Electronic ballast circuits enhance resonant-mode power supplies

Tom Ribarich - May 15, 2009

Resonant-mode topologies offer many benefits over traditional buck, boost, and flyback solutions. These include soft-switching, higher operating frequencies, higher power density, and higher efficiency. Electronic ballast circuits for fluorescent lighting applications have already been taking advantage of these benefits for many decades, while standard power-supply circuits using resonant topologies are slowly gaining momentum. Much can be learned from electronic ballast circuits and applied to resonant-mode power supplies. Also, the control ICs used in electronic ballast applications are being used more frequently in resonant-mode power-supply applications.

A fluorescent lamp load requires a current to preheat the lamp filaments, a high voltage to ignite the lamp, and a high-frequency AC current during running. Electronic ballast circuits used to control fluorescent lamps include a series L, parallel R-C, resonant tank output circuit driven by a half-bridge switching circuit ( ). This resonant topology allows the preheat, ignition, and running requirements to be satisfied by adjusting the operating frequency of the half-bridge. During preheat and ignition, the lamp is not in the circuit, so the circuit is a series L-C with a high Q-factor ( )
The amount of current supplied to the filaments during the preheat mode is set by the operating frequency and is usually much higher than the resonant frequency of the tank.

Figure 1a

Figure 1b

Figure 1: R-C-L ballast output stage (a) and corresponding Bode diagram (b).
(Click each image to enlarge)

After preheat mode, the frequency is then swept down toward resonance and the lamp voltage increases. When the lamp voltage exceeds the lamp ignition voltage threshold, the lamp ignites and...
the circuit becomes a series L, parallel R-C, with a low Q-factor due to the loading of the lamp. The final running frequency is then decreased further until the correct nominal lamp current is achieved. An additional capacitor (CDC) is also used to block DC, allowing only AC current to flow through the lamp. The half-bridge circuit operates in zero-voltage switching (ZVS) mode, resulting in low switching losses and high efficiency (measured in lumens/watt). Additional circuitry is also required to protect against line and load fault conditions such as AC mains brown-out, lamp non-strike, lamp removal, and open filaments.

A power-supply load has a different set of requirements than a fluorescent lamp but still benefits from the resonant-mode topology. In a power supply, the output voltage must be isolated and regulated to a fixed level within a given accuracy over the complete load range. The resonant output circuit used in power supplies is a series L-L-C topology, also driven by a standard half-bridge circuit

![Circuit Diagram](image)

The transformer has a leakage inductance ($L_s$) and a magnetizing inductance ($L_p$) that form the two series inductors in the circuit. The Q-factor of the circuit depends on the amount of parallel resistance reflected back to the primary from the load on the secondary. This topology results in more complex resonant curves


), but all load requirements are still satisfied by varying the frequency. As the load resistance increases or decreases, the frequency is then increased or decreased to keep a constant gain across the tank to keep the output voltage constant. The operating point for each load resistance resides on the appropriate load curve, and all operating points remain on a constant gain line.

Power supplies do not require preheat or ignition but do require a soft-start. The resonant topologies are different but both are driven by a half-bridge and controlled by frequency. Also, power supplies require similar fault-protection circuitry against AC mains brown-out, open load, and short-circuit conditions. A comparison of the requirements for electronic ballasts versus power supplies has been
summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Electronic Ballast</th>
<th>Power Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant Circuit Topology</td>
<td>RCL Series/Parallel</td>
<td>LLC Series</td>
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<tr>
<td>Isolation</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Switching Circuit</td>
<td>ZVS Half-Bridge</td>
<td>ZVS Half-Bridge</td>
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<tr>
<td>Control Parameter</td>
<td>Variable Frequency</td>
<td>Variable Frequency</td>
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<tr>
<td>Soft-Start</td>
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<td>Yes</td>
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<tr>
<td>Preheat</td>
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<td>No</td>
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<tr>
<td>Ignition</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Load Requirement</td>
<td>Constant AC Current</td>
<td>Constant DC Voltage</td>
</tr>
<tr>
<td>Open/Short Circuit Protection</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Brown-Out Protection</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 1: Electronic ballast versus power-supply summary**

A typical electronic ballast circuit is shown that is designed around the IRS21571D ballast control IC.

![Diagram of IRS21571D ballast control IC](image)

The IRS21571D includes all of the control necessary for preheat, ignition, and running the lamp. The oscillator architecture is very flexible and allows programmability of the minimum and maximum frequencies, frequency sweep times, and dead-time. Brown-out and over-current protection features are also included, as well as a 600V high- and low-side half-bridge gate driver that is ideal for driving the half-bridge MOSFETs (MHS and MLS) without the need for external pulse transformers.
The minimum frequency is programmed at pin 4 with resistor RT and pin 6 with capacitor CT. The dead-time between HO and LO gate drive outputs is programmed at pin 7 with resistor RDT. During the lamp preheat time, the capacitor CPH at pin 2 is charged up with an internal current source and pin 3 is connected internally to COM for connecting resistor RPH in parallel with resistor RT. This parallel combination programs the preheat frequency operating point (
When the voltage at pin 2 exceeds 4V, then preheat mode ends and pin 3 is disconnected from COM. The voltage at pin 3 charges up to the 2V level at the RT pin at a rate programmed by capacitor CRAMP and RPH. This rate is the frequency sweep time from fmax to fmin necessary for lamp ignition. Once the lamp ignites, the minimum frequency sets the correct AC lamp current. Pin 1 is for AC mains brown-out detection and reset, and pin 8 programs the half-bridge over-current threshold measured at pin 10 to protect against open-load and short-circuit fault conditions. Finally, pin 9 detects lamp removal and automatically resets the ballast when the lamp is inserted again.

**Power-supply circuit**

A resonant-mode power-supply circuit is shown (that uses the same electronic ballast IC to control an isolated LLC-type output stage. In this configuration, the output voltage is fed back through an opto-coupler to the oscillator circuit of the IRS21571D. In this way the frequency can be directly controlled to keep the output voltage constant as the load or line conditions change.)
The oscillator section has been slightly modified from the ballast implementation. Pins 3 and 4 are not used, and the soft-start function has been added directly to the RT pin using a capacitor, resistor, and diode (CSS, RSS and DSS). Resistor RT sets the minimum frequency, and the feedback loop from the opto-coupler (OPTO1) increases or decreases the frequency as necessary by sinking additional current out of the RT pin through resistor RMAX. A reference diode circuit (U1) is used to regulate the 12V-dc output voltage to a constant level, and the error is used to increase or decrease the LED current of the opto-coupler. A compensation network (Cf, Rf) is also used to ensure loop stability over all line, load, and transient conditions.

**Experimental results**

The power-supply circuit has been built for 300W and tested over different load and dc bus voltage conditions. During start-up (  

), the soft-start function ramps the frequency down from a maximum frequency to the working
frequency over a time of about 10 milliseconds. This reduces transient voltage and current stress in the output stage and ramps the primary current and output voltage up to their steady-state values softly.

During full load, steady-state conditions ( ), the half-bridge switches at 50% duty cycle and at a frequency controlled by the feedback loop to keep the output voltage maintained at 12V-dc. The primary current leads the half-bridge voltage, which means that the circuit is operating on the inductive side of resonance. This allows for zero-voltage switching (ZVS) at the half-bridge.
When the dc bus voltage is increased from 350 to 420V, the feedback loop increases the operating frequency ( ). This will decrease the primary current to keep the output voltage maintained at 12V dc.
During no load conditions, the feedback loop increases the operating frequency even further to reduce the primary current and continue to keep the output voltage maintained within the tolerance requirements.
The similarities between electronic ballasts and power supplies allow for the same control IC to be used for both applications. The IRS21571D ballast IC provides a simple and flexible solution that provides 600V high- and low-side gate drive, protects against all line and load fault conditions, and allows the oscillator to be used in different configurations depending on the control method. Although the resonant topologies are different, both solutions use the same half-bridge switching circuit with variable frequency control. Most important, both solutions also take advantage of the higher efficiency and higher power density that resonant-mode topologies offer.