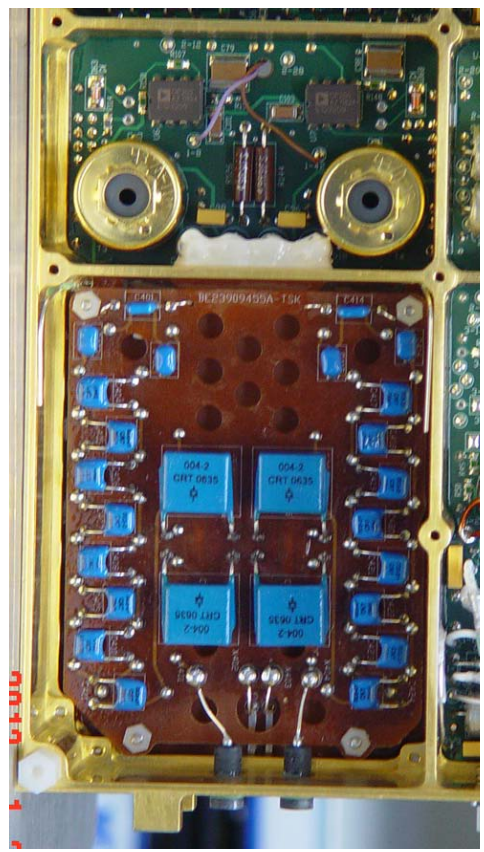
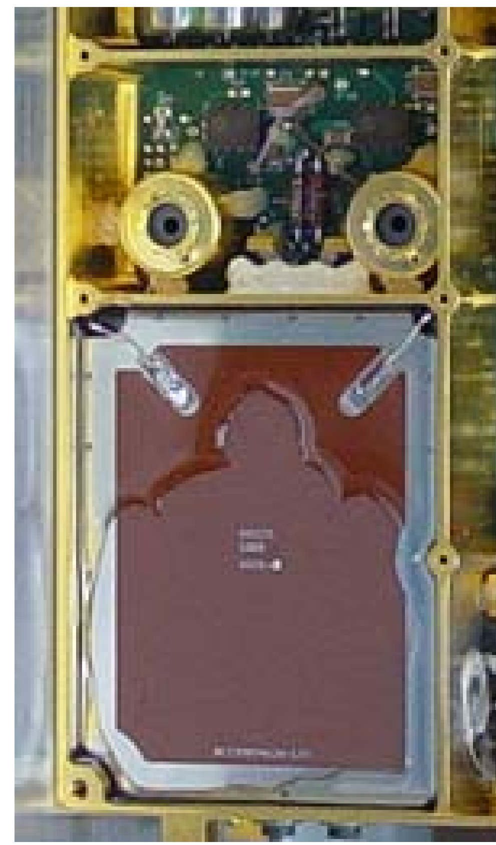
Shielding Example…

- *Many applications require a shield installed over the potted area for E-Field control and/or environmental isolation.*
- *This application for MAVEN shows the primed unit in Phase-1 test and the final potted and shielded unit in Phase-2 test.*
- *For this application the shield is applied after the initial pot and cure.*

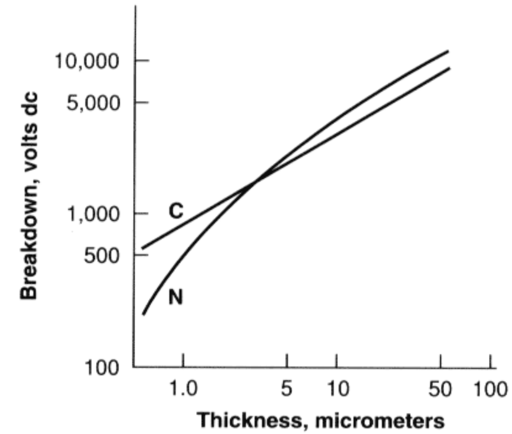




Insulating Coatings… 1

- *Solder mask is NOT a high voltage coating since there is no process control of voids and pin holes. It does offer the advantage of doing testing in air without supplementary insulation for parallel traces with voltages under 1000 volts and can be used if the insulation properties are not critical in the application.*
- *In critical applications it is better to leave the board bare in high voltage trace areas and then use a brush-on coating. Solder mask can be used under Parylene although in most cases I prefer to coat the bare board for high voltage applications.*
- *If properly applied, conformal coating can be effective in many applications for both field reduction at the surface of a conductor and to prevent both corona and flashover. I prefer using un-thinned EN-11 in one coat applied by brush to pre-baked surface although 2-3 Arathane coatings of surfaces also works okay.*
- *Parylene-C and -N (–C is the best all around coating except for exceptional high voltage applications) applied via gas deposition is the absolute best dielectric coating due to its 50L/1D penetrating ability, hydrophobic nature, void-free deposition, good adhesion and superior insulating properties.*

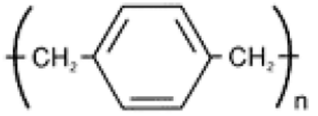
Insulating Coatings… 2



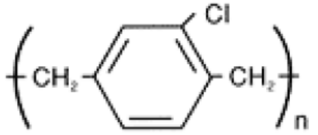
Properties (1)	Parylene N	Parylene C	Parylene D	Epoxides (2)	Silicones (2)	Urethanes (2)
Dielectric Strength, dc volts/mil short time, 1 mil films[a]	7,000	5,600	5,500	-	-	-
corrected to 1/8 in	630	500	490	400-500	550	450-500
Volume Resistivity, ohm-cm, 23 °C, 50% RH[b]	1.4×10^{17}	8.8×10^{16}	1.2×10^{17}	10^{12}-10^{17}	10^{15}	10^{11}-10^{15}
Surface Resistivity, ohms, 23 °C, 50% RH[b]	10^{13}	10^{14}	10^{16}	10^{13}	10^{13}	10^{14}
Dielectric Constant[c] 60 Hz 1 KHz 1 MHz	2.65 2.65 2.65	3.15 3.10 2.95	2.84 2.82 2.80	3.5-5.0 3.5-4.5 3.3-4.0	2.7-3.1 2.6-2.7 2.6-2.7	5.3-7.8 5.4-7.6 4.2-5.2

1 mil is 25 um
1.5 mils is 37 um

Parylene Coating Design Considerations… 1



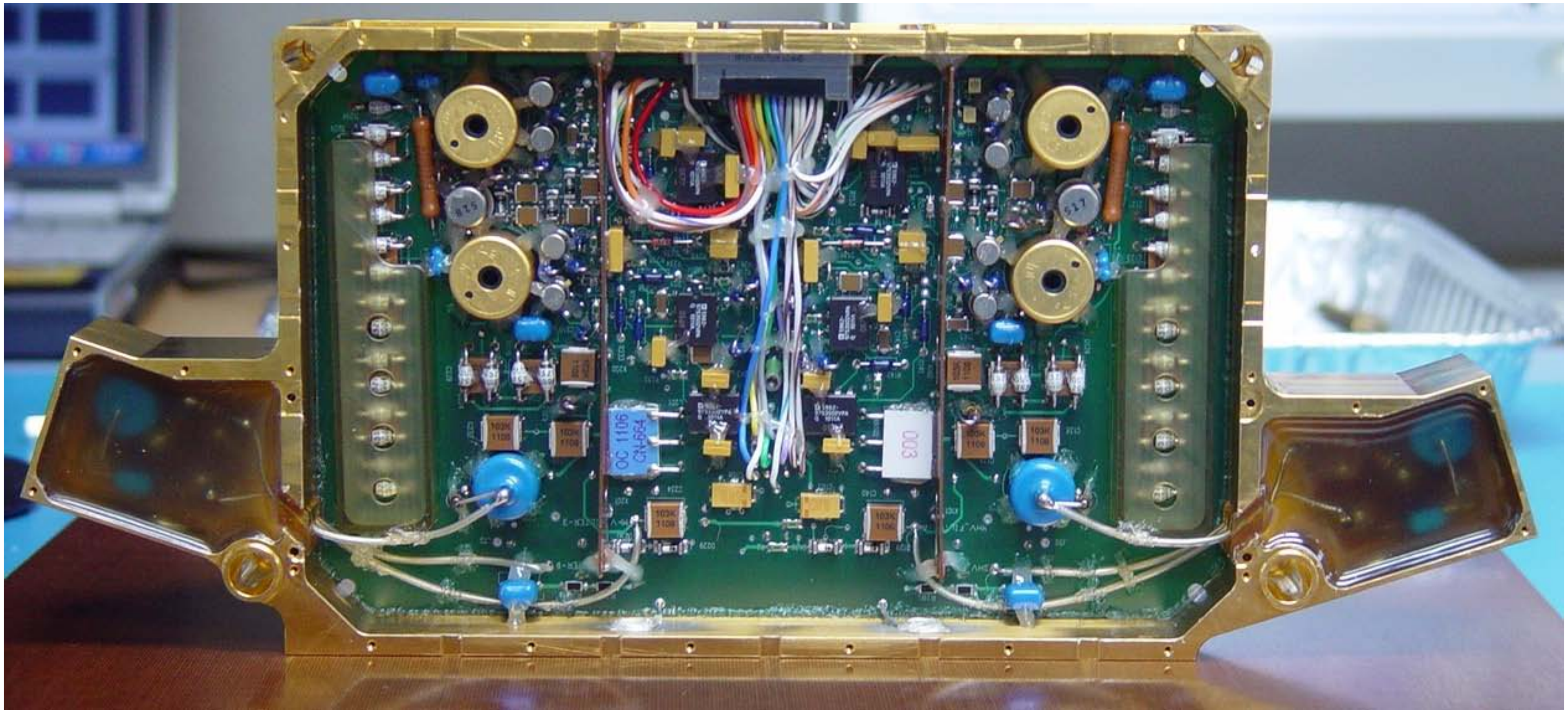
Parylene N



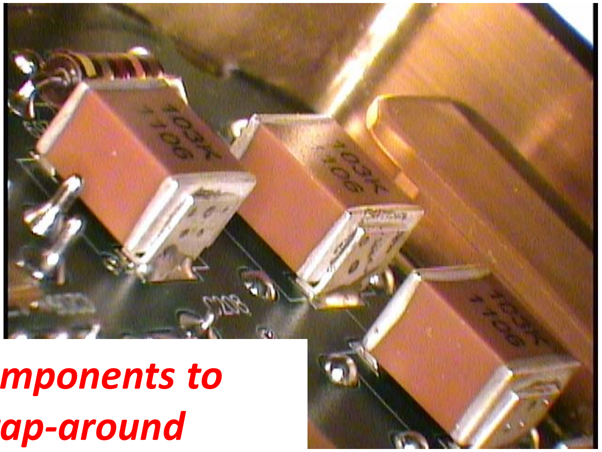
Parylene C

- Note that Parylene is NOT a way to save a mediocre design but does provide an opportunity for achieving designs that can operate in air and vacuum at higher voltages than is possible using standard non-potted techniques.
- -N has modestly better electrical properties but –C is easier to apply, is pinhole-free and is the most hydrophobic. Thus, -C is preferred for most applications, especially if good properties are desired in air operation as well as vacuum.
- Parylene coatings require special design considerations to assure proper coating and expected performance. Most important is to design parts with spacing's that assure full coating around the entire part.
- Careful and absolutely impermeable masking is essential due to the penetrating ability of Parylene. The design must build in the ability to implement masking that can be successfully applied and removed without impacting the high voltage reliability.
- Staking is typically done prior to coating. Typically the thickness is controlled in the range of 1.4 to 2.0 mils (I prefer around 1.5 mils). An organic silane primer is typically used ahead of application to improve adhesion.

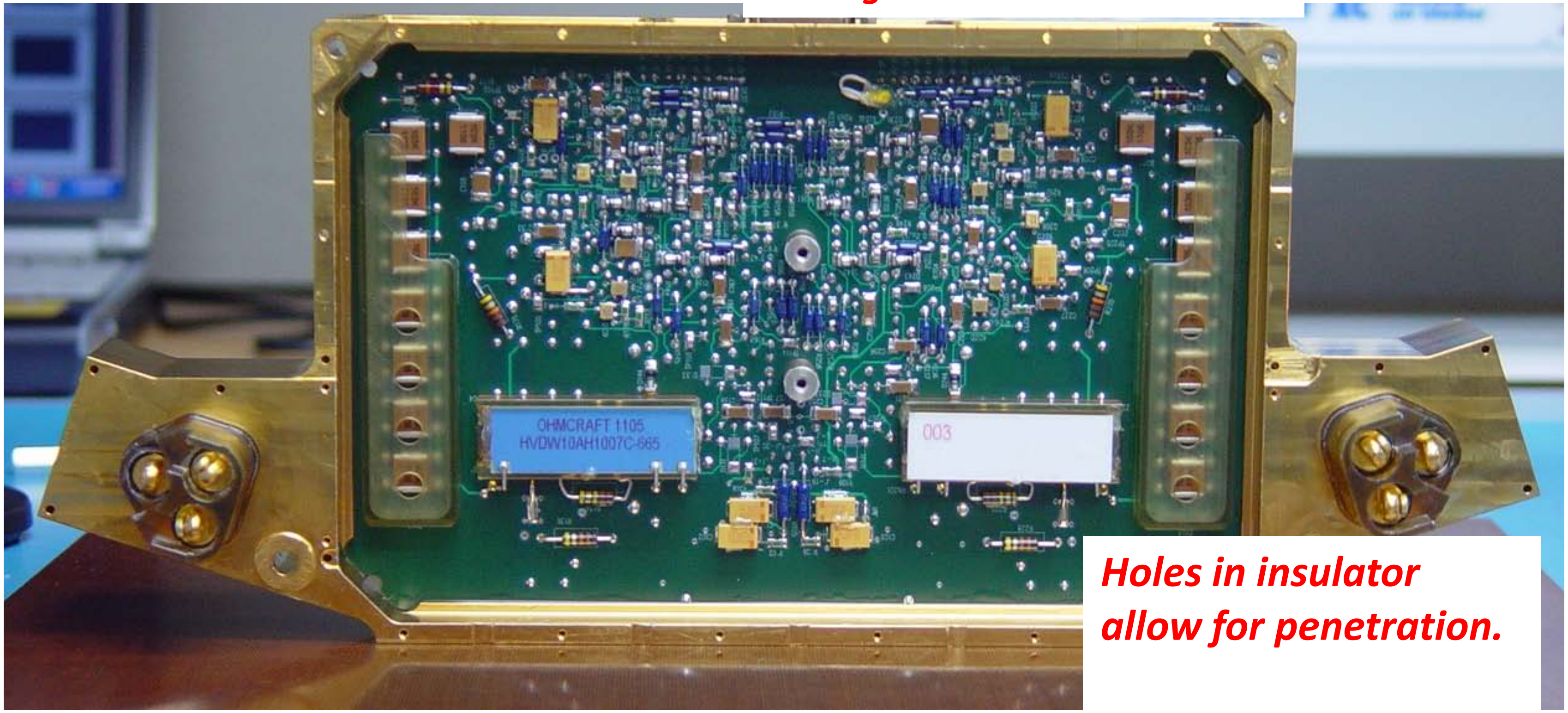
Parylene Coating Design Considerations… 2



Parylene Coating Design Considerations… 3



Space critical components to allow for full wrap-around coating.



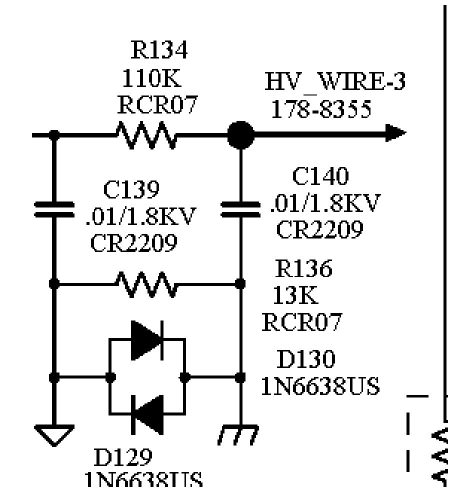
Holes in insulator allow for penetration.

Grounding Approaches… 1

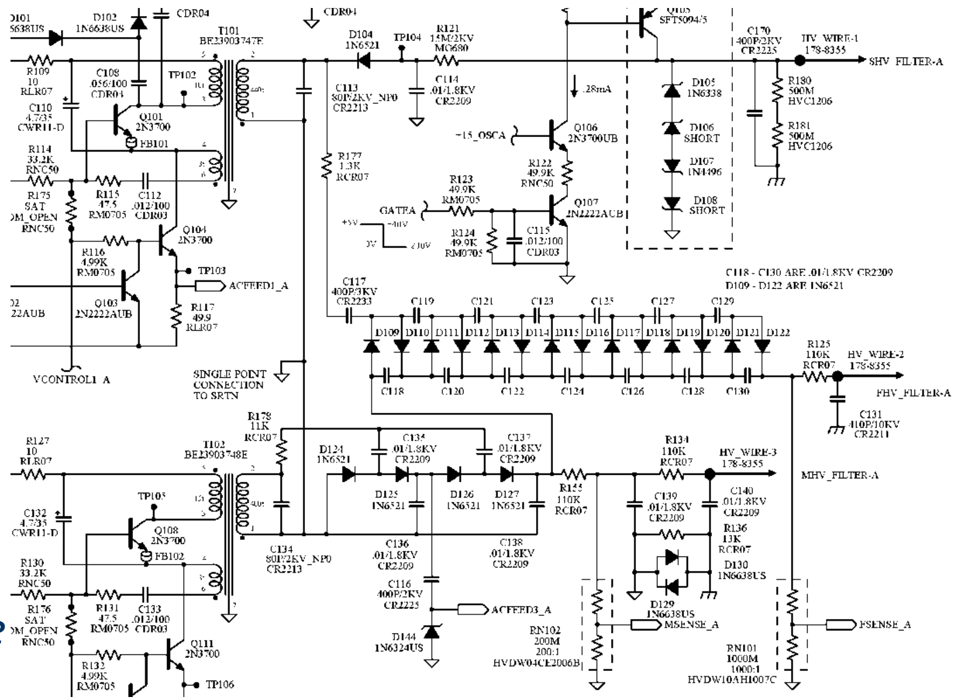
- *Recognize that the HVPS system, if designed and shielded correctly, is actually very quiet as a stand-alone system AND typically has a direct connection to your detector or some other sensitive sensor element. Thus, incorporating digital functions or other power functions is likely to make the HVPS a noise transmitter despite the most careful engineering approaches.*
- *Building a high voltage system is already challenging and can get even more challenging from a noise and performance perspective if rational grounding principles are not carefully followed.*
- *For low power systems, a KIS (Keep it Simple) rather than DIS (Design it Stupid) approach is strongly advised. KIS principle K1 is that the HVPS system should be designed without primary-secondary isolation such that the entire system runs at signal return potential.*
- *Principle K2 follows from K1 with the recommendation that power bus isolation and the first level of regulation occur some place else in order to suppress noise, better manage thermal dissipation and simplify packaging.*

Grounding Approaches… 2

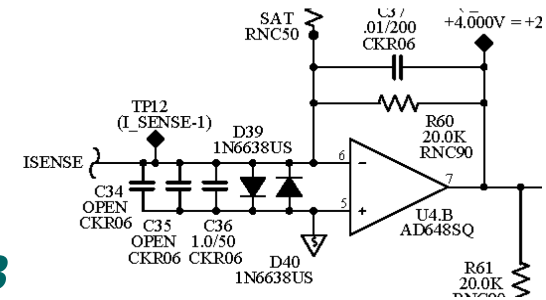
Use a "zap-trap" at all key structure to ground return locations to ensure safe bypassing of an arc.



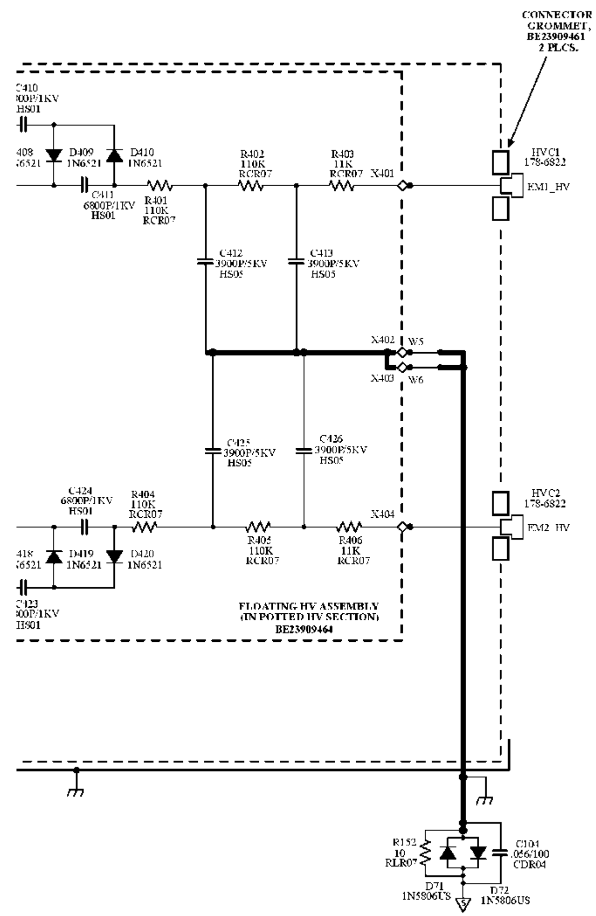
- *Although you are not isolating grounds for the HVPS, the step-up transformer does allow for flexibility on how the grounding is implemented (more on this later).*
- *The most important thing to recognize that an inadvertent high voltage arc will almost always occur to structure in the supply or downstream in the user element.*
- *Therefore, structure must be (and typically should be) treated as the primary high voltage return for an arc with associated mitigation approaches.*



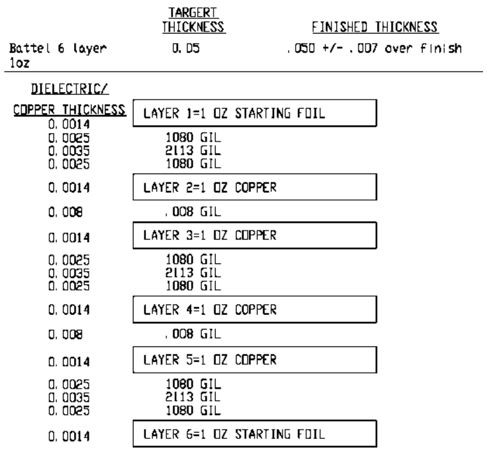
Grounding Approaches… 3



- *Despite what the Golden Rules might say, resist trying to design the system to either isolate the signal return from structure. Also, do not make the principle return a wire or the cable shield unless you take arc suppression measures.*
- *Always use arc suppression resistors and protection diodes configured as "zap traps" to protect circuits and manage ground faults.*
- *Use "zap traps" in multiple locations if necessary to assure local protection against ground faults.*
- *Low capacitance diodes can be used in critical applications although standard diodes are generally good enough.*
- *Zener diodes are also useful in some cases where the sensing junction is not at zero potential.*



PC Board Design Considerations… 1



- *Except for very specialized designs, PC boards are the way most high voltage system designs are implemented.*
- *Like all other elements exposed to high voltage, it is essential to control all aspects of the board design and manufacturing process.*
- *Work with your trusted vendor to design a simple and reliable board structure that they can process reliably.*
- *If possible limit to 4-6 layers using stacked up clad laminate cores in order to minimize pre-preg build-ups. For pre-made cores you can go to 100 volts per mil if the fields are controlled. For pre-preg structures you are safer using 50 or 75 volts per mil (or lower).*
- *1 oz copper gives the most repeatable build-up of high voltage layers. Talk to your vendor and try not to go too thick or too thin.*
- *Maintain your manufacturing documentation so that you can repeat the process in the future. Also, keep one of the boards for reference!*

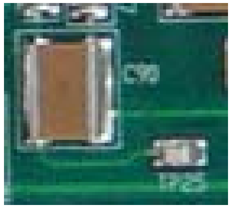
PC Board Design Considerations… 2

	Tg °C	UL-94	Key Feature(s)	Td (5%)	Z-Expansion 50-260°C (%)	Tc W/m-K
Polyimide						
85N Pure Polyimide	250	HB	Best Thermal Stability	407	1.2	0.20
84N Filled Polyimide	250	HB	Crack-resistant Fill	407	1.0	0.25
35N GP Fast Cure	250	V1	General Purpose Poly Fast Cure	407	1.2	0.20
35NQ Quartz Reinforced	250	V1	Low Dk and Loss Tangent	407	1.1	0.20
33N GP UL-94 V0	250	V0	Best Flame Retardant Polyimide	389	1.2	0.20
37N Low Flow	200	V0	Low Flow For Polyimide Rigid-Flex	340	2.3	0.30
38N Low Flow	200	V0	Enhanced Process Poly Low Flow	330	1.5	0.30
85NT Non-woven Aramid	240	HB	CTE Control for SMT Application	426	2.3	0.20

- *We have had very good success with GI polyimide laminates so try to stick with proven materials and processes unless there are special issues that force special engineering considerations.*
- *Main trade with your vendor is to achieve good laminating in combination with good drilling and plating, especially in areas with high voltage.*
- *Generally 35N material gives the best processing and 85N gives the best performance. In general, the ability to reliably process is usually more important than the slightly better properties so make sure that your vendor understands your priorities.*
- *Also remember that you can make multi-layer stack-up thicknesses that are "non-standard in order to save mass or achieve a particular insulation build-up. I tend to prefer a 6-layer .050 or .062 structure.*

PC Board Design Considerations… Some useful rules and suggestions 3

- *Try to balance your layers and have thicknesses of at least 8-10 mils in high voltage areas. Thin layers in the range of 3-4 mils that are used in low voltage systems are prone to defects that can break down under E-field stress.*
- *Wicking, cracks and other problems due to drilling damage occur in any type of PC board system but have a greater impact on high voltage systems. Minimize vias or penetrations in the PC board that have high voltage unless you specifically design to control the local E-field.*
- *If you use swage turrets for high voltage connections be very gentle with the swage to minimize cracks.*
- *Use "standard" test points only in non-high voltage areas and design the attachment trace to be a "spur" from a pad rather than being in line with the main signal. This will minimize the impact of a test point delamination.*

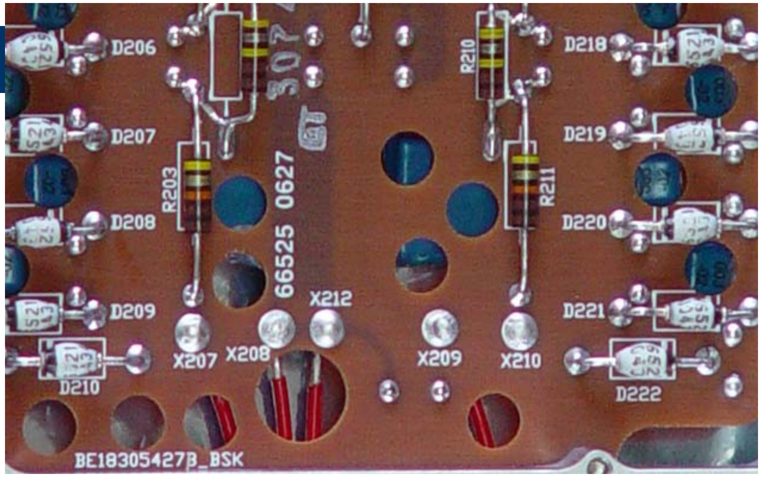


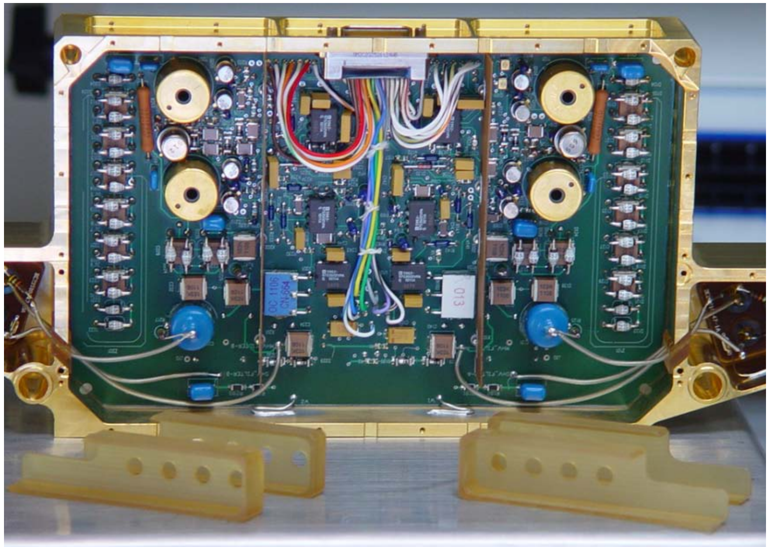
PC Board Design Considerations… *Some useful rules and suggestions 4*

- *There are many opinions and "standards" related to safe trace spacing on a board surface. The key thing to remember that one serious flashover should mean a permanent compromise of the insulation. Thus, you want to be conservative especially if you do initial testing uncoated.*
  - ***Flashover depends on many factors but tends to run around 50 volts per mil** in air**.***
  - ***Commercial Class III safety standards require around 19 volts per mil.***
  - ***The NASA standard is 8 volts per mil which is probably conservative.***
  - ***My general rule of thumb for parallel traces is 100 mils for 1000 volts (10 volts per mil) if you coat the traces. In reality the best rule is DON'T run parallel traces if it can be avoided!***
  - ***I also allow at least 100 mils (and generally more if possible) for any trace near the edge of the board or near the wall of an enclosure.***
- *Buried parallel traces can be run around 30 volts per mil for long life and 50 volts per mil for shorter life.*

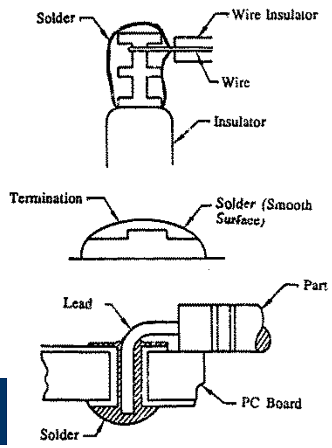
PC Board Design Considerations… *Some useful rules and suggestions 5*

- *The most important thing to remember is that the best designs are ones where you specifically design to control the local E-field.*
- *Sharp corners are the enemy so make sure to shape pads with high voltage and design smooth bends.*
- *Grooves or cuts in the PC board can help with high voltage isolation but they weaken the board and often do not help with flashover since they can act as source of "jumping" electrons.*
- *Shields work better and can also act as stiffeners if properly implemented.*





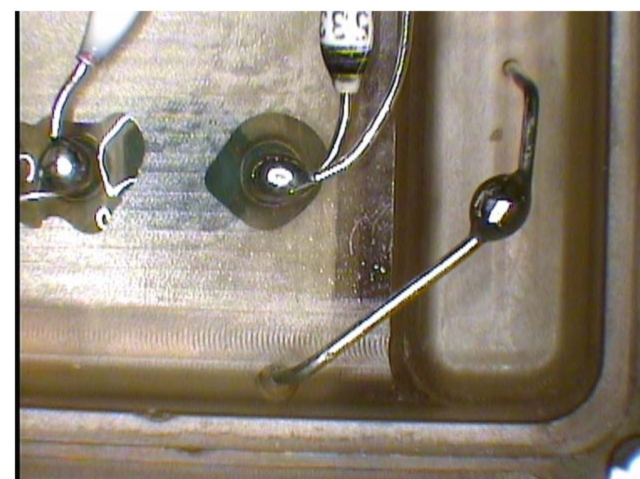
High Voltage Solder Joints… 1



- *As we have discussed, high voltage reliability fundamentally comes down to controlling the local E-Field to acceptable values at each point in each element of a system design.*
- *We also know that soldering as a process is also a critical contributor to achieving electronic system reliability.*
- *The key challenge of soldering in high voltage systems is to merge the above 2 process demands into an approach to making joints that possess inspectable criteria while also being reliable and immune to breakdown.*
- *There are generally two types of joints with spherical "balls" being used for floating joints (either on a PC board on in a potted assembly) and "flattened balls" used for pads with protruding wires on PC boards.*

High Voltage Solder Joints… 2

- *The “ball” solder joint is typically floating so must be both a solid mechanical joint as well as acceptable high voltage joint.*
- *Making a good joint is challenging and required good technician experience along with some practice in matching solder amount, tip-time, tip temperature.*
- *Rework almost never improves a joint so successful first time results are very important for flight reliability.*
- *A finished joint must be smooth and in the range of 2.0 to 3.0 mm in diameter. If bigger joints are required due to voltage requirements, it is possible to use conductive caps or dielectric layering to reduce the local E-field gradient.*



High Voltage Solder Joints… 3

- *Most high voltage joints on PC boards are assumed to be at voltages where a semi-flat joint is possible.*
- *The key is to trim and then reflow without overheating the joint.*
- *If too hot, it is possible to introduce an internal crack or defect that can ultimately result in failure.*

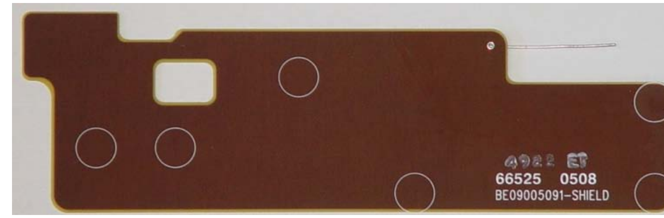
PROCEDURE

.010" LEAD TRIMMING AND HV SOLDERING

Note: This procedure is to be used in applications where high voltage (in excess of 300 volts) is applied to leads that protrude through the bottom of a PC board. In such cases, high electric fields can be induced by the sharp points created by the leads. Because this approach reduces the strength and inspectability of the solder joint, it should only be used in applications specifically called out in the assembly procedure. It should not be used in applications where the parts are potted and/or subjected to unusually high tensile stress.

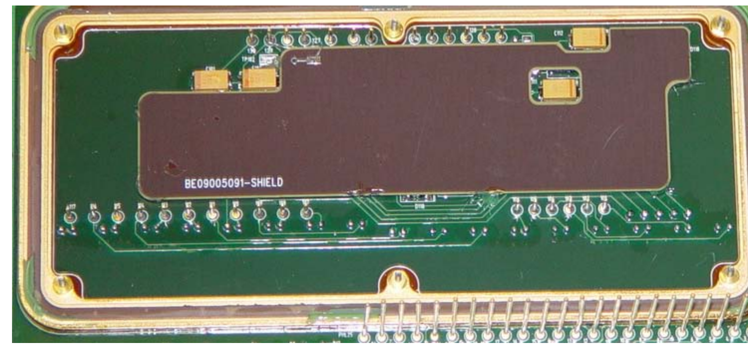
1. Pre-tin parts and Install using normal techniques for spacing and holding in place.
2. Solder using standard procedures but with a lighter than normal application of solder.
3. Inspect joint for integrity and solder pull-through.
4. Trim leads to <0.010 such that the lead is trimmed almost flush to the PC board.
5. Apply flux and apply more solder from the bottom side such that the joint is completely covered and takes on a rounded "ball" type appearance. (A lower soldering iron temperature often helps with this step. Some practice may be required to achieve the desired solder ball effect.)
6. Clean joint thoroughly with an approved solvent.
7. Inspect soon after completion of work to minimize time between initial soldering and any rework. (When properly accomplished the solder joint should look round and smooth. There should be little or no evidence of the lead sticking through the solder.)

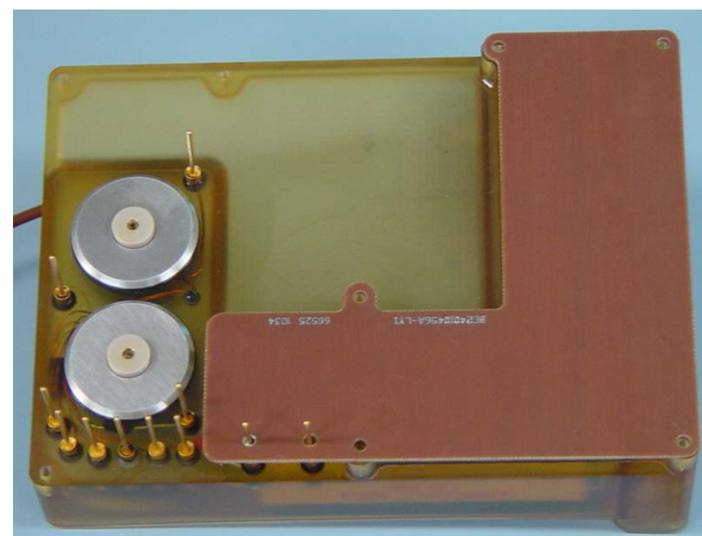
The circles are Ultem bumper locations glued on to the shield.



Electrical Shield Designs…

- *High voltage systems generate both high AC and DC fields that need to be managed in order to achieve accurate performance and low noise.*
- *I typically make .020 thick shields with an internal copper layer and outside insulating layer.*
- *Horizontal and vertical shields are both possible. Vertical shields can be supported using bifurcated turrets.*





Packaging and Construction… 1

- *The reliability of high voltage systems is determined by many factors. One constant factor for higher voltages is to have the package contribute to the system reliability by functioning as a deterministic "wrap" for the system that controls the T-E-M-P aspects of the design.*
- *Over time, my personal preference has moved toward "board in frame" (BIF) designs plus plastic enclosure approaches for the more challenging applications.*
- *Single layer planar designs and vertical designs using "plug in" boards are both practical allowing for adaptable E-field management as well as reliable coating and encapsulation.*
- *Mating pin-socket approach allows for simple and reliable interconnects with less management of spacing. Typically use 0.040 swageable Concord pins with a Tyco-AMP mating socket.*
- *Other approaches are certainly possible if properly managed. Just make sure you have a solid qualified process that manages all key parameters.*

Packaging and Construction… 2