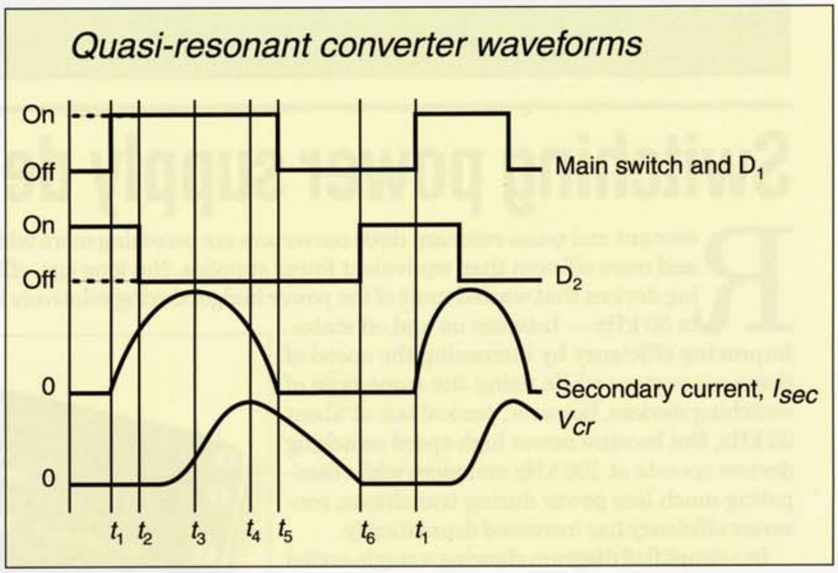
In a simplified diagram showing a single-ended forward converter, for example, the energy transfers from source to load during the "on" time of a single solid-state switch cycle. The circuit shown is quasi-resonant because the energy stored in capacitor C_r does not return to the inductor L_r as is done in a full-resonant converter.

When the main switch, Q_1, turns on, about a half cycle of current flows through the switch, transferring the energy from the input source to an LC circuit composed of L_r and C_r. The transformer here provides voltage scaling, electrical isolation from primary to secondary, and magnetic storage in the leakage inductance. The leakage inductance of transformer T_1, is modeled as the inductor L_r in series with the secondary, and the capacitor C_r is across D_2. The inductor stores energy as current, $\frac{1}{2}(L_rI^2)$, and the capacitor stores energy as voltage, $\frac{1}{2}(C_rV^2)$.

Both diodes, D_1 and D_2, transfer energy from the input to the output. Diode D_1 conducts when the main switch conducts and transfers energy from the leakage inductance to capacitor C_r. The diodes also block the reverse transfer of energy. Diode D_2 provides a path for the current in output inductor L_o and prevents reverse voltage on C_r after the energy removed from the leakage inductance moves to L_o. Moreover, the transformer core in a single-ended forward converter is magnetically reset to use more of the material's flux swing. This maximizes



Quasi-resonant converter



Quasi-resonant converter waveforms

the power output from a core of a given size.

The low-pass LC filter primarily reduces the output ripple voltage across the load. Because it's a relatively large inductance, L_o at full-load current stores more energy than any other element in the circuit. Under steady-state operation, the energy pulses through C_r match the energy delivered to the load.

The converter transfers energy in a specific sequence. For a given input voltage, each resonant sequence transfers an identical amount of energy which may be delivered at different rates (higher rates for more power), thus varying the total power or voltage delivered to the output. The L_o-C_o output filter then averages or smooths this voltage.

The converter's operation can be analyzed over a single resonant sequence referring to the *Quasi-resonant converter waveforms* diagram. The sequence divides further into three sections. Here, I_o is about 50% of the maximum rating, and assuming steady-state operation, the current in L_o is always positive. This is known as continuous-mode operation. In contrast, if the current in L_o reached zero, the operating mode would be discontinuous.

The period, t_1 to t_6, defines one complete resonant sequence consisting of three sections. At the end of this sequence the energy built up on C_r transfers to L_o. Between t_6 and the t_1 of the next resonant sequence, energy for the load comes solely from L_o. The first two sections of the period t_1 to t_6 are measured in tenths of microseconds and primarily depend on the tightly controlled values of the resonant parts L_r and C_r. The time in the third section, which is most often variable, is assumed to be fixed when I_o is taken as 50% of the maximum rating. Likewise, the t_1 to t_6 period is also assumed to be fixed for this analysis.

Variations in the number of resonant sequences in a given period control the energy delivered to the load. This becomes a fixed "on" time, variable-frequency control algorithm. When the input voltage V_{in} changes, the amount of energy also changes. But the allowable input voltage range never exceeds a 4:1 ratio, so the magnitude is bounded. A negative feedback loop adjusts the operating frequency to regulate the amount of energy the inductor (L_o) outputs. In other words, L_o receives just the correct amount of energy from C_r to replace the amount it delivered to the load. This sequence ensures a smooth, continuous, and regulated converter output voltage within the power rating of the converter. ■

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