Design of a 120-W volt resonant lighting circuit

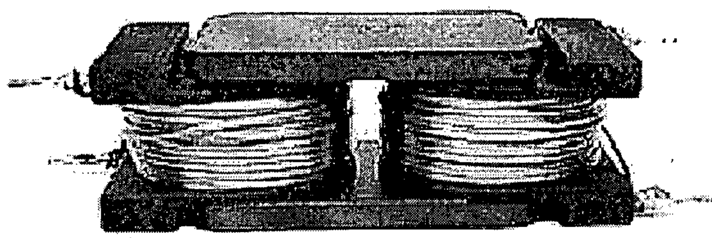
A novel lighting circuit enables the unit to operate even when some of the lamps fail.

IAN WILKINSON
MMG-North America

This article describes the design of a novel lighting circuit that utilizes a low profile ferrite U-core, and uses the core leakage inductance to provide the current limit and excellent current regulation. The lamps in the circuit are connected in series for continued operation, even when lamps fail. Special sensor circuitry is added to short-out the failed lamps. Ideally, the load should always be connected as under a no-load condition. The core would then see a high flux density at approximately 50 kHz.

Advantages of this design include:

- Excellent isolation, achieved by placing the windings on each core leg
- Excellent current regulation
- Low component count
- High efficiency
- Low EMI
- Reduced surge currents
- High power output
- Simple circuit
- Low cost



DESIGN

This design operates by resonating the leakage inductance on the secondary side via an innovative ferrite U-core. Excellent regulation is achieved by controlling the leakage inductance (Tables 1 and 2). The circuit maintains a constant current within the load constraints. A typical design drives six 20 W halogen lamps in series. Each lamp is shunted by a current-driven triac sensor. In the event of a lamp failure, the voltage across the sensor resistor rises, causing the gate current to increase. This fires the triac, causes a short circuit, and thus maintains the circuit continuity. Due to the behavior of the resonant circuit, a constant current is maintained. As the circuit operates under resonance, high circulating currents can occur in the secondary winding under no-load conditions. To prevent damage to the drive MOSFETS and drive chip, a feedback loop is included. This is not absolutely necessary and this protection can be provided by either an opto-isolator or another winding on the output transformer. Output current can be fixed using long, short-circuited, twisted cables. With the excellent current regulation provided, the full load current will be very similar. Individual lamps would be shut down using a switch. Figure 1 illustrates the generic block diagram of the resonant lighting circuit. Originally, NTC resistors were

Frequency	Leakage A_L Gap = 0.0 mm	Leakage A_L Gap = 0.2 mm	Leakage A_L Gap = 0.4 mm	Leakage A_L Gap = 0.6 mm	Leakage A_L Gap = 0.8 mm	Leakage A_L Gap = 1.0 mm
10 KHz	129.8	103.9	88.8	79.9	72.5	66.8
50 KHz	129.5	04.2	89.0	80.1	72.7	67.0
100 KHz	131.6	105.6	90.0	80.9	73.3	67.4

Table 1. Leakage inductance factors for ferrite "U" core # 1 (turns ratio 200 : 200).

Frequency	Leakage A_L Gap = 0.0 mm	Leakage A_L Gap = 0.2 mm	Leakage A_L Gap = 0.4 mm	Leakage A_L Gap = 0.6 mm	Leakage A_L Gap = 0.8 mm	Leakage A_L Gap = 1.0 mm
10 KHz	186.1	157	140.6	125.9	118.9	109.8
50 KHz	186.5	157.2	140.8	126.0	119.0	109.9
100 KHz	188.1	158.4	141.7	126.7	119.6	110.4

Table 2. Leakage inductance factors for ferrite "U" core # 2 (turns ratio 200 : 200).

considered for circuit protection, but they were found to be inefficient and slow.

GENERAL THEORY OF OPERATION

The heart of the resonant lighting circuit is comprised of a self-oscillating half-bridge driver which generates the necessary drive signals required for the implementation of a low cost, low component count, resonant lighting circuit.

Low electromagnetic radiation and higher efficiency can be achieved by resonating the transformer leakage inductance with a calculated series capacitance at a specific frequency to form a resonance tank circuit. To prevent damage to the MOSFET transistors, the circuit switching frequency has to be higher than the resonance frequency of the tank circuit so that the MOSFET drivers always see an inductive load.

Under no-load conditions, excessive circulating currents can flow through the secondary winding of the transformer and this can seriously damage the MOSFET output transistors and driver chip. Therefore, a feedback protection circuit is used to monitor open circuit conditions. The short-circuit current is calculated using the leakage inductance, voltage and duty cycle.

RESONANCE FREQUENCY CALCULATION AND CIRCUIT DESCRIPTION

In order to calculate the value of the resonance capacitor which is connected in parallel with the secondary windings of the output transformer to form a resonance tank, the leakage inductance and the operating frequencies have to be selected. For example, the chip has a frequency range up to 100 kHz. The illustration in Figure 2 shows the resonating capacitor shunted with the secondary transformer windings.

The secondary current is controlled by the resonating capacitor value. A large capacitor value will yield a low reactance and therefore, a high secondary drive current. Reducing the capacitor value produces a lower secondary drive current.

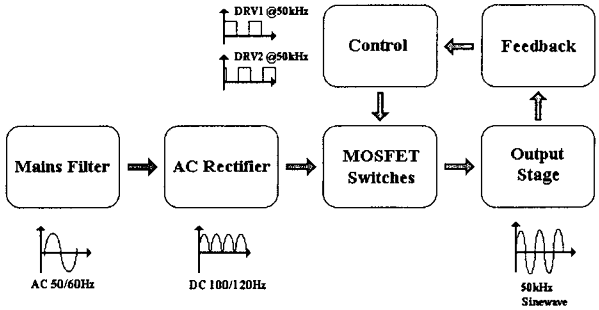


Figure 1. Generic block diagram of a 120 W V resonant lighting circuit.

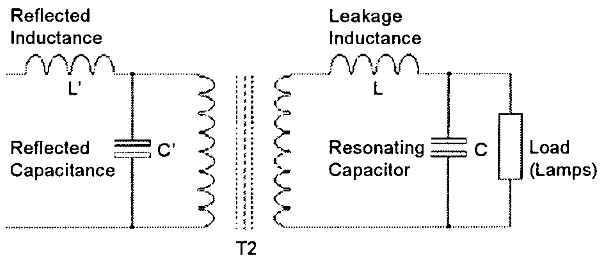


Figure 2. Generalized equivalent circuit of the output transformer.

Output regulation is controlled by the leakage inductance. A high leakage value indicates good current regulation. This value can be achieved by having more turns on the secondary leg of the transformer. As both regulation and output current are related, a compromise must be reached. The final values are based on the specification application.

The circuit used in this example has a 47 μF smoothing capacitor. This may be undesirable for some potential users due to the effect on the input power factor. It is possible that it could be omitted (with the appropriate changes in other circuitry); however, the idea is to promote the use of a resonance driving method. The triac circuit used to sense a lamp failure has to be reset if a bulb is removed or replaced. The power supply has to be switched off

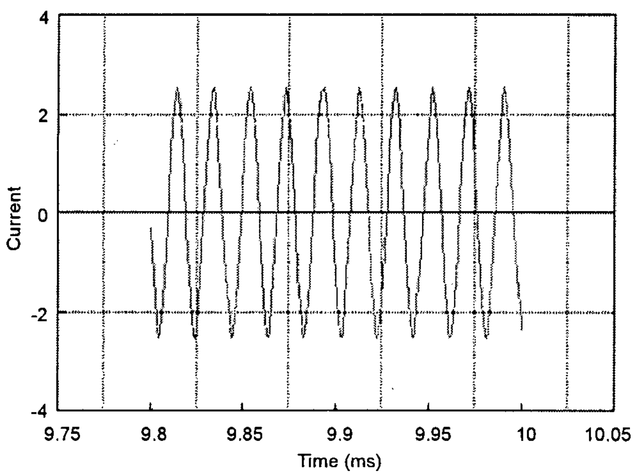


Figure 3. Current with 48-ohm load.

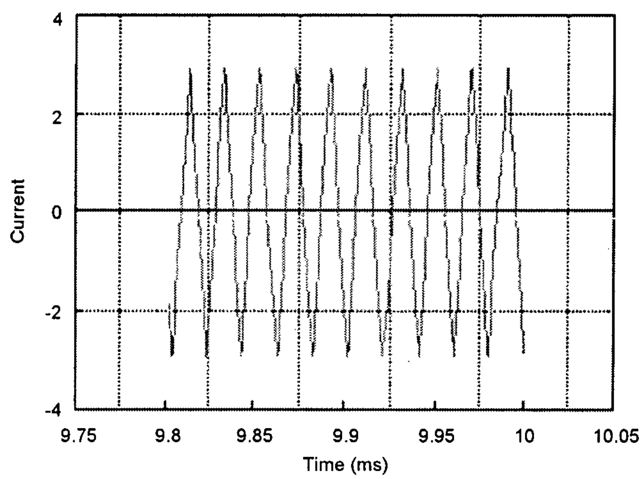


Figure 4. Current with 6-ohm load.

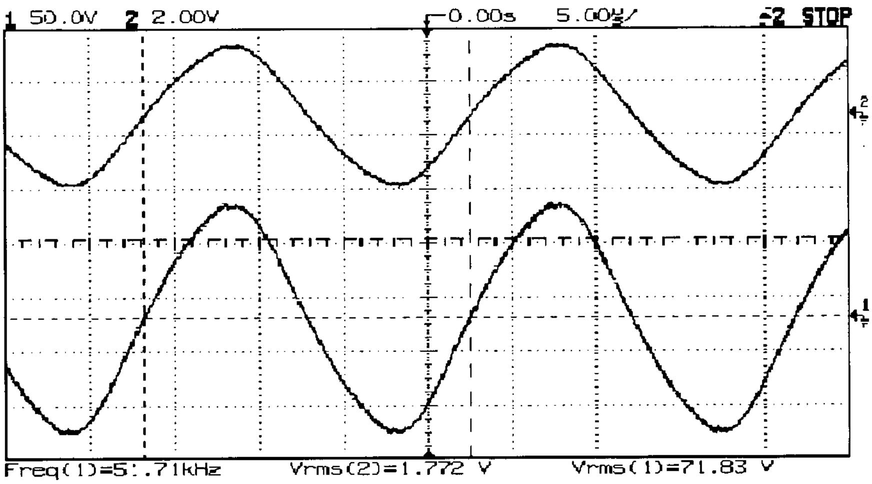


Figure 5. Six lamps, 43.2 ohms.

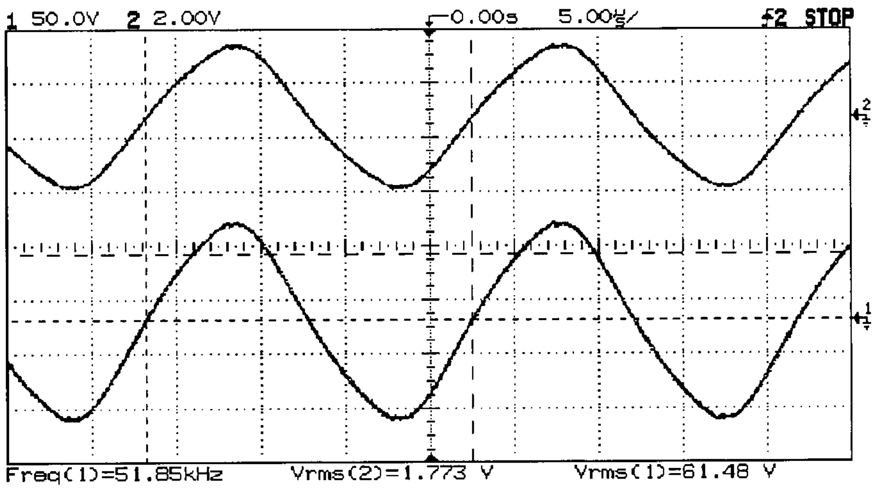


Figure 6. Five lamps, 36 ohms.

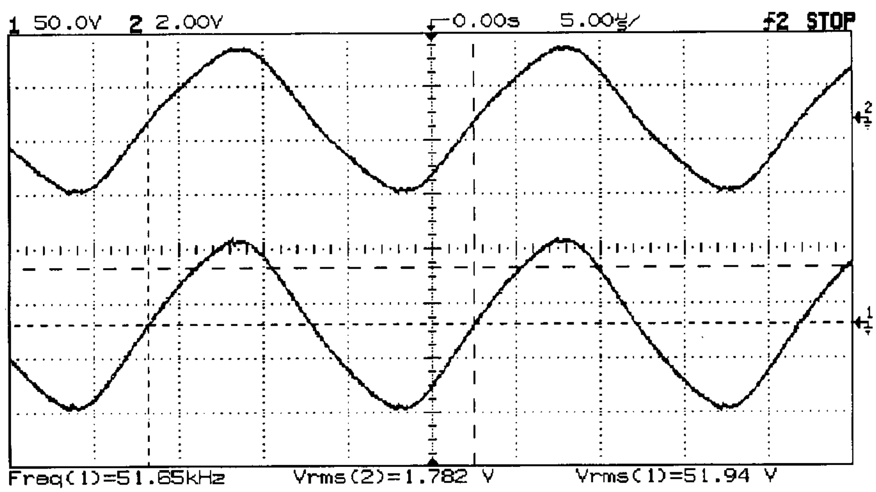


Figure 7. Four lamps, 36 ohms.

order to change the switching frequency, a 22 kilohm trimming pot is used in the timing circuit. This allows the user to select a suitable frequency dependant on coil design and leakage inductance. Minor alterations in the secondary current can also be achieved by this potentiometer; however, the oscillator frequency able to replace a failed lamp with a new unit without resetting the power. This can be achieved with a different detection circuit. In order to change the switching frequency, a 22 kilohm trimming pot is used in the timing circuit. This allows the user to select a suitable frequency dependant on coil design and leakage inductance. Minor alterations in the secondary current can also be achieved by this potentiometer; however, the oscillator frequency must be slightly higher than the resonance frequency. The output transformer should be either taped or clamped with a non-magnetic clip. In testing it has been found that conventional metal clips make the circuit more inefficient. Measured results showed an efficiency of 89 percent compared to 95 percent with a taped core.

To evaluate the secondary leakage inductance for a specific number of turns, the primary turns are shorted and the inductance that appears on the secondary side is the leakage inductance. The leakage inductance and the shunted resonance capacitance form the resonance tank. A resonance frequency slightly below the circuit operating frequency has been chosen so that the MOSFET drivers always see an inductive load.

Once a resonant frequency has been selected, the corresponding resonating capacitor value can be calculated by re-arranging the following formula:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where
L = the leakage inductance
C = the resonance capacitance
f_0 = the resonance frequency

To eliminate the need to measure the leakage inductance at various frequencies and air gaps, the following data has been compiled. If the leakage inductance is known, the designer can

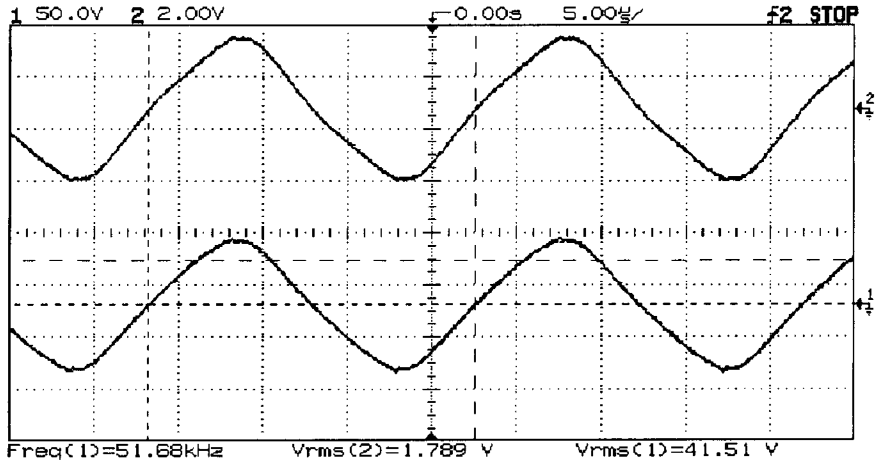


Figure 8. Three lamps, 28.8 ohms.

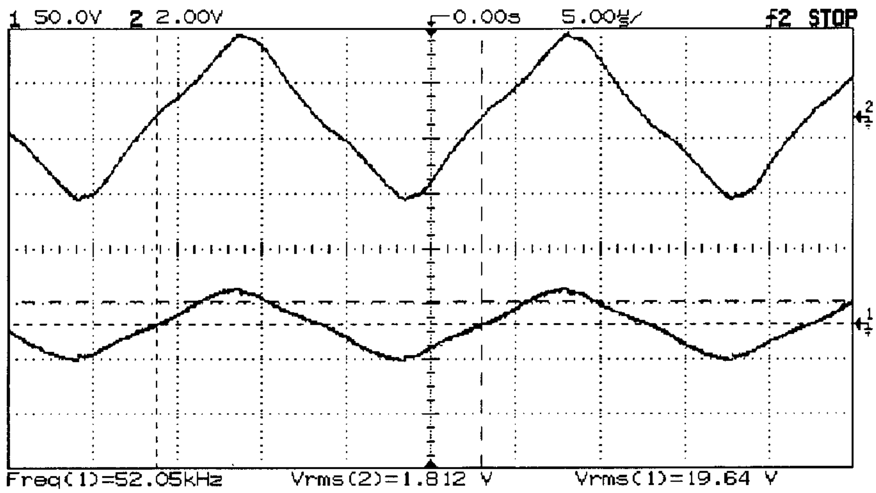


Figure 9. One lamp, 7.2 ohms.

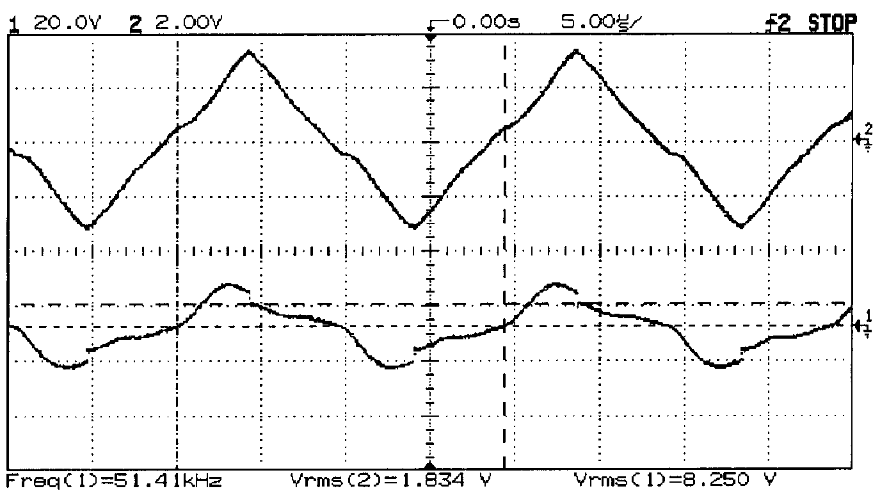


Figure 10. Shorted load.

calculate a capacitor value for the selected resonant frequency. Any capacitor chosen must have a very low dissipation factor to avoid heating effects.

Tables 1 and 2 show the leakage inductance factors for two specific ferrite "U" cores.

The secondary leakage inductance can be calculated from the formula below:

$$L(nH) = A_L \cdot N^2$$

where

A_L = the leakage inductance factor at a specific frequency and air gap

L = the leakage, inductance is in nanohenries (nH)

N = the number of turns squared on the secondary

TESTING AND SIMULATION

Before any construction was undertaken, the design was simulated to give an approximate idea of how well the circuit would perform. The lamps were represented by resistors. The lamps were open- circuited in turn to check the current regulation and the response time of the triac circuit used for shorting the lamp. Figures 3 and 4 show the effect of varying the load conditions:

The simulation was done with a standard SPICE-type software package. The secondary current and voltage are very close to a sinusoidal waveform and therefore contain lower distortion. This indicates that EMI will be lower.

The circuit was built and tested; first on standard vero board, and then as a PCB package. Output voltages and currents were measured using an oscilloscope and the data was transferred to a computer. The following waveforms (Figures 5 through 10) show the change in load current over a wide range of different load conditions. As can be seen, the current regulation is excellent. The overall circuit efficiency is about 95 percent. This was measured using a VAW meter on the input and output. Maximum circuit power is 120 W; however, a higher power output can be achieved by changing the output transformer from ferrite "U" core # 1 to ferrite "U" core # 2. Output power up to 400 W is possible.

CONCLUSION

Testing reveals that through the use of a low-profile ferrite U-core, a resonant lighting circuit can be designed for excellent isolation, high efficiency and other advantages. Such a design yields an advanced, novel lighting circuit which maintains circuit continuity in the event of a failure in one of the lamps. As demonstrated, employing the ferrite U-core and designing the circuit with core leakage inductance to provide the current limit and regulation, enables the design of a more efficient lighting circuit.

FOR MORE INFORMATION, call Kyle Marshall. Phone: (919) 872-8172 □