

# About vacuum power tubes.

By Matt Erickson KK5DR

The info I am putting forth here comes from engineers at CPI/EIMAC, Rockwell/Collins, and my years of experience with RF power tubes. The data I am publishing here, is supported in the technical article "**Care and feeding of power grid tubes**".

**Fact:** There is no such thing as a perfectly sealed vacuum tube. All tubes leak.

**Fact:** Over time, molecules of air pass through these "imperfect" seals, contaminating the inside of the tube.

**Fact:** A tube that sits on the shelf collects a relatively large amount of air inside over time.

**Fact:** The longer the tube sits inactive, the more air is accumulated.

**Fact:** The larger the tube, the greater the leakage.

**Fact:** The high level of vacuum, and removal of contaminant molecules is maintained by something known as the, "getter", which is usually a form of "rare earth minerals", that absorb the air, when heated by the filament in the tube.

**Fact:** Over-heating of tube seals, can compromise the seal, and cause rapid tube failure. Tube seals can also be damaged by high current start-up in-rush, which can crack seals by mechanical stress.

**Fact:** There is no such thing as, "too much cooling air flow" over the tube. Too

little cooling air can be a big problem, and lead to seal over-heating.

**Fact:** Broadcast radio/TV stations keep all their final amp tubes running with filament current, at all times, for two reasons.

1. To keep the tube ready for instant use, should the other tube fail.
2. To keep internal contamination to a minimum.

It would be impractical for amateur radio stations to keep our tubes on at all times, an alternative is to "rotate" the final amp tubes on an annual basis.

Many hams have a "spare set" of tubes. I have heard of several cases where a ham had a spare set of tubes stored "safely" away in the closet for years. One day, they decide to place the spares into operation in his aging amp. Little does he know that over the years these tubes sat in the closet, molecules of air have been sneaking into the tube, gathering in a "pile" near the bottom of the tube, which is usually the negative cathode. The ham puts the tubes into the amp, turns it on, and begins to tune up as normal, suddenly, BANG!, the tubes flash-over internally and "self-destruct".

**Here is what happened inside**, the "pile" of air inside the tube, was ignited into a "plasma" (a super hot ionized gas) by the combination of high voltage, heat, and the igniter RF, the plasma is negatively charged, which then travels toward the positively charged anode of the tube. Most of the time, between the anode and cathode, lays the delicate grid, which has a large hole burned through it by the traveling plasma cloud, which is extremely hot (up to 30k degrees). This rarely happens to small receiver tubes, but it is not completely unknown. I have had a number of 12BY7A RF driver tubes that over time became "gassy". The lower plate voltages in these tubes, was not enough to "ignite" the gas, but strange behavior of the tube made its replacement necessary. A good indication that a tube has become "gassy" is a "blue/purple" color near the top of the tube, or around the plate. A tube that is free of contaminant gas has no color, aside of the filament glow.

**Solution:** Keep your tubes "de-gas-ed", by "rotating" the "spares" with the regular tubes. A good rule of thumb; is to swap out the tubes annually, while removing dust, lubing the fan, etc. This may not be the "best" way, but likely the most practical one.

You may ask, "how long should I allow the tube to burn-in, prior to operation?" On a tube that has an unknown amount of shelf time, 10-12 hrs would do well. For a tube that has been in your closet for known amount of time, I have developed a rule; 2 hrs per year of shelf-time. When you "rotate" your tubes, allow them 2 hrs of burn-in time prior to applying RF drive. With a new tube fresh from the factory, 6-8 hrs for large glass envelope tubes, 2-6 hrs for metal/ceramic tubes, burn-in time. A little patience, and conservative use, your tubes should see full life.

Another reason to "burn-in" a new tube is that it will finish the vacuum, removing the last remaining gasses and brings the filament/cathode up to full electron emission.

## **Other contaminations**

There is another source of internal tube contamination other than the outside atmosphere. When a vacuum tube is driven by excessive RF levels, particles of oxide and metal gases are released into the tube. These metal gases and oxides can cause atmosphere contamination of the tube, which can lead to HV "flash-over" inside the tube. When a flash-over happens it can cause extreme levels of current to flow which cause further damage to grids, cathode, and tube seals, which then causes further flash-over, you can see where this is going. A tube that has had a history of flash-over can be opened and inspected, metallic powder and or tiny bits of gold or oxide coating will likely be found.

This is just one more reason NOT to over drive your tube(s).

## **Filament voltage?**

EIMAC states that; " A 3% increase in filament voltage above the maximum rating will result in a 50% decrease in tube life." For example: a filament with a max rating of 5.00Vac, increased to 5.15Vac (3% above max) can expect a 50% decrease in life span. However, decreasing the filament voltage to a low level can cause a radical drop in electron emissions. Check your filament voltage at the tube socket, using a VOM that reads "True RMS". If the voltage is too high (many times it is), and your amp has a separate filament transformer, install an adjustable power resistor in the transformer primary, and carefully adjust the secondary voltage till it is within the specified range, preferable slightly lower. If your amp uses an "all-in-one" power transformer, you can use a length of small wire to lower the filament voltage, but this will take a great deal of "trial & error" to find the right size and length of wire.

## **Plate voltage?**

Exceeding the manufacturer's maximum plate/anode voltage can lead to an HV flashover, and possibly destruction of the tube and or damage to the PSU or other parts.

A good rule of thumb; is to not exceed the maximum voltage by more than a 2% margin. Meaning that if your tube has a max plate voltage rating of 3000vdc, the max safe voltage would be 3060vdc. So, if you are using 3200vdc, you are taking a gamble. The key would be to closely match the plate voltage to the tube in use. For maximum gain, and best safety margin. This rule is most important when installing a new tube, which has a large gain level when compared to the old weak tube. Also, the new tube may have a high level of gas remaining in it, and operating the tube over its max plate voltage rating may well push it "over the edge".

A tube operating at maximum plate voltage, will reach its maximum RF gain level, and max power output level too. Anything over that max level becomes wasteful, dangerous, and sometimes unstable. Sure, it looks great on the watt meter, but it might come at a high price.

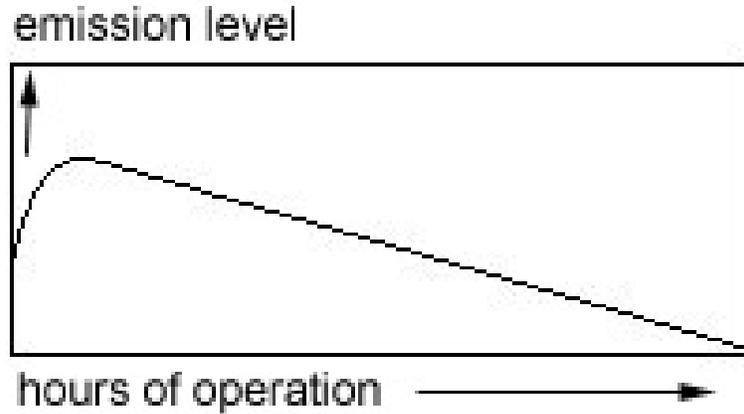
## Emission

Every vacuum tube has an element that is known as the electron emission source usually it is either an oxide coating as in indirectly heated cathode tubes, or a treated filament as in directly heated cathodes. When the element is heated, either directly or indirectly, it emits "extra" electrons that are driven by the electro-motive force & current flow within the tube, to the anode, this is how a tube amplifies. This process is continuous, as long as the tube heater/filament is active, electrons flow, even when the tube is in standby/cut-off mode. The supply of electrons is NOT endless, every tube that is active, is on the way to the end of its life span. However, turning the tube "off" and "on" a number of times unnecessarily would cause more damage than to leave the tube on for a few hours between uses. Thermal cycling is more harmful than continuous operation, but a balance of the two should be had.

For example; If you use your amplifier for a morning schedule, and then again for a noon sked, it would be better to leave the unit on and in standby mode during the interim time. If you operate several times during the day with your amp, it is far better to leave the amp on all day than to turn it on and off several times each day. This minimizes the thermal cycling of the filament/heater elements. Thermal-cycling is far more damaging than loss of emission levels.

Emission levels remain nearly constant all the way from new tube, to 10,000 hrs or more of continuous filament operation. When a tube is brand new its emission will be lower than after it has been in operation for a few dozen or more hours. This interval is known as the "burn-in" time, where-in the tube's vacuum is "finished" by the heat applied to the "getter", also the emission element is coming up to full electron flow during this time. After a few hundred hours the tube emission will reach a peak, after this the tube will have a very long slow glide to the end of its life span which is the point where the emission falls too low to be usable, or the filament/heater fails. Usually the end of the tube life is somewhere between 12,000 and 24,000 hours of filament/heater on-time. By amateur radio usage standards this is a very, very long time. I would not worry too much about your tubes failing in this mode, 90% of all tubes used in ham radio fail due to

chronic over-drive conditions, which damages the oxide coatings of indirectly heated tubes, and or the grid structures of directly heated filaments. This is NOT my opinion alone, but info shared with me by the engineers at EIMAC. They have seen it far too many times, for too many years for it to be an accident.



Above is a graphic representing the emission level verses hours, of a typical power tube. The graph is not to scale, the hours side is 12K hours.

Keep the thermal cycles of the tube to a minimum, and RF drive levels to the proper settings as prescribed by the amplifier manufacturer.

Keep your [tune-up](#) times down, and extend the life of your tubes.

To read much, much more about RF power tubes, stop by the [EIMAC web site](#), and read the technical article titled "**Care and feeding of power grid tubes.**" Mind you, this booklet is fairly technical and might be above the level of the average ham today, but it is very informative. Please download the PDF, you will learn much more than I can go into here.

### *How does a vacuum tube amplify RF power?*

The EIMAC booklet goes into much greater detail, but here is a quick and dirty explanation. The cathode surface emits free electrons, which are propelled by the flow of DC current and RF, driven by the RF voltage and DC voltage combined. These free electrons account for a greater number of electrons arriving at the plate

than are accounted for by the DC current alone. Thus we have amplification of any signal, audio or RF, that is imposed on the DC current stream.

### **Tube conditioning:**

New tubes should be carefully "burned-in", some will have "flash-over" problems in the very beginning of their life due to residual gases and metal vapors remaining inside the tube. I have found that this process can take some time, and RF drive should be very carefully applied to the tube during this time. If plate current levels become unstable, the RF drive and or the plate voltage should be reduced. Sometimes the process of "conditioning" the tube could take all day (8-24 hrs). During the process, the tube is run with heater/filament only (no RF drive) for at least the first 4 hrs of operation. Then, a small amount of RF drive is applied, if abnormal operation is noticed, the drive should be removed and the tube should be "burned-in" for a few more hours. Gradually, during the conditioning period the RF drive signal is increased, operating conditions are closely monitored during this time. When full power out is reached, and normal operating conditions are observed, the tube can be considered fully "conditioned" and ready for regular use in the amp.

Used tubes that have been sitting in storage for a number of years should be treated in the same way, but the time of "burn-in" is shorter since the tube has already been conditioned when it was new. The main reason for repeating this process is to "burn-off" any contaminating gases that have reached the inside of the tube. The general "rule of thumb" for the number of hours of conditioning required for a used tube is simple. If the number of years is known that the tube was out of service, add one hour of burn-in for each year. If the number of years is unknown, use 4 hours to begin with, if the tube does not behave well after this, repeat the burn-in period.

More difficult cases of HV flash-over can require that the HV be removed from the tube for a number of hours until residual gases are absorbed. A tube that refuses to settle down after more than 24 hours of conditioning may be beyond help. If they do not settle after 48 hours of burn-in, they should be removed and

discarded.

**Remember;** have a spare tube on the self, and swap them out every year. The set will likely out last you, even with daily use.

### **End of useable life:**

Every tube will have an "end of life" point. Directly heated cathode tubes usually drop off emission until they are no longer usable. Some say that the tube has gone "soft" at this point. When the filament opens is an obvious sign, but this can happen at nearly any time during its life span.

Indirectly heated cathode tubes end their lives a little more abruptly with a sustained HV flashover that damages the grids and or cathode surface to the point where the tube is no longer stable at any voltage or drive level, or the heater opens. Emission will have dropped off a great deal by this point. The cause for the HV flash-over is usually barium contamination of the atmosphere in the tube making the vacuum conductive at all plate voltage levels. The oxide coating of the cathode will have been reduced to the point where areas will super-heat, causing ionization and then HV flash-over and or sparking to the plate. This is not a reversible condition and indicates end-of-life for the tube. The HV arc in this condition can cause enough magnetic field that the heater can be distorted to the point which it opens under such mechanical stress. Either way, it is end of the line for the tube.

With careful attention to these details, you can get a full life span from your tubes.

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