

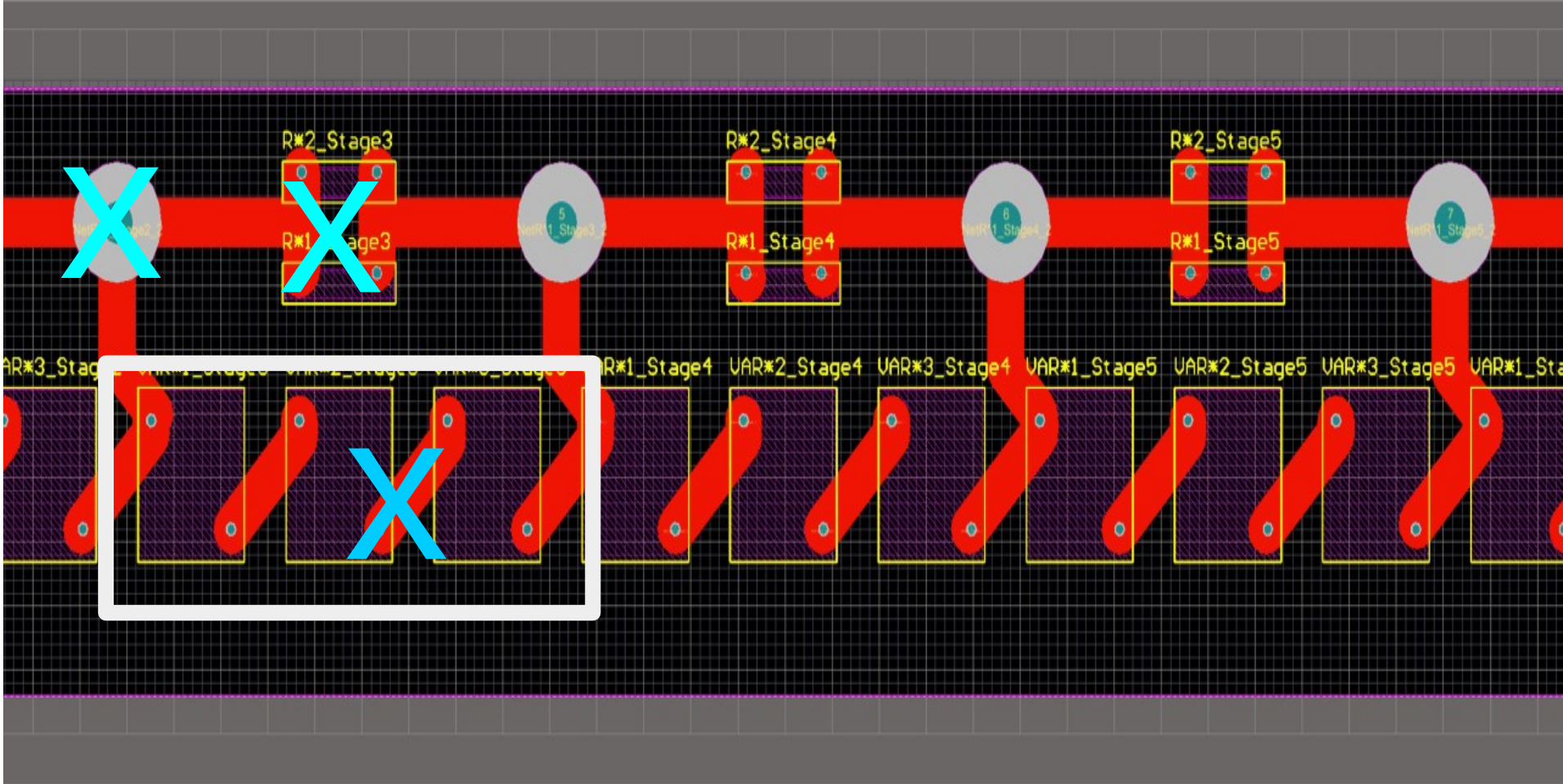
# Update on the FC electrical components

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# Outline

- Redundancy of a single PCB board : Chances of failure
- Alternate PCB board design
- Design finalization
- Understanding of varistors
- Conclusion

# Chances of PCB board Failure



# All possible conditions for a single stage to failure.

| Condition                                       | Function of PCB board                    | Note                              |
|---|--|-----------------------------------|
| If only resistors die in a stage or many stages | Current will flow through the varistors. | No failure of PCB board.          |
| If only varistors die.                          | Current will flow through the resistor.  | No failure of PCB board.          |
| If both resistors and varistors die             | Open circuit condition                   | Failure of PCB board.             |
| Circuit board failure                           | No current will flow                     | Entire chain will be disconnected |

# Failure rate of the PCB board

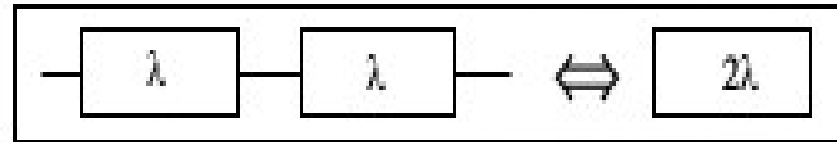
- **Resistors failure :**
  - The primary failure modes of resistors are open circuits and resistance drift.
  - In case of 2 GOhm resistors (below 2 watt power consumption) the probability of failure is less than 1%.
- **Varistors failure :**
  - The varistor short circuits when an overpotential caused by lightning surges is applied to it.
  -

# Circuit board failure

- **Environmental problem :**
  - Temperature, dirt, debris.
  - electrostatic discharge.
- **Manufacture problem :**
- The failure rate (probability) of PCB board is very small, less than 0.1% (once it has been tested after production).

# Failure rate calculation

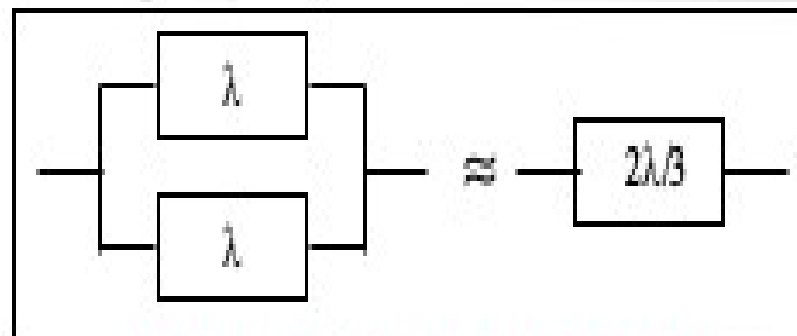
- Series Network :  $\lambda$  is the failure rate of each component.



$\Leftrightarrow$  indicates equivalency

*Figure 1. Series Network*

- Parallel network :



*Figure 2. Parallel Network*

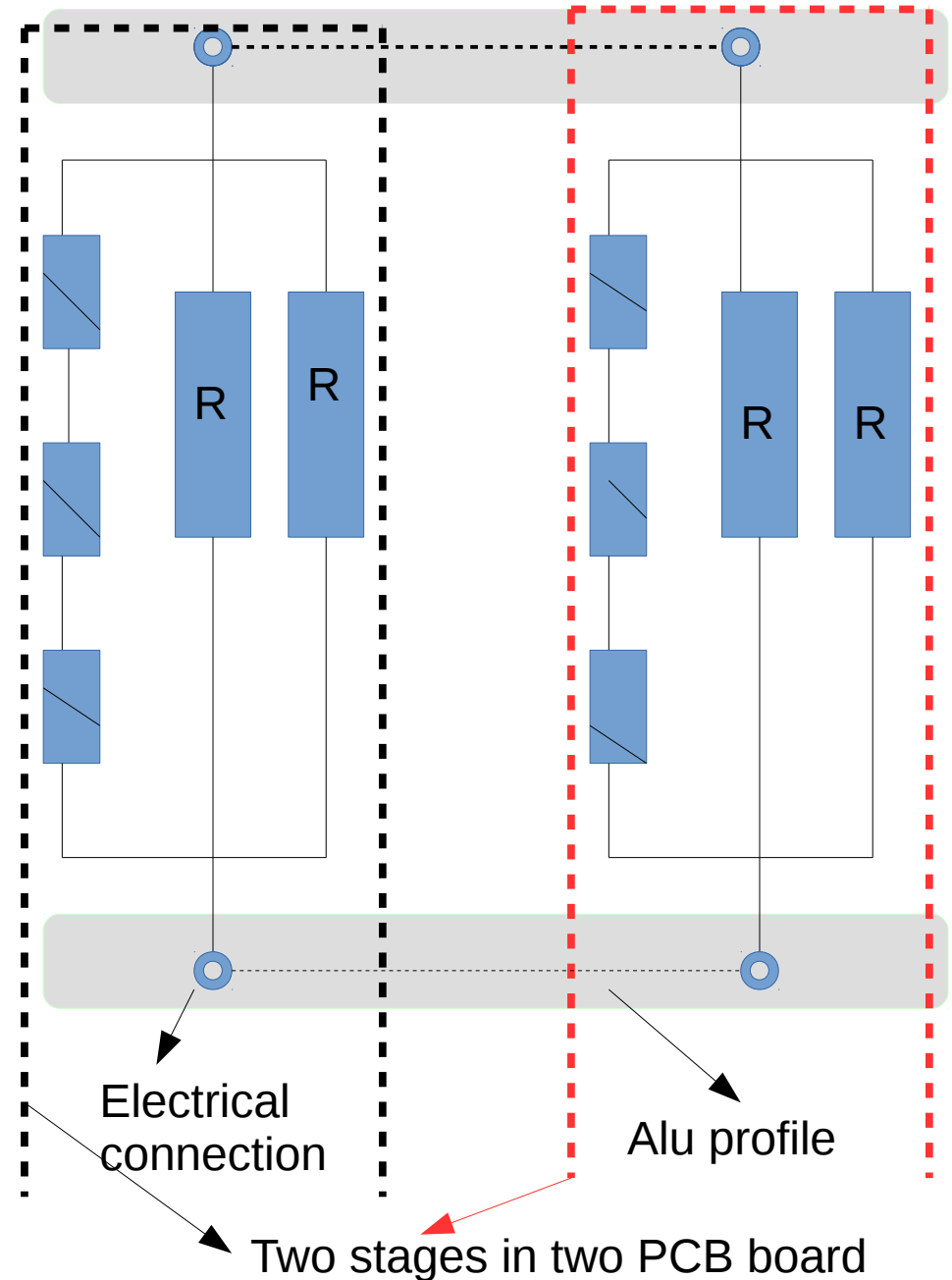
# Failure Probability of PCB board

| Components  | Failure probability           | Note  |
|---|-------------------------------|---|
| 1. Each Resistors in a stage                      | $P = 0.5\% = 0.005$           | If one of the resistor fails, still the circuit will be on.         |
| 2. Two Resistors in parallel                      | $P_{res} = 2 * P / 3 = 0.003$ | If both of them die, still current will flow through the varistors. |
| 3. 3 varistors in series                          | $P_{var} = 3 * 0.005 = 0.015$ | Current will flow through the resistors                             |
| 4. Failure rate of the components in single stage | $P_{com} = 0.0025$            | No current flow   |
| 5. Failure of trace in single stage               | $P_t = 0.001$                 | No current flow   |
| 6. Failure rate of single stage                   | $P_s = 0.001 * 0.0025$        |   |
| 7. Failure rate of a PCB board                    | $P_{pcb} = 10 * P_s$          |   |



# Alternate design : Two PCB board in parallel

- Two PCB board in parallel.
- 4 resistors in parallel of value 2 GOHm each.
- 1 Gohm in each PCB board, total resistance in a stage will be 0.5 Gohm.
- Current =  $294 \text{ kV} / 0.5 \text{ Gohm} = 6 \text{ uA}$ .
- Number of components will be double.



# Advantage and disadvantage

- **Advantage** : More effective in term of sustainability of electrical connection.
- Chances of failure will be very less.
- Probability of failure will be drop by a factor of half.
- **Disadvantage** : More current flow.
- Double number of components, more costly.

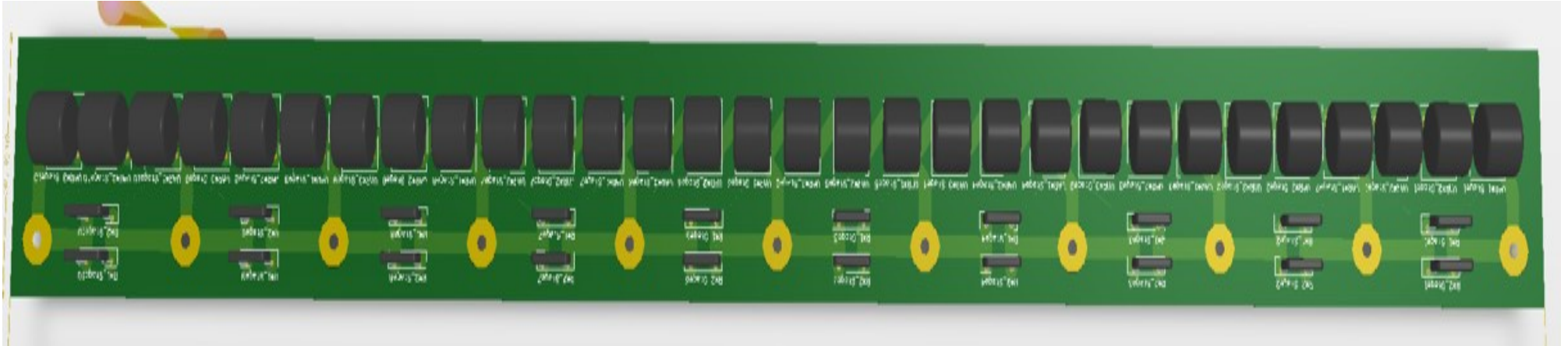
# Price estimate

| Elements                  | Values (unit)         | Part#         | Requirement for each board | #Total (with spare) | Price for a one board | Price for two board parallel |
|---------------------------|-----------------------|---------------|----------------------------|---------------------|-----------------------|------------------------------|
| Resistors                 | 2 GOhm                | SM102032007FE | 20                         | 200 (260 )          | \$600.00              | \$1200.00                    |
| Varistors                 | 3 varistors in series | ERZV14D182    | 30                         | 300 (400 )          | \$700.00              | \$1400.00                    |
| Connections with profiles | M4 size brass screw   |               | 11                         | 110 (150)           |                       |                              |
| Nuts and washers          |                       |               | 11                         | 110 (150)           |                       |                              |
| PCB board                 |                       |               | 1                          | 10                  |                       |                              |

**Cost will not be huge, may be extra \$5000 for the two board in parallel**

# Latest design of the PCB board

- **Option 1:** Single PCB board through the entire FC
  - Extra 0.5 mm tolerance at copper connection with the profile.
  - thickness of the PCB board 5 mm.

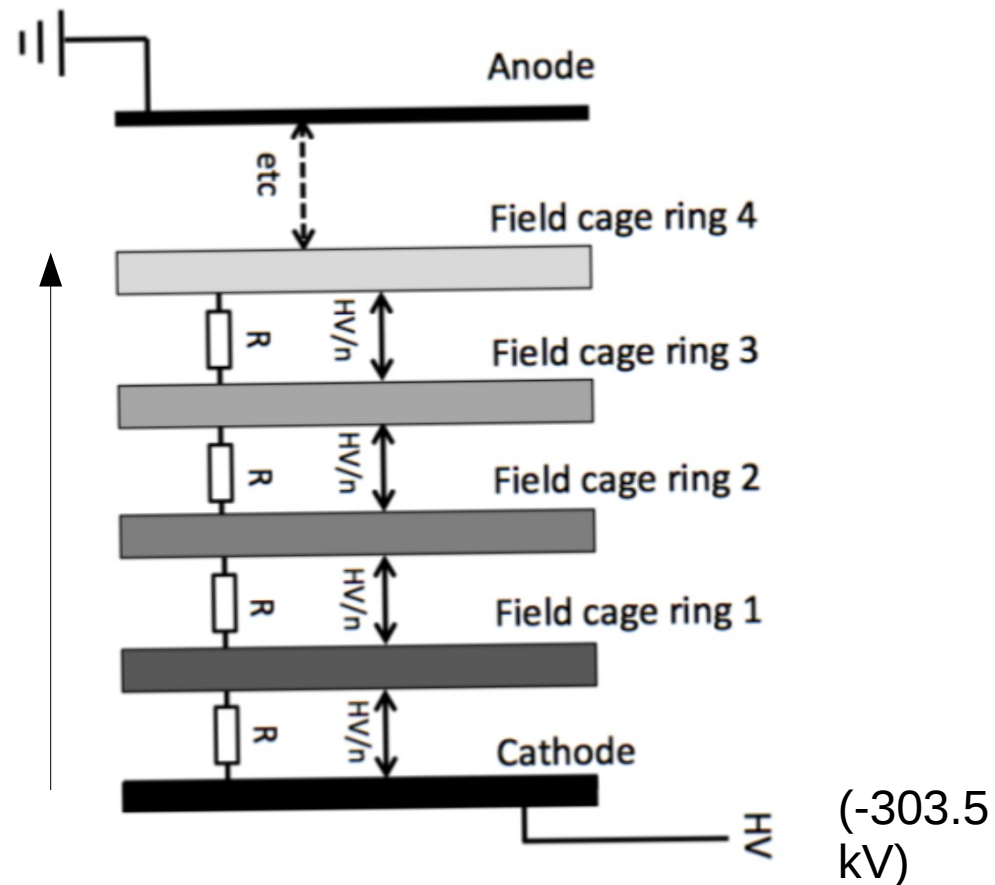


- **Option 2:** Two 2 PCB board in parallel.
  - Components will be same, number will be double

# Varistors : Why MicroBooNE has used

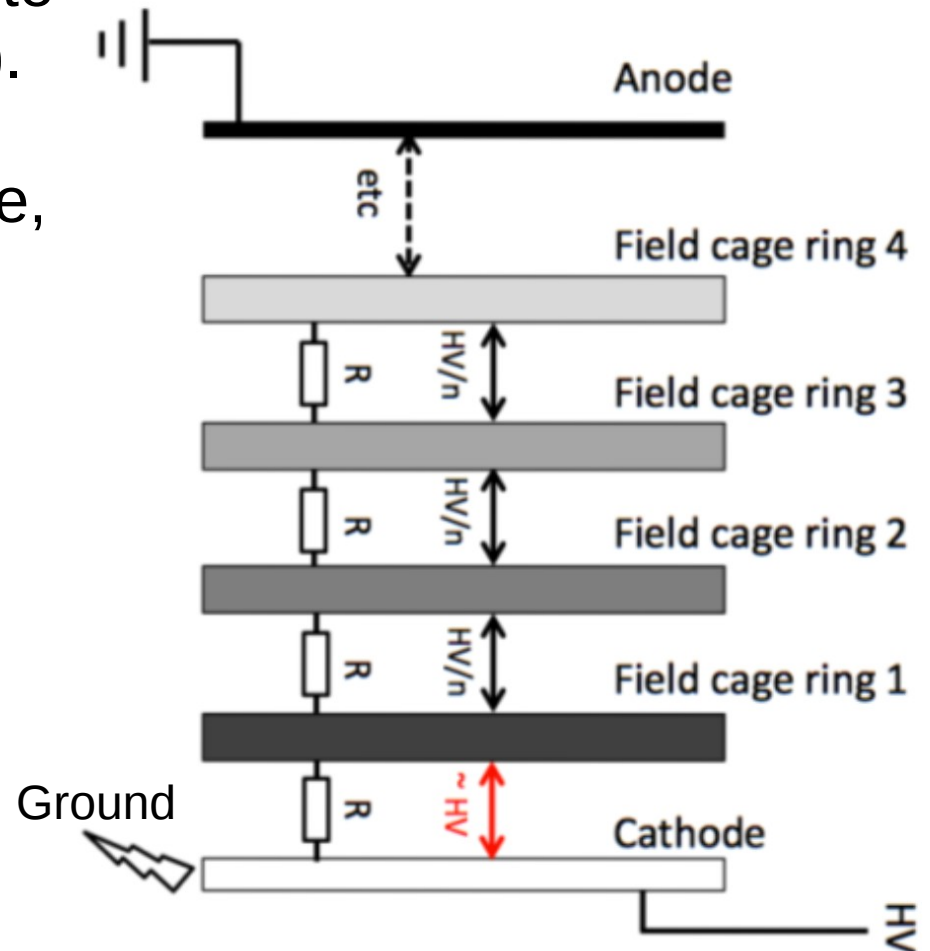
- Main purpose of using the varistors
  - Circuit works if any case resistor dies.
  - protect the circuit from discharge.
- Protection during discharge :

Field cage distribute the high voltage and creates uniform electrical field



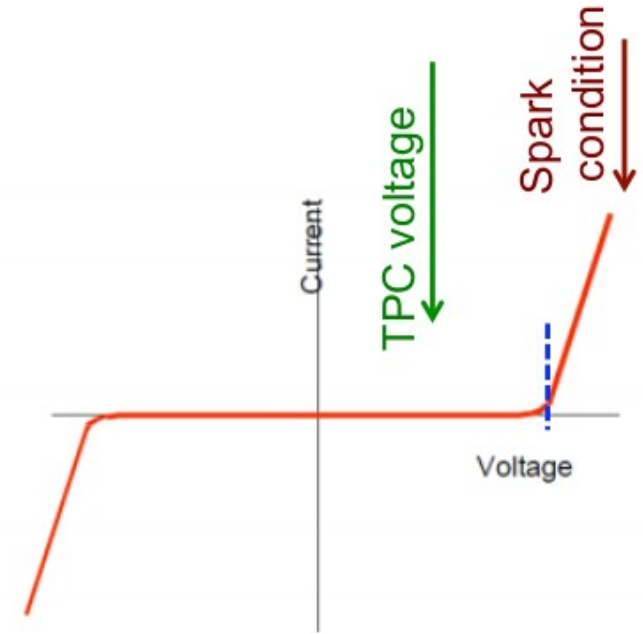
# What will happen to the discharge (breakdown)

- Lets consider cathode discharge to ground (due to some breakdown).
- Field cage profile has capacitance, so remain charged.
- Large resistance prevent charge redistribution in the field cage.
- The relaxation time of a single stage is  $= 1 \text{ Gohm} * 1 \text{ nF} = 1 \text{ s}$ .
- In this time the large voltage difference (much higher than resistors rating) will damage the resistors.
- Same thing will happen if any profile discharges.

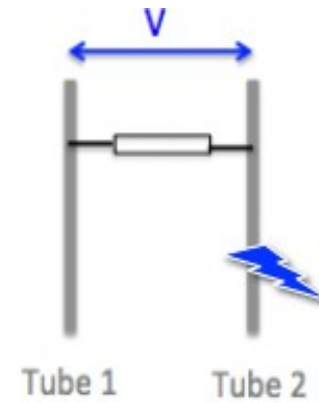
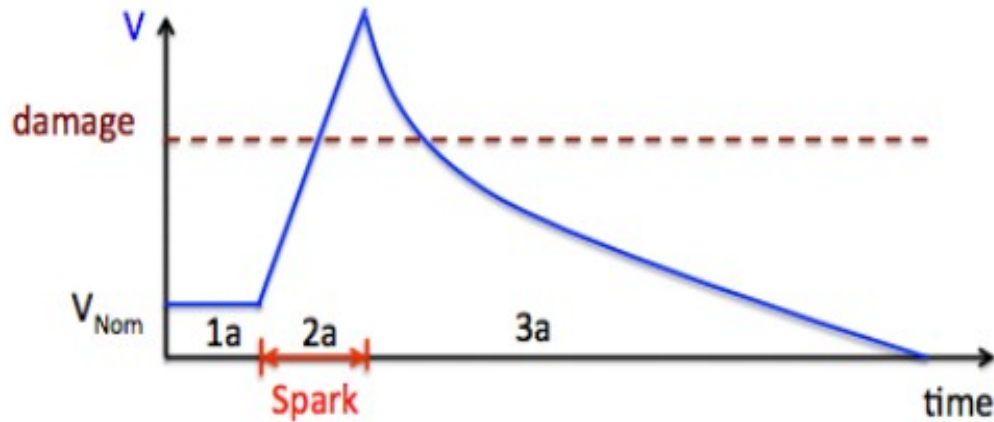


# With Varistors

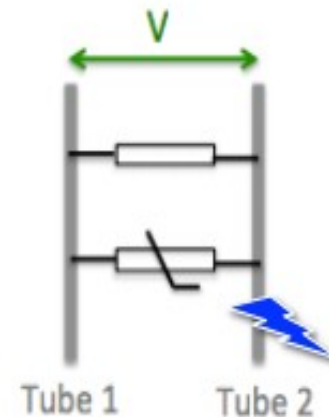
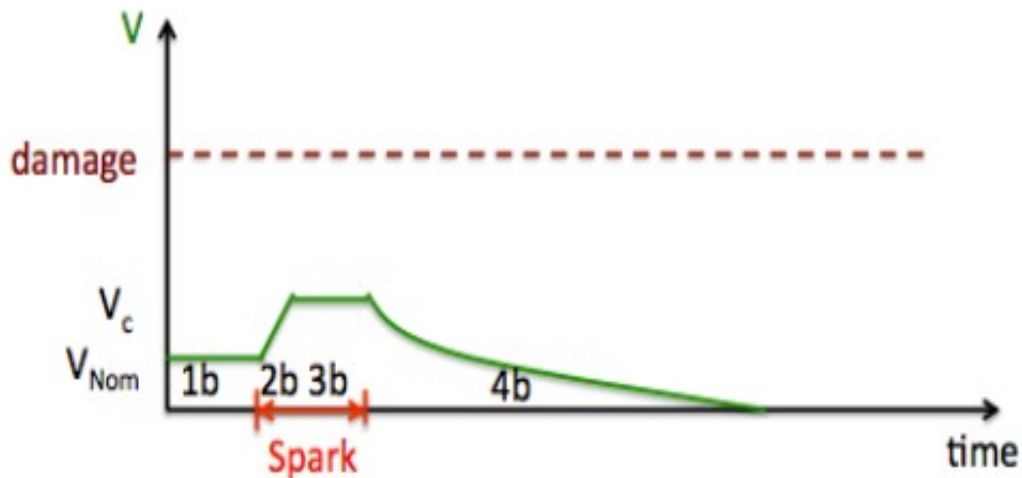
- Varistors have non-linear I-V characteristics.
- During the discharge, the voltage difference will be much higher than the clamping voltage of the varistors
- The resistance will go to be very low and voltage will be fixed at the clamping voltage.
- The relaxation will become very less and will be redistributed quickly.
- The voltage rating of the resistor should be higher than the clamping voltage of the varistors.



# Without varistors



# With Varistors



- With the varistors, the voltage never increases than the clamping voltage.
- It also helps G10 and argon breakdown.



# Conclusion

- We have to finalize whether we will use only single or two PCB board in parallel.
- All other components will be the same.
- Varistors are necessary for the safety in case of discharge.
- We will place order for the components and the PCB board once it is finalized.
- Any issue missing?