IGBT Gate Drivers in High-Frequency Induction Cookers

Efficiency of induction cookers is 84 percent

Today, with the constant demand for energy saving devices, high-frequency induction cookers, already a trend in Europe, are gaining popularity in the rest of the world. These kitchen devices offer high efficiency that reduces energy usage, reduces cooking time and, simultaneously, improves user safety, particularly around children, since all heat is localized to the pan itself.

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According to the U.S. Department of Energy, the typical efficiency of induction cookers is 84% compared to the 40 percent of gas cookers. In this article, two typical induction cooker designs, the half-bridge series-resonant and the quasi-resonant topology, are discussed. The merits and disadvantages of these two high-frequency inverter topologies along with three gate driver circuits, discrete transistors, optocouplers integrated circuit and transformers for high frequency operation are also discussed.

What is induction cooking?

In an induction cooktop, a magnetic field transfers electric energy directly to the object to be heated. By inducing an electric current into the ferrous cooking utensil, heat is generated in the object, and the cooking surface only gets hot from the heat reflected from the object being heated: no heat is directly produced by the induction element. Because of this direct transfer of energy, there are fewer losses, which translates to a higher level of efficiency.

This compares with conventional cooking in which a heat source, for example an electrical resistance element or a flame, transfers heat energy to the cooking pot. The two-step energy transfer is inherently less efficient than direct inductive heating.

How does an induction cooker work?

Figures 1 and 2 show two circuit topologies for induction cookers: the half-bridge series resonant converter, Fig. 1, and the quasi-resonant converter, Fig. 2. In both topologies, there exist the resonant elements Lr and Cr. For circuit simplification, the load pot, R, is assumed to be a purely resistive element. In both

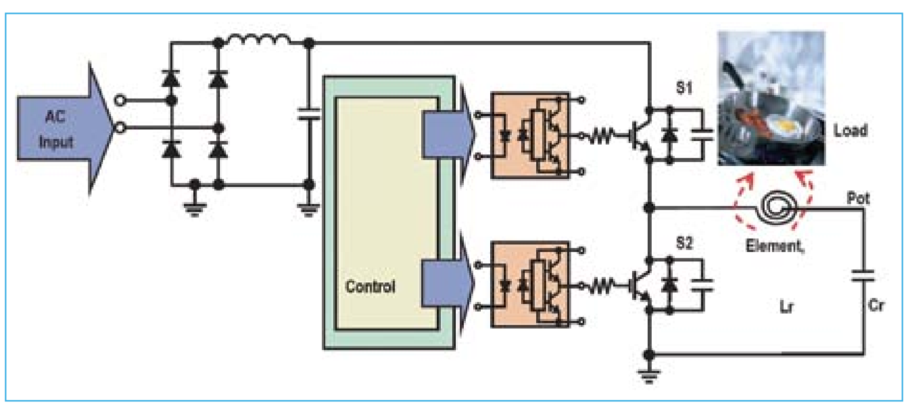

Figure 1: Half-bridge series-resonant topology for induction cookers.

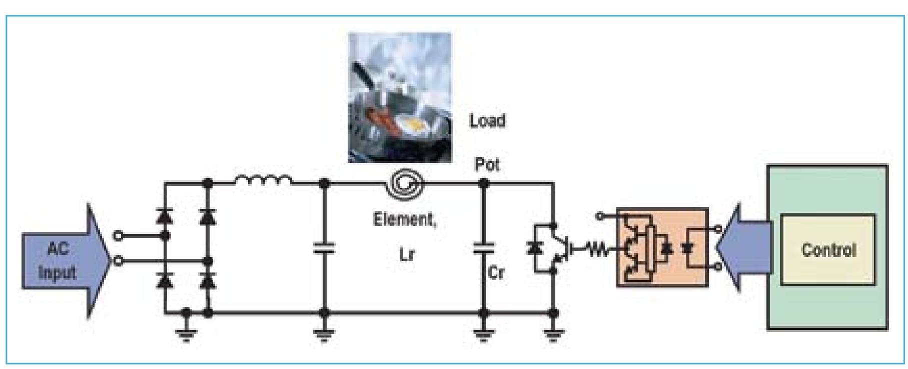

Figure 2: Quasi-resonant topology for induction cookers.

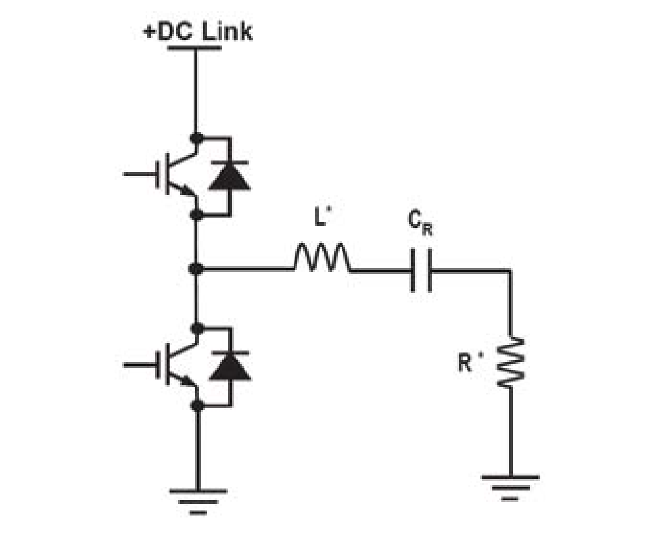

Figure 3: Equivalent half-bridge series resonant circuit.

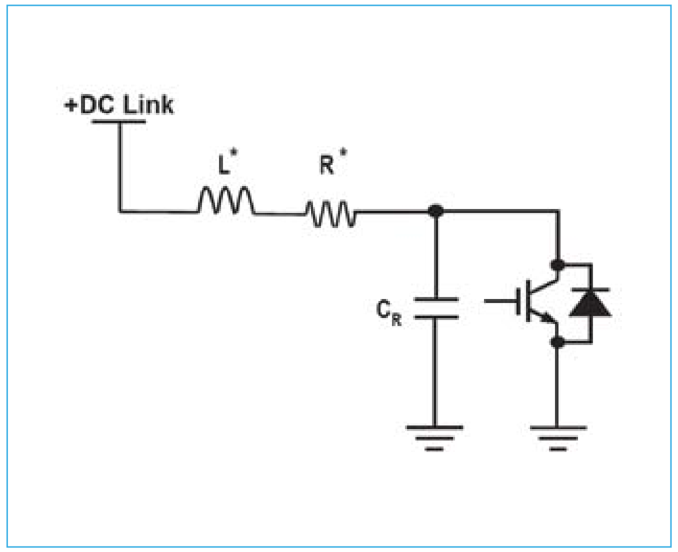

Figure 4: Equivalent quasi-resonant circuit.

topologies, an AC input supply of 220V 50 Hz is converted into an unregulated DC voltage by a full-bridge rectifier. This DC voltage is then converted into a high frequency AC voltage by the inverter IGBT (insulated gate bipolar transistor) switches—S1 and S2 in the case of the half-bridge circuit—which can be controlled using a microcontroller. Due to the high frequency switching AC, the element coil will produce a high frequency electromagnetic field which will penetrate the ferrous material of the cooking pot. From Faraday's Law and skin effect, this generates eddy current within the cooking pot which then generates heat to cook the food inside the pot.

By applying the transformer equivalent circuit, designers are able to map the load pot (secondary of transformer) to the primary side of the circuit where the resonant inductor, Lr, and capacitor, Cr, are located. From this, we can obtain the equivalent circuit for the half-bridge and quasi resonant circuits, shown in Figs. 3 and 4. From these equivalent circuits, the operation of the induction cooker, and the values of the resonant inductor, capacitor and control algorithm can be derived.

In order to reduce component size, minimize switching losses and reduce audible noise during operation, induction cooker circuits typically utilize resonant or soft switching techniques. Soft switching can be subcategorized into two methods: zero-voltage switching and zero-current switching. Zero-voltage switching occurs when the transistor turns-on at zero voltage. Zero-current switching refers to the elimination of turn-off switching loss at zero current flow. The voltage or current provided to the switching circuit can be made zero by using the resonance created by an L-C circuit. This topology is named a "resonant converter."

The advantages of a half-bridge series resonant circuit are stable switching and lower cost due to simplified design. The voltage within the circuit is limited to the level of the input voltage, which reduces the voltage stress across IGBT power switch. This, in turn, allows the designer to lower the cost by choosing an IGBT with a lower voltage rating. The disadvantage of this approach is that the control of the half-bridge circuit is relatively complicated and the required size of the heatsink and PCB area is greater, because of the high side gate driver circuit required for the upper IGBT, S1 in Fig. 1)

The advantage of a quasi-resonant converter is that it needs only one IGBT power switch, which reduces the size of the PCB and heat sink. The disadvantages are that the quasi-resonant switching develops a resonant voltage which can be higher than the DC input voltage, increasing stresses on the IGBT power switches. This requires higher-cost components with higher blocking voltage capabilities.

Gate driver circuits for IGBT power switches

Three types of driver circuits, using discrete transistors (Fig. 5), gate driver optocouplers (Fig. 6) or gate driver transformers (Fig. 7) can be used to drive the power switches in the induction cooker. There are several issues

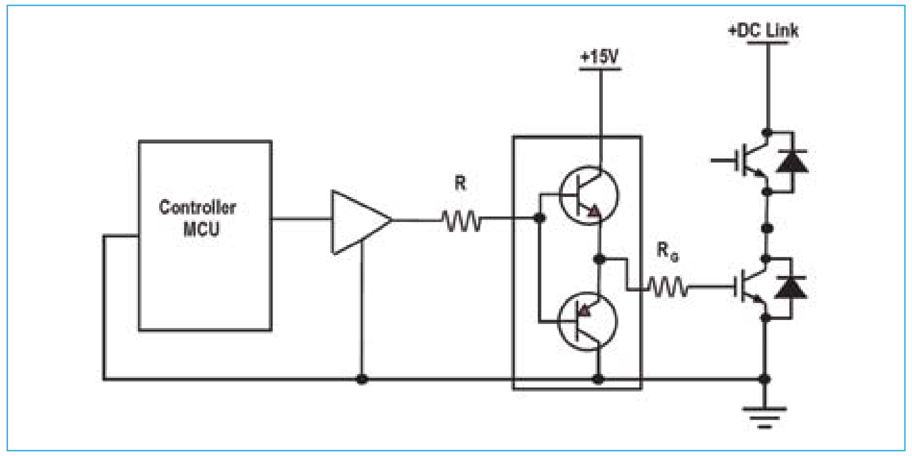

Figure 5: Discrete transistor gate driver (low side drive).

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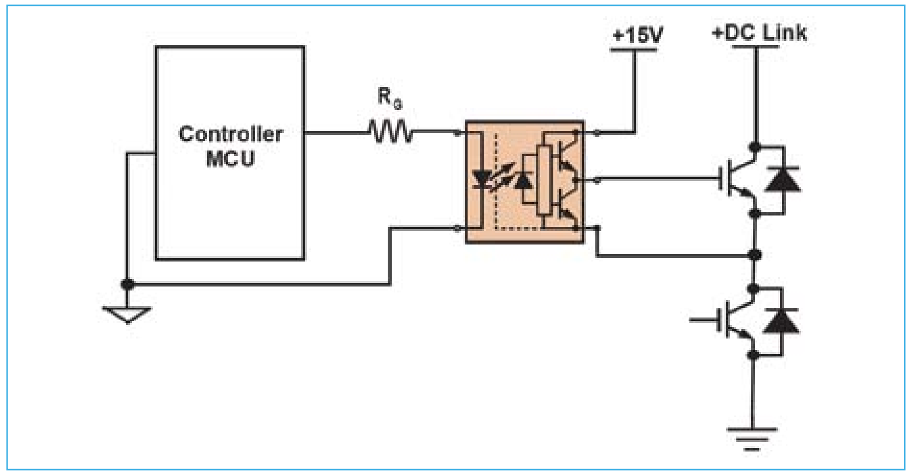

Figure 6: Gate drive optocoupler.

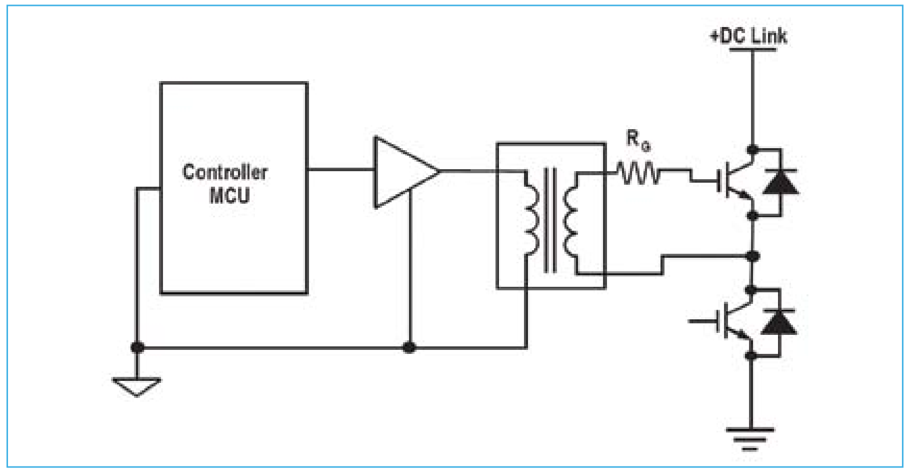

Figure 7: Gate drive transformer.

associated with high-frequency gate drivers: parasitic inductances, power dissipation in the gate-drive circuit and the losses in the power switching devices in the gate driver, all of which are involved when selecting an appropriate driver circuit.

Typically, the switching frequency of an induction cooker is between 25 kHz and 40 kHz. In order to rapidly turn on and off the power switch, the gate current inductance loop between the driver and power switch should be as low as possible. Hence it is advisable to design the layout of the circuit to reduce the parasitic inductances. Since the driver rapidly charges and discharges the gate capacitor of the IGBT, a relatively high peak gate current may be needed for proper operation. A higher peak current is also desirable to increase the charging and discharging rates during turn-on and turn-off, to help reduce the switching losses of the IGBT. Due to this, managing the power dissipation within the gate drive circuit becomes increasingly important as the switching speeds are increased.

Discrete gate drivers are constructed using bipolar transistors, and NPN and PNP emitter followers can achieve reasonable drive capability. However, using several discrete components to build the driver, while simultaneously incorporating necessary operational and protective functions such as under voltage lockout (UVLO), is not as space efficient as using integrated circuits. Moreover most discrete transistor driver designs do not provide sufficient safety isolation or noise immunity.

Two methods of providing electrical isolation are pulse transformers and gate driver optocouplers. The pulse transformer is a traditional and simple solution, which, however, suffers from the potential for core saturation in a reasonably-sized transformer, resulting in reduced efficiency. A pulse transformer can only transmit AC signals, and most designs have a limited duty cycle ranging up to 50 percent due to the transformer volt-second relationship. An additional capacitor and zener diode on the transformer secondary can be added to permit a higher duty cycle. However, this increases the circuit board size and parasitic inductances, which, in turn, increases power losses in the driver circuit.

The gate driver optocoupler IC integrates an LED light source and optical

Table 1: Summary of gate driver solution for induction cooker.

	Half-Bridge Series Resonant	Quasi-Resonant
Discrete Transistor Driver	Complex high side drive circuit, increased parasitic inductance due to higher component count and no isolation provided	Cost effective but no isolation
Gate Optocoupler Driver	High side driving while providing isolation, reduced parasitic inductance, integrated safety function and noise immunity	Provide integrated safety function and reduced parasitic inductance
Transformer Gate Driver	Provides isolation, requires more components and space for better performance	Provides isolation

receiver for safety isolation, with transistors to provide sufficient drive current, and protection functions such as UVLO or desaturation detection.

Gate driver ICs are easy to design with, and will save PCB board space. Due to the integrated design, the drive circuitry can be located very close to the power switch, which not only saves PCB space but also improves the overall noise immunity of the system. However, as with any ICs, power dissipation is a major concern.

For the single-switch resonant converter, the designer has the option of the discrete gate driver, gate transformer or gate driver optocoupler topologies. As discussed previously, the quasi-converter resonant voltage can be higher than the DC link voltage and this voltage stresses the power semiconductor switch. In most commercial low cost single switch induction cooker designs, the discrete gate driver circuit is used as there is no upper power switch, and both the controller and power semiconductor are able to share the same power ground. However, in cases where safety isolation and reduction of driver losses becomes an issue, the gate drive optocoupler or transformer are excellent alternatives.

For the half-bridge converter, a floating or high-side power switch needs to be driven. A high-side discrete solution would increase the component count, and not provide any isolation. As shown, the pulse transformer galvanic isolation solution becomes increasingly complicated for duty cycle switching above 50 percent. Also, the solution size is larger because of the additional discrete components on top of the transformer size. The gate driver optocoupler IC provides a good level of protection, isolation, and common-mode noise rejection. This resolves many of the problems that are associated with transformer or discrete transistor drivers.

Summary

In this article, the half-bridge series resonant and quasi resonant induction cooker topologies along with three gate driver methods were discussed. In order to reduce the design size and audible switching noise while improving power efficiency, these resonant converters are chosen. The discrete transistor gate driver circuit is cost effective but increases design complexity while providing no safety isolation. The required size of the gate drive transformer consumes board space, and requires additional work, cost and board space to achieve switching duty cycles above 50 percent. Finally, the use of gate drive optocoupler ICs saves board space through high level feature integration while providing high voltage safety isolation and noise immunity all in one package.

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