Technical Article

Power Tips: Designing an LLC Resonant Half-bridge Power Converter

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Unlike traditional pulse-width modulation (PWM) power converters, resonant converter output voltages are regulated by frequency modulation. Therefore, the design methodology of a resonant converter will be different from a PWM converter.

Among various types of resonant converters, the LLC series resonant converter (LLC-SRC) in Figure 1 attracts interest because of its better output regulation, lower circulating current and lower circuit cost.

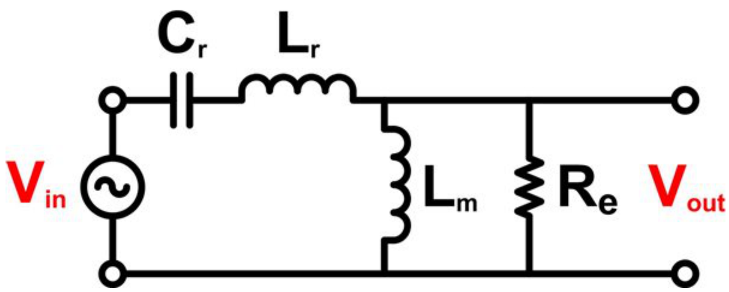

Figure 1. LLC-SRC with AC Input/output Voltage

The series resonant characteristics allow the switching network in a DC/DC LLC-SRC, such as that shown in Figure 2, to have very wide region of zero-voltage switching (ZVS); hence, the LLC-SRC can easily achieve over 94% efficiency in front-end power-supply applications and operate at a high switching frequency.

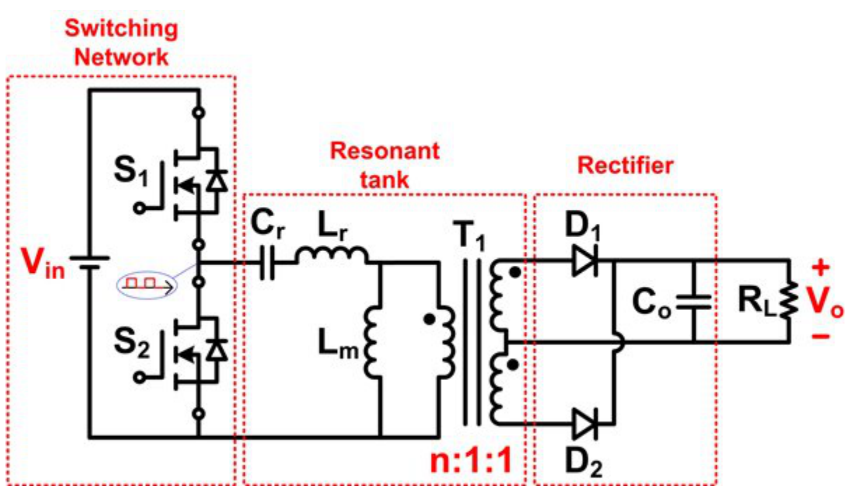

Figure 2. LLC Resonant Half-bridge Converter

Similar to the design process for PWM converters, the first step when designing an LLC-SRC is to select the desired operation frequency at full load. The remaining steps are different, because there is no duty-cycle factor in a resonant converter. The duty cycle remains unchanged in an LLC-SRC and is ideally 50%. Figure 3 shows a design flow chart for an LLC-SRC from TI Power Supply Design Seminar topic "Designing an LLC Resonant Half-Bridge Power Converter."

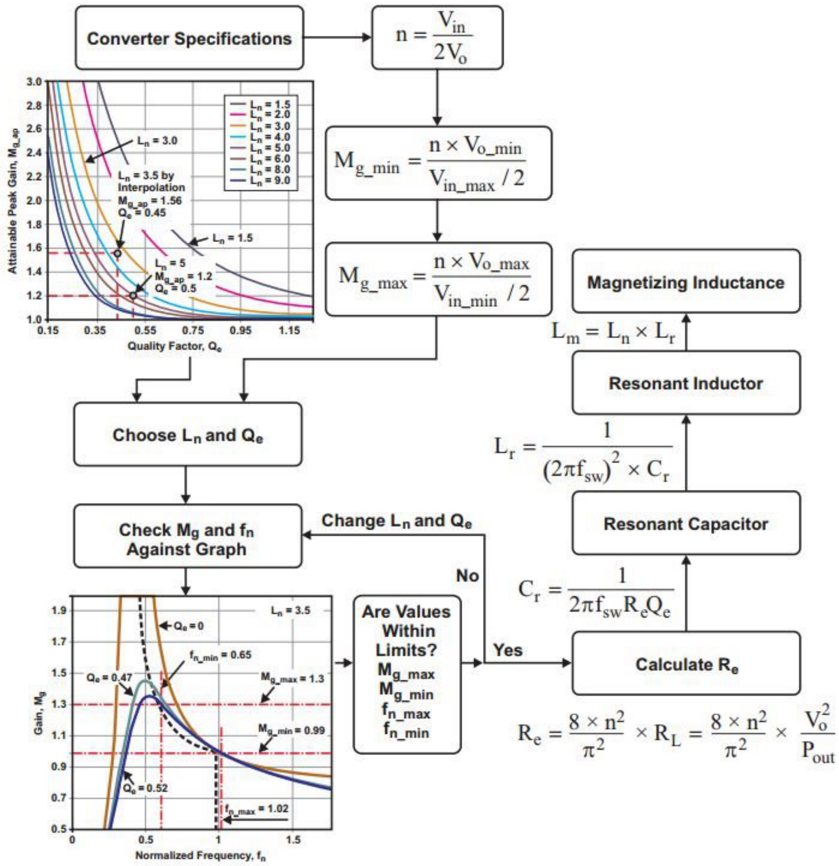

Figure 3. LLC Resonant Half-bridge Converter Design Flow Chart

Notice that M_g is the DC voltage gain, L_n is the ratio of L_m and L_r, and the quality factor is defined as Equation Figure 4:

$$Q_e = \frac{\sqrt{L_r / C_r}}{R_e} \qquad (1)$$

Figure 4. (1)

Also, f_n is the normalized frequency defined as $f_n = f_{sw}/f_o$, where

$$f_o = \frac{1}{2\pi\sqrt{L_r C_r}}$$

The gain curves in both the M_g/Q_e and M_g/f_n charts are derived from the LLC resonant tank shown in Figure 1, which is also a linearized circuit of a LLC resonant half-bridge converter.

Figure 3 provides a simple circuit parameter selection process of an LLC resonant half-bridge converter. By checking the f_{n_min}, f_{n_max} locations on the gain curves, you will be able to design a high-efficiency LLC resonant half-bridge converter with ZVS on the switching network under all input conditions.

When designing a LLC resonant half-bridge converter, keep in mind that:

- f_{n_min} needs to be above the ridges of the gain curves in the M_g/f_n chart at all times. This is to make sure that the MOSFETs maintain ZVS.

- LLC-SRC efficiency can only be optimized at one operation point. When $f_{sw} = f_o$, the series L_r and C_r become zero impedance (Figure 5); the converter has best efficiency at that point. You will need to decide the line/load condition that you want to optimize and make sure that your switching frequency is at resonant frequency at that condition.

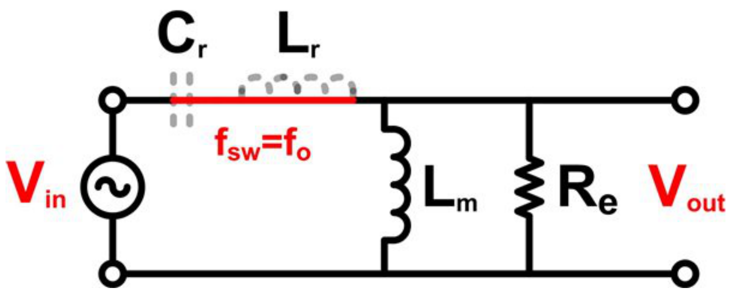

Figure 4. LLC-SRC with AC Input/output Voltage When $F_{sw} = F_o$

Additional Resources

- Find more information about LLC-SRC design and optimization in the TI Power Supply Design Seminars papers.
- Read my previous blogs on LLC converters
  - Get to know LLC series resonant converter design
  - How much can a LLC series resonant converter do?

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