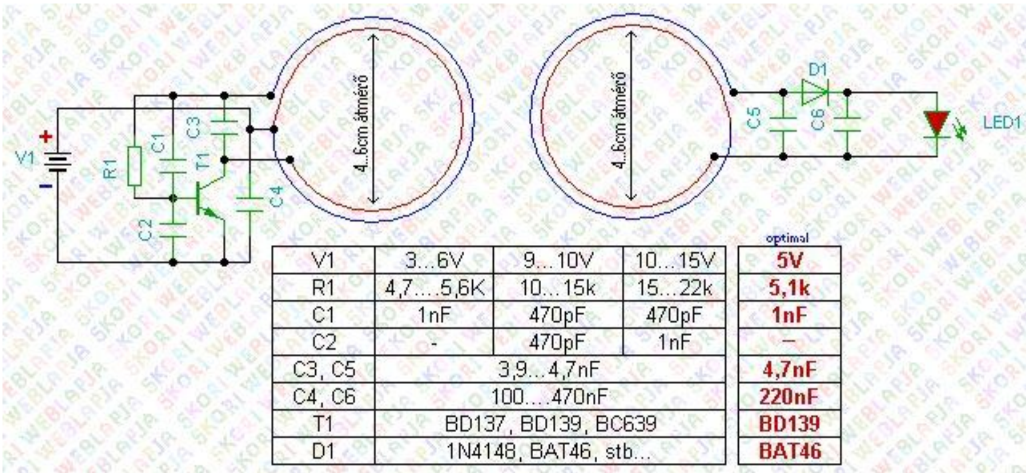
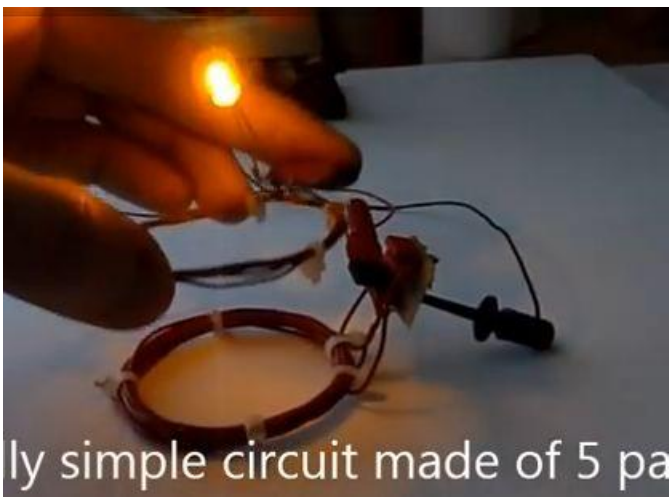
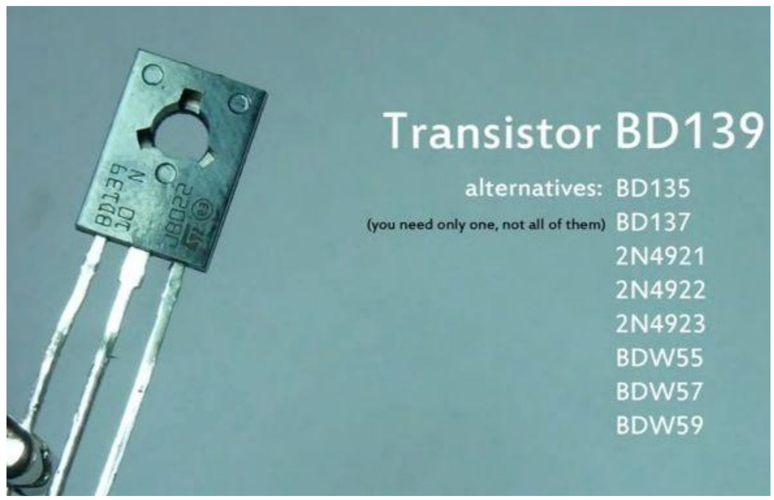
From video: - **wireless transfer of energy** diagram circuit

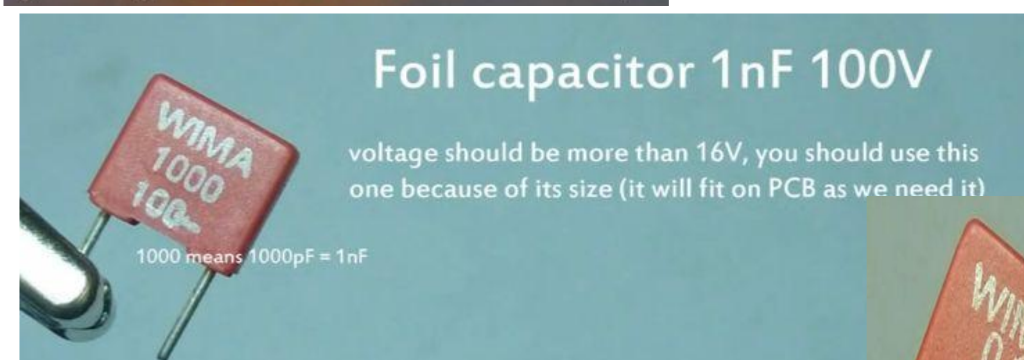
https://www.youtube.com/watch?v=YLu16Yd-c20 – DIRECTION OF IMAGES GOES LEFT COLUM TO RIGHT COLUM



				optimal
V1	3...6V	9...10V	10...15V	5V
R1	4,7....5,6K	10...15k	15...22k	5,1k
C1	1nF	470pF	470pF	1nF
C2	-	470pF	1nF	–
C3, C5	3,9...4,7nF			4,7nF
C4, C6	100....470nF			220nF
T1	BD137, BD139, BC639			BD139
D1	1N4148, BAT46, stb...			BAT46

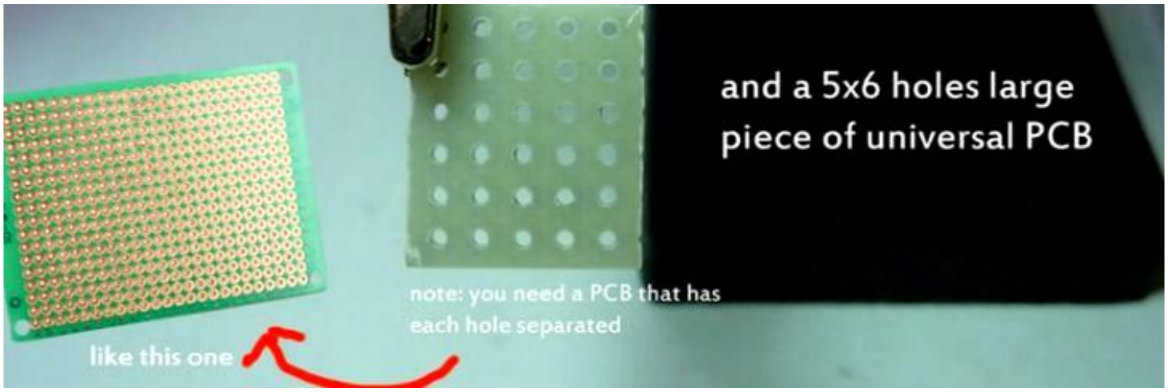


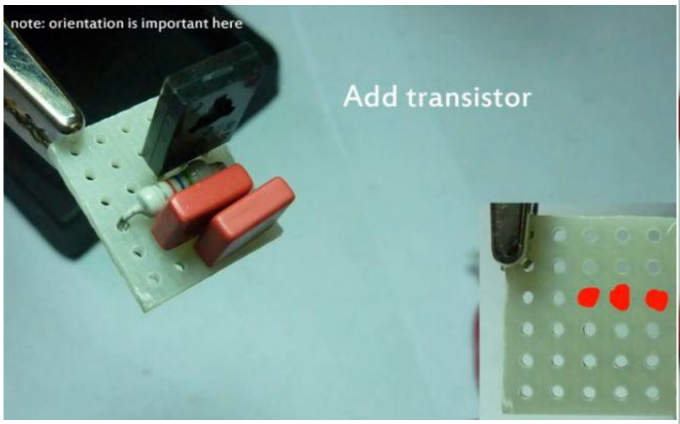


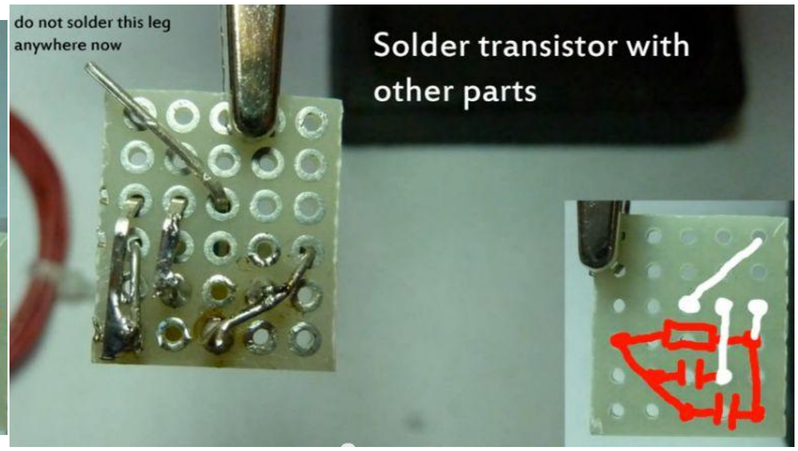


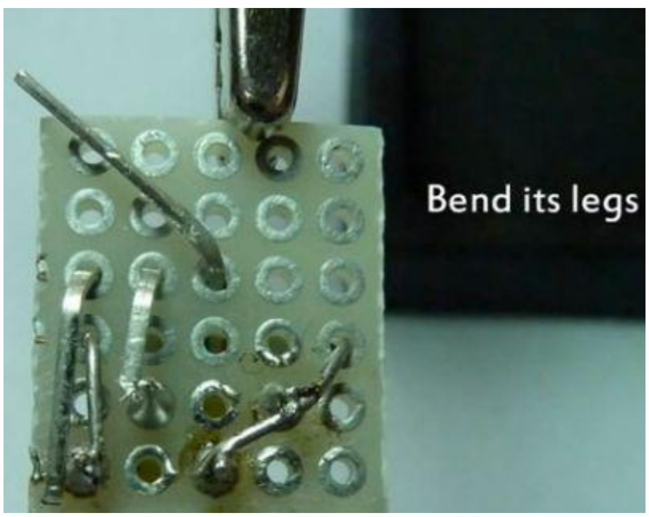
Parts:

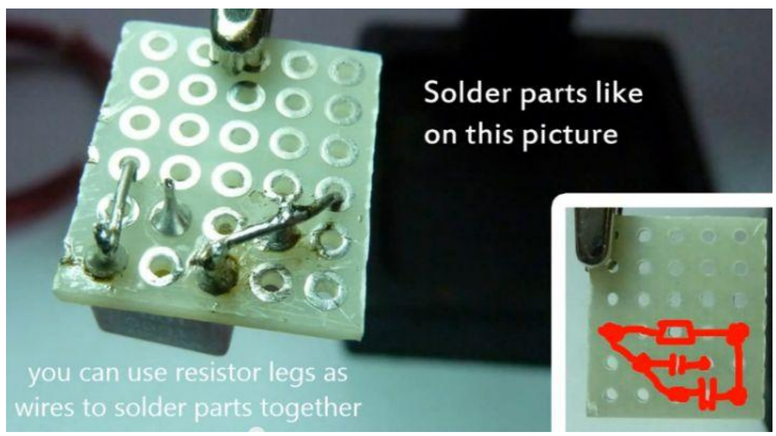

Resistor 5k6 0.5W
5k6 = 5.6kR = 5600R

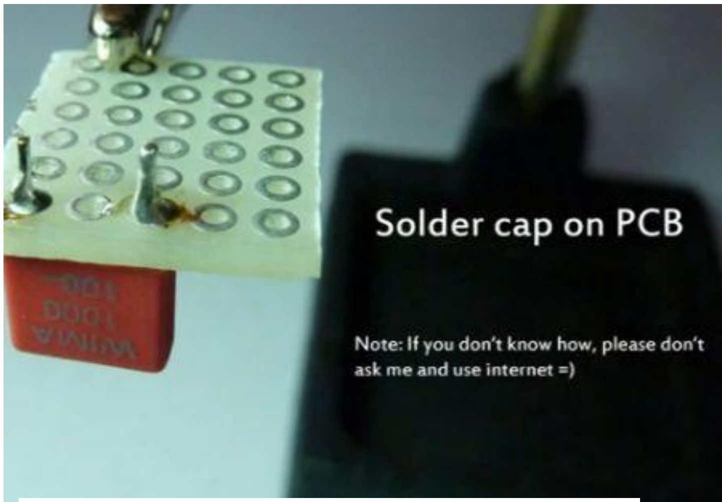

and a 5x6 holes large
piece of universal PCB
note: you need a PCB that has
each hole separated
like this one

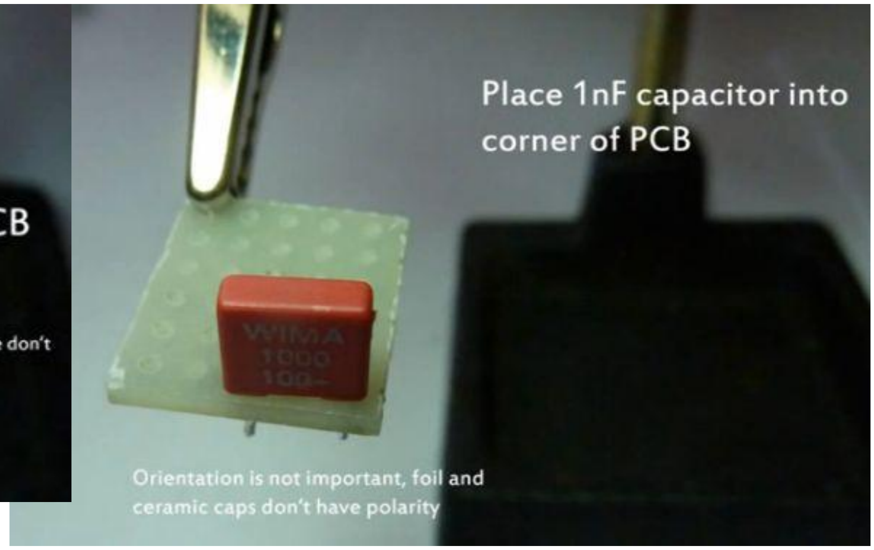

note: orientation is important here
Add transistor


do not solder this leg
anywhere now
Solder transistor with
other parts

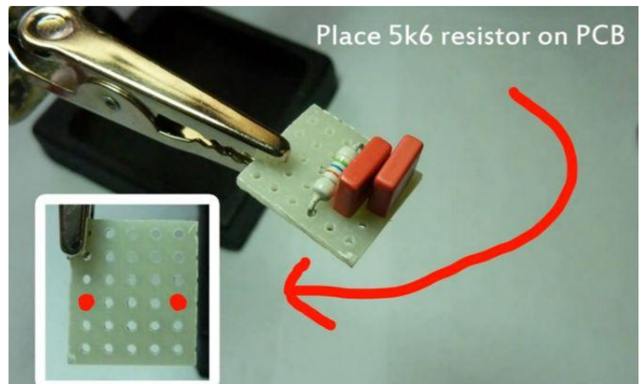

Bend its legs

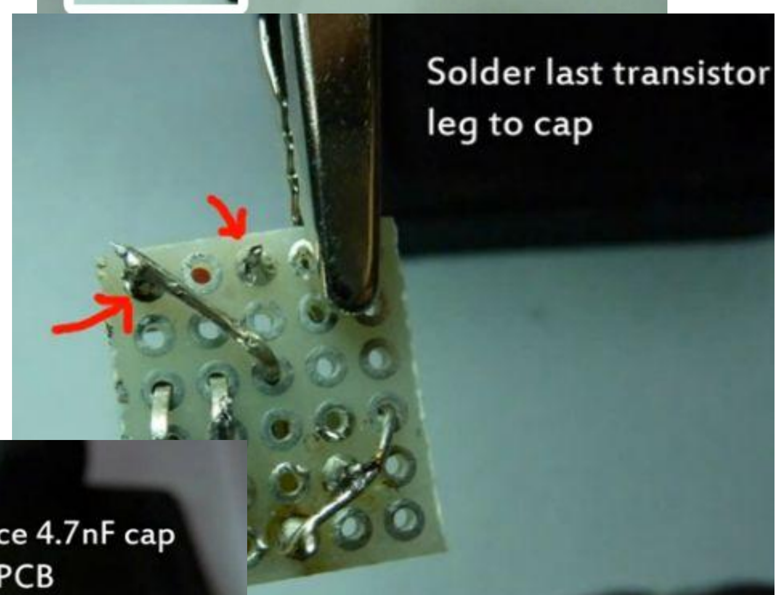

Solder parts like
on this picture
you can use resistor legs as
wires to solder parts together

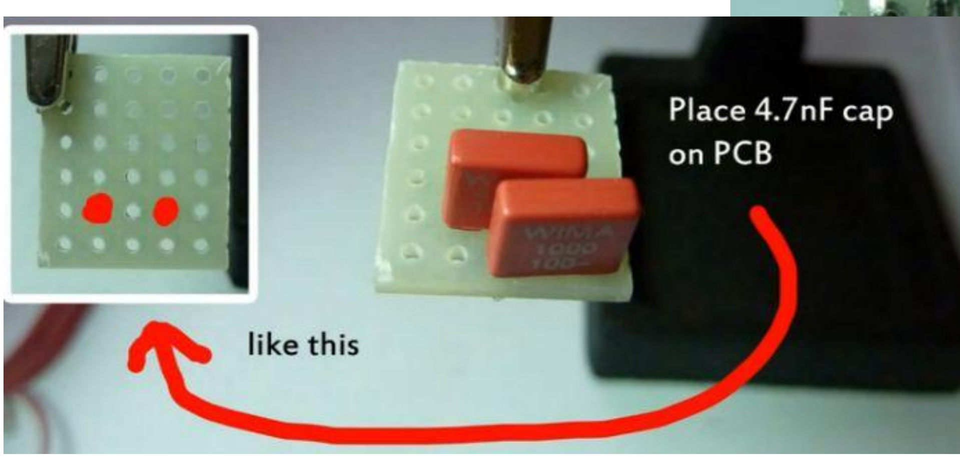

Solder cap on PCB
Note: If you don't know how, please don't ask me and use internet =)


Place 1nF capacitor into corner of PCB
Orientation is not important, foil and ceramic caps don't have polarity

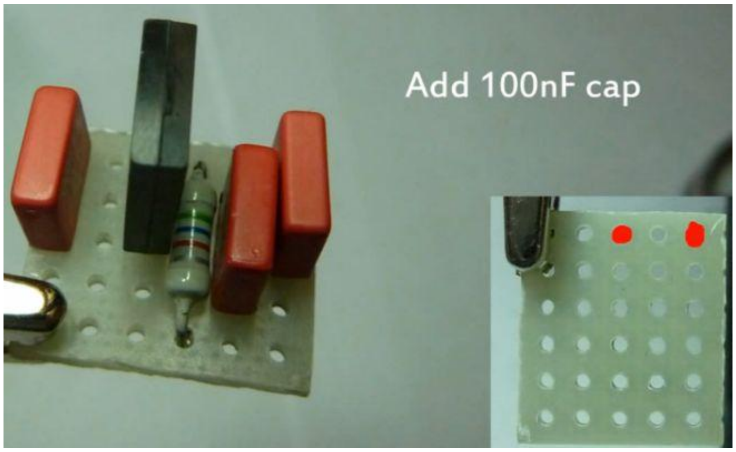

...and solder it

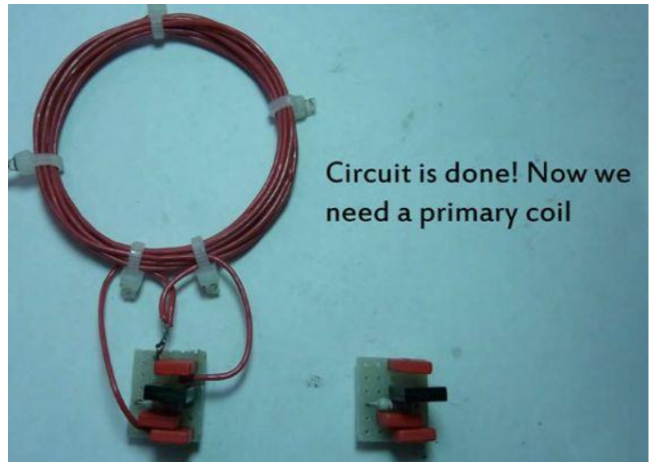

Place 5k6 resistor on PCB


Solder last transistor leg to cap

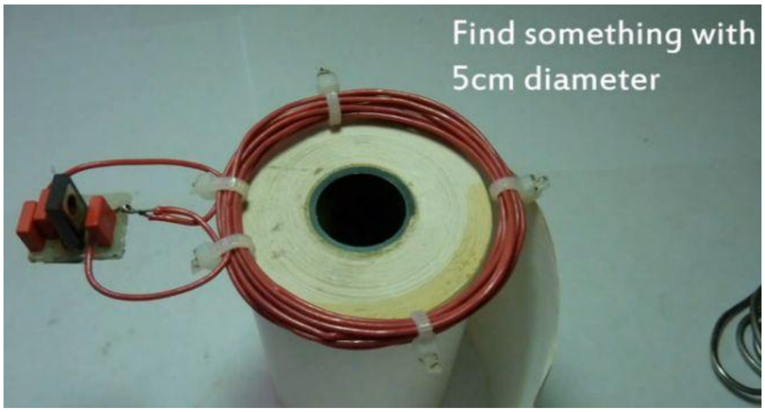

Place 4.7nF cap on PCB
like this

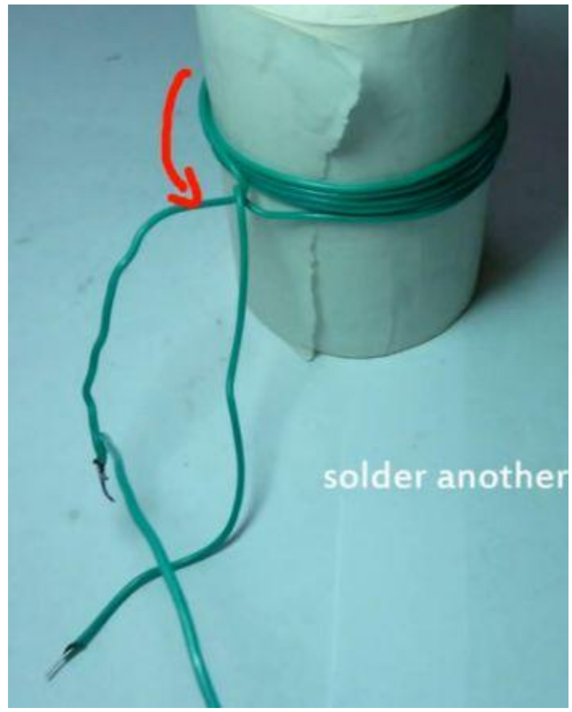
The image on the lower right is the 2nd coil winding details shown here to

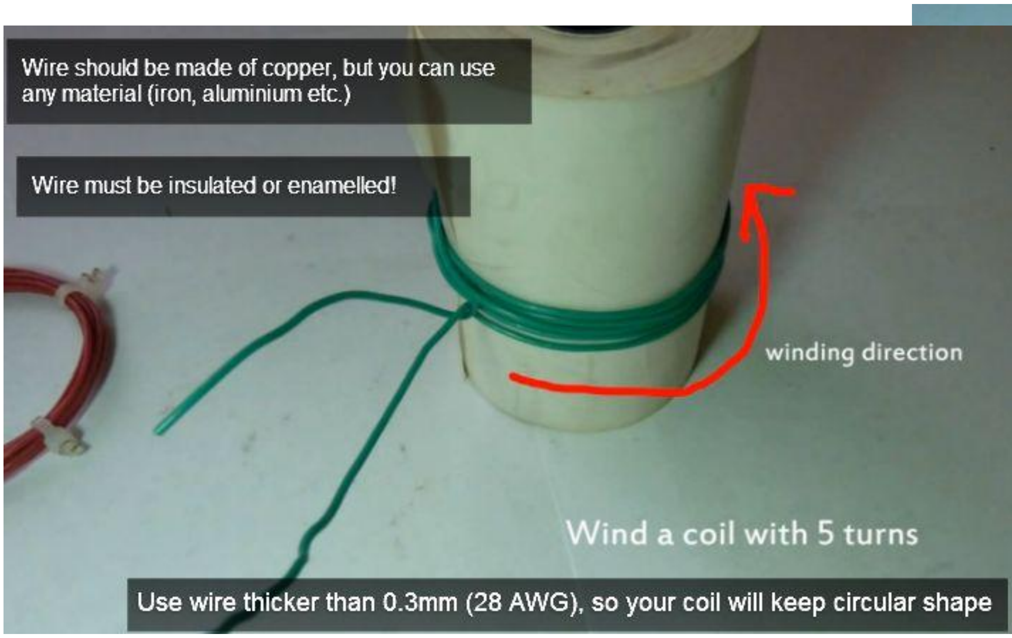


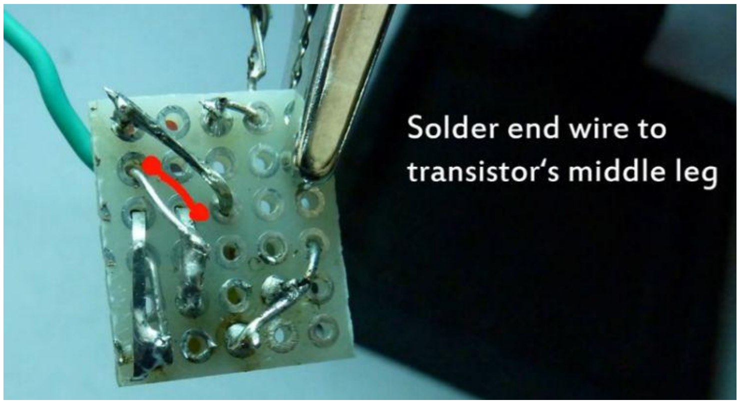


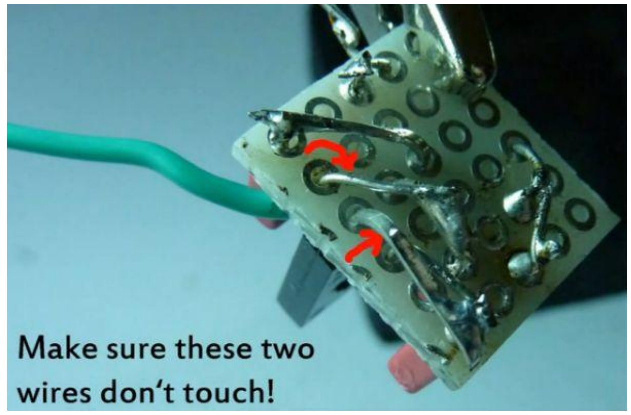
the below. ..also by using a reel of paper towels, you can change the diameter of the coil by removing // adding more towels.

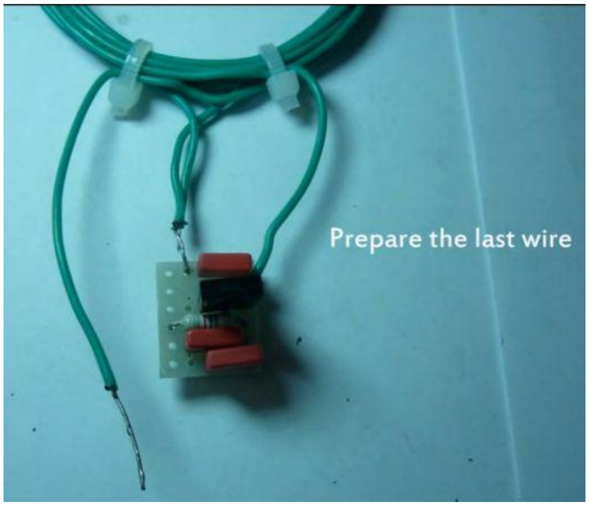


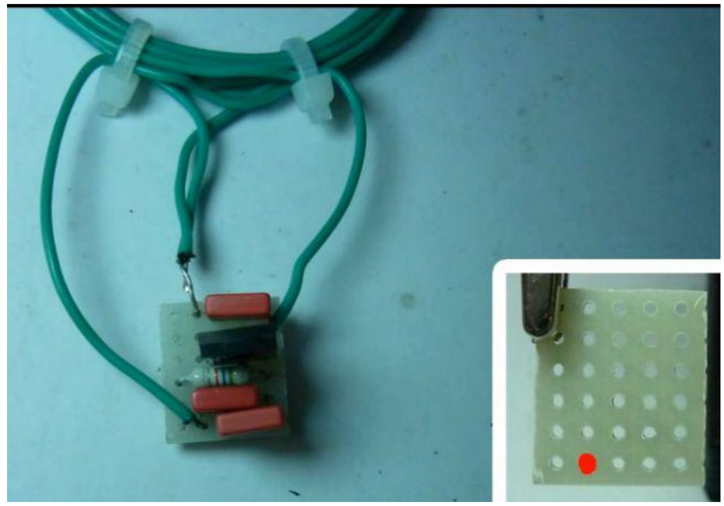


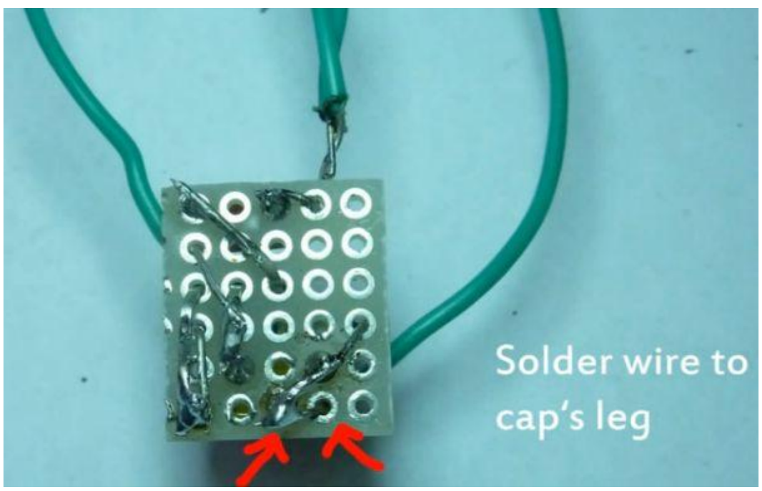


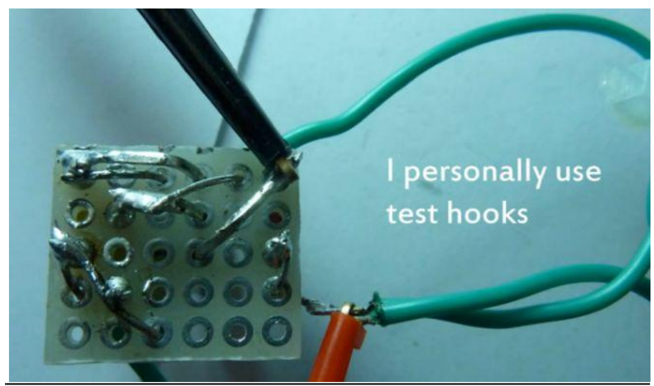

Solder end wire to
transistor's middle leg

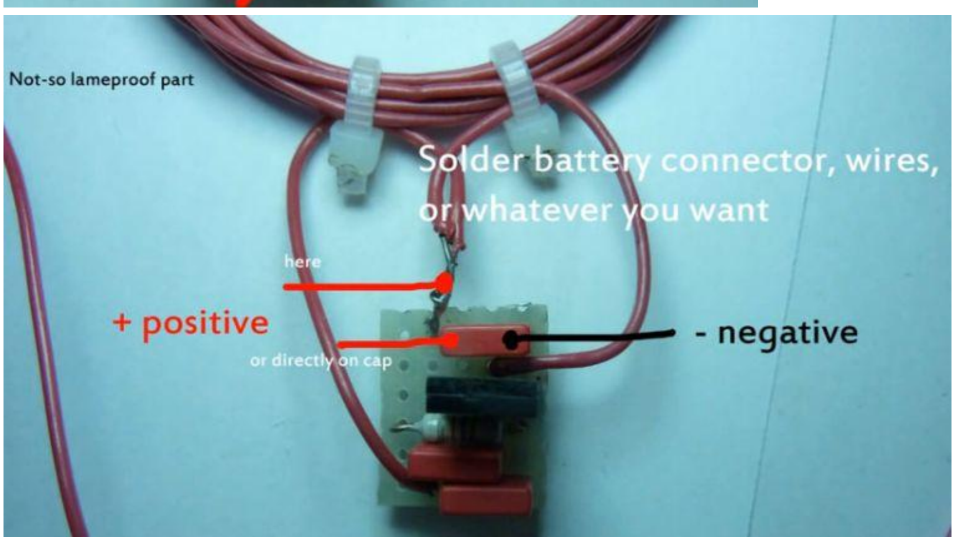

Make sure these two
wires don't touch!

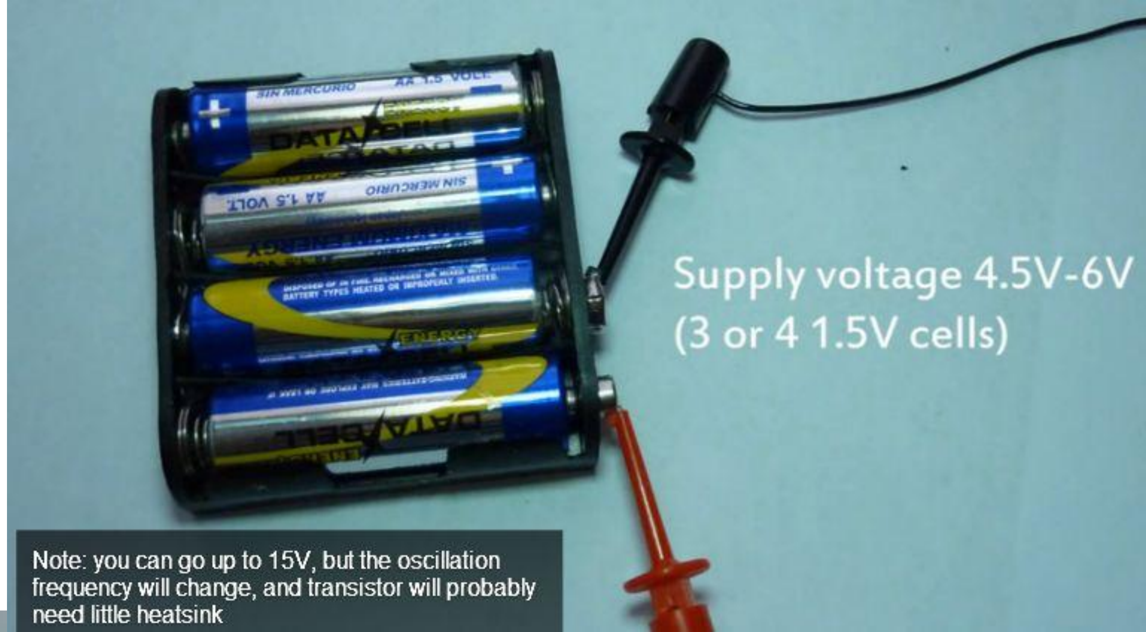

Prepare the last wire

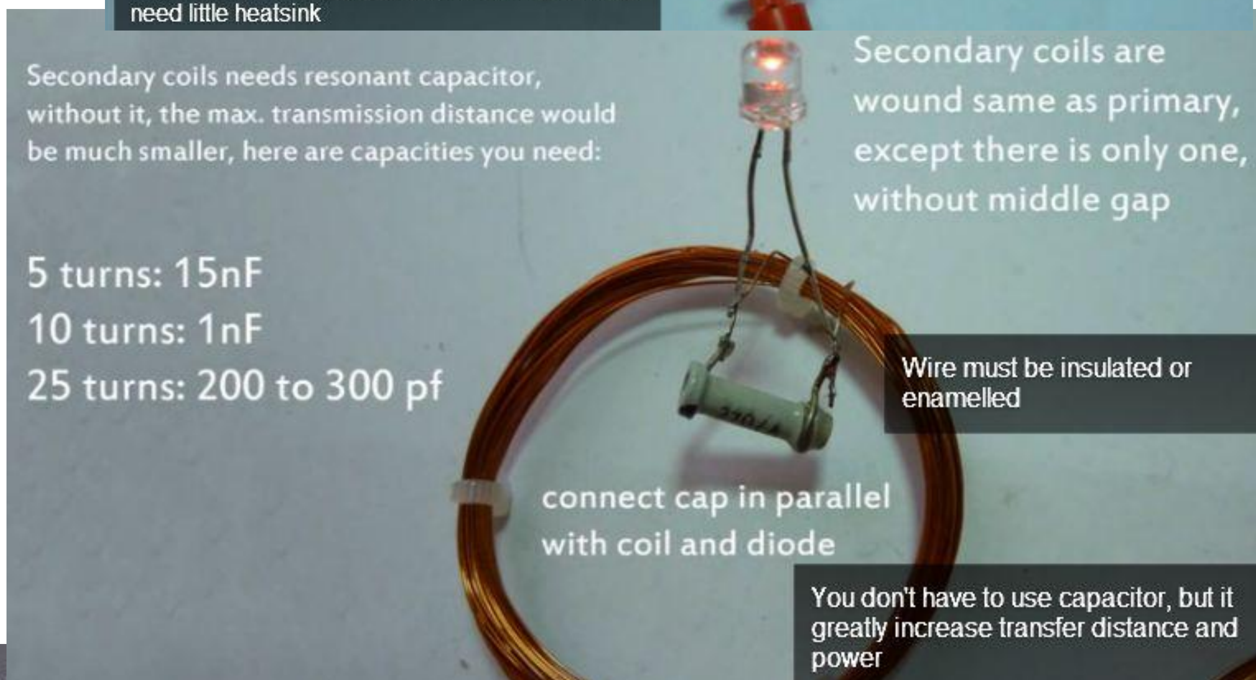


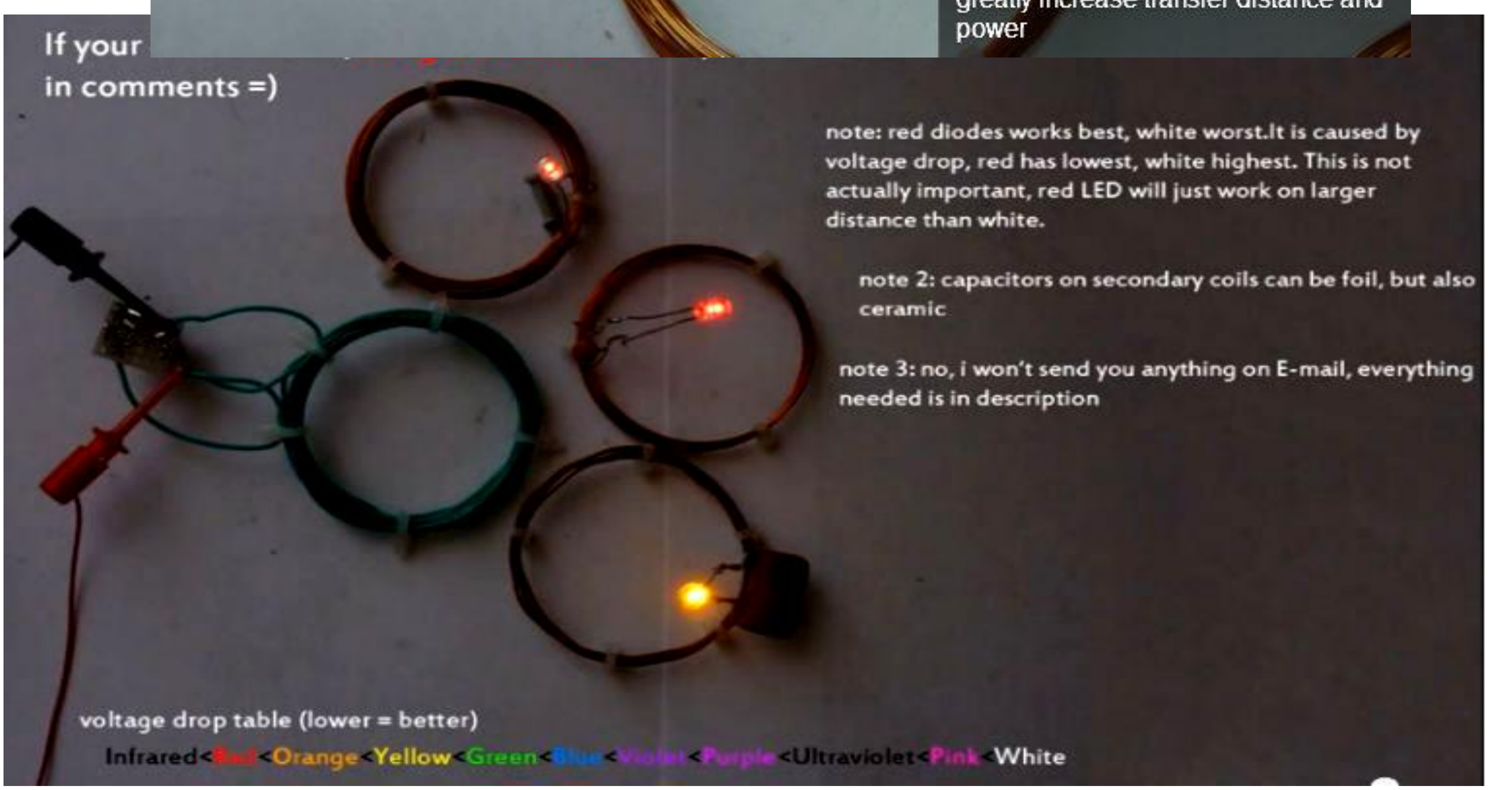

Solder wire to
cap's leg


I personally use
test hooks


Not-so lameproof part
Solder battery connector, wires,
or whatever you want
here
+ positive
or directly on cap
- negative

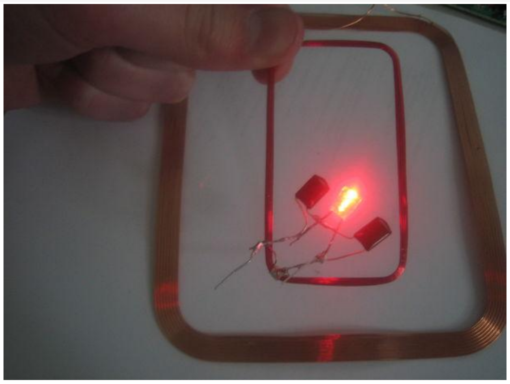

Supply voltage 4.5V-6V
(3 or 4 1.5V cells)
Note: you can go up to 15V, but the oscillation frequency will change, and transistor will probably need little heatsink


Secondary coils needs resonant capacitor, without it, the max. transmission distance would be much smaller, here are capacities you need:
5 turns: 15nF
10 turns: 1nF
25 turns: 200 to 300 pf
Secondary coils are wound same as primary, except there is only one, without middle gap
Wire must be insulated or enamelled
connect cap in parallel with coil and diode
You don't have to use capacitor, but it greatly increase transfer distance and power


If your
in comments =)
note: red diodes works best, white worst.It is caused by voltage drop, red has lowest, white highest. This is not actually important, red LED will just work on larger distance than white.
note 2: capacitors on secondary coils can be foil, but also ceramic
note 3: no, i won't send you anything on E-mail, everything needed is in description
voltage drop table (lower = better)
Infrared< <Orange<Yellow<Green<Blue< <Purple<Ultraviolet<Pink<White

Next Circuit:

Step 1: What is it? How does it work?



A few years ago MIT created a system for transferring power wirelessly. They transmitted power over a two-meter distance, from the coil on the left to the coil on the right, where it powers a 60W light bulb. Back in 2006, this was a pretty cool thing. You can only imagine what the implications of something like this would be. Well, unlike most of us, we do not have the time or material goods like MIT has. So i have made this simple and easy to follow Instructable, so all of you good people can experience the joy of wireless power.

Inductive Coupling uses magnetic fields to transfer power. There is a primary coil, which generates a magnetic field. Then there is another secondary coil which is composed of a capacitor and a coil, the capacitor creates a resonant circuit with the primary and secondary coils. Seem easy? Well, before publishing this instructable I found many useful and a lot of non-useful info on the subject.

In my research I found, that to transfer power in very complicated. Once i did it I found that you do not need to go to MIT do do this sort of stuff. With a little electrical know how, this is easy.

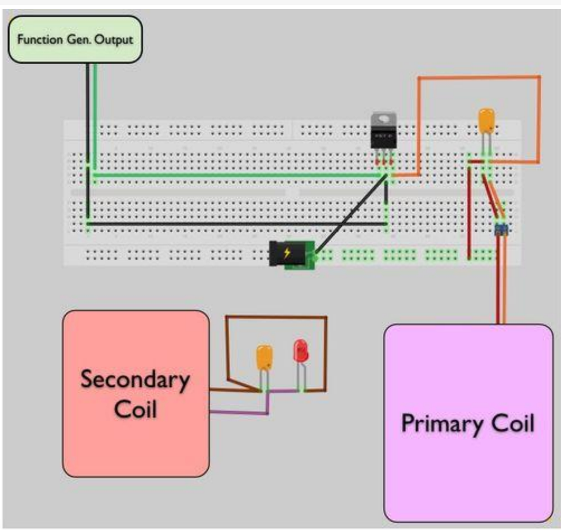
It all starts with the transmitter. This transmitter needs to create 147.7 kHz square wave AC signal. Let me take a minute to explain this all. Level one on the frequency scale is Hertzs, then there is kHz, then MHz. MIT used a 10 mHz wave to drive there coils, but for this we will be using a 147.7 kHz signal so it does not get too complicated.

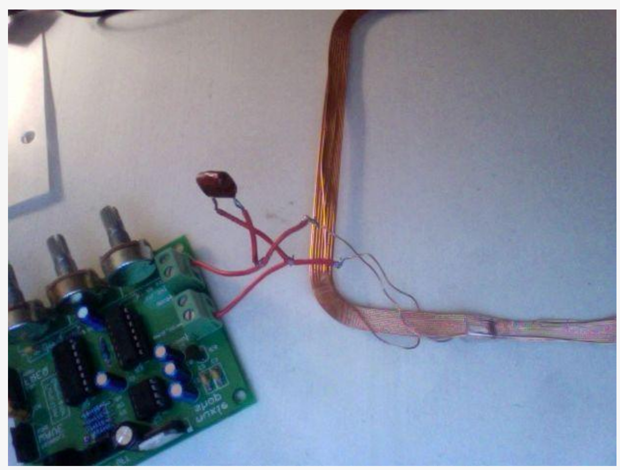
The secondary coil has a 0.02 uF capacitor. This will allow the two circuits to be coupled therefore, transferring power efficiently. The 0.02 uF capacitor is used only for this frequency, and the value of this capcitor will change depending on the frequency.

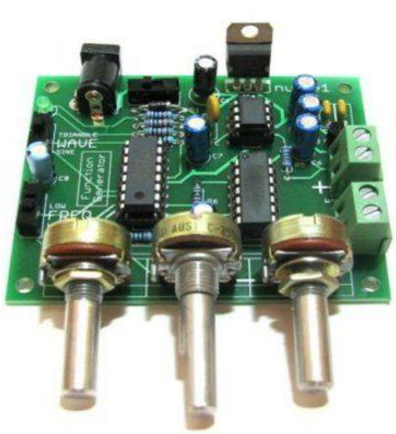
The primary coil creates a magnetic field, when another coil is placed near it, energy will be induced into it.

Be in mind that i could not get a hold of a 0.02uF capacitor so i used two 0.01uF capacitors connected together.

Step 2: Creating the Primary Coil







The primary coil uses magnet wire, which is easy to get at RadioShack.
http://www.radioshack.com/product/index.jsp?productId=2036277
We will use magnet wire as the material for our coils.

Next we need something to create the 147.7 square wave AC signal. I saw videos on youtube like this one. http://www.youtube.com/watch?v=SSgo_N-5JOg Which uses a function generator. Sadly, these cost a lot of money, so i wanted to get a low cost one, that still did the same thing, just not as high of a frequency. This http://www.sparkfun.com/commerce/product_info.php?products_id=9002 is great for what i needed. Cheap and simple.
This will be the main board to create the signal.

By using a pencil or nails on a 2 x4 and your magnet wire, you can make a pretty good coil. I did about 30-40 turns, depending on the thickness of your magnet wire. Magnet wire has a very thin coating on

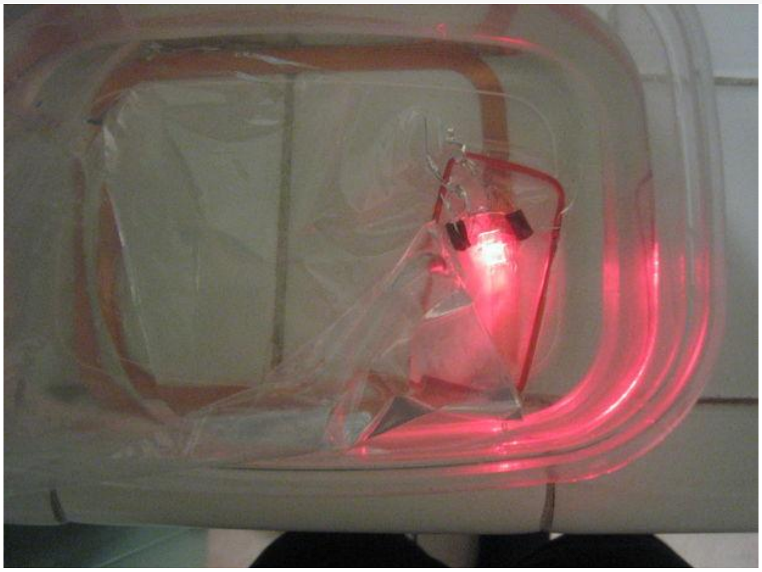
the top of it. To get this off you can light a match and put the magnet wire in the flame for a few seconds. Take the two ends of you coil and put it into the function generator on the top two screw terminals, one in each terminal. Polarity is not a problem right now because the signal will be AC. Now place your 0.02 uF film capacitor in parallel with the terminals you put the wire magnet ends into. Turn the function generator on and use your multimetter to get it to somewhere near 147-149 kHz by turning the potentiometers. Make sure the switch on the left of the board is set to square, and your good to go. The top to terminals will allow for an AC signal.

Step 3: The Secondary Coil

le="width:600px;" />

This circuit is one of the simplest you can ever create. It is composed of magnet wire coil but smaller like the primary, a 0.02uF capacitor also like the primary, and some leads you can attach things to. For LED's the circuit looks like that. Yet, for powering your iPod and other devices that use DC power you need a diode bridge, or rectifier which can turn AC into DC to power your portable device. Take a look for yourself that the secondary coil has an AC output which will only power LED's.

Step 4: Testing Wireless Power Through Different Materials

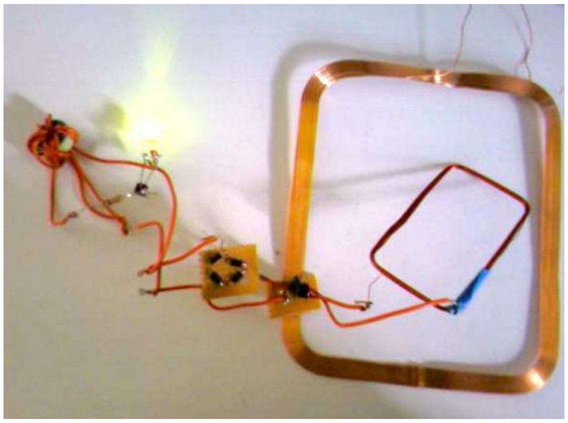


Yes, I decided to go a little further because of the response that I received.

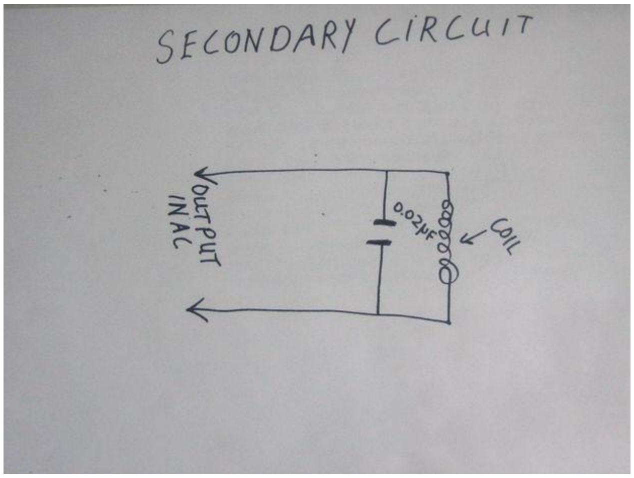
You were always told as a kid, water and electricity DO NOT MIX, and that may be true, but not with wireless power. I tested this in water. No, I did not get shocked, but you may. NO! You will not I promise. This Step shows that this type of wireless power can pass through almost anything, except metal, I know, I was sad when i found that out. I mean, for a practical use, many people have desks made of metal where the coil is. This is not good, but I digress, we must move on.

Water! I mean who would think that this kind of technology has this kind of potential! It works that same exact way as if it was not in water. It is in a plastic bag as you can see. Only to protect the electronics. Unlike WiFi which is can be weakend by walls and other things, Wireless Power is not!

Step 5: Circuits



alt="FunGenv2Final.jpg" s



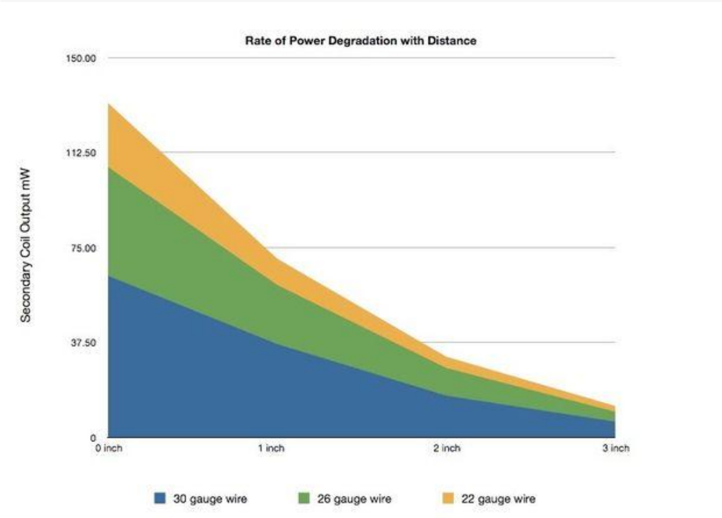
<img class="photoset-photo"

These three pictures I have posted are of the circuits that I used. I have also posted a third picture of a theoretical circuit (has not been tested so i am not sure if it works) which turns the received energy into DC so you can hook it up to your favorite electronic device, iPod, cell phone...

Primary Coil-The function generator is the Main circuit of the primary, but you can easily buy it from the link posted earlier. Alon with the magnet coil.

In the Secondary Coil Diagram, the only capacitor is a 0.02 uF as I explained why.

Step 6: Data



Gauge	22-gauge wire	26-gauge wire	30-gauge wire	Circuit w/out coil
0 inch	63.86 mW	42.98 mW	25.258 mW	0.01 mW
1 inch	36.90 mW	23.34 mW	10.41 mW	0.00 mW
2 inch	16.523 mW	10.93 mW	4.458 mW	0.02 mW
3 inch	6.24 mW	3.923 mW	2.257 mW	0.005 mW

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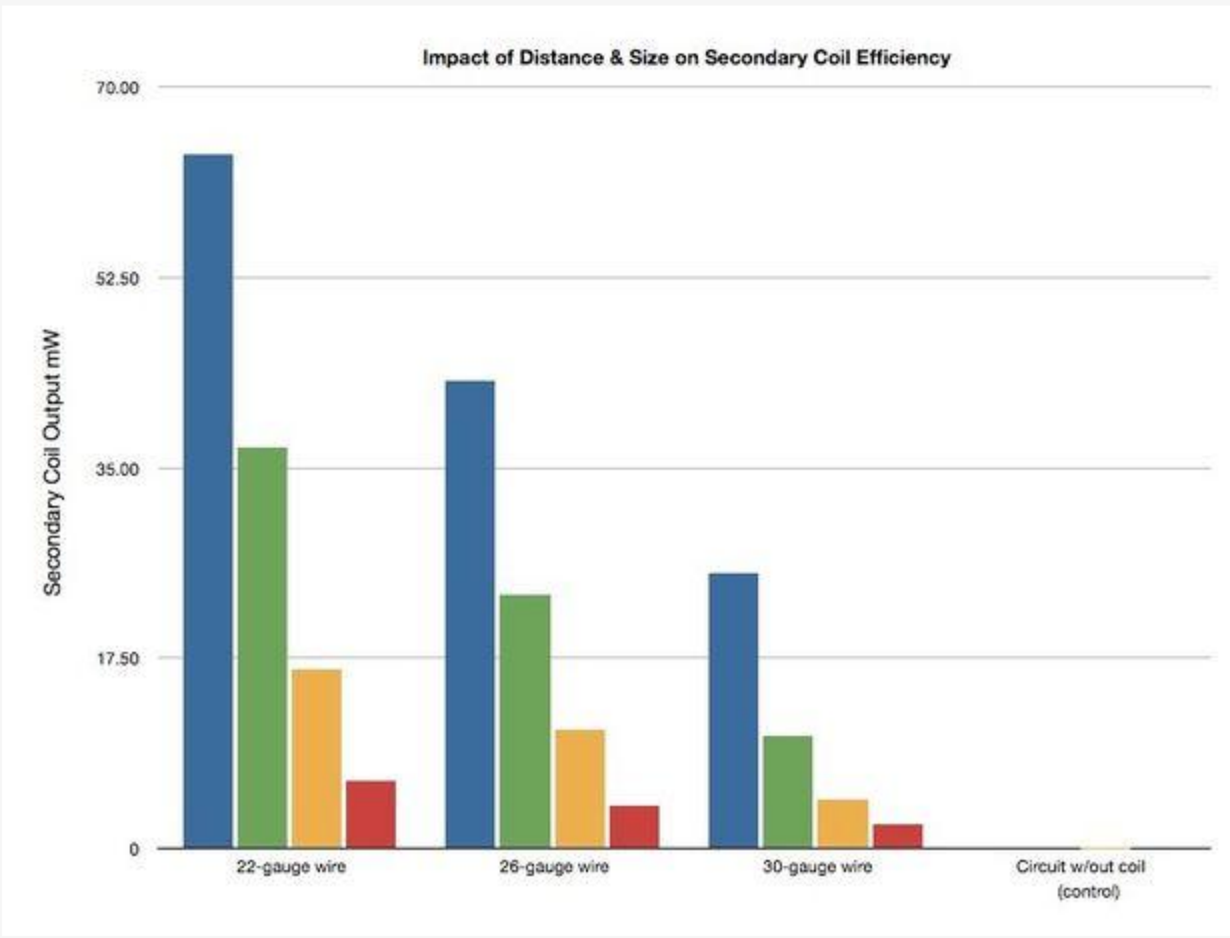
src="http://cdn.instructables.com/FUO/A5N1/GO5IHQMB/FUOA5N1GO5IHQMB.MEDIUM.jpg" style="width:295px;" />



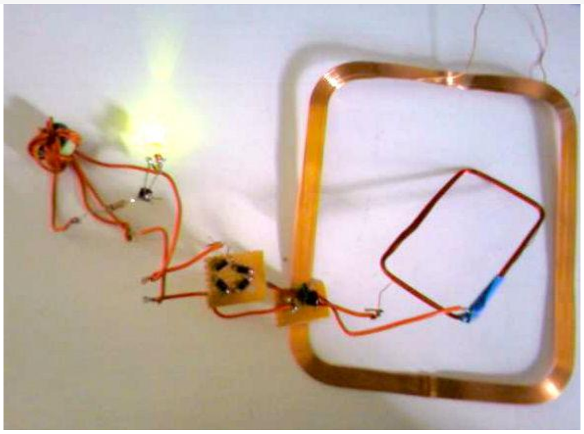
The power coming directly from the function generator to the coil: 110.5 mW.

Maximum power efficiency achieved is 42.2%. This is a very respectable power efficiency considering a limited budget and short experimentation time period.

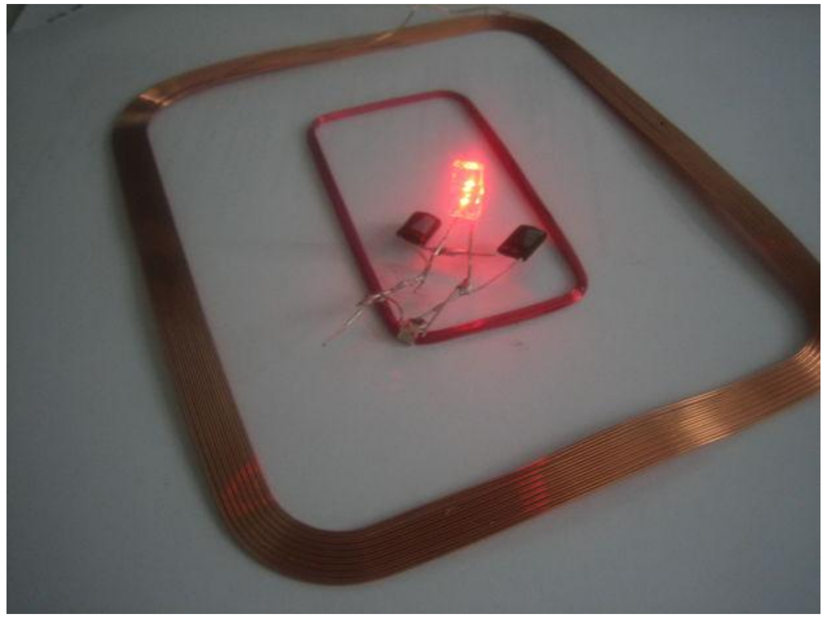
The following chart is a visual representation of the above data points.

The following graph represents how the power output of the secondary coil was effected by efficiency at certain distances from the primary. At three inches, the current technology outputs a value that is very minute and is not efficient enough to power much of anything. However, at zero inches, the power output is very capable of achieving the goal in the engineering objectives.

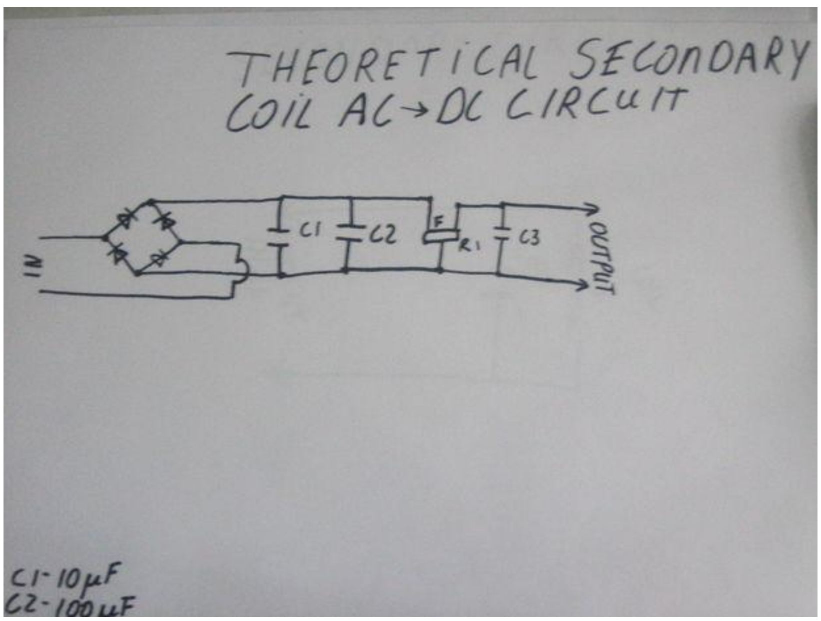
Step 7: Extra Hardware



I have now added a AC to DC diode bridge which converts AC to DC. Then i added a Joule Theif to the diode bridge, which is a very simple circuit that can amplify input power (the Dc voltage from the diode bridge).
http://www.youtube.com/watch?v=gTAqGKt64WM



This allows the LED to be lit when its father away from the coil, because the voltage going to the LED is higher. It is now able to power DC devices.



Step 8: Extra Information

I have shown you the basics of transmitting power wirelessly over short distance. Now it's your turn to make your own and comment on how your made your Mat and what you used it to power.

-If you have access to a larger function generator you can use that in the same way we used here.

-Then you can also use the 555 timer, which can create the same kind of signal, but is a bit more complicated.

-So for all of the comments, here's some more info about about how this system functions.
With my size coils as seen in these pictures, based on how well you can tune the frequency, your looking at an efficiency range of about 70 to 85%. The led in the secondary coil, starts to fade when it is about 2 inches away from the primary. At about five inches, it is pretty well dark, but at four inches it is still a bit lit. If the coil is turned vertical, the led is dark. Please comment if you know why it is not bright when the receiving coil is vertical.

-Here's some variables that may change the outcome:

Wire gauge - 22

Amount of Wire - 40 feet

Capacitor value in primary and secondary - 0.02 uF

input voltage - around six volts; hint; i used a irf520 mosfet to amplify the power input from the function generator, which increase the secondary voltage tremendously. I'l post some pics soon.

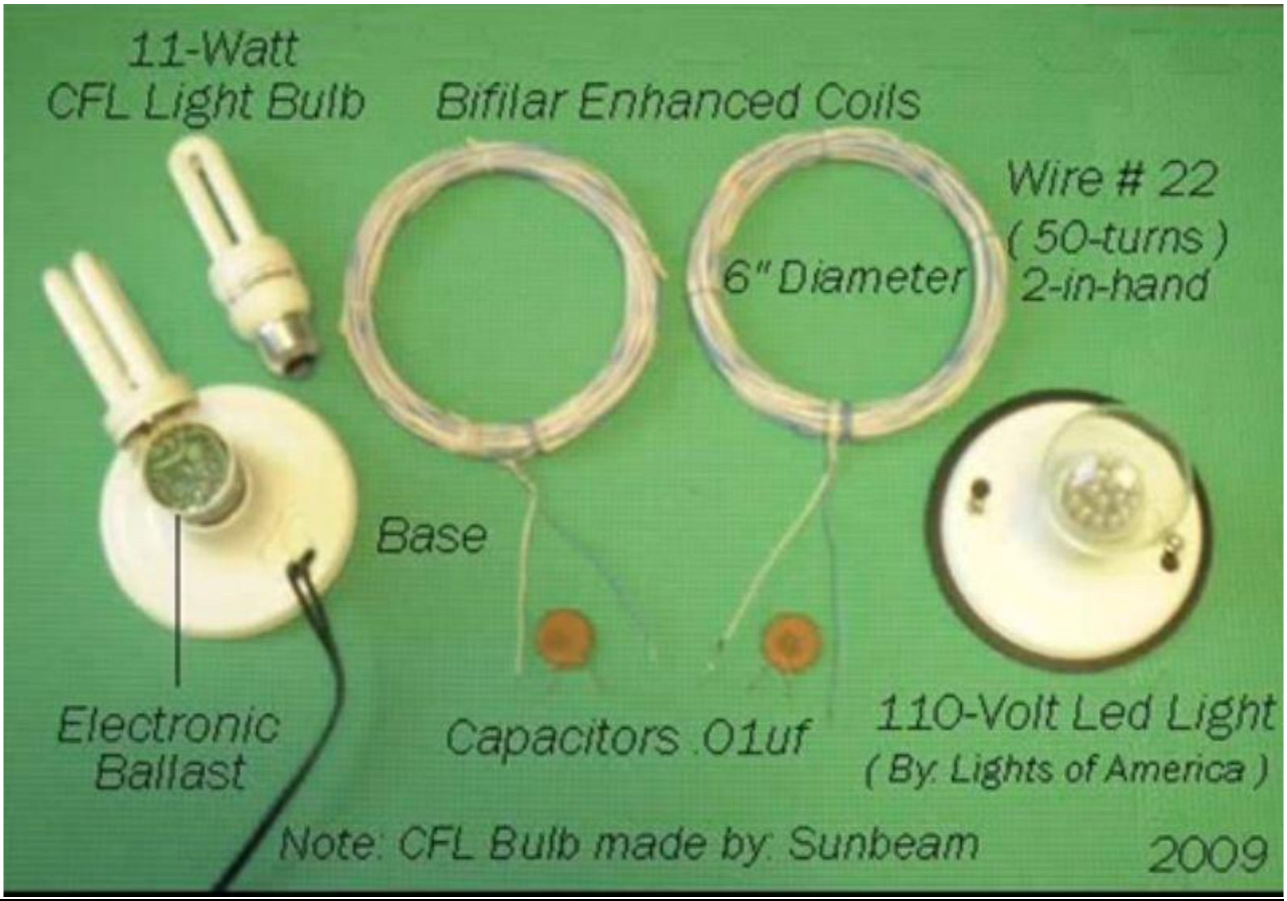
usage of secondary coil - a voltage meter should be used first to see if there is any voltage; then you can attach an LED. I've gotten 5v from the secondary with my circuit from a 6.3 input voltage to the primary

Step 9: List of Components
Plastic Project Box
http://www.radioshack.com/search/index.jsp?kwCatId=&kw=project%20box&origkw=project+box&sr=1
Function Generator
http://www.nuxie1.com/guides/fungen-v2-kit.html
Breadboard
IRF510 or IRF520 MOSFET
0.02µF capacitor x2

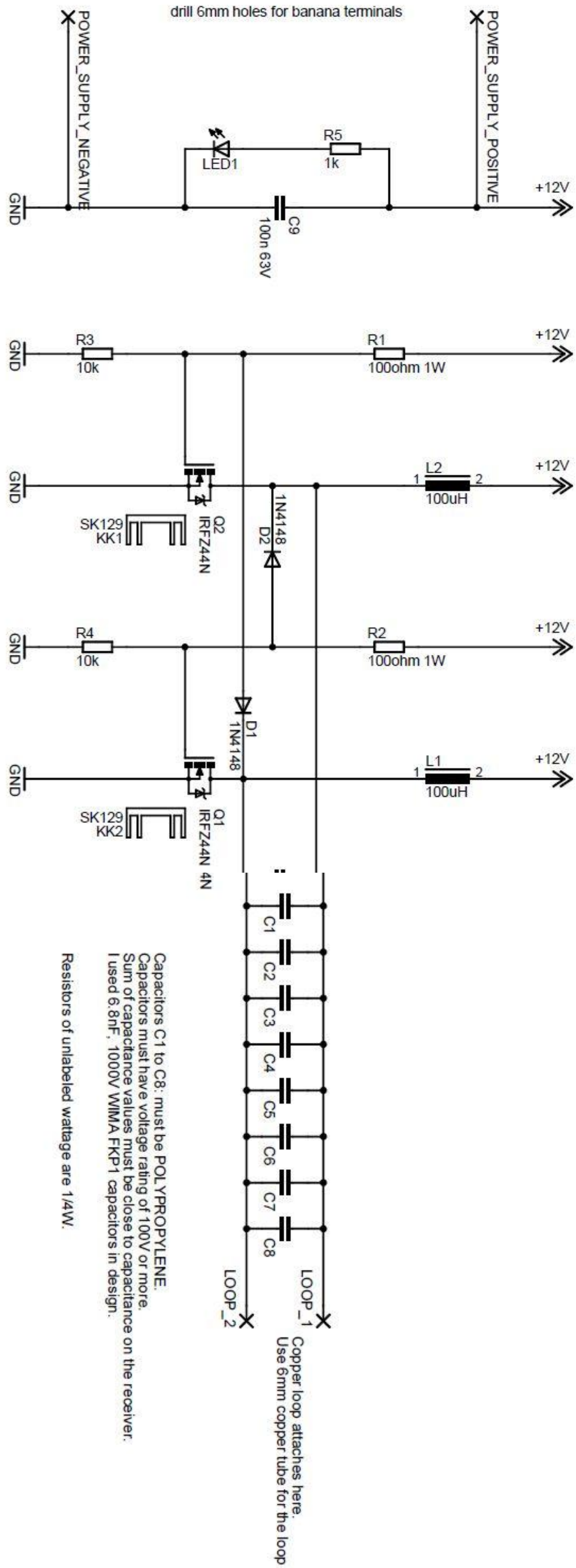
Magnet Wire (Gold for Primary, Red for Secondary)
http://www.radioshack.com/product/index.jsp?productId=2036277
L.E.D.
Wall Power Converter 9-18VDC

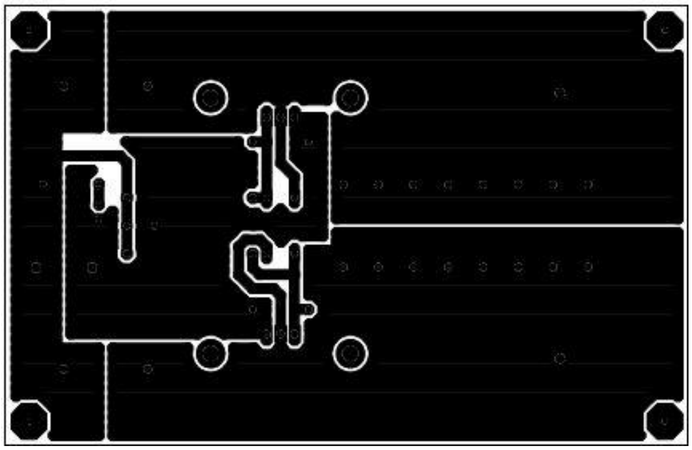
From link:
http://www.instructables.com/id/Wireless-Power-Transmission-Over-Short-Distances-U/?ALLSTEPS

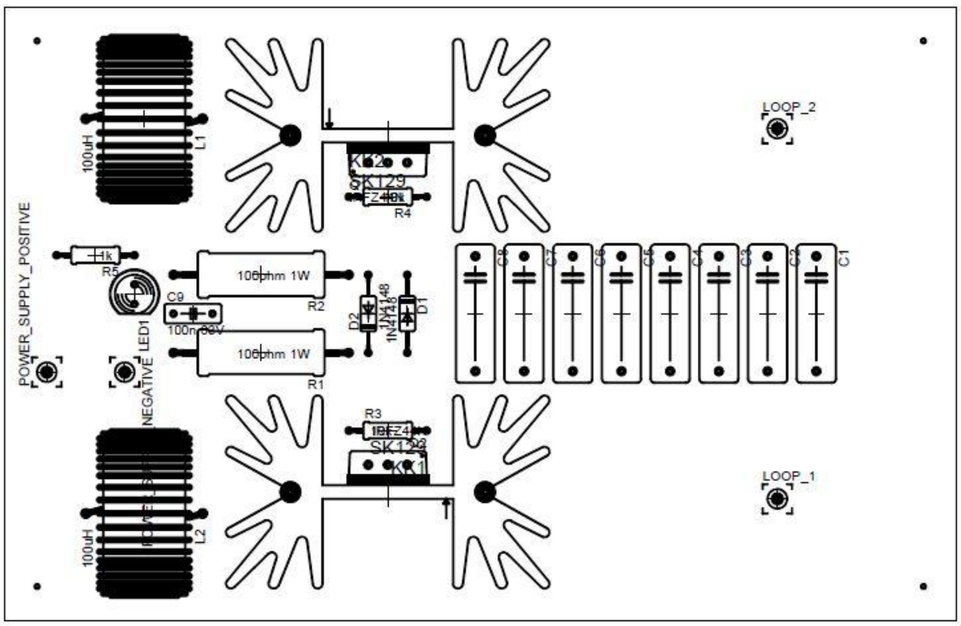
<u>Next Project</u>



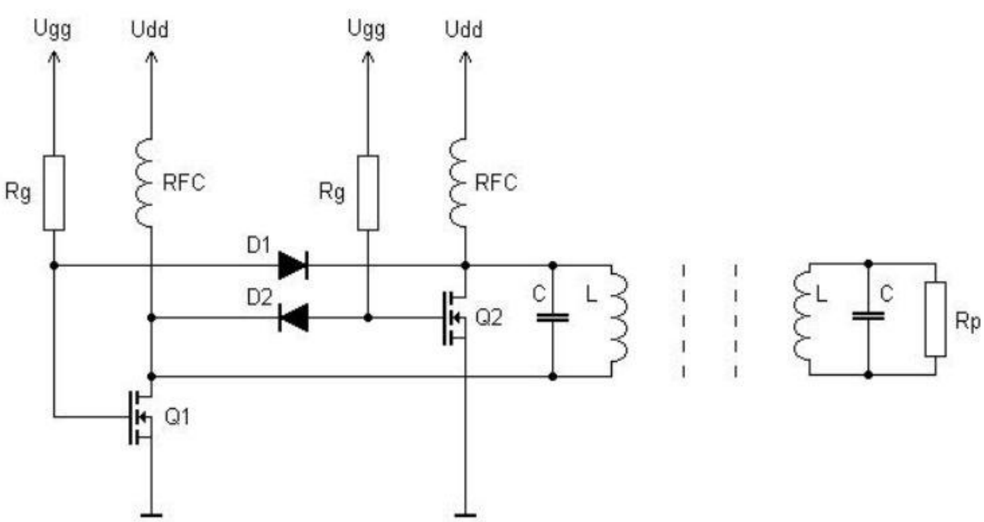
Next Project

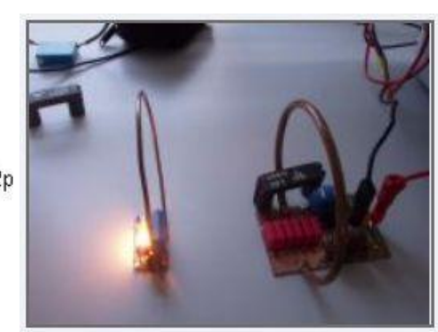


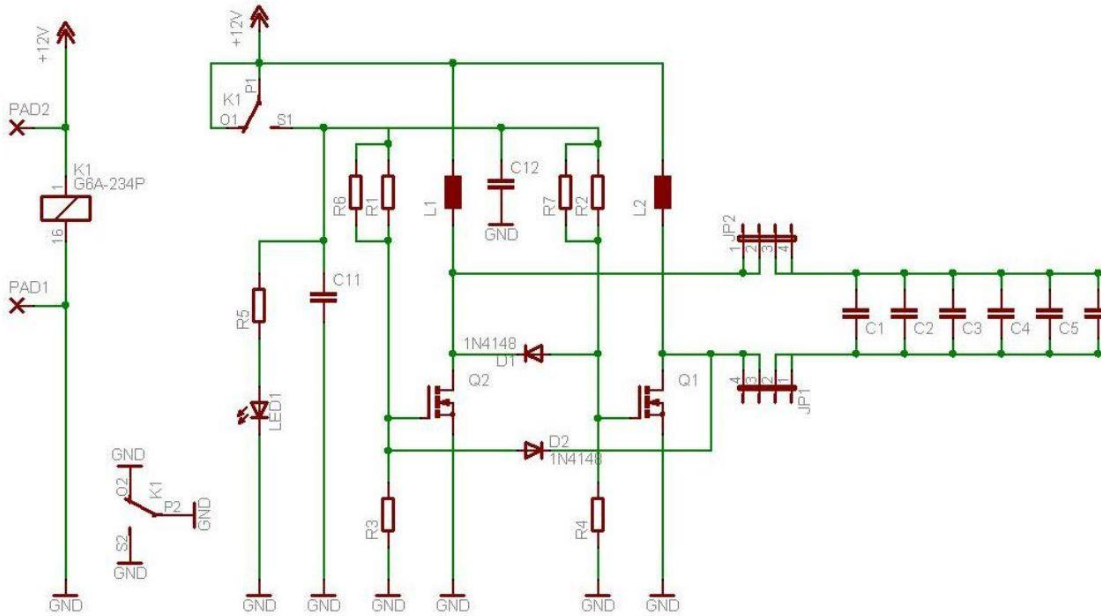




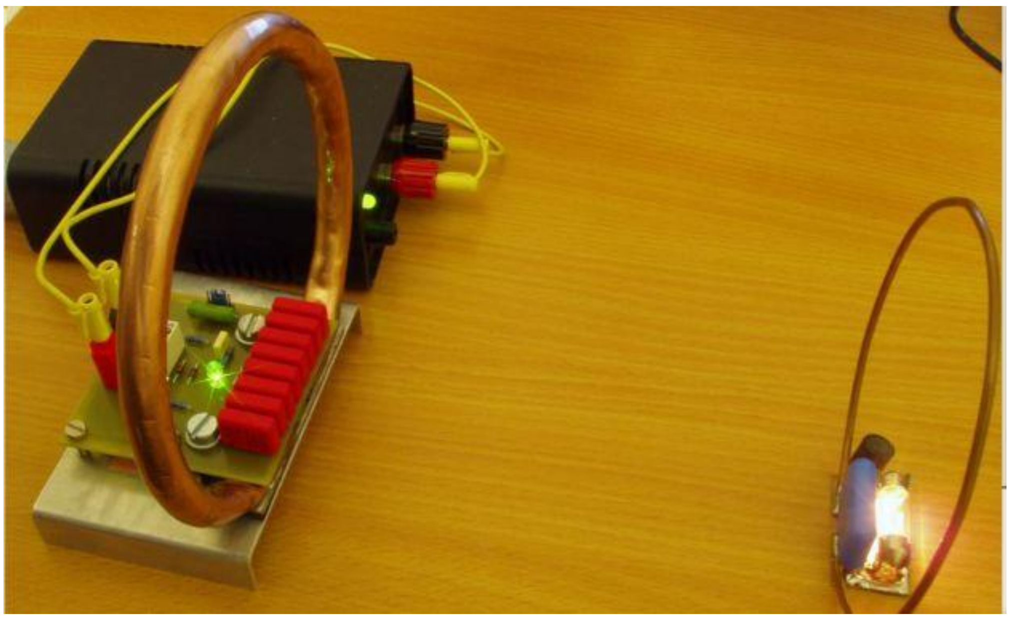
For the below image the schematic is on the right at base of page.







Schmatic and picture shown



Here is accompanying text for pages 6 and on:

20. 04. 2010 - update:

I added little FAQ summarizing the questions I've been most frequently asked about the project. I may update it with time and feel free to post a question you think might be suitable for me to add.

FAQ

- Are there kits or complete models available for sale?

Not yet as I'm currently unable to build any. I might make some this summer if I find increased interest, although I'm not promising anything as I have a number of hurdles to overcome regarding sales.

- I can't find the WIMA FKP capacitors like you used. Can I use ceramic/MKP/other type of capacitors available in my store?

No. Other types of capacitors, if they work at all are most likely going to be very lossy and overheat and melt in minutes.
Capacitors don't really even need to be WIMA brand, pretty much any polypropylene capacitors should work well.
This includes CDE942 caps generally used by tesla coilers here, as well as various brands of 'MKP' and similar caps. MKP is somewhat more lossy than FKP but worked fine in my first designs.

- I want to use the circuit to charge a mobile phone. Can I have schematics/plans?

I just don't have time to write about it now, and if you built the circuit I think it's straightforward enough for you to figure it out yourself.
Hint: a rectifier of suitable high speed diodes and a DC/DC converter chip.

- What is the diameter of transmitting and receiving loops?

Not sure why does everyone need to know this exactly, since I don't really remember the diameter I used myself. A larger loop is going to help transmit the power somewhat farther at cost of devices being about proportionally larger. Larger loop with same capacitor will result in lower resonant frequency.

- I can't find the copper tube and wire you used for the loops, what can I do?

Choice of the conductor used is really not critical as long as there is enough surface area to keep conductivity high and avoid overheating. A 6mm copper tube is OK for the transmitter and it should be easy to find in air conditioner stores. Receiver doesn't need to use wire, copper tube is fine

too. If you have a large amount of thinner wire you could make a litz conductor by twisting several of them in parallel. 15-20mm width of copper strip should also make excellent conductor for the purpose.
Having equal loops on both transmitter and receiver will make the tuning easier.

- The transmitter circuit does not oscillate, instead it shorts the power supply and one mosfet and inductor heat up rapidly, what to do?

Firstly, if you are using a version without the relay, this is a common problem, and is caused by power supply voltage rising too slowly on powerup. To fix make sure you use a switch on low voltage side, that is immediately between your power supply and the circuit, to turn the circuit ON.

If it'+s still happening, make sure:
1. that the mosfet that suffered the condition is still working
2. check for connections of your circuit, misplaced components, directions of the diodes...
3. The circuit won't run without the loop attached!

Hope this helps.

- The transmitter oscillates but I get very little power on the secondary side. What can I do to improve?

There are two problems (or two parts of a same problem, more precisely); tuning and load impedance match.

Firstly, we want both LC circuits to resonate at about the same stand-alone f0 - the best starting point is to make them both with identical loops and capacitances.

But, to achieve maximum power throughput, we will need to fine-tune the system, prefferably during runtime. This can be done by increasing or decreasing the stand-alone resonant frequency of either the receiver or the transmitter. Some of ways to acheive that are -

1. Changing the diameter of loops - may be difficult to impossible depending on the construction, probably easier on receiver. Should not be done on the transmitter while it's operating, and it's loop should be soldered down anyway.
2. Changing the tank capacitance.
3. Much more convenient to do while system is running - is to insert a large ferrite core (AM radio ferrite rod, or a TV flyback transformer core) into a loop which we want to decrease f0.
4. Alternatively, we can bring a copper or aluminium plate behind the targeted loop to do the opposite.

Secondly we want to match the load impedance to the best possible way to the "transmission line" we created with coupled LC circuits. Playing with the circuit you will notice that the "tuning" methods described above also work to match the system to different loads! There are some reasonable limits we need to follow with the load if we want best power throughput. We can't use unreasonably low (like a car headlight) nor unreasonably high load resistances (25W 230V incadescent bulb?).
I found a 24V 5W bulb to be a decent load, although I suspected 3x 12V/2W bulbs in series might have performed better.

- I want to supersize the circuit/increase the input voltage/transmit the power over a few meters?

None of those are really practical with this design. The best shot for increasing the power throughput would be to use a ferrite transformer between the active section and LC tank - I tried it and it works but at cost of even greater mosfet heatage... if you are already at this point then you probably already understand that this circuit sucks and have better ideas than it anyway.
Just increasing the voltage to the circuit as it is beyond 18V is most likely to cause it to blow up. And using higher voltage mosfets is actually just going to make the problem worse.

Transmitting power this way on a scale of meters with sub-metre sized devices at any reasonable efficiency is pretty much science fiction as of today.

- Have you been developing any new ideas on wireless power? When may we see updates?

Yes, but I'm keeping it top secret as of now. It's not going to be simple and I don't have time to explain it anyway. ANd builds are unlikely to start before this summer.

- I built the circuit, but I measured a different frequency at the transmitter than your 1.5Mhz. What is wrong with my circuit?

Nothing may be wrong, you might just have used a larger loop diameter or more capacitance than me. If parts are really closely matching mine, thenthere might be a problem. Some things to try:

1.Just try powering something if you have the receiver - if not build one from a piece of wire and a light bulb, capacitor isn't even required for proof of concept.
If you get any incadescence on the bulb then your circuit is working already! Just proceed to tune up the receiver then.

2. Look for the current drawn from the power supply. If it's less than 0.5A or more than 1A without load then something is wrong. It's recommended to use a current limited supply for initial tests.

3. Try measuring the LC tank voltage with an oscilloscope, not a frequency counter - this also has to show the peak voltage which has to be about pi*supply voltage (37V for 12V supply). Some precautions are required while doing this - the power supply must not have grounded " - " (like a PC power supply does) because placing an oscilloscope ground clip to one of 'hot' ends of LC tank will cause short circuit. In that case we need to measure with scope input set to DC input and measure between ground and one "hot end". This will yield a "halfwave rectified" waveform but the peak voltage value should remain the same.

New update 24. 8. 2009. :

I designed a new PCB with goal of ease of replication by newbies. Including schematic with explanations. Preliminary board, may be subject to change.

I also modified the old, prototype PCB (without the relay) a bit to make it more practical to use. All components are intended to be surface mounted on the copper side so there is no drilling involved.

****

A number of people has expressed interest into this project, and I decided it would be best to post it up here as a project thread.

The idea behind the project was to create a small tabletop demonstrator of magnetically coupled wireless power transfer, resembling a miniature version of the MIT 'witricity' device. The goal was to keep the circuit simple with easily obtainable parts, and to keep voltage and power levels low so the device is safe for handling and doesn't require special methods of cooling.

The basic idea is to feed a parallel LC tank circuit from an AC voltage source at it's resonant frequency, which allows large reactive current to circulate in the circuit while only real power is being drawn from the source. This sets up a large alternating magnetic field in the inductor, which is designed as a single conductive loop in this case.
Now, another LC tank with load attached is brought in proximity to the excited LC circuit, significant amounts of power can be transferred via weak magnetic coupling between them. This is because AC current itself in the transmitting loop is very large, and inductive reactance of the receiver loop is canceled out by the capacitor.

For a practical device, the AC voltage source had to be substituted with an appropriate oscillator, which would take feedback from the tank circuit itself and hence always drive it at it's resonant frequency.

The circuit of choice was a slightly modified royer oscillator, such as popularly used in CCFL inverters and for flyback drivers.
Input voltage was limited to 15V for safety and because the circuit tends to become unstable at higher voltages.

The idea of the prototype circuit is rather simple.

Mosfets I used were IRFZ44, but any similar ones will do. A small piece of Aluminum for a heatsink is recommended, although in prototype I just soldered the mosfets onto the PCB.

Rg were at first 50, but later increased to 100 ohms which is enough and wastes less power. Resistors need to be rated 1 watt at least and they get quite hot.

Radio frequency chokes were 100uH, at first iron powder cores, but later switched to ferrite which produced much better results.
Powdered iron cores tended to heat up from magnetic flux they picked up from the transmitting loopas well.

Diodes - 1N4148's. Similar small high-speed diodes are ok.

The LC tank circuit is the part where heavy current circulates, and is required to be sturdy. The copper pipe used as conductor heats up significantly under ~20A it's passing continuously. To handle the current while keeping losses tolerable, capacitor consists of 6 paralleled 6.8nF 1000V wima FKP1 capacitors. It's important that capacitors are polypropylene dielectric and foil or foil+film based - other types will heat up and melt in this application.
The transmitter still oscillated at relatively high frequency and had to be tuned by insertion of a ferrite core into the loop, as shown on the picture. This lowered the frequency to about 1.5Mhz without load.
Alternatively a copper or aluminum plate can be brought near the loop to increase frequency, by decreasing inductance.
Number of capacitors was later increased to 8, removing the need of additional tuning.

On the receiver side only a single capacitor and a loop of 3mm solid copper wire was used. The wire heats up significantly, though.
You can notice I used a small matching inductor in series with the load, which is a 24V 5W. It's choice was guessed at 6uH and it improved performance somewhat at larger distances.

This prototype, though, had one problem - if the supply voltage rose too slowly, such as while DC filter capacitance is charging, it tended to fail to oscillate and just keep shorting the power supply with one mosfet ON. In the final design this was solved with a relay, which acts as undervoltage lockout of sorts, applying Ugg power rapidly after supply voltage rose high enough.

Jumpers in the schematic are to allow connection of a step up autotransformer between the mosfet amplifiers and the LC tank circuit.

I provided the schematic of the finished circuit, but not the PCB since it's a fairly odd design with odd components (SMT inductors) which I thought might not be too useful for most people. PM me if the PCB layout is desired.

Peltziers

Peltier elements come in various forms and shapes. Typically, they consist of a larger amount (e.g. 127) of thermocouples arranged in rectangular form, and packaged between two thin ceramic plates. Multi-stage modules, to reach higher delta T values, are also available, but less common.

The commercial TEC unit of interest for PC geeks is a single stage device, about 4 - 6 mm thick and somewhere from 15 to 40 mm on a side.

The TEC will have two wires coming out of it, if a voltage is applied to those wires, then a temperature difference across the two sides is achieved, if the polarity is reversed on the wires - then the temperature difference is also reversed. The TEC is placed in between the CPU/GPU and the heatsink with appropriate thermal interface materials (thermal grease). So one thing we might note is that if the voltage is applied in the wrong direction then the TEC will cool your heatsink and heat your CPU!

Peltier elements come in padded and non-padded versions. On non-padded peltiers, the thermocouples are visible from the side. On padded peltier elements, you can only see the padding material (often silicon) from the side.

Instructables user scraptopower designed a thermoelectric lamp that can convert heat into small amounts of electricity. One of the best uses for this is building an LED lamp that runs from tea candles. Yes, candles generate usable light, but if you've ever tried reading by one of them you might appreciate a more powerful light source during a blackout or camping trip without having to worry about batteries. P

The thermoelectric lamp is an LED light powered by two individual devices, a Peltier cooler and a joule thief. A 100-watt peltier thermoelectric cooler is normally used to cool down computer processors, but in this application it is used with a copper/aluminum heatsink to generate electricity from the temperature difference between the heat generated by the candle and the cool surface of the heatsink. A joule thief is a circuit that boosts voltage from the power source—they are most popularly used in battery-operated cell phone boosters. The Peltier cooler generates small amounts electricity and the joule thief pulls a little more voltage than what would normally be supplied from the cooler to power the LED lamp.P

Following the guidelines on Instructables you'll spend around $50-60 in source materials for this project, which was wired so that it can also power other small items such as radios. The only actual electronics work is attaching your LED lights and joule thief to the Peltier cooler and this can be done without a soldering iron in a pinch. If you love the idea but have no desire to build one for yourself you can purchase a premade unit from Ubertechnics for $100.P

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3 The Peltier device

Peltier devices are named so because, typically, they are used as a heat pump based on the Peltier effect. In this case, a constant current, I_{el}, is driven through the Peltier device, and the Peltier effect generates a temperature difference, $\Delta T \propto P_{el} = \Pi I_{el}$.

3.1 n- and p-type Peltier elements

When a semiconductor is used as a thermoelectric material, its majority charge carriers (electrons or holes) determine the electrical behaviour. For example, when n- and p-type semiconductors are biased in the same direction, their charge carriers flow in opposite directions. As a result, n- and p-type Peltier elements create opposite temperature gradients (see Fig. 3).

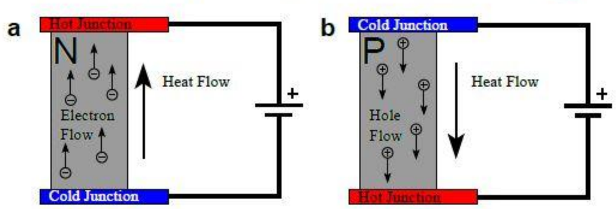

Figure 3: n-type versus p-type Peltier elements. a) An n-type semiconductor is biased externally creating an electrical current. The negative carriers (electrons) carry heat from bottom to top via the Peltier effect. b) The positive carriers (holes) within a p-type semiconductor–biased in the same direction as (a)–pump heat in the *opposite* direction, that is, from top to bottom.

3.3 Electrical power production

Though primarily used as heat pumps, Peltier devices nonetheless generate a thermovoltage, V_{th}, when subjected to a temperature gradient, ΔT. An electrical current, I will flow if the Peltier device is connected to a load resistor, R_{load}. In this case, the Peltier device converts heat energy to electrical energy quantified by the dissipated power, $P = IV_{load}$, where V_{load} is the voltage drop across the load resistor.

In the laboratory, P can be determined by measuring I and V_{load}. The Peltier device is not an ideal voltage source; therefore, its internal resistance, R_I, must be included in the analyses of power data. Furthermore, R_I is typically on the order of a few tens of Ohms. Therefore, the resistance of the ammeter, R_a, cannot be ignored.

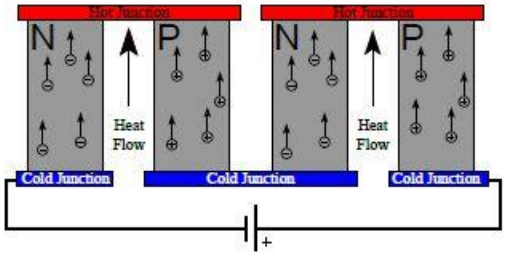

Figure 4: A series of alternating n- and p-type semiconductor elements, which pump heat from bottom to top when a voltage is applied.

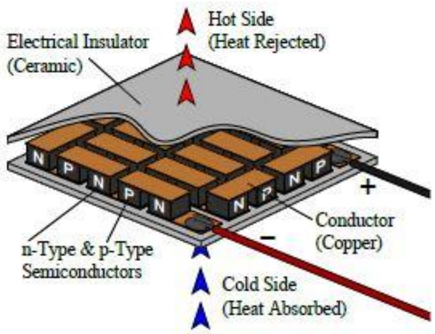

Figure 5: The design of a commercial Peltier device. Sandwiched between two ceramic insulators, alternating n- and p-type semiconductors elements are arranged across a plain and are connected in series electrically with copper junctions. When current is supplied to the Peltier device, heat is pumped from one surface to the other.

3.4 Thermal conductance

When current, I, flows through the Peltier device, heat flow $P_{el} = \Pi I$ generates a temperature difference, ΔT. In response, heat conducts from the hot to the cold side of the Peltier device given by $P_{th} = -\kappa \Delta T$. The electrical power dissipated in the Peltier device (that is, the Joule heat) is $P_J = RI^2$, where R is the resistance of the Peltier device. P_J flows into both sides of the Peltier device. Finally, heat P_{air} flows from the hot side to the surrounding environment. These heat flows are shown in Fig. 6.

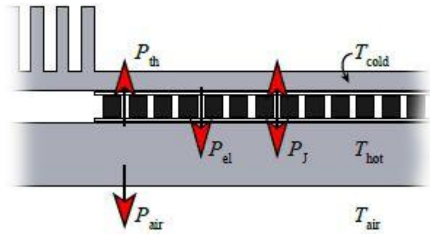

Figure 6: Heat flows in the Peltier device. Current, I, flowing through the Peltier device pumps heat $P_{el} = \Pi I$ and generates the temperature gradient, $\Delta T = T_{hot} - T_{cold}$. In the opposite direction as P_{el}, heat flux P_{th} conducts through the Peltier device from hot to cold. Joule heat, P_J, flows into both sides of the Peltier device. Heat P_{air} conducts from the heat block to the surrounding air at temperature T_{air}.

General Design Info

60. Are there any special safety concerns?

There are two areas of concern here. First, *never* power up a Peltier device unless at least one side is mounted to a *suitable* heat sink. By 'suitable', we mean one that can at least handle the wattage dissipated by the device—not some little sink made for a small transistor package (like a TO-220). A typical Peltier device may dissipate 60 W or more internally. How long can you hold a powered 60-watt incandescent bulb in your hand before it burns you? The hot side of a thermoelectric device can get even hotter—and faster—when it is not mounted to a proper sink. This is not just a safety issue, either—a device powered without proper sinking, can destroy itself very quickly.

The other safety concern is electrical. Although the electrical hazard potential associated with most thermoelectric systems is very small, there are some issues which deserve attention. Typically, Peltier devices are mounted to either aluminum or copper hardware (sinks, liquid heat exchangers, etc.). It is *possible*, therefore, for debris or moisture to create a short-circuit condition between the hardware and an electrically-live part of the Peltier device. It is up to the designer, therefore, to prevent such a problematic condition from occurring. From a safety standpoint, it is highly recommended that designers employ DC power which is fully-isolated and properly fused. The use of autotransformers or direct wiring to an AC service line is generally not recommended; if employed, a ground fault interrupter should be included in the design.

Be sure to use appropriately-rated wire in making connections, too. Thermoelectric devices can draw appreciable current and inadequately-sized wire may become very hot.

62. Can these devices be used for power generation?

Yes. The 'flip-side' of the Peltier effect is the *Seebeck effect*—when thermal energy moves through an electrically-conductive material, charge carriers are transported by the heat. Thus when you create a temperature difference across a thermoelectric device, the movement of heat and charge carriers creates an electrical pressure (called Seebeck voltage). If an electrical load is connected across the device, current will flow—if not, the pressure builds to a steady state condition and a 'no-load' voltage will be present. While a standard Peltier unit can be used in this fashion, if higher temperatures are involved, special thermoelectric modules are employed.

Because TE power generation devices are fairly inefficient in converting thermal energy to electricity, their use is largely confined to applications where 'waste heat' is readily available or in remote areas where dependability is more important than efficiency. In these types of situations, the power conversion process may be less than ideal, but the 'fuel' is free. Furthermore, because their small size makes it possible to mount them in tight spaces, they can be used to reclaim energy in places where it would otherwise be impractical. Potential users should be mindful, however, that a ΔT still must be created across the device—there has to be a 'cold' side as well as a source of heat—and this can present a challenge to designers.

In using power generation devices, one of the principle objectives will be to extract as much power as possible from the thermoelectric modules. Because power generation devices have significant internal resistance, designers who want to employ this technology should review the principles of *maximum power transfer* in electrical circuits. It is essential to grasp that maximum power will be transferred when the load resistance *equals* that of the TE device configuration. In the end, a designer must come up with a series/parallel array of modules that will assure generation of the desired voltage while coming as close as possible to a 'matched load' condition. It is also critical to design to the worst-case ΔT—and to make sure that T_{Hot} never exceeds the maximum rating for the device. Furthermore, if voltage regulation is important and the ΔT or load will be variable, a *shunt* regulator or DC-DC converter will be needed.

1. How does this technology work?

The basic concept behind thermoelectric (TE) technology is the *Peltier* effect—a phenomenon first discovered in the early 19th century. The Peltier effect occurs whenever electrical current flows through two dissimilar conductors. Depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. Explaining the Peltier effect and its operation in thermoelectric devices, is a very challenging proposition. It ultimately keys on some very complex physics at the sub-atomic level. Here we will attempt to approach it from a conceptual perspective with the goal of giving readers an intuitive grasp of this technology (i.e., without getting too bogged down in the minutiae).

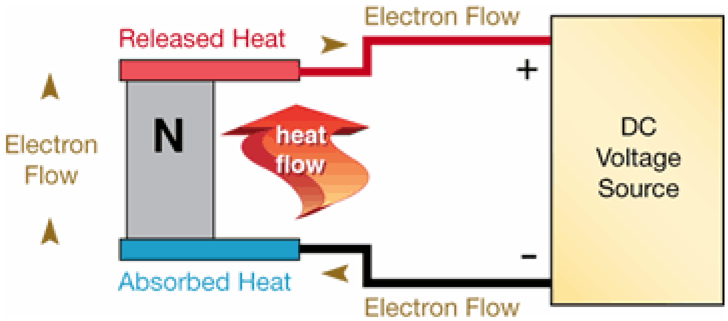

Figure 1

In the world of thermoelectric technology, semiconductors (usually Bismuth Telluride) are the material of choice for producing the Peltier effect—in part because they can be more easily optimized for pumping heat, but also because designers can control the type of charge carrier employed within the conductor (the importance of this will be explained later). Using this type of material, a *Peltier device* (i.e., thermoelectric module) can be constructed. In its simplest form, this may be done with a single semiconductor 'pellet' which is soldered to electrically-conductive material on each end (usually plated copper). In this 'stripped-down' configuration (see Figure 1), the second dissimilar material required for the Peltier effect, is actually the copper connection paths to the power supply.

It is important to note that the heat will be moved (or 'pumped') in the direction of charge carrier flow throughout the circuit—actually, it is the charge carriers that transfer the heat. In this example, 'N-type' semiconductor material is used to fabricate the pellet so that electrons will be the charge carrier within the molecular structure. With a DC voltage source connected as shown, electrons will be repelled by the negative pole and attracted by the positive pole of the supply; this forces electron flow in a clockwise direction (as shown in the drawing). With the electrons flowing through the N-type material from bottom to top, heat is absorbed at the bottom junction and actively transferred to the top junction—it is effectively pumped by the charge carriers through the semiconductor pellet.

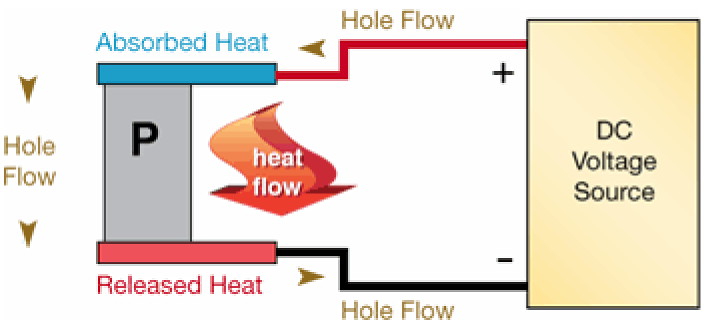

Figure 2

In the thermoelectric industry, 'P-type' semiconductor pellets are also employed. P-type pellets are manufactured so that the charge carriers in the material are positive (known in electronics as 'holes'). These 'holes' are places where electrons can easily fit when a voltage is applied and they enhance the electrical conductivity of the P-type crystaline structure. Positive charge carriers are repelled by the positive pole of the DC supply and attracted to the negative pole; thus 'hole' current flows in a direction opposite to that of electron flow. Because it is the charge *carriers* inherent in the material which convey the heat through the conductor, use of the P-type material results in heat being drawn toward the negative pole of the power supply and away from the positive pole. This contrasting heat-pumping action of P and N-type materials is very important in the design of practical TE devices (as will be explained in the next question). While the illustration here—for simplicity's sake—shows 'hole' flow through the connections to the power supply, in reality, electrons are the charge carriers through the copper pathways.

2. Why are two types of material (P and N) required?

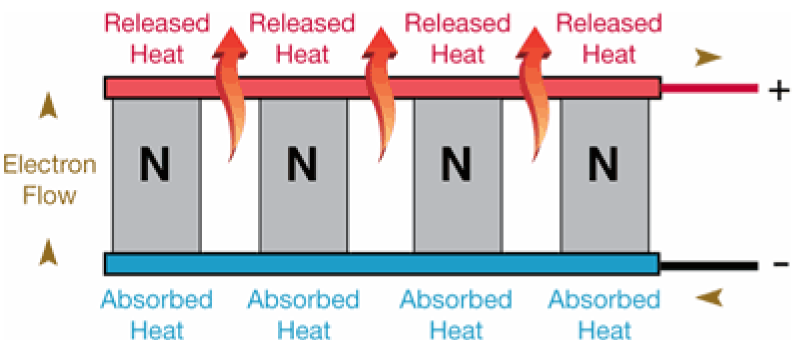

Figure 3

Unfortunately, while you can make a simple thermoelectric device with a single semiconductor pellet, you can't pump an appreciable amount of heat through it. In order to give a TE device greater heat-pumping capacity, multiple pellets are used together. Of course, the

initial temptation would be to simply connect them in parallel—both electrically and thermally—as shown in the *Figure 3*. While this is possible, it does not make for a very practical device. The 'fly in the ointment' here, is that the typical TE semiconductor pellet is rated for only a very small voltage—as little as tens of millivolts—while it can draw a substantial amount of current. For example, a single pellet in an ordinary TE device might draw five amps or more with only 60 mV applied; if wired in parallel in a typical 254-pellet configuration, the device would draw over 1270 amps with the application of that 60 mV (assuming that the power supply could deliver that much current).

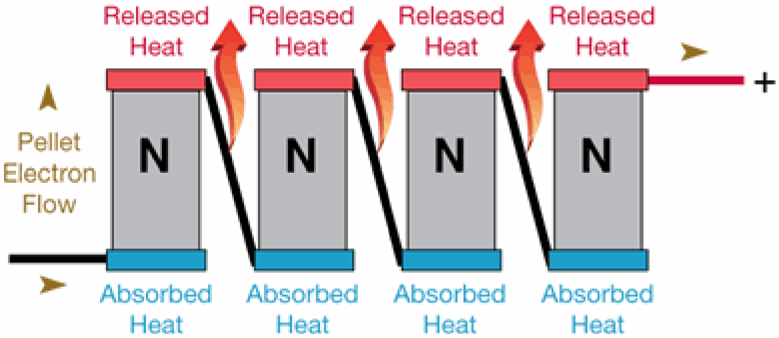

Figure 4

The only realistic solution is to wire the semi-conductors in series, and doing so in a way that keeps them *thermally in parallel* (i.e., pumping together in the same direction). Here, we might be tempted to simply zig zag the electrical connections from pellet to pellet (see Figure 4) to achieve a series circuit. This is theoretically workable, however, the interconnections between pellets introduce thermal shorting that significantly compromises the performance of the device. Fortunately, there is another option which gives us the desired electrical and thermal configuration while better optimizing the thermoelectric effect.

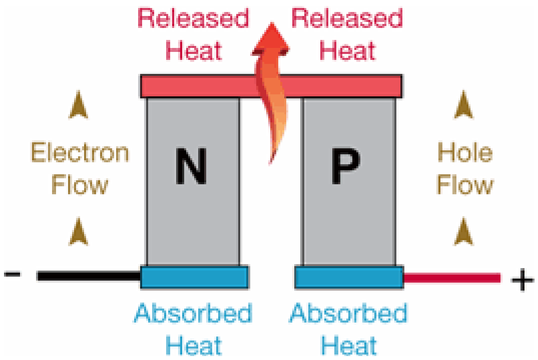

Figure 5

By arranging N and P-type pellets in a 'couple' (see *Figure 5*) and forming a junction between them with a plated copper tab, it is possible to configure a series circuit which can keep all of the heat moving in the same direction.

As shown in the illustration, with the free (bottom) end of the P-type pellet connected to the positive voltage potential and the free (bottom) end of the N-type pellet similarly connected to the negative side of the voltage, an interesting phenomenon takes place. The positive charge carriers (i.e, 'holes') in the P material are repelled by the positive voltage potential and attracted by the negative pole; the negative charge carriers (electrons) in the N material are likewise repelled by the negative potential and attracted by the positive pole of the voltage supply. In the copper tabs and wiring, electrons are the charge carriers; when these electrons reach the P material, they simply flow through the 'holes' within the crystalline structure of the P-type pellet (remember, it is the charge *carriers* inherent in the material structure which dictate the direction of heat flow). Thus the electrons flow continuously from the negative pole of the voltage supply, through the N pellet, through the copper tab junction, through the P pellet, and back to the positive pole of the supply—yet because we are using the two different types of semiconductor material, the charge *carriers* and heat are all flowing in the same direction through the pellets (bottom to top in the drawing). Using these special properties of the TE 'couple', it is possible to team many pellets together in rectangular arrays to create practical thermoelectric modules (see *Figure 6*). These devices can not only pump appreciable amounts of heat, but with their series electrical connection, are suitable for commonly-available DC power supplies. Thus the most common TE devices now in use—connecting 254 alternating P and N-type pellets—can run from a 12 to 16 VDC supply and draw only 4 to 5 amps (rather than 1270 amps at 60 mV, for example).

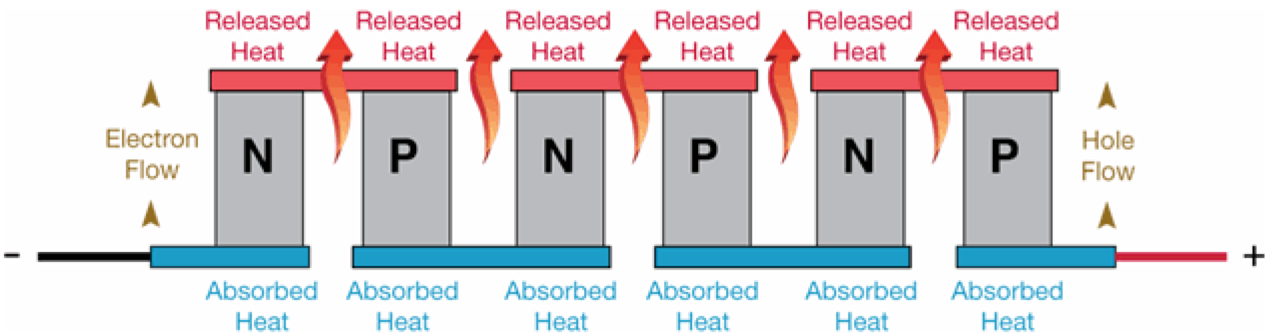

Figure 6

Of course, in fabricating devices with multi-pellet arrays, you must have a means to mechanically hold everything together. A solution is to mount the conductive tabs to thin ceramic substrates (as shown Figure 7); the outer faces of the ceramics are then used as the thermal interface between the Peltier device and the 'outside world'. Note that ceramic materials have become the industry standard for this purpose because they represent the best compromise between mechanical strength, electrical resistivity, thermal conductivity, and cost.

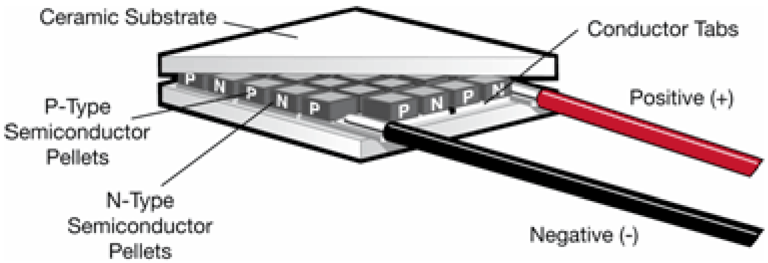

Figure 7

3. Do these P and N couples function like diodes?

No. It is easy to see why many people expect couples to operate like diodes, given the pairing of P and N materials, but there is a crucial difference. In the manufacturing of diodes, a depletion region is created between the immediately adjacent P and N layers. When the diode is forward-biased, charge carriers are drawn into the depletion region and the diode becomes conductive; when reverse-biased, charge carriers are drawn away from the depletion region and the diode acts like an open circuit. Without a depletion region, a TE couple cannot act like a diode; the couple will conduct in both electrical polarities and there is no fixed voltage drop across the couple (unlike the nominal 0.6 to 0.7 VDC typically dropped across a forward-biased silicon diode).

4. How is a typical thermoelectric (TE) system configured?

Let's look conceptually at a typical thermoelectric system designed to cool air in an enclosure (e.g., picnic box, equipment enclosure, etc.); this is probably the most common type of TE application. Here the challenge is to 'gather' heat from the inside of the box, pump it to a heat exchanger on the outside of the box, and release the collected heat into the ambient air. Usually, this is done by employing two heat sink/fan combinations in conjunction with one or more Peltier devices. The smaller of the heat sinks is used on the inside of the enclosure; cooled to a temperature below that of the air in the box, the sink picks up heat as the air circulates between the fins. In the simplest case, the Peltier device is mounted between this 'cold side' sink and a larger sink on the 'hot side' of the system. As direct current passes through the thermoelectric device, it actively pumps heat from the cold side sink to the one on the hot side. The fan on the hot side then circulates ambient air between the sink's fins to absorb some of the collected heat. Note that the heat dissipated on the hot side not only includes what is pumped from the box, but also the heat produced within the Peltier device itself (V_{TE} x I_{TE}).

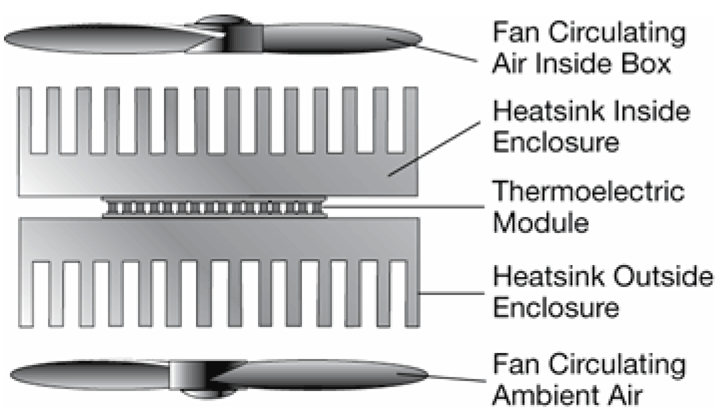

Figure 8: Conceptual Drawing of Air-to-Air Thermoelectric Cooling System

Let's look at this in terms of real numbers. Imagine that we have to pump 25 watts from a box to bring its temperature to 3°C (37.4°F). The ambient environment is at 20°C (68°F). To accomplish this, we may have to take the temperature of the cold side sink down to 0° C (32°F) so it can absorb sufficient heat from the air. Let's assume that this requires a Peltier device which draws 4.1 amps at 10.4 V. The hot side of the system will then have to dissipate the 25 watts from the thermal load plus the 42.6 watts it takes to power the TE module (for a total of 67.6 watts). Employing a hot side sink and fan with an effective thermal resistance of 0.148 C°/W (0.266F°/W), the temperature of the hot side sink will rise approximately 10°C (18°F) above ambient (67.6 w X 0.148 C°/W). It should be noted that, to achieve the 17° C drop (30.6°F) between the box temperature and ambient, we had to create a 30° C (54°F) temperature difference across the Peltier device.

5. Can thermoelectric systems be used for heating, as well?

Yes. One of the benefits of TE technology is that you can switch the direction of heat pumping by simply reversing the polarity of the applied voltage—you get heating with one polarity, cooling with the other. Thermoelectric modules make very efficient heaters—in fact, because of the unique properties of Peltier devices, any given TE system will have a greater capacity for heating a load than cooling it.

6. Are TE systems used only for heating or cooling air?

No. Systems are often designed for pumping heat from both liquids and solids. In the case of solids, they are usually mounted right on the TE device; liquids typically circulate through a heat exchanger (usually fabricated from an aluminum or copper block) which is attached to the Peltier unit. Occasionally, circulating liquids are also used on the hot side of TE cooling systems to effectively dissipate all of the heat (i.e., a liquid-to-liquid system). Note that liquid cooling is *never* achieved by *immersing* the Peltier device in the fluid—thermoelectric modules are *not* the equivalent of 'electric ice cubes'.

7. Do I have to use a heat sink in my design?

Whether heating or cooling a thermal load, you must employ some form of heat sink to either collect heat (in heating mode) or dissipate collected heat into another medium (e.g., air, water, etc.). Without such provisions, the TE device will be vulnerable to overheating; once it reaches the reflow temperature of the solder employed, the unit will be destroyed. When the heat sink is exchanging heat with air, a fan is usually required, as well, to minimize the size of the sink required.

8. Can these devices be immersed?

Only for cleaning purposes and never while under power. TE devices should always be dry when under use to prevent thermal and electrical shorting.

9. What type of products currently use this technology?

There are an increasing number and variety of products which use thermoelectric technology—from picnic boxes to water coolers, food service equipment, laser applications, and highly-specialized instrumentation & testing equipment. The compatibility of many TE's with automotive voltages, makes them especially suitable for small cooling jobs in that industry. With each new year, the imaginations of design engineers widen with the immense possibilities of thermoelectric cooling and heating.

10. Why would I want to use a thermo-electric system instead of compressor-based technology?

Both technologies have their advantages and disadvantages, but where thermoelectric technology really shines, is in making it feasible to do very small cooling jobs—ones which would be wholly impractical with a compressor-based system. Can you imagine cooling an individual integrated circuit with compressed gasses? What about thermally cycling a test tube or cooling a very small enclosure? TE's are also strong in products which demand both heating and cooling in the face of a changing operating environment; here a simple switching of TE current polarity allows the system to shift to the mode required. In addition, unlike compressor technology, TE system components can be mounted in any physical orientation and still function properly. Of course, one other advantage of TE systems, is that they do not require evaporative chemicals which may be harmful to the environment. Thermoelectric devices open up a whole new world to cooling and heating possibilities.

11. Are there situations where compressor-based systems make more sense?

Yes. Generally, whenever a small compressor-based system would clearly be 'overkill' in providing a cooling solution, TE systems become the most viable choice. You find a 'gray area' amidst the medium-sized cooling jobs; here decisions ultimately come down to critical cost/benefit or design engineering considerations which are unique to each application. Given the present state of technology—unless there are unique overriding concerns—the compressor-based approach has distinct advantages in larger cooling systems such as standard-sized refrigerators and air-conditioning systems for buildings & vehicles. However, ongoing research into materials may one day make thermoelectrics practical for many of these larger applications.

12. For heat-only applications, do thermo-electric devices have advantages over resistive heaters?

Yes, but... Resistive devices create heat solely by virtue of the power dissipated within them. TE devices, on the other hand, not only provide this I^2R heating, but also actively pump heat into the thermal load; this, potentially, makes them much more efficient than resistive heaters. Unfortunately, the need for a DC power source and the generally higher cost of TE systems compared to resistive heaters, precludes their use in most heat-only applications. Furthermore, Peltier devices have a far more limited temperature range than most resistive heaters. Generally, TE devices are only used for heating in systems that also require cooling or where efficiency is extremely important.

13. Why would I want to use thermoelectric technology instead of a passive cooling system (heat sink and fan alone)?

With passive cooling, at best, you can only *limit the rise* of temperature above the ambient condition. On the other hand, TE systems (like compressor-based approaches) can *actively* pull heat right out of a thermal load; this makes it possible to reach *below-ambient* temperatures.

14. How cold can these devices get?

That depends upon a great many things—ambient temperature, the nature of the thermal load, optimization of current delivery to the TE device, optimization of heat sinks etc. It is *theoretically* possible to get a ΔT (hot side to cold side) of around 75° C working against a T_{Hot} of 35° C (note that this is the temperature drop across the TE device, itself, and does not include system losses such as the hot side's temperature rise above ambient). However, this theoretical maximum only occurs if there is *no* thermal load—which is not going to happen in a 'real' system. In a typical application, you will achieve about half of the theoretical maximum using a single-stage TE device. In order to reach colder temperatures, a multi-stage approach must be employed, either by using multi-tiered Peltier devices, or by using other technologies to create part of the desired ΔT. For example, you might use a compressor-based system to provide a below-ambient condition for the hot-side of a TE device, then employ Peltier cooling to further reduce the temperature of your load—this is sometimes done to get down into cryogenic levels. It should be noted, however, that TE devices become less efficient at colder temperatures and the ratings for ΔT will be markedly reduced when you operate under extremely cold conditions. Furthermore, even though multi-stage Peltier devices can achieve greater ΔT's, they have much less cooling capacity (in terms of watts pumped) than their single-stage counterparts and are far more expensive to produce.

15. Can I physically stack TE devices to get a greater ΔT?

Yes... but it is not so simple as merely stacking two identical Peltier devices, one on top of the other. The critical reality here is that the second device must not only pump the heat from the thermal load plus its own internal power dissipation (I^2R), but it also must remove the heat dissipated within the first TE device. It is usually most sensible from a cost standpoint, therefore, to employ a much smaller device on the first stage than the second. Be aware in stacking modules, however, that the overall heat-pumping capacity (in watts) of the stack will be limited to the throughput of the *smallest* device (while ΔT is enhanced with multi-staging, Q is sacrificed).

16. How hot can these devices get?

This is purely a function of the melting temperature of the solder employed in manufacturing the device. Our standard Peltier devices are rated for 100°C on the hot side. It is very important that users keep temperatures below that rating; if the solder reflows, the device will be compromised or destroyed.

17. Can these devices be used at cryogenic temperatures?

Yes, but they are far less efficient in this range. Note that you *cannot* achieve cryogenic temperatures from a single-stage Peltier device working against a typical room temperature ambient.

18. Does Z_{MAX}® offer any performance advantages over other thermoelectric technologies?

Definitely! The patented Z_{MAX}® technology offers performance which is unachievable with the more conventional processes employed by other manufacturers.

19. How big can these devices get?

Theoretically, there is no limit, but practicality does impose some restrictions. Issues related to thermal expansion/contraction—and cost—tend to keep module sizes down. Typical devices range up to 50 mm (2") square and about 4 mm thick, but there are exceptions. In the general case, when greater cooling capacity is required, multiple TE devices will be employed rather than fabricating some sort of gargantuan module.

20. How small can these devices get?

Here again, the theoretical limit goes far beyond what is practical. Devices are commonly manufactured at sizes well below 8 mm square, many for such applications as laser diode cooling. Very small modules, however, are more expensive to produce because they are less suitable for automated processing—many of them, in fact, require manual attention under a microscope. As a result, in creating designs for very small cooling jobs, devices must be carefully optimized for cost as well as size and capacity.

21. Is it possible to purchase custom devices?

Yes, but the expense for new tooling (if it is necessary) or special handling will be included in the overall price. Whenever possible, it is generally more cost-effective to employ a stock item. To explore the possibilities, contact a Tellurex sales representative at 231-947-0110 or sales@tellurex.com.

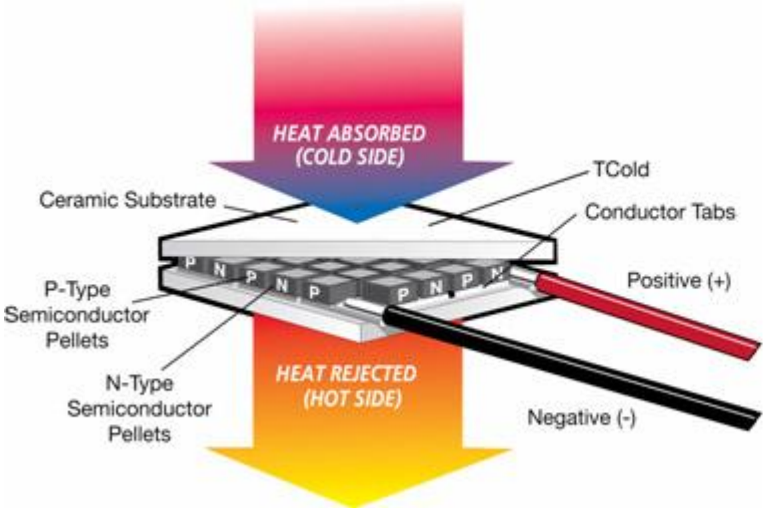

Figure 9

22. What does the specification, T_{Cold}, mean?

This is the temperature at the cold-side mounting surface of the Peltier device (see *Figure 9*).

23. What does the specification, T_{Hot}, mean?

This is the temperature at the hot-side mounting surface of the Peltier device.

24. How can I measure T_{Hot} or T_{Cold} in a thermoelectric assembly?

This is somewhat challenging because you have to get the measuring device as close as possible to the outer ceramic of the Peltier device while it is in operation. The best choice of sensor here is typically a non-sheathed thermocouple fabricated from fairly fine wire. One way to approach the placement of the thermocouple, is to take the heat sink or block which will be mounted to the TE device and cut a shallow groove at the interface. The thermocouple wire can then be placed so that it will be in close proximity to the module's center once the system is assembled. Of course, except for the exposed end of the thermocouple, the wires should be electrically insulated along the length of the groove to prevent shorting. The thermocouple should be potted into the groove using a thermally-conductive adhesive; be sure to clean off any burrs or excess adhesive to maintain the flatness of the interface.

A compromise which can sometimes be employed when using heat sinks, is to mount the thermocouple on the fin side of the sink (at the base), opposite the center of the TE module. The thermocouple should then be covered with a small piece of insulating foam. Some accuracy will be lost with this method because of the inevitable thermal gradient between the thermocouple and module surface, but it can yield an acceptable approximation. The insulating foam is critical or air movement will significantly affect the reading.

Some people have attempted to mount fine thermocouples on the inside of Peltier devices to measure these parameters, but this is generally not a good idea. First of all, it would be difficult to successfully mount a thermocouple on an interior surface and there would be significant potential for damaging the device in the mechanical manipulation. Also, without any form of insulation on the inside, the thermocouple would actually pick up a thermal gradient between the ceramic surface and the air temperature inside the device. Other thermal gradients within the module could also effect the accuracy of the reading. If a data acquisition system is employed to measure system variables, there would also be a potential for introducing a ground loop if the thermocouple touches anything which is electrically live.

54. Are there any special considerations which apply to 'clamping' the device?

Although spring compression systems are sometimes used on OEM products, generally, machine screws are employed to compress the Peltier device between the hot and cold sides. Because thermoelectric devices can be crushed through improper handling, some care must be taken in designing and implementing the clamping method. For optimal results, try to use only two compression points per module (if possible) and keep them in close proximity to the device (usually within 0.25"). Naturally, the two compression points should be along the center line of the module. In bringing up tension on the machine screws, take extra care to adjust *slowly* at each compression point and alternate between the two frequently; in this way compression across the surface area of the module can be roughly equalized throughout the adjustment process. A common error is to tighten one side so that it tips below the top surface of the module (*Figure 13*); then when pressure is increased on the opposite side, it creates leverage which crushes the module (*Figure 14*). The greater the number of compression points or their distance from the module, the greater the likelihood of damaging the module in this manner. Patience is definitely a virtue here.

With multiple device deployment, it is not always possible to use two screws per device, and sometimes the space between the compression points will span more than one module. Here, the user must watch out for bowing of the mechanical interface; this can not only damage the Peltier devices, but compromise the thermal interface, as well. In these instances, it is usually best to decrease the amount of compression to insure flatness.

55. Where do I start in designing a TE system?

If you are doing a heat/cool application, focus first on the cooling side of the equation; if you have enough capacity for cooling, you should have plenty for heating. Establish some initial design parameters. What load temperature do you want? What is your worst-case ambient (always design against the worst case)? What is the targeted temperature rise for your hot side above the ambient? Do you have constraints on available power for your system? If so, what are they? What physical limitations do you face (space, weight, harshness of environment, etc.)? Are there sources of radiant heat in the environment?

Probably the most challenging area in design, is coming to terms with your load. Thermal load is made up of two distinct components—active and passive. The active load is the part which actually creates heat. For instance, if your thermal load is an electrical circuit, its power dissipation would be the active load. In some cases, there will be no active load—this is the situation with a picnic box, for example.

Much of the load in any TE system will be passive. Passive load is the amount of heat (in watts) which must be pumped to maintain the temperature difference between the load and the ambient environment. It is like bailing out a leaky boat; water (like heat) is continually coming in and you must labor to pour out a comparable volume to maintain the level of the boat. The greater the ΔT you require between your load and the ambient, the greater the passive load will be.

Once you know all of these quantities, you can begin looking for a thermoelectric solution which conforms to your requirements.

Success!!