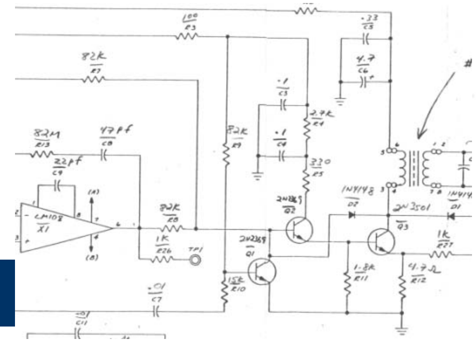
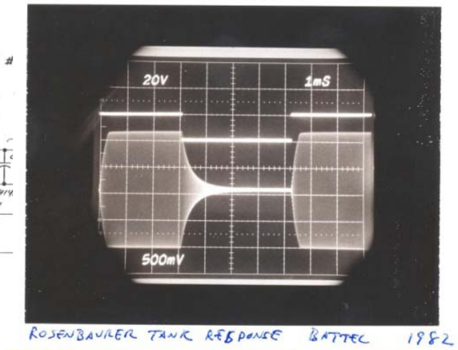
Pre-Modulator Approaches…

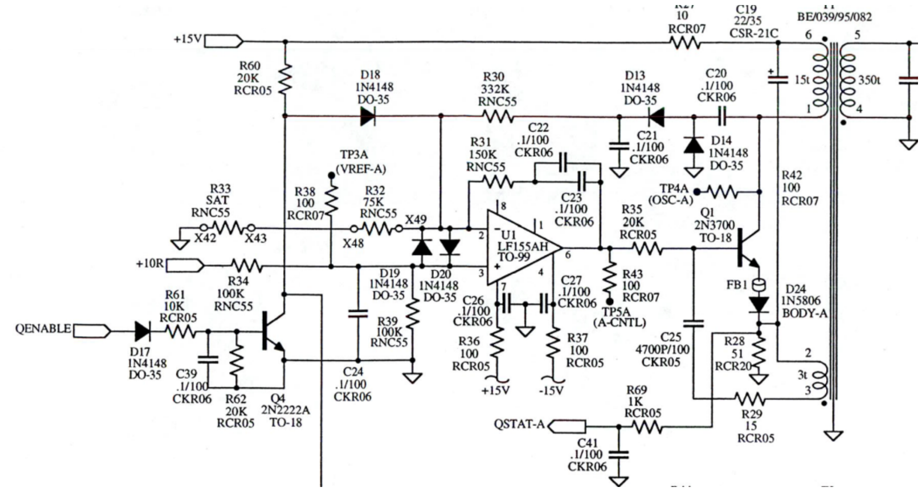


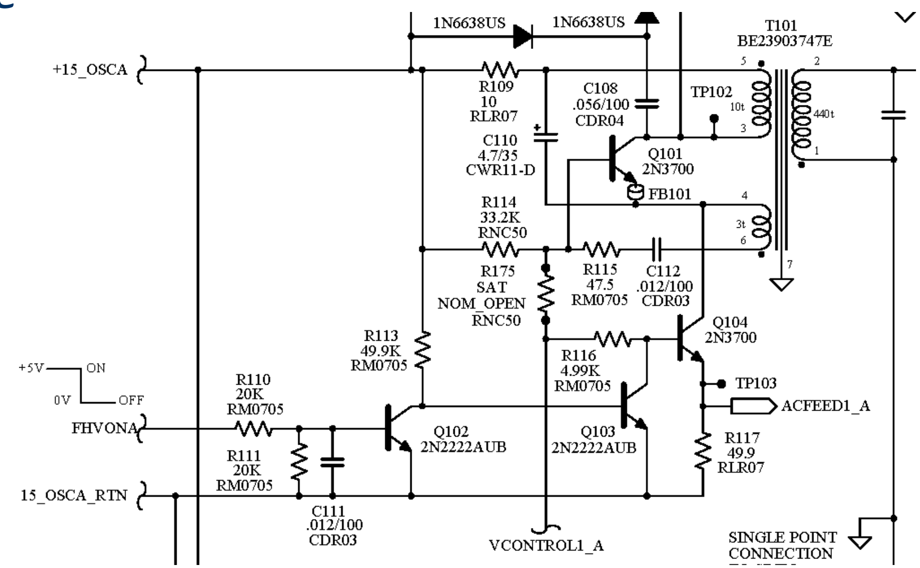


- *Pre-modulator approaches include both pre-regulator and intermediate-stage modulation control methods.*
- *To achieve accurate DC control, linear pre-regulator approaches are nearly always best.*
- *If fast transitions are required, speed is dominated by the combination of stored energy in the tank circuit energy and the high voltage multiplier. In general, the oscillator transistor is both DC gain controlled and On/Off modulated in these applications.*
- *Most fast transition designs, such as for stepping spectrometer applications with multiple outputs, have moved to post-modulator approaches.*

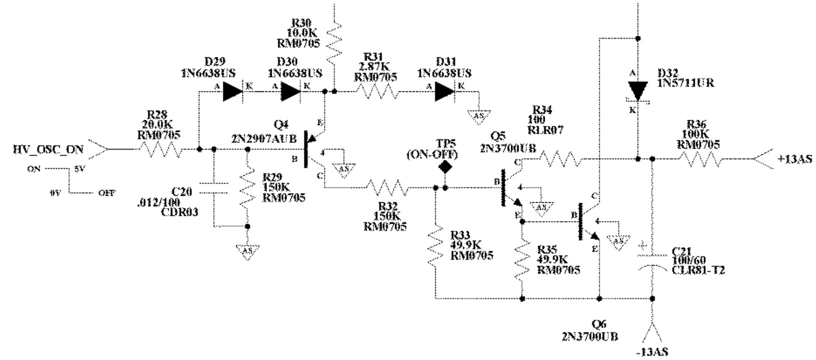
DC Regulation Approaches… 1

- *There are many ways of doing DC control based on experience and design preferences. The main issue to consider is that the loop response of most high voltage systems is very slow. Thus, some means of improving noise rejection is usually valuable.*
- *The single-ended oscillator is operated as a current source so generally the loop control is implemented using either direct control of the oscillator transistor or via cascode control.*

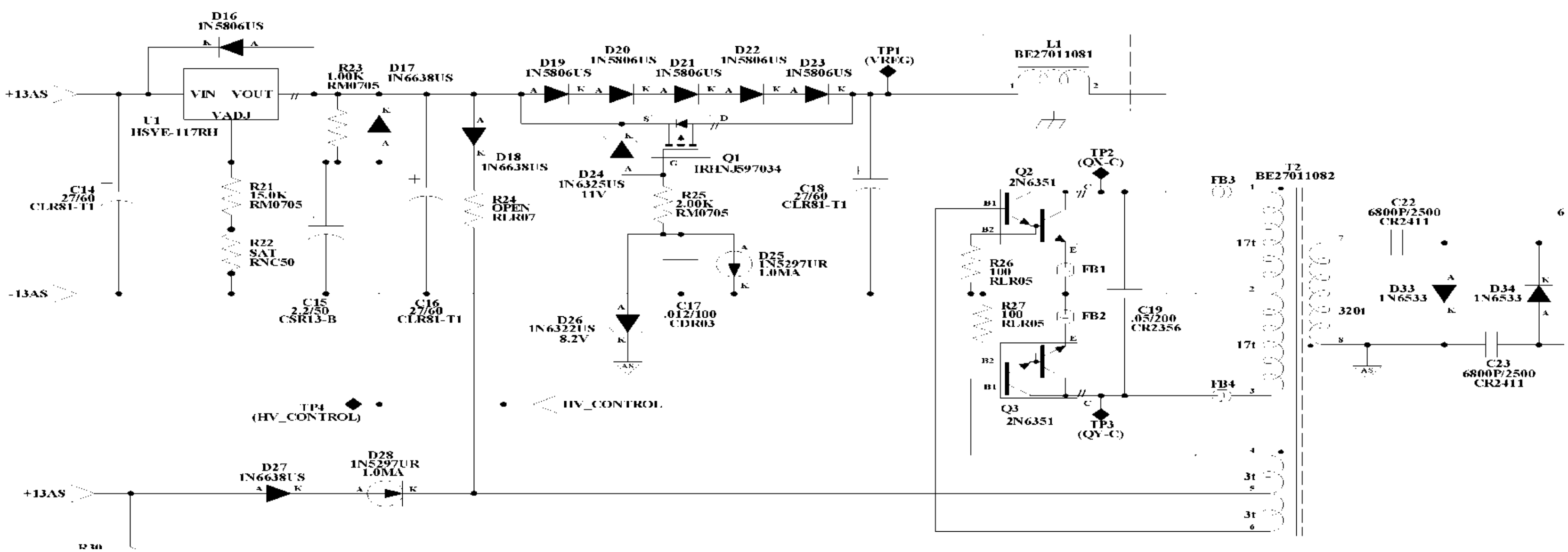




DC Regulation Approaches… 2

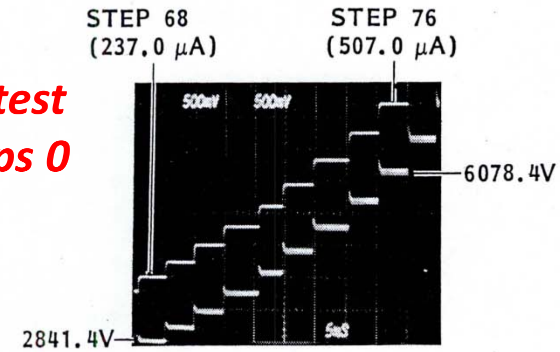


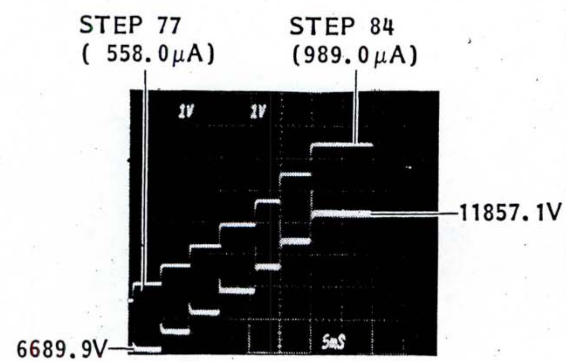
- The push-pull oscillator is also current-fed but I generally employ a pre-regulator in a dual-loop configuration due to its simplicity and high level of noise rejection.
- A soft start approach is also a good idea at power application to reduce the high voltage stress at turn-on, eliminate overshoot and reduce the turn-on current transient.

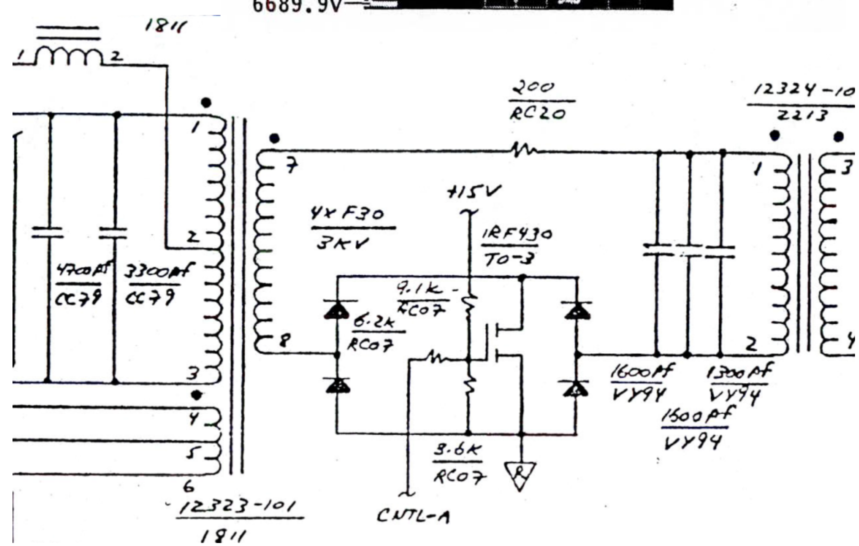


Intermediate Modulator Approach…

EAPS prototype test results. 5 ms steps 0 to 12 kV (1984)







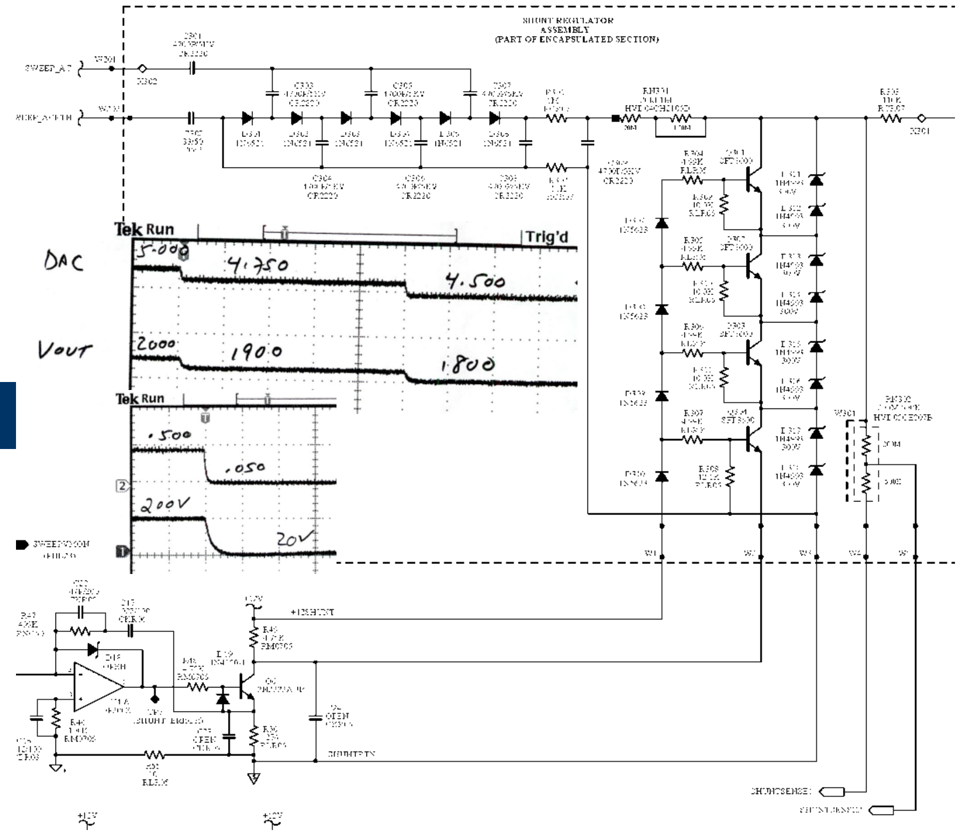
- *An intermediate modulator generally is implemented using 2 transformers and an intermediate diode bride modulator.*
- *The approach allows for a larger total step-up ratio distributed between the two transformers in combination with tank energy stored in the second modulated stage.*
- *The performance can be very fast and accurate if properly implemented.*
- *The big disadvantage is the need to match the resonance between the 2 transformers.*

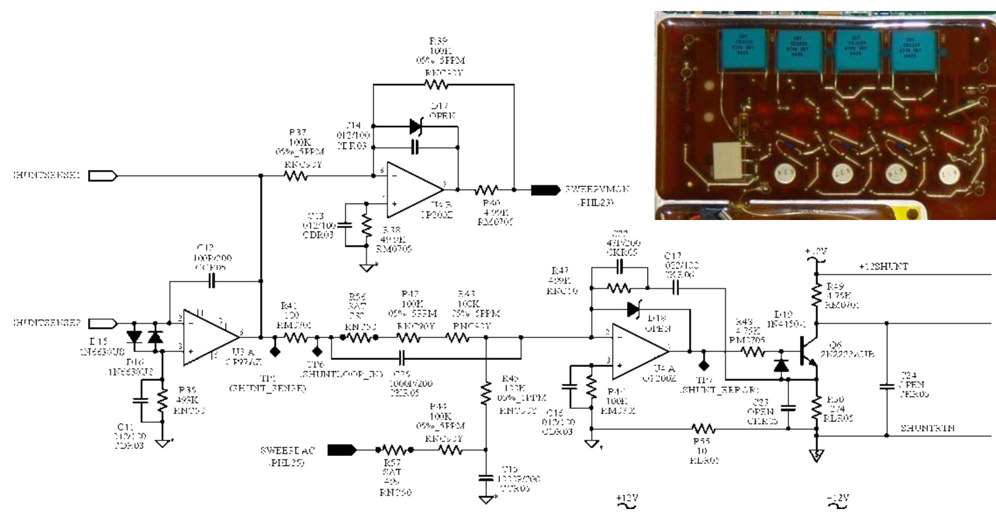
Post-Modulator Approaches… 1

- *Post-modulation approaches have the great advantage of being after the resonant tank circuit and multiplier. They can also be implemented off of voltage taps and in many different combinations from a single bulk supply.*
- *There are two general approaches with many variants. The first uses stacked transistors in a shunt configuration. The second approach uses an LED optically coupled to a high voltage diode operated as a current-controlled-current- source.*
- *The first space LED opto-coupler modulators were done by Rosenbauer at MPI on the Giotto ion analyzer systems. In the early 1990's the Amptek HV601 (followed by other designs) came on the scene and became the dominant approach for most space physics instrumentation requiring output voltage modulation.*

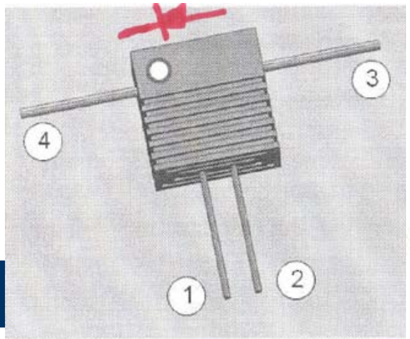
Post-Modulator Approaches… 2

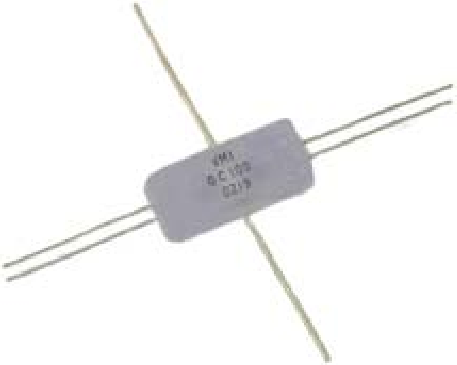
- *The shunt approach is well-proven and can be very fast and efficient when operated in its active direction.*
- *Approach is especially effective in applications that require filtering and have a large output capacitance.*
- *The approach also works really well near zero volts.*
- *I generally prefer cascode control of the stack in order to the manage the overall circuit gain.*





Post-Modulator Approaches… 3

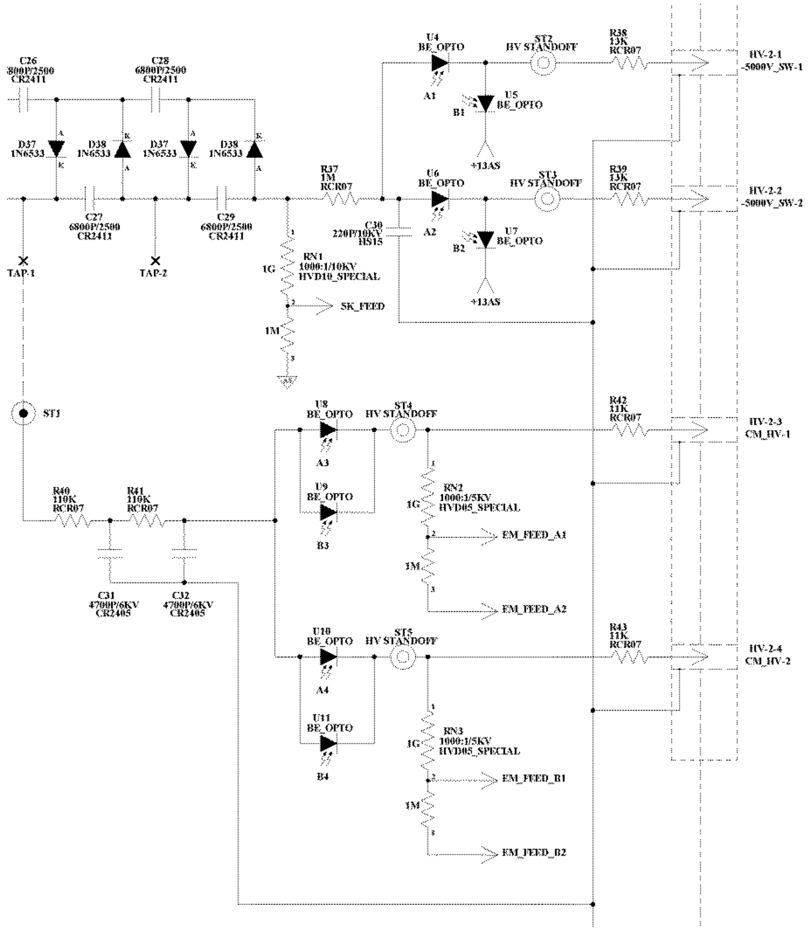




- *The Amptek HV801 and variants such as the VMI OC100HG/150HG and Micropac 66353-XXX are now in common use in high voltage applications requiring fast stepping of high voltages.*
- *In general, the devices are operated off of a "bulk" supply to allow for multiple outputs from a single supply. Devices are fairly small and can be configures in series with a load or as a shunt if the device gain is sufficient and the power dissipation is managed.*
- *Most applications drive electrodes and cables as a capacitive load in combination with the DC resistance of a feedback resistor. Since the device operates as a current source, the speed of transition in these applications is proportional to LED drive current and inversely proportional to load capacitance.*
- *Devices can also be configured single-ended (working against a resistor or current source), in a push-pull configuration or, if you are really clever, in combination with a transistor shunt to achieve better low voltage performance.*

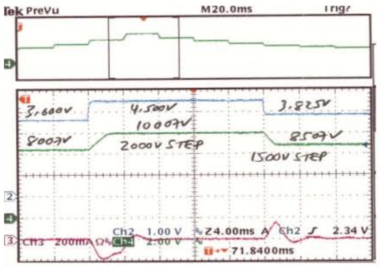
Post-Modulator Approaches… 4

- *The application to the right shows a -5000 volt shutter switch at the output plus a series regulator application for a detector of a selectable multiplier tap.*
- *Applications where the device is used in series with the load are usually the most stressful and must be carefully managed since both the LED and diode need to be on continuously.*
- *For example a 100 uA load through the high voltage diode with a 1000 volt drop results in 100 mW of dissipation.*
- *Remember that the devices are well insulated thermally as well as electrically!*

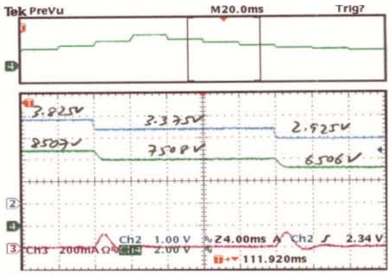


Post-Modulator Approaches… 5

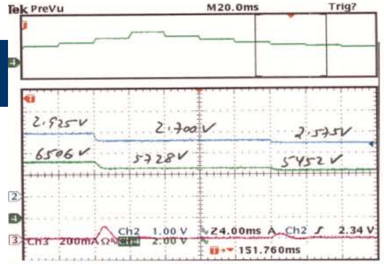
- *Stepping applications require attention to many design factors if performance is to be accurate and stable over temperature and other environmental factors such as radiation.*
- *LED wearout will occur with time so the LED current should be managed within constraints that are consistent with both proper derating lifetime requirements.*
- *Switching speed and settling is dominated by LED current and load capacitance in combination with the sense amplifier frequency response and error amplifier slew rate.*



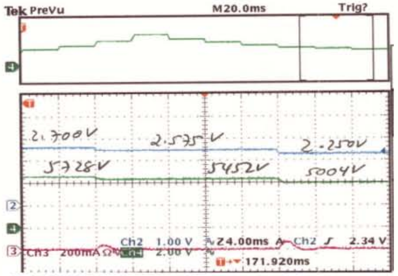
PIC17- Upper Range Expanded (DN368)



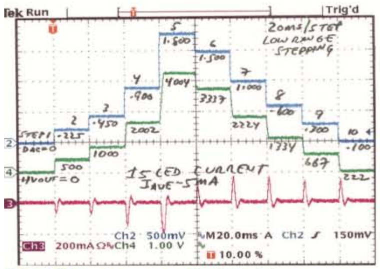
PIC18- Upper Range Expanded (DN369)



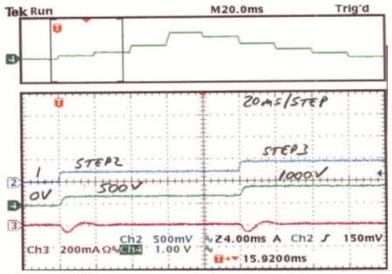
PIC19- Upper Range Expanded (DN370)



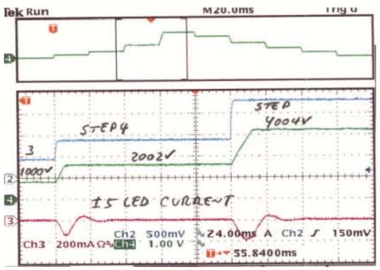
PIC20- Upper Range Expanded (DN371)



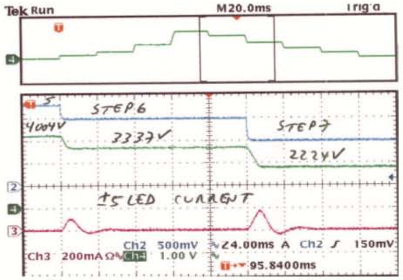
PIC21- Lower DAC Range Stepping; +52/-50 mA (DN352)



PIC22- Lower Range Expanded (DN358)

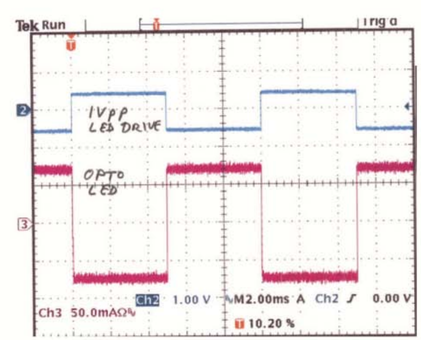


PIC23- Lower Range Expanded (DN359)

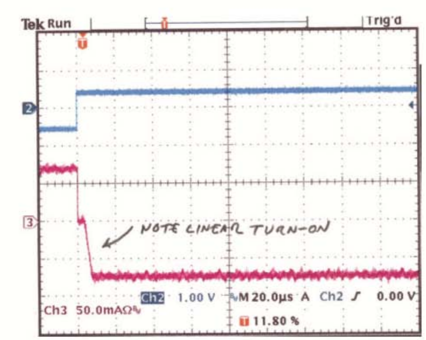


PIC24- Lower Range Expanded (DN360)

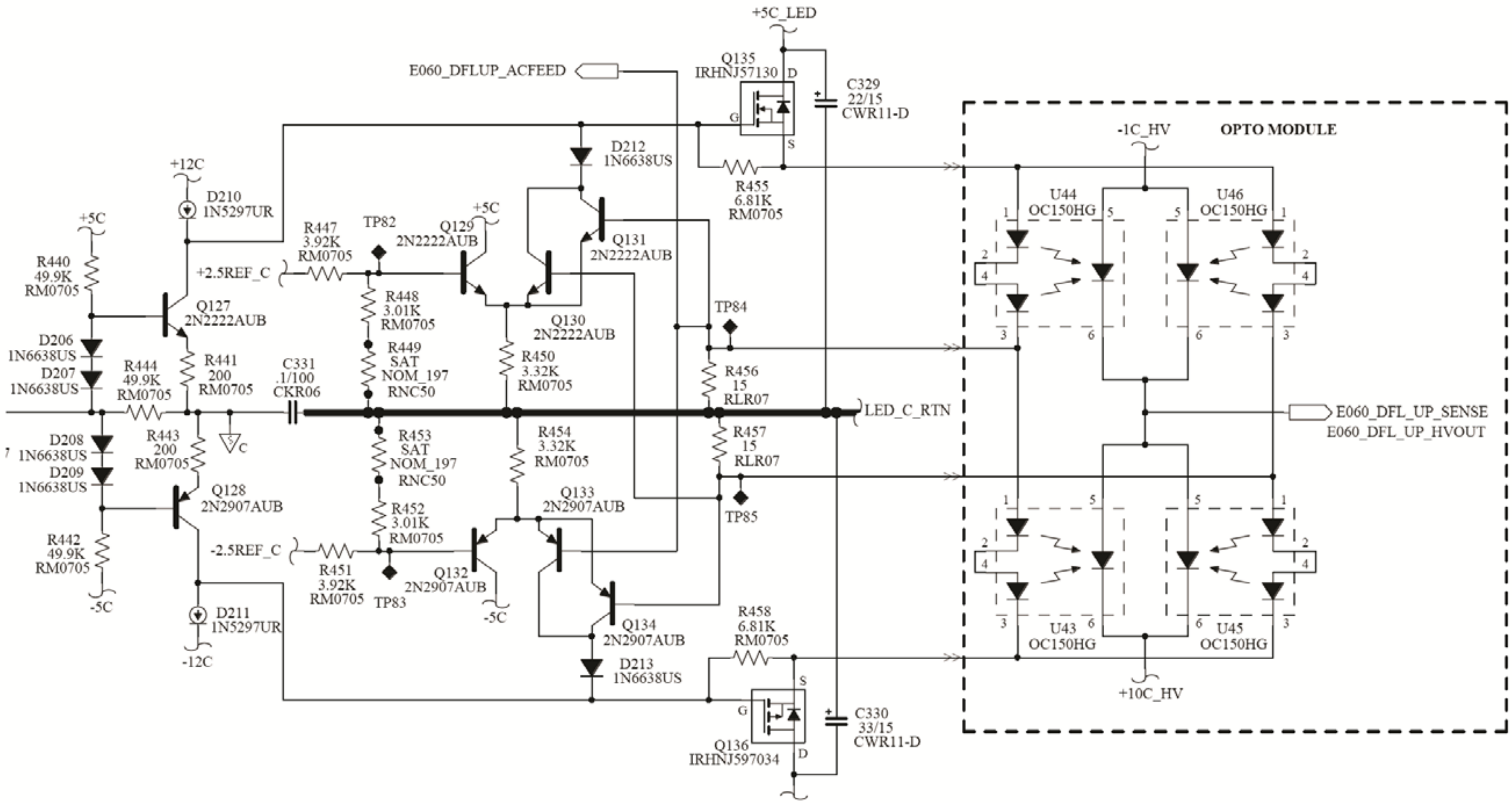
Post-Modulator Approaches… 6



PIC9- +/-500 mV Drive Active 75 mA CL (DN319)



PIC10- Active Control Range Narrow for Rapid Capture (DN320)

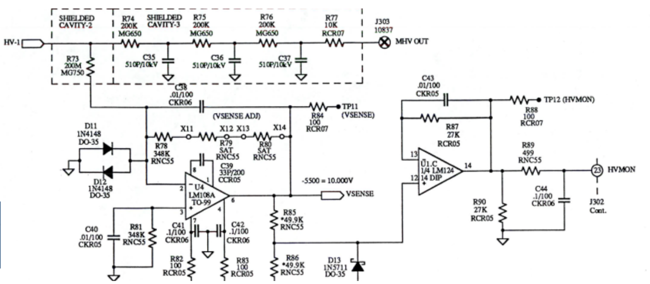


A Few More High Voltage Opto-Coupler Notes…

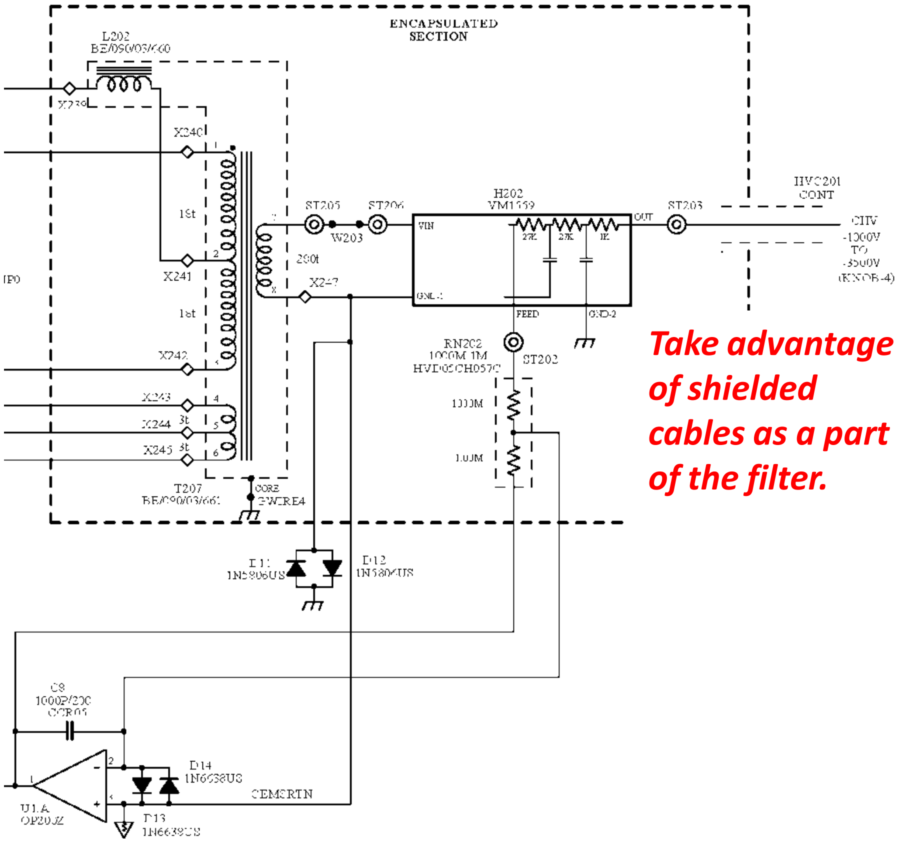
- *Remember that the device is a low volume production hybrid. Each lot will be different so design to accommodate parametric variation.*
- *Devices WILL be damaged if you exceed temperature range, thermal limits or voltage derating so take care with the design and with your test approach.*
- *Device reliability will be affected by the mounting and termination method so take care to design with assembly in mind.*
- *LED life and radiation effects mean the EOL gain will be lower than BOL. Adaptive designs that can adjust speed are helpful.*
- *Floating designs where the LED can operate at the high voltage potential puts a lot of stress on the device. The stress cannot be avoided in most applications so take the precaution of designing the drive circuit to be tolerant do an arc or breakdown problem.*

Output Filter Design… 1

HST-COS multi-pole filter



- High voltage filters designs must combine acceptable performance with absolute reliability.
- If you have the room, multiple smaller stages are more effective than a single stage.
- Feedback should , if possible, be on the inside of the filter for minimum phase shift.
- Use "zap traps" at strategic points to control ground faults.
- Isolate the source end with a resistor and connect the output capacitor to the structure to create a proper arc return path.

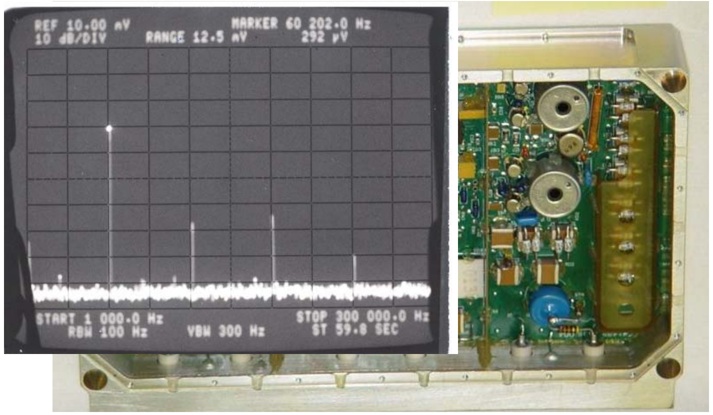


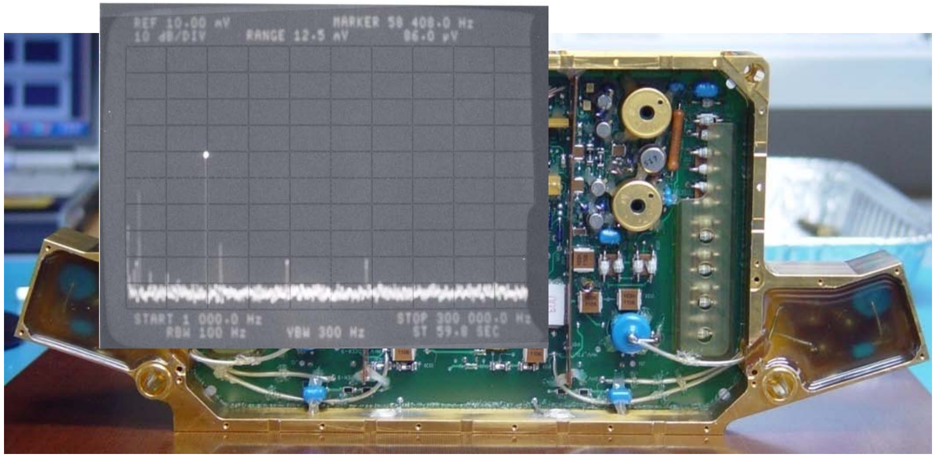
Take advantage of shielded cables as a part of the filter.

Output Filter Design… 2

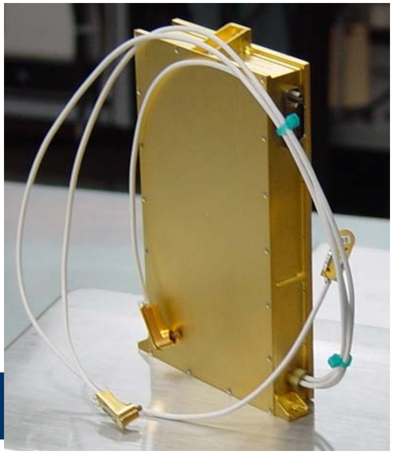
Noise reduction from AIM (2005) design (292 mV) to IUVS (2012) design (86 mV) due to separation into isolated "ear".

- *Separation and/or isolation from the high voltage multiplier is essential if you need good filtering.*
- *Parasitic capacitance (especially in potted sections) can reduce filter effectiveness.*
- *Axial lead capacitors make great a filtered standoff if implemented properly.*
- *Use only carbon resistors or film resistors specifically designed for arc tolerance.*
- *Filtering at the user end is more effective than at the source end.*

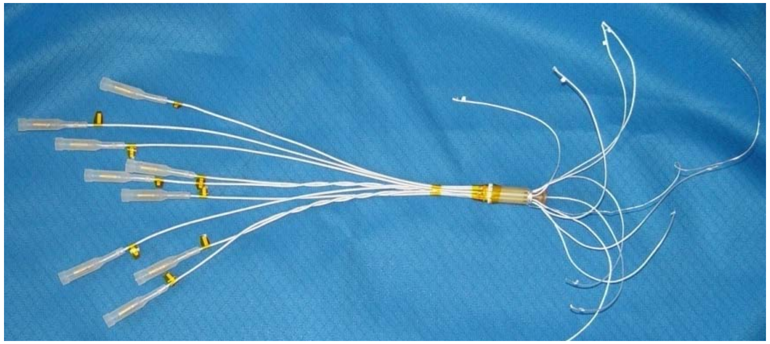


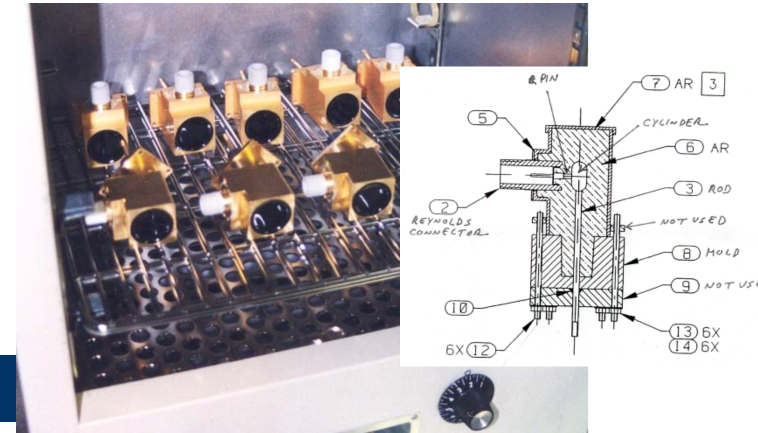


Output Termination Approaches… 1



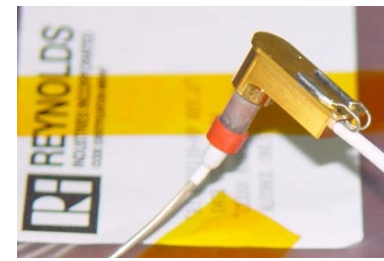
- *Output terminations are often overlooked with respect to their effect on performance and reliability. If not properly selected and implemented they can be the weak point in an otherwise good design.*
- *Basic connection types are umbilicals, connectors and custom terminations using screw or caps.*
- *Umbilicals are the easiest and have been very successful in applications where a connection can be conveniently made at the user end (or vice versa).*

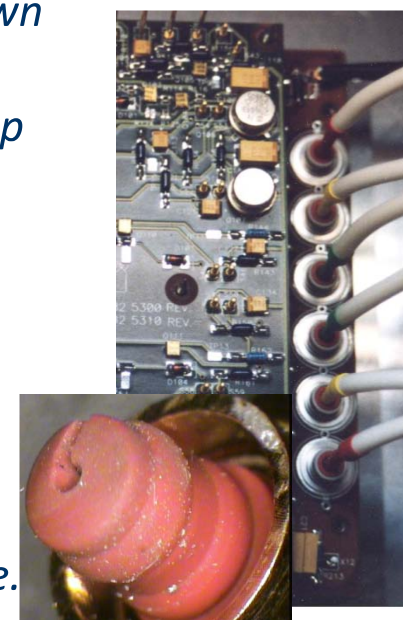




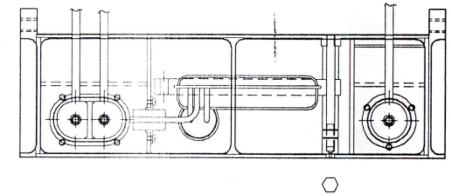
Output Termination Approaches… 2

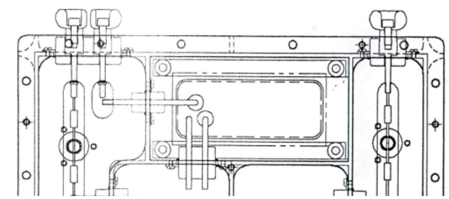
- *Teledyne Reynolds makes a standard set of spaceflight rated connectors that can be reliably used is properly applied. My preferred connectors for space applications are the PeeWee and 725 series. The 600-S series is also good at lower voltages.*
- *A key issue with any connector is managing the internal field gradient while voids or gas pockets that can slowly pump down over time in vacuum.*
- *Well sealed connectors can take as long as 4-6 weeks to pump down into the Paschen region.*
- *Depending on voltage and application a light coating of Bray 601 grease can eliminate voids and increase connector reliability.*
- *Custom connectors are almost always derived from standard connectors.*
- *Another issue is avoiding metal or dielectric particle contamination or damage to the boot at the mating interface.*



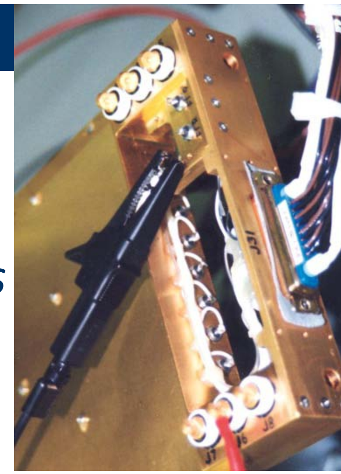


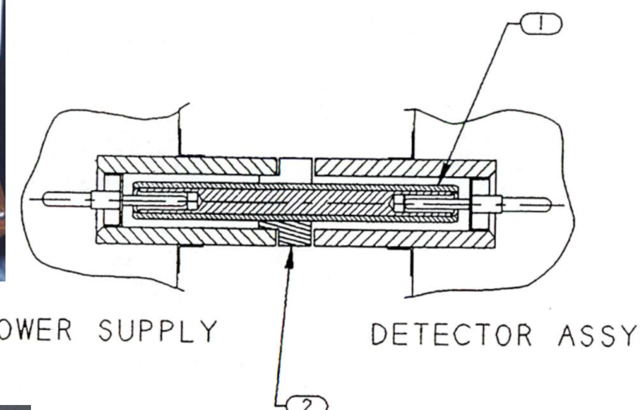
Output Termination Approaches… 3

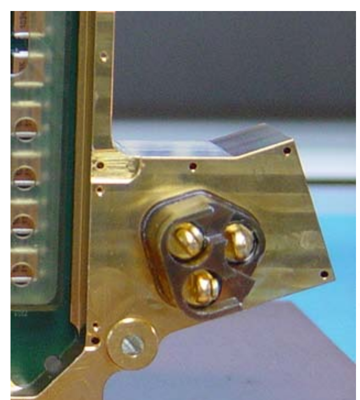


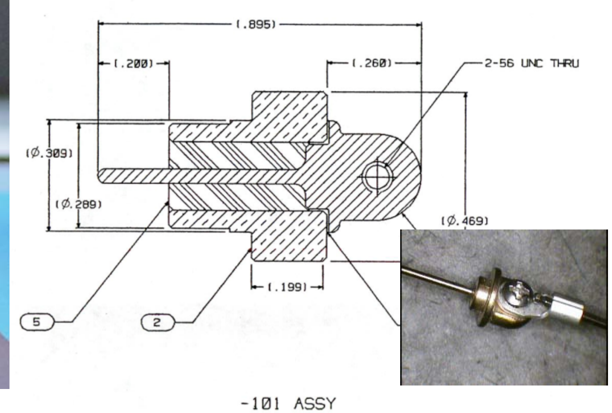


- Custom terminations can be made very reliable and should be considered in applications where connectors or umbilicals are not well suited.
- Generally require field shaping at point of attachment so best applied to unshielded applications.
- Ceramics and plastics are both useful but ceramics offer unique metallization options.
- Screws or toroidal caps are generally used for wire connections.









High Voltage Cables…

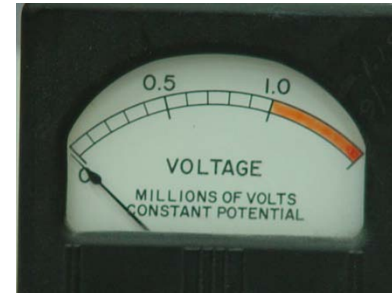
- *Teledyne Reynolds makes excellent quality high voltage cables in both shielded and unshielded versions.*
- *Unique cable constructions using semiconducting coatings are also possible in special applications.*
- *Coaxial cables have the advantage of both shielding and controlled E-field properties but are more complex to handle and terminate.*
- *Reliability is dependent on proper cable handling including compression, cut damage and/or improper bend radius.*
- *Biggest problem with unterminated coaxial cables is field controlled separation of shield from surface of inner conductor. Triple-junction can form unless approach is "gap-free" using an insert or filler.*
- *An O-ring is often a useful means of pealing away shield in a controlled manner.*

What to do on the other end…

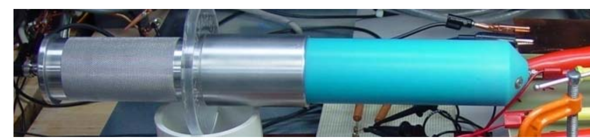
- *It is important to treat the "user end" as part of the high voltage system.*
- *Try to design the terminations, shields and grounding to be consistent and equally reliable on both ends.*
- *Incorporate "zap traps" and ensure both internal grounding and structural pathways can safely sustain an arcing event.*
- *As noted previously, filtering at the user end is more valuable than at the source end.*

15 MINUTE BREAK
EARLY ADJOURN POINT

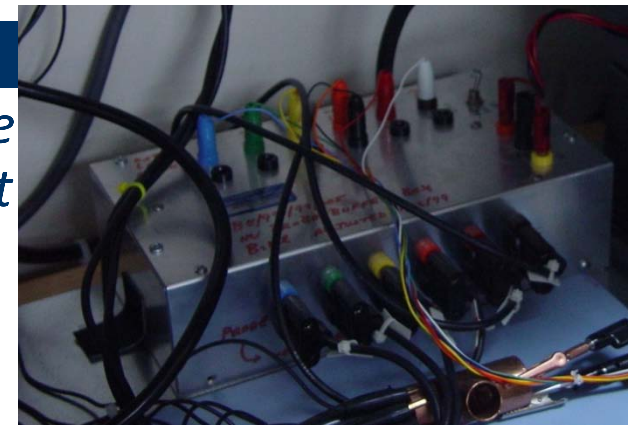
Voltage Measurement Approaches… 1



- *There are many types of voltmeters for high voltage measurement applications.*
- *For **direct DC measurement**, the Fluke 80K-40 1000M 40 kV probe is inexpensive but precise, stable with age and repeatable up to ~20 kV with very little voltage coefficient (accuracy will be discussed shortly).*
- *Accurate AC measurements requires special impedance matched probes and dividers.*
- *Probe shields are easy to make with PVC pipe and are highly recommended to maintain a safe setup.*
- *Custom probes make sense in some applications.*



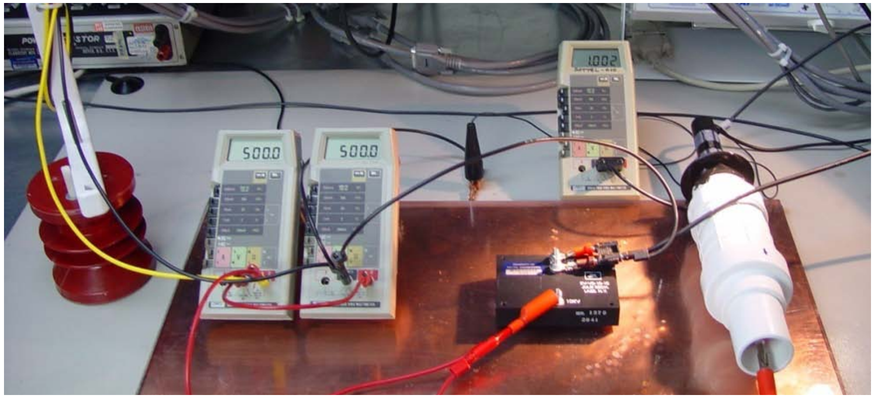
Voltage Measurement Approaches… 2



- *Measurement precision with a Fluke probe is in the 13 to 15 bit range if measurement conditions are properly controlled (0.2 to 0.7 volts per 10,000 volts).*
- *Measurement accuracy depends on DVM input matching and tends to be in the 9-bit range (I match probes to meters and get ~11-bit accuracy)*
- *14 bit performance is routinely possible if matching electronics are built and tuned to each probe. The 6 probe array shown with its matching electronics has maintained 0.1 volt accuracy for over 10 years.*

Probe Calibration…

- *The sad truth is that the only time I have calibrations problems is after equipment returns from calibration! Precision high voltage measurement devices do not go out of calibration if they are kept clean, dry and stored properly.*
- *Rather than calibrate probes, I maintain a testable secondary standard (Julie Research KV-VB-10-10) that can be used to verify calibration at 1000.0 volts using a calibrated combination of DVM's. of probes and setups as part of each test procedure.*

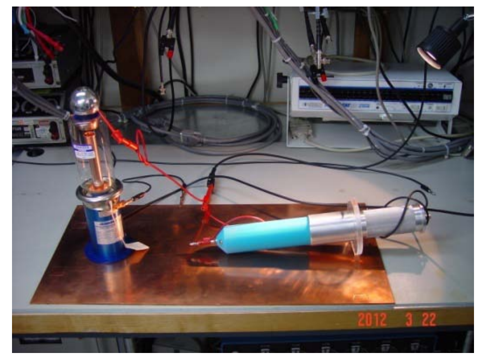


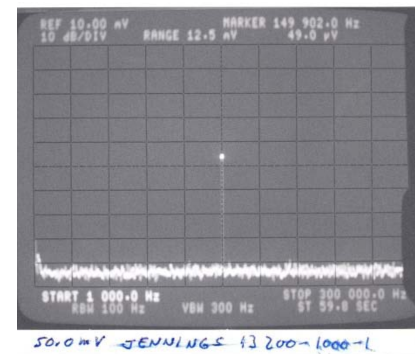
Output Noise Measurements… 1

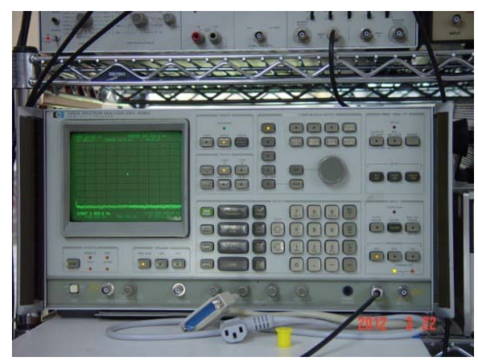
- *Output noise measurements on high voltage systems serve multiple purposes.*
- *Direct measurements of noise are essential to the design verification process as well as to the quantify performance margins between the source and user.*
- *Partial Discharge (Pd) measurements on components (especially transformers during development and capacitors during screening) gives insight into the quality of the design and manufacturing processes.*
- *Partial Discharge measurements at the system level give good insight into the expected reliability and are also an indicator of possible noise problems in sensitive detection equipment.*
- *Corona detection capability (beyond your eyes, ears and nose!) is also helpful for troubleshooting problems during development and test.*

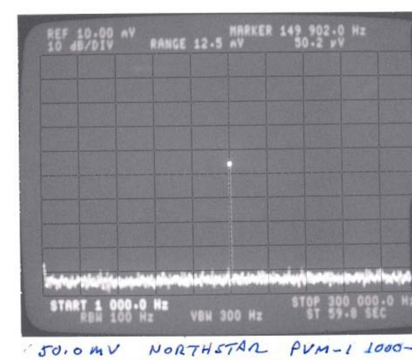
Output Noise Measurements… 2

- *Probe calibration is essential for making accurate and meaningful measurements of output noise on system.*
- *I prefer a direct DC measurement using a Northstar PVM-1 1000:1 probe IF the unit can tolerate a 1000M load.*
- *If the unit cannot tolerate a load, the Jennings 13200-1000-1 vacuum capacitor divider is a little harder to use but also makes an accurate measurement.*

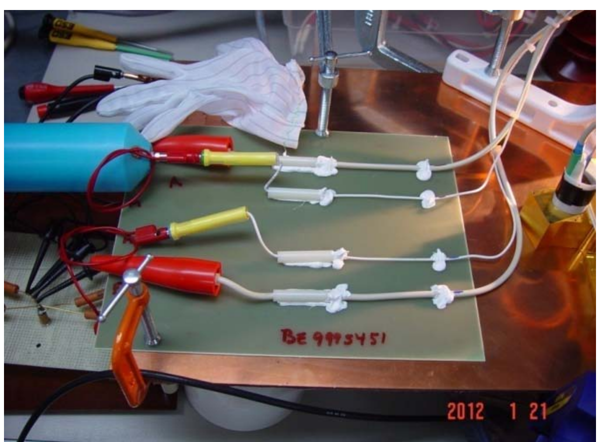


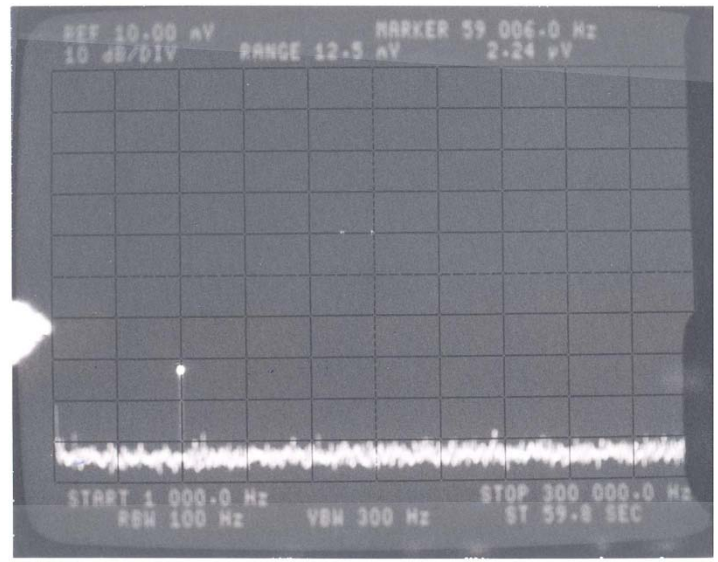






Output Noise Measurements… 3

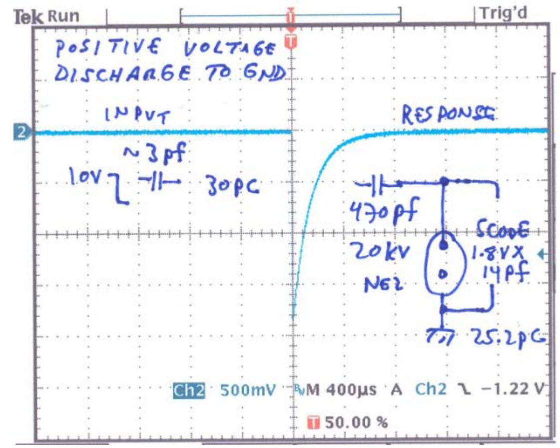


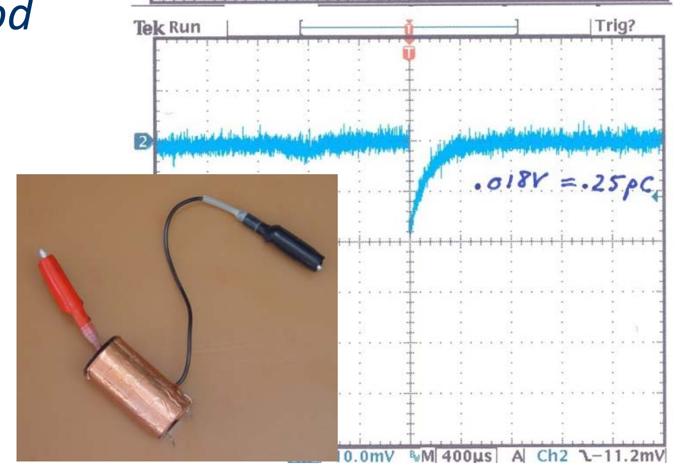


With a good spectrum analyzer measurements down to <500 uV are possible even with the 1000:1 attenuation of the probe.

Pd Measurement…

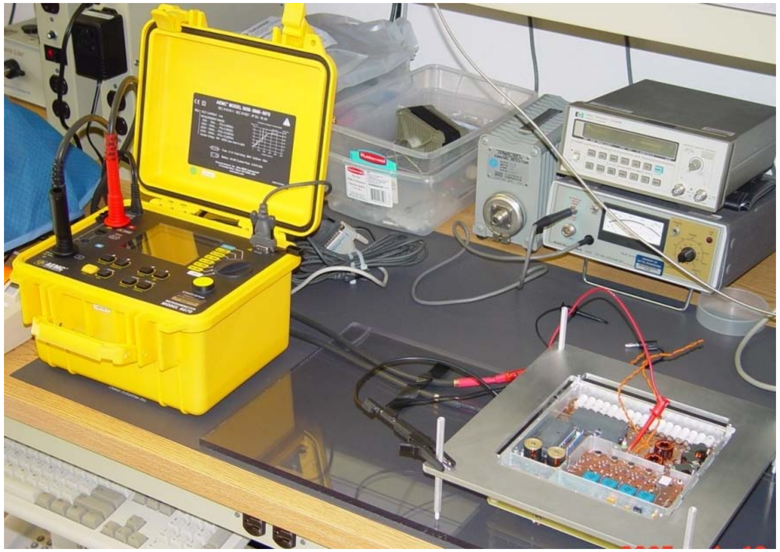
- *Biddle testers are the traditional means of making Partial Discharges. They use an AC drive signal and are really focused on commercial production market for motors and power equipment.*
- *A simple DC measurement can be made using a capacitive coupler capable of holding off the DC voltage. I prefer the "trigger and count" method where the scope trigger is calibrated for a 50% trigger rate at the measurement threshold.*
- *1 pC is the traditionally accepted threshold for long term damage although numbers up to 2-5 pC are typical and don't seem to have a big effect on reliability.*





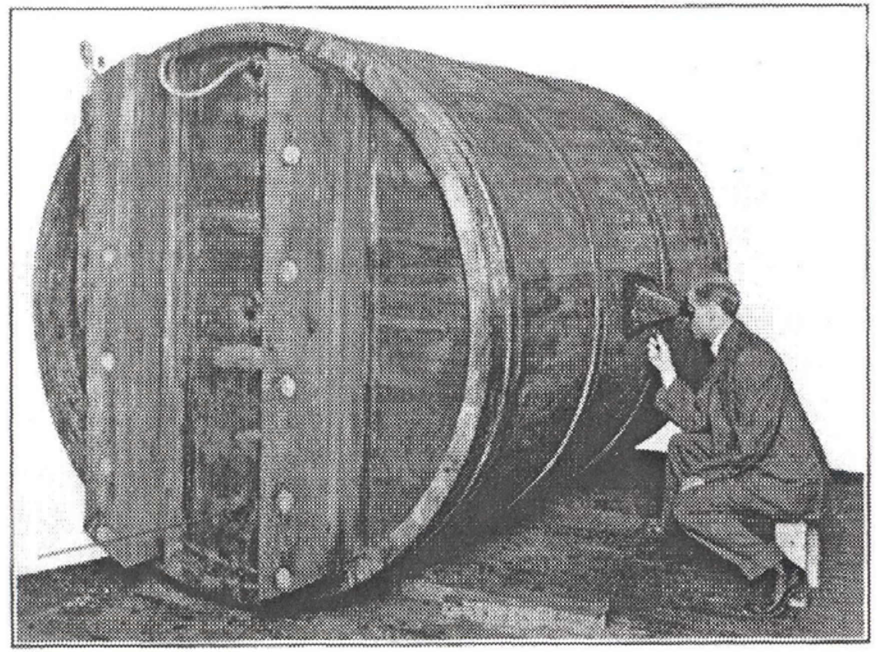
High Voltage Isolation Measurements…

- *Like Pd measurements, most high voltage isolation measurement equipment is geared for the power generation market.*
- *For dielectric measurements I prefer to use DC and make the measurement in a representative test condition.*
- *I mostly use the AEMC 5070 Megohmmeter for step voltage testing although my one and true love is the venerable GR 1863.*



Corona Measurements…

- Methods have not changed too much since the famous 1912 studies by Peck and others.
- If corona does occur, troubleshooting is typically done with a combination of visual observation, photography, gas quenching, RF sensing and analysis.
- Low level corona (as opposed to sustained arcing) generally has a damage rate low enough to allow for reasonable troubleshooting.



. 96.—Cask for the study of the variation of spark-over and cor- voltages with air pressure.

Radiation Effects…

- *Parts issues are well managed by other experts and there is not much I can add other than the fact that there are not many substitutes for some of the key devices. The design and test approach should allow for graceful degradation.*
- *LET and associated upsets need to be carefully manages since a crash of the control circuitry can truly result is a catastrophic failure.*
- *The many excellent dielectrics make charging in the space environment a more interesting issue although one that can typically be managed.*
- *Radiation effects on insulators are usually not a problem since the dose rates need to be really high. However, there are cases such as cables where the surface and penetrating effects need to be carefully evaluated.*
- *The one area worth some discussion is the ability to both partition designs and use potting or other insulators as a radiation shield. The components in the transformer, multiplier and filter are not strongly radiation sensitive. Thus, the shield can be substantially less in these areas.*