Coffee mug warmer by induction heating

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Most of the coffee mug warmers available in the market utilise resistive heating. These warmers can be used with ceramic mugs or outer-body stainless steel mugs. However these are unsuitable for stainless steel-mugs with plastic outer cover used for insulation. Furthermore, these warmers are inefficient; most of the heat generated by the heating element is lost in the environment rather than warming coffee. The idea of a coffee mug warmer employing induction heating targets the stainless steel mugs with or without the outer plastic cover. The mugs with the outer plastic cover are highly efficient, as there is less chance for heat-escape. The basic principle of inductively heating a coffee mug is depicted in Fig.1. An RF generator is connected to a coil, which creates oscillating magnetic field around the coil. A stainless-steel coffee mug if placed on top of the coil or brought in close proximity to the coil, will induce eddy current in the stainless steel body causing the generation of heat. Coffee put inside the mug will be kept warm or heated according to individual's test. The temperature can be controlled by controlling the current in the coil. The working system consists of a square wave generator, a couple of semiconductor power device (MOSFET or IGBT), a power supply and a working coil with a capacitor in parallel. The basic block diagram of the entire system is shown in Fig.2.

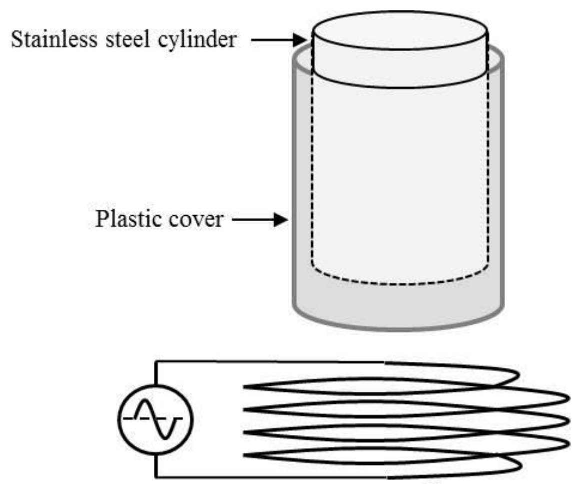

Fig.1

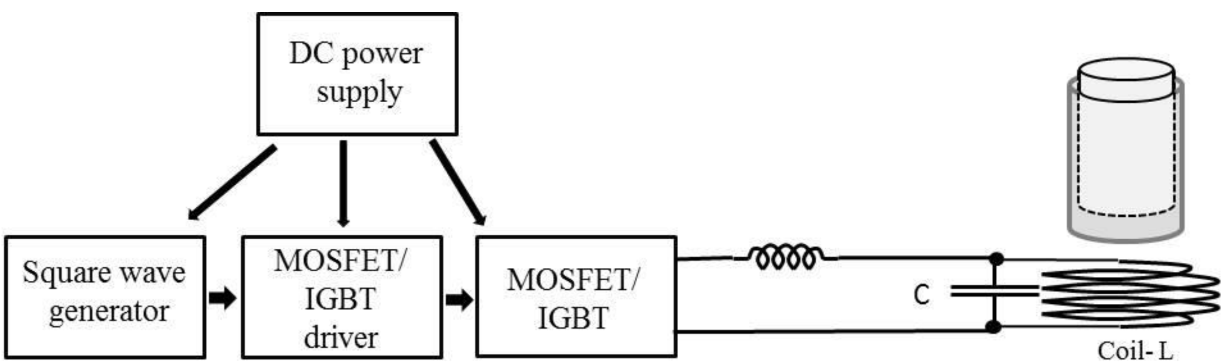

Fig.2. The basic block diagram of the coffee mug warmer.

The square generator produces square wave with adjustable frequency. The square wave output drives a pair of power MOSFETs or IGBTs through a suitable driver to obtain high current pulses. The working coil is connected with a capacitor in parallel to form a tank circuit. The frequency of the square wave is adjusted to match the resonant frequency of the LC tank circuit. At resonance, though high current flows through the working coil, much less current flows through the power devices. The current flowing to the tank circuit is for replenishing the energy losses in tank circuit due to the resistances of the working coil and the capacitor. When the stainless steel-mug is placed in the coil, due to mutual induction eddy current heats the stainless steel. The amount of heat produced depends on the stainless steel properties, working coil current and the proximity of the coffee mug to the coil.

The circuit description:

The circuit diagram is shown in Fig.3. The heart of the circuit is an IC by International Rectifier, IRS2153; this IC is a half-bridge MOSFET driver and has built in square wave oscillator. Capacitor CT and Resistor RT determines the oscillation frequency expressed by:

$$f \approx \frac{1}{1.453 \times RT \times CT}$$

With capacitor CT= 0.01 μF and RT from 1K to 101K (variable), we find frequency, *f* adjustable from 688 Hz to 68.1 kHz. To make the circuit operable from 24V to 48V, a ~21 V voltage regulator is implemented using a Zener diode D1 and a transistor Q3. Two outputs (Ho and Lo) of the IC is such that, half the cycle transistor Q1 is ON and Q2 is OFF, the other half cycle the opposite occurs. There is a little gap between the ON times of Q1 and Q2 which is called the dead time for a safe operation. At the output of the power MOSFETS, where source of Q1 and Drain of Q2 joins we get a square wave voltage; the lowest is 0 V and the peak is the supply voltage. A 30μF capacitor, C3 is used to filter out the DC component; at the output of C3

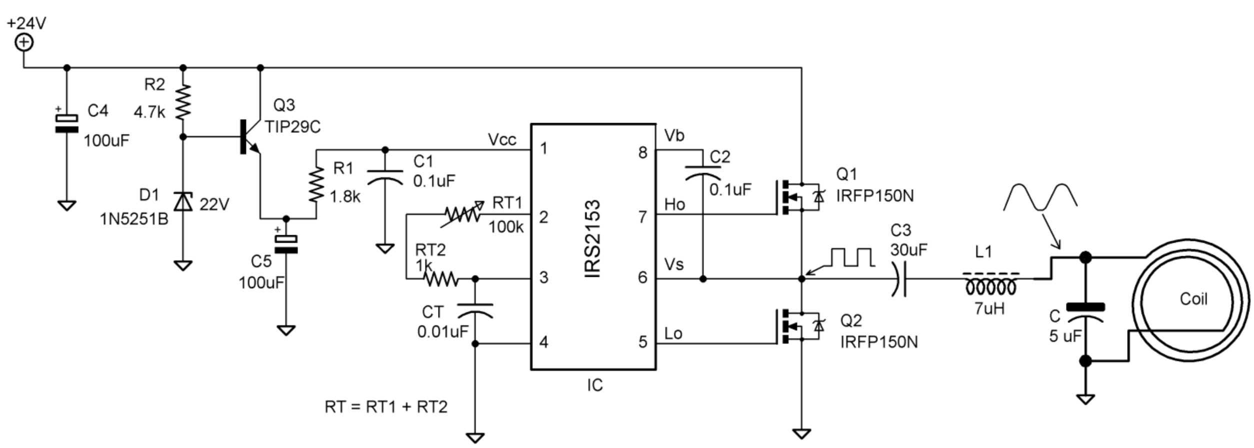

Fig.3. The schematic diagram

We get 12 V_{pp} AC voltage. The inductor L1 is used to reduce the higher order harmonics and we get a nearly sinusoidal voltage across the coil-capacitor tank circuit. L1 is made using a toroidal ferrite core, 10 turns with AWG #14 copper wire on the core makes ~7uH.

The working coil:

The coil was made with AWG #12 copper wire (plastic coated). Coil diameter was chosen ~10 cm, which is little bigger than many of the coffee mugs available in the market. Number of turns was ~7, after the coil is wound; several cable ties were used to make the coil tightly packed as shown in Fig.4. The resistance and the inductance of the coil were measured using an LCR meter; the values found are, inductance: ~ 9.5μH and resistance R: ~0.015Ω. A low ESR film capacitor of value, 5 μF was connected in parallel of the coil as shown in Fig.4.

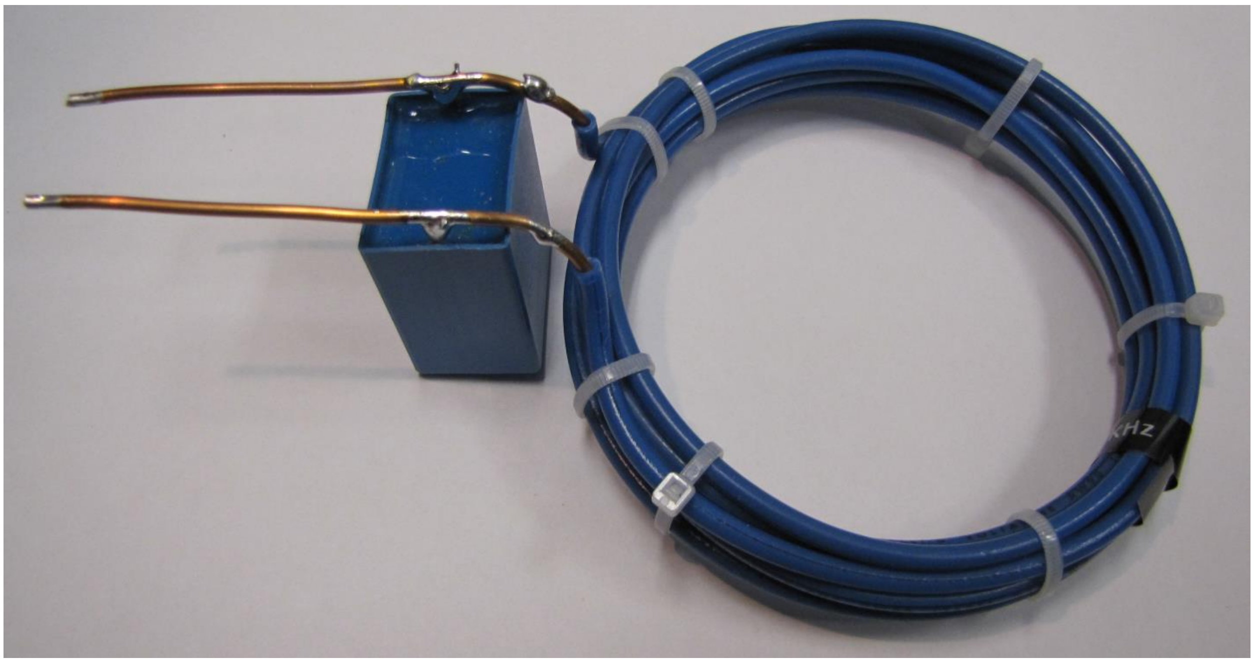

Fig.4. The working coil with a capacitor in parallel.

The calculated resonant frequency of the tank circuit is, f_r ~ 23.1 kHz.

Testing the induction warmer:

The coil was connected to the circuit; an ammeter was also connected in series with the 24 V, 2.1 A power supply. Initially the coil was kept out of touch of the coffee mug or any other metal object. The potentiometer, RT1 is slowly increased from minimum value and the ammeter reading was observed. Initially the current was high (~ 2 A) as the frequency approaches the resonant frequency current goes down, at around the resonant frequency the current is the minimum. This should be the set point of the potentiometer, RT1 at this minimum current. With no metal object close to the coil, the minimum current found was ~0.12 A. Now with a plastic covered stainless steel- coffee mug in the coil gives rise to higher current. For the mug we used, gave us a current of ~ 0.59 A. Of course, different types of mugs will produce different current, thereby varying amount of power dissipation in the mug. The mug I used was of 9cm –diameter made by Thermos. Instantly after putting the mug in the coil we can feel the heat inside the mug by touching the wall. Though an oscilloscope is not essential to test the circuit, however to get a better idea about the waveforms and frequency we can use one. The voltage waveforms found before and after the inductor L1 is shown in Fig. 5. After L1, the higher order harmonics are reduced to a large extent, the sharp voltage spikes are also gone. When the mug was in the coil, due to induction the voltage across the coil was little reduced.

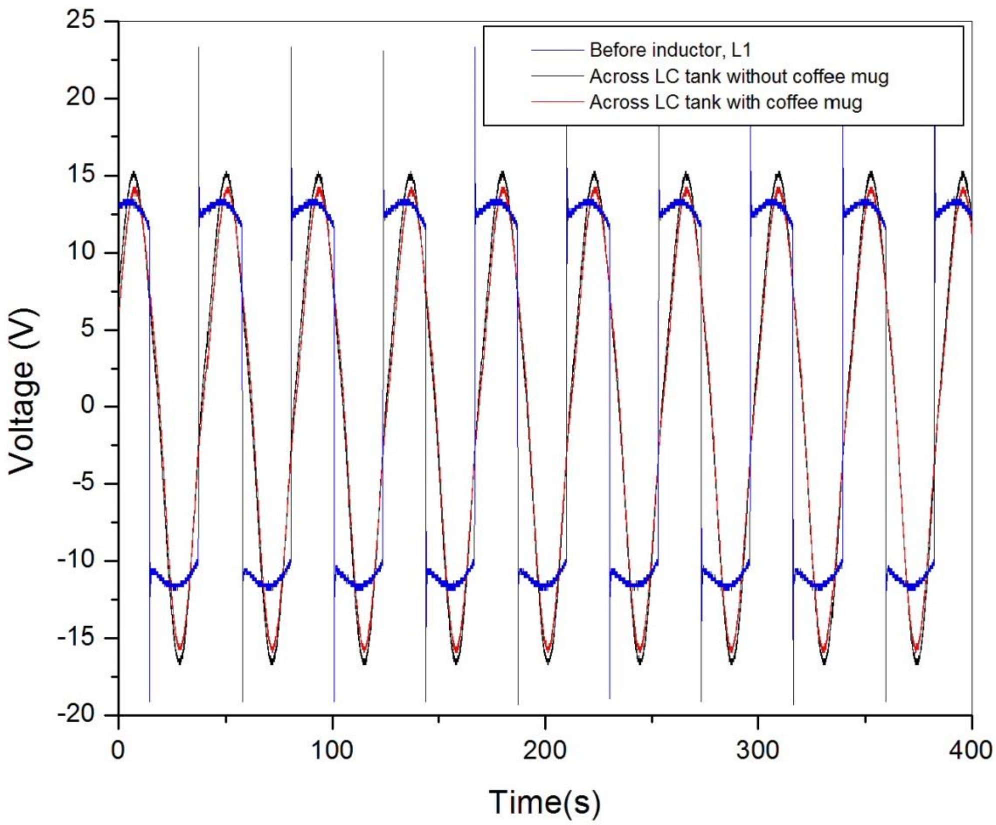

Fig.5. Oscilloscope waveforms across the coil-capacitor tank circuit and before the inductor L1

After the tuning was done, the coffee mug was filled with a volume of water around 300 mL and put in the coil. A thermocouple was also inserted in the mug, the tip of which was touching the water. The lid of the mug was put on and the power supply was connected. The current remained ~0.59 A with the mug in. The test setup is shown in Fig. 6. Temperature was recorded when the power was switched ON. Temperature slowly rose to ~72 ^{o}C in an hour and remained nearly unchanged at ~ 80 ^{o}C after a prolonged period. At ~80 ^{o}C the rate of heat generated by induction heating in the mug equals the rate of heat escape the mug to the ambient. This means that an already warm coffee will remain at ~70 – 80 ^{o}C with this gadget. If the same circuit is powered by a 48V supply instead of 24 V; with and without the mug the DC power supply-current was 0.27 A and 1.28 A, respectively. With 48 V supply temperature of 300 ml water quickly increased and to reach 100 ^{o}C, it took only 35 minutes. The rise of temperature with time for 24V and 48 V supplies are shown graphically in Fig.7

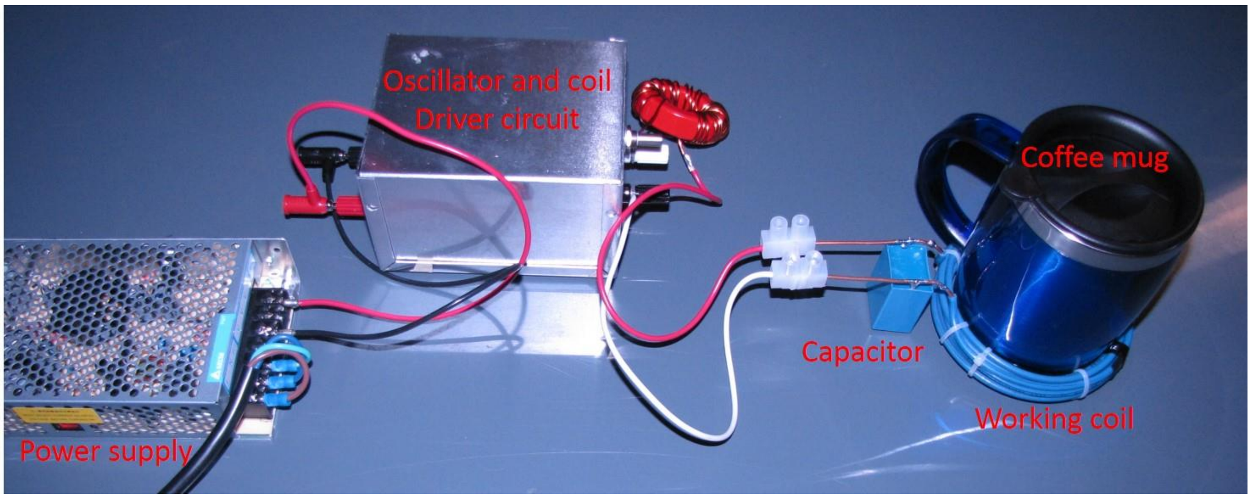

Fig.6. The test setup.

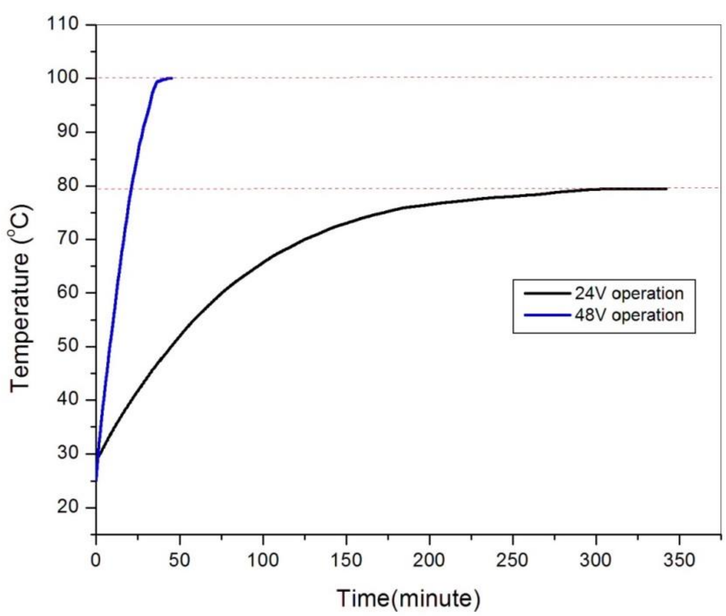

Fig.7. Temperature rise of 300ml of water in a coffee mug. Black and blue lines are for operation with 24 V and 48 V power supplies, respectively.

Bill of material (BOM):

Qty.	Value	Parts	Description	Allied Electronics Part#
1	IRS2153	IC	H-Bridge, MOSFET Driver, Oscillator	70017317
1	0.01uF	CT	Capacitor	70195788
2	0.1uF	C1, C2	Capacitor	70195939
1	1.8k	R1	Resistor	70024412
1	100k	RT1	Potentiometer	70154227
2	100uF	C4, C5	Polarized Capacitor	70187364
1	1N5251B	D1	Zener Diode	70061648
1	1k	RT2	Resistor	70522113
1	30uF	C3	Capacitor	70233336
1	4.7k	R2	Resistor	70183451
1	5 uF	C	Capacitor	70233333
1	7uH	L1	Inductor	70065370
2	IRFP150NPBF	Q1, Q2	N-Channel MOS FET	70017034
1	TIP29C	Q3	NPN Transistor	70013794
1	24 V	ZPSA60-24	Power Supply	70177449
1	TH-K-1-0-5		Thermocouple	70209691

Other items: Small box, two heat sinks for the MOSFETS, PCB, screws, banana plugs, hookup wire and terminals.