Operation of the R-390A power supply at 'power on' and the voltage regulator, V605.

I first wrote this up in a different form on October of 2014. At that time I had all the pictures out on a photo sharing web site, where they were readily visible. Well, that didn't last very long, so I'm rewriting it and imbedding them.

There are two points of operation I feel is worthwhile covering, B+ voltage during power on and 0A2 operation and usage. I'd like to start with the operation of the 0A2 regulator used in our receivers.

There's lots of good information written on the subject. I've read the following and more:

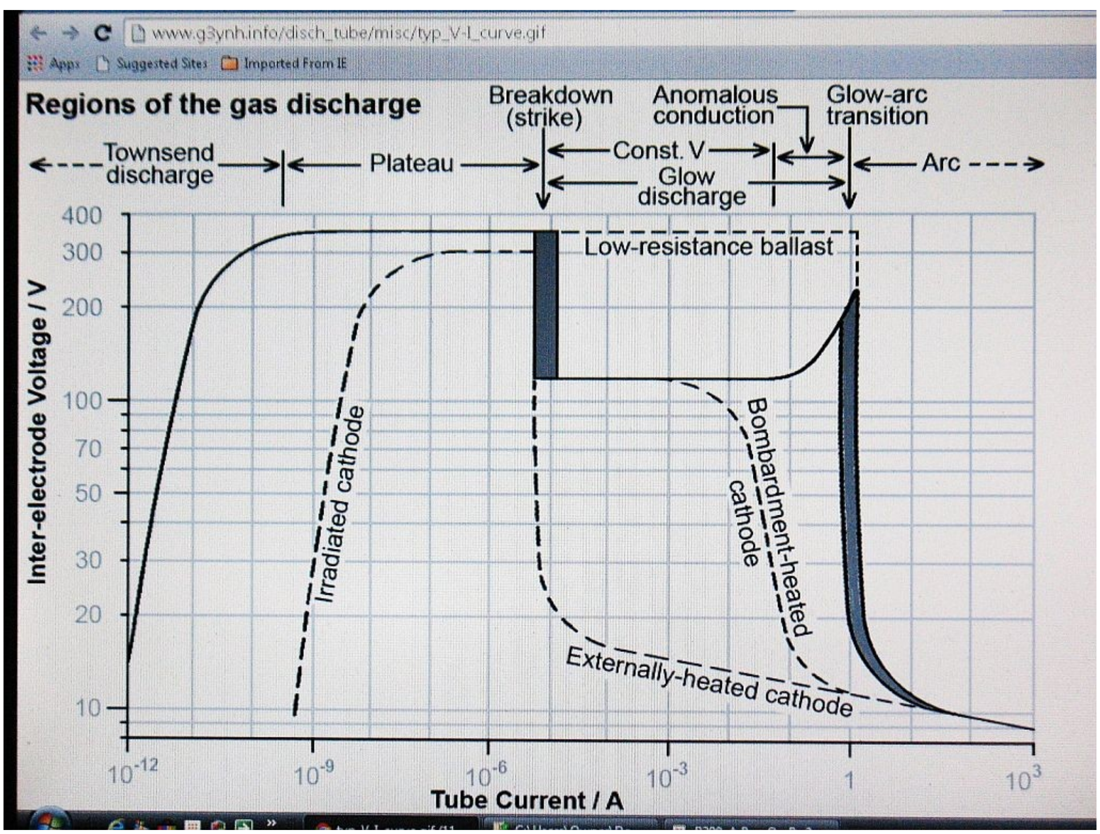
Neets - Naval Electrical Engineering Training Series, module 6, Introduction To Electron Tubes and power supplies.
http://electriciantraining.tpub.com/14178/

Gas Discharge Tubes - Introduction, D. W. Knight, 2013.
http://www.g3ynh.info/disch_tube/intro.html

Engineering Electronics, G E Happell, W M Hesselberth. McGraw-Hill 1953.
http://www.tubebooks.org/Books/Happell_engineering.pdf

Electron Tube Design, RCA 1962. 'Gas Tube Design' by H H Wittenberg'.
http://www.g3ynh.info/disch_tube/Wittenberg_gas_tubes.pdf

Let's look at the very commonly used generic 'voltage/current' graph referenced by most of the documents I read. This is the one in D. W. Knight's document 'Gas Discharge Tubes - Introduction':



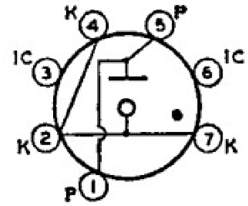
What this shows is as the voltage applied to the anode through a resistor is increased, the current is increased and the 'strike' (Breakdown) point is obtained. Then the regulator transitions quickly into the 'Constant V' area. The transition does not require much more current and this is where we want it to stay for proper regulation operation. For an 0A2, the current range is 5ma to 30ma for the 'constant voltage' area and the 'strike' point is about 156 volts and 5 ma. Also notice in the chart that there is no current or voltage spike during the transition into the 'Constant V' area. For detailed information on the 0A2, you can refer to part of the RCA spec sheet here:

Note: the industrial type is electrically the same as the commercial type.

OA2

INDUSTRIAL TYPE

VOLTAGE REGULATOR



5BO

Miniature type cold-cathode, glow-discharge tube used in voltage regulator applications. Outlines section, 5D; requires miniature 7-contact socket.

MAXIMUM RATINGS (Absolute-Maximum Values)

Average Starting Current♦	75	mA
DC Cathode Current	{30 5 min	mA mA
Frequency	0	Hz
Ambient-Temperature Range	−55 to +90	°C

MAXIMUM CIRCUIT VALUES

Shunt Capacitor	0.1	µF
Series Resistor	See Operating Considerations	

CHARACTERISTICS RANGE VALUES FOR EQUIPMENT DESIGN

	Min.	Av.	Max.	
DC Anode-Supply Voltage	185■	—	—	volts
Anode Breakdown Voltage	—	156	185*	volts
Anode Voltage Drop	140●	151	168*	volts
Regulation (5 to 30 mA)	—	2	6*	volts

♦ Averaged over starting period not exceeding 10 seconds. This starting period must be followed by a steady-state operating condition of at least 20 minutes, or tube performance will be impaired.

■ Not less than indicated supply voltage should be provided to insure "starting" throughout tube life.

* Maximum individual tube value during useful life.

● Minimum individual tube value during useful life.

At below 5ma it drops out of ionization (regulation) and at more than 30ma it leaves the linear regulation area headed for impaired operation of the tube and possible damage. The resistor feeding the voltage to the regulator must be selected to keep it in the preferred area in accordance with the other load in the circuit.

There is an interesting spec listed in the 0A2 spec sheet 'Average Starting Current .... 75ma Max' that is easily misunderstood. The brief explanation could lead one to belief that 75ma was required to start the tube for proper regulation. That is NOT true at all, 5 or 6ma is all that is needed. This spec is there so that designers will know that if the circuit causes the 0A2 to draw 75ma for 10 seconds, impaired operation will occur and damage is imminent. Refer to the paragraph below that I copied from the 'Operation Considerations' section of the 0A2 spec sheet above.

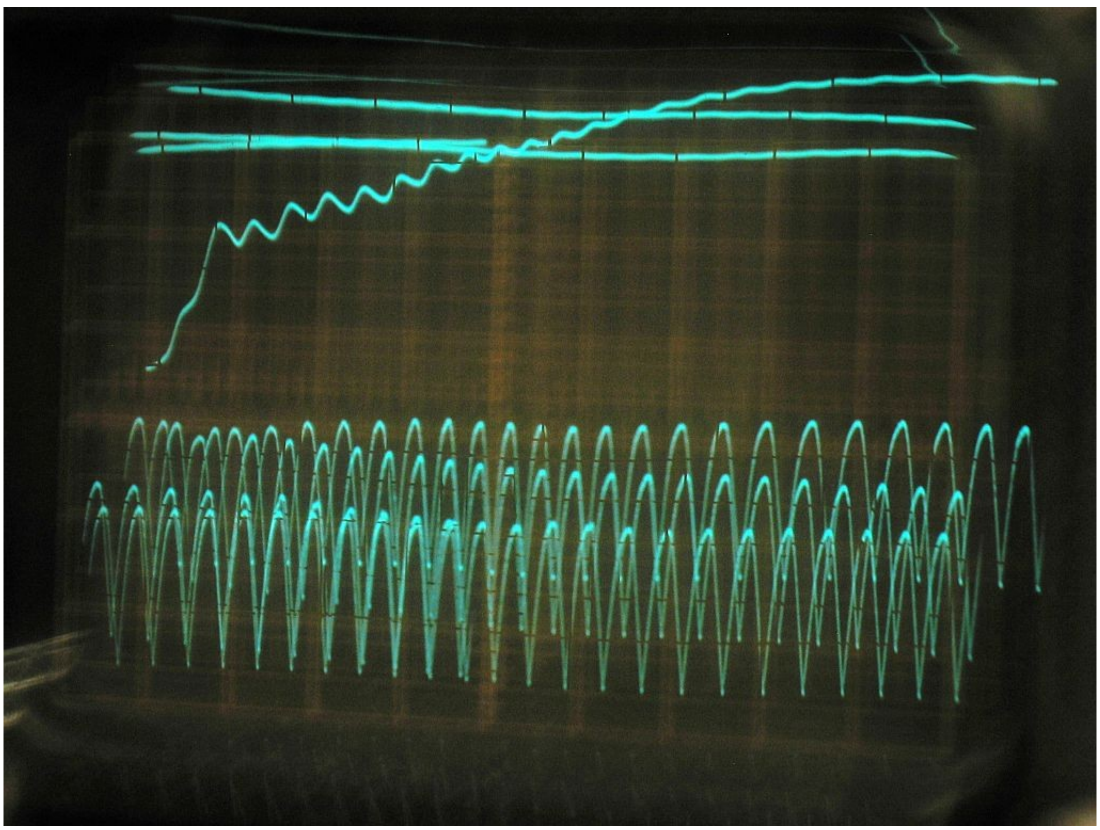
When equipment utilizing the tube is "turned on", a starting current in excess of the average operating current is permissible as indicated under Maximum Ratings. When the tube is subjected to such high starting currents, the regulated voltage may require up to 20 minutes to drop to its normal operating value. This performance is characteristic of voltage-regulator tubes of the glow-discharge type. Similarly, the regulation is affected by changes in current within the operating current range.

These are the spec sheets that you can refer to if you like:

commercial: http://frank.pocnet.net/sheets/049/0/0A2.pdf
Industrial: http://frank.pocnet.net/sheets/191/0/0A2.pdf

I tested this on three 0A2's (because I don't have any more), and they all showed me the same result on my scope - a smooth increase to the transition 'strike' zone of 155V to 163V and then dropping quickly to the 'constant voltage' area of 150V when applying 200V, 225V, or 250V using a 3.6K feed resistor (as the R390-A uses). There was no spike in current or voltage. This was substantiated by all that I have read on this.

Now let's get back to the 'Average Starting Current .... 75ma Max' spec. If we look at the paragraph above that I copied from the above 0A2 spec sheets under 'Operating Considerations', it means that any current over the 'Maximum DC Cathode Current' (30ma for an 0A2) will impair it's operation for up to 20 minutes. Now, we know this does not happen in our R390-A's and I see no reason that it does or should. This spec is just a statement to designers that you can exceed the 30ma limit up to 75ma for 10 seconds without permanent damage to the tube, but if you do, the regulation will be impaired for up to 20 minutes. This normally does not happen in an R390-A. The 0A2 feed resistance is 3.6K in standby. That's about 25ma with no additional load at power on. Since my 'power on' scope trace at C606A shows no voltage excursion above 245V, more current than that will not be drawn. Here it is:



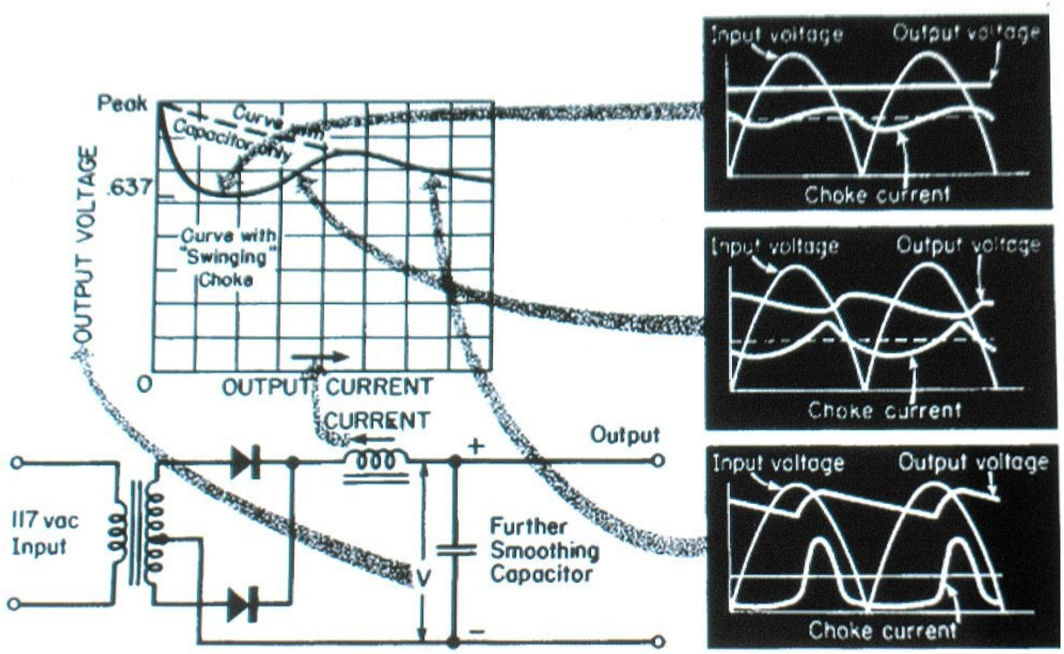
I powered on my R390-A's using my variac to produce 200V at C606A with 3 different 0A2's and they regulated correctly. I scoped the voltage and again saw no voltage above 200V during warm up.

This concludes how the 0A2 works and how it's used in the R-390A.

Now let's look into the R-390A power supply and what happens at 'power on'. First we need to know what kind of power supply it is. It's a choke input filter type employing a 2-12 Henry swing choke (see the tech ref analysis section simplified schematic). It's important to understand how this works, so I copied the following excerpt from Norman H. Crowhurst's book, 'Basic Audio' from 1959. I like this explanation of a swing choke as it is short and clear:

>
> Another kind of filter circuit employs the so-called "swinging" choke. All smoothing chokes employ iron cores
> with air gaps that prevent saturation. By properly choosing the size of the air gap, a special action is
> produced. At low load currents, the core is not saturated, but for higher current it progressively approaches
> saturation, which makes the circuit act as a capacitor-input filter. Capacitor-input filters produce higher output
> voltages; hence, the output at the filter can be made to rise with increased load current.
>
> At small load currents, the inductance of the choke is sufficient to make the filter behave as a choke-input
> arrangement, and the output voltage is not more than 0.637 of the alternating peak voltage. As the current
> drain increases, the choke begins to saturate, and the rectifier starts pulse-feeding the capacitor at the
> output end of the choke. The circuit then begins to act as a capacitor-input filter and the output voltage rises.
>
> Because the current is increasing at the same time, the output cannot possibly reach the peak value of the
> applied a-c because the drain effect will cause dips between the peaks, but the average voltage can rise with
> a carefully designed filter of this kind. This is useful because it will serve to offset the voltage drop in the
> supply circuit that always tends to reduce the output voltage with increased load current. If the rise produced
> by the swinging choke just offsets the losses produced by increased current through the rectifier, the power
> transformer, and possibly a further smoothing choke, the output voltage of this kind of filter will be almost
> perfectly constant as the load current is changed.
>

Look at the picture below of the associated choke input graph, also in Norman's book. This is the same graph used in many articles. Notice that this scenario is for a 'solid state' rectifier power supply, but it does show what a swing choke input filter system does at 'power on'. The output voltage immediately goes to it's peak value (when there is no load), then very quickly drops to somewhere close to the average voltage output. Because this is a SS supply, the 'power on' voltage goes to some high level immediately (depending on the instantaneous load caused by resistors, capacitors, and regulators) for a very short time. And, this effect is reduced with a tube rectifier with heated filaments. Instead, if the immediate load is sufficient (which it is in an R-390A), the voltage slowly climes to the average output voltage and stays there. This is what we want to happen to minimize stress at 'power on'. The following graph is used in many articles:



The swinging choke filter

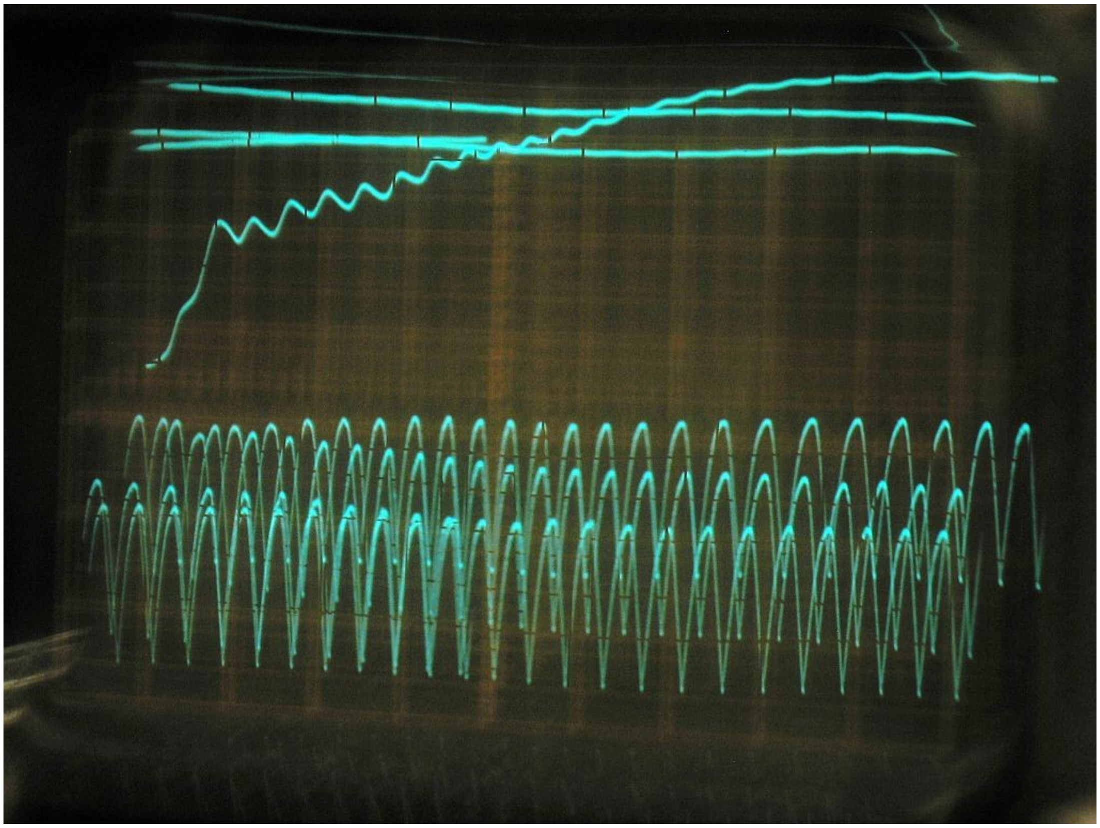
I know that 1 book is not proof that this is all true, so you can google 'choke input filter' and find many articles written about them. I found the following:

1. Aiken Amplification - Randall Aiken, 1999
2. Wireless World - Cathode Ray, 1957
3. Power supply design - Henry A. Pasternack, 1995
4. Basic Electronics - Albert Malvino, David Bates, 2008
5. Analog Electronics - Ian Hickman, 1990, 1999

If the rx has been solid stated or uses fast warm up rectifier filaments, then it would be interesting to know where the 'knee' is at (on the left side of the graph pointed to by the top chart in the picture above). According to Norman, the formula for figuring the knee point (where the voltage is down to the RMS value) is: max supply ma / choke H. For the R-390A, this equals 180ma / 12 or 15ma. This means that when L601 is drawing more than 15ma, the output voltage will be approximately equal to the RMS value at C606A. This will happen at about the 185V point. This is the sum of the immediate load current from capacitors charging (180 mfd), 0A2 current, and circuit resistors (in standby, about 6.7 ma plus capacitor charging current).

I have done indepth testing on my 2 R-390A's with 26Z5's in this area and have found that the B+ at C606A (1st filter cap) rises quickly to a maximum of 245V in Standby and slowly (about 15 seconds) goes down to 232V, where it holds. This is based on 115 vac input. The attached picture of my scope trace of this shows that this is the case (the A trace is the C606A point and the B trace is the F102 point and scope trigger point).

Turning an R-390A on by switching immediately to AGC yields a little lower initial maximum voltage (242V), as you would expect and is an identical scope trace shown in the next picture.



Since the R-390A uses a 'swing choke' input power supply filter, the 'immediate load' (before tubes warm up) on the supply in standby is 6.7 ma and in AGC is 16.9 ma. This load is from: in Standby: 4 ma (150V regulator), 2.7 ma (audio resistors to ground); in AGC: 'standby current' (6.7 ma) + resistors to ground: 2.2 ma (RF amp), 8 ma (IF amps 1, 2, and 3). I have verified that my 2 rx's do not have any undo load (ie: leaky caps, gassy tubes, or additional resistors from B+ to gnd or anything else). The AC input I'm using is 115 VAC with the aid of a 'bucking' transformer or variac at my home. The reason that the additional 10.2 ma load in AGC only reduces the initial maximum voltage by 3 volts is the way a 'swing choke' input power supply filter works.

As you can see from Norman's voltage versus current graph above, it takes very little current to hold the output voltage down. That's one the purposes of the large 12H swinging choke as input. As the current load increases, the inductance reduces to a low 2H. The way I verified I have no leaky caps is I removed all the tubes (except the rectifiers) and plugged it into my variac. While measuring the voltage and current at F102, brought it up to 245V, in AGC I read 12.9 ma, as it should be (16.9 ma - 4 ma for the regulator).

So, if your R390-A's are working correctly and using 26Z5 recs, it will never see more than 245V DC on any capacitor (even C551 because there is no agc voltage at initial power on). If you measure the voltage at F103, it will reflect the voltage at C606A -2 volts at initial power on (within a few seconds) if L601 is working correctly (it's probably ok if it measures 125 ohms (you could easily measure L601 and L602 in series for about 245 ohms)).

There is one other aspect of using a choke input filter that is very important and that is it reduces the power on capacitor charge stress. As for the SS recs, if a series resistor is incorporated, then that will also relieve some of the power on stress that is normally provided by tube rectifiers. This is another reason why the designers probably rated the 5 electrolytic filter caps C603 and C606 in the power supply mounted in the 2 cans on the audio deck at 300V (specified in the Y2KR3 part list) and not higher. 300 V gives the caps a 55 V margin, which is 22.4% over the 245 V max seen.

While I was doing my testing and measuring, I recorded some voltages that you might be interested in (rx set below 8 MH, BFO off, Cal off). Keep in mind that your readings may vary a little due to tube and component condition:

Power on (standby) at C606A: 1 second: 245 V, 7 seconds: 241 V, 20 seconds: 222 V, 1 min: 222 V
Power on (AGC) at C606A: 1 second: 242 V, 7 seconds: 237 V, 20 seconds: 205 V, 1 min: 205 V

So if your AC input is higher than 115 VAC, it would adjust upwards by the percentage. 125 is about 8.7% higher, so your initial C606A would be about that percentage higher, or 267 V.

Current at F102 at 1 second after turn on (26Z5's and 0A2 just starting) in:
Standby: 6.7 ma total, 4 ma regulator, 2.2 ma audio
AGC: 16.9 ma total, 4 ma regulator, 2.2 ma audio, 2.2 ma RF, 8 ma IF

If you are using **SS rectifiers**, your initial C606A voltage I would estimate (I have no way to test this) would be about 15V to 20V higher or **265 Volts.** This may seam low, but if you consider that the only additional voltage is from the much lower anode voltage drop in the SS recs and the load is the same, that's it. Now if your AC main input is also 125 VAC, well then the voltage is starting to get up there at **287 Volts.** Even with the dropping resistor added to adjust the operating voltage to the correct 'warmed up' level, the 'power on' voltage will still be about **285 Volts.** I do know that you will need to watch C606 A & B and C603 A & B for excessive leakage if they are still the original 300 V caps. For 115 VAC input where C606A high is 265 VDC, I'd use at least 350 VDC caps because 300 V is only 13.2% over. And at a line voltage of 120 VAC, C606A will be about 276 VDC, so with 350 VDC caps, that's a 26.7% margin and with 300 V caps, an 8.7% margin. And at a line voltage of 125 VAC, the caps will see 285 V, which is a 5.3% margin using 300 V caps and with 350 V caps, a 22.8% margin.

Please note that 4 of the 5 caps talked about here will see this same high maximum at power on, but C603C will not. The most it will see is about 200 to 225 VDC.

At 115 VAC input, I don't think that a 13.2 % margin is ok when using SS recs, so you can see that in all cases, using SS recs without changing C603 and 606 to higher voltage caps could be a mistake. If good quality caps are used, I think that 350 VDC is safe.

Regards, Larry Haney

February 27, 2019