

Plasma Displays & Inert Gas Discharge Tubes (IGDT)

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Foreword:

I learned about plasma displays many years ago when I was intensely fascinated with the genius of Nikola Tesla. My personal fascination with plasma filaments began when I saw such things in sci-fi movies. I had always assumed it was some sort of special effect, but when I saw the movie *My Science Project*, which featured a large portable and *obviously real* display, my interest peaked. I started reading about them at every opportunity but detailed theory was really hard to come by, until I found out about Nikola Tesla. He invented the *inert gas discharge tube* (IGDT), high voltage power supplies, electromechanical machines of every type and practically everything else that has rushed the human race into the space age in just a single century.

About 10 years ago, I built my first plasma display based on what I'd learned from Tesla's work. I used to take it to mall shows and schools and such to show it off. There was always a line-up to see it. I loved it. A couple years after that, you could buy several models in stores. The most popular being Rabbitt Industry's *Eye of the Storm*, which sold first in the *Consumers* chain stores. Unfortunately, neither that store nor the product still exists. Radio Shack still sells a small one, but it's pretty lame compared to mine because it is quite small and relatively weak. There are also a few old Radio Electronics magazines, which have some power supply circuits and explanations on how they work. Unfortunately, copyright laws prevent me from reproducing them here.

The circuit in my homemade unit (pictured above) has driven a homemade globe quite well. It has also driven a store-bought globe extremely well. Add to the list Neon bulbs (I get trails in candle-flicker bulbs and calculator displays.), florescent tubes, Xenon flash tubes, and even normal light bulbs, etc.

The truth is, I've been a very serious electronics hobbyist for about 15 years now. I have an electronics technology degree, and also have worked for several big electronics companies. For the past several years, I've worked at Siemens Canada Ltd. where all I've done is design, build, and program custom systems of every type you can probably think of. Still, there's nothing more fascinating to me than a plasma filament, except maybe anti-gravity and immortality but I'm still working on those, secretly of course.

What are inert gas discharge tubes?

In their most basic form, IGDTs are simply a glass envelope which has one or more electrodes and which has had some or all the internal air removed & replaced with inert gases. This may sound simple, but IGDT design can be quite complex.

What happens if the tube has nothing in it at all?

Tubes like this are not IGDTs. They are called *Cathode Ray Tubes*. When enough voltage (25kV or higher) is applied between electrodes in a tube that is completely evacuated, electrons will leap from one electrode's surface and travel to the other electrode. When this occurs, *cathode rays* are produced which can be useful as well as harmful. Also, you cannot see the rays. Visible light comes from the changing energy levels of atoms, and in a vacuum, there are none. Often, such tubes are coated with an internal phosphor, which absorbs the energy of the rays and re-emits it as light such as ultraviolet, X-rays, gamma rays, colored light (such as in TV picture tubes), etc.

What are inert gases and how are they used in plasma displays?

Inert gases are atomic elements that have a set of specific characteristics. They are all in the rightmost column of the Periodic Table. They are elements that are gaseous at room temperature and that do not spontaneously react with oxygen or anything else. Typical inert gases include Neon, Xenon, Krypton, Argon, Nitrogen and a few others. Yes, there actually is a Krypton gas, which Superman was luckily not affected by. The atoms of the gases produce light when they are excited by enough voltage to cause them to ionize and conduct current. Different gases produce different colors of light. Neon produces pink to orange, Xenon produces blue, Nitrogen looks very bright blue, almost white (typically recognizable as lightning), Krypton produces green and Argon produces yellow. I've even heard of Helium being used but I have no idea what color that would produce.

Other gases can produce light as well, but they can also react with the other materials present in the tube such as the metal electrodes. They can also produce wavelengths of light, which are harmful, such as excessive ultraviolet, X-rays, Gamma rays, etc.

A typical recreational plasma display can use many different gases to produce the desired color or effects. All the gases must be inert so that they will not react with metal electrodes or the other gases inside the display. Also, all the gases have a different *ionization energy (IE)*, which is determined by the periodic table of elements. The lower the IE, the lower the voltage required to produce a plasma stream. Neon has the lowest IE and is therefore the most commonly used gas in visible displays. It produces pink trails or pink/orange haze. You can see examples of such displays all over the place. *Candle-flicker* bulbs use neon. Although at a higher pressure than you want for a plasma globe, your power supply can ionize candle-flicker bulbs if you simply hold the bulb in your hand near a working globe. A direct connection will also work but you should reduce the power output. The nice thing about a neon display is that because of Neon's low IE, the operating voltage is lower so the globes can be quite large. Since neon will not produce tightly focused streams, they limit the current and are inherently quite safe. Neon also will not emit harmful rays.

Xenon is the 2nd most commonly used gas in displays. It makes attractive blue hazy trails, which can tighten up to produce focused blue-white lightning-like trails if there's enough power and the display is operating at the resonance frequency. Often, Xenon & Neon are mixed together and the trails that result start out as pink at the center electrode and turn blue on the way towards the glass. The filaments hit the glass, then split into pink fingers, which is a very nice effect.

Typical applications of CRTs:

- Television picture tubes.
- Radio vacuum tubes
- Oscilloscope picture tubes.

Typical Applications of IGDTs:

- X-ray tubes used for medical or security purposes.
- Visual displays such as *Eye of the Storm*, Neon signs and calculator numerical displays.
- Candle flicker bulbs and other decorative lighting.
- Camera flash tubes.
- Lasers.

What kind of energy is emitted?

Most of the energy that radiates from IGDTs is in the form of electromagnetic waves (radio waves & light). Some heat is also produced. The wavelengths emitted can be visible (typically harmless) or invisible radio waves, ultraviolet, X-ray, Gamma rays, etc. Of course, you will wish to keep the harmful wavelengths to a minimum. Fortunately, it is easy to do so.

What pressure is used in the tubes or globes?

In a nice plasma display intended for human interaction and observation, the typical pressure in the display is about 2 to 7 Torr. Note that 760 Torr = 1 ATM. From this you can see that the pressure needs to be pretty darn low. If it is too low, the display's brightness will suffer and it may emit harmful cathode rays. If it is too high, the display will require much more voltage to create plasma streams and then the streams will be very dense and possibly dangerous such as those produced in the typical light bulb.

When I say *pressure*, I mean *absolute pressure*, not *pressure relative to atmosphere*. Some people refer to any pressure lower than atmosphere as a vacuum or partial vacuum. It is not. Only the total absence of gas represents a vacuum and there's no pressure level lower than that. All existences of gases produce a positive pressure. There is no such thing as negative pressure because you can't have less than *nothing*. That said, you wouldn't think I mean you have to have a globe whose pressure is higher than atmospheric pressure when I say it is pressurized to 2 to 7 Torr.*

What is the difference between Neon-sign tubes and plasma displays?

Neon-sign tubes have an electrode at each end. Typically, they operate at only several hundred volts and they use a standard 60Hz transformer with a 110VAC primary coil as a power supply. Current flows from one electrode to the other. A DC power supply of a few hundred volts would also work because the 2nd electrode and wire serves as an easily accessible *return path* for the current flow. Several colors can be produced using different inert gases, but it is very common for sign tubes to have internal phosphor coatings, which absorb energy and re-emit it in almost any desired color. Using phosphors means all tubes can run with Neon, which has the lowest IE, and almost any color can still be achieved.

Plasma displays, such as the very common *Eye of the Storm* displays, typically have only one electrode from which plasma trails or streams propagate. This type of IGDT requires a very high voltage, high frequency AC power supply. Since the IGDT has only one electrode, the return path for the current flowing inside the tube is the air itself. The capacitance between the high voltage electrode and the circuit ground is the only return path. Current must flow via this stray capacitance through the surrounding air to the circuit ground. The stray capacitance is quite low which is why the voltage and frequency must be so high. The path that the plasma trails follow varies a lot during operation for several reasons.

The plasma trails created in the IGDT tend to move rather randomly and are generally dimmer and thinner than plasma flowing through sign-tubes, which have two electrodes. The trails keep moving because the charged or ionized gas areas keep moving. Charge builds up in areas without trails until they ionize. Then the charge carriers in a *cloud region* collapse into an *ion trail*, which is a good conductor, which allows current to flow to circuit ground, draining the charge. Once the region is discharged, the trail may disappear or migrate in some direction towards another area, which is charged. The trail will continue to exist as long as sufficient current can flow. You yourself can become a return path by touching the glass surface because you are a better conductor than the surrounding air. One very important thing to consider is that since the power supply is operating at a high frequency, the plasma globe or tube is in fact an antenna. You are like an antenna in many respects as well. High frequencies cause a *skin effect*, which prevents you from receiving a shock. The currents you carry are very low and tend to flow along your surfaces. The glass envelope and the plasma trail itself are also providing decoupling from the power supply electrode. This protects you to some degree. Since the display globe acts like an antenna, it conducts or transmits more power near its *self-resonant* frequency. It will have the most trails when operating at that frequency because the power transfer is most efficient. The oscillating field that is generated can transmit power into and through other objects, which come into the field. It is very easy to make other tubes, especially Neon and florescent ones, glow in your hand just by holding them inside the electromagnetic field near the operating plasma globe. You can then use a simple Neon candle-flicker bulb to observe the relative field strength at any point in space surrounding the display because the bulb will light up accordingly as the field excites the gas within.

Power supplies designed for plasma displays can also drive neon sign tubes. If you want to do this, you should connect only one electrode and leave the other electrode disconnected and insulated. If you connect both electrodes, the current that flows through the tube can be very high. At the high frequency at which a plasma power supply operates, the thin Neon tube's electrodes may concentrate the current towards the metal surfaces of the electrodes. This *skin effect* can increase the apparent impedance or resistance of the electrode and cause a significant (exponential) rise in power dissipation & therefore they'll run a lot hotter than they were designed to.

Why won't a Van De Graff generator work as a power supply for my plasma display?

A Van De Graff generator wouldn't work to light a plasma display because it relies on slowly pulling all the electrons out of an isolated electrode along a charge-carrying insulator belt. This is a purely mechanical process, which via friction between dissimilar materials produces a static charge. A plasma display lights when current passes through it, which is not static. A static discharge through the display can make it flash, but that's it.

Can I make a plasma display from a normal light bulb?

Yes, but I advise against it. A typical tungsten filament lamp has had all of the air inside of it replaced with the inert gas nitrogen. The gas is used to carry heat out of the bulb and to prevent the filament from reacting with oxygen, which would degrade or destroy it. The gas is not low

enough in pressure to make ionization easy, but a sufficiently powerful power supply can still produce bright plasma filaments or streams. Note that you can easily get a shock by touching this type of bulb while it's operating. This is because the plasma streams are extremely tightly focused and they can carry a lot of current. This is typical of Nitrogen. You'll notice that the streams in a light bulb have the very familiar *lightning-like* appearance. Considering that about 80% (or whatever the value) of our atmosphere is nitrogen, this should come as no surprise.

You might wish to be informed that emitting that much power directly from the metal bulb filament & support wires is very likely producing a sizable amount of unfriendly radiation. Included would be ultraviolet light, which will damage your eyes, as well as X-rays, which will damage everything else inside of you if you keep exposing yourself that way. Many of Tesla's buddies who once liked putting their hands on the operating tubes to see the effects later died of cancer. You better watch what you are playing with. Low level displays are as safe as a TV but the gases used and the electrode materials are also important to *safety*, not just the *look* of the plasma streams.

How does the current flow in IGDTs?

When current flows, people have described electrons moving in one direction and positive ions moving the other way. This in fact occurs in certain circuits, which rely on the electrochemical transfer of atoms of an electrode through an electrolyte material. This process occurs in batteries. This does not occur in IGDTs or typical semiconductor circuits. While the electrons do in fact move from atom to atom, the atoms themselves pretty much remain where they are. Light is emitted when an atom loses an electron, thereby changing to a lower energy level. This happens to the atoms in the slurry of gas millions and millions of times per second as the electrons make their way along the plasma trail. This means they are constantly changing their state of charge relative to their neighbors and they'll just bounce around willy-nilly all over the place. As a result, the positive ions do not remain positive ions for long. Even if they did and even though it is true that positive ions would be slightly attracted to a negatively charged electrode at one end, they really don't move much because the physical forces of pressure continuously act to keep the gas evenly distributed throughout the tube. Some people call the places left behind when an electron leaves an atomic orbit a *hole* oddly enough, which technically makes the atom a positive ion. It is said that the *holes* move one way while electrons move the opposite way. Holes are not actually *things or particles* as electrons are so even though both statements made about what is moving is technically true, I prefer to say the electrons are moving rather than the absence of them or the nothingness. In either case, the atoms themselves pretty much stay put. Proof of this is simple to observe. Just look at the light emitted in a normal florescent tube. Pretty evenly distributed isn't it? By the way, that white phosphor is in florescent tubes only because more energy is emitted in the ultraviolet spectrum and it's more efficient in that range. The phosphor absorbs the dangerous UV and re-emits the light in the visible spectrum. Handy stuff, those phosphors.

Before a gas ionizes, its resistance is very high. Applying a high enough voltage causes some atoms to ionize and some current flows. This begins the formation of an ion trail. Once the trail forms, it becomes an excellent conductor. Only the trail's resistance or the capacity of the transformer supplying it limits the current.

Home-made Plasma Globes:

First of all, do not use a regular light bulb for your display. The trouble with a light bulb is that it produces plasma filaments, which are extremely focused, and as a result, the streams are extremely good conductors. The current they conduct is very high, much higher than you'd want in a typical display. The current can be high enough to kill you under the proper conditions. Most of the voltage drop that must occur from output to ground happens across yourself, but what you

want is for most of the drop to occur inside the display globe. This is accomplished by using the proper gas types, electrode design, and globe pressure.

The two biggest hurdles in building a plasma display are creating or buying the display globe itself and finding the best flyback transformer for the job. Making your own display globe is practically an art in itself. Finding a good vacuum pump and designing a reliable sealing method are the most difficult steps. You don't actually have to worry about finding inert gases like Neon or Xenon or Krypton because you can easily ionize low-pressure air quite nicely. In fact, I prefer Nitrogen and air is mostly just that. Air makes plasma filaments, which are very tightly focused and bright, well, like lightning. If the metal electrode ball is sealed from the air, the ball's surface won't be able to react with the oxygen, which remains inside the globe.

My globes made from typical round glass lamp globes, which you can buy at any store. They are about 0.030" thick. The best way to make display safe is to build it such that it is not over-powered for the display it drives. Also, it should be constructed such that the main electrode is not exposed directly to the gas within the display globe/tube. It should be situated well into the center of it. All commercially available Eye of the Storm displays route the high-voltage lead up the center of the globe, into a small hollow glass ball about 1.25" in diameter which is the *emitter*. The emitter ball is filled with a conductive material such as carbon-impregnated putty or steel wool. This material distributes the voltage all about the inner surface of the emitter and prevents almost all arcing within the glass ball. Most hobbyists install a metal ball (possibly custom machined or a simple brass drawer-pull knob) inside a globe, which is in direct contact with the gases within the globe. I do not believe this is harmful but if you want to be extra careful, then you should completely seal the ball from the gases by coating it with some relatively hard, inert material. Possibly several coats of a hard, clear lacquer.

Making the globe is really easy. Start with a base-plate made from piece of plastic about 0.5" thick. Do not use wood or some other fibrous material because it may leak. Route a 0.25" wide, circular groove about 0.20" deep into the top surface of the base-plate. This groove will accept the lip of a glass globe. Drill a hole in the center and install the electrode. The electrode will be composed of a metal rod with a metal ball about 1" in diameter attached to one end, which serves as the electrode for the display. Put the rod through a piece of plastic tubing, which is cut to the proper length, which places the ball in the center of the globe when assembled. The plastic tube not only sets the height of the electrode ball above the base; it also acts as an insulator. The metal rod will protrude from the bottom side of the base-plate and this is where you'll connect the high-voltage lead from the flyback transformer. Anywhere inside the area of the groove, drill a small hole and install a small brass tube. Seal it with epoxy. This tube will be used to evacuate the globe and gas up the globe. You'll need to install some sort of leak-proof valve on the tube or come up with some method for sealing it after the globe is properly filled with your desired inert gases. Fill the round groove with epoxy and place the lip of the glass globe into it. You can check the finished globe for leaks by placing it under water and blowing air into the fill-tube and checking for bubbles. Once you are sure the globe has no leaks, you can attach a vacuum pump and evacuate it, bleed in some inert gas or gases of your choice, then seal it. Now the globe is ready to operate. It is also possible to evacuate and gas up your globe while it's being driven by your power supply. You would do this in order to view the display quality *on the fly* and achieve the best pressure and gas mixture.

Does a plasma-globe *have* to be low-pressure to work?

I have read on the internet in a few places that a globe filled with Helium at 1 atm works well with the same power supply as a typical low-pressure globe using Neon/Xenon. Also, *doping* the Helium with 1 part in 1000 of air helps a lot. Also, a globe filled to 1 atm of industrial grade Argon is reported to work incredibly well, producing long white arcs. In this case, air is bad for the display, so the globe must be filled only with Argon. I would try to fill the globe using a distilled-

water displacement method to ensure no air remains. If these gases really do work at 1 atm pressure (I've never tried it.), it would eliminate the need for a good vacuum pump.

The plasma display power supply:

Typically, plasma power supplies circuits you see in many books are either a bit crude or are overly complex. Some run from 110VAC directly which complicates them unnecessarily. These high-voltage circuits are also too risky for a beginner. My circuit is much simpler, much more power efficient, and the output is just as good. There are two basic types of circuits. One that uses a fixed frequency oscillator (like a 555 timer) and one that uses a self-resonant *Hartley oscillator (HO)*. The fixed frequency type is typically preferred by beginners, although it is a little more complex than a HO and the output suffers due to the presence of harmonics and the fact that the oscillating frequency is almost never the self-resonant frequency. One of the most important factors in generating a strong plasma display is the frequency. The display itself is actually an antenna. As with all transmitters, impedance matching is crucial. Some folks might argue that the display globe or tube is simply one leg of a capacitor but I tend to prefer the antenna analogy. Since there's virtually nothing you can do about the impedance of the display, you must allow the circuit to *find* its own *natural frequency*. This is accomplished by using the HO configuration, which simply employs a simple *feedback winding*. For some odd reason, beginners typically shy away from this, but I found it quite easy to make it work. It's even easier than using the 555 timer.

The operating frequency should be around 20kHz to 40kHz but should not be controlled rigidly by a 555-timer circuit or such fixed oscillator. Tesla coils (plasma displays included) operate most efficiently when they are allowed to run freely at their resonant frequency. Really good plasma trails only appear when running at peak efficiency. Also, the power supply runs the coolest, the quietest, and produces the peak voltage when running at the resonant frequency. Tesla could not express the importance of this enough. Neither can I. I used to employ 555 timers and suchlike and I ran into all kinds of problems with squealing, heating, frequency drifts, and poor trails. Terrible harmonics produced RF interference at several frequencies, wasted power, and made the driver run hot. The display was usually awful and simply irritating.

Some commercially produced globes also used a 555 timer and they managed to work pretty well, but the globe design produced the proper impedance load for the flyback transformer. The 555 output was heavily filtered until almost a sine wave and the transformer was custom designed to run at that frequency. Trust me, they could have saved a lot of manufacturing costs and reduced the parts count and increased reliability if they had simply stopped trying to force the circuit to work the hard way and done it *the simple way*.

The simple way is the 2nd oldest way and it produces the best trails, has the quietest operation, uses the least power, radiates the least RF energy, has the fewest components, ... need I say more?

Yes, a little more... the simple way is (drum roll please) all the way from 1885 (or so), the *Hartley Oscillator!* (Referred to in this document as HO.)

Yes, the simple HO is the best when it comes to making plasma displays. The concept is elegant in its simplicity. All you need is a couple of resistors & transistors, a feedback winding, a flyback transformer, and a DC power supply. The great thing about a good HO is that it sets its own oscillation frequency, which is best for the particular globe, transformer, etc. and that is called the *resonant frequency*. It is simply the most efficient frequency that a particular system can operate at and it will always produce the best plasma display.

One thing you must note about a HO is that the overall gain of the circuit must be greater than 1 or it will not oscillate. That is a simple basic law of all oscillators. When you try to attenuate the

output, or *tone-it-down*, you are reducing the gain of the system overall, and it will likely just stop. I get a pretty good range of power out of mine however because it has a lot of gain. Some circuits have only one transistor in the whole oscillator. The big old power transistors have a very low gain ($H_{fe}=30$). They require a relatively high base current and that current comes in limited quantities from a feedback winding. Consider the increase in gain if it had two transistors, or used a Darlington transistor ($H_{fe}=1000$ to 3000) like the TIP122. My circuit uses two transistors in tandem for exactly these reasons and it kicks butt.

As for voltage, about 10kV to 25kV is more than enough to make a good 7" to 10" diameter globe fill up with streams.

There's never a need to *re-wind* the primary coil of a flyback transformer. Most of them will have at least one winding which will be suitable to run on a +35VDC drive circuit. If you are using a high voltage (HV) supply like 110VAC rectified to about +160VDC, be extremely careful and make sure you have a high-power current-limiting resistor in series with the primary. This HV driver also requires a HV transistor. The simpler, safer +35VDC driver can use a normal cheap transistor like the 2N3055 or similar device.

If you do rectify full wall voltage to about 160VDC, I'd be very surprised if your primary coil or transistor could withstand it. My first unit wired this way needed 40ohms (4 x 10ohm, 10 watt ceramic) in series with the primary to keep the 400V, 8A, \$40 transistor from exploding. If this were a transistor driven by a square wave, and especially if operating without a flyback diode, it would pop for sure. It's no wonder you'd need a large and expensive high voltage transistor. I built such a circuit at first, but it ran very hot because it was very inefficient. My best circuit runs on 35VDC. I used a normal 25VAC, 1A transformer to drop the wall voltage and then rectified and filtered the output to produce a nice low level voltage of +35VDC. The extra voltage (130V) is not useful because it forces you to use big high-voltage parts, which typically end up running hot and costing a lot as well. My best unit uses a common and very inexpensive transistor. It has been running strong since August 1988 so I guess it was a pretty good choice.

The exception to the rule (Sort of):

Rabbitt Industry's *Eye of the Storm* is to this day the *only* 555 driven unit I've seen, which does not squeal hardly at all and works very well. Actually, its frequency is limited to one octave and it *does* have a *sweet spot*, as you'd expect. Its flyback transformer was designed expressly for this application and for a globe of known impedance. The drive circuit was heavily filtered to remove the harmonics. It also had a high component count as a result. Why they didn't use a sine-wave oscillator is likely because the 555 timer is so darn cheap and because you can easily adjust the frequency of a 555 without effecting the amplitude. The whole thing really is a nice design and the audio response circuit works well and employs an automatic-gain-control amplifier. The gain is controlled by the average volume level of the audio source so the display never stays dead or saturated. This means that within limits, you can adjust the volume of an audio source to any level and the display will react properly. Also, the globe was a large 7" in diameter and the ratio of Neon and Xenon gases was perfectly chosen. The globe's center electrode was glass and the interior of it was carbon-putty-filled and sealed to prevent the generation of Ozone. The case was attractive and compact. The price of this unit was a real deal at about \$100. This was possibly the best unit mass produced to date. Very nicely done.

There are a lot of 555-oscillator designs out there because:

- They are very cheap, easy to build, and they oscillate regardless of the load being driven. Also, this little chip is commonly discussed early in college & university programs, and there are a zillion little 555 books out there so almost everybody and their dog wants to use one.

- A lot of people don't want to fart around with feedback windings and such. It's surprising how few people know the basics of resonant oscillators anymore. Most people are not aware of the importance of impedance matching or of the operation of capacitive loads (globes, tubes) at high frequencies.

The common problem associated with using a 555 circuit to drive a plasma display:

- **Harmonics:** A simple square-wave drive signal, switching the primary winding, is poor because the shape of the square wave includes several orders of harmonics. In fact, a square wave is described mathematically by a standard Fourier series. The big sine wave that would fit into the square is the fundamental frequency. The best impedance match between the globe and the circuit ground exists at this frequency. Each harmonic frequency adds more of the *square-ness* or *corners* to the square shape. The globe will work best at its natural resonant frequency. The problem with harmonics in the signal is that they force the oscillator to drive the display at frequencies that cannot transfer power efficiently. At non-resonant frequencies, the globe (basically an antenna) transmits less energy due to a bad impedance match. The result is a poor display. The 555 driven globes tend to rattle or squeal a lot, and don't look to great either. The noise is caused by vibration in the glass and sometimes the transformer as well.
- **Flyback Diode:** Most people forget to install, or install incorrectly, a proper flyback diode (or freewheeling diode) across the primary coil of the flyback transformer. Without the diode, the current shape of the primary coil is very messy and really stresses the switching transistor. Try to remember that the *secret* to a great supply is *resonance, harmony, and efficiency*. The diode helps the circuit run cooler and also protects the transistor from voltage spikes produced by the primary coil when it turns off. You must put the diode across the coil, not the transistor. It provides a path for current to flow in a loop through the diode and coil after the transistor switches off. The diode protects the transistor because the forward voltage drop of the diode is fixed at about 0.5V. Since the top of the coil is tied to the positive rail, the other end of the coil is clamped to 0.5V higher than the rail, which is a very safe level for the transistor. After the transistor switches off, current flows through the coil and flyback diode while the transformer's magnetic field is collapsing.

Once you build your power supply, you'll find that display tubes exist everywhere and you'll be trying it on everything. My favorite thing to do with my *Eye of the Storm* display was to simply hold various tubes up close to it and watch them light up in my hands. Many tubes you can play with you can find lying around your own house. There is fortunately no danger in doing so as long as you leave your main plasma globe connected to the power supply, don't touch anything metal which is either grounded or powered, and just use the radiated EM field to light things up.

Some really cheap easy to find display tubes which you can use to test your new power supply's output include:

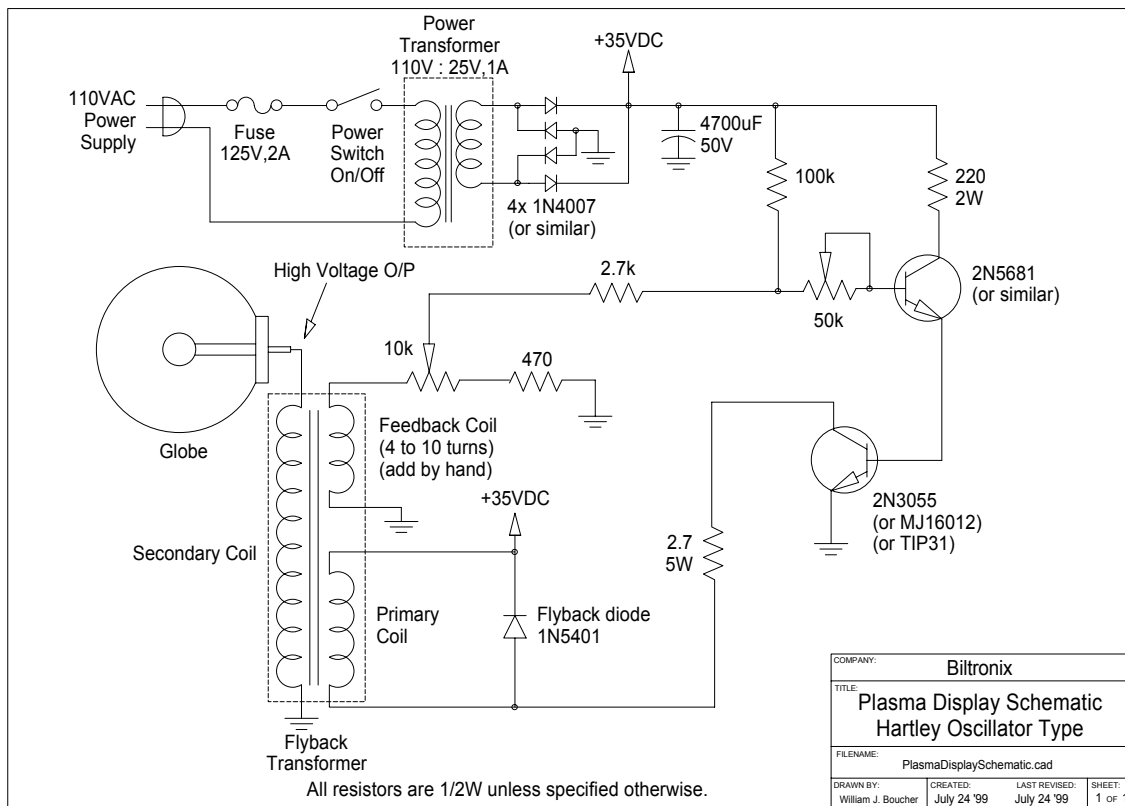
- Any florescent tube will light if you just touch the output wire to any one metal terminal. Don't touch any metal yourself.
- Any Neon candle-flicker bulb.
- Any Xenon flash tube from an electronic camera or flash cube or Radio-Shack store. These tubes work great if they have any metal layer removed from the outside of them. Some U-shaped tubes have a metal layer deposited on the outside, which acts as a trigger for flashing. This layer impedes plasma but is easy to scrape off. These Xenon tubes produce nice bright lightning-like filaments. Note that if you connect one electrode directly to the high-voltage output wire, do not touch the other end. You can easily get a shock because the plasma filaments in a Xenon tube can be tightly focused and thus can carry a lot of current.

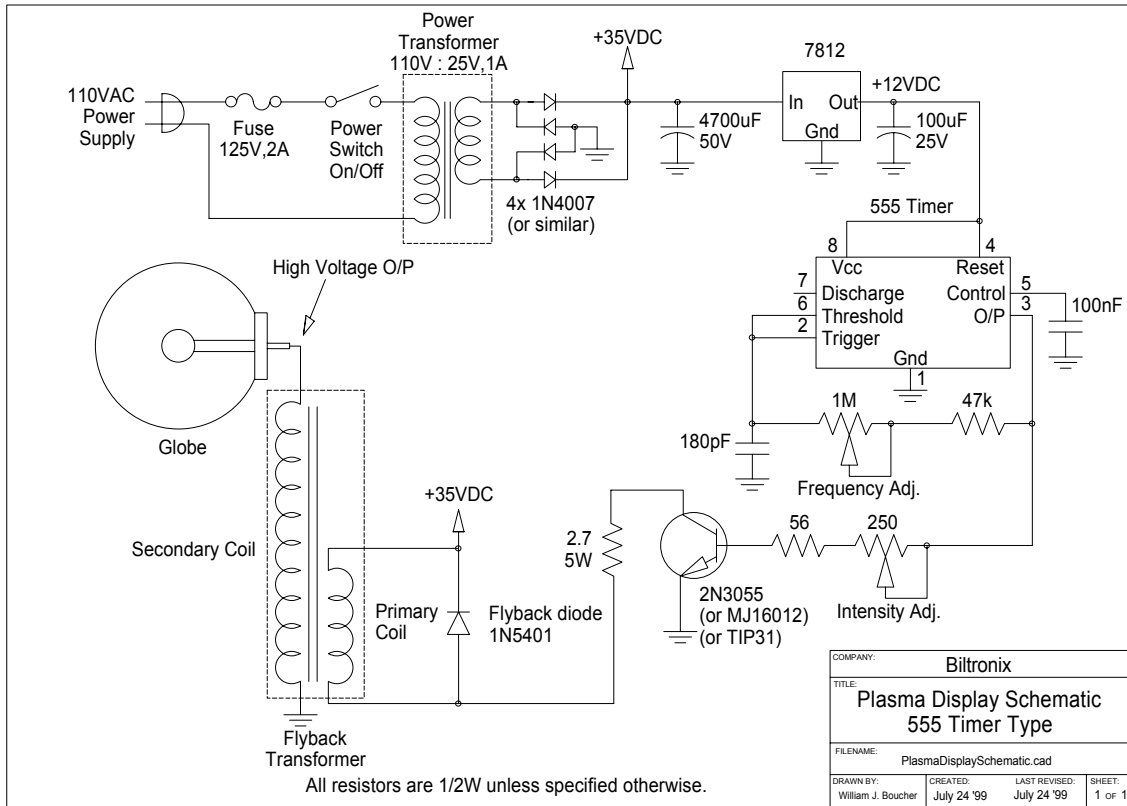
Finding a flyback transformer with the *magic*:

This can be the longest journey of your life if you worry about milliHenries (mH) and the like too much. I never did. An appropriate flyback transformer (FBT) is probably the toughest part to get next to the globe. Some surplus houses will have boxes of them. Practically any FBT out of any black & white TV will be pretty good. Try to get an older one with a donut shaped secondary coil and with an *open-frame* square ferrite core. Those are easy to add a feedback winding to. I also avoid the small, encapsulated FBTs. They often work poorly simply because they have high-voltage rectifiers (HVR) inside them. That's what prevents most FBTs from working in plasma supplies these days. Remember that the globe acts like a capacitor to ground. To keep an ion trail blazing, you have to keep it active by energizing *and* de-energizing the atoms. If there's a rectifier in there, the coil can *charge it up*, but it cannot *discharge it* during the relaxation of the primary & secondary coils. You'd be amazed how many people do not understand this. The trails require certain things to exist for more than an instant and that's plenty of voltage and exercise. Most of the old B&W TVs had FBTs without HVRs in them. Also, they had open-frame ferrite cores. The open core makes adding the feedback winding a snap. My best plasma supply has exactly this type of transformer in it. There was a time when I cursed it, because it was popping expensive transistors, running hot, working lousy, etc. I solved all these problems by using a *lower* voltage to drive the primary coil and using a *resonant* mode as previously described. With the sinusoidal drive, the primary coil's impedance came way up and the power output was amazing (I was tempted to say shocking).

Most of the time, the primary coil has several taps. I just try all the combinations of the primary taps until I find the one that works best. Typically, it's the one with the highest DC resistance.

Typical display power supply circuits:





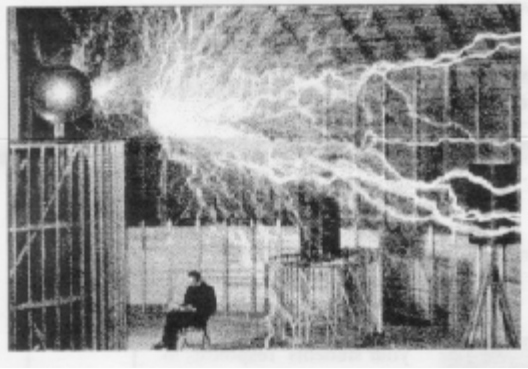
Words of Caution:

Now I want to make sure you know what you are messing with here. Your new hand made tubes running on high-voltage supplies can and very likely do emit X-rays, possibly gamma rays as well, which cause genetic damage to your cells. You better be dam careful with those things or you'll likely get cancer later in life. You know how many of Tesla's friends died from excessive exposure to X-rays? Too many, I can tell you that. Back then, people just said, "Wow, look, I can see through there!" and it didn't hurt so they loved it. Too bad what you don't know can kill you. Even the type of metal used for the electrodes determines the type of rays emitted. Also, so does the gas itself. Air is loaded with different ones so there's potential for many wavelengths, and several are not friendly. I wouldn't think your project is worth not seeing your grandchildren so I urge you to think about what you're doing when you mess around. Maybe I'm over-reacting, but I know I wouldn't risk messing with it unless I knew for a fact it was low power enough to not pose a hazard.

About Ozone:

All plasma displays like this will produce some amount of Ozone. A freestanding display produces very little and is not a problem. However, when you are playing around touching them, and having fun, little tiny sparks will jump from your fingers to the glass of the tube. You can see them in the dark. These *open sparks* produce Ozone, which you can actually smell. It smells weird so you'll notice it. Sufficient amounts of ozone will make you feel a little nauseated but there will be no permanent effects. Just limit yourself, and have a well-ventilated room. Normal plasma displays are never a problem, just the really powerful ones. No need to be paranoid but I thought I better mention it.

About Nikola Tesla:



When I saw a plasma display (Eye of the Storm) on a movie, I wanted to create one, so I researched the subject, a lot, and discovered this amazing genius, and from his history, I extracted much valuable information with which I built the plasma ball of my dreams. I obviously do not dream as large as Tesla did! Nikola Tesla was a genius of the highest order, literally to the point that *all* the other scientists in the world could not comprehend his theories, which are all still proving true to this day as modern scientists catch up. He was so gifted and creative, you'd swear he was actually an alien from an advanced race

marooned on Earth and trying to advance the society since he is stuck here anyway. This guy teaching the scientists and scholars of that era would be like me trying to teach English to some fish in a pond. You can try, but...

Suffice it to say that literally *all* of our wireless communication technology *started* with him. He built absolutely *huge* antennas, which generated millions and millions of volts and could transmit Morse all the way around the world, & also this radiated power was so strong, such a unit powered up a lot of light bulbs at a world's fair from 80 miles away without wires. Top *that* in 1890! And if that were not good enough for one lifetime, he also built the first inert gas discharge tubes, including X-ray tubes, which then lead him to discover the medical application of X-rays. Then came Gamma ray tubes, Neon indicator lamps, Xenon flash tubes, and laser tubes.

He also is the man who literally thought up and designed the magnetic and mechanical designs for almost all of our modern day electromechanical devices such as:

- AC induction motors.
- AC synchronous motors.
- AC & DC brushed, brushless, and 3-phase motors & generators.
- Stepper motors.
- Solenoids and linear induction motors.

He also was hired to design the hydroelectric generators, which were first installed in the Niagara Falls and also the ones in the Hoover Dam if I'm not mistaken.

His biggest problem was that he was so incredibly intelligent that almost nobody believed his machines were real, or even possible, until after he died with a relatively poor financial status and lack of recognition. He was literally considered a kook by most. Small brains still exist which still think he was a quack. It's a good thing Tesla was correct or none of us would have electricity! He generated it in massive quantities way before anyone else even knew what it was. Even before the internal combustion engine so don't ask me how he powered that huge antenna in the middle of a prairie! Nobody has ever figured out that one! He kept it a secret. But thousands of people saw it running, saw the lightning, the corona at night, and the lighted town a mile away, which it was powering without wires! This is no bologna. The guy was a true master.

Only years after he died, did scientists study his apparatus and notes and models and begin to realize there was something bigger there than they'd ever thought. Many did not want to believe it, but believe it or not, they built machines according to his design, and they *all* worked great. Amazing!

Some people have claimed that soon after his death, the government seized his project notes in an effort to keep valuable and advanced information from falling into enemy hands. It is claimed that Tesla outlined, in his notes, methods for producing unlimited free energy and weapons of such power as to split the Earth in two. It is not too hard to imagine that this might in fact be possible when you consider the amazing technologies, which Tesla presented to the world.

I have read every book I could find about him. All pretty amazing, fascinating history of a poorly understood and superior intellect. If Tesla were born 20 years ago, I bet we'd be flying around in anti-gravity cars by now!