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THE UVC SCR CATHODE VOLTAGE REGULATION SYSTEM

Circuit Analysis and Troubleshooting Techniques

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U.S. Department
of Energy

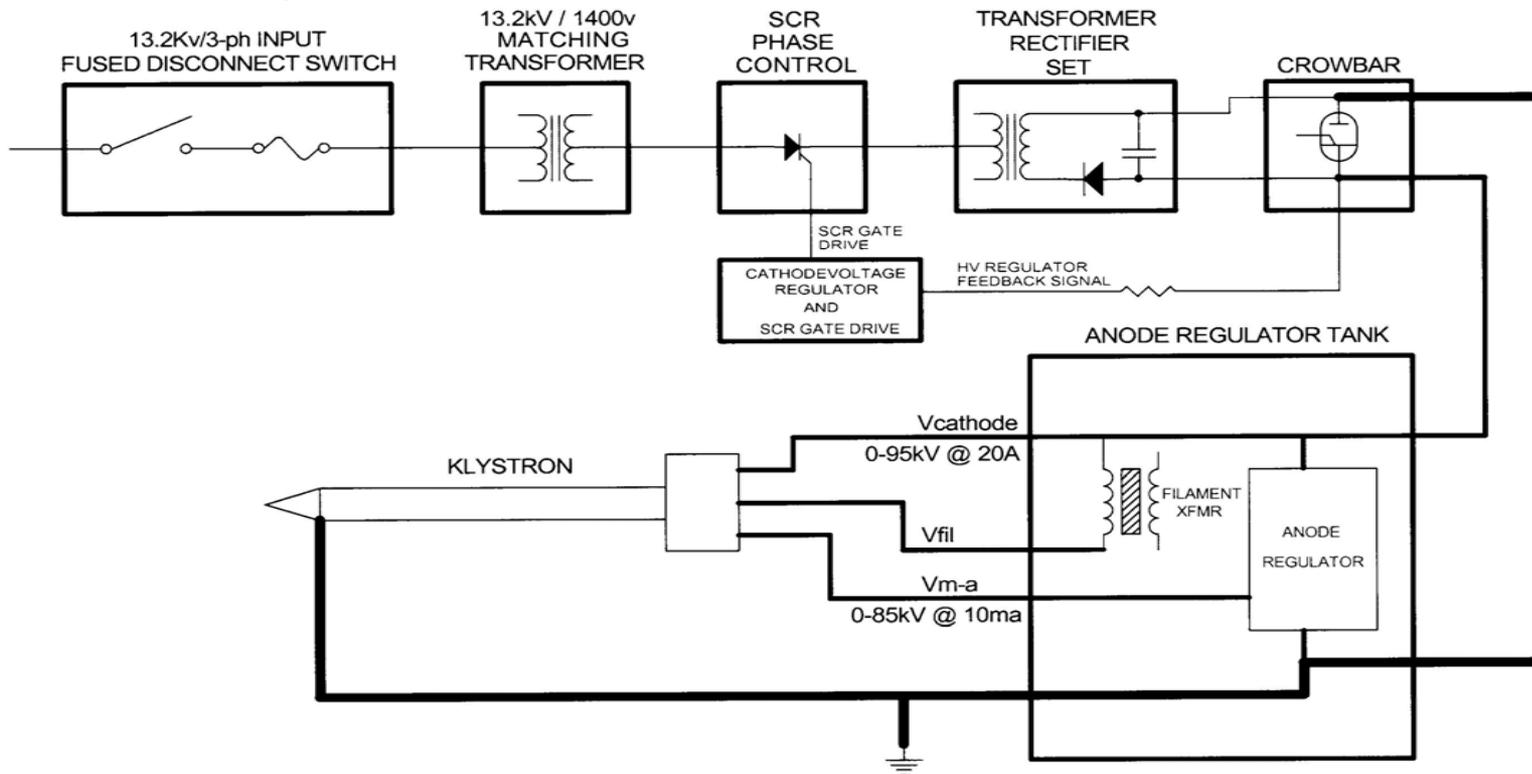
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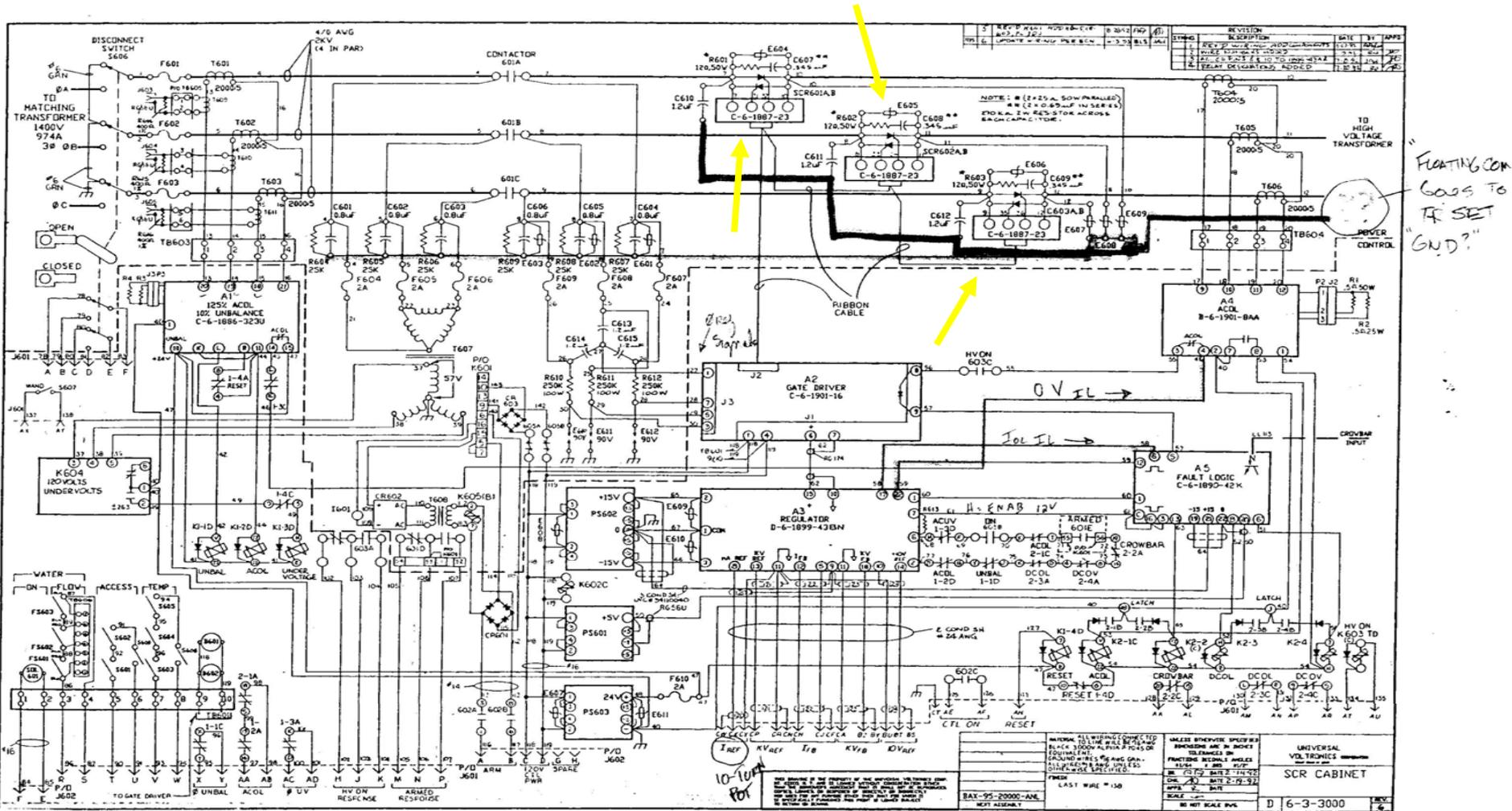
The UVC SCR Cathode Voltage Regulation System

SCR (“thyristor”) phase-angle control is utilized to produce and regulate the cathode voltage output of the UVC power supply system by controlling the average primary voltage applied to the Transformer-Rectifier at the 1400-volt level:

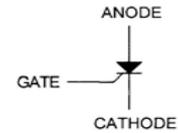
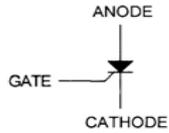


The UVC SCR Cathode Voltage Regulation System

Changing the firing angle of the SCR's varies the average voltage applied to the primary of the Transformer-Rectifier set, which results in control of the DC output



Basic SCR Theory



A **S**ilicon **C**ontrolled **R**ectifier (aka “Thyristor”) is a three-terminal device that acts as a gate-controlled switch with diode characteristics:

- *Will not conduct until gate signal is present, even if forward voltage is applied*
- *Turns on very fast (rise time in microseconds) with the application of gate current, thereby limiting losses in the off-on transition*
- *Once in the conducting state, the gate loses control and the SCR will remain in conduction until the current through the device falls below the “holding current” value (the next zero-crossing in ac applications)*
- *FYI.....the vacuum-tube equivalent of an SCR is a thyatron!*

Basic SCR Theory

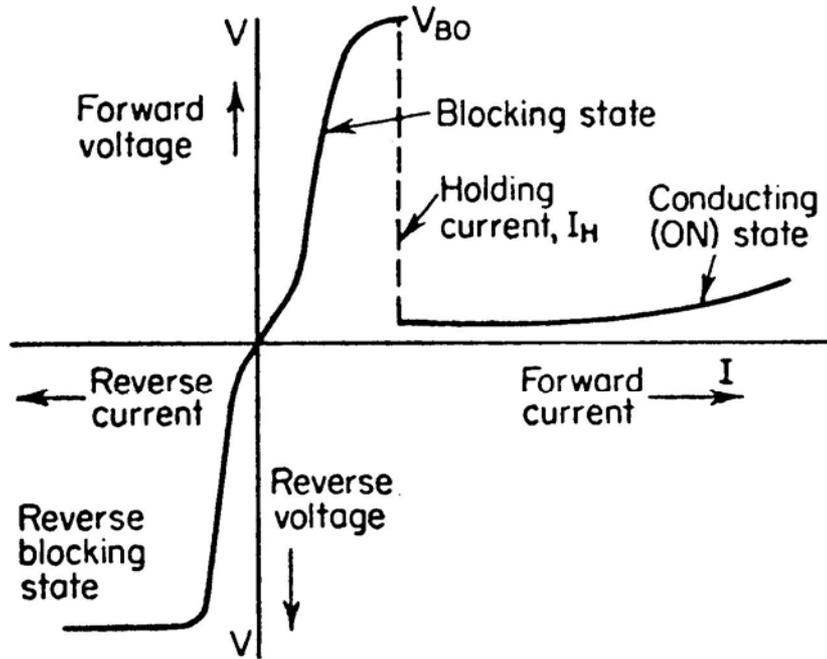
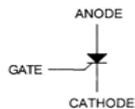
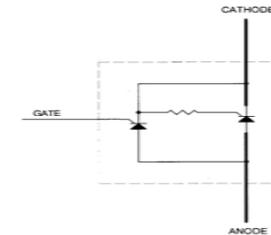


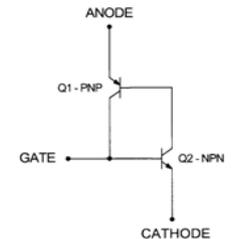
FIG. 5-105. Current-voltage characteristics of the silicon-controlled rectifier.

- The combination of *very fast switching time* and *very low forward voltage drop* allows the SCR to control very large amounts of power with relatively low internal losses.

- SCR's designed for very high power (UVC system is an example) typically utilize an internal pilot SCR to provide gate current to a main SCR ("amplified-gate SCR"):

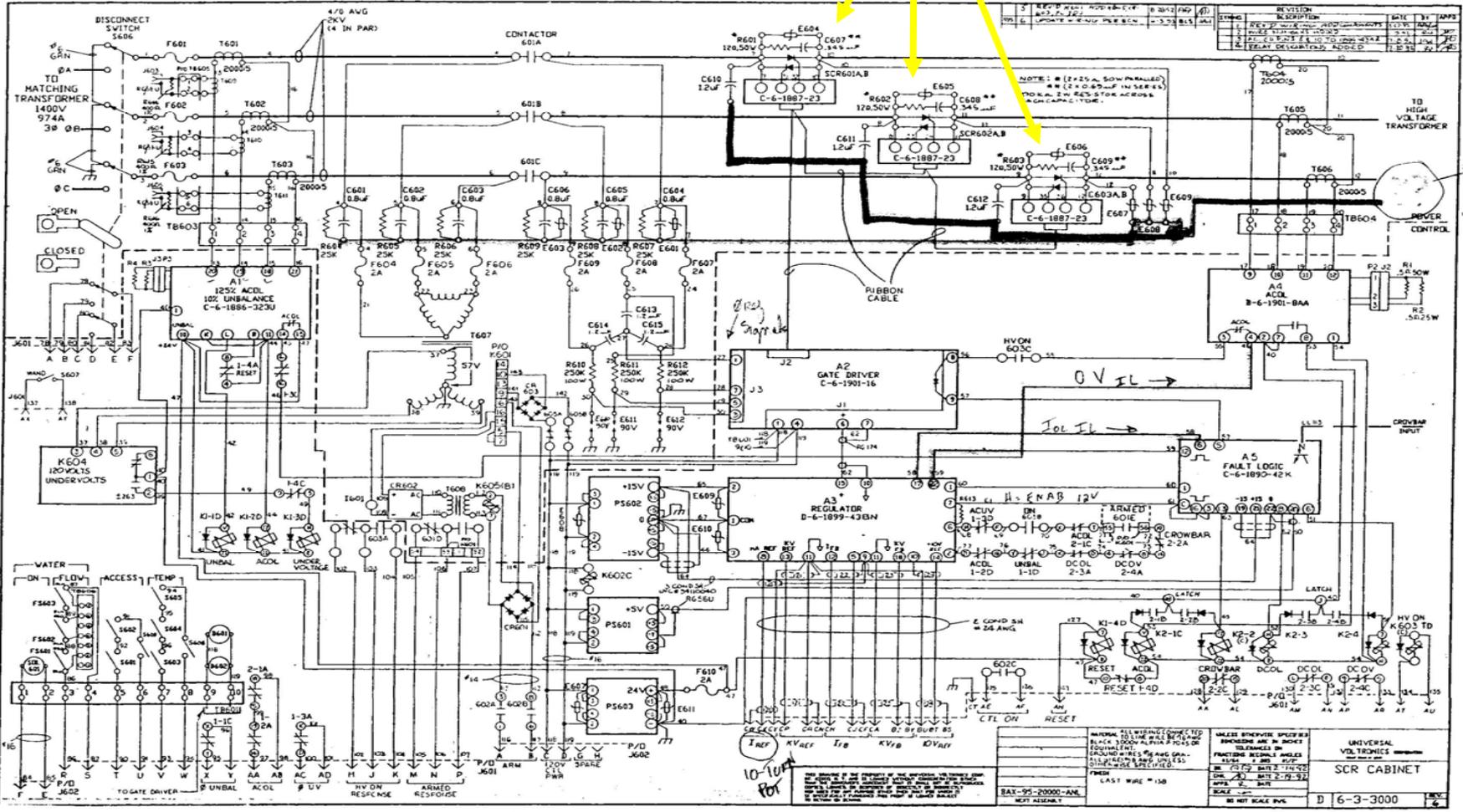


A two-transistor equivalent model can be useful in understanding the characteristics of an SCR.



The UVC SCR Cathode Voltage Regulation System

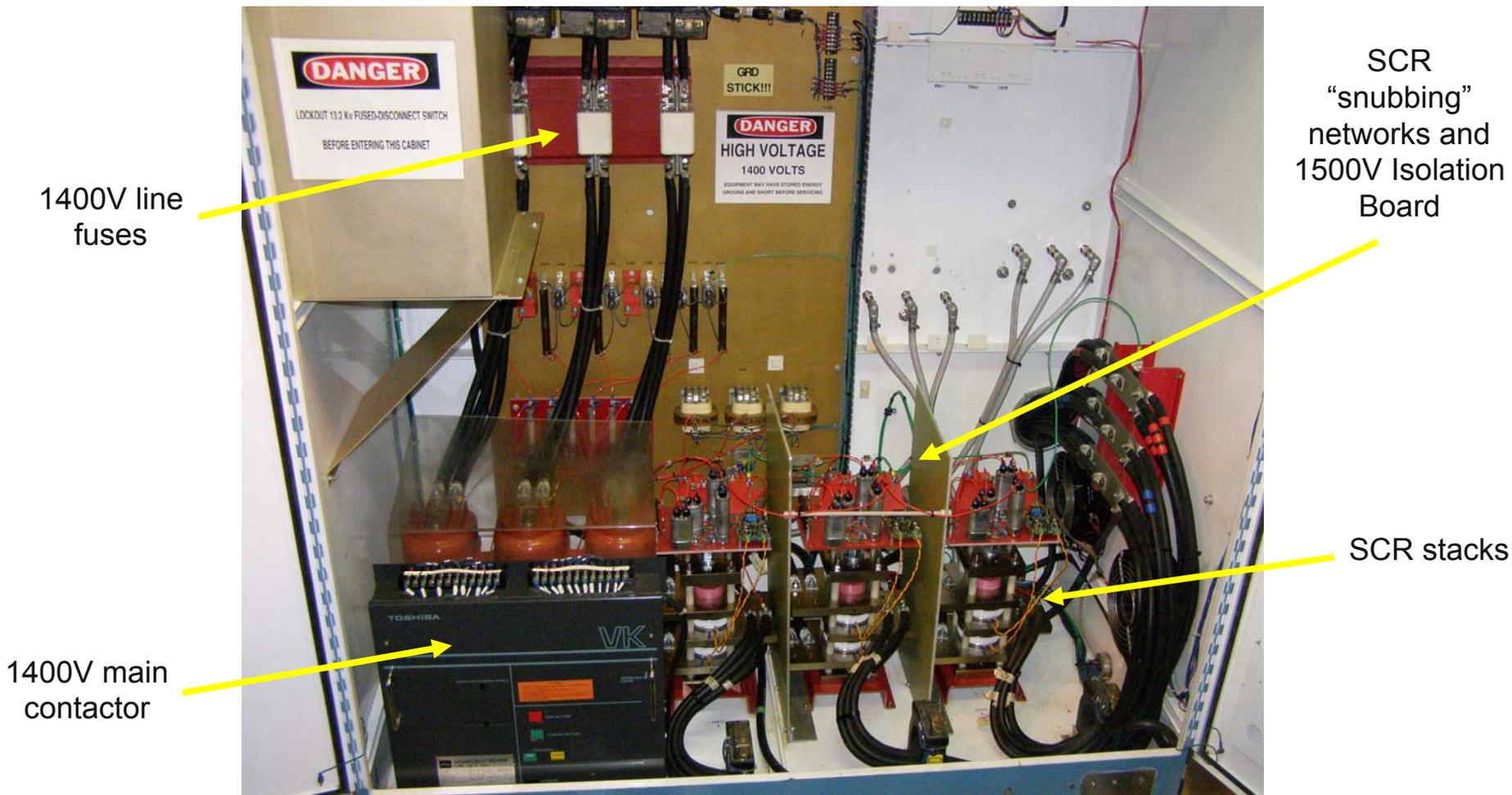
Schematic of UVC SCR Cabinet showing SCR's in series with 1400V input:



Handwritten note: "FLOATING COM GOES TO THE SET 'GND?'"

The UVC SCR Cathode Voltage Regulation System

- Photo of UVC SCR Cabinet Interior

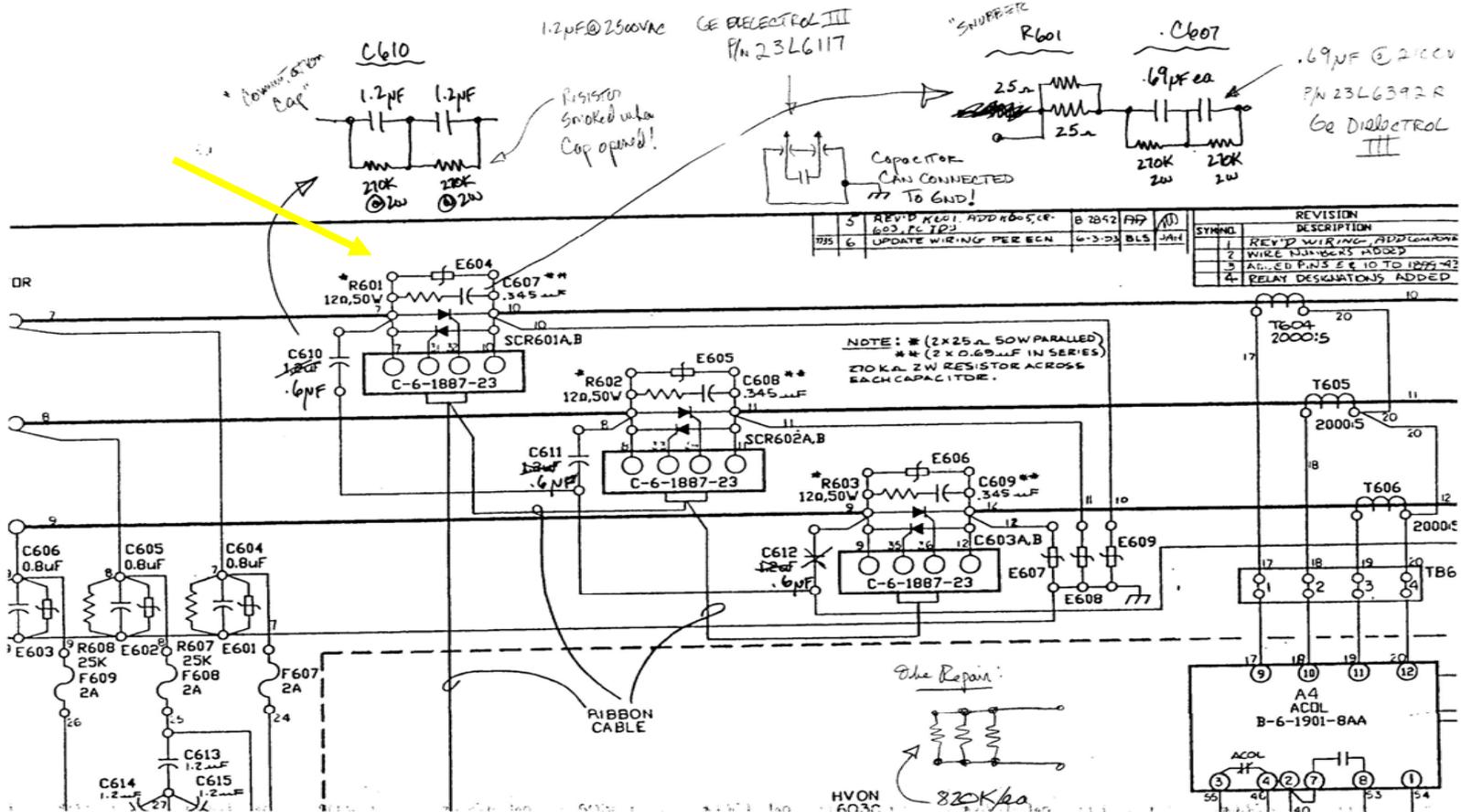


The UVC SCR Cathode Voltage Regulation System

- Close-up detail of UVC SCR Circuitry

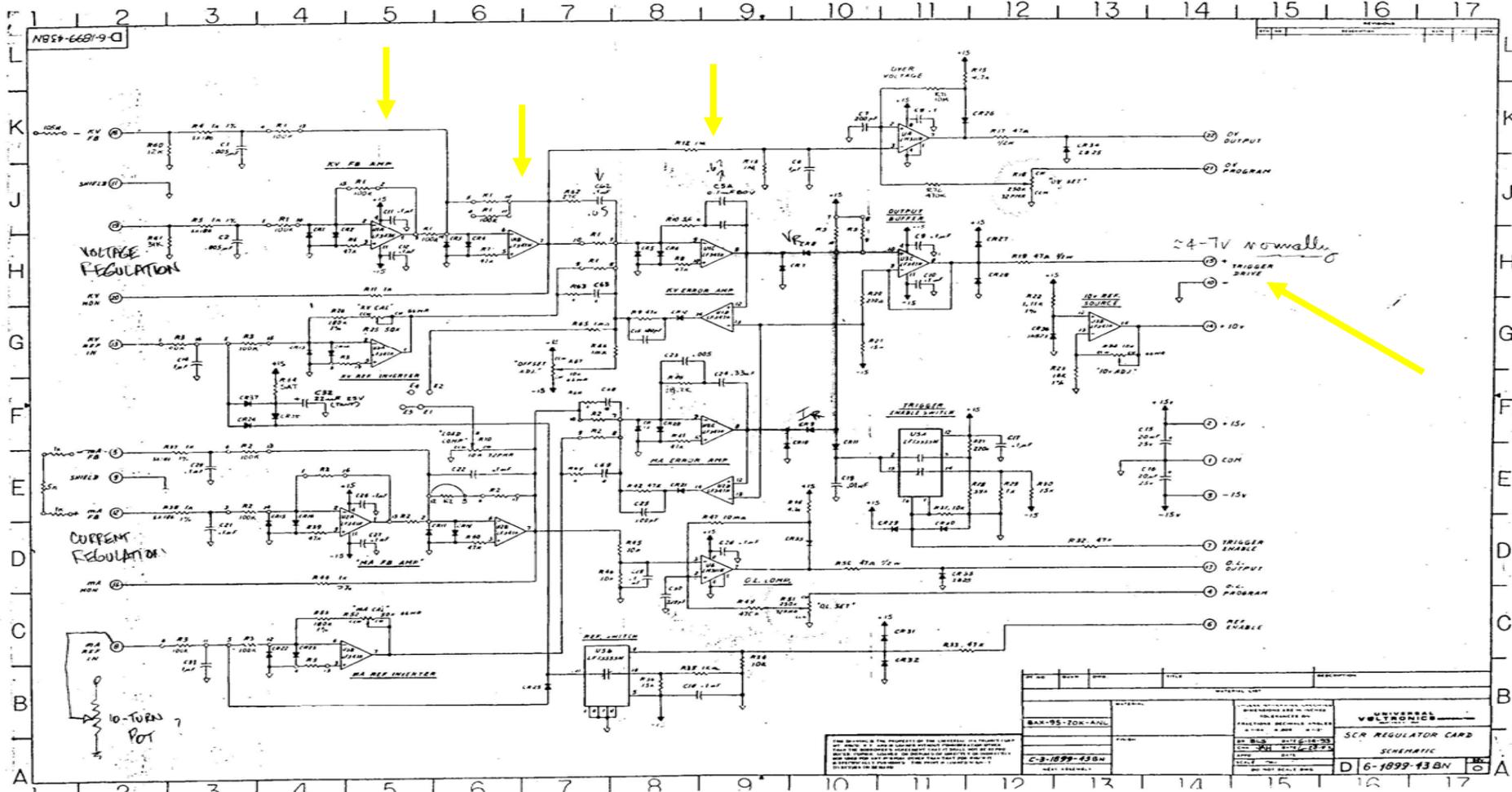
→ R-C/MOV networks (“snubbers”) limit potentially damaging voltage spikes across the SCR’s generated by fast current changes in load inductance

NOTE: Handwritten notes indicate actual components used!



The UVC SCR Cathode Voltage Regulation System

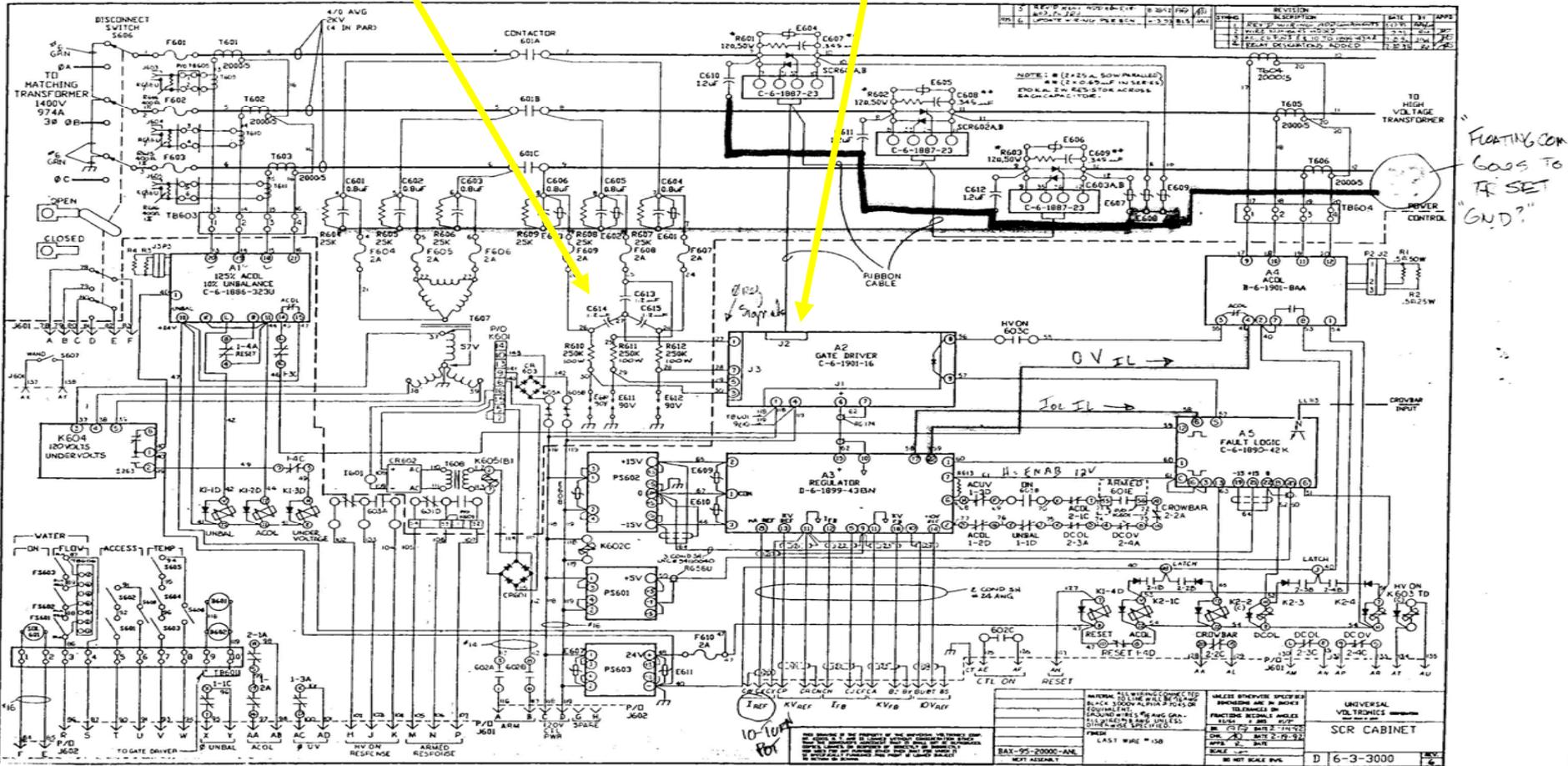
Cathode voltage regulation is achieved by voltage follower U1A, amplifier U1B, and error amplifier consisting of U1C and U1D. Setpoint and output voltage readback are summed, forming an error voltage that is amplified by the error amp, buffered, then sent to the gate driver card to control SCR gate pulse width.



The UVC SCR Cathode Voltage Regulation System

Gate pulses for the SCR's are generated using reference signals from the applied 1400V

The gate driver card uses the reference signals and the dc command output of the regulator card to generate variable-width gate pulses for the SCR's

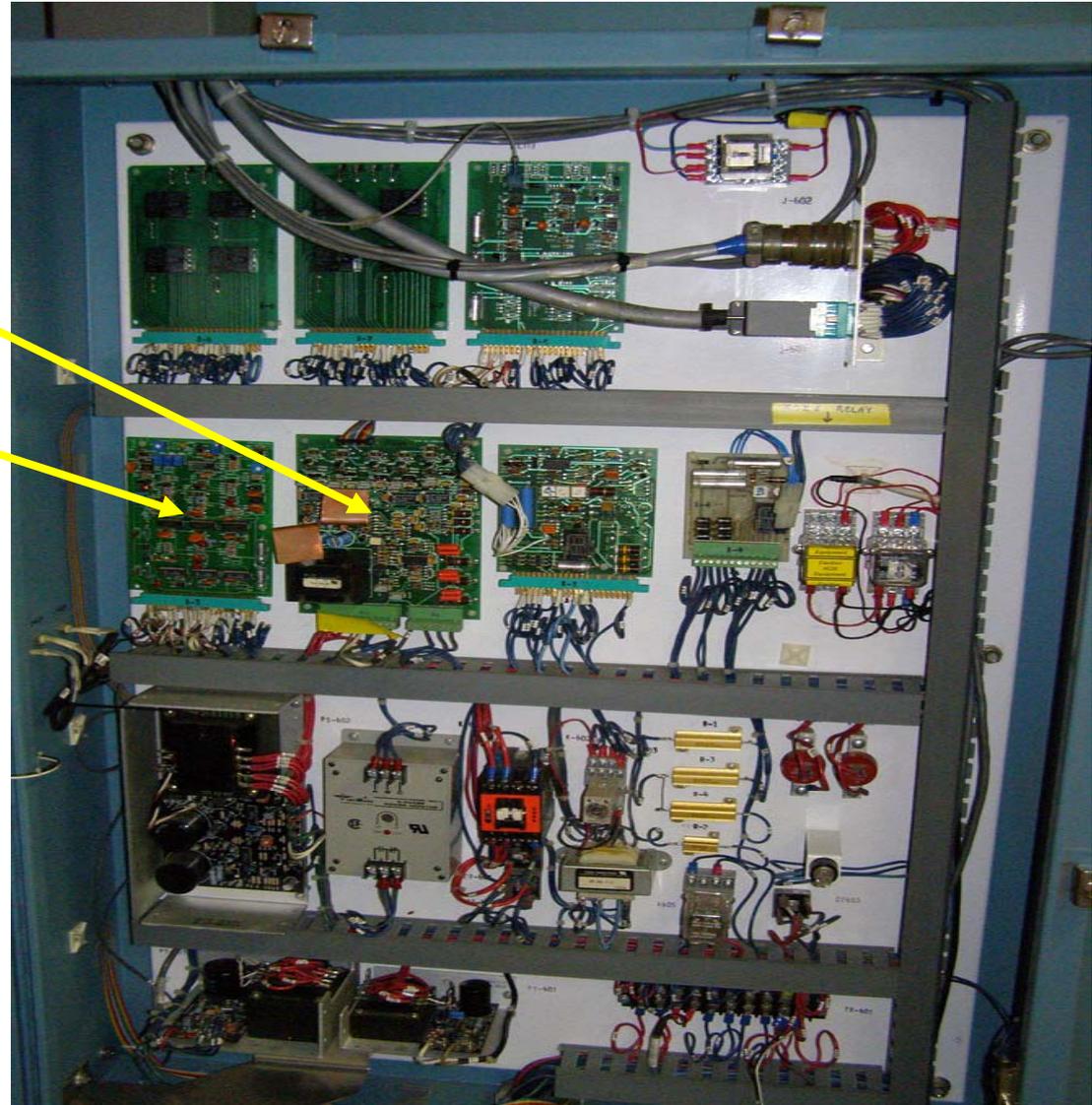


The UVC SCR Cathode Voltage Regulation System

The SCR Control Cabinet

- A2 gate driver card
- A3 regulator card

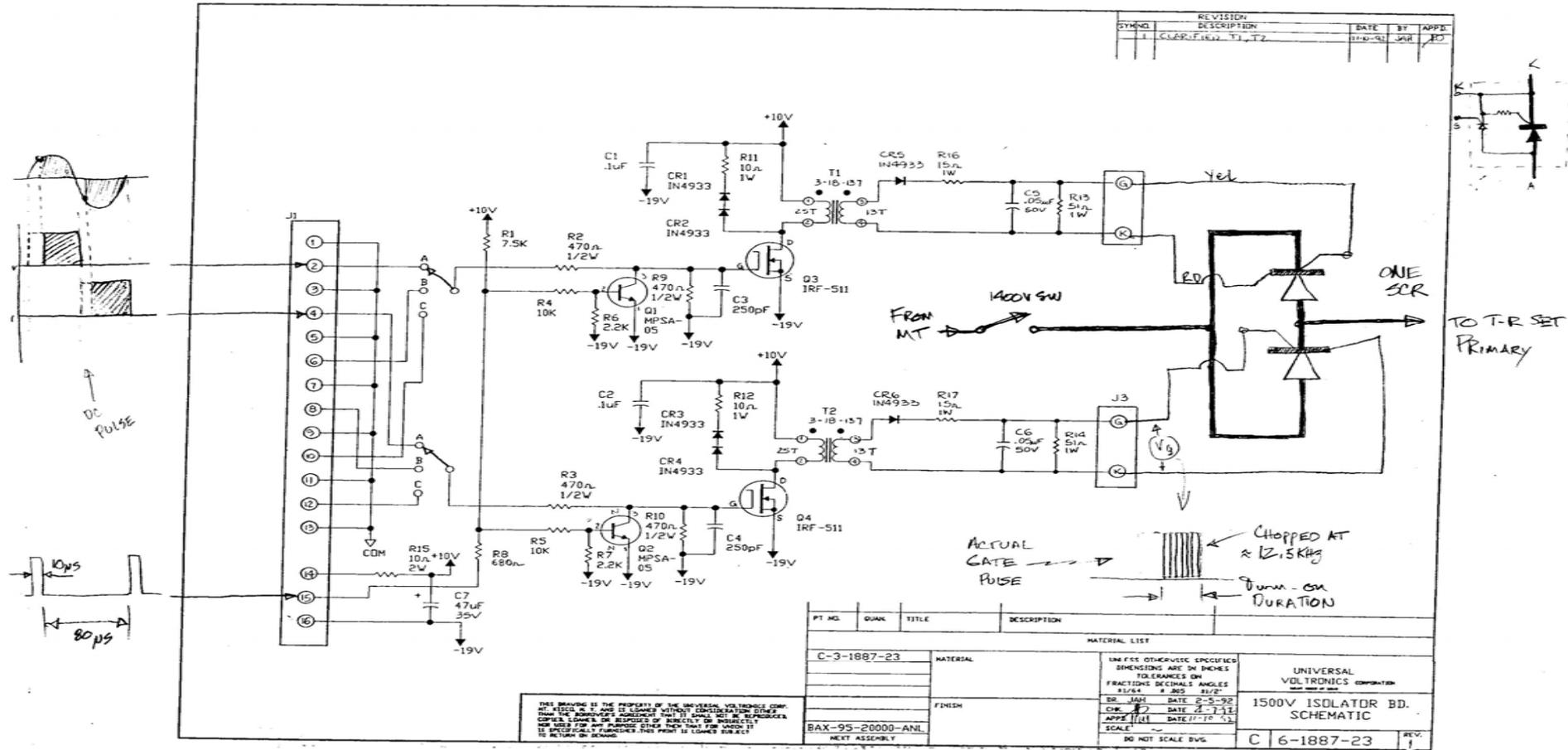
Note: There is exposed 120vac inside this cabinet when control power is applied – follow the Safety requirements listed on the RF Group Energized Electrical Test & Measurement Authorization!



The UVC SCR Cathode Voltage Regulation System

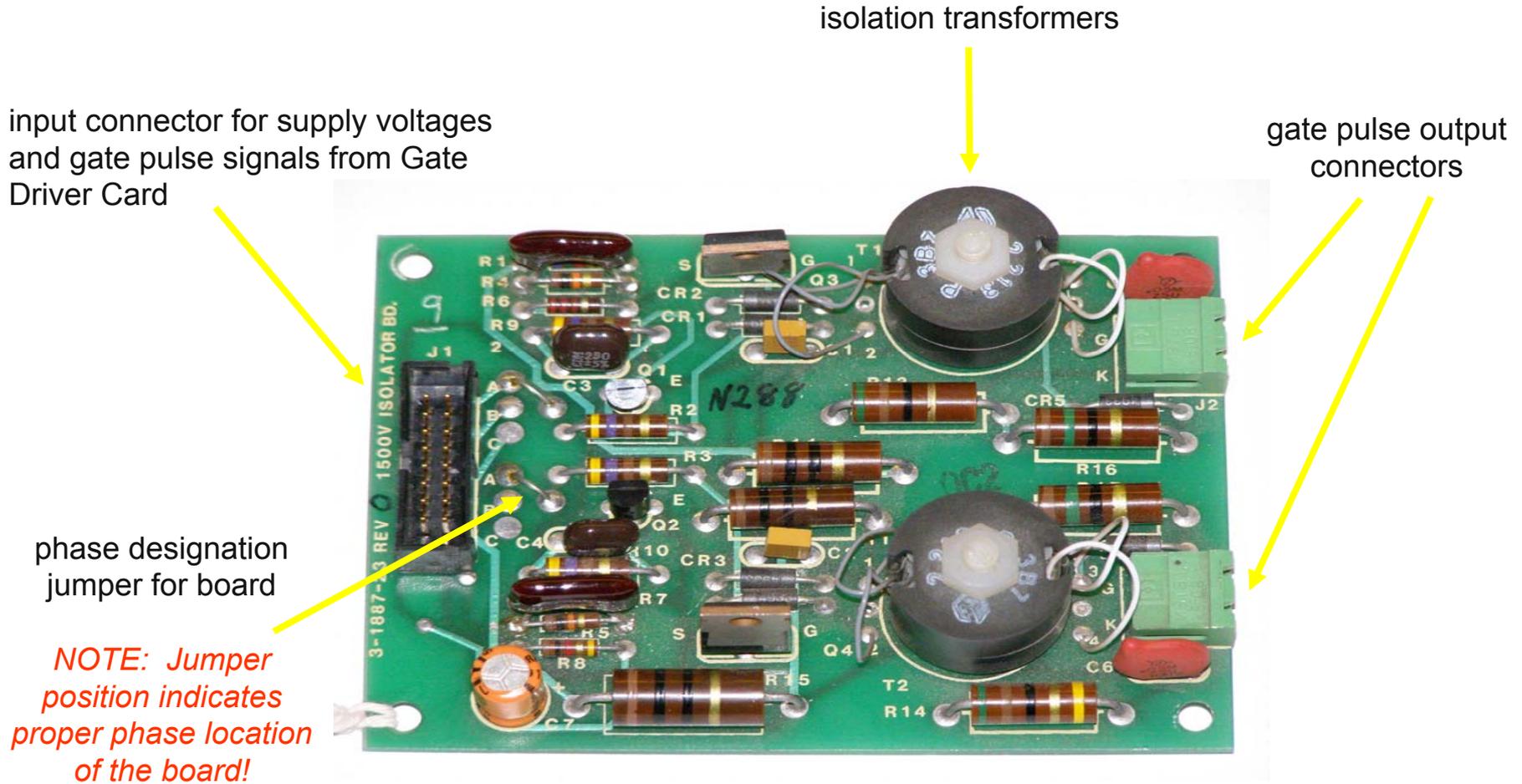
The 1500V Isolator Board

- chops variable-width gate pulse at ~ 12.5kHz (to limit gate dissipation)
- provides electrical isolation between the 1400V supply voltage and the low-voltage gate generation circuits



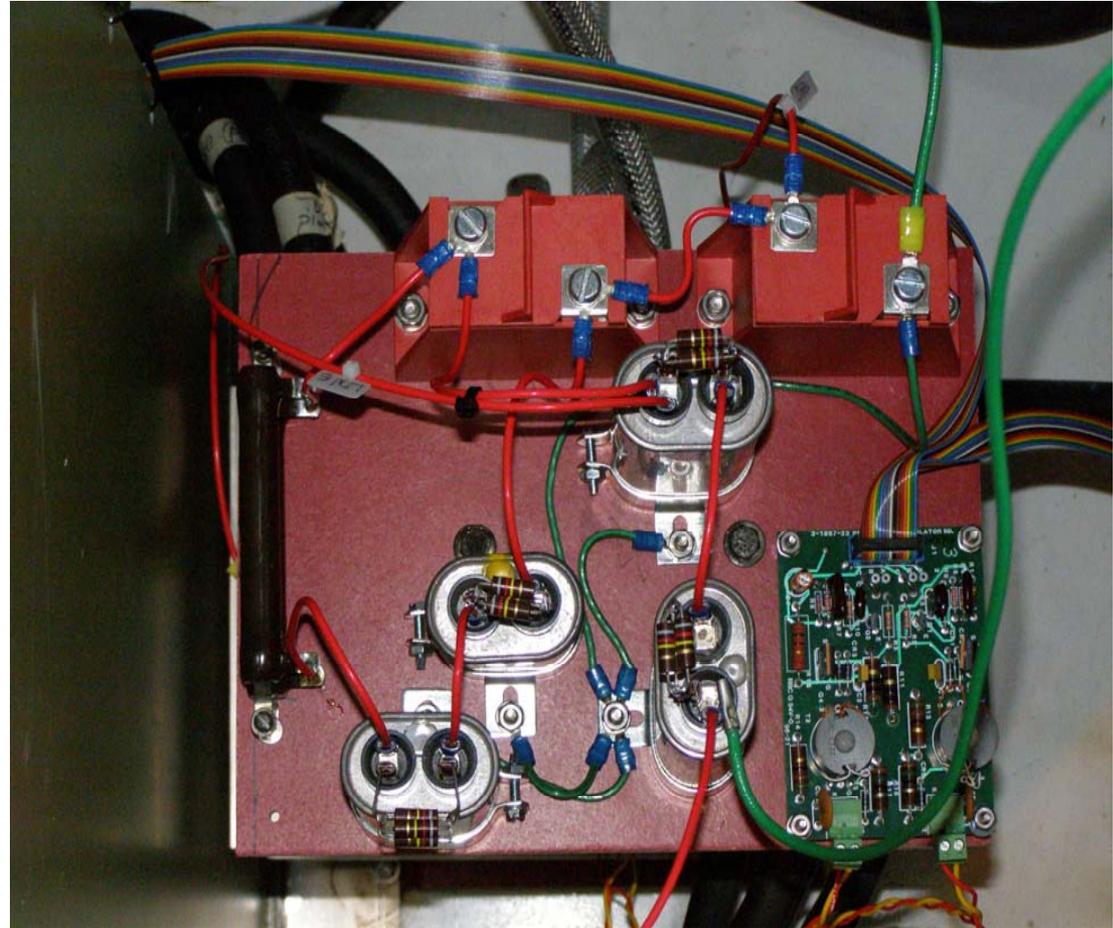
The UVC SCR Cathode Voltage Regulation System

• Photo of 1500V Isolation Board



The UVC SCR Cathode Voltage Regulation System

- ▶ Photo of 1500 Isolator Board and snubbing network mounted on SCR stack.



UVC SCR System Troubleshooting Techniques

The proper troubleshooting technique is determined by the nature of the problem:

▶ **No cathode voltage output**

- Setpoint cannot be entered
- Setpoint can be entered, but there is no output

▶ **No cathode voltage control**

- setpoint has no control on output, dc output stays at zero, or goes to maximum and fires crowbar on OV fault

▶ **Unstable cathode voltage**

- poor voltage regulation under load
- excessive 60Hz-related ripple in dc output
- SCR “searching”, resulting in phase current unbalance

You need to know and understand how the system operates to be effective at finding the problem!

► No Cathode Voltage Output

1. Setpoint cannot be entered
 - Is UVC computer interface accepting setpoint value?
2. Setpoint can be entered, but there is no output
 - Is setpoint voltage present at setpoint input of A3 regulator card?
 - *measure directly at input of card*
 - Is the A3 regulator card generating a trigger drive signal? (4-7Vdc typical)
 - *measure directly at output of card*
 - Is the A2 gate driver card producing gate and 12.5kHz oscillator pulses?
 - *measure directly at output of card*

UVC SCR System Troubleshooting Techniques

► No cathode voltage control

- Setpoint has no control on output.....dc output stays at zero, or goes to maximum and fires crowbar on OV fault.

1. DC output stays at zero

-- Are gate pulses being generated?

→ *Measure at output of A2 gate driver card*

2. Dc output goes to maximum

-- Is feedback voltage from cathode divider present at regulator card input?

-- Trigger drive stuck at maximum value due to component failure?

→ *Measure at input and output of A3 regulator card*

UVC SCR System Troubleshooting Techniques

► Unstable cathode voltage output

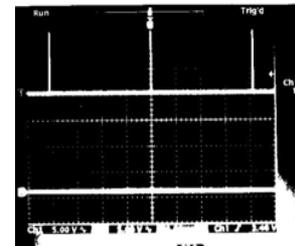
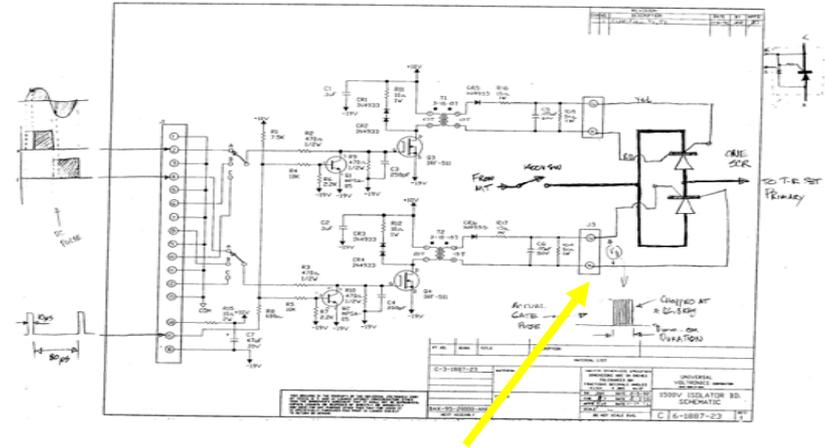
1. Poor voltage regulation under load
 - +/- linear power supply somewhere with low output?
2. Excessive 60Hz-related ripple in dc output
 - +/- linear power supply somewhere with high ripple?
 - regulation loop unstable (oscillating)?
3. SCR “searching”, resulting in phase current unbalance
 - regulation loop unstable (oscillating)?
 - ramp generators on A2 gate driver card improperly adjusted?

UVC SCR System Troubleshooting Techniques

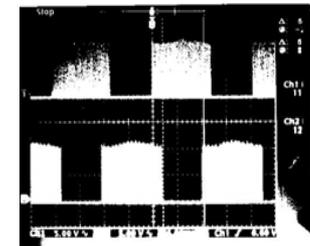
• Measuring SCR Gate Drive Signals

- **NEVER** done with 1400-volt power applied!
- Typically only performed after a major SCR cabinet repair to verify presence of gate drive
- Requires a bypass of the under-voltage interlock and the use of a function generator at the phase reference inputs to the gate driver card to generate gate pulses.
- LOTO at SG-R3 and UVC 13.2kV fused-disconnect switches before making measurement!

Note: There are exposed voltages greater than 50 volts inside the SCR cabinet when control power is applied – follow the safety requirements listed on the RF Group Energized Electrical Test & Measurement Authorization!



Minimum voltage command



Maximum voltage command

Gate pulse output from 1400V Isolator Board

Gate pulse waveforms generated by using a function generator to supplying reference signals to the gate driver card. Under such conditions, the voltage regulation loop is open, resulting in an SCR gate drive command for either minimum or maximum output, depending on regulator setpoint value.

UVC SCR System Troubleshooting Techniques

▶ Suspected component failure at 1400-volt level?

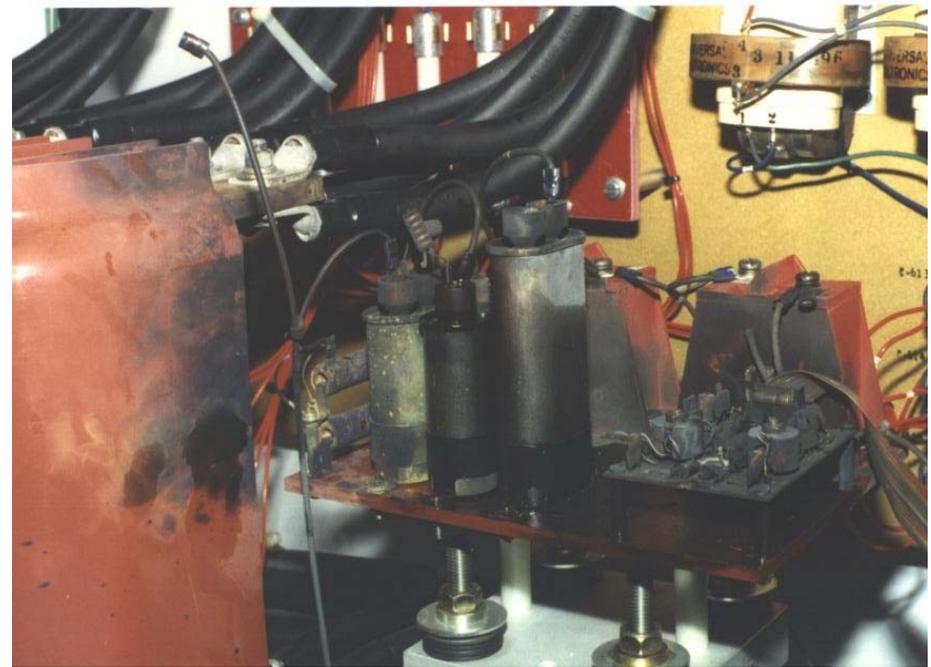
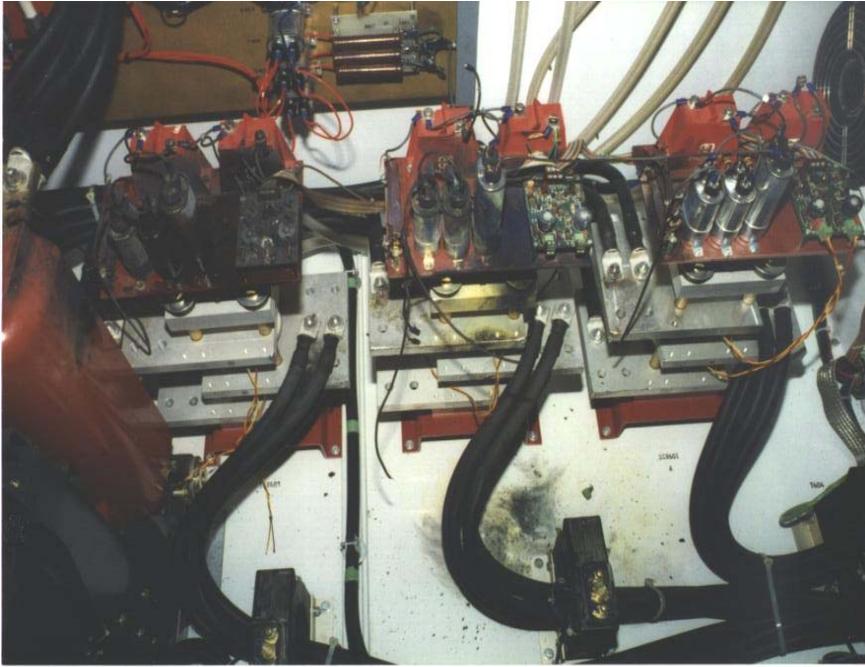
→ *Highly unlikely without visual/audible evidence of violent failure!*

-- Almost any fault at the 1400-volt level will be easy to see.

-- Blown fuses at 1400-volt or 13.2kV level call for a mandatory power-off (LOTO!) cabinet inspection to look for damage and shorted components.

Open and LOTO both 13.2kV fused disconnect switches (RF/UVC and SG-R3) before entering an SCR cabinet when damage to the high-power circuits is suspected!

Previous UVC SCR Cabinet Failures at 1400V Level



7/6/94 – Snubbing capacitor failure at RF5

- Wires connected to the failed capacitor became disconnected during the initial fault and caused a 1400-volt phase-to-phase short, resulting in considerable collateral damage:
 - Loss of two SCR stacks and 1400-volt fuses (~ \$25k)
 - Destruction of gate driver cards

This failure prompted installation of insulating barriers between SCR stacks to help prevent shorts, and reinforcement of cabinet doors to prevent opening during 1400-volt faults

Previous UVC SCR Cabinet Failures at 1400V Level

9/6/96 – 1400-volt fault at RF3

- Caused by energizing the 1400-volt input to the SCR cabinet and closing the 1400-volt contactor with a cabinet grounding stick hanging on one 1400-volt phase.

Equipment damage included blown 1400-volt and 13.2kV fuses, destroyed cabinet hardware and wiring.



Successful recovery from any fault at the 1400-volt level requires a thorough checkout of all components!

Failure to do so may result in a repeat failure as soon as 1400-volt power is applied!

Previous UVC SCR Cabinet Failures at 1400V Level

7/17/07 – Failed snubbing capacitor at RF1

- The capacitor shorted internally and ruptured its case, which caused wiring to become disconnected and result in 1400-volt phase-to-phase shorts.
- Equipment damage included blown 1400-volt fuses, destroyed SCR stacks, cabinet hardware, and internal wiring.



Even though fast fuses are used as system protection, any fault at the 1400-volt level will result in considerable equipment damage!

UVC SCR System Troubleshooting Techniques

General Good Practices:

- ▶ Refresh your knowledge of the UVC SCR system operation before you begin troubleshooting.
 - *Take effective notes*
 - *Ask for help if you are not confident in understanding of the system*
- ▶ Write a work plan, and have it reviewed by a second person.
 - *Avoid energized test and measurement if at all possible*
- ▶ Make ledger-size copies of system schematics for note taking and tracking progress.
 - *A very useful practice that will save time and avoid confusion!*
- ▶ Do not perform energized test and measurement at odd hours or if you or your work partner are tired or stressed.
 - *Delay the work until the next morning if at all possible*
 - *Follow your instincts.....resist external pressure to hurry the job!*
- ▶ **Follow all safety rules, and refer to specific LOTO procedures for putting the equipment in a safe state!**