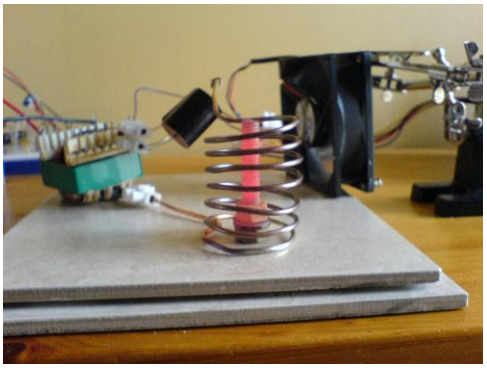
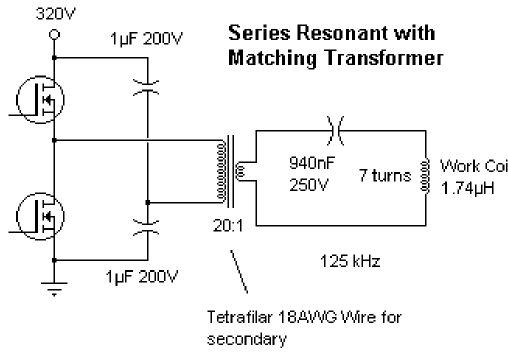
SERIES RESONANT INDUCTION HEATER



Red hot bolt, run time of about 1 minute, about 120 kHz

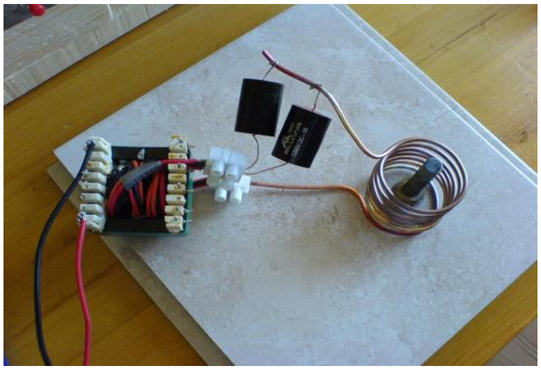
Induction heating is heating conductive metals with no physical contact, by using high frequency electricity. Large currents are forced through the object which is to be heated. The object is often called a work piece, and the heating coil a work coil. Some interesting drive techniques are needed to push enough current through the workpiece for noticeable heating, and all of them use resonance. Most commonly used are series and parallel resonance, but the parallel resonance variation LCLR rox0rs their b0xors. Richie Burnett has a very good page on it >HERE<. Unfortunately I didn't have any success with LCLR, so I went with good ole' fashion series resonance. Basically an impedance matching transformer with a series resonant LC arrangement on the output, like so:



Obviously the worst topology of the three because the switches will have to pass all of the current, both current draw by a load and reactive current. But it worked best first on my first try, so I stuck with it. A series resonant circuit consists of a capacitor and an inductor in series. At their resonant frequency the combined impedance is minimal, which allows one to push current through the work coil at high frequencies with relative ease. In case you didn't know, that would be difficult otherwise (read up on reactance if you don't know why). Let's take a real-world example. A half-bridge run from 320V gives +/-160V on the transformer primary. With a step-down ratio of say 20, a work coil inductance of around 3µH and frequency of 150kHz. That's 8 volts over 2.8 ohms of inductive reactance, so 2.8A of current through the work coil. Even with many turns on the work coil, the work piece would only have relatively small currents flowing in it. Add some series resonance however, and the work coil reactance suddenly approaches zero, allowing huge currents flow through the work coil.

But how does large amounts of invisible current flowing through the wires heat the work piece? Think of the work coil/ work piece (I'm getting tired of typing that) as a transformer. The primary turns are made up of the work coil, and the secondary turn of the work piece which represents one shorted turn. Now the point of getting all that current to flow through the work coil becomes clear. Maybe a few hundred amps flowing through the work coil, stepped down further by transformer action. Some quick math gives 1 -3 kA in the work piece! Now with that much current even a few milli-ohms of resistance in the metal work piece will result in massive losses. (I^2 * R!) In other words heat! To top it off magnetic work pieces will also be heated by hysteresis losses!

The workpiece lowers the Q of the work coil, which dampens the resonance action. (Q is reactance divided by DC resistance, just a quality factor of sorts. Low Q means the impedance is dominated by DC resistance) If the workpiece is removed during operation however, the Q of the work coil greatly increases and the current drawn by the series resonant circuit sky rockets. Which in turn results in a blown half-bridge. Trust me, I've had it happen. Never let your brother take care of important tasks like power control...



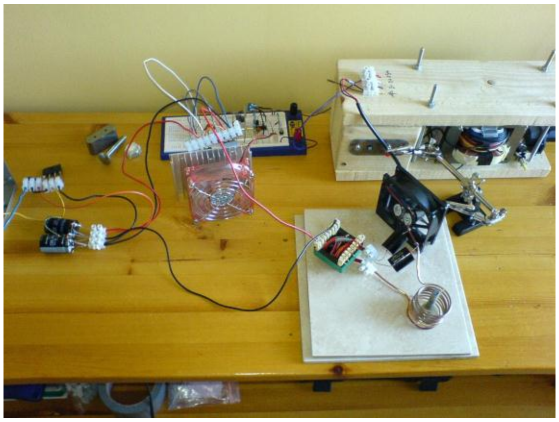
Series resonant setup, with matching transformer.

Since we want huge currents flowing through the work coil, we'll need to step up the current we get from mains. A typical inverter can only supply high voltage, low current, which is the last thing we want with our series resonance setup. The impedance matching transformer steps up the current by a large magnitude and the voltage down by an equal amount, matching impedances. The power drawn by the induction heater can be controlled by the turns ratio of the matching transformer, a larger ratio means less power. I stuck with about 20:1, but if I had a better capacitor bank and matching transformer I wouldn't hesitate to take it down to 10:1. I'm not really sure why more power was drawn by reducing the ratio, but maybe I was just seeing more reactive current. I'll need to investigate this further in my future setup.

The currents flowing in the secondary side will be enormous, so use litz wire, or at least tetrafilar (that's four braids) of 18 AWG wire on the matching transformer secondary.

Thinner wires, and more of them would be ideal, since the skin effect limits the usable diameter of wire at high frequencies. The capacitor bank should consist of at least four capacitors for increased current handling. The two I used became hot after one minute, and the entire setup was untouchable after two. Since they are configured in a series resonance setup the voltage across the components will be much higher than what the matching transformer actually supplies. In my case the voltage across the capacitor was almost 200V. If you plan to use a larger ratio, like 10:1, remember to buy high voltage capacitors.

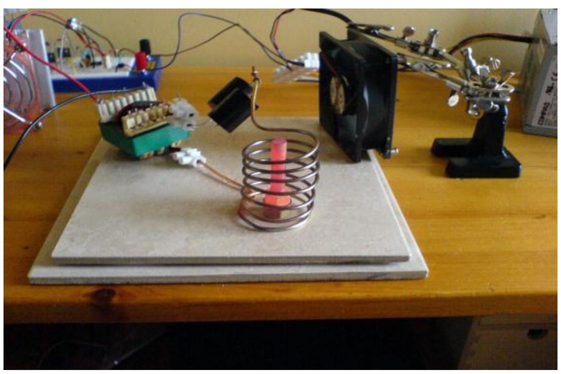
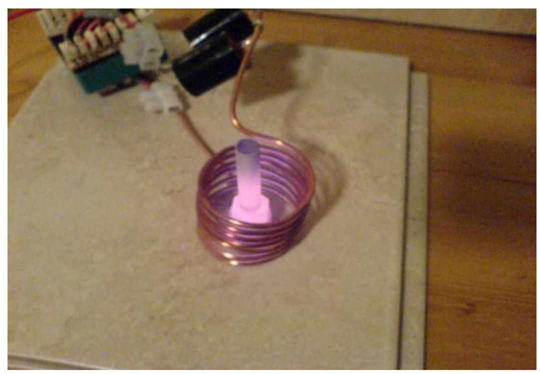
To drive the setup I would have used my Multi-purpose Inverter if the frequency control was installed at the time. This would save the inverter from failing with no load, simpler frequency control and easier current monitoring. I was forced to lash up a quick driver, which was almost identical to my Offline flyback driver.

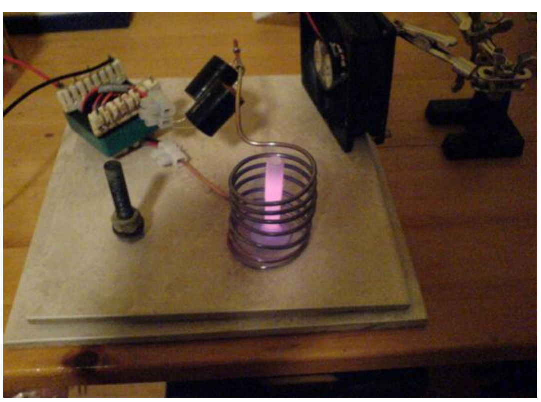
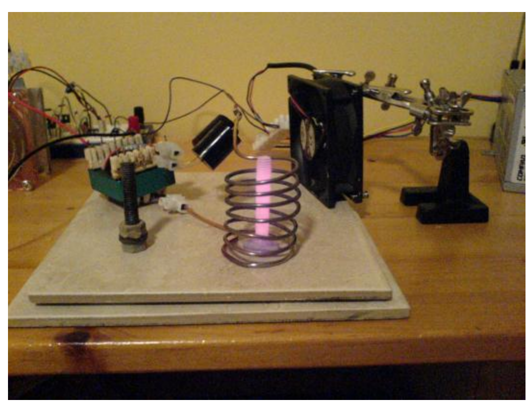


Lash-up, notice the cooling fans required to keep everything alive.

Basically you want good frequency control since this controls power. Frequencies on either side of the resonant frequency will result in increased impedance, and less power. Tuning for resonance is done by either watching the output on a scope, or watching the current draw. Max current draw at resonance. Scope the tank capacitor while changing the frequency. When off resonance the waveform will be square, and as you approach resonance the waveform will become more sine/triangle like. At resonance the waveform will have the largest amplitude.

On some of the pictures the bolts will appear to be pink/violet. This is caused by my digital camera misinterpreting the IR in the low light photos.

Source: http://uzzors2k.4hv.org/index.php?page=seriesresonantinductionheater