the Bell Jar
Vacuum Technique and Related Topics for the Educator & Amateur Investigator

Notes from the Vacuum Shack **No. 14 January 2021**

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Floating Filament and Grid Power Supply

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Background

Having acquired a small high-vacuum system, one of the fields I plan to explore is the generation and direction of streams of electrons. The good-old cathode-ray tube provides a good starting point for electron-gun design, but my field of interest is wider than that, in that it also includes homemade valves, and the like.

A first attempt (which was much to my surprise successful) in building a triode resulted in quite a spaghetti of wiring, and the use of several digital voltmeters.

Requirements

It took quite some effort to outline the specification for a small self-contained power supply that might be useful for applications where the filament is operating close to ground, as well as potentially up to –2500V. Given that the control grid (G1) is usually referenced to cathode potential, and in my case, the use of directly heated devices means that the filament is also the cathode, then it also made some sense to include a variable- grid supply within this unit.

At least two sorts of filaments are anticipated to be used: low voltage, high current; maybe 2V at 2A, and high voltage, low current; 6V, 300mA. In both cases plain metallic tungsten will be used given its relatively ease of purchase, relatively high work function, and immunity to oxygen poisoning. Given the quite high resistance/temperature coefficient of the material, it makes sense to feed them with current, rather than voltage.

Having done a quick search, the highest power filament I could find was for the old VCR97 CRT which requires 4V at around 2A; 8W is quite a bit of power to dissipate in a vacuum, and was then chosen as the maximum power that the PSU needed to deliver.

Final unit. Grid -49.9V, Filament 0.90A

One of the other desirable attributes for the filament supply is having it voltage-limited. If for example the PSU was set to 1A and there was no appreciable voltage limit, it would be quite easy to destroy a 6V/300mA filament. By setting an upper potential to 7V for any given current, this affords a degree of protection to the lower current, higher voltage applications.

From the above observations, it seems that a mains-powered, floating supply capable of withstanding ±2.5kV with respect to ground, able to deliver 0 to 3000mA, limited to 7V, and capable of delivering 8W would be a good thing.

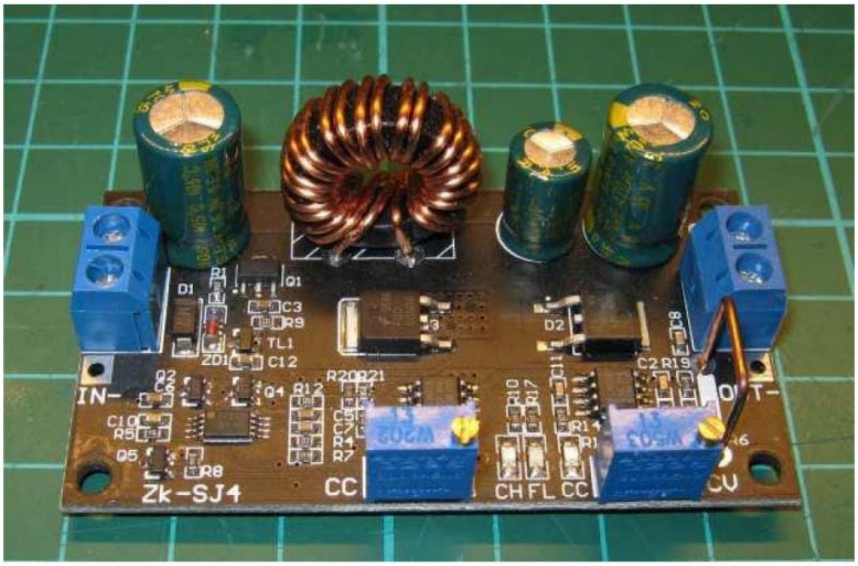
A couple of final notes on the subject: a filament current disable switch is desirable, allowing power to be removed while the vacuum chamber is equalised to atmospheric pressure without having to remove mains power. Also, regulated DC is much more desirable for directly heated applications for various reasons.

The grid supply was straightforward to specify; a simple smooth, but unregulated rail, adjustable from 0 to around –50V capable of delivering a few tens of micro-amps should be adequate.

The complete unit also needs indication of generated current, and voltage.

Electrical Details

The singly most complex part of the venture was the design, or purchase of a low voltage, constant current, voltage limited power supply. It was with considerable delight that a suitable module was located within an hour or so of searching on the Internet.



Unmodified ZK-SJ4 current regulator

This is quite a useful module, with an input range of around 5 to 30V, an output range of 0.5 to 30V, and it is also buck/boost. The square copper-loop on the right is the output current sense resistor (18mΩ), so is a useful monitor point. The ten-turn 2k trimmer marked CC can easily be replaced with an external 10k 10 turn pot for variable current control. Also, for this application, the output potential was set to 7V using the CV trimmer.

A pair of CX102 4-digit DVM modules were used to monitor filament current as well as grid voltage. The latter was simply a 1001:1 voltage divider, with any calibration error being taken out by twiddling the associated reference trimmer on the rear of the DVM.

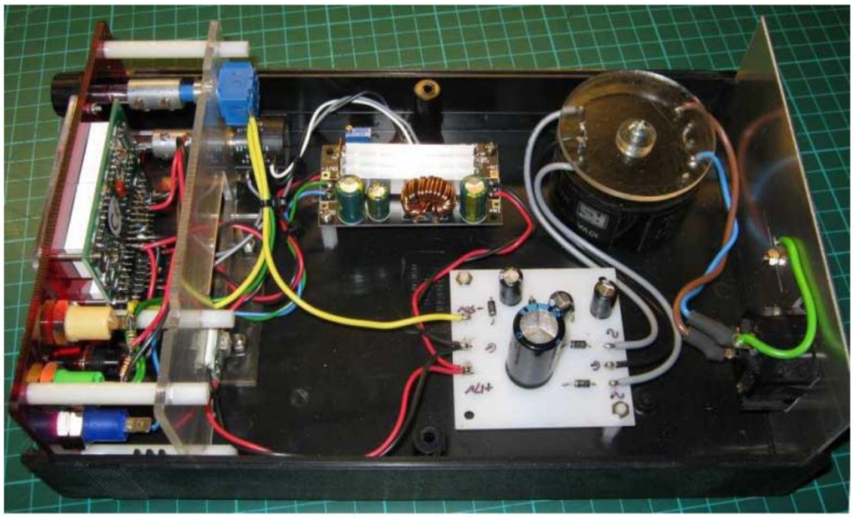
As supplied, the CX102 has a ±200mV input range, giving a ±3.5 digit display range. For this application a 1A output current passing through an 18mΩ sense resistor will drop 18mV, but a display value of 100 is required. To resolve this problem, the associated voltage reference needs to be increased by a factor of 5.55 (100/18). This was made by changing the resistor in series with the Vref trimmer on the rear of the DVM module.

Power for the DVM modules was derived from the 16V unregulated rail, via an MP2307 SMPSU module set to 5 volts.

The grid supply was generated using a Cockcroft-Walton voltage multiplier connected to the secondary of the mains transformer..

Mechanical Details

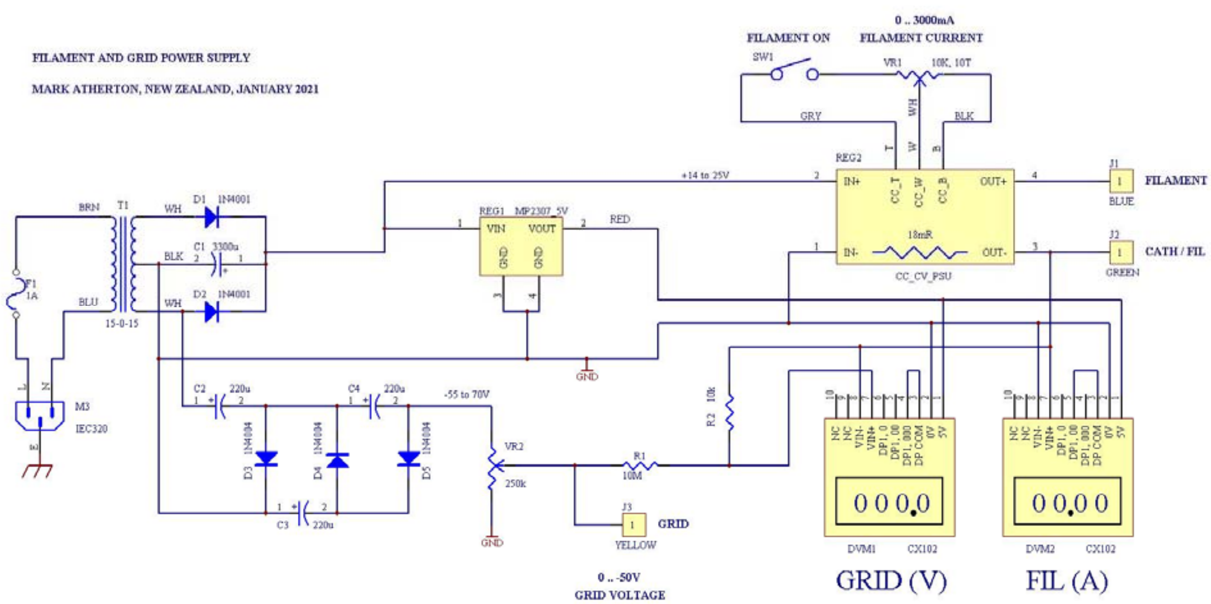
The unit was fabricated inside a Hammond plastic enclosure; the front ali panel being replaced with a pair of laser-cut acrylic plates held apart by 6mm plastic spacers.



Internal view

Considerable effort was taken to ensure that the user is isolated from any of the (possibly) high voltages floating around within the unit. Control knobs from the front panel are attached to 6.3mm round acrylic shafts and couplers to associated pots. Board assembles are mounted on nylon stand-offs, and the mains transformer has an acrylic idiot-shield in place. Finally, the front panel has a pair of 2mm clear acrylic sheets protecting the user from the 2mm mounting screws holding the DVM modules in place.

Below is the schematic for the unit. Please note the the points designated as ground are floating.

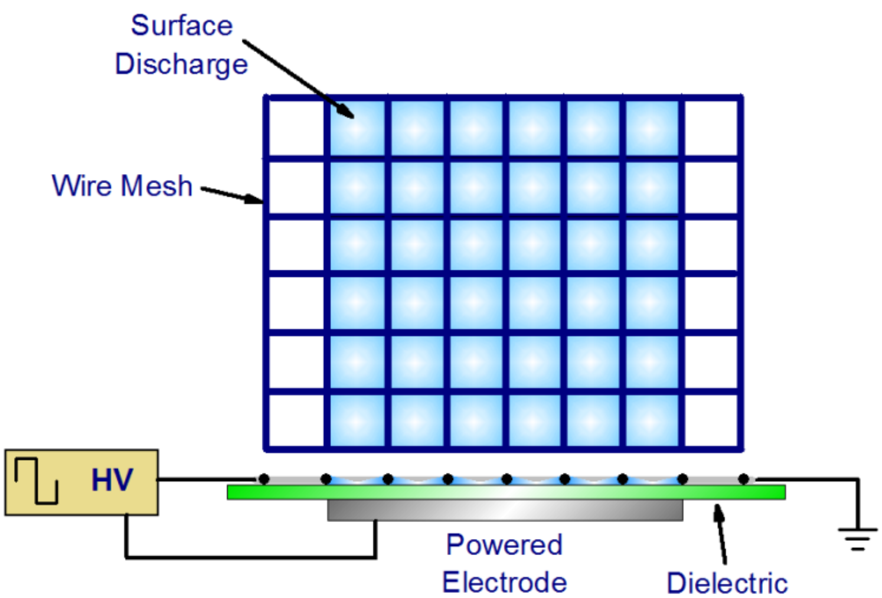


High Voltage Testing

With the unit disconnected from the mains, all three output-terminals were shorted together, and connected to the +ve output of a high-voltage tester. The associated –veoutput was attached to the ali rear panel (also connected to the transformer shield pin). The HV tester was then gently cranked of to 2500V and left for a few minutes. The test system was then disassembled and plugged back into the mains; the unit having survived this electrifying ordeal without incident.

The Surface Micro-Discharge (SMD) Plasma – Another Atmospheric Pressure Plasma Source

Past issues of this newsletter have covered a number of configurations for atmospheric pressure plasmas. These have included the dielectric barrier discharge (DBD) and various forms of atmospheric pressure plasma jet (APPJ). One configuration that has not been covered is the surface micro-discharge (SMD) plasma. This is related to the DBD with the exception that the discharge does not occur between two dielectric covered electrodes but rather within the mesh of a grounded screen electrode. Between the mesh and the powered electrode is an insulating layer. The general configuration is depicted in the figure below.

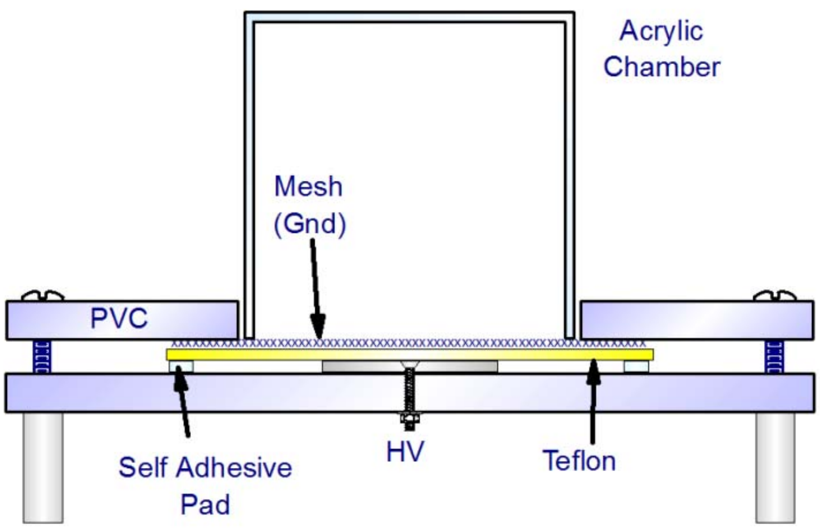


In this configuration, any item that is being treated is not immersed in the plasma as is the case with the DBD. Instead, the plasma generates reactive gaseous species and ultraviolet energy which can then be used to treat a nearby specimen.

While I haven't built an apparatus yet, I am thinking of something along the lines of what is depicted in the figure on the next page. The structure consists of a sandwich of the electrodes and dielectric between two 1/2 inch thick pieces of PVC. These are cut to 6 x 10 inches. The powered electrode is a tentatively a 2-1/4 inch diameter aluminum disk. The dielectric is 6 x 6 x 0.039 inch thick Teflon (McMaster Carr 8545K12) and the stainless steel wire cloth mesh is 10 x 10 mesh with a 0.077" opening (McMaster Carr 85385T49).

The upper PVC sheet has a 4 -1/8 inch diameter opening. Note that the active area (as determined by the diameter of the powered electrode) is smaller than that of the mesh and opening. The acrylic chamber is from a supplier of retail store display items, Azar International (https://azardisplays.com) and is their part number 556404 (4” diameter x 4" high). These are available from the seller and from other on-line retailers. Other heights are also available. The cylinder can be drilled for gas fittings, etc. The rubbery plastic adhesive pads are standard hardware store items that are normally used as bumpers. These are a bit thicker than the powered electrode and serve to keep the Teflon and mesh flat when the assembly is clamped together. The ground connection for the grid is not shown in the illustration.

For an excellent overview with details on an SMD apparatus and research into the antimicrobial properties of SMD, the 2014 dissertation by Jin Jeon [1] is highly recommended. As with some other atmospheric pressure discharge configurations, the SMD would seem to be a good area for exploration by amateurs and students looking for an unusual science fair project in physics, biology or chemistry.



Reference

1. Jin Jeon, *Surface micro-discharge (SMD) - analysis of the antimicrobial effect and plasma chemistry*, thesis, 2014. https://edoc.ub.uni-muenchen.de/17873/1/Jeon_Jin.pdf

Update on Richard Hull’s Fusor V and Activation Experiments

The following is from an email exchange with Richard in early January, 2021.

Folks all over are activating the elements, rhodium, silver, indium, manganese, copper, gold, dysprosium and many more tough-to-do activations. One fellow is now working with a water cooled 6” aluminum “cube” fusor at 125 kV and claiming, with good instrumentation, 10^8

neutrons/sec TIER, (Total Isotropic Emission of Radiation). They prove it via presenting beta decay curve Excel plots using an Arduino to capture, record and save data streams from a GM counter or via gamma ray spectrographic analysis. Yes! Many of us have gamma ray spectrographs.

Here is a link to a posting at fusor.net:
https://www.fusor.net/board/viewtopic.php?f=13&t=13568&start=20

This shows my recent activation efforts with my personally recorded data rhodium Excel graph and a separate reduction against the mathematically resolved expected, "best fit" curves done by my friend Bill Kolb.

As you scroll down the page you can see the effort involved at a high level. Vacuum is just one major, important leg in this effort that requires one to have relatively mastered one technology after another to obtain, prove and use fusion from table top apparatus. This is not to mention natural hands-on mechanical skills demanded from machining to welding and electronics and electrical skills. Much like *the Bell Jar* continuously presented projects, and the old "Amateur Scientist" articles of the 50s and 60s, the old song about New York applies here…….."if you can make it here, you can make it anywhere". The future involves "high order"! High order skills, high order self directed learning, high order failures and high order wins to keep us moving forward (progress).

I love the Yogi Berra quote: "Progress may have been a good thing once, but it just went on too long". Let us hope this humorous quote by a simple man will not presage an era of stagnation among mankind.

If you have not seen the documentary, "Planet of the Humans", I suggest you avail yourself of this amazing 100 minute effort. It was on YouTube but has been removed and is currently being streamed for a couple of bucks, (well spent). I watched it all the way through 5 times while on YouTube, from Feb-July. I picked up more insight with each re-watch. (I'm a slow learner but always get there)

In this era of dumbed down education, kids buried in their smart phones making virtual friends they will never see or meet, it is heartening to see a few out there who still have the chops, the verve, and the skills to actually "do" as a result of the "hands-on imperative" in the sciences.

With regard to my new Fusor V, my Fusor IV, which was a great one, ran from 2003-2019. It used an adapted Leybold ISO 63 diff pump. Fusor V was made in 2020 and is working great. It uses a Pfeiffer TCP50 turbo that I bought from my long time friend Bill Connery shortly before his death for $100 with all cables and controller. A large internal arc in Fusor V early on blew up the controller box. I spent a month repairing it and it is now fully functional again. (It helped being a retired electrical engineer and lifelong electronic hobbyist), On the next page are two photographs.

7/16/20 Completed Fusor V. Deuterium gas line is hooked up. Doing fusion! Some minor finishing details are needed, but what remains is to condition the new Fusor V to wall loaded deuterium. This is always a long and tedious multi-day process and commensed in earnest on 7/17/20.

The Saddle Field Ion Source

Overview

Most everyone here is familiar with the various manifestations of the cold cathode ion gauge from the original Penning (or Philips) ion gauges to the inverted magnetron configuration. The approach is also found in ion sources. These are high to ultra-high vacuum gauges where the pressure measurement is based on the current through a plasma discharge. Since plasmas don't like to ignite at very low pressures, given that the gas density is too low for a sufficient number of electron-molecule collisions to occur, the gauge's electrodes are immersed in a magnetic field. This increases the electron paths significantly, permitting a useful electron impact ionization rate.

The saddle field "electron oscillator" operates on a similar principle but with no magnetic field. The original configuration is very simple, consisting of a cylindrical cathode that surrounds a pair of axially symmetric anode wires or rods.

The basic design was developed by McIlraith [1, 2] in the late 1960s and developed into an ion source by Franks [3, 4]. As described in the Franks patent:

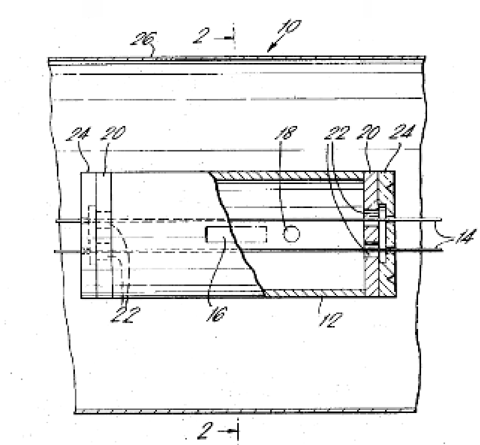
> ...an electron starting from rest within a specified region follows a long oscillatory path between the anode rods, thus creating ions in the residual gas before being brought to rest on one or other of the anode rods. When operated as a cold cathode device, the gas discharge formed is concentrated about the axial plane normal to the plane of the rods.
>
> The gas discharge is maintained by ions bombarding the cylinder wall, thus producing further electrons. The bombarded regions of the cylinder are situated in the two areas where the gas discharge sectors intersect the wall of the cathode cylinder. The areas extend as two substantially parallel strips along most of the length of the cylinder on opposite sides of the diametrical plane normal to the plane of the anode rods. The strips terminate before reaching the ends of the cylinder because here the field is largely

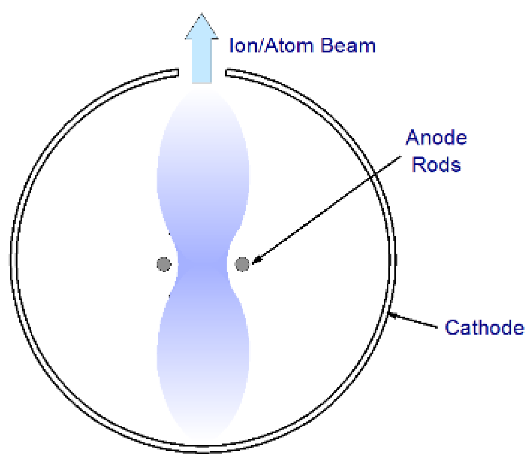
directed parallel to the axis of the cylinder instead of radially, in order to prevent electrons from drifting out of the tube. The cylinder is provided with end caps at cathode potential to prevent such drifting. An ion beam emerges from the aperture if the latter is located in the region of a strip. The aperture may be small or may extend along the length of the strip but as the aperture is increased in length the operating voltage and/or pressure must be increased to maintain the same ion beam density because the aperture perturbs the field and reduces the area from which electrons are produced to maintain the discharge. With a small aperture, however, the beam current is limited by the geometry of the system. The ratio of the beam current and the total cylinder current will approximate to the ratio of the area of the aperture and that of the strip regions of the cylinder wall.

In McIlraith's paper [2] he notes "A minimum condition for the maintenance of a cold cathode discharge is that for each oscillating electron lost by collision at the wires, one secondary electron should appear at the cylinder. From this it follows that if the cross section for an ionizing collision is 10^{-6} cm^2, and the probability for the production of a secondary electron at the cylinder is 0.1 per incident ion, each electron must travel about 5 km to maintain a discharge at a pressure of 5 x 10^{-6} Torr."

Below is a figure from the Franks patent and a depiction of the discharge region based on [2]. The cathode is stainless steel, 25 mm in diameter and about 50 mm in length. The anode rods are tungsten, 1 mm in diameter with a 6 mm separation. The ion exit is shown as a slit and the gas inlet port is just to the right of the slit.

Saddle field sources have found use in a variety of applications including sample thinning for transmission electron microscopy, as a source for fast atom bombardment (FAB), as an ion gauge, PVD and many others. Typical operating pressures, as an ion source, are in the range of 10^{-5} to 10^{-4} Torr.





There is a lot of information in the literature. Thatcher's [5] thesis is very informative and dates from the time of the early work on saddle field devices. More recently, there are several papers by Abdelrahman *et al*. [6, 7, 8] that are very interesting. In going through the literature, you will see that there are a number of electrode configurations besides the parallel rods.

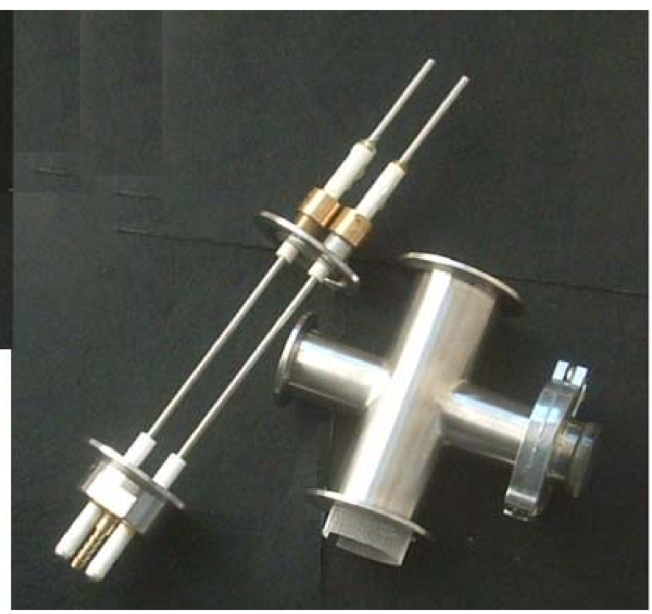
My Prototype Saddle Field Source

A number of years ago I made a source that was for the most part comprised of bits and pieces I had in my parts bins. I put it away when we moved but earlier this month I decided to dust it off and try it out again. In looking at it now, the construction was a bit of overkill and non-optimal. It was built around a KF50/KF40 adapter tee. The rods go through the KF50 tube. The rods are very beefy at 3/16 inch in diameter and the spacing is on the order of 22 mm which is quite wide. In fact, too wide for efficient operation.

The KF40 ports are also far too large and if left open and will disrupt the field. To alleviate this I've used a fairly dense stainless steel mesh insert and also a tight-fitting aluminum tube that has either a slit or round hole as depicted in the Franks patent. The mesh was handy for viewing the discharge through a view port. Pictures of the device are shown on the next page.

After running it again, I found that several leaks had developed around the epoxied rod to ceramic tube seals. After a bit of troubleshooting with a Pirani gauge and dust remover spray, I applied some fresh epoxy to the offending areas.

Pumping down with my mechanical pump (my high vacuum diffusion pump is being swapped out for a rebuilt turbo) with up to 7 kV applied to the anode rods there was a conventional rod to cathode glow discharge until I got below about 0.1 Torr. As the pressure declined further, the discharge moved to the left hand side of the Paschen curve. Then the device went in the oscillatory mode and the glow was quite visible between and normal to the rods. The discharge remained quite strong down to the pump's base pressure of 10 milliTorr.



Above: Complete saddle field source showing viewport and anode rod feedthoughts.

Right: Disassembled source showing anode rods, retention insulators & gas feed port. Also shown is the mesh screen, partly exposed.

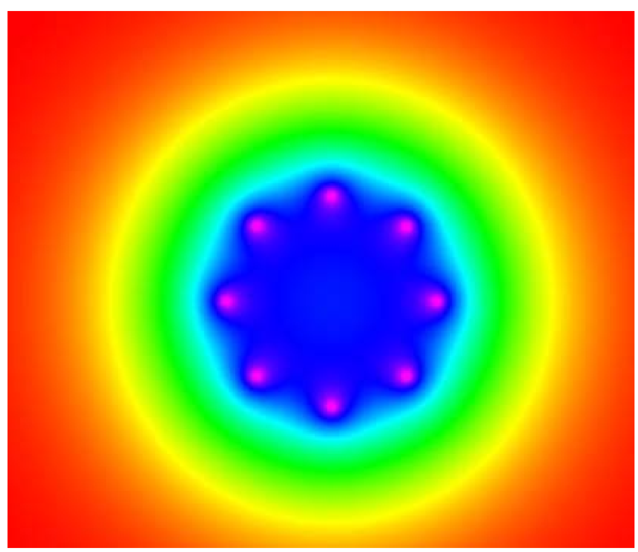
The next iteration is in the works. The main change will be that the thick rods will be replaced with 3 mm diameter stainless steel rods and the rod separation will be on the order of 6 to 8 mm. I'll use the same KF50/40 adapter tee along with a slotted and/or round aperture aluminum insert. A number or researchers have also covered much of the inner cathode area, except for the area surrounding the slit, with an insulating material such as Lucite. I've got some Teflon film that should serve nicely should I try that.

References

1. R K Fitch, T Mulvey, W J Thatcher and A H McIlraith, *A new type of ion source*, J. Phys. D: Appl. Phys, 3, 1399 (1970).
2. A. H. McIlraith, *A charged particle oscillator*, J. Vac. Sci. Technol. 9, 209 (1972).
3. Joseph Franks, Ion sources, US Patent 3,784,858, issued January 8, 1974.
4. J. Franks, *Properties and applications of saddle-field ion sources*, J. Vac. Sci. Technol, A 16, 181 (1979).
5. Westford John Thatcher, *A study of the properties and applications of electrostatic charged particle oscillators*. PHD thesis, Aston University, 1970. https://publications.aston.ac.uk/id/eprint/20587/
6. M.M. Abdelrahman and A.G. Helal, *Developments of saddle field ion sources and their applications*, X Radiation Physics & Protection Conference, 2008. https://tinyurl.com/y4em9rxo
7. M. M. Abdelrahman and F. W. Abdelsalam, *Modified Saddle Field Ion Source Using A Ring Focusing Electrode*, Journal of Nuclear and Particle Physics 2012, 2(3): 26-30. https://tinyurl.com/y25qwlfv
8. M. M. Abdelrahman , M. Osman and A. Hashhash, *Electrical properties of irradiated PVA film by using ion/electron beam*, Prog. Theor. Exp. Phys. 2016, 023G01. https://tinyurl.com/y4ef3okk

Electrostatic Field Simulation Code

Joe Malek (joe.malek@eleksys.com) writes "I dusted off some old code I wrote back in 2008 and debugged it (I think). It plots 2D potential fields from a configuration of specified electrodes. Just started to write code to fly particles through the fields. The code uses the Leibmann Procedure which is simple but not too efficient. I got it from an old book I have on electron optics. " To the right is a plot that Joe sent. This depicts the fields around an electrode configuration like that of a Farnsworth Fusor.



Amateur Friendly Suppliers

Do you have any favorite vacuum component vendors that will sell to amateurs? I have a pretty good stash of stuff, much of which was procured via eBay. I also have an LLC which helps in dealing with the major suppliers. Recently I had to get some components that I could not find through eBay. Richard Hull had suggested LDS Vacuum Shopper (https://www.ldsvacuumshopper.com/) in Longwood, FL. I made up a small shopping list and placed an order. The service was fast and friendly. One of the items was an overstock and came with a very good discount.

Articles of Possible Interest in *Vacuum Technology & Coating* Magazine

June 2016
Thermal Transpiration: Theory, implications and uses
Thermal transpiration, also called thermal creep, is how the Crookes radiometer decorative toy and Knudsen pumps operate. The article includes a section on hacking a commercial Crookes radiometer.

February and March 2018
The Evolution of the Cold Cathode Gauge (in two parts)
Part 1 covers the progression from the Penning configuration to the inverted magnetron, the pressure vs. current relationship, starting time, user maintenance, etc.

Part 2 covers the electrical characteristics of the crossed-field discharge and enhancements to extend upward (to atmospheric pressure) the operating range. With regard to the latter, MKS, for a time, sold a wide range inverted magnetron gauge and I received a unit to evaluate. It works quite well. However, from a marketing standpoint, it lost out to combo gauges such as the cold cathode/MEMS Pirani package.

Articles may be accessed at http://vtcmag.com/. Scroll to the bottom of the page to the back issue selection box. Look for my columns and you can probably find other articles of interest in each issue.

End Notes

The consulting project I am working on is going to keep me busy for the next 3 months or more. This has limited the time I can spend working on "fun" projects. I do plan to finish installing my new (refurbished) turbo pump, building the next iteration saddle field source and have a functioning SMD device.

As always, please send your project contributions, large or small.

Steve