Why Does Electrical Clearance Increase with Altitude?

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WHY DOES ELECTRICAL CLEARANCE INCREASE WITH ALTITUDE?

Electrical spacing rules are an increasingly significant design challenge for PCB layouts which are becoming more and more dense. The rules, often termed "creepage and clearance rules" must be adhered to in order to prevent unwanted shorting between conductive elements over the life of a product. The terms are defined:

- **Clearance** is the shortest path between two conductive elements measured through the air
- **Creepage** is the shortest path between two conductive elements measured along the surface of the insulation

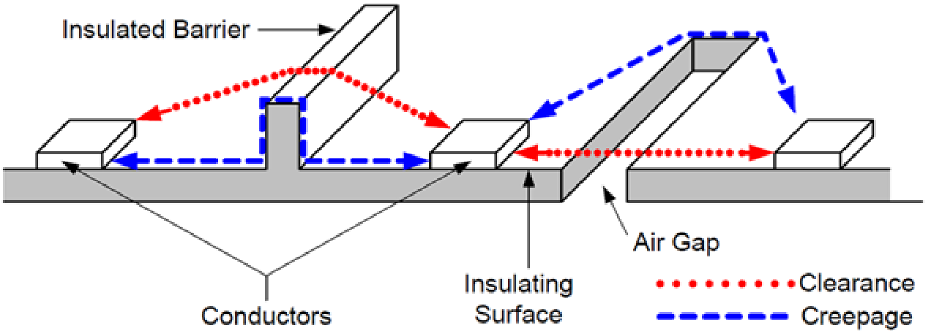
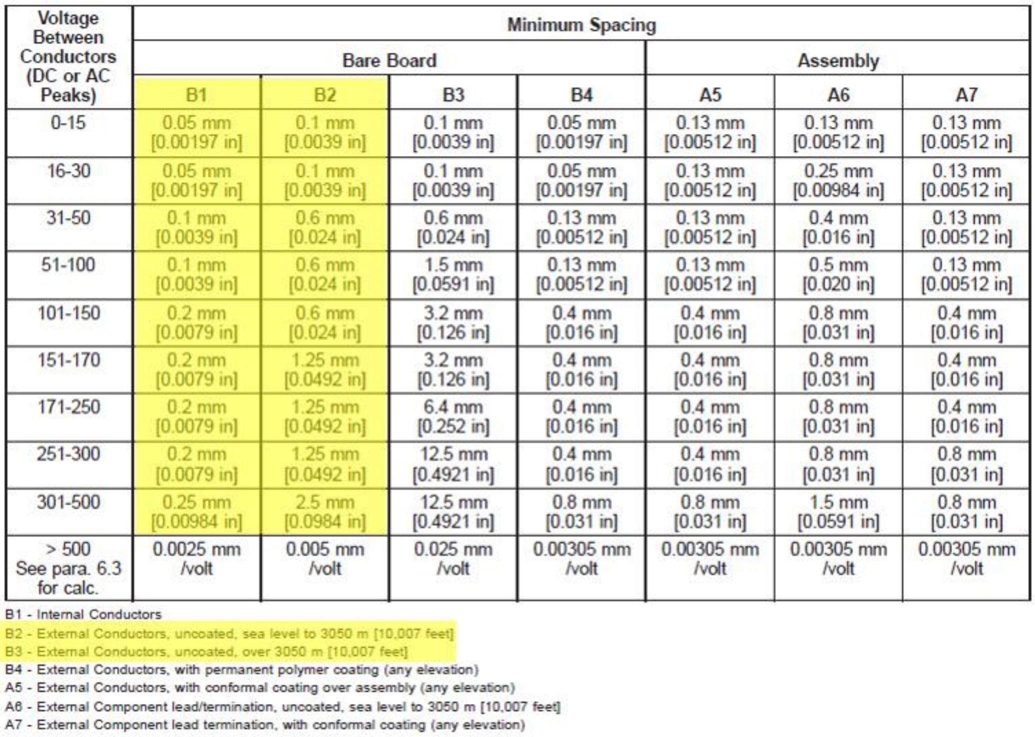


FIGURE 1 - DEFINITIONS OF CREEPAGE AND CLEARANCE [1]

While the creepage distance is dependent on the material used as an insulator (the electrical tracking breakdown properties, known as the Comparative Tracking Index, are not discussed here), the clearance distance is dependent on the medium between the two components. In typical rugged applications, this is ambient air.

One might assume that as air density decreases with increasing altitude, there would be a decrease in air conductance, because there are less air particles, and thus less media for charge carriers to travel in. However the conductor spacing requirements in VITA-51.4 (derived from IPC222A) show that as altitude increases so must the clearance, see Figure 2.



Voltage Between Conductors (DC or AC Peaks)	Minimum Spacing						
	Bare Board				Assembly		
	B1	B2	B3	B4	A5	A6	A7
0-15	0.05 mm [0.00197 in]	0.1 mm [0.0039 in]	0.1 mm [0.0039 in]	0.05 mm [0.00197 in]	0.13 mm [0.00512 in]	0.13 mm [0.00512 in]	0.13 mm [0.00512 in]
16-30	0.05 mm [0.00197 in]	0.1 mm [0.0039 in]	0.1 mm [0.0039 in]	0.05 mm [0.00197 in]	0.13 mm [0.00512 in]	0.25 mm [0.00984 in]	0.13 mm [0.00512 in]
31-50	0.1 mm [0.0039 in]	0.6 mm [0.024 in]	0.6 mm [0.024 in]	0.13 mm [0.00512 in]	0.13 mm [0.00512 in]	0.4 mm [0.016 in]	0.13 mm [0.00512 in]
51-100	0.1 mm [0.0039 in]	0.6 mm [0.024 in]	1.5 mm [0.0591 in]	0.13 mm [0.00512 in]	0.13 mm [0.00512 in]	0.5 mm [0.020 in]	0.13 mm [0.00512 in]
101-150	0.2 mm [0.0079 in]	0.6 mm [0.024 in]	3.2 mm [0.126 in]	0.4 mm [0.016 in]	0.4 mm [0.016 in]	0.8 mm [0.031 in]	0.4 mm [0.016 in]
151-170	0.2 mm [0.0079 in]	1.25 mm [0.0492 in]	3.2 mm [0.126 in]	0.4 mm [0.016 in]	0.4 mm [0.016 in]	0.8 mm [0.031 in]	0.4 mm [0.016 in]
171-250	0.2 mm [0.0079 in]	1.25 mm [0.0492 in]	6.4 mm [0.252 in]	0.4 mm [0.016 in]	0.4 mm [0.016 in]	0.8 mm [0.031 in]	0.4 mm [0.016 in]
251-300	0.2 mm [0.0079 in]	1.25 mm [0.0492 in]	12.5 mm [0.4921 in]	0.4 mm [0.016 in]	0.4 mm [0.016 in]	0.8 mm [0.031 in]	0.8 mm [0.031 in]
301-500	0.25 mm [0.00984 in]	2.5 mm [0.0984 in]	12.5 mm [0.4921 in]	0.8 mm [0.031 in]	0.8 mm [0.031 in]	1.5 mm [0.0591 in]	0.8 mm [0.031 in]
> 500 See para. 6.3 for calc.	0.0025 mm /volt	0.005 mm /volt	0.025 mm /volt	0.00305 mm /volt	0.00305 mm /volt	0.00305 mm /volt	0.00305 mm /volt

B1 - Internal Conductors
B2 - External Conductors, uncoated, sea level to 3050 m [10,007 feet]
B3 - External Conductors, uncoated, over 3050 m [10,007 feet]
B4 - External Conductors, with permanent polymer coating (any elevation)
A5 - External Conductors, with conformal coating over assembly (any elevation)
A6 - External Component lead/termination, uncoated, sea level to 3050 m [10,007 feet]
A7 - External Component lead termination, with conformal coating (any elevation)

FIGURE 2 - IPC222A SPACING TABLE SHOWING INCREASE IN REQUIRED GAP SIZE FOR ALTITUDE [2]

THE PHYSICS

The physical system behind this is the ability of ionised air molecules to carry charge across the determined gap. If we assumed that a conductive element on one component acted as a simple cathode, and the grounded heat frame acted as a simple anode, we could draw a plate electrode system as in Figure 3.

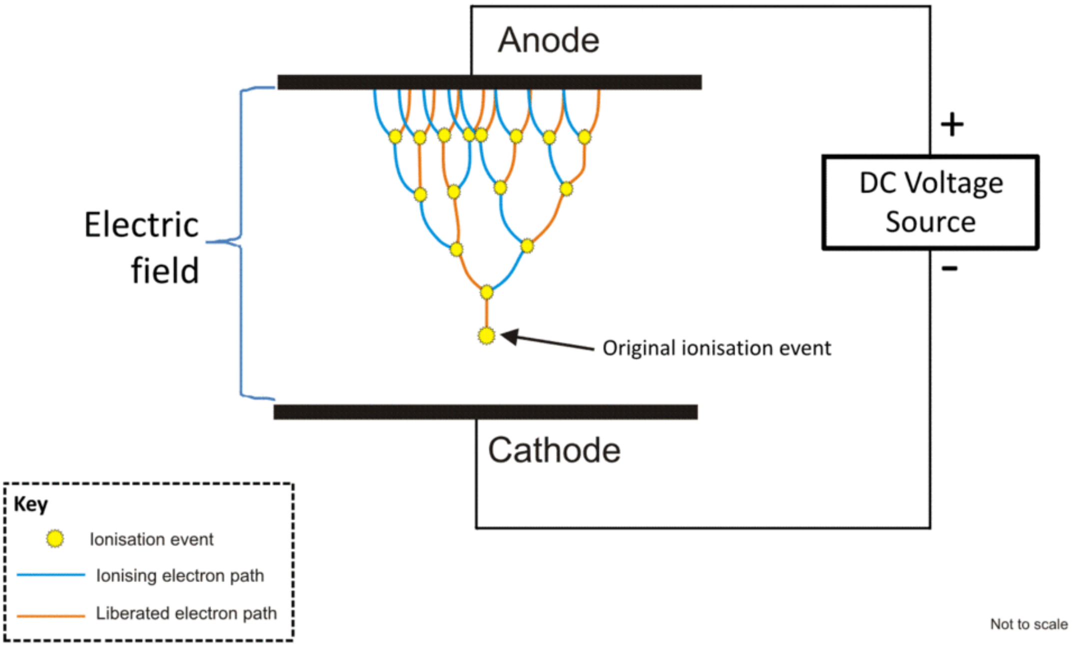


FIGURE 3 - IONISATION EVENT OF AIR BETWEEN TWO ELECTRODES

For arcing to occur between these two plates, sufficient energy will be needed to ionise an air molecule close to the cathode, and for this excited electron to in turn accelerate through the electric field and ionise further air molecules. A chain reaction will then lead to an avalanche breakdown, and an arc takes place.

Simply put, if this avalanche breakdown cannot occur, then a short between components is prevented.

In order to achieve this cascade event, the air medium between the electrodes must have: a) sufficient air molecules between them in order to physically allow a chain reaction; b) a short enough distance between to ensure that energy lost during the chain reaction doesn't dissipate before reaching the anode.

Logically, these two requirements are contradictory and their relationship is defined by Paschen's Law. This law states that the breakdown voltage required to start an electric arc between two electrodes in a gas is a function of pressure, *p*, and gap length, *d*, and can be determined by the curve in Figure 4.

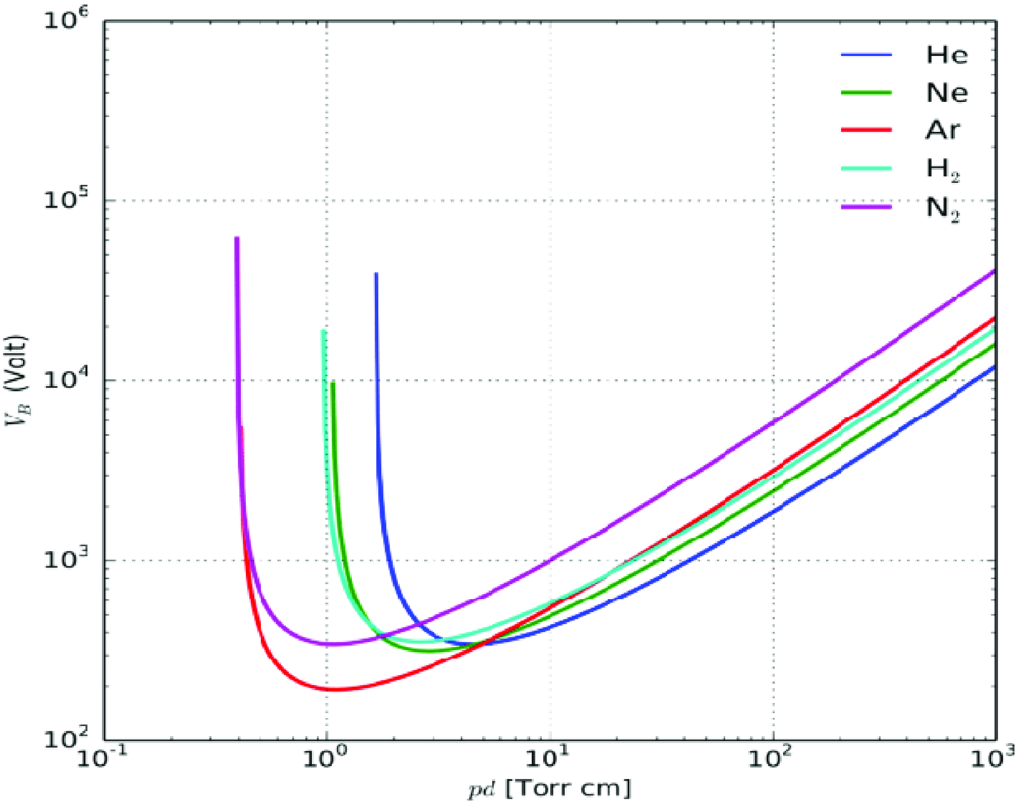


FIGURE 4 - PASCHEN'S CURVE [3]

For an extremely low gap size or low pressure, there will simply not be sufficient molecules to create an avalanche event and so risk of arcing is lowered. A much greater voltage will be needed to ensure ionisation of enough molecules to start an avalanche, if possible at all.

For high gap size or high pressure, more energy is needed to travel the large distance between the plates, or to provide the free electrons with enough energy to overcome the losses from collisions with many different molecules as it travels from cathode to electrode. Each of these collisions randomises the direction of travel (including backwards) and decelerates the molecule through the field.

IN SUMMARY

The designer must consider clearly the requirements to which he is designing to, and whether these are appropriate for the product. VITA-51.4 is a standardised method of determining design safety at high voltage, however if the full requirement is not necessary (for example, 500V isolation was removed from VITA-46 in 2017) then marginal mechanical gains could be achieved.

Most rugged systems designers will require a product be developed with clearance pertaining to the 60,000ft test altitude outlined in MIL-STD-810. If the end application was for a land system, or low altitude craft (ie troop carrier or helicopter) this altitude may be redundant and the design clearance can be reduced.

In a system where space is already at a premium, and increased component density is only increasing with more functionality, every opportunity helps.

REFERENCES

[1] sundberg84, “Clearance, creepage and other safety aspects in "MySensors" PCBs,” My Sensors, 27 June 2016. [Online]. Available: https://forum.mysensors.org/topic/4175/clearance-creepage-and-other-safety-aspects-in-mysensors-pcbs.

[2] IPC, “IPC-2221A Generic Standard on Printed Circuit Board Design,” IPC, Northbrook, 2003.

[3] S. Das, G. Dalei and A. Barik, “A Dielectric Barrier Discharge (DBD) Plasma Reactor: An Efficient Tool to Measure the Sustainability of Non-Thermal Plasmas through the Electrical Breakdown of Gases,” IOP Conf. Series: Materials Science and Engineering, 2018.