DESIGN & BUILD YOUR OWN

ARC WELDER

from salvaged microwave oven parts

(and other parts never intended)

Build your own Arc Welder

Dedication

To home shop enthusiasts,

scientists, students, teachers,

professors, and inventors at large,

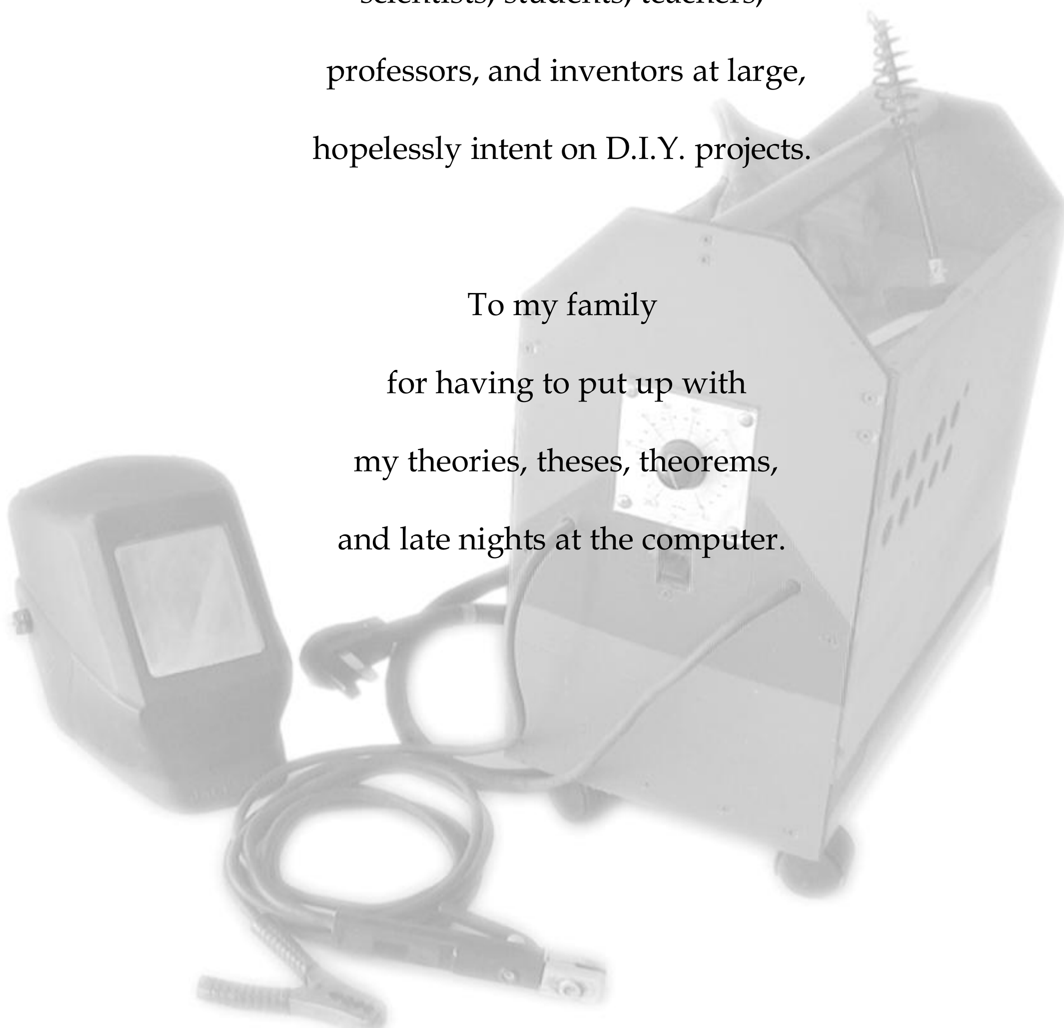
hopelessly intent on D.I.Y. projects.

To my family

for having to put up with

my theories, theses, theorems,

and late nights at the computer.



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and not to use

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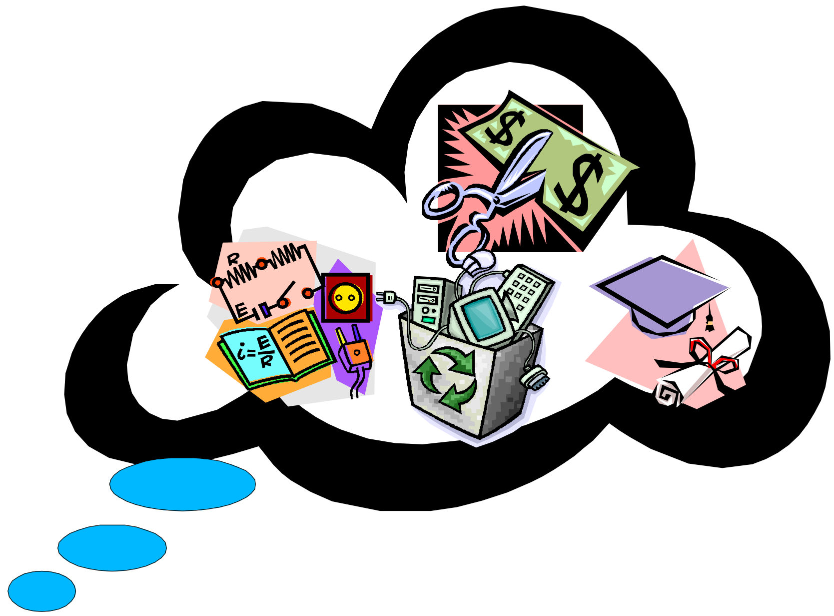
That said, please do indeed read, understand, print out, and enjoy this book and project of building your own arc welder!

About building welders



So why build a welder?

Here are a few good reasons:

- **Save money**
- **High school shop project**
- **Learn about electronics**
- **Recycling (save the earth!)**
- **Need a useful tool**

But that's not all. Most of us have a natural instinct for tinkering. Some of us collect junk. We just can't bring ourselves to see 'perfectly good' stuff going to waste. And we take great pleasure in the process of building something (I refer to this sometimes as "joy in the journey"), especially if it's out of materials we salvaged and saved from the landfill.

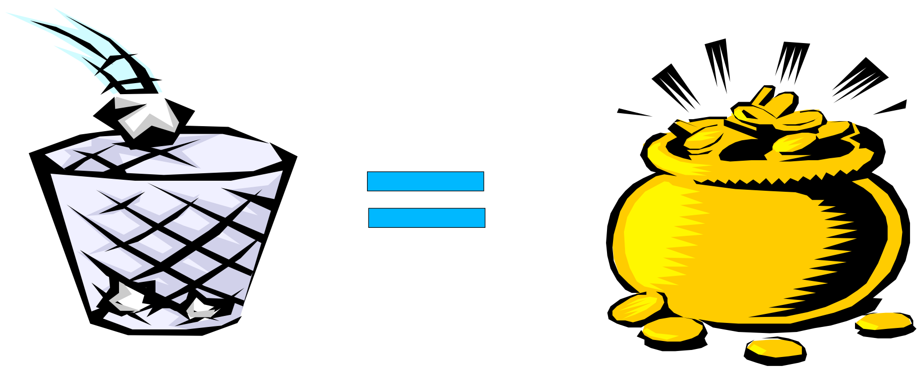
If you see yourself in this list of qualities, then you understand why anyone would want to build something like a welder. You are probably also the type that wants a welder, so that you can WELD THINGS. You want control over the output of your workshop, and anyone can go out and buy a welder, but the one YOU built is made the way YOU wanted it.

Okay, enough stroking of the ego. Really, building your own welder is a practical thing to do. From start to finish it is really quite straightforward, and the unit you end up with will be dependable for years of service. I built mine five years ago (before the time of this writing). Some other good reasons for building a welder:

Building from salvaged parts

Did you ever take apart things as a child? Your mother's alarm clock, your dad's camera, or your bike? It sure was interesting finding out how it worked wasn't it? Well, this plan will take you on a similar odyssey, taking scrapped household appliances and extracting useful parts and materials from them, and transforming them (pun intended) into a working AC arc welder.

Turning junk into treasure



There are some things to consider when building from salvaged parts. While this is certainly not rocket science, it does require a degree of careful thought and planning. Building working machinery from the guts of other machinery is NOT like building those Heathkit ham radio circuits that were popular back in the 70's. The electronics kits had neat little bags of parts, all well-labeled. Everything was laid out very neatly and the instructions were to be followed verbatim.

Not an ordinary design

These instructions are NOT intended to be followed verbatim. Component values and part numbers are not etched in stone (or steel for that matter). What I want you to understand are the concepts that are basic to the working of the arc welder; once these concepts are mastered, you can make your own adjustments to the plan to fit the particular set of components that you find available.

The purpose of this book is to illustrate and explain what makes a welding power supply work, and how microwave oven transformers can be salvaged from their existing environment, modified, and adapted to welder use. The same principles can be applied to taking most any transformer such as a battery charger transformer, and adapting it to welder applications.

You might wish that I take a shortcut and just lay out the plans like a Heathkit kits, those electronics kits that were popular back in the 1970's. But after more than 5 years worth of email on the subject, I think better of it. Many of you will want to customize your home built welder to a specific application, or just have different ideas about how a welder should be built, and that is just fine. You can make a very simple welder that works with one type of steel and one size rod, or you can make a more sophisticated one that uses a solid state circuit for heat control. Or something in between. It's up to you.

And that's why the home built welder is not an ordinary design. You can take an extra degree of satisfaction in the accomplishment of building a welder because you educated yourself on the details of what makes a welder work, and then you applied your knowledge successfully. You will learn things in the process that can be useful in other projects as well.

Reading schematics

One thing that you can count on in this book is the notation of the electrical schematics. It is very standard and ordinary, and follows the basic rules of schematic drafting.

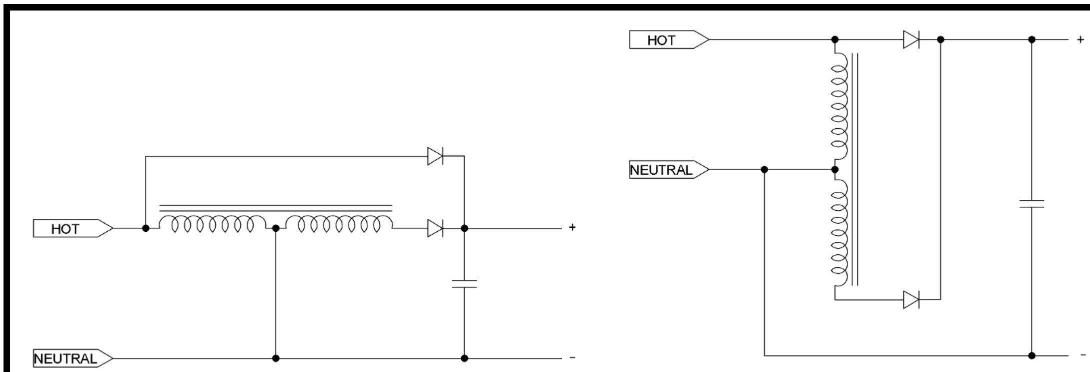


Figure 1: These two rectifier schematics are identical, even though at first glance they appear very different. (Note: These are not complete welder schematics. Full schematics are in later chapters.)

However, there is something about reading electrical schematics that you need to know. There are electrical schematics in this book. Schematics can be confusing. Physical connections from here to there may be made in a way that is identical to the schematic, but doesn't appear to be according to the schematic at all. Or, a two schematics may be identical, but appear totally different.

At any rate, you need to carefully look over the schematic and understand what is connected to where, and what is not. On paper, errors in connecting diodes to transformers to line current is no big deal. But if you connect it wrong in real life, you have fireworks! Make sure that your connections are correct before applying power. Establish in your mind where the power goes when there's power.

I've done my best to draw the schematics in a logical and easy to read and understand way. A bit later in the book I'll address a frequently asked question about a schematic that asks, “where does the power come from?” The answer is pretty simple, but in spite of my best efforts, it is not readily evident from the schematic.

Getting the parts

Parts checklist

Here's a partial checklist to get you started (this list is perhaps the most entertaining part of this book):

___ 10 or 15 microwave ovens, in almost any condition (newspaper ad)
___ 30 or 50 amp 240v "pigtail" (can often be salvaged)
___ 30 or 50 amp 240v receptacle to match above item
___ Wire, conduit, etc to wire up a 240v circuit (skip if you're making a 120v welder)
___ Breaker for your circuit panel to match circuit wire (call electrician if in doubt)
___ Plywood scrap to build case OR metal cabinet such as computer case
___ Wire for modified secondaries (see chapter "Modifying Transformers")
___ Electrical connectors (different types depending on size of welder)
___ Cheap spray paint (looks better than bare wood)
___ Small quantity of #18 telephone wire for making connections in solid state controller.
___ Large SCR's (can be gotten cheap on eBay) like the IRKT71 and IRKT91
___ Casters (scavenged from an old office chair) for your welder, so you can move it (heavy!)
___ 1 megohm potentiometer for control dial (Radio Shack)
___ Solderless breadboard for solid state controller (Radio Shack, cheaper than etching!)
___ Assortments of resistors from Radio Shack (if you don't know how to scavenge them)
___ Assortments of capacitors from Radio Shack (ditto, they can be scavenged cheaply)
___ Jumbo European style terminal strip (handy for many other uses too!)
___ Slabs of copper or aluminum to use for heat sinks (see later chapters)
___ Crimp on connectors that attach to spade terminals on MW transformers
___ Aluminum grounding bus bars (home improvement center, electrical aisle)
___ Lots of bugle head drywall screws, 1-1/2" for building cabinet
___ 20 feet of #4 welding cable (welding supply house)
___ Ground clamp and electrode holder (welding supply house)
NOTE: jumper cable clamps work in a pinch, not as safe
___ Patience (you're probably doing this because you're like me—no time or money)

And that's about it...I'm sure I'm missing something, but remember this is no Heathkit and depending on what is available to you, and what kind of welder you're going to build, you may not even need everything on this list.

Microwave ovens, dead or alive

At the heart of the home built arc welder is the recycled microwave oven. Many of the parts you will use come from this “free” stream of materials.

What I did was post an ad in the local newspaper that read something like this: “Accepting dead microwave ovens. No charge for disposal. Call me.” In our town, and I suppose most in the United States and other parts of the world, it costs money to throw things away. It's a shame. But many people who are disposing of old microwave ovens have encountered this, and are more than willing to bring them to you for “free” rather than pay the local appliance shop a disposal fee. In about 2 weeks, I had accumulated 20 old microwaves.

The folks will also be very intrigued and impressed when you tell them what you are going to do with them. It is a great way to recycle. Save the trees! (Huh? what does this have to do with trees?)

Figure 2: The metal shell, stripped of all components and plastic parts and ready for the recycler.

Of course, the rest of the oven that you don't use in building a welder needs to be disposed of. That you will have to attend to, but the scrap yards usually accept stuff like this, especially if you strip the metal shells clean of wiring and plastics, and flatten them. (Note: Don't try to get any money for the sheet metal scrap you take to the scrap yard, unless you have several tons of it.)

Another thing is to go around town and knock on the doors at the appliance shops, and tell them your intentions. They, too, are likely to be amazed. These are the folks that charge money to accept the old ovens from people who come in shopping for a new one. But it doesn't stop there. The appliance shops are probably paying a fee to a disposal company to relieve their pile of cast-off ovens. So they shouldn't mind if you relieve them of some of these old ovens.

TIP: If you can get permission, remove the transformers from the ovens right on site (usually out behind the appliance store). Then the burden is not on you to dispose of all the parts that you can't use, such as the metal shell. Be careful not to leave a big mess. Carry your own tools and work fast.

If you do have a choice of which ovens to accept, don't mess with the small ones under 900 watts. The transformers in them are so small, it would take a large quantity of them to build a very large welder. If your ambitions are only in building a 120 volt welder, go ahead; but it might take 3 or 4 of the transformers to get enough power to weld with using the small ones.

Why use microwave oven parts?

In the United States and in other parts of the world, home appliances are so inexpensive and readily available, that repairing them when they fail isn't considered a practical option. As a result, they become throw-away, and the scrap market is overflowing with a lot of not-very-old appliances that have a little something wrong with them, usually in the control electronics.

Figure 3: Low prices of new microwave ovens make repairing the old ones impractical.

With microwave ovens, the minimum bench fee at a repair shop is often more than the replacement cost of the oven. At the time of this writing, I saw that Wal-Mart had brand new "apartment-size" microwave ovens for around $30. Even the more elaborate over-the-range ovens are not outrageously priced, with relatively few models over $200. It seems that the ubiquitous microwave is especially plagued by this throw-away mentality.

So the result is a steady stream of perfectly good electronic components, riding to the landfill (or recycler) in a metal box along with one failed component. Be it a door switch, a bad computer chip on a circuit board, or a bad display module, the otherwise healthy ovens are doomed to their fate. My parents had an oven that worked perfectly, but the display was dead. They continued to use it, but most people would have thrown it out the day it failed, and replaced it with a new one.

The Bonanza of parts!

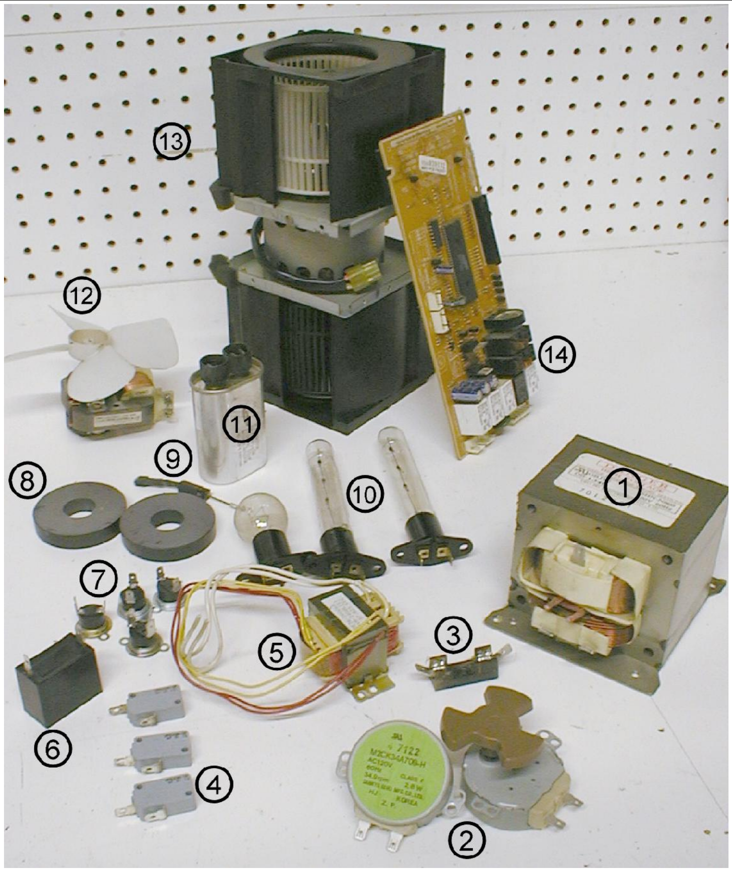


Figure 4: These parts came out of an over-the-range microwave oven.

1-H.V. Transformer (the main part to use in a welder!!)
2-Low-rpm motors
3-Fuse holder
4-Micro switches
5-Low voltage transformer
6-Blower capacitor
7-Thermal cutouts
8-Large magnets
9-H.V. Diode
10-Light bulbs & sockets
11-H.V. Capacitor
12-Cooling fan
13-Squirrel cage blower
14-Control module ("brain board")

A robust inventory of perfectly good components can be salvaged out of a typical "dead" microwave. However, the oven was probably thrown away for a reason, usually a failure of some sort. So you need to keep in mind that one or more of these parts may be bad. (**Note:** I've encountered perfectly good ones that were being thrown away because the color didn't match the new decor!)

The most frequent parts to fail are not the ones you need to use to build a welder. Out of the several dozen ovens I've encountered, not one of them had a bad transformer (the main part used in the welder). Usually it's something on the control module. And often it's a door switch—one of those micro switches.

The high voltage transformer is the main part that you will use to make a welder. In a microwave oven, this transformer produces a low-current, high-voltage output. You will modify it to produce the correct type of current needed in a welder.

The high voltage transformer is easy to identify: it's the big, square, heavy block of steel with copper or aluminum windings in it. It is not made of solid steel. If you look closely, you can see that it is made of many thin sheets of steel stacked up. This is a special design to minimize “eddy current” losses within the transformer.

You may also use the thermal cutouts (item 7 in the photo) to shut your welder down if it overheats. They served the same purpose, to shut down the microwave in case of overheating.

The low voltage transformer (item 5 in the photo) can be used in your welder as a current sensor, to trigger an “easy arc starting” mechanism in the controller. This transformer originally powered the control module or “brain board” in the microwave oven.

The cooling fan is also put to good use, cooling the insides of your welder. So as you can see, many parts are re-used, making the home built arc welder an example of recycling at its best.

What to do with the extra parts?

As for the extra parts that you get, I have not had a problem knowing what to do with them. The high voltage diodes can be sold on online auctions, as well as the micro switches and magnets. List them as “untested, used” unless you are going to test them one by one. The tempered glass plates work nicely as cutting tables for photos and artwork. And most of the 40-watt bulbs that proliferate in microwaves are usually interchangeable with your refrigerator, range hood, and other appliance's bulbs. I've accumulated pretty much a lifetime supply of 40-watt appliance bulbs.

The larger microwave ovens have big, flat sheets of metal on them, usually the top of the shell. These big flat pieces come in very handy as side panels on your welder, that you can drill ventilating holes in, and they take paint and graphics very nicely. You can fasten the panels on the sides of your welder with just a few screws for easy removal.

And, finally, but not as a last resort, you can add the extra parts to your collection of goodies for use in other projects. I have collected a plethora of knobs, electric timers, rubber feet, and blower fans for my next big project! The chances are, if you purchased instructions to make your own arc welder, that you have a tendency to take on other do-it-yourself projects that the extra parts will come in handy for, some day...or so my philosophy goes, hah!

Other sources of parts

In addition to microwave ovens proliferating in the throw-away realm, another reason that microwave ovens are chosen is because they contain **transformers.** Transformers are an important electrical component in a welder. I should say the **most important** component in a welder.

There are very few other household appliances that contain a large enough transformer to make a welder. Washers and dryers **DO NOT** contain welding-size transformers, and most do not have transformers at all! (Believe me, I've had folks write me and ask if it was possible to build a welder out of the transformers from old washing machines.)

If you can get your hands on old battery chargers, you **might** be able to build a welder out of the transformers in it. But often these transformers have coaxial windings—this means that the primary and secondary are one inside the other as in the illustration. It is harder to modify these transformers. They would need to be used with their existing primary windings, which may not be the right voltage and amperage for a welder.

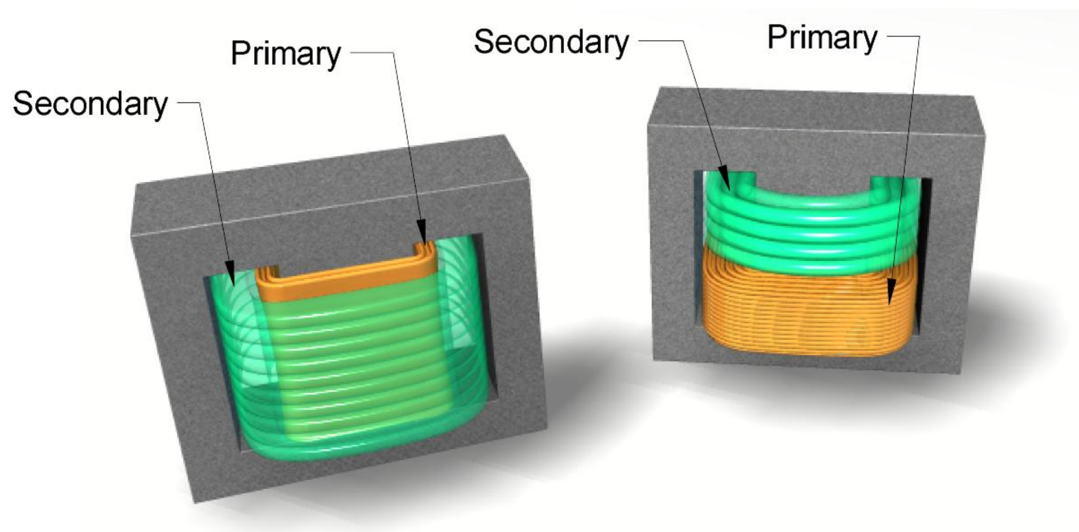


Figure 5: Coaxial vs. split bobbin transformers. Microwave ovens have the much preferred split bobbin style transformers. Split bobbin transformers are easier to modify.

Because of the high voltage produced by the secondary winding in a microwave oven transformer, the primary and secondary winding are in a "split-bobbin" configuration to keep spikes from high voltage arcing from leaking to the primary and into your house wiring. Your advantage in using this type of transformer is that the secondary can be easily removed and replaced with another.

Disassembling Microwave Ovens

While you will generally only need a Phillips screwdriver to disassemble a most microwave ovens, the older ovens were put together with security hardware, probably to discourage users from doing their own repairs. Sets of security screwdriver bits can be gotten cheaply at hardware stores and flea markets. It may benefit you to pick up a set.

When the cost of ovens came down drastically, the manufacturers switched to standard hardware because there was little practical use for anyone to open an oven to repair it.

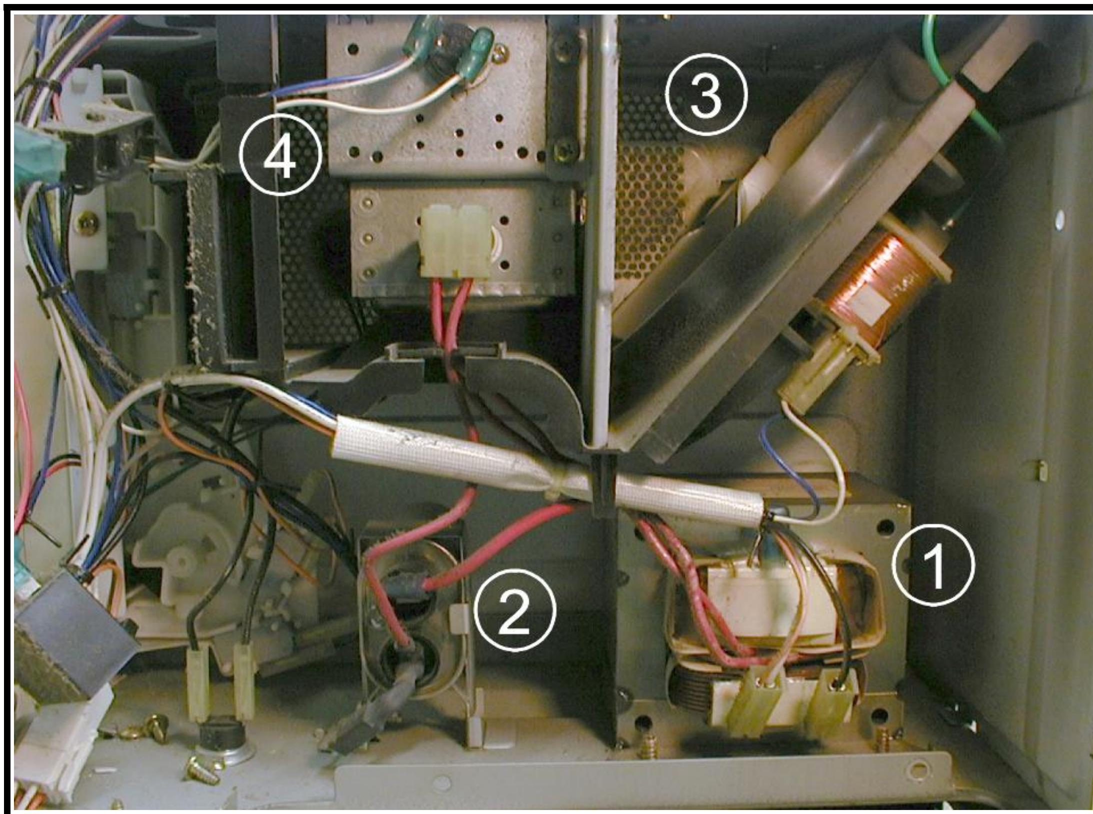


Figure 6:
Compact internal layout of typical oven:
1. High voltage transformer 2. Capacitor 3. Cooling fan 4. Magnetron tube

Safety Concerns

A lot of people ask me about being exposed to microwave radiation when taking ovens apart. This is not a non-worry. With the power off, there simply is no microwave radiation present. As curiosity tends to afflict most cats (and kills a few), you may be tempted to tamper with the door switches or try to operate the oven with the covers off. Don't do it. You are inviting trouble. Keep the unit unplugged while disassembling. There is no reason to apply power to it. A bit of common sense goes a long way.

However, you should be careful of the high voltage capacitor. It can hold a charge of high voltage that you should be careful of. Take a **plastic handled** screwdriver (come on, who ever heard of a metal handled screwdriver anyway) and put the metal shaft across both capacitor terminals to discharge it. You may see (and hear) a spark. The newer capacitors have built in bleeder resistors to drain off the charge, but it's still a good idea to discharge it in the case that it may be an older oven without a bleeder resistor, or maybe the bleeder has malfunctioned.

Different types of welders

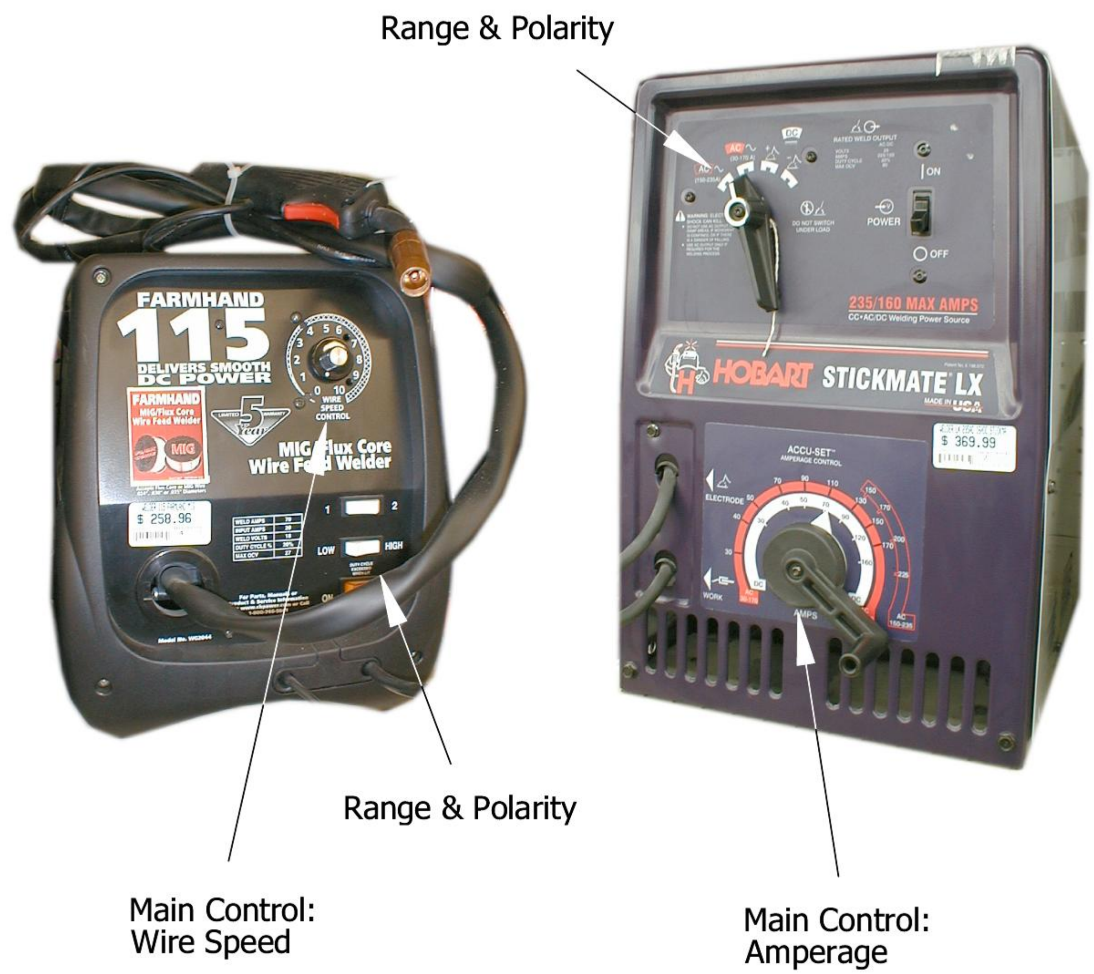


Figure 7: Left: Wire feed welder. The voltage is fixed and amperage control is based on wire speed. Right: Stick welder. The amperage control is directly set by a dial.

Sticks, Migs, Tigs

There are two basic types of electric arc welders. There are "stick" welders and there are wire-feed (MIG) and TIG welders. There are fundamental differences in the design of each. There are different power supply requirements of each.

Stick welders use a flux coated rod that forms a protective slag while the rod is being fed into the workpiece by hand. Wire-feed welders use a motor driven wire feeding mechanism that feeds flux core wire, or a solid wire with a shielding gas to protect the molten metal. Molten steel needs to be protected from oxygen or it will actually burn away, turning to black crumbly dust when unprotected.

The welder that is described in these instructions is a stick welder. There are other differences between the two main types of welders than just the feeding and shielding methods. A stick welder can weld with an alternating current, or AC, at the electrode. Wire feed welders are exclusively direct current, or DC. Stick welders can also use DC, and have the potential for smoother welds on DC, and a wider variety of attachments are available for DC capable welders, such as high frequency TIG (tungsten-inert-gas) attachments.

You may find it interesting to go to a store where these welders are sold and take a peek at the manuals for each one, and explore the schematics that are in them. Note how they compare with the schematics for the welders in this book, and how they differ.

The Hobart Stickmate LX in the photo uses the movable shunt method of control described in the chapter "Control Methods" later. This clever method allows an infinitely-variable (no steps or "notches") control of the power output.

The FarmHand 115, being a wire feed welder, uses a variable speed wire feeding mechanism to vary the welding output. Other welders such as the Lincoln 225 have a selector dial with "clicks" where the dial has internal contact points that select from a variety of power taps at various locations along the transformer's windings that connect more or fewer turns.

Building other types of welders

You are certainly encouraged to take the information you gain from this book and build other types of welders. With the right type of rectifiers and choke inductors you can add DC capability to the stick welder you build. More ideas can be found later in this book in the chapter "Enhancements and Modifications."

If you can conquer the wire drive mechanism, you can very easily build a wire feed welder. They are in some ways simpler than a stick welder. I attempted this once with a "transformerless" welder that I won't go into detail here, and the wire drive used a rubber wheel to drive the wire. The problem is that a groove wore into the rubber wheel and the wire would stop. But otherwise, the weld was formed beautifully, and had a very light dust on it rather than the thick flux that a stick weld makes.

You can also learn more about the different types of welders in the chapter "Other Control Methods." These control methods are used in many different types of welders, all depending on the requirements of the welding, and the quality assurance expected from the manufacturer.

In the next chapter, "Basics of electricity," I will explain the process of taking the alternating current (AC) that is delivered by the electric utility, and "transforming" it into the correct voltage and amperage for a welding power supply.

Basics of electricity

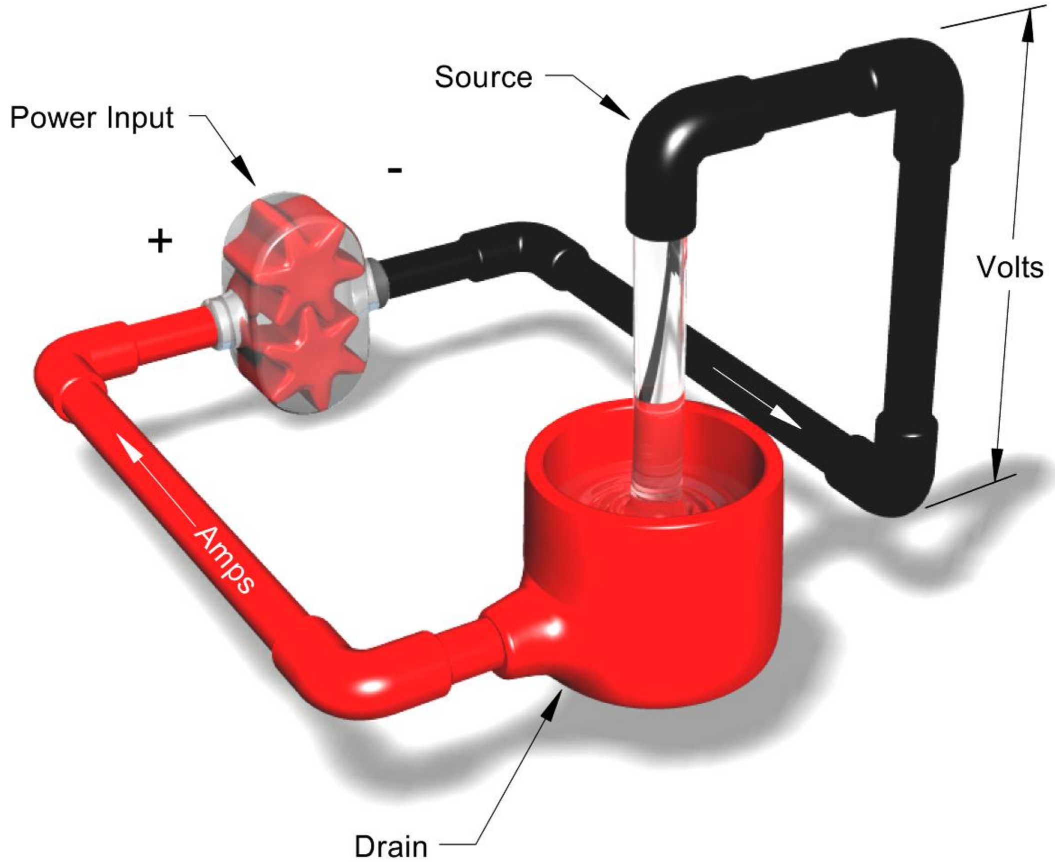


Figure 8: Like a pump and fluids, electricity has both flow (amperage) and pressure (voltage). Note also that red is positive and black is negative. This is what you would call a "short circuit," where the current flows with almost no resistance.

There are several things that can be compared to electricity, as a means of better understanding how it works. Electricity is a rather mystifying force, and there are some rather complicated laws that it follows. But the basics can be understood with a few comparisons from the world of simple machines.

Amps of current flow

Electricity can correctly be described as a flow of current, so we naturally think of water flowing through pipes. Interestingly, electricity is sometimes referred to as "juice." This is an accurate understanding of one of the laws of electricity: Amperage. Just like a hydraulic machine with pumps and hoses and flowing fluid, the work of an electric circuit is accomplished by the flow of electrons.

Volts of potential

Electricity can also be correctly described as pressure or tension. A scuba tank has very high pressure when it is charged, and a battery also has a kind of pressure when charged. This pressure, or tension, is called voltage. It is also referred to as potential, with a similar meaning of kinetic energy, in that it is in a ready state, waiting to be used.

Without pressure in a scuba tank, there is no potential for air flow. Without voltage in an electrical system, there is no potential for flow of amperage. If you've ever left your car's lights on, you become acutely aware of the lack of potential for a flow of amperage. Some flowing of current needs to take place through a set of jumper cables from a vehicle with good potential (voltage) to “pump” the dead battery back up to a potential where it can once again supply a flow of electrons to the starter.

Water hoses and air hoses are hollow and thus they carry their respective fluids to and fro in their systems. This is where the comparison breaks down a bit. Electricity is not a fluid. But it depends instead on certain materials that have a tendency to have “room” for an extra electron in their atom.

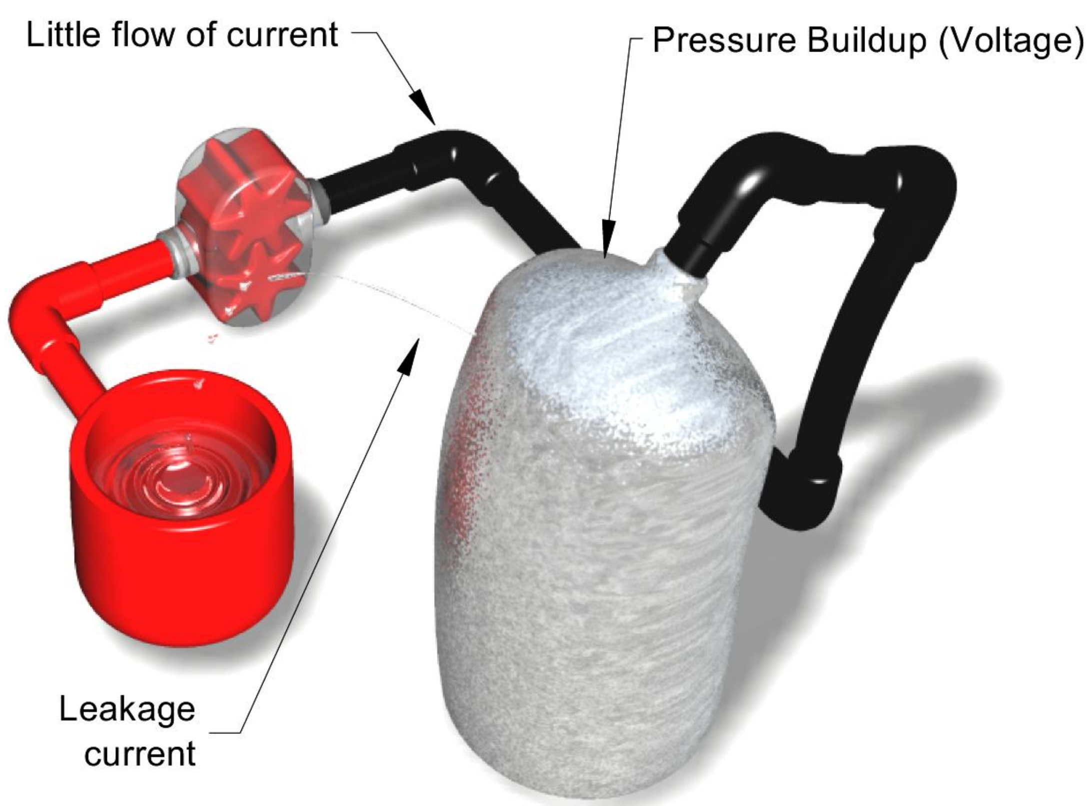


Figure 9: Don't dive with a leaky scuba tank. Nonetheless, this illustration demonstrates voltage as a pressure, and that there is sometimes a leakage current.

These materials, called conductors, being a structure of many such joined atoms or molecules means that the "room" is shared with the other molecules. When one electron is inserted at one point, another electron pops out somewhere else. A plate that is full of one layer of marbles illustrates this quite well. When you try to push one more marble in somewhere, one will pop out somewhere else.

The path of least resistance

Many materials are conductors of electricity. Copper is a very good conductor of electricity. The electrons that get pushed into one end of a piece of copper will "pop out" very readily at other end. But other materials such as steel are not very good conductors and interesting things happen to the flow of electrons. The electrons do not flow as well through steel. The flow of electricity is resisted. When a voltage (think: pressure) is applied to such a resisting conductor, the electrons flow through with resistance, and just like friction, the conductor heats up.

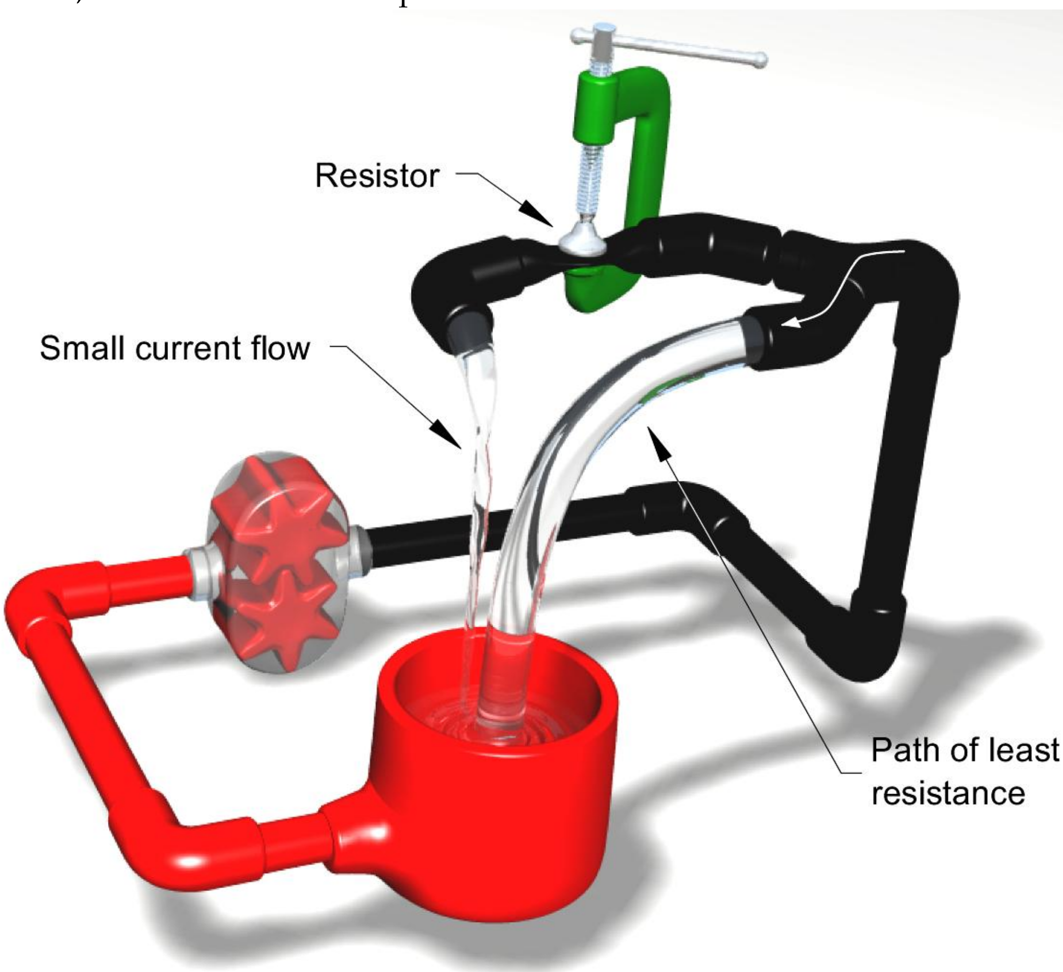


Figure 10: Just like a fluid, the flow of electricity can be resisted. It will flow the most through a path of less resistance.

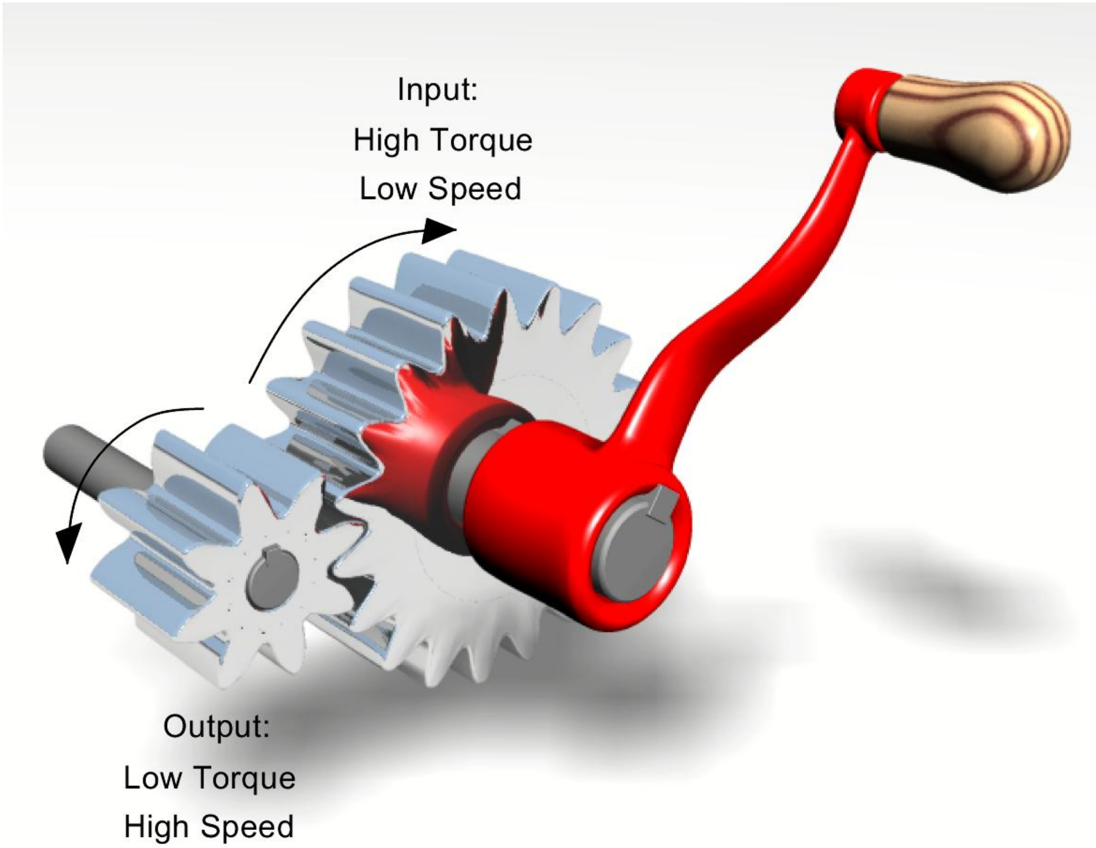


Figure 11: Gear ratios match up power sources with the work to be done. Shown above is a "step-up" gear set. The small gear rotates faster than the large one, "stepping up" the speed. In a microwave oven, the transformer is the "gearbox" that steps the voltage up for the work at hand also.

There are other conductors. Even water conducts electricity. Hence the warnings about working on electrical things while standing in water. A flow of electrons can enter one end of your body where you might be touching a live circuit, and exit where your feet are in water which is a conducting path to ground.

Your body (heart included) is 70-some percent water. An electric shock can be lethal because the heart becomes a path to electrical current. Your heart has its own intricate electrical circuits that are disrupted or even destroyed by a surge of electrical current through it. This shall serve as a warning to you in working with electricity. You yourself can become a conductor of electricity in a way that you were never intended.

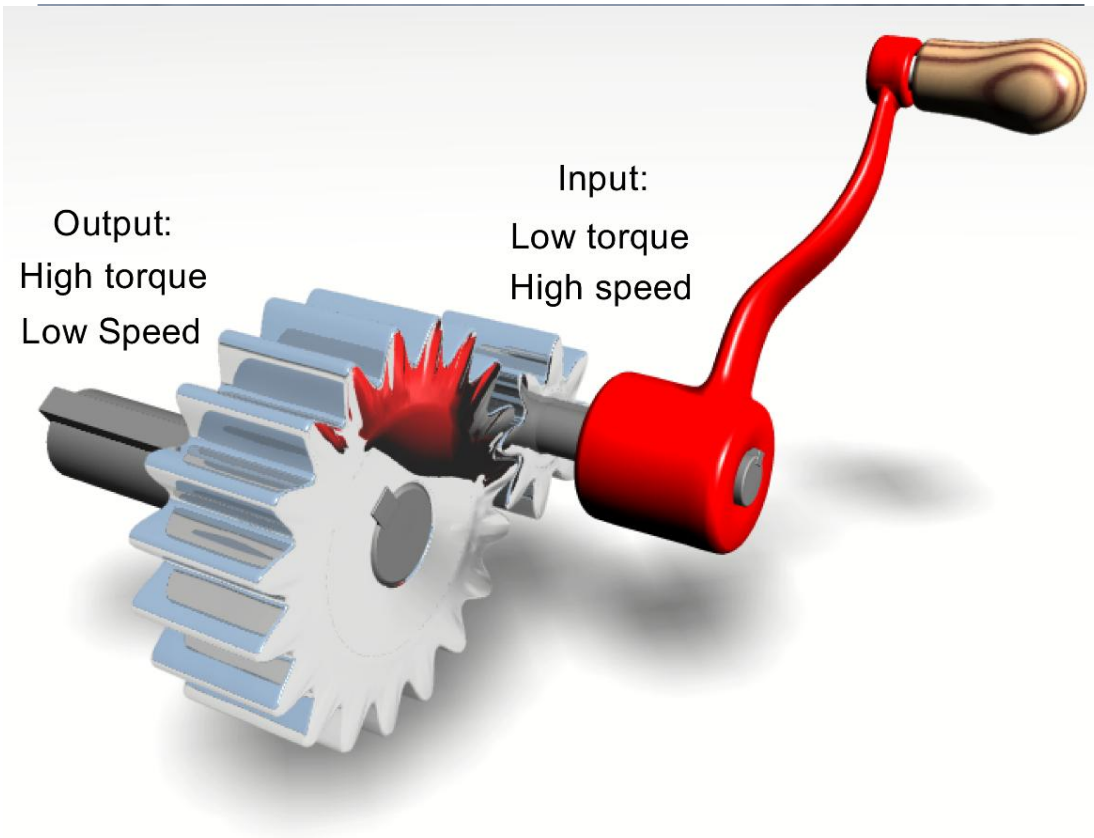


Figure 13: This gear train has a reducing ratio, now that the crank handle is attached to the smaller gear. Low torque, high speed energy is transferred or "stepped down" to high torque, low speed energy. In battery chargers and welders, the input is high voltage / low amperage, and the output is low voltage / high amperage.

There are yet other conductors. Air and gases conduct electricity when presented with a high enough voltage. (Think: pressure!) A lightning bolt is simply air that has become a path to conduct electricity. Hot air and hot gases conduct electricity even better. Exponentially better. Air is a poor conductor of electricity at room temperature. But when it becomes a path to electrical current, due to the resistance of air to current, it becomes heated and ionized. Then it conducts electricity even more and rapidly heats up (with a bang, mind you) to a blinding bluish white. The high voltage (think: potential) that was in the cloud has succumbed to a flow of current.

The arc of a welder also conducts electricity. It consists of a mixture of air, gases, and metal vapor. Burning gases produced by the flux conduct electricity even better than just hot air. The arc of a welder is sometimes referred to as the arc flame. This arc flame is a resistive conductor and gets very hot because of the electricity that is "lost" in its poor conductivity. And thus the work of melting and fusing a small pool of metal is accomplished.

Cranking up the watts

Here's where it gets really fun. We all know the thrill of horsepower and loud speakers. What's the zero-to-sixty? How many watts does this baby crank out? Huh? What's a watt? Watts are how we measure power transfer. A sound system converts electricity into vibrations in air, with more watts needed to make stronger vibrations. (Louder sound!) A car engine converts fuel into mechanical power, with bigger pistons, more fuel, and better tires to transfer that torque to the highway, pushing the objects in your rear view mirror far into the distance. (Uh, oh. This could become a country song.)

With electricity, power can also be transferred. This transfer can be measured in watts. The power company sells you power by the kilowatt. The electric heater at your feet is rated in watts. An arc welder also transfers measurable watts of power to the workpiece.

The formula for calculating the transfer of electrical power is AMPS x VOLTS = WATTS. This is not any more complicated than TORQUE x R.P.M. = HORSEPOWER (basic formula, with some minor factoring). You can even convert watts directly into horsepower by dividing watts by 748. That's right, 748 watts in one horsepower.

The power transmission

Now we need to depart a bit from the fluid analogy of electricity. Mechanical things become the key comparison to understanding the transmission of power. There is an important reason that your car has a transmission. Even a bicycle has a transmission. And a welder has the electrical equivalent of a transmission.

A car's transmission uses gear ratios to match up the torque and rpm of the engine to the ever changing and varying torque and r.p.m. requirements of the wheels.

Pedaling a bicycle, with a variety of gears to choose from, illustrates vividly the need for a power transmission. The conditions, whether it be a high hill, or wind against your face, may require that you configure the transmission with a set of gear ratios that match your pedaling effort (torque) and cadence (R.P.M.) to the work.

Similarly, many electric machines use a type of transmission. This “electric transmission” has ratios, much like gears, to match the amperage and voltage (like torque and r.p.m.) of the power source to the “final drive.” In a computer monitor, a high voltage circuit steps up the voltage to accelerate the

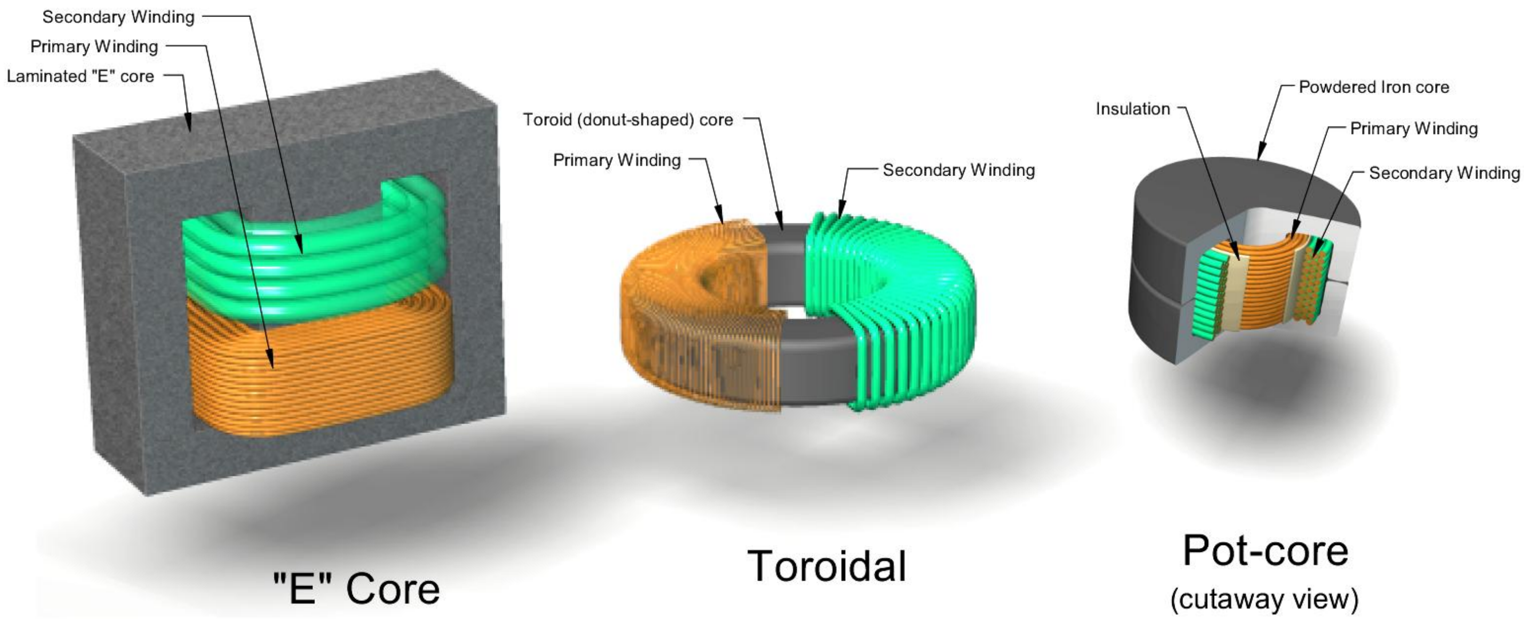


Figure 14: Transformers come in many shapes, sizes and styles. These are just a few.

spray of electrons that paints the picture on the screen. The amps of current flow drop way down, but the total power output is dissipated in visible light.

For example, in a battery charger, a step-down circuit reduces the voltage to a level suited to the voltage of the battery, while the amps are substantially increased for charging. The low amperage / high voltage input has a great deal of "leverage" over the output.

At the heart of many of these electrical "power transmissions" is a very fundamental component: the transformer. Instead of gears with a ratio of teeth, transformers have a ratio of turns of wire. A transformer with a primary winding of 200 turns and a secondary winding of 20 turns will step 120 volts of potential from your utility down to 12 volts to charge a battery. A transformer with a primary winding of 100 turns and a secondary winding of 3,300 turns will step 120 volts of potential from your utility up to around 4000 volts to energize the magnetron in your microwave oven.

A transformer works with alternating current. Direct current, such as the plus and minus from a battery, will not flow through a transformer. Even the special transformer in an automotive ignition system requires that the solid state circuitry (or points in older engines) "make and break" to provide alternating "on and off" pulses to make the spark.

A transformer utilizes an important relationship between electricity and magnetism. A rising or falling magnetic field will generate a rising or falling voltage potential (and/or current flow) in a conducting material. Similarly, a rising or falling current flow in a wire will generate a rising or falling magnetic field.

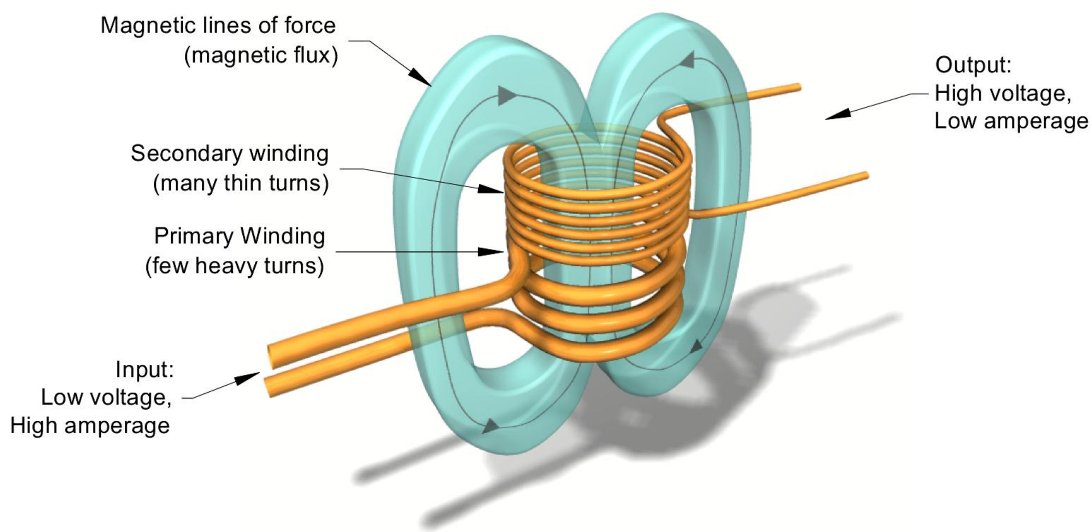


Figure 15: In a microwave oven transformer, the "gear ratio" steps up the voltage. Torque (oops, I meant AMPERAGE) is decreased in this step-down configuration.

In a transformer, there are 3 main parts:

• Primary windings (input)

• Core (mostly iron, but some are “air-cored”)

• Secondary windings (output)

There are several different designs of transformer cores also. Most are of the center-cored “E” design like the microwave ovens contain. There are also donut-shaped (toroidal) and pot-cored transformers, and others, but they all share the three basic parts listed above.

The windings in a transformer are usually copper. In your quest for scrap microwave ovens, you will encounter a few transformers with windings of aluminum. The choice of materials that the windings are made of depend on how well the designer wants the windings to conduct electricity. Copper is better than aluminum, but it is more expensive. Copper windings will run cooler and therefore more efficiently.

The primary windings are the transformer's power input. An alternating current is applied to this winding. The rising and falling of the alternating current sets up a rising and falling magnetic field in the iron core of the transformer. The magnetic field of the iron core tends to rise and fall very readily with the alternating current, and actually generates “back” e.m.f. or electromotive force, and so as long as the transformer does not have a load on its secondary winding, it draws very little current in this “idle” mode.

Even though a transformer's primary winding may be made with #12 or #14 copper wire and powered with a voltage such as 120v house current, it will draw very little power in an idle mode. A welder makes very little sound, a faint humming, until you strike an arc. Then it will hum louder, and wouldn't you know, some wise guy noticed that and coined the term “buzz box.”

Now the secondary winding comes into play. The rising and falling magnetic field in the iron core induces an alternating voltage potential in the secondary winding. If a load is present across the leads of the secondary winding, the winding draws current and depletes the “back” e.m.f. mentioned earlier. This in turn causes an increase in current in the primary winding, drawing power from your utility, and making your electric meter spin faster.

In a microwave oven transformer, the secondary winding is wound with fine wire, #22 or #24 (some maybe finer). There are many turns. As a result, the voltage output from the secondary is quite high, around 4,000 volts, and about a quarter of an amp. In its application in the oven, the transformer charges up a D.C. capacitor through a high voltage diode. This high voltage direct current is utilized by the magnetron, a special vacuum tube that emits high frequency radio waves at a harmonic frequency (in the giga-hertz range) that causes certain substances such as water and grease to heat up.

In a welder, the secondary winding is made with just a few very heavy turns. A few turns of thick copper wire will make a low voltage, high amperage output. A typical 240-volt welder puts out 250 amps at around 25 or 30 volts. In order to adapt a microwave oven transformer to welder use, you will be removing the original fine-wire high voltage secondary winding, and replacing it with a heavy duty low voltage secondary winding.

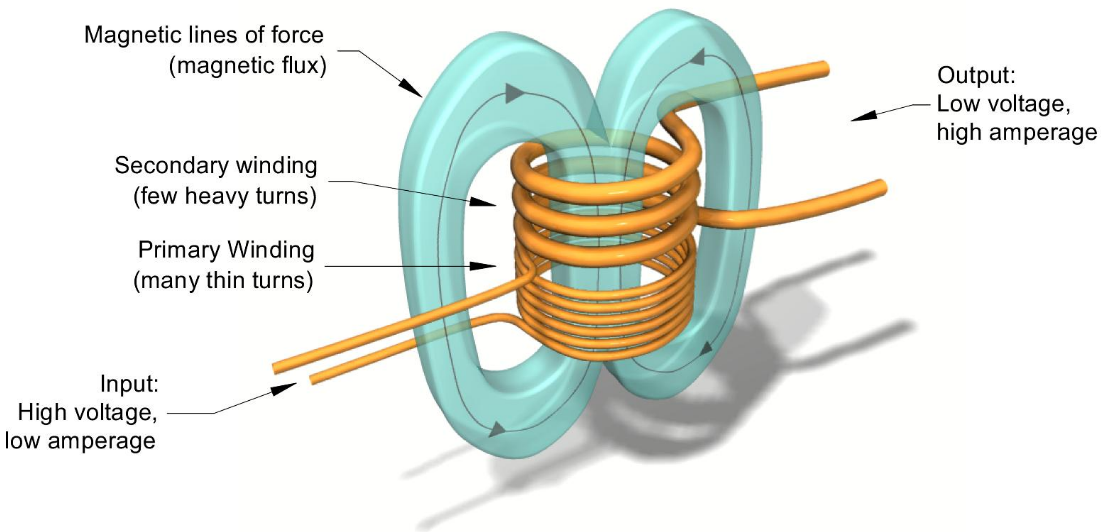


Figure 16: Again, like the gear illustration, the turns ratio in a transformer alters the ratio of inputs to outputs. This is a step down transformer, with many turns in the primary winding and fewer, heavier turns in the secondary.

So you can see how transformers in many applications are like a transmission: some are geared with high ratios for high speed like a race car, others lumber along with a very low-speed ratio but proliferate with torque like a bulldozer. A welding transformer is a heavy duty workhorse, not with a lot of volts, but throbbing, metal sizzling amps from windings as thick as a pencil.

Limiting factors in design

Now that we've covered the basics of electricity, some practical aspects of readily available electricity need to be looked at. This chapter covers some important limitations that you will encounter in the designing of such things as shop wiring and welders to be powered from it.

Figure 17: Don't count on more than about 2400 watts from here.

Household circuitry

Some of my readers email me and ask if they can build a 120 volt version of the welder using 4 microwave transformers. I always chuckle. This would be like plugging 4 microwave ovens into one receptacle. The only way it would be remotely possible is if the transformers were extremely small, like under 500 watts.

When approaching the design of a homebuilt welder, you need to keep some things in mind. There are "protocols" of household electricity that need to be considered. For example, if you want to build a 120 volt welder that can plug into any standard outlet, the power output is limited by the standard wiring that is found in the wall behind standard outlets. With 240 volt designs, there are 20, 30, 50 amp plugs and sockets commonly available.

The size of the wiring in your house or shop directly affects the amperage, and therefore the wattage, that is available from the outlets that it connects to. Wiring with #12 wire gives you a 20 amp circuit, and wiring with #14 wire gives you a 15 amp circuit. On 120 volts, a #12 wire has a 2400 watt limitation, and #14 circuits present a 1800 watt limitation.

An “ideal” 120 volt welder with no inefficiencies will not give you more than 96 amps of welding current assuming a 25 volt arc. A “real” 120 volt welder with realistic efficiencies of 70-80% will give you a maximum of 76 amps. That's plugged into a 20 amp receptacle. Plug this welder into a 15 amp circuit, and any welding above 60 amps is likely to trip the breaker. So don't try to make a 250 amp welder and expect it to run on 120 volts.

Heavy duty circuitry

The welder I built is patterned after the volt-ampere characteristics of the Lincoln 225 ac welder. It plugs into a 50-amp, 240-volt receptacle for an ideal wattage of 12,000 watts. At the welding rod sizes and currents of this type of welder, the arc voltage can be as high as 30 volts. So assuming a 30 volt arc at an efficiency of 80%, the maximum amperage to be expected when applying these mathematics is 320.

However, there is something else that comes into play. There is something called power factor. This is a ratio between the apparent power draw by simply doing the (amps x volts) wattage mathematics, and the “voltampere” power draw of the transformer input (primary winding). A power factor exists in inductive loads (such as welders and other transformer based equipment). The Lincoln 225 has an approximate power factor of 0.704. Interestingly, you get approximately 225 when you multiply 320 by 0.704. What you end up with is the right amount of wattage at the arc to weld with up to a 3/16” rod.

Welder durability ratings

If you look at welders in the stores, you will notice that they have another rating called the duty cycle. This is based on a 10-minute welding cycle. A 20% duty cycle means that you weld for 2 minutes, and rest the welder for 8 minutes. A 50% duty cycle means that you weld for 5 minutes, and rest the welder for 5 minutes. A 100% duty cycle means that you can weld 'till the cows come home.

The welder that you build with microwave oven transformers will have a duty cycle comparable to that of a microwave oven. Microwave ovens are rated for cooking cycles of 30 minutes and longer. Most use of microwave ovens is shorter than that, closer to a 8 or 10 minute cycle for cooking/heating a typical packaged dinner for one. In the dozens of microwaves that I collected, not one of their transformers showed any signs of “over-duty” stress.

Frequently asked questions

Maybe the middle of the book isn't the best place for this chapter, but hang with me. I hope you didn't skim over too much to get here. But if you did, some of your questions may already be answered in an earlier part.

Regardless, you can't get this far into a book without some burning questions going through your mind. This is kind of a condensed list of the many questions I've gotten over the years via email, and no doubt you may have even asked some of these before you purchased this book.

How many turns on the secondary?

This is frequently asked question #1. You might be shocked at my answer, but it goes along with something I said way back at the beginning under the heading NOT YOUR ORDINARY DESIGN. The answer is that the actual count of turns isn't that important. When I built my home made welder and other modified-secondary transformer projects, I didn't always count how many turns I put on them. There's a chart in a later chapter that gives some approximates as a guide.

You should pack as many turns of the recommended wire size and type into each transformer as you can. If wire with thinner, more durable insulation was available, I would recommend it.

Ok, ok. I got between 12 and 15 turns of #6 type-THHN pvc insulated multi-strand (as opposed to solid) copper wire per transformer. I hope this helps.

Will bare copper wire work, or must it be insulated?

No. It MUST be insulated. Bare copper wire will short out between the turns. Some of my more ambitious readers have attempted to make their own enameled magnet wire with #6 solid core magnet wire, but you are on your own if you want to try this. My gut feeling is that you will waste so much time or money messing with other wire types and trying to make them work that in the end you will wonder (and so will I) why you didn't just go out and purchase a welder off the shelf somewhere.

Can a spot welder be made from these plans?

Maybe. But there are some things to understand about spot welders that are fundamentally different from an arc welder. Most notably the arc. A spot welder clamps the two workpieces between electrodes, turns on the power for an exact amount of time, and then lets go after a cooling period.

Spot welders also typically have a one-turn secondary. Usually a big heavy copper loop of thick solid copper. The electrodes are sometimes water cooled. If there is a way to take multiple microwave oven transformers and gang them up into a big one-turn transformer, then it can be done. But I think that would be a different set of plans.

Is it easy to modify the design, and make a plasma cutter?

You might, if you know what the voltage and amperage is needed to supply a plasma cutter torch with the right kind of power.

One thing that makes the design of a microwave-oven-transformer machine such as a welder or plasma cutter not an ordinary design is that there is no assurance of consistency in the materials you get to work with. The transformers specifically. Some of them have copper windings, some aluminum. They're not all shaped the same. Some are short and squat with many layers of steel in their laminations. Some are taller and thinner. There are different wattages, from big ovens and small ovens.

Where does the control circuit get its power?

From the gates of the SCR module. This question is answered in more detail in the chapter "The Controller."

Some of my readers have suggested designing the controller with a 555 timer so it would be easier to understand how it works. But at the end of the day, the 555-based design would require many more components and be more complicated that this design. Show me a cheaper, simpler, and more compact way to control **KILOWATTS** of power than my design and I'll gladly concede the challenge.

Isn't it dangerous to connect microwave transformers in series?

There has been concern expressed over connecting high voltage microwave oven transformers in series. This is indeed a valid concern, because only one end of the high voltage winding on these transformers is made to be high voltage. In fact, the other end is often grounded or connected to the neutral wire.

As a result, when you connect two or more microwave transformers' secondaries together, one of the transformers frame (or core) is going to be at a doubly lethal voltage than that of a single transformer. So don't do this with the high voltage windings that microwave ovens come with. But read on.

In building a welder with microwave transformers, enough of the right kind of modifications are done to completely eliminate the high voltage concerns described above: First, the new secondary windings only produce 10 volts each, as opposed to 4,000 volts in the original application. Second, you will not be connecting any of the secondary windings to the transformer frames.

Good welding practice involves grounding your work, and then treating the electrode and its holder with respect. The total voltage output of your homebuilt welder is no more dangerous than any commercially available welder out there.

Would [x-part number] work as a substitute?

Maybe. Electricity does not care what the part number is of the components it makes its path through, but if the path isn't good enough, you may have parts getting hot and burning up. I used some small TO-218X cased 60 amp SCR's in place of the 70-amp IRKT71 module at first, and they were no where near as heavy duty as the module, even though the amperage rating is fairly close.

One way that I tell if a component is heavy duty enough is by the size of its leads. If it has big screws or lugs to attach the wire, it can handle a lot more amps than one that is made to solder into a circuit board.

Can I use the transformers from washers and dryers?

No, you cannot. Washers and dryers do not have welder sized transformers in them. They only have motors and heating elements in them. This question was not all that frequent, but I publish it here because of its absurdity.

You can, however, use the laminated field stator to make your own transformers for other uses, possibly. But this will involve removing ALL of the original windings, starting from scratch and making primary and secondary windings. I don't recommend this for building your welder. It is more work and more expensive than using the readily available microwave transformers.

Modifying the transformers

Now that some basics of electricity have been covered, all the burning questions answered, and a formidable pile of old microwave oven parts collected, lets roll up the proverbial sleeves, get out the tools and get to work on building a welder.

Original application: voltage step up

The transformers in a microwave are a step-up transformer. But you can easily change that. The part that makes it a step-up transformer is the secondary winding. The primary winding can be left intact, because it is made to take straight 120 volts with no modifications. In fact, the primary winding doesn't care whether there's so much as a secondary winding at all. But of course, we need a secondary winding to get any power out of the transformer.

Another thing that makes microwave oven transformers ideally suited to modifying for welder use is their split bobbin configuration. That means that the primary windings and secondary windings are beside each other, two separate "bobbins" of wire. This is probably to keep the high voltage of the secondary from "arcing-over" and sending high voltage spikes into the primary, and back down the line into your house wiring. While I don't suppose the designers had welder modification in mind, it very conveniently facilitates removal of the secondary winding while leaving the primary intact.

Figure 18: A variety of transformers. Pick a group of nearly identical transformers for your welder.

Modified application: voltage step down

The modifying of the transformers consists of removing the old high voltage secondary and putting a new, low voltage, high amperage secondary with heavy turns of wire in its place. This changes the "power transmission ratio" from a microwave oven "gear" and down shifts it to an arc welder "gear."

Removing the old secondary

In thinking about getting that old primary off, you will notice that there is usually a bead of weld several places that hold the parts of the transformer core together. It may be tempting to grind this weld off, and open the core of the transformer to get the old secondary off, and to put the new secondary on. Don't do it. I found it very difficult to get the transformer put back together again without it buzzing loudly, or getting hot. It is also much harder than you might think to wind heavy turns of copper wire with the transformer opened up. They just want to pop out sideways.

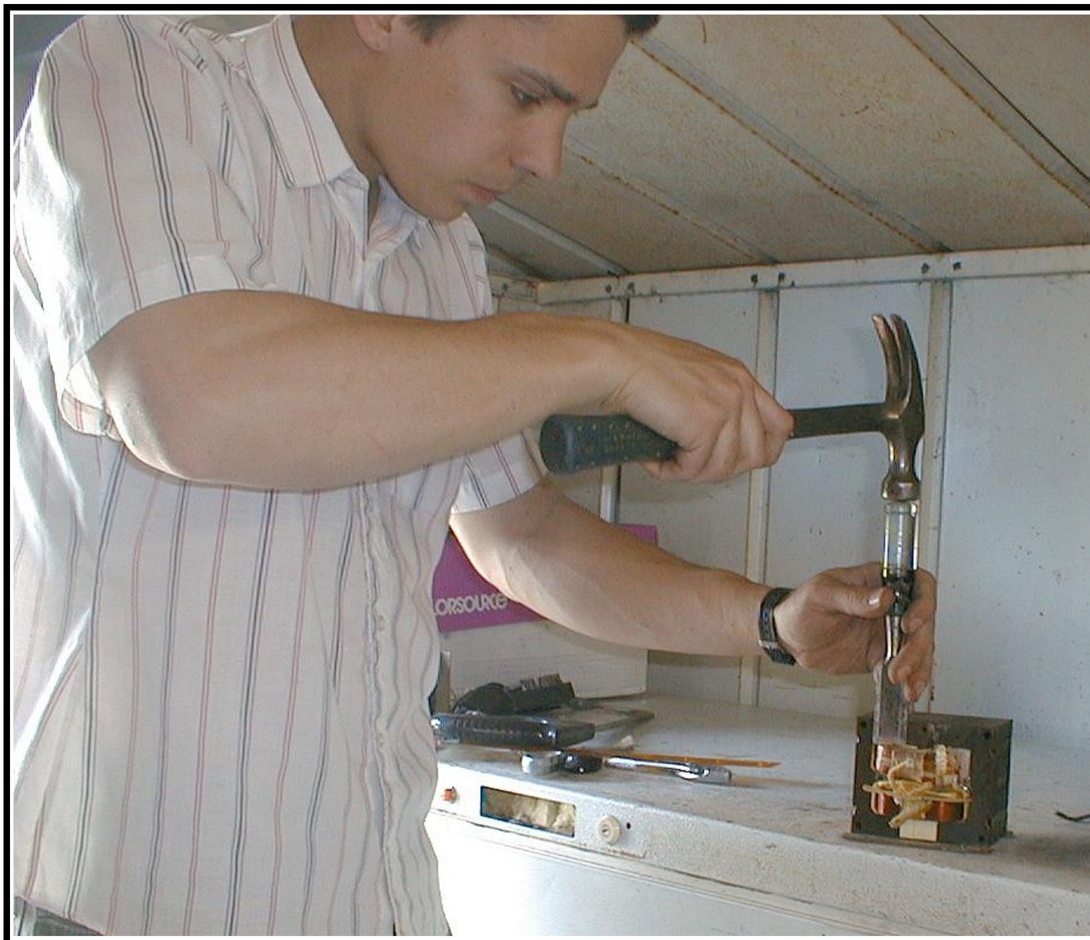


Figure 19: Using a sharp wood chisel to remove the high voltage secondary windings. Be careful not to nick the primary winding.

After trying both ways to remove and replace the secondary winding, I decided that chiseling off one side of the secondary with a good sharp wood chisel was the best way. Then I drove the rest of the winding out with a 5/8" metal punch, tapping first on one "leg" and then on the other to "walk" the remaining u-shaped pack of wires out. Once the secondary is driven out, you have a transformer with holes in it, all ready for the new windings.

In tapping out the original secondary, you may accidentally dislodge a small stack of plates between the primary and secondary. There is one on each side of the core center. These stacks of plates should be left in. It may be tempting to remove them so there's more space for the new secondary, but don't do it. They are called magnetic shunts and they affect the magnetic "saturation point" of the core. Without them, the primary winding will draw way more amps than the design of the primary winding can handle, on 120 volts. It may also trip the circuit breaker long before this happens, and nobody can weld with the circuit breaker always tripping.

Wire types for the new secondary

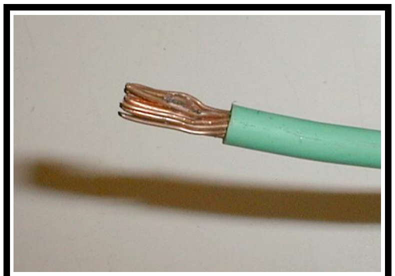


Figure 20: Type THHN multi-stranded wire is readily available, and carries current well.

After driving out the fine-wound secondary winding, the new high amperage, low voltage winding needs to be wound in.

In commercially available welders, a heavy guage enameled wire called "magnet wire" is used in the secondary. I had no success at all finding this heavy guage wire, either from local or mail order sources.

So I went to my local home improvement center (a Home Depot) and headed for the electrical department. I came out with a #6 guage, type THHN single conductor, multi-strand wire. The insulation is thicker than desirable, but was the best choice of what was available in this regard. **Please note that this is SINGLE CONDUCTOR, but it is MULTI-STRANDED. SEE PHOTOGRAPH.** (I'm yelling here because many folks trip up on this one, and get jacketed 6-3 with ground or something strange.)

As it turned out, this was an excellent choice of wire for winding an new secondary on microwave transformers. It is flexible, and the insulation is tough. Even then, it was hard work to wrestle the heavy wire into the transformer core, and solid wire would have been next to impossible.

I recommend that you use this kind of wire in building your welder. The insulation is tough enough to withstand the sharp bends and pulling required to tightly wind the new secondary winding. But if you have heavy guage enameled wire and know the techniques to work with it, feel free to substitute.

Calculating what you want, need

I've done most of the tough math for you, and condensed the practical number of configurations down to a couple of handy tables of configuration. Note that the numbers are rounded. For example, you can't build a welder with three and a half transformers. Also, notice how the 240 volt configurations always have an even number of transformers. This is because of how the schematic puts two banks of transformers together, in equal parts.

Chart of Transformers Required

Welder amperage and voltage:	Transformer Wattage:				
	700	900	1000	1200	1500
70 amp, 120 volt	4	3	3	2	2
70 amp, 240 volt	4	4	4	2	2
100 amp, 240 volt	6	6	4	4	4
150 amp, 240 volt	10	8	6	6	4
200 amp, 240 volt	12	10	10	8	6
250 amp, 240 volt	16	12	10	8	8

Table 1: Use this chart to decide how big of a welder to build.

Now, earlier I told you that the number of turns on the new secondary was not that important. It still isn't, but I'm going to give some approximates so you know you're within spittin' distance of a good number of turns. These approximates are estimated from transformers that I have on hand from my experiments; your encounters will vary.

Also, the following table gives the wire size and breaker you should use for the circuit that supplies power to the outlet that your welder will be plugging into. The wire size for the secondary windings that you will wind into the transformers is given also.

I suggest you calculate the amount of wire to use by getting a piece that is long enough to do one transformer, and measure it before winding it in place. Then measure the remnant and subtract to get the length of the piece in the transformer. Don't forget to leave 6 or 8 inches of "tail" on each end of the winding!

Or if you're too lazy to do this kind of figuring, just go by the "Approx. Feet" column in the following table, but remember it might be too much or not enough, as it is only approximate!

Chart of Wire sizes and Ampacities

Welder amperage and voltage:	Breaker Amps	Circuit Wire	Secondary Wire	Approx. Turns*	Approx. Feet**
70 amp, 120 volt	20	#12	#10	36	69
70 amp, 240 volt	20	#12	#10	36	69
100 amp, 240 volt	30	#10	#8	24	92
150 amp, 240 volt	30	#10	#8	24	92
200 amp, 240 volt	50	#8	#6	12	70
250 amp, 240 volt	50	#8	#6	12	92

Table 2: Use this chart to as a guide for wire sizes and approximate numbers of turns.

*Note: The number of turns may vary considerably. These estimates are based on using 1500 watt transformers. Using smaller transformers requires the same guage of wire as the larger ones, but fewer turns will fit on them.

**Number of feet is also a fairly rough estimate. The shape of the gaps in the transformer core where the secondaries are wound may make this number greater or less. If you have some left over, you can always use it here and there inside your welder to make some connections.

When you wind the secondaries, you should pack as many turns on the transformers as possible. There is no reason to be sloppy, it will only hinder your efforts. Here are some tips on winding the wire neatly and tightly:

1. On the first layer of turns next to the steel core, use a pliers to make bends in the wire, **EXACTLY** where it makes the turn around the edges of the core. This will help relieve the pressure of the wire on the edges, and reduce the chance of it shorting out on the core.

2. The wire has a tendency to assume a curved shape when wound around the core. Try to bend it straight, or even a little the opposite way, to help the turns lay flat.

3. When the core is almost wound full of wire, use a screwdriver or something similar as a prying tool to pry open the last remaining spaces to make room for just one more turn or layer of turns.

4. If you use the recommended type THHN wire, don't worry too much about minor nicks in the insulation of the wire between turns. Any two turns of wire next to each other are “double insulated” because each turn has its own insulation.

5. Leave a “tail” of wire long enough to make the connections between your transformers without having to splice in a connecting wire between them.

6. Don't get in a hurry. It took me two evenings to wind eight transformers with #6 wire. It takes a little time, and attention to detail to get the new secondary windings packed in neatly and enough quantity to achieve good voltage output. If you skimp in this department, you'll find yourself standing corrected in the last chapter of the book “Troubleshooting.”

Principles of Paralleling

The schematic of a homebuilt welder is highly customizable. This chapter deals with the principles and guidelines of "fitting" the parts of the schematic together. Connecting a group of microwave transformers together is a lot like harnessing a team of horses. We'll cover the basics of when and why to connect in parallel, and in series, and combinations of series and parallel.

Transformer array

The schematic really consists of just two major components: the transformer array, and the controller. First we'll cover the transformer array. The first schematic doesn't show the controller schematic, for simplicity:

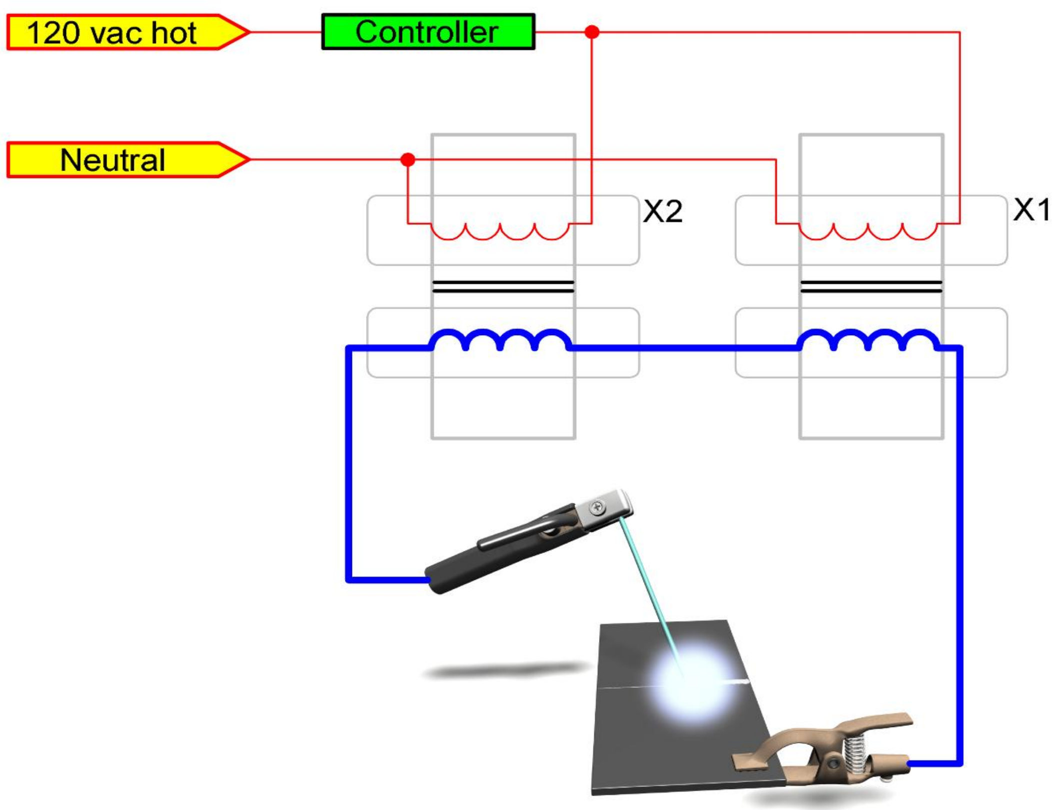


Figure 21: Simple 120 volt welder with primaries in parallel, secondaries in series.

From there we break it down. This schematic is easy to understand. Current flows from transformer X1 to transformer X2, where it picks up additional voltage potential, and then on to the arc. The current flows through the arc, through the workpiece, and out the ground clamp, and back to transformer X1. (In the other half of the AC cycle, it flows the other way.) The arc is a resistive load, dissipates energy as extreme heat.

Now we have some things to add to the discussion on basic electricity back in chapter 2. Remember that a fluctuating magnetic field in a transformer would induce voltage potential in a transformer's secondary winding? Well, when you take several transformers and connect their secondary windings in series (one after another), you get a voltage potential that's a total of the secondaries. For example, if the two transformers each put out 20 volts at their secondary windings, connecting them in series like the schematic will produce 40 volts.

This “series” connection is preferable whenever harnessing two or more voltage sources in many applications, whether it be transformer windings or batteries. With secondary windings, it is important to have both (or all) the windings made of the same size wire for equal current carrying capacity. On the same note, small electronic devices almost always use a set of batteries of the same size. For instance, you won't see many electronic device that asks for an AA battery and a C battery together. On the contrary, there are even warnings not to mix battery types, such as alkaline and rechargeable types together.

Series, parallel, and polarity: the battery illustration

Even though you won't be using batteries in your welder, I use them as an illustration to make a point about connecting secondary windings between transformers in a home built welder. The transformers that you build your welder with are like batteries in several respects:

One, because the secondary winding is a “self contained” voltage source just like a battery, it is easy to connect it in series with other secondaries to get a greater voltage. You can generally think of a group of transformers with their secondary windings connected together as one big transformer.

If you took apart an alkaline 9v smoke alarm battery, you would notice that it is not just one battery, but that there are six little individual batteries, smaller than AAA batteries, all connected in series. Similarly, in a N battery, such as the ones in a TV remote, there are eight little button batteries all stacked up.

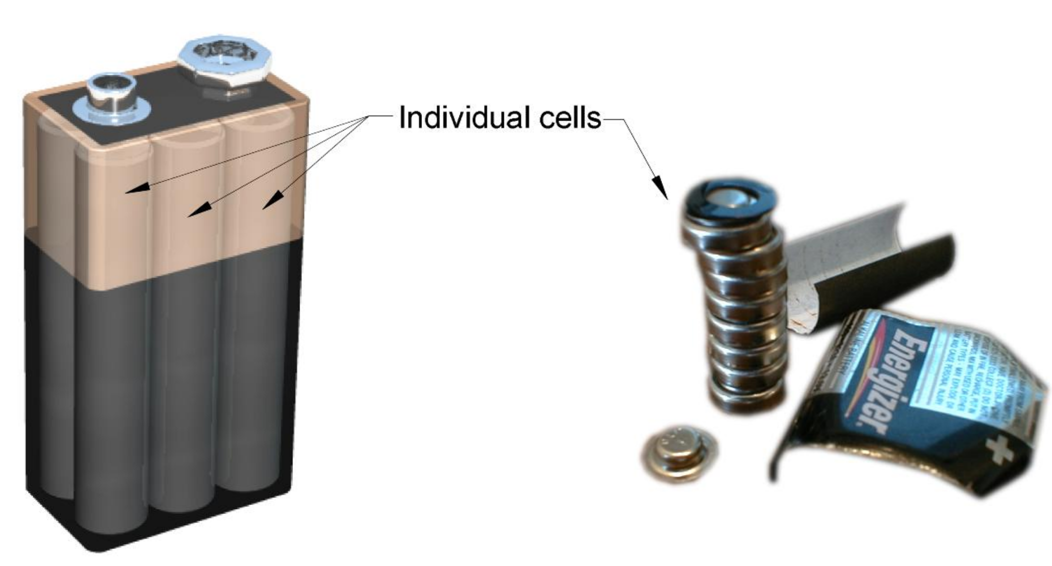


Figure 22: The familiar 9-volt has six 1.5 volt cells inside it, connected in series to make it produce 9 volts. Similarly, the 12 volt N-cell has eight 1.5 volt button batteries stacked up (in series!) to produce its 12 volts.

Just like many of these batteries are actually an array of smaller batteries connected in series inside their cases, a welder made with microwave oven transformers is an array of smaller transformers connected in series to make "one large one."

Two, batteries have a plus and minus. You are no doubt familiar with the "protocol" for inserting batteries in devices that asks for the plus and minus to be oriented a certain way. This is so that the batteries "boost" each other. If you hooked up two batteries in series, minus to minus, with a load connected between their plusses, you would theoretically get no current out of the arrangement. Connected this way, they "buck" each other, and the one cancels out the voltage of the other.

Similarly, transformers have a plus and minus of sorts. In schematics, this is indicated by a dot at one end of the winding symbol. An actual plus(+) and minus(-) is not used because transformers are alternating current devices and their plus and minus alternate back and forth. The important thing to understand is that two separate alternating currents, when connected in series, are either "boosting" or "bucking" depending on whether the connection between them is a connection that is plus-to-plus or minus-to-plus. A plus-to-plus or minus-to-minus connection will "buck," while a plus-to-minus or minus-to-plus connection will "boost." See the illustration of the 9-volt batteries connected two different ways.

By the way: No, you won't be using 9-volt batteries to build a welder. The illustration is given to help understand the principles of polarity in series circuits!

This is an important concept to understand. If you build a welder with, for example, 4 transformers, and each of them put out 20 volts at their secondaries, you might power up the welder and find that it is only making 40 volts. This doesn't make sense, right? They each had 20 volts, and there are 4 of them, so why aren't they adding up?

What you will find is that (in this particular scenario) one of the transformers is connected backwards, just like a bank of four 20-volt batteries with one in backwards would only produce 40 volts. Not only is the backwards battery not adding to the cumulative voltage, but it is actually subtracting ("bucking!") voltage from the pack.

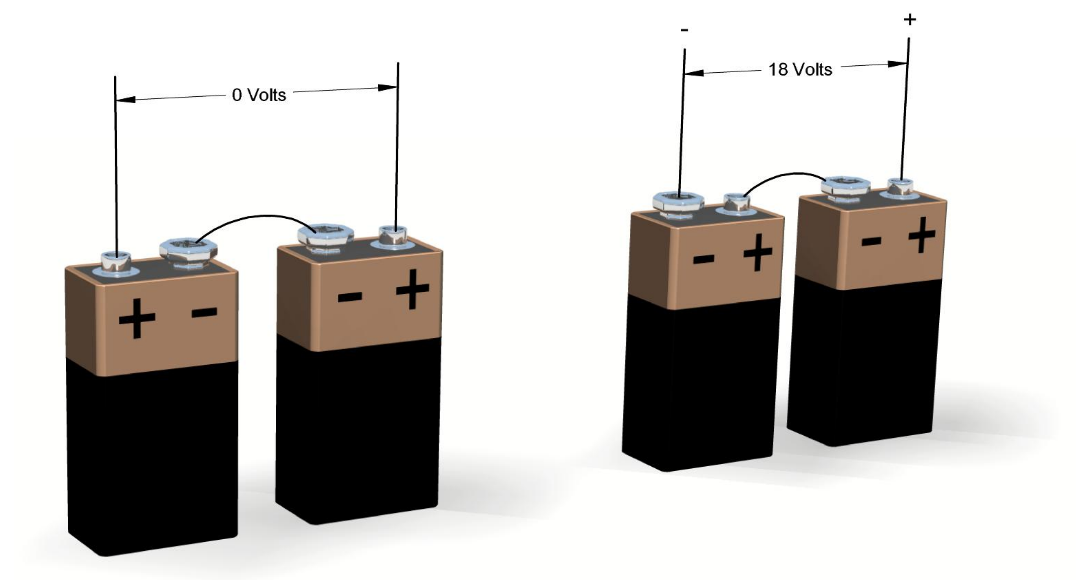


Figure 23: Left: Wrong series connection yields no output voltage. This can be confusing if the plus and minus aren't well marked. Right: Correct plus-to-minus connection gives sum of voltages.

With a battery bank, the only thing left to do in this case is to disconnect the reversed battery connect it properly. With transformers, the reversal can be corrected either of two ways: Obviously, by reversing the secondary winding connections, the problem is corrected. Or, there's another clever trick--you can swap the primary winding's leads, and this effectively reverses the magnetic field in the core. Instead of "zig-zag," the magnetic field now goes "zag-zig." The resulting voltage induced in the secondary winding is reversed also.

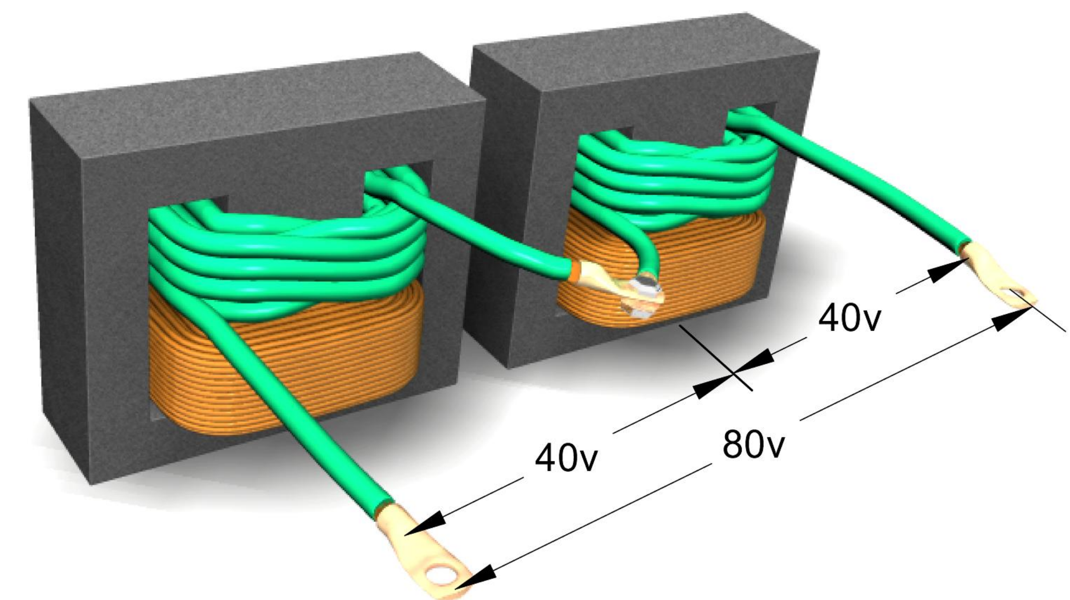


Figure 24: Series connected transformers, correctly connected to boost voltage to the sum of the outputs.

There may be situations in building your welder that you would much prefer to reverse the connections on the primary winding. One good reason that I found is that the secondary wire is thick and stiff, and when connecting the transformers one to the next, to the next, and the next, it's logically and visually sensible that the leads not cross one another, but connect so the wire that exits one transformer meets the wire that enters the next. And so if one of the transformers happens to be "in backwards" in this situation, rather than messing up our neat arrangement with the secondaries, we just reverse the primary connection on this errant transformer.

On schematics, instead of a plus and minus, there is a dot at one end of the primary winding as well as the secondary windings to indicate polarity. Note how they appear on the schematic, and that the same thought that I showed in the illustrations apply.

Primaries parallel, Secondaries series

After studying the “Chart of Transformers required” and you decide on your welder's important specifications like how many transformers will be needed of a certain size, you will be wondering how to connect them. If you are building a 120 volt welder with just two transformers, then the schematic for connecting them is quite simple and has already been shown. But if your design calls for 4 or 6 transformers, and a 240 volt supply, things get a little more complicated.

I say a only a little, because all the basics of electricity still apply. What I will provide from here is a discussion on parallel vs. series and when to apply which, and then a number of example schematics that employ different numbers of transformers.

As opposed to the series connection of the secondary windings, the primary windings in your welder are connected in parallel. It's easy to remember: P for Primary and Parallel. S is for Secondary and Series. Just like the 5 different things that are plugged into your computer's power strip (if it's like mine anyway), each of the primary windings in your welder are “plugged in” to the supply current. When you plug your computer and your monitor into a power strip, and the power strip plugs into a wall receptacle, you have a parallel circuit.

What is at work here is a principle of supplies and loads: Power supplies (outputs), when connected in parallel, need to be closely matched in voltage, or the lesser one will try to discharge the greater one.

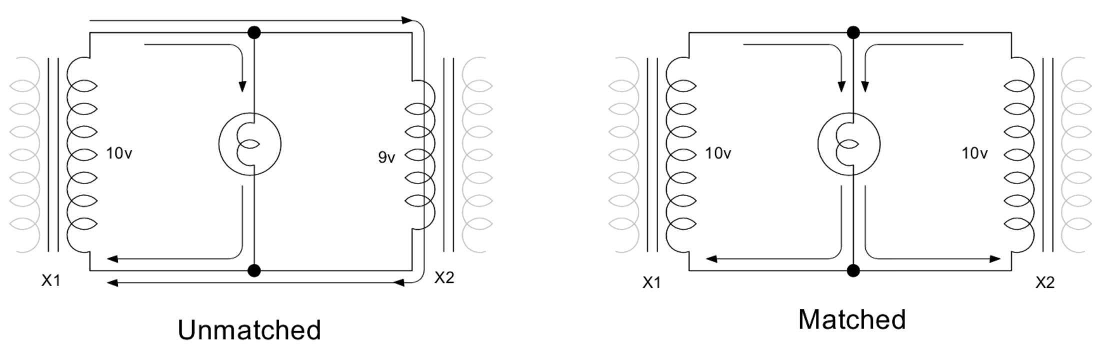


Figure 25: A problem to solve when attempting to connect power supplies in parallel. In the unmatched schematic, X2 is contributing little power to the light bulb. Rather, some current from X1 may be getting wasted through X2. In the matched schematic, both X1 and X2 are contributing equally to the load. In building a welder, this problem is avoided by connecting the secondary windings in series rather than parallel.

The solution is to connect lower voltage sources in series, and use bigger conductors to handle the resulting greater amps. You will notice that in all of the actual welder schematics in the next chapter have the secondary windings connected in series, in a sequential fashion.

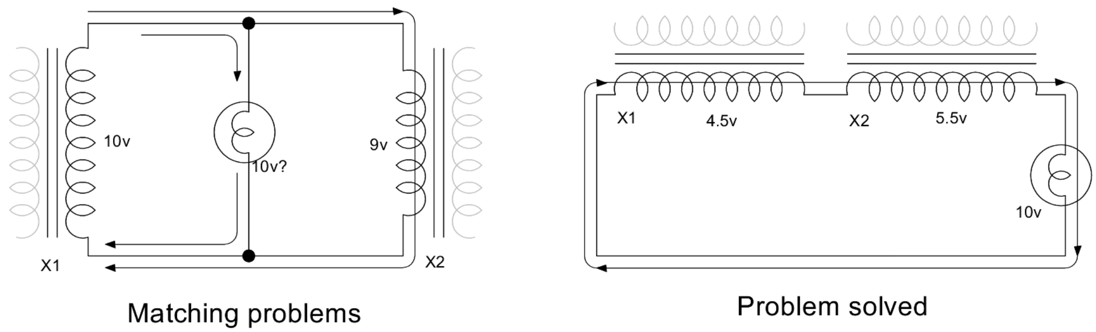


Figure 26: By connecting secondary windings in series, we effectively solve the matching problems encountered in paralleling. The current flows serially from X1 to X2, rather than "colliding" with it. The light bulb acting as the load sees the sum of the voltages, and the same amperage flows through the entire circuit.

Loads on the other hand, such as a light bulb or a primary winding that is a load on the 120v supply, can very peaceably exist in parallel with other loads. The electric meter just spins faster. Bigger loads draw more amps, but the input voltage stays basically constant, within the limitations of the power supply equipment.

Conversely, when loads are connected in series, one will try to "hog" voltage from the other one. They are each "hogging" a half of the available supply voltage, and neither one gets full power. This does not always present a problem, and later we will make good use of this "voltage dividing."

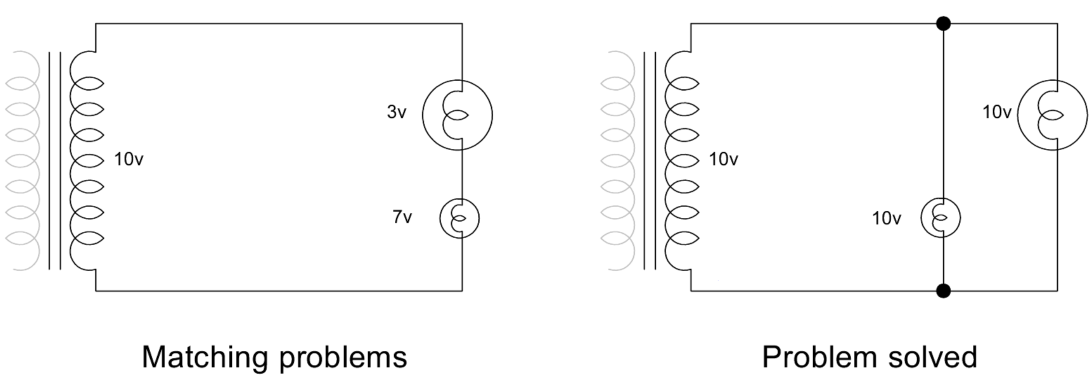


Figure 27: Two light bulbs of different sizes in series result in an unequal distribution of voltage. By paralleling them, each one gets an equal share of the voltage. In the welder schematics, groups of 120 volt primary windings are always connected in parallel.

Earlier I mentioned a good use of the fact that two loads connected in series will each hog half of the available supply voltage. With this principle, there are special configurations that can be made that allow two 120 volt loads (microwave oven transformer primary windings!) to be connected in series, and each one gets the full 120 volts! (No, there's no free energy here. My apologies to those of you over-unity people.)

The trick? The supply is 240 volts. Yep. Connect two microwave oven transformer primary windings in series, and you can operate the setup on 240 volts. But NOTE: The two transformers must be as near equal to the same as possible. Any inequality between the two will result in one of the transformers from "hogging" the available voltage, and instead of both of them getting a nice equal 120 volts each, the one having the lower resistance will have a lower voltage across it. This might leave a dangerously high voltage across the primary winding of the other. For example, one transformer might have only 90 volts at its primary, and the other 150 volts!

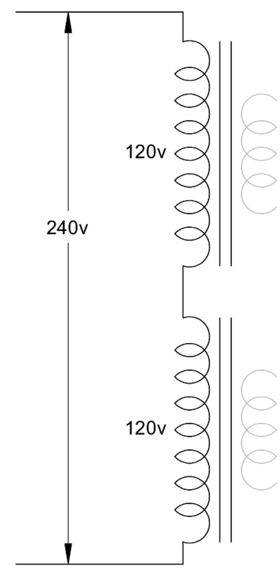


Figure 28: Dividing up the 240v supply to two 120v loads. The two transformers (and the loads on their primaries) must be very close to equal.

As you can see, there is a good purpose for introducing this series-load principle. Some of you will be wanting to make a large welder with amps higher than 70. Such a welder will need to operate on 240 volts. Microwave oven transformers operate on 120 volts. (Exceptions are European countries where 240 volts is standard.) So all these 120 volt transformers can be put to good use and will operate very nicely on "split-240" when properly configured.

Twin array for 240v welders

It's not likely that a 240-volt welder will be made with only 2 transformers. A welder this small should be run on 120 volts. The 240-volt welders will have somewhere between 4 and 12 transformers. Or you can make it as big as you like. So the next schematics show this principle of series-load applied very practically.

While I don't recommend this idea, you could actually connect these circuits to two separate 120 volt supplies. The problem is that you won't likely find a single 120 volt circuit with the amperage capacity (ampacity) to operate this

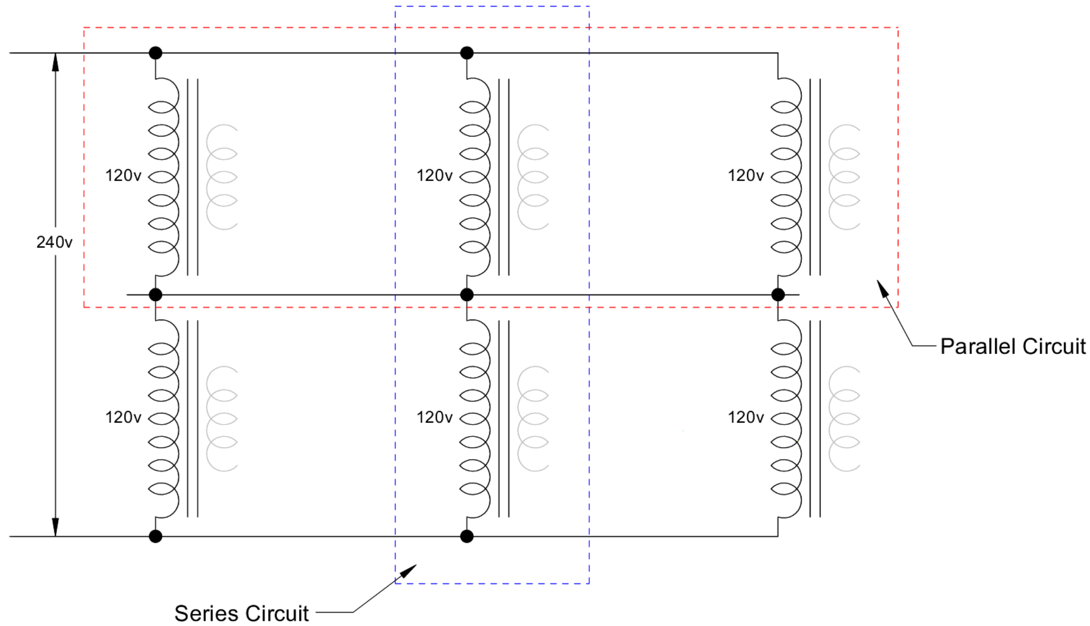


Figure 29: Two "groups" (connected in series) of parallel connected transformers will nicely divide the 240 volt supply into nice 120v pieces. The centerline connection between the two helps the dividing to be equal.

circuit. (I have had one reader that had a 50-amp 120 volt output on a Honda generator, and got away with all-120 volt operation!)

Here, we marry the two 120-volt circuits and plug them into a 240 volt supply. If the two arrays are equal in their power draw, the two sides of the circuit will evenly split the supply into equal 120 volt parts.

Some of my readers have asked if the center connection between the two arrays should be connected to the neutral wire of a 3-wire 240-volt circuit, and my answer is "no" for several reasons. One, commonly installed welder receptacle circuits are usually two-wire with ground. There is no neutral to attach to.

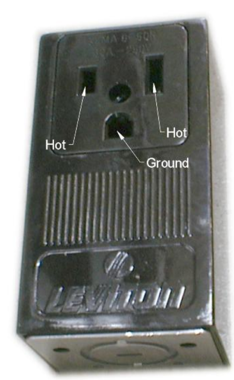


Figure 30: There is no neutral on a 50-amp welder receptacle.

Two, attaching the center connection may interfere with the control circuitry's function, discussed in a later chapter. A center neutral would force 120 volts across one side of the array. The control circuit effectively reduces the supply voltage for lower welding heats. In doing so, the split of voltage between the sides of the array, being an even 50/50, is designed to be less than 120 volts.

Series connected cooling fans

Another application of the series-load principle is the cooling fans. The welder that I built has two cooling fans, both salvaged from microwave ovens. One of them draws air through the transformer array, and the other blasts air across the controller's heatsink. Again, these fans are made to run on 120 volts. If they are nearly identical, they can be connected in series and will sing right along beautifully on 240 volts.

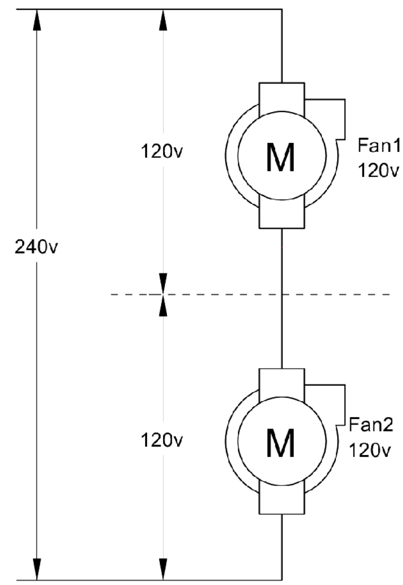


Figure 31: Two 120v fans can be made to run on 240 volts, when connected as shown. They need to be nearly identical in terms of power draw.

The Schematics

The stuff you REALLY wanted

Now for some real schematics. So far in this book, I've been focusing on calculations and principles. That is of great importance, and if you don't understand something about the electrical principles so far, please go back and re-read. Hooking up these schematics in the real world can be mighty confusing if you don't understand "why the doohickey attaches to the thingamajiggy HERE, and not over THERE."

There's one schematic for each entry in the table earlier, titled "Chart of Transformers Required." Refer to it again, and decide on a number of transformers that you are going to use in your welder, if you have not already. By looking at these schematics and noting their similarities and differences, you can begin to see a method to all the madness.

120 Volt Welder Schematics

I'll begin with the 120 volt welders, and it's not hard at all to see how a welder with 2 transformers is similar to one with 3. Then on the 240 volt schematics, again, you can begin to understand how to "scale up" the schematic, if you want to build an even BIGGER welder than what I lay out here.

You've already seen a similar schematic to the one at the right in an earlier chapter. You need two large transformers for this configuration.

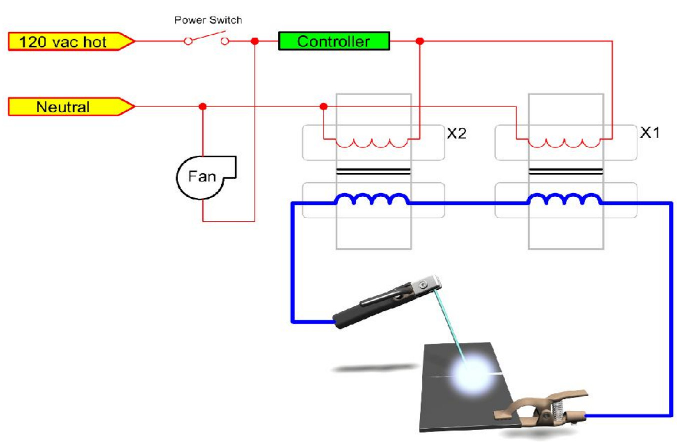


Figure 32: 120-volt, 2-transformer welder.

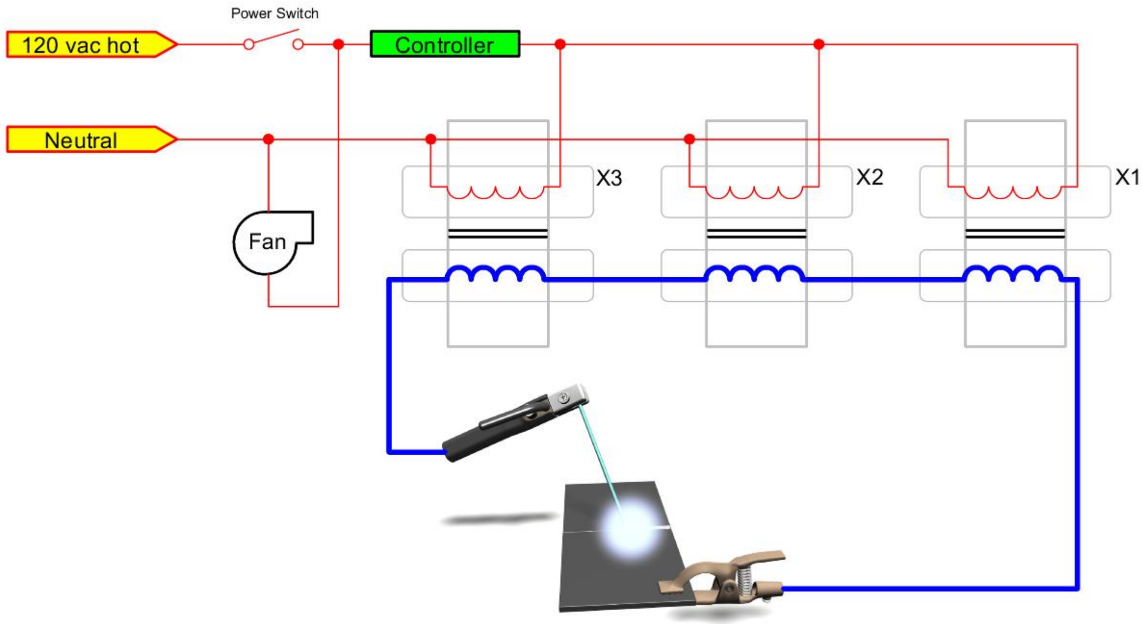


Figure 33: 120 volt, 3-transformer welder.

Note: The green box with the word “Controller” represents another schematic in the next chapter, “Control Methods.” Its detail is not shown here, to help keep the schematics uncluttered. (Did I mention doing my best to draw clear schematics?!)

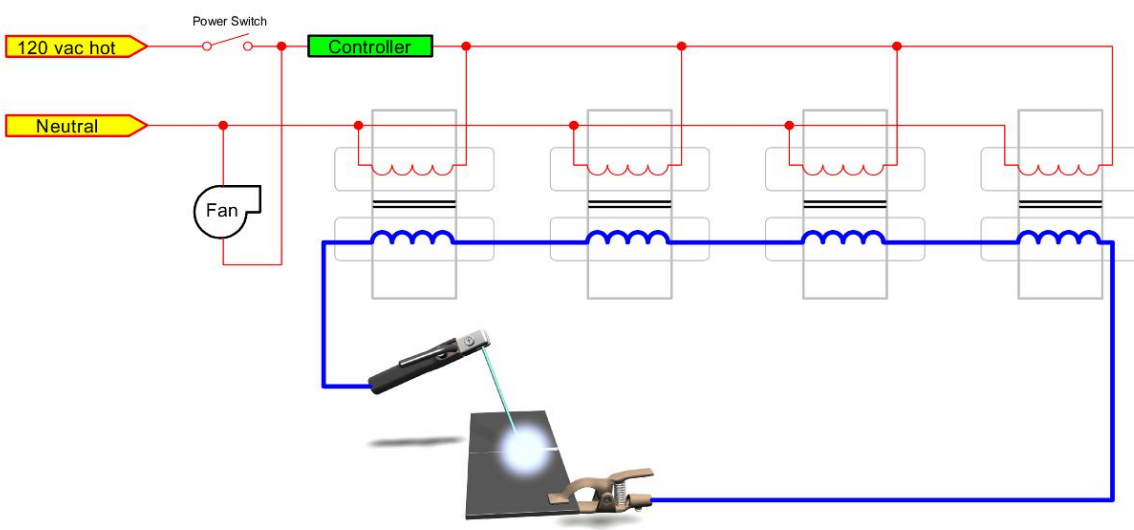


Figure 34: 120 volt, 4-transformer welder. This is not recommended, unless you have a source of 120 volts greater than 20 amps, such as a generator.

240 Volt Welder Schematics

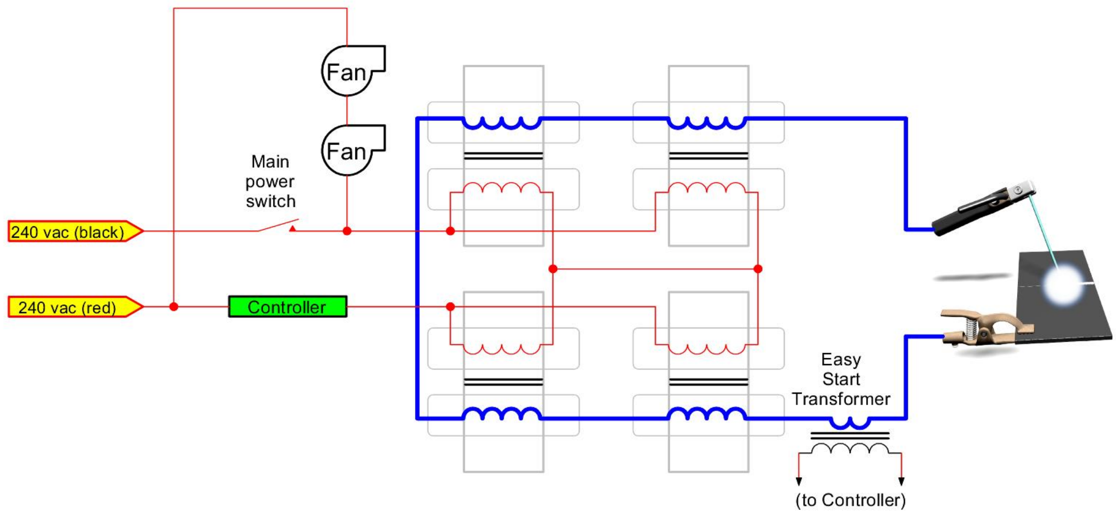


Figure 35: 240 volt, 4-transformer welder. Runs nicely from a 20-amp 240v receptacle or 240 volt, 20 amp twist-lock extension cord. A good balance of portability and welding heat.

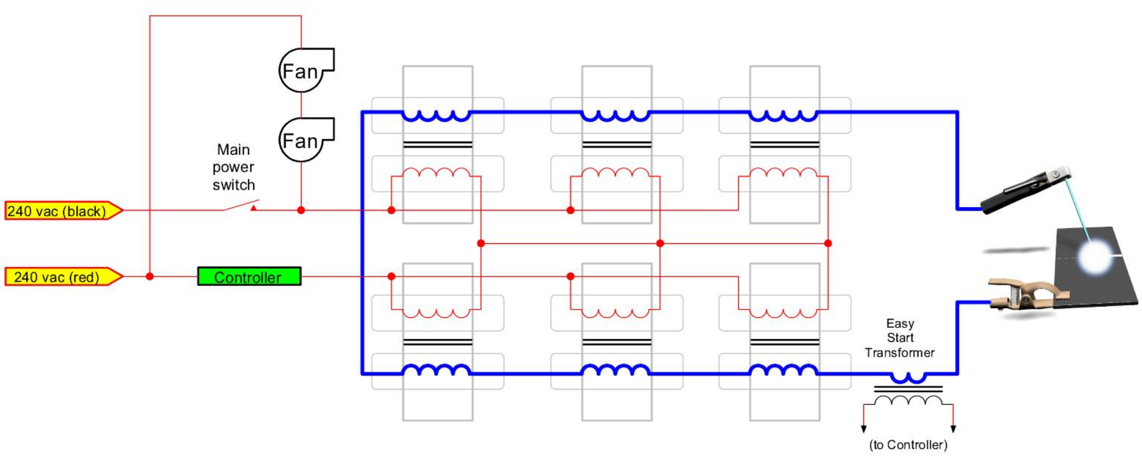


Figure 36: 240 volt, 6-transformer welder.

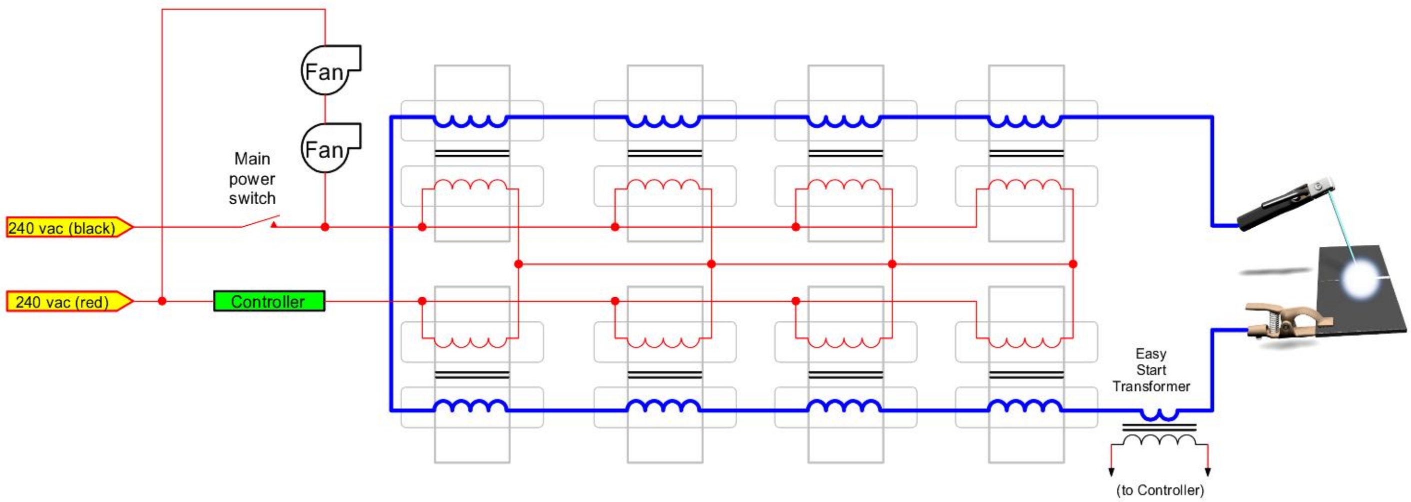


Figure 38: 240 volt, 8-transformer welder. This is the first one I built. It requires a 50-amp 240 volt circuit to operate.

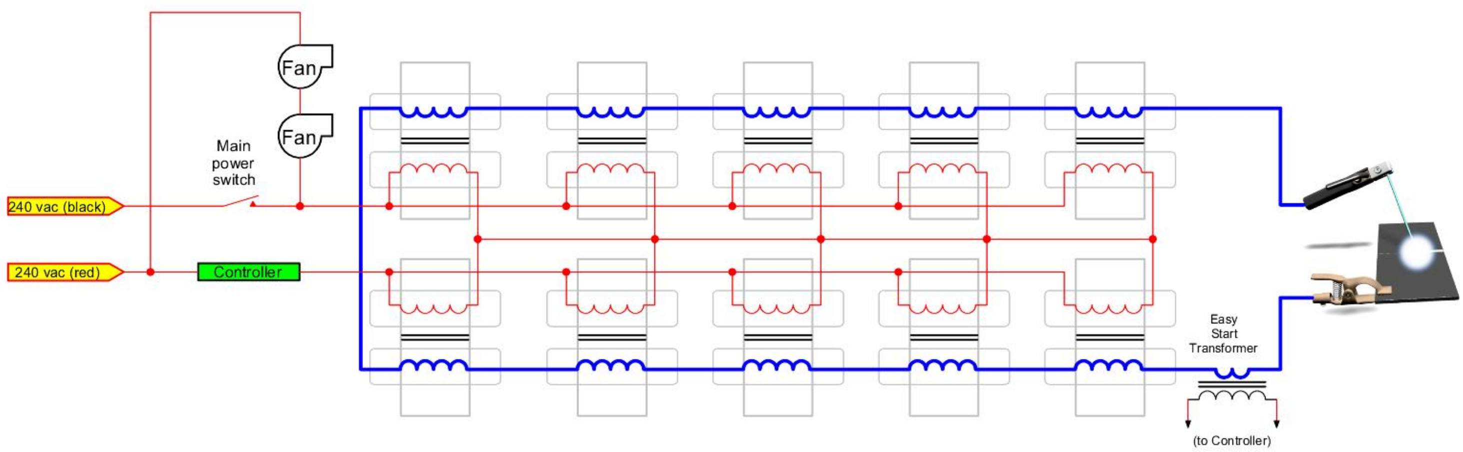


Figure 39: 240 volt, 10 transformer welder. You can operate this welder on a 50 amp breaker, but it may trip if the overall wattage of the welder is too great. This would be typically built with smaller than 1500-watt transformers.

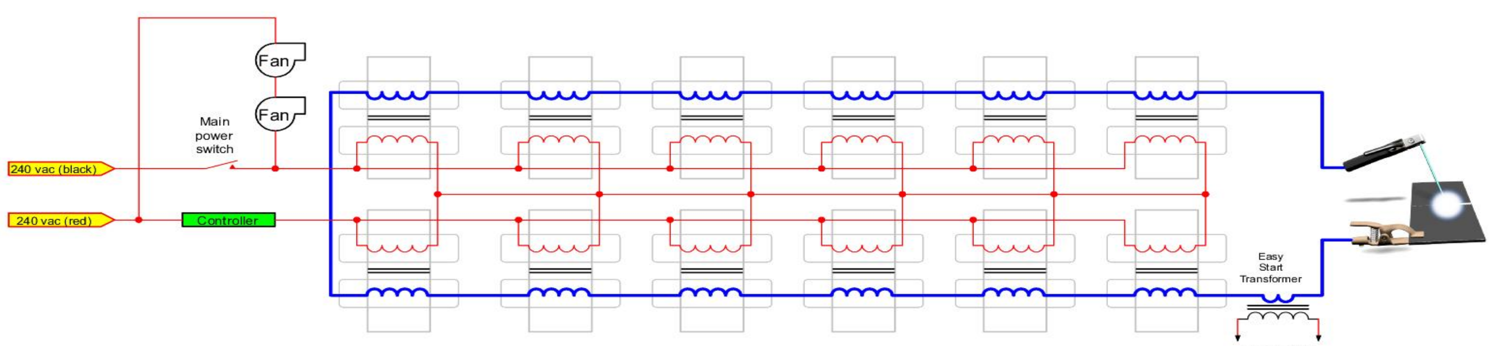


Figure 37: 240 volt, 12 transformer welder. By now you should get the idea, so I'm not going to bother drawing the 14- or 16-transformer welder schematics. You figure it out.

So you can see in the schematics how to "scale" the welder up by connecting more transformers in series. The primaries are in parallel (series-parallel for the 240-volt welders) and the secondaries are all in series.

When the time comes to actually connecting all the wiring together, you will need to take care that the polarity is correct on all the transformers. I suggest connecting all the primaries with spade connectors so that they can easily be changed to correct polarity problems. There's more information and a procedure for getting the polarity right in the chapter "Making all the Connections."

Also, in the schematic, the secondary windings are represented in a heavy blue line that just flows smoothly from one transformer to the next. In real life, connecting these heavy wires (as big as #6!) isn't quite as simple as the schematic makes it look. I used pieces of aluminum bus bar (sometimes called grounding bar) cut to lengths of 2 holes each, used that gray aluminum-to-copper connection compound goop, and torqued them down with a big screwdriver. You don't want to lose amps here, or worse, catch anything on fire with inferior connections. No tape or wire nuts, please. (Electrical tape is ok for insulating exposed connections.) More on this in the chapter "Making all the Connections."

The Solid State Controller

This section of the book discusses the need for controlling (varying) the output of an arc welding machine. There are about as many ways to vary the amperage of a welder as there are to clean a fish. The underlying reason for choosing a particular control method is always good to consider as well.

Why Solid State?

The reason I chose a solid state controller for my welder was that I wanted an “infinitely variable” (that means fine tuning, without “notches”) control. The Lincoln 225 has a knob that moves in big clicks (or clunks?) and a message below it that says “DO NOT SWITCH WHILE WELDING.” Huh? Why not? There are expert welder operators that can actually benefit by reaching back and changing the setting while laying a bead of weld! Some welding machinery also have a little dial right on the electrode holder (or “stinger”) that remotely controls the heat setting.

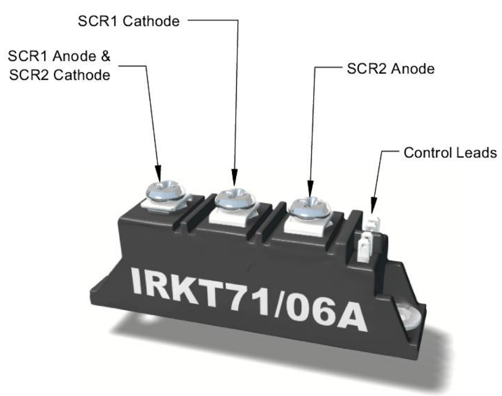


Figure 40: The internal configuration of the IRKT series SCR modules is ideal for the "back to back" circuit that is used in the solid state controller.

I also wanted a control that would work with microwave oven transformers, and it had to be cheap. It's homebuilt after all, and if it all gets too expensive, we just go out and buy a welder, not? Well, the solid state controller is actually quite inexpensive, and it adds very little bulk to the machine. The heart and soul of the solid state controller is the IRKT71 SCR module, shown in the illustration.

The IRKT series modules have two SCR's integrated into one package. By simply connecting screw terminals two and three, the two SCR's are wired “back to back” to form a power-handling control element that is very efficient. There are 4 smaller leads, two gate leads and two cathode leads. (The cathode leads are internally equivalent to screw terminals 1 and 2.)

The IRKT modules can be found online from a variety of sources. I got mine from Newark Electronics (www.newark.com), but Digi-Key (www.digikey.com) also carries them. There are quite a variety of them; be sure to get the 75 amp or the 95 amp (or greater) model, with a voltage rating of 600 volts or higher. From there it really doesn't matter which exact part number you get. I used an IRKT71/06A because that was available at the time. You could certainly get away with the IRKT91/12 or IRKT92/16A, it just doesn't matter. By searching eBay you might be able to find one of these modules very inexpensively.

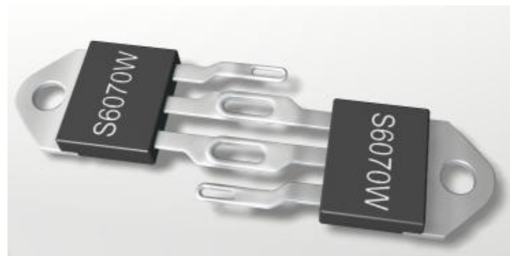


Figure 41: Connecting two "discrete" SCR's back to back. The gate leads are the smaller leads.

Also, if you are building the 120-volt welder, you don't need such a heavy duty SCR to handle the input current. For this I recommend the Teccor S6070W. I have also used this device in my aluminum melting furnace controller. They work very well for lower amperage applications. You will need two of them, because unlike the IRKT module, there is only one SCR per package. They need to be connected back to back, and installed on separate heat sinks because their mounting tab is not insulated from the internal components. Or if you want to go to the bother, you can get away with insulating the tab and mounting all on one heatsink.

That Mystic Circuit!

One of the frequently asked questions about the solid state controller is, “Where does the control circuit get it's power?” A fine question indeed, and a tricky one. By looking at the schematic, there doesn't appear to be a power source for the control circuitry.

The secret is in the gates of the SCR. In an un-triggered state, the SCR's have a voltage present on their gates. This is plenty to trigger the SCR's. But when sufficient current is drawn by the control circuit at the moment of triggering, this voltage is “shorted out” and one of the SCR's is triggered.

SCR stands for Silicon Controlled Rectifier. An SCR is basically just a diode. It has a layer in it, however, that blocks conduction in any direction until a break over voltage is applied. This layer is referred to as the “gate.” Only a small current needs to be applied to this gate to trigger the SCR into conduction. Then it becomes a diode, and stays triggered until the amps quit flowing. On DC, this would be indefinitely until the power source was

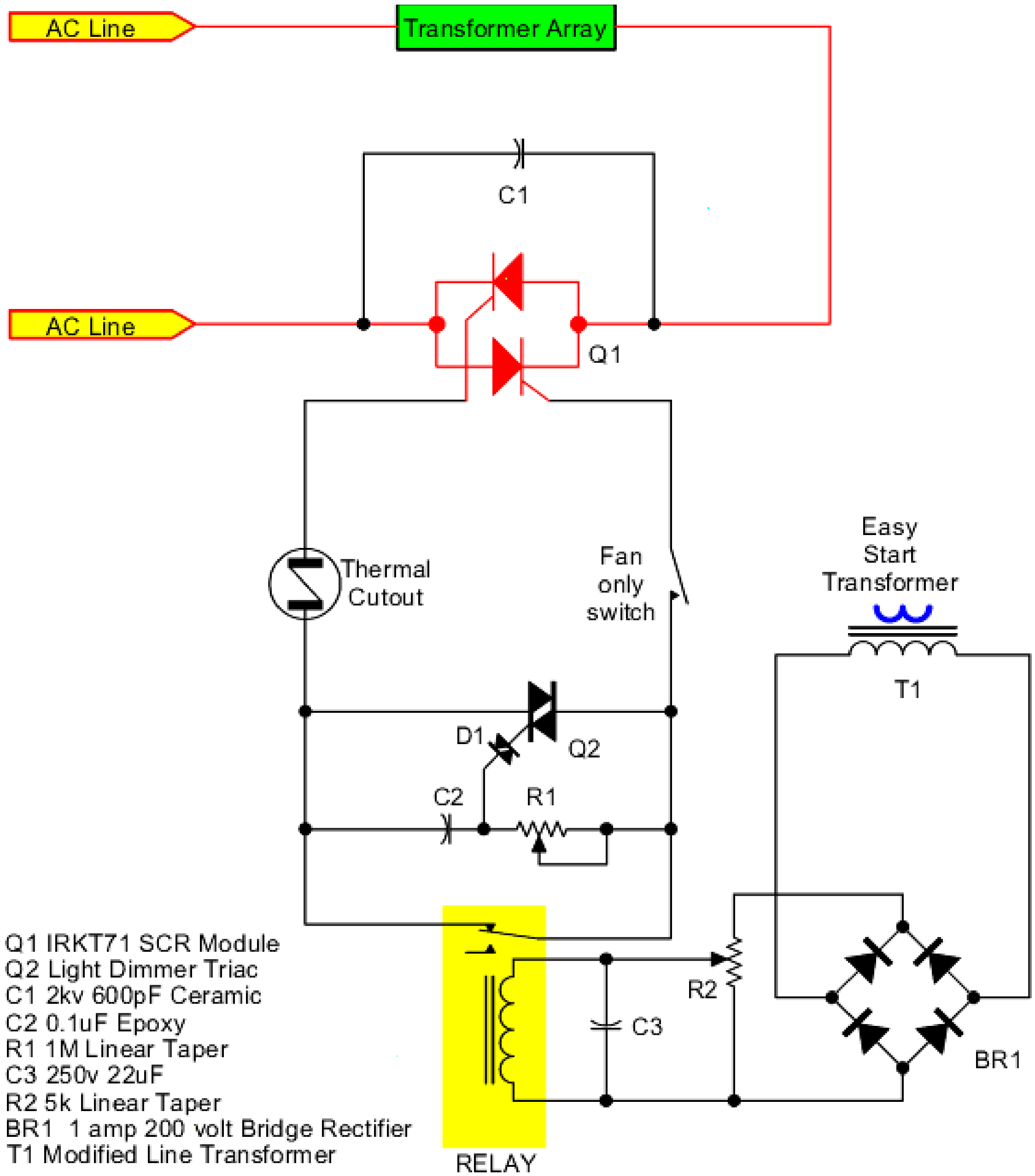


Figure 42: Controller schematic. It is not readily evident where the control circuit gets its power to operate, but the secret is in the SCR's gates. You might want to print out this page for reference as you read the explanation of this schematic.

removed. On AC, this moment comes 120 times a second, at the zero-crossing of the alternation, when the voltage is at zero on its way to "alternating" from positive to negative or back again.

By adjusting R1, the triggering level on timebase capacitor C2 is reached earlier or later, triggering Q2 earlier or later in a given 60Hz pulse. Because the current AC, the circuit needs to operate on plus or minus, and it does! This is an amazing thing and there are a few schematics out there that use a principle like this. Because our brains tend to be wired with a better understanding of plus and minus like batteries use, it can be difficult at first to spot the underlying principle of a circuit like this.

Some of my readers have suggested I make the controller with a 555 timer in monostable mode so that it is easier to understand. Then I would need additional circuitry to detect the zero crossing to begin the timing cycle of the 555, which in turn would require an optocoupler to get its signal across to the SCR module. In addition, there would need to be a power supply circuit to power up the 555 timer, and someone thinks all this would be easier to understand? I don't think so.

How it works

I'll try not to bore you with too long of a dissertation on the operation of the circuit, because I'm sure you want to get on with the construction of your home built welder.

The voltage present on the SCR's gates begins to charge timebase capacitor C2 through variable resistor R1. Soon this charge is enough to trigger Q2, a triac. The triac snaps into conduction and delivers a triggering pulse to one of the SCR's.

Depending on where R1 is set, this happens earlier or later in a given positive or negative pulse of the AC sine wave. The charge on C2 is drained, and when the zero point is reached as the sine wave begins its descent into the negative half of the alternating current cycle, it begins to charge in the opposite polarity, until it reaches the triggering level once again in the negative half.

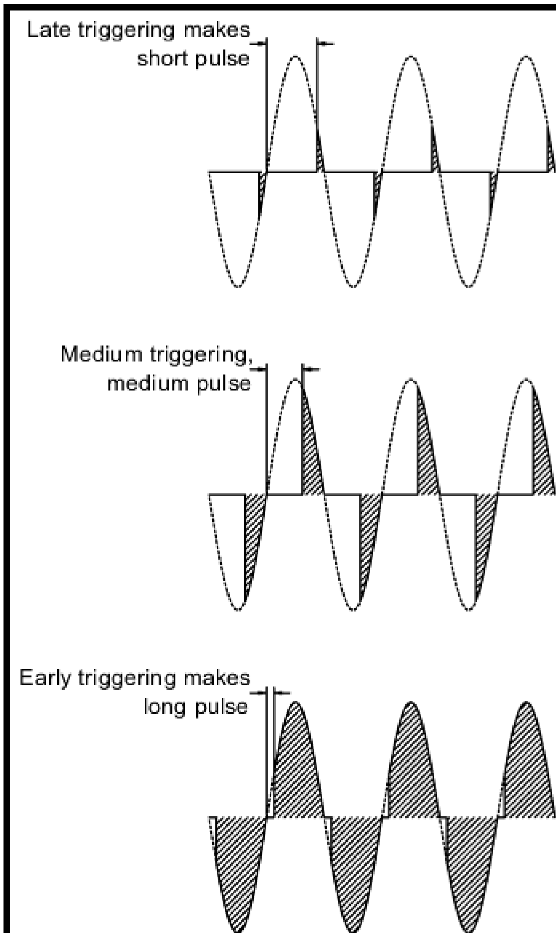


Figure 43: By adjusting potentiometer R2, the "phase angle" of the triggering moment is changed, resulting in a longer or shorter pulse of power.

And so on it repeats, with a lower resistance on R1 charging C2 faster to reach the triggering voltage earlier for a longer pulse of power, or a higher resistance charging up slower to reach the triggering voltage later, for a shorter pulse of power.

Since the controller is varying power by varying the width of the pulse, this circuit could be referred to as a pulse width modulator, or PWM. It is very efficient, because the circuit is not “resisting” current flow like a rheostat (or large variable resistor), but rather sending wider or narrower spikes of power. This is a very popular and effective method of controlling large amounts of alternating current.

The other components

You may be wondering about the other components in the circuit. C1 has a function called “snubbing.” A capacitor takes time to charge, as we've already discovered. It also keeps the voltage from too rapidly rising across the leads of the SCR module. This is important because noise or spikes of voltage here will cause the SCR module to trigger when it shouldn't. So C1 limits the rate of rise, or dv/dt across the SCR.

The “easy start” circuit also deserves explanation. It senses the current flowing through the welding cables, and keeps the welder on full power until the arc is struck. The surge of current induces a voltage in the secondary winding of the easy start transformer, and energizes the relay. The relay is wired into the circuit with the points “normally closed.” This simply keeps the gates of the SCR triggered constantly.

Then when the arc is struck and the relay is energized and opens, all of the wonderful timing and pulse-width power controlling functions explained earlier go to work. The charge on C2 is allowed to build until triggering...and so on. The bottom line is that you have full power to make the arc easy to start. The sensitivity of the easy start circuit is controlled by R2.

Component values

IMPORTANT: Please note that many of the parts in the solid state controller are also salvaged. This is especially important to note with the easy start transformer and relay.

The values of C1, C3, R2 especially are subject to variation with differences in the parts that you put into use for the easy start transformer and the relay. Depending on the current required to energize the relay, you may need more or less than a 5k resistor for R2. And depending on this current, it C3 may need to be made smaller or bigger so that the easy start circuit does not energize too quickly, before the arc is established (this all happens in microseconds, you just have to try different values to determine what works for you).

As I said toward the beginning of this book, this is not a Heathkit project where everything is very absolutely defined from the start. You may have to use your gray matter just a bit to figure some things out along the way.

Also, I recommend for R1 a 1 megohm variable resistor (also called a potentiometer). This will vary depending on whether you build a 240 volt or 120 volt welder. This value should be 500k for 120 volt welders. It affects the range of control that you have by turning the potentiometer from zero to 100%. Too low of resistance in this component (fewer ohms) results in the low end of the dial not being as low as you want it. Of course, you won't be welding on 5 amps, so it's better to have a potentiometer that does not reduce the power all the way down to zero, but closer to 25% or similar. For example, if you build a welder that has a range of 50 amps to 200 amps, you want the dial to adjust the power output from 25% to 100%.

Calibrating the control dial

I calibrated the dial of my welder in open circuit volts rather than amps, because I had no method of testing amps at the time. If you have a clamp on ammeter, have a helper scribe notches on a circle of paper taped under the knob of potentiometer R1 while you weld at different settings. These notches can be marked with the amperage that the welder was drawing at the different settings. Below is a sample dial that you can print out for this calibration process. When you done, you can copy and paste the dial into your favorite graphics program and very neatly print the numbers onto it to make a permanent dial for your welder.

Note that this template is marked in percent gradations, these are not values that mean anything except to denote position for calibration purposes.

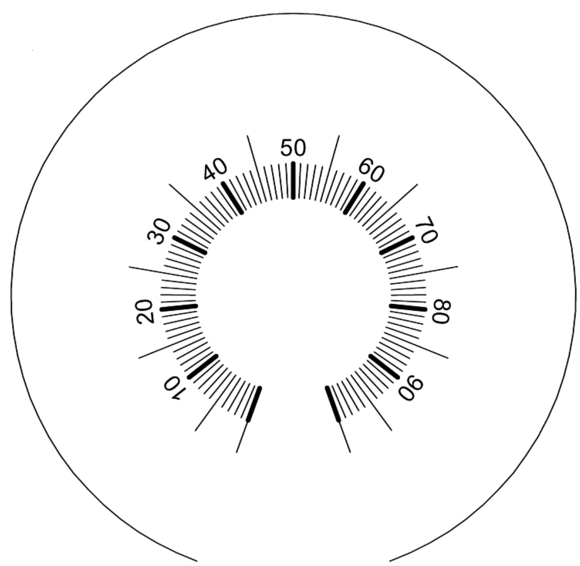


Figure 44: Print this page and cut out the dial to use as a calibration template for the knob on R1.

Other Control Methods

If you are just not at all comfortable with building the solid state controller, I pity you. Just kidding, not really. There are other ways that the welder can be controlled in the range that you need. For the 120v welders, there is not much range to be controlled anyway, so one of these alternate methods may be right for you.

Transformer Tapping

In building a 120 volt welder, the total output amperage is limited to about 70 amps, and you won't want to weld much below 50 amps anyway, so it is not hard to vary the power simply by "tapping" into one of the transformers at one or two locations in the secondary windings.

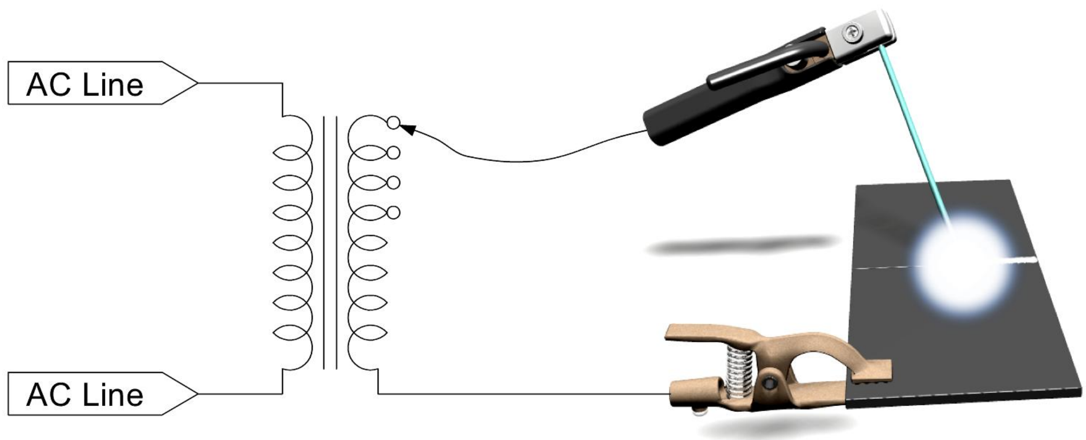


Figure 45: Rudimentary welder that allows you to select current from a limited number of choices. In a welder built with a quantity of microwave transformers, you might tap between the transformers rather than within the windings.

There are some disadvantages to this control method. In some designs the power lead has to be unfastened and re-fastened to a different terminal on the welder. In other designs, such as the Lincoln 225, there is arcing at the switch if it is changed while welding, so the put a little sign by the dial that says "DO NOT SWITCH WHILE WELDING." Most of us don't switch the power while welding anyway, so this is a fairly decent control method for most of us.

Magnetic Control Tricks

There are also ways we can interfere with the magnetic magic that takes place in a transformer to control the power output of a welder. Magnetic flux (or flow) is a very interesting thing. It can be diverted and controlled just as well as electricity.

The methods I outline in the following texts and illustrations are methods that I have actually seen in use in commercially available welders. For varying reasons, usually cost of production or reliability, one of these methods is chosen over another when a manufacturer designs a welder.

Movable shunts

In a transformer, the magnetism flows in a circle out of the coil, around the end of the coil, loops back around the outside of the coil, and back in the other end of the coil like you saw in an illustration earlier. If the magnetism can be diverted so it loops back into the primary winding with very little of it going through the secondary, then the power output can be limited.

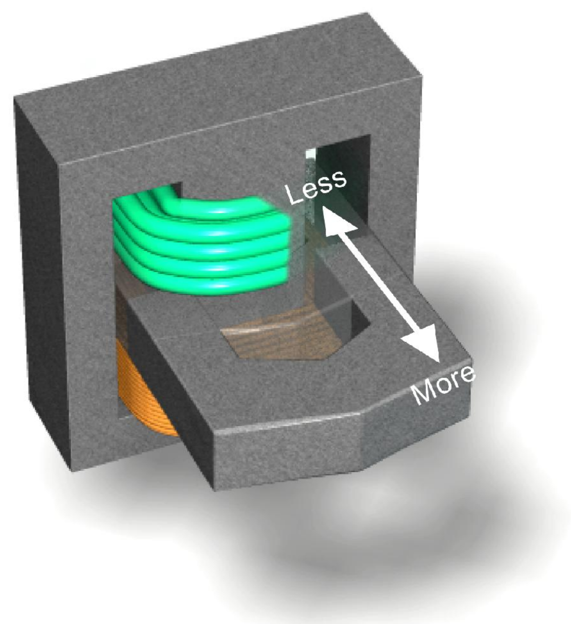


Figure 46: The sliding shunt method of controlling power through the transformer.

The Hobart StickMate LX pictured earlier uses this method of infinitely varying the welders output over a certain range. This is a good method and it can be changed while welding, but changing the heat very much requires many turns of a little crank.

In building a welder with microwave transformers, you will notice that there are shunts between the primary and secondary windings. But the shunts need to stay in place; the primary windings will draw too many amps with the shunts not in place because of not enough of the magnetism returning to the primary winding to provide back e.m.f. (electromotive force) and satisfying the original amperage draw characteristics of the transformer.

The other problem with trying to implement this method with microwave transformers is that the transformers are small and you would need to come up with a mechanism that can move a whole bunch of little shunts, all in perfect alignment. I think my solid state controller is easier to build...

Movable windings

Craftsman and several other brands of welders use this technique for varying the output. It is similar to the moving shunt method in that the power output is varied without notches—infinitely variable.

In this method, the secondary winding is mounted fixed and the primary winding (because the leads are smaller and more flexible) is moved closer or farther from the secondary winding on a screw mechanism.

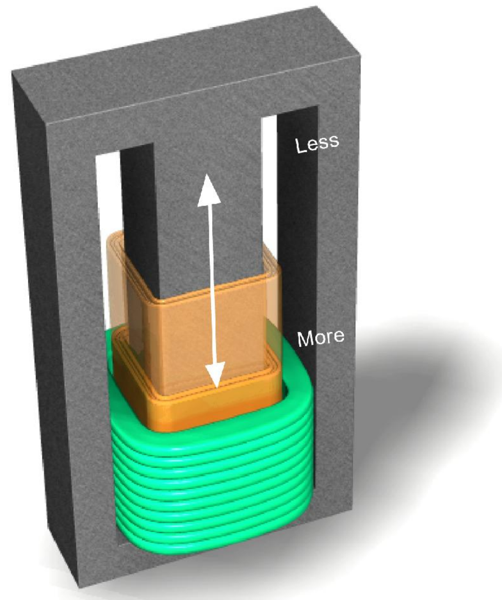


Figure 47: Movable primary method of controlling welding amperage. The closer together the primary and secondary are, the more power is transferred.

Movable core reactors

Some of the cheap 120 volt welders use this method of varying the power. A "reactor" made with a transformer core and only one winding (no secondary) is provided where the core can be moved in or out of the winding.

Because the magnetic permeability of air and iron are different, the magnetic saturation point of the reactor is changed by moving the core. A reactor coil begins to conduct amperage only after this saturation point is reached, and it sort of "triggers" and conducts. This saturation point is sooner in time with the iron core out of the reactor coil, and later with the core fully inserted.

Saturable core reactors

This method is similar to the solid state controller in that there are no moving parts. It also shares some concepts of the movable core reactor, such as the magnetic saturation time being varied.

In this method, a reactor core has a main winding and a control winding. This is not the same as a primary and a secondary; their functions are totally different from primaries and secondaries. Instead, the control winding has a small amount of DC current applied to it, partly saturating it magnetically. Then when the pulse of AC comes through, the core reaches full saturation and then conducts full current. By variably saturating it with the direct current, the effective saturability is varied and the resulting output is varied.

Here is one example of a saturable core reactor system. There are others, but I give this example because it is easy to understand what happens.

In this example, there are two coils and two rectifiers. They are configured so that each "half" of the AC waveform is alternately controlled by each of the coils. This allows the coils a magnetic recovery time to "unsaturate" between positive or negative peaks, and a wide range of control is achieved with a small DC current applied to the control windings. The cores are special air-gap cores (powdered iron in some cases) to resist magnetic saturation, to help them recover between cycles.

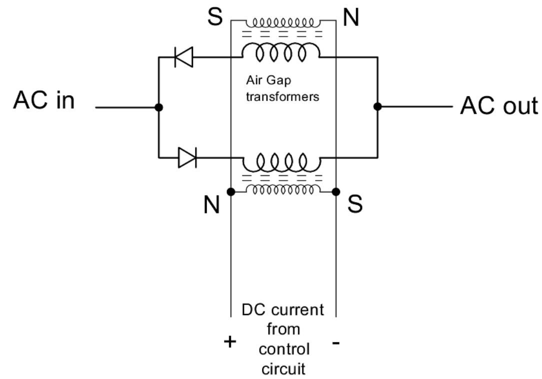


Figure 48: Saturable core reactor system using two transformers and two rectifiers. The input and output are both alternating current.

Furthermore, if the saturable core circuit is on the secondary winding side (and most of them are), the rectification circuitry to produce direct current can be integrated. Output filtering is already performed by the saturable cores, so no filter choke is needed.

I've seen some wire feed welders use the saturable core method of control, and my general observation is that it tends to be on the "higher end" of welders.

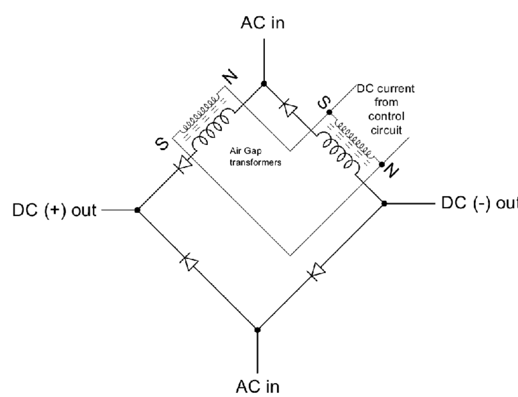


Figure 49: Integrated saturable core control circuit and DC rectification.

The AC/DC Welder

Your AC arc welder can be easily upgraded to produce DC (direct current with plus and minus). Different types of welds and more challenging welds can be done with direct current. There are two main things to add to your welder to make it a DC welder: the rectifier bridge and the filter choke.

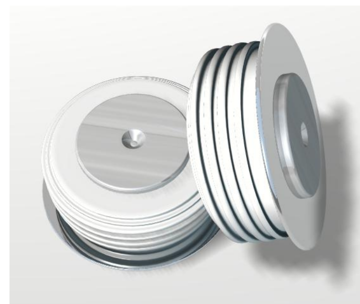


Figure 50: Hockey-puck style rectifiers.

There are several types of rectifiers you can use to build a rectifier bridge to convert the AC that your welder's transformer (array) makes to DC.

The Rectifier Bridge

To get DC from an AC welder, we simply need to convert or "rectify" the pulses of alternating current so they all pulse in one direction, hence the term "direct current." This is most easily done with four diodes wired up in a special configuration, or "bridge." I recommend that you go to eBay or other source of surplus electronic parts for these diodes. They have to be BIG diodes, capable of handling the output of your welder. If your welder makes 200 amps, get diodes that can handle MORE than 200 amps. Calculate in a safety factor, and make sure they can handle a few volts higher than the 80 volts that your welder makes.

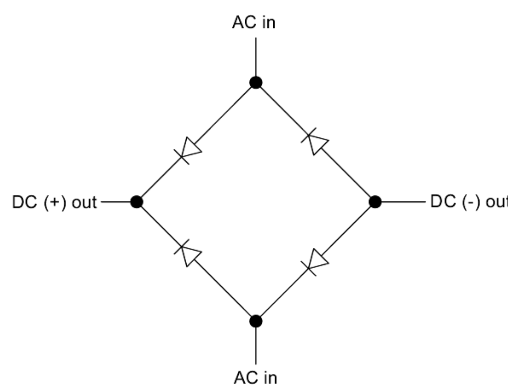


Figure 51: The rectifier bridge. Alternating current in, direct current out.

When connecting these diodes in real life, it looks a bit different. If you use the "hockey-puck" type diodes, I advise you to stack them up one on top the other with plates of copper or aluminum between them to attach the heavy welding cable to for connections. These plates should be big enough to serve as heat sinks as well, unless you plan to liquid cool them. The heat sinks need to stay electrically insulated from each other.

See the exploded view for detail on insulating the mounting hardware from the heat sinks. Rubber hose can be used to run the long bolts through to keep them from contacting the intermediate plates. The top and bottom plates are electrically connected by the negative terminal, so no insulating is needed at these points. Consult the diode manufacturer's specifications to determine heat sink area and mounting specs. Note that white heatsink grease will probably not work because the faces of the diodes that get pressed against the heat sinks also serve as the electrical connection, and white heatsink grease may interfere with a good connection.

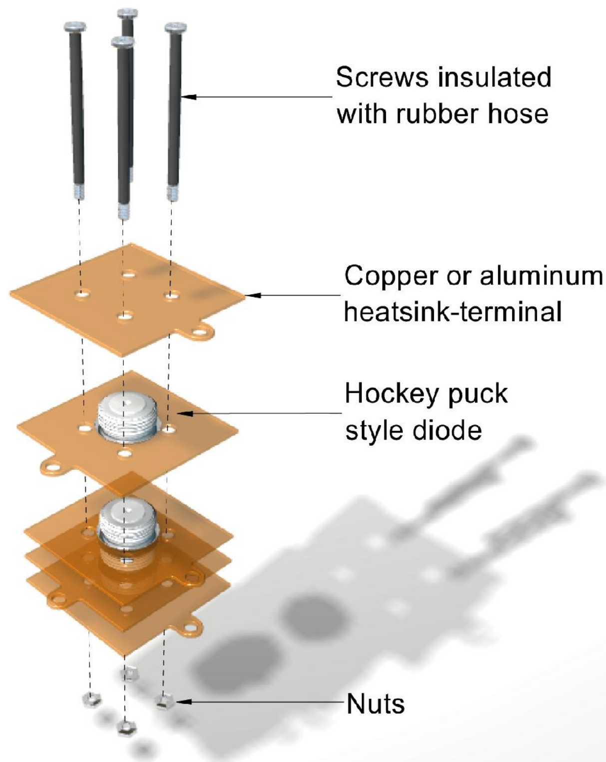


Figure 52: Exploded view of the hockey puck style bridge rectifier assembly. Note that neither the heads of the screws nor the nuts need to be electrically insulated from the top and bottom heatsink plates.

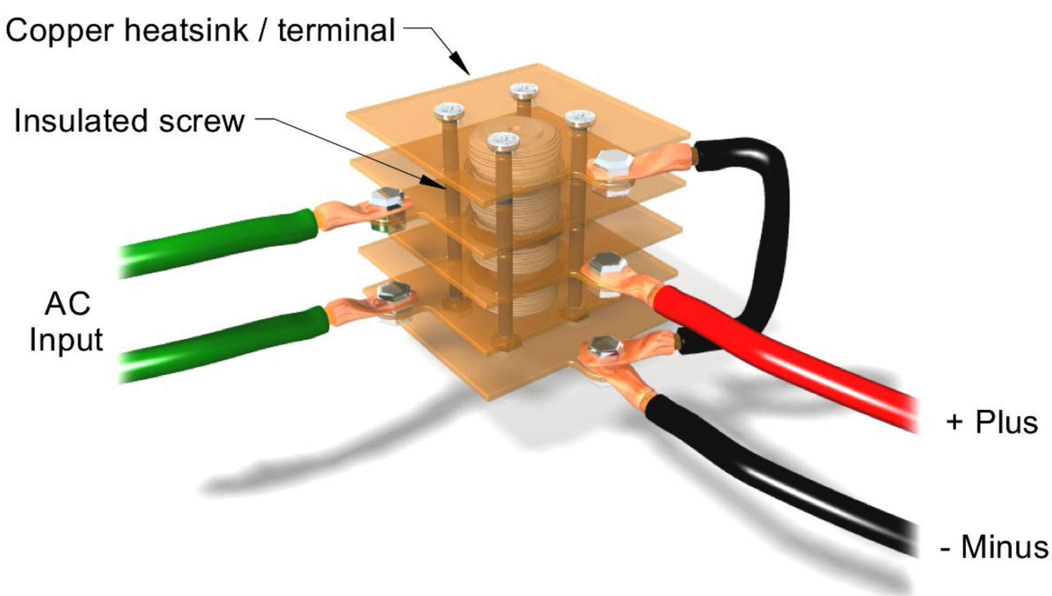


Figure 53: Copper heat sinks and "hockey puck" style diodes assembled into a rectifier bridge. Note that the top two diodes are oriented with anodes up, and the bottom two are oriented anodes down. Test your configuration with a light bulb in series with the input before applying full power.

If you use the stud-type rectifiers, they must be mounted on heat sinks that are properly insulated one from another. Some stud rectifiers have a “pigtail” on them with a screw-eye for attaching to fixed hardware. Others have just that—a stud. Attach your own “pigtail” made up of very flexible welding cable to these. Never attach anything rigid to these studs. The heating and cooling expansion can internally break the diode chip loose from its die and destroy the device.

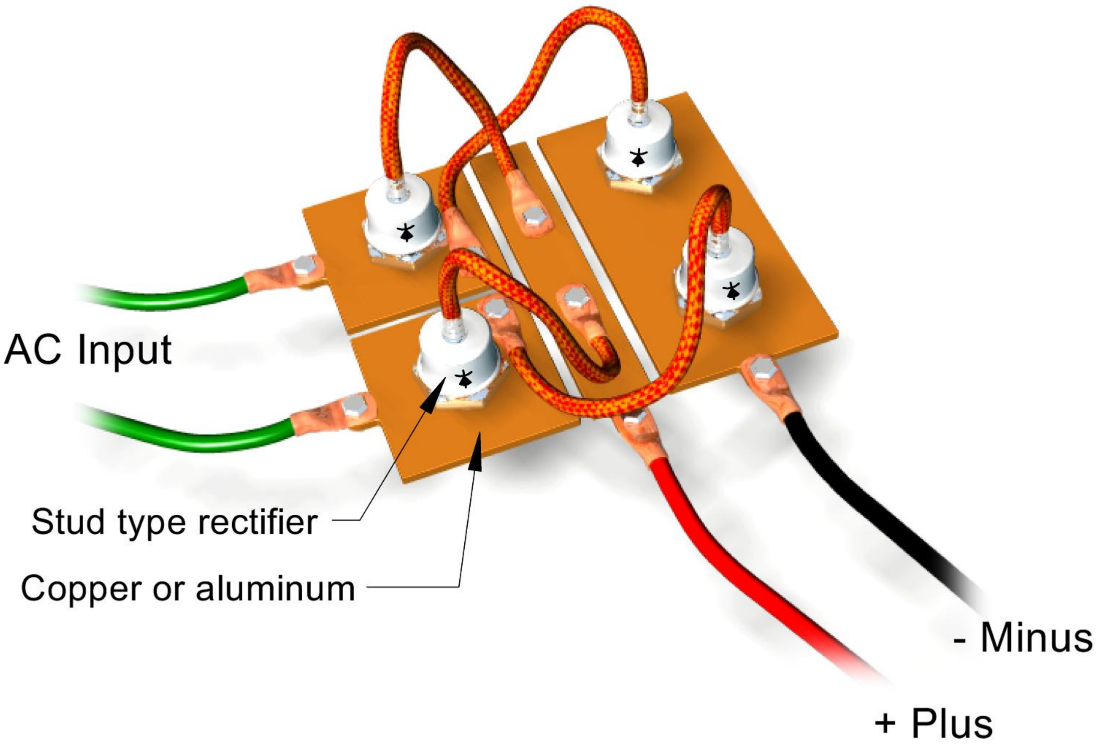


Figure 54: How to mount stud-type rectifiers to their heat sinks. The heat sinks must be mounted in such a way that they are insulated from each other and from the frame of the welder. Always test your configuration with a light bulb in series with the input.

The Filter Choke

The voltage waveform that comes out of the diode bridge is not quite the straight line of direct current that you expect out of a battery. It has little gaps in it. These gaps are big enough that, as far as the arc is concerned, you might as well be still welding on alternating current. So a special coil called a filter choke needs to be put to use to fill in these gaps and to help the current be more “clean.”

The way the reactor works is that it absorbs energy (by magnetically saturating) during the “on” part of the pulse of DC from the rectifier. Then in the short “off” spikes it releases the energy to fill in the gaps.

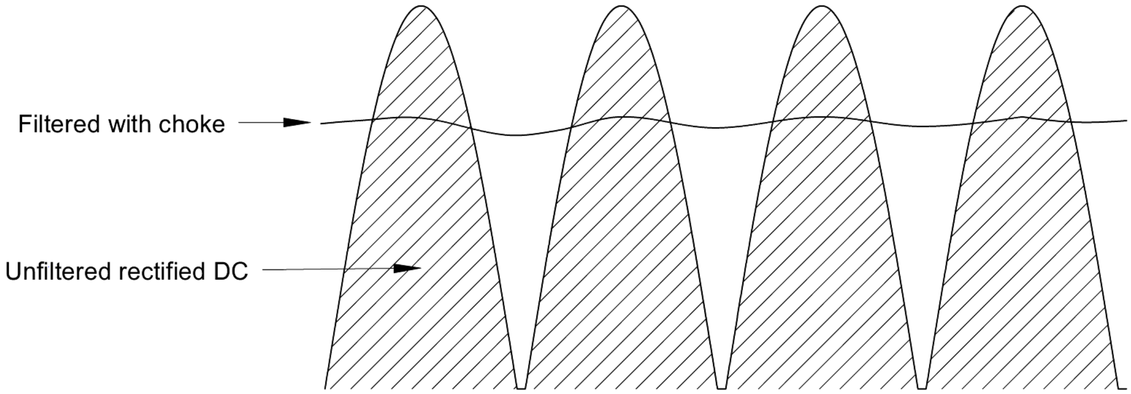


Figure 55: Waveform comparison of unfiltered rectified DC with choke-filtered rectified DC.

The choke needs to be put in series on the power lead after the rectifier, as shown in the schematic. (Note: if you are adapting your DC welder for high-frequency TIG use, you need to put a capacitor across the leads downstream from this choke. This keeps the filter choke from absorbing the high frequency pulses from the TIG attachment. This is outside the scope of this book, I may address TIG and high frequency in a future edition.)

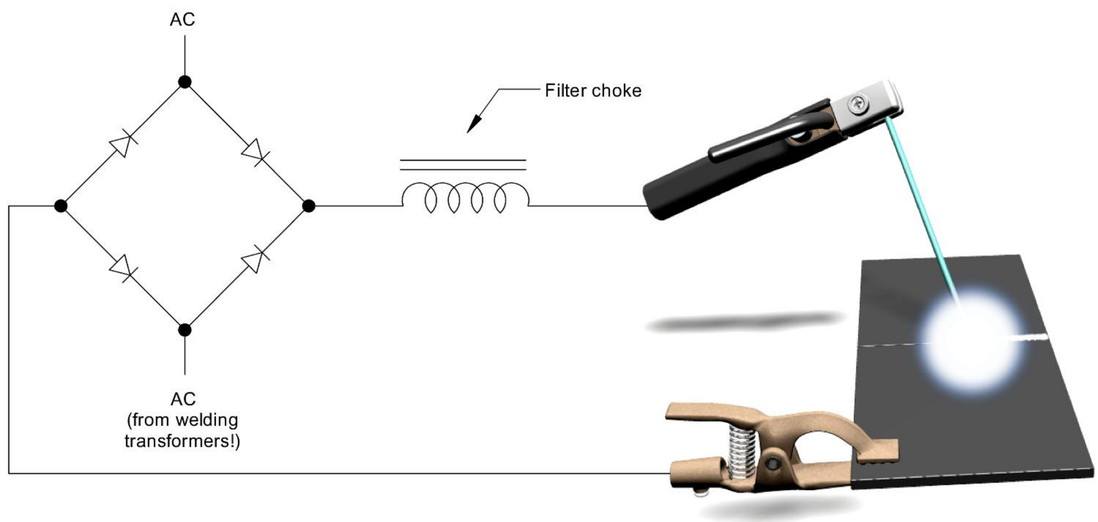


Figure 56: Schematic showing the location of the filter choke. Note that it does not have to be on the positive lead, it can be on either the positive or negative lead. Also note that with DC welding, the polarity of the electrode varies with the type of weld being done.

To make a filter choke, just take a microwave oven transformer, and remove all the windings, and the little shunts that were between the windings. Then wind it full of the same size wire you used to wind the primary windings. You may need two chokes like this, in series, to be effective.

Building the Cabinet

Cabinet construction materials

This is more of the "non-technical" part of building your own welder, but it is probably the most fun part because you can begin to see your creation coming into being. You can paint your welder industrial gray, or you can paint orange flames on the side. Or those of you artsy-type sculpture-welding folks can paint them pink and put flowers and flamingos on it.

All this aside, the cabinet of your welder serves some important purposes. You are building a heavy duty piece of machinery and you don't want it falling apart. The cabinet also directs the flow of air from the cooling fans where it should go.

I built my first welder mostly out of left over plywood and a piece of pressure treated 2x12 from a construction project. Wood is an excellent material to build cabinets. Metal is a better choice, but it is harder to work with and is generally not as readily available. I used some flat sheets of metal from the shells of salvaged microwave ovens for the side panels of my wooden-cased welder. These side panels fasten with just a few screws, and remove easily for inspection.

One of my readers used an old computer case to build a small 120 volt welder in. This is very convenient for smaller welders and is also an "environment friendly" thing to do as there is an abundance of old computers filling the landfills. Rather than burying this perfectly good steel, people should put welder guts in their old computer cases!

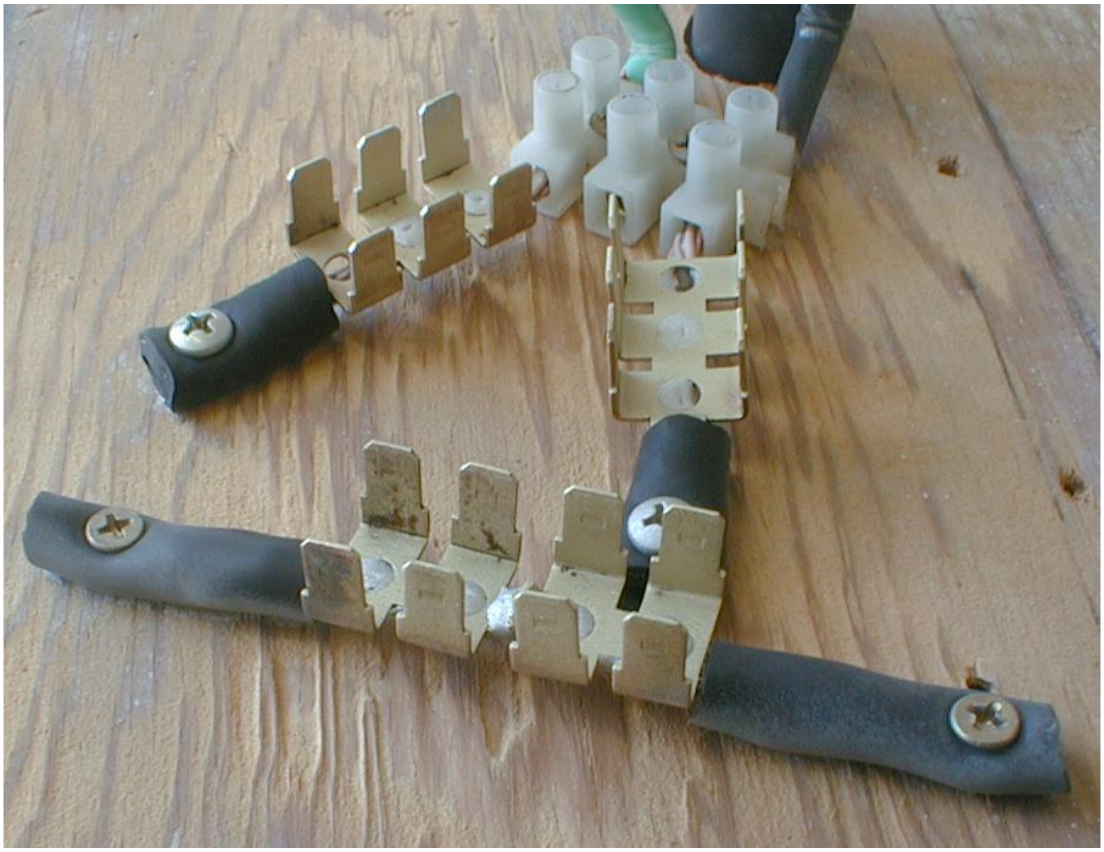


Figure 57: The main terminal lugs for my welder's power distribution are "shock mounted" on pieces of rubber hose. Rubber is an excellent insulator, as well as being able to take some heat.

Electricity and wood?

Some of my readers may justifiable argue and debate my use of wood as an enclosure for anything electrical. Well, let's just suffice it to say that we're not submitting a home made welder to Underwriter's Laboratory for a “UL” sticker. But I don't throw all caution to the wind. I am careful to insulate my electrical components from the wood they are mounted to. You can be, too.

In building a wooden cabinet, I recommend starting with a piece of 2x12 pine for the base. (The exact dimensions of a two-by-twelve is actually 1-1/2 by 11-1/4 approximately.) This will provide a solid frame for your array of transformers, which will turn out to be quite heavy. My welder has 8 large transformers, and the total weight of the welder is about 140 pounds! I got some wheels from a castaway office chair and mounted to the underside of this 2”x12” so I can roll it about in my shop easily. For smaller welders that can be carried easily, the rubber feet off of one of your salvaged microwaves will do fine.

Dimensions for the 8-transformer welder

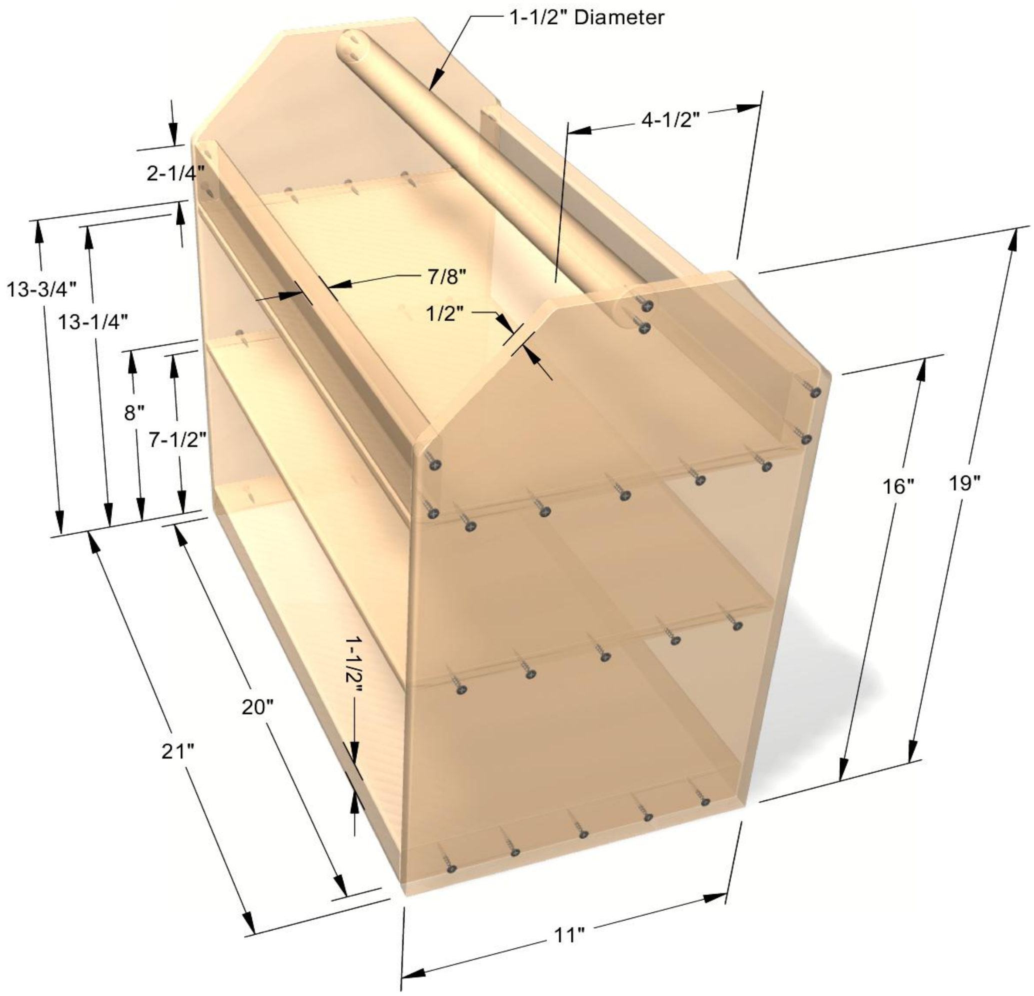


Figure 58: All the exact measurements from the cabinet of the 240-volt, 8-transformer welder that I built. The base is a 2x12, and the middle and top decks are 1/2" plywood. The ends are also 1/2" plywood. The carrying handle is a 1-1/2" hickory dowel. The sides of the top "tray" is a 1x6 ripped in half.

Keep wiring in mind

Lay out the transformers on the 2x12 base with enough space to get to the wiring. Keep in mind that you will likely need to get your fingers between the transformers to unplug and reconnect the transformer primary windings in the chapter titled "Making all the Connections."

Some of your transformers will have mounting flanges, and some not. I used a ripping of lumber about 3/4" square to make substitute "flanges" to mount the ones that didn't have flanges, or that the flanges were on the wrong side of the transformer. Screw them to the base through their mounting flanges with 1-1/2" wood screws or drywall screws.

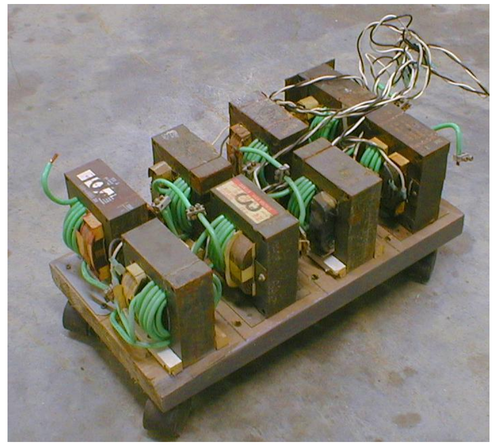


Figure 59: A sturdy, wheeled base to mount the transformer array to.

Leave room for airflow

Lay out the control circuitry, the bus bars, main power switch, and the cooling fans on the middle deck. (The bus bars and power switch will be mounted to the end panels, but they still take room out of the middle deck.) Mark their outlines and cut holes for the cooling fans. The air will be drawn upwards through these holes from the "transformer room" and into the middle deck. One of the fans should blow across the heatsink for the SCR module of the controller (if you opted for this control method). The air will exit through a row of holes in the side panels.

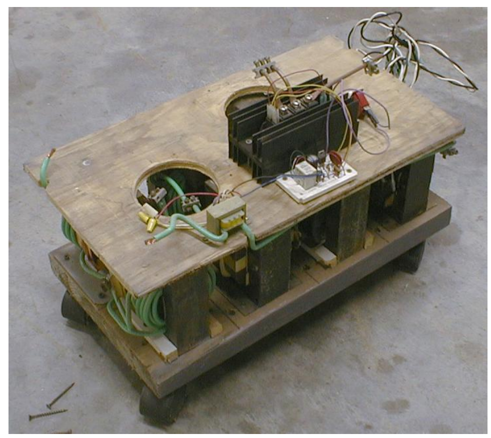


Figure 60: Middle deck with holes cut for cooling fans. Heat sink and control circuit on breadboard already in place.

It's like Building a House

Step by step, build up the frame of your welder. You may need to jump ahead to the chapter "Making all the connections" to complete the polarity correction procedure before closing in the transformer array in the bottom section. It will be harder to get into this bottom section to make any changes after you mount the middle deck.

It can be a bit tricky mounting all the components on the middle deck, and on the end panels because of the clearances for the mounting screws. You may need to mount some components on the end panels before fastening the end panels to

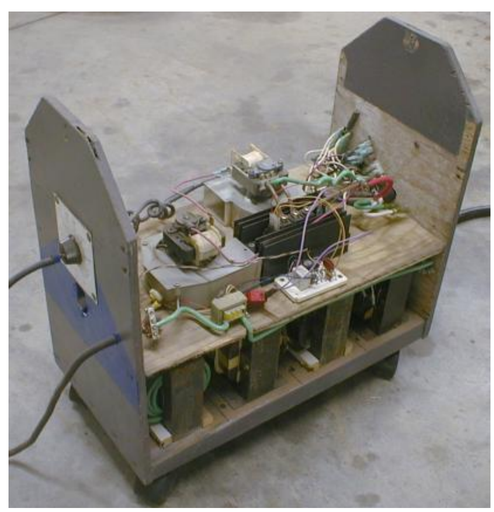


Figure 61: End panels fastened in place, and cooling fans and controller mounted.

the rest of the assembly. Note how the solderless breadboard is mounted close to the edge of the middle deck. This makes it easy to access if changes or adjustments need to be made.

Figure 62: Almost complete cabinet assembly, just need some side panels.

Finally, mount the tote tray and the carrying handle. You may want to glue the carrying handle as well as screwing it. But the rest of the welder, I recommend not using any glue, just screws. You will be glad you did it this way if disassembling for repairs is necessary.

I left the metal side panels on my welder a bit short to leave a gap on each side for air to be drawn into the lower section. This gap can be covered with a piece of air conditioner filter to keep dust from coating your transformers. Dust is not good—it thermally insulates the windings of your transformers and allows them to overheat. If you omit the filters, just remember to blow the dust out periodically with compressed air.

Figure 63: Side panels in place, and tote tray put to good use! There's plenty of room for gloves, chipping hammer, and your assortment of welding rod.

Making all the Connections

In building the cabinet for your welder, you were advised to keep the routing of the wiring in mind for all the connections to be made. You may need to partly disassemble the cabinet to connect all the wiring. If you are going to paint the wood on the inside of the welder, now is the time to do it, before you get a whole bunch of wiring and gizmos mounted inside it.

Types of connectors to use

Figure 64: Insulated crimp-on spade connectors are already compatible.

For connecting the primary windings to the hookup wire leading to the main power lugs, use crimp on spade-type female connectors rated for #14 or #12 wire. The primary windings on the microwave transformers almost always have the male spades (very conveniently) already on from the factory. The cooling fans also use these connectors, and when you get all done, you will be amazed at the neatness and professional look of this method of making connections. Changes and replacements are also very easy to make with these connectors. Wire nuts are not that much cheaper anyway, and you will be glad you used the crimp on spades.

For the secondary connections, cut up some aluminum grounding bars into 2-hole sets for the transformer-to-transformer connections, and 3-hole sets where needed for connections where 3 wires come together (if you have any

Figure 65: Various electrical connecting hardware: Left, spade type bus bars. These are used to connect all the primary windings in parallel. Middle, aluminum grounding bus bar cut into short lengths for connecting the high-amperage connections. Right, insulated terminal blocks for main power inputs.

such connections in your welder). I cut some 3-hole "connectors" to make connections here and there in situations where there were 3 wires coming together, such as the SCR module where it connects to line voltage.

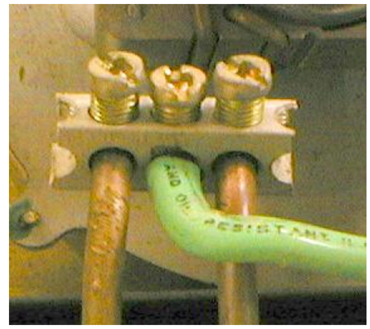


Figure 66: A 3-hole bus bar section allows 3 wires to come together.

Wiring up the Transformer Array

As seen in the photo, I first solidly mounted all the transformers to the base board and began hooking up wiring. With all the wiring open and easily accessible, now is the best time to energize the transformer array and correct any polarity problems. After the end panels and middle deck are in place, it's difficult to get down in between the transformers and reverse the primary winding connections.

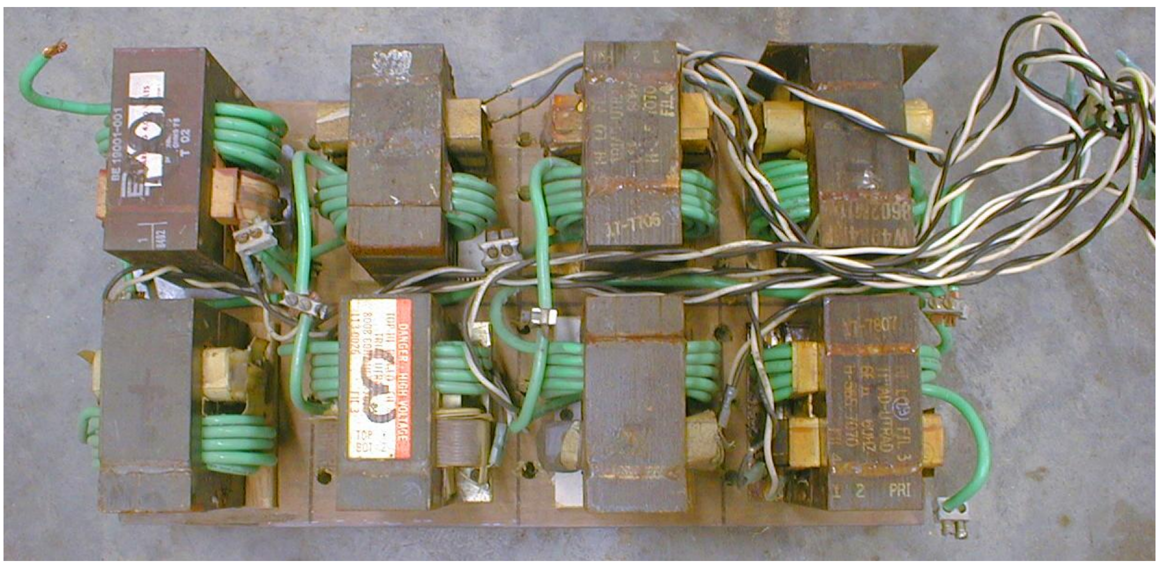


Figure 67: It doesn't look much like the schematic, does it? The secondary windings are all connected with the short sections of aluminum bus bar, and each primary has it's own "power cord" that ends up at the main power lugs. Black and white wire is used to help organize hot and neutral.

Correcting polarity problems

When you get all the connections made and are ready to power up the welder for the first time, you will find that the output of all your transformers' secondary windings in series is some ridiculously low voltage, or maybe only half of what you expected. This is because of polarity problems in your connections. Don't sweat it—the same thing happened to me. What needs to be done is to verify and correct if necessary the polarity on each transformer.

In theory, the polarity problems could be corrected by reversing either the secondary connections or the primaries, but my advice is going to be to make the corrections by reversing the primary connections. First, it is much easier to pull apart the spade connectors and switch them. Second, the two connections to the primary winding are almost always side by side and your wires will easily reach.

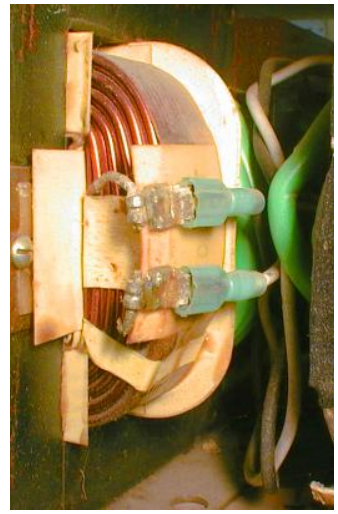


Figure 68: It's easy to reverse the polarity of the primary windings when you have spade connectors.

This can be easily done with a multimeter. The procedure is as follows: Measure the voltage on the first transformer's secondary winding in the "string." Then measure the voltage across the first *two* transformers' secondaries together. Now, if the voltage is roughly double measuring these two together, the polarity is correct. If not, like just a volt or nothing, the polarity is backward. To correct,

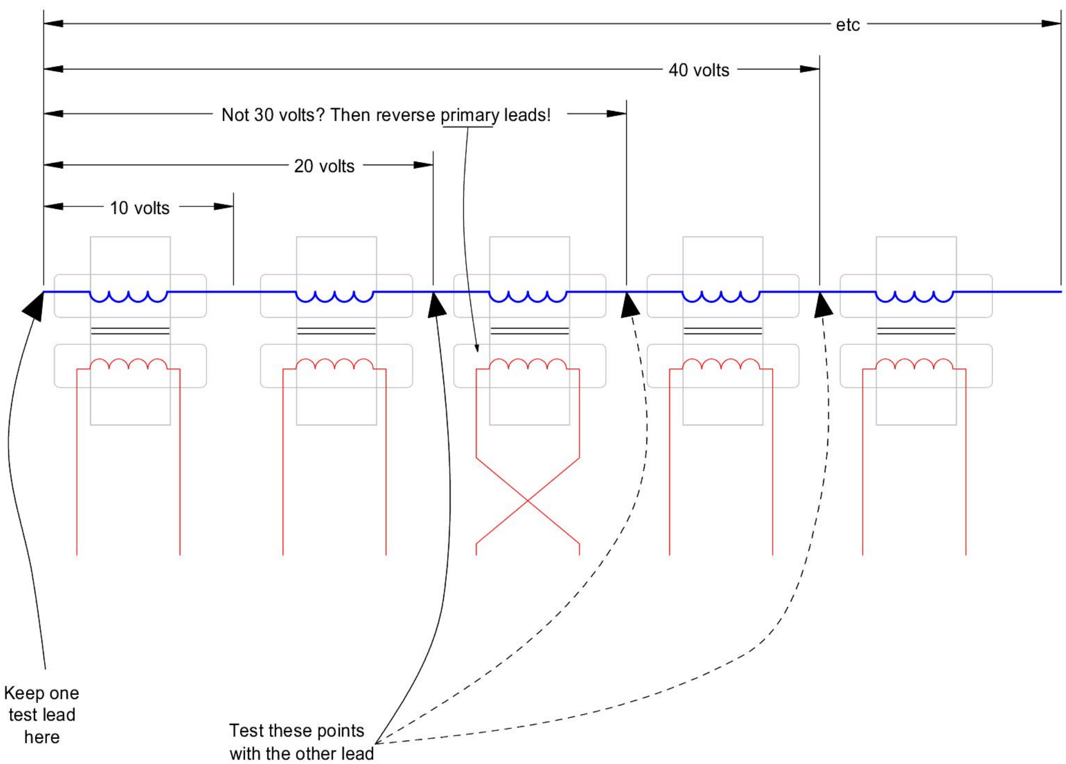


Figure 69: Given the assumption that each transformer has exactly 10 volts, you can expect that the voltage increase by 10 as you move down the string of transformers. It's easy to pull the spade connectors on the primary windings and reverse them, and it corrects the polarity problems effectively.

unplug the welder (always do this before messing with the wiring), and reverse the connections on the primary winding. Power up and test again to see the change.

Next, test three transformers in a row. You should have roughly triple the first one. If not, unplug the welder and reverse the third transformer's primary connections. Test again. Continue this procedure, with four transformers together an appropriate increase in voltage, reversing if not. Five should make 5x the voltage of one, and so on until you get to the end and are testing the entire array of transformers together for a total voltage of 75 to 85 volts.

A receptacle for your 240v welder

You may need to hire an electrician to wire up a 50-amp 240 volt receptacle for your welder. You can use a 3 or 4 wire receptacle, it doesn't matter. Just be sure to get the right “pigtail” for your welder to plug into it! These can be scavenged as well from old ranges. Just make sure you get one with a grounding prong to meet code. (The 3-prong range receptacles and cords with neutral but no ground should be avoided.)

If you use a 4-prong receptacle and pigtail, then the outlet can be used for other things that may require the neutral lead such as large air compressors or other 240 volt applications.

Another excellent suggestion is to wire up the welder receptacle on a “drop lead” that is made with flexible-conduit-encased wire to allow your welder some mobility in your shop. This is handy when welding on a large object like a vehicle or trailer and it's more feasible to move the welder around where it's needed, rather than moving the workpiece. You can also make extensions for the welding cables, but it's more expensive and the leads drop a few volts.

Figure 70: I have my panel wired with a wall mounted 240v receptacle, and this “drop lead” receptacle that allows me to move the welder about the shop.

Power it Up!

Pre-flight Checklist

Correct Wiring. Make sure that the circuit you are plugging your welder into is of sufficient size to handle the power draw of your welder, and that the wiring is done correctly (i.e., correct wire size for the ampacity of the breaker used, etc).

Proper Grounding. Make sure your welder is connected to a properly grounded receptacle, and that the frame (if it is metal) is grounded. The workpiece that you are going to weld should also be grounded, in addition to the work lead (sometimes referred to incorrectly as the grounding clamp). This can be accomplished by welding on a metal workbench that is grounded properly, or by using a grounding clamp that is properly grounded.

Proper personal protection. Hopefully, your mommy and daddy told you not to stare into welding arcs with your bare eyes. They were right. Make sure you have a welding helmet (not just goggles) rated for stick-type arc welding. The arc will burn spots in your retina just like the sun burns a blade of grass under a magnifying glass. The auto darkening helmets seem to be the greatest thing lately, but you will pay a bit more for them.

Also, you need leather welding gloves and a fire-retardant apron, leather being a good choice. A fire retardant bill cap can help to keep the sparks from igniting your wig on fire. Don't skip the next subtopic, Operator Safety.

Figure 71: Helmet and gloves are a start. A leather apron and leather boots are also a good idea, to keep from catching yourself on fire.

Operator safety

Welding produces heat, sparks, intense light, and noxious smoke. These are things that are generally incompatible with the human form.

The rays from a welding arc can give you sunburn. Make sure you have adequate protection on your skin to keep the rays from harming you. The welding shops carry a full line of welding apparel to protect you from these harmful rays. As previously mentioned, the correct shade of welding glass is needed in your welding helmet.

Pay attention to your atmosphere. The electrodes have a flux coating that burns when you weld. The smoke from this burning can quickly fill a confined area and choke you. Make sure you are welding with plenty of ventilation.

Sparks from welding can fly out from your work area and catch things on fire. Be very cautious about your work area and keep flammables out of reach of your sparks. If your welding shop shares space with a woodworking shop, be warned about sparks flying into sawdust. Sawdust can smolder for days before bursting into flame and burning down your garage or house!

Keep a fire extinguisher handy. Don't weld gasoline tanks or other tanks with residues of flammable liquids in them, and don't weld in atmospheres of flammable gases. Welding should be thought of as fire and if you are welding indoors, you need to take every precaution that should be taken when lighting fires indoors. Did I mention keeping a fire extinguisher handy?

Treat the live electrode with the respect of a loaded rifle, with the added exception that there's no trigger or safety lock, but it “shoots” the instant the “barrel” touches anything! Different that any gun you've ever shot, eh? (No recoil, just more likely to stick.)

Use the Noodle. If you got this far, you have some brains. Don't stop using them now. Welding involves exposed electricity that can electrocute you. Think through what you are doing before you turn on the welder and get ready to send a shower of sparks flying. Warn bystanders that are not wearing eye and other protection that you are about to strike an arc.

Striking the arc

If you already know how to weld, you can pretty much skip the rest of this chapter. I am not a professional welder, but I can weld and I can give you some tips to get you started. If you want to become proficient at welding, then practice. If you want to become professional at welding, then enroll in a welding class and get a welding certificate.

Also, don't write me email telling me that the techniques that I give here are wrong. Call your mother-in-law and complain to her instead. I already said, I'm not a professional welder, but I have successfully welded a lot of things. If you wish, get a pro to show you how to use a welder first. This is a book about building a welder, not about learning the fine arts.

That being taken care of, the next order of business is to clamp an electrode in your electrode holder, connect the work lead to a practice piece, and turn on your welder. Don your welding helmet and tighten the band. Unless it is the auto-darkening type, adjust the knobs so that a quick nod of your head will make it fall down. This way, you don't have to have a hand free to lower the helmet.

Position the end of the electrode about 1/8" or 1/16" from the work. Lower your helmet, and make a motion with the tip of the electrode like striking a match. This will be somewhat of a jabbing motion, however, because unlike striking a match, the electrode needs to stay close to the workpiece. If you remove it too far, the arc will go out.

Another technique for starting arcs is to scratch across the workpiece lightly. This only works, obviously, where there is space on the workpiece to make such a motion, but it is quite effective.

When the arc starts, it produces a small stream of superheated gases and smoke (sometimes referred to as plasma) that conducts electricity. The intense heat in this stream actually vaporizes the metal of the electrode and erodes it rather quickly, depositing it into a "puddle" on the workpiece.

Maintaining the arc involves feeding the electrode into the arc pool as fast as it burns off. The correct arc distance needs to be maintained here to keep it from extinguishing or the electrode sticking to the workpiece.

Laying the bead

Most welds are more than just in one spot, they are quite often a seam along two pieces of metal or around pipe shaped sections. This strip of weld is referred to as a bead of weld.

When you strike the arc, you should already have planned which direction you are going to start moving, because if you stay in one spot you will burn through the workpiece. This is especially tricky with thin metal sections like bicycle frame tubing or angle iron.

The flux that burns off the electrode forms a slag coating on the weld bead as it is formed. It is important to not lay the bead too fast that this coating cannot keep up to properly shield the white hot metal from the effects of air.

The electrode needs to be moved along slowly enough, and maybe from side to side depending on the width of bead desired, to form a large enough “heat affected zone.” Properly heating up the metal in the area of the weld is extremely important in a strong bond. If the surrounding metal is not heated well enough, it cools too rapidly and makes a brittle weld that is prone to cracking.

If the power is set too low, the puddle will not be hot enough and the result is “cold” welds that will break also. Test your welds by clamping the practice pieces in a vise and bending them around till they break. They should not crack or break at the weld, but rather the workpiece itself should bend and finally break outside of the weld area.

If the welding power is too hot, there will be a lot of electrode being splattered out and wasted, and holes being burned into your work. Other than that, I have not found a consequence of welds being too hot. The worst problems are when welding too cold or laying the bead to fast.

When welding long beads, it is a good idea to go along and “tack” weld every 6″ or so, and assemble the item as completely as possible this way, and then go back and lay the beads solid. This helps to prevent warping of the finished good.

Further study

A very great deal can be said about how to weld. Welding a bead that is vertical or overhead can be very tricky, but it all comes with practice and proper technique.

In the welding supplies section of most stores there are well illustrated books on how to weld. I recommend them, as proper welding technique is outside of the scope of this book.

Also, as I mentioned earlier, make friends with someone who is experienced at welding, and let them “test out” your welder. They will not only be able to show you the techniques, but also point out a problem with your welding machine, such as not producing enough amps.

Most experienced welders will be fascinated with the idea of welding with a homebuilt machine and have a certain respect for you for having built the welding machine. I get a lot of email from people who are experienced at welding, but the innards to these machines is a bit mystic to some of them. They sort of look up to me, but I always try to remind them, however, that just because I built the machine does not mean I know how to operate it—it's just a tool that requires an expert hand and eye to apply it correctly.

Questions, comments? Answers? Send me a note! Go back to my website at www.dansworkshop.com and click the email me link and fire away!

Troubleshooting

This chapter is at the end of the book, because you should have completed all the steps necessary this far. If you are here because you skipped some important reading, well, the answers to these questions refer back to material earlier, so at some point you will be going back and reading some more. No problem at all, I often start at the end of a book just to satisfy myself that the information is complete!

Solid State Controller Problems

Problem: No heat variation, full power.

Solution 1: Remove the control leads to the gates of the SCR module, but leave the connections to C1 intact. Power up the welder. If the welder is still stuck on full output, the problem is in the SCR module (or one of the SCR's if you used two discrete SCR's). Replace the offending SCR.

Solution 2: If the welder did not turn on after disconnecting the gate leads, then the SCR's are ok. They are effectively “blocking” current by having their gate leads open. So the problem may lie in Q2, the lamp dimmer triac. If this unit is fried from an over voltage or spike, it may have become “fused” or shorted. Replace Q2.

Solution 3: Replacing or otherwise eliminating Q2 as the problem still doesn't fix the problem, so there may be other things that are keeping the controller from varying the output. If you built the controller with the easy start circuit, it may not be set sensitive enough to switch the controller down to the heat that is selected on the dial. Turn R2 one way, then test, then the other to try to vary its sensitivity. Finally, you could simply eliminate the easy start circuit to see if turning the heat dial makes a change in the open circuit voltage.

Problem: No output at all, no humming

Solution 1: Connect a jumper wire across the gate leads of the SCR module. Power up the welder. If it comes on at full power, then the SCR module is ok.

If the welder does not power up at all, then the SCR module is suspect. Replace it.

Solution 2: The welder does power up with shorting the SCR's gate leads as in solution #1 above, so there is something else amiss. It could be the thermal cutout, Q2 or even the trigger diac D1. You can simply eliminate the thermal cutout by connecting a jumper wire across it's connections. D1 and Q2 are a little bit trickier, you should probably just replace both of them.

Note that if you are building a 240v welder you need a triac for Q2 that will handle the higher voltage. Some of the triacs from lamp dimmers are already capable of handling the higher voltage, so it's not hard to just try it and see how far you get. But if not, Radio Shack handles the 400v triacs which I have had good success with.

Problem: Transformers hum, but little or no output

Solution: This is probably not a controller problem. It is more likely that the transformers are connected with incorrect polarity. Yes, transformers have polarity even though they are alternating current devices. Go back and follow the procedure in the chapter "Making all the connections" for correcting polarity problems.

Breakers tripping

Problem: The breaker trips immediately after turning the welder on.

Solution 1: Go back and check all your connections for problems. Especially on DC welders that have a number of heavy connections to big chunks of copper or aluminum, if you have a diode connected backwards or something, the power supply may be "seeing" a dead short.

Solution 2: The breaker may be too small for your welder. The welder typically does not draw much current when idle, but there can be a phenomenon called "current inrush" when the welder is first powered up. This is from residual magnetism remaining in the transformer cores from the last time the power was shut off. Then when the power is turned back on, it just happens to be during an AC pulse that tries to saturate the transformer further in the same polarity and it draws a sudden surge of power and trips the breaker.

Welding Problems

Problem: Trouble sticking

This is a very common problem, and I don't know that the solution is a written one. But there are a couple things that are essential for good arc starting:

1. **Sufficient open circuit voltage (O.C.V.).** You need about 70 volts to be able to easily start an arc. With DC this requirement is less. But if you are impatient and build a welder with too large wire size and resultantly few turns, you are likely to run into this problem. Or if you don't pack your turns tight enough and don't get enough of them to build a good open circuit voltage, this can happen to you. But if you built your welder according to these plans, you will have a welder that already has enough volts so this shouldn't be a problem. Sometimes the polarity corrections can be easy to skip over and miss, you'll find this procedure in the chapter "Making all the connections."

2. **Sufficient amps for the rod size you are using.** If the welder doesn't have large enough transformers for the job you are trying to do, the rod will stick and be hard starting, etc.

3. **Fresh rod.** If the rod you are using has moisture damage (and rod that has been left exposed to air will pick up moisture from the air) then it will not work well. Go to the store and pick up a box of fresh rod (it's not that expensive).

4. **Started rod.** You experienced welders are probably going to laugh, but I'm simply relating my own experience. A brand new fresh rod has a tiny bit of rod protruding from the flux coating. After you've struck an arc with a rod, this metal part gets eroded up into the flux coating and after this it becomes a lot easier to start an arc. One thing I like to do is to strike an arc on a piece of scrap metal to "condition" the end of the rod so that it is easier to start on my workpiece.

Problem: Worked fine for a while, now nothing

Solution 1: Check the breaker. Some breakers will simply trip because they are getting too hot. Give it a few minutes to cool (your welder may thank you for the break too) and flip it on again. If the problem persists, you may need a heavier circuit wired up. DO NOT just put a bigger breaker in, it will probably be too big for the existing wiring.

Solution 2: If you built your welder closely according to these plans, you attached a thermal cutout switch to the heatsink. It may be that the SCR module has overheated and the thermal cutout simply did its job and shut down the welder for a while to cool. Give it a break.

Most welders have a "duty cycle." This is a 10-minute cycle of welding for a few minutes, then pausing. For example, a 20% duty cycle means welding for 2 minutes, then waiting for 8 minutes before starting up again.

Since you built a welder, you can't say for sure what the duty cycle is. The manufacturers of commercially available welders figure in factors like, how long they expect their welders to last, and if the warranty will be expired before the duty cycle on the nameplate is too generous for the realistic capabilities of the product, etc. Electric motors refer to this as "service factor" and welders are not much different.

So it is a good idea to pay attention to your welder while you are using it. During a welding session, turn it off, unplug it, and reach into its innards to see how hot it is getting.

When the SCR on your welder fails (I've not had any problems with the IRKT modules) it will do one of two things. It will either fuse or open. A fused device conducts electricity at full strength because it's insides have done just that – fused together. An open device is like a switch that is turned off and you can't turn it back on.

Ask for help

Like I said early on, this book about building a welder is not a cheap, get-rich-quick "ebook" like so many. I've built welders, and I know the answer to many of your questions if you will just ask. In future editions of this book, I'll post more of the frequently asked questions as well, but your feedback is (and has been) a necessary part of this process.

Just go back to my website at www.dansworkshop.com and click the link to email me (my email address can be a moving target at times) and send me any question you have.

Sincerely

Dan Hartman