UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF ELECTRICAL AND INFORMATION ENGINEERING

Lightning Structural Protection:
How to do it Wrong

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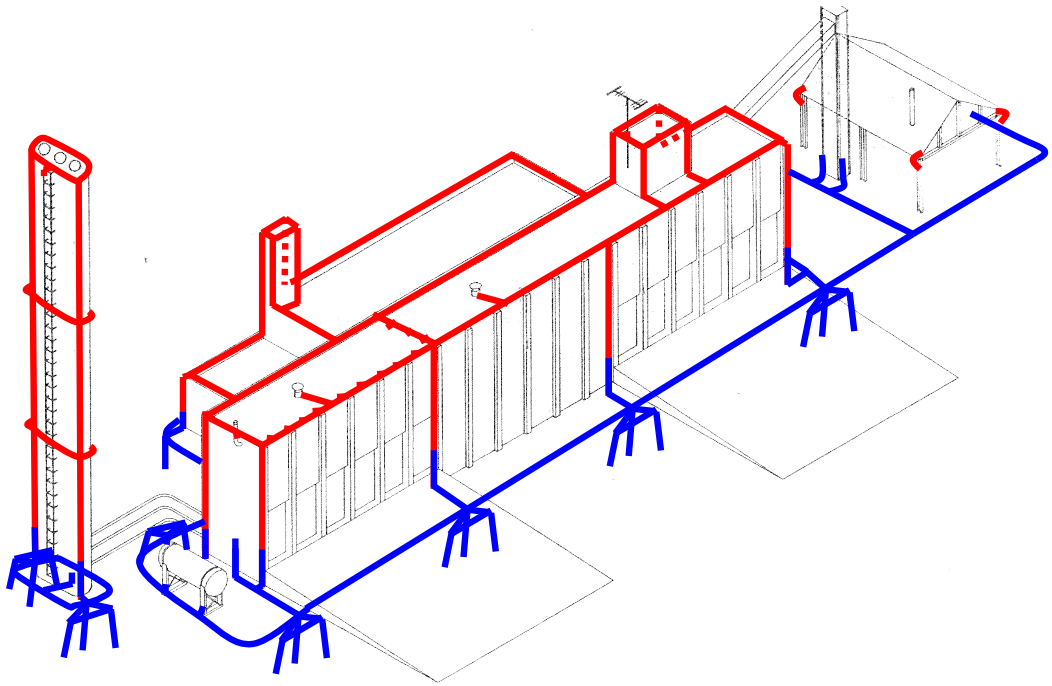
Lightning Protection

Protection of Structures

Protection of Equipment



A structural protection system consists of two parts

(If you do it right)

External Protection system

a) intercept a direct lightning flash to the structure - with an air-termination system

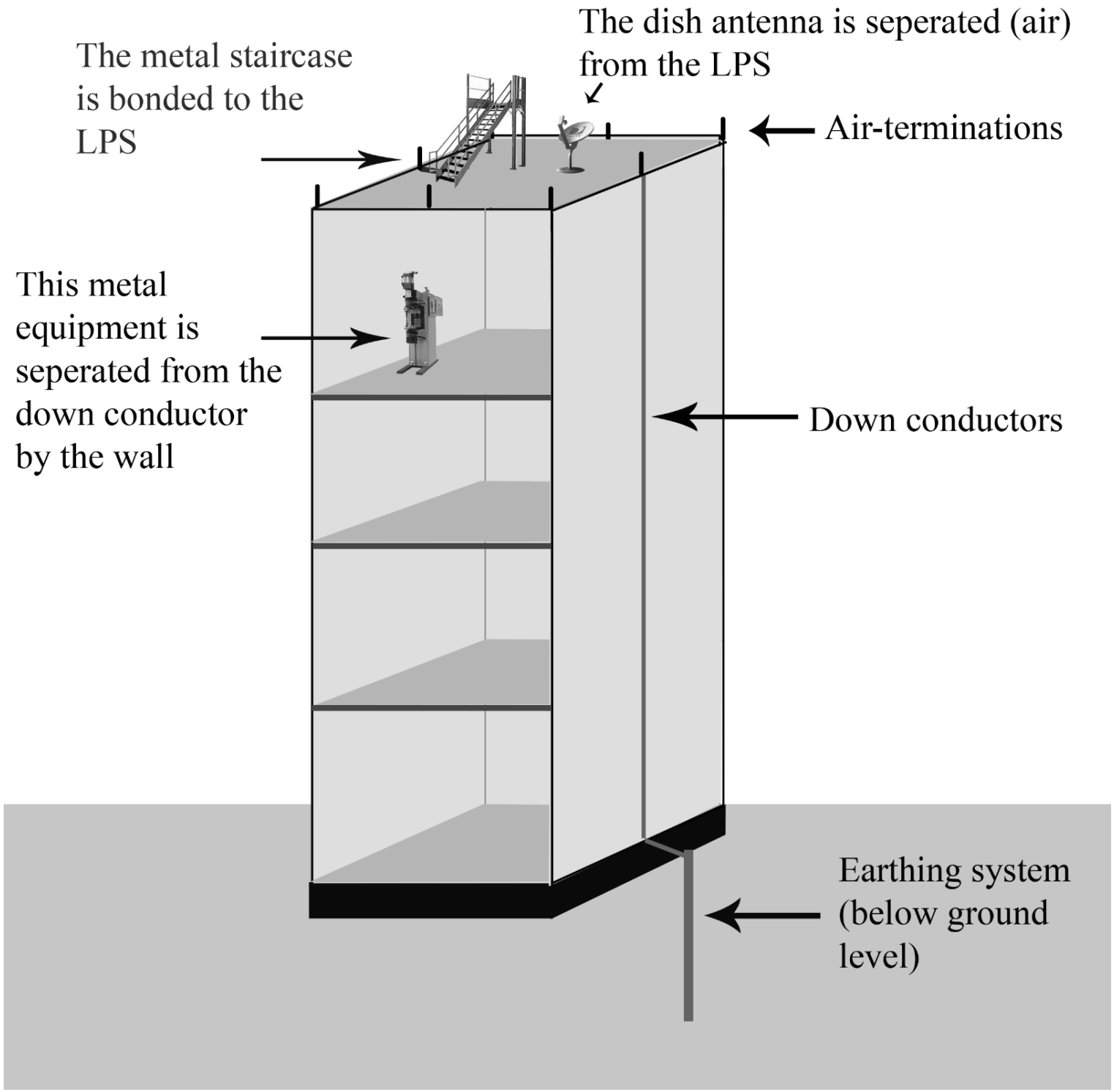
b) conduct the lightning current safely towards earth - using a down-conductor system

c) disperse the lightning current into the earth - using an earth-termination system

Internal protection system

a) prevents dangerous sparking within the structure using either equipotential bonding or a separation distance (and hence electrical insulation) between the external LPS components and other electrically conducting elements internal to the structure.

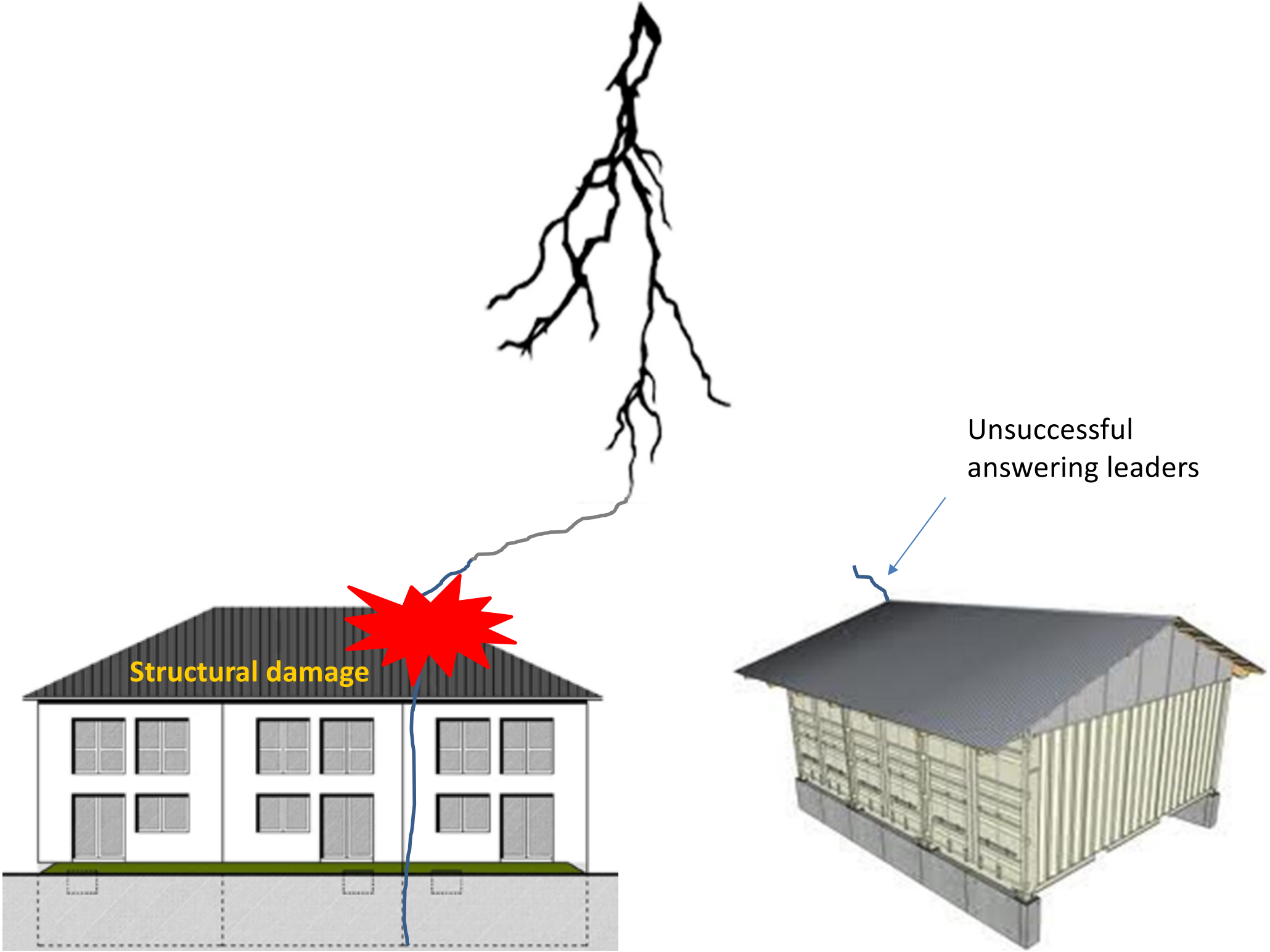
(If you do it right)

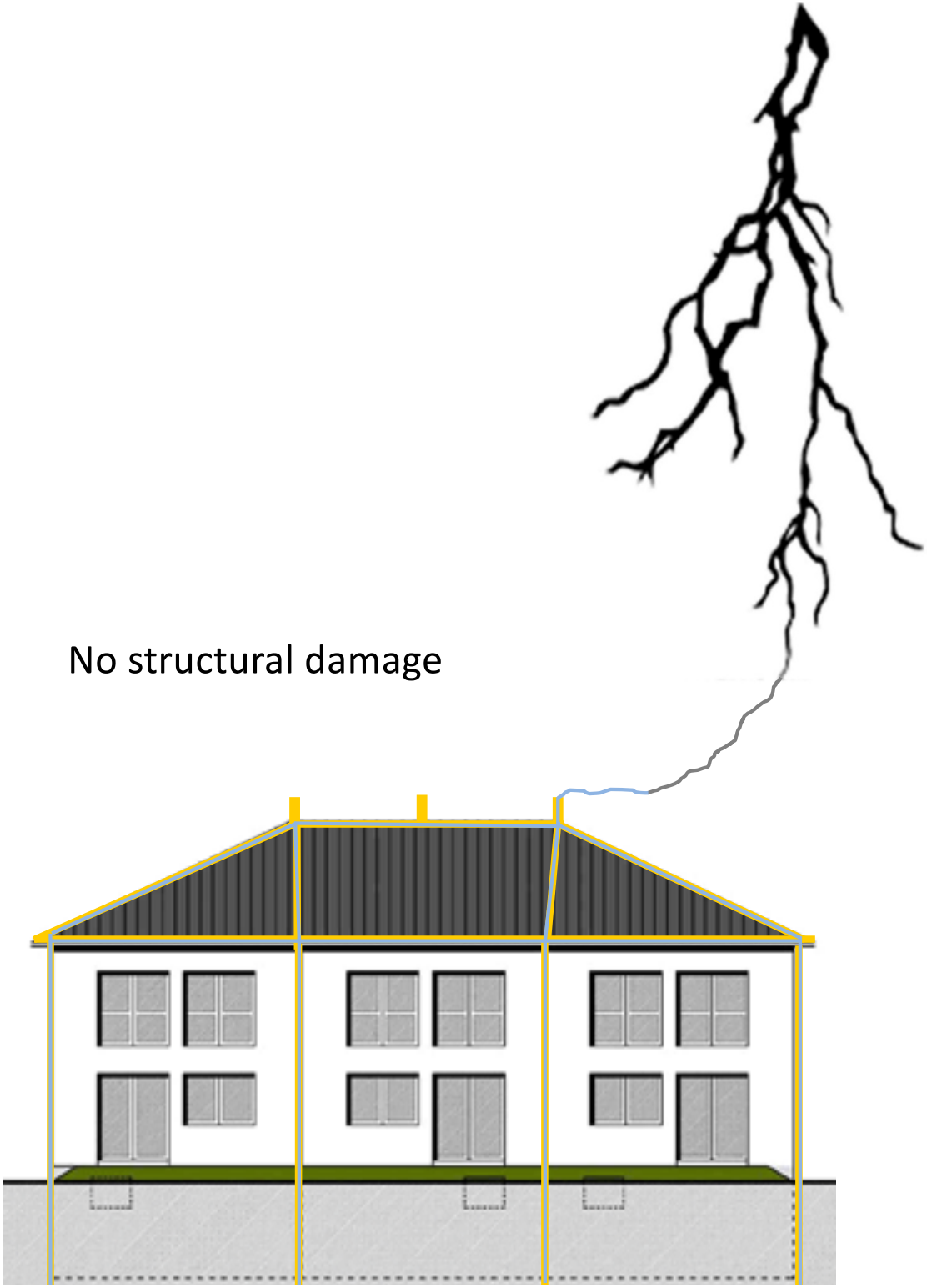


Concept of Lightning Protection

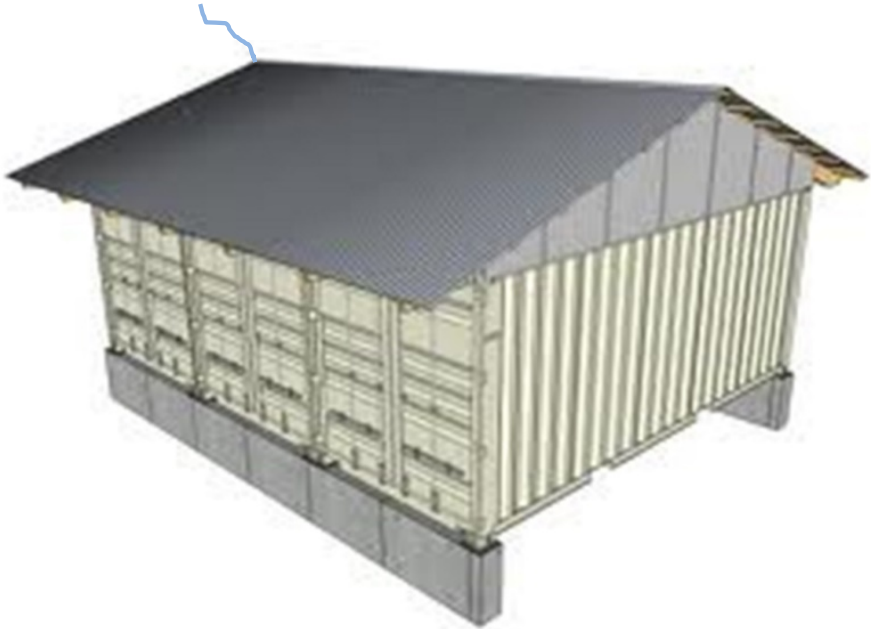
(If you do it right)

- **Interception** of downward lightning Leader with the protection system and safely passing the current into ground


Structural damage
Unsuccessful
answering leaders



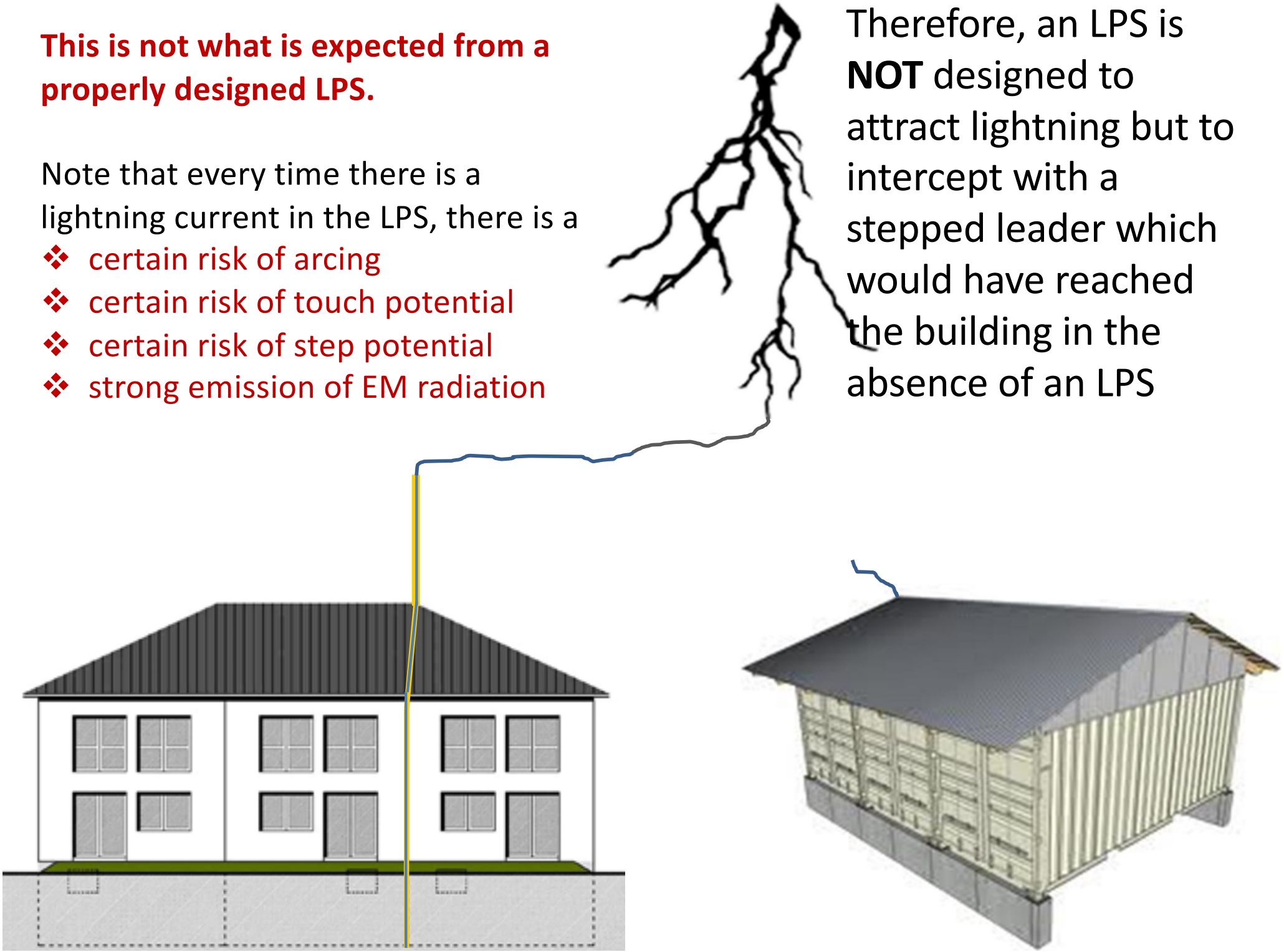
No structural damage



This is not what is expected from a properly designed LPS.

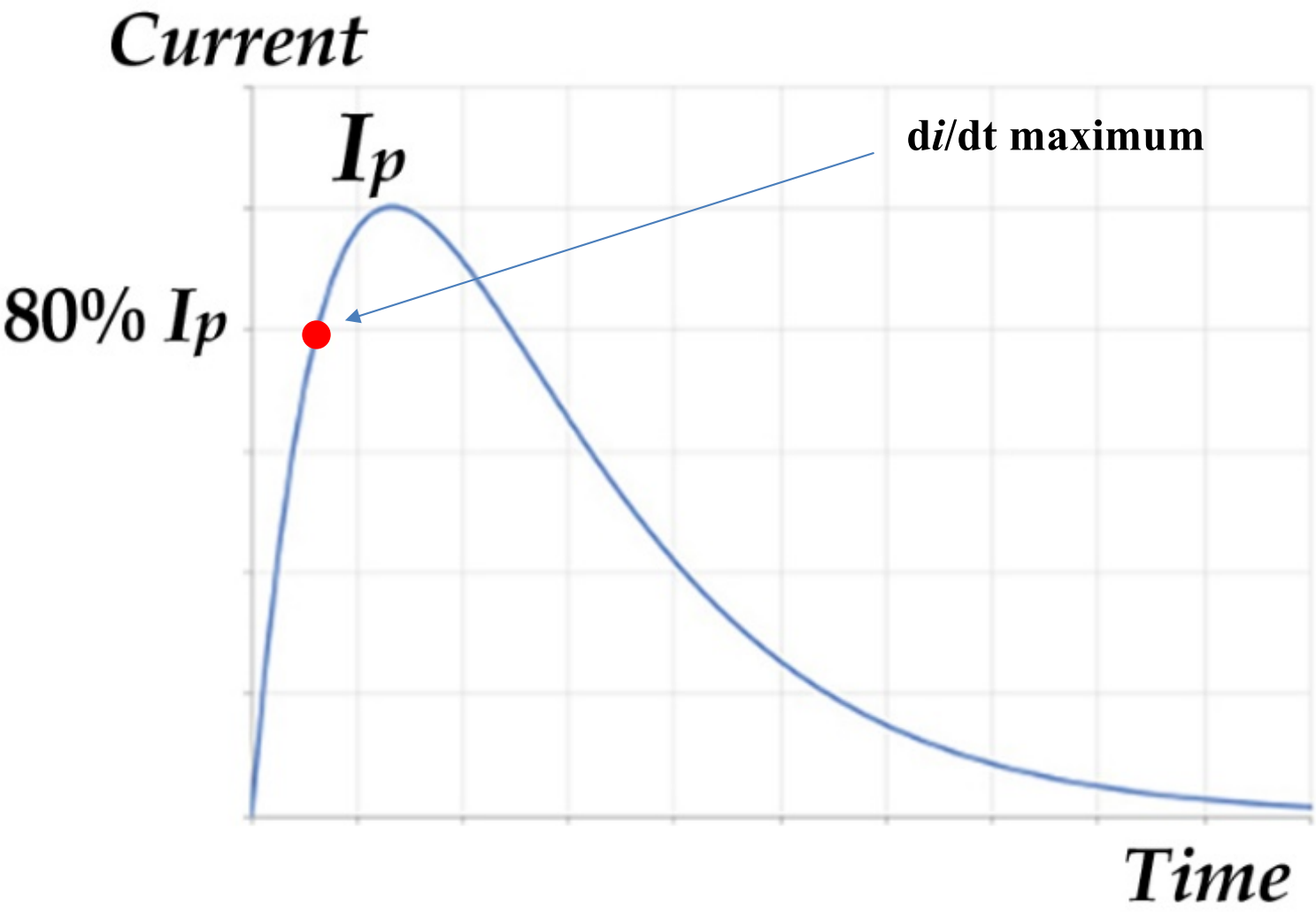
Note that every time there is a lightning current in the LPS, there is a

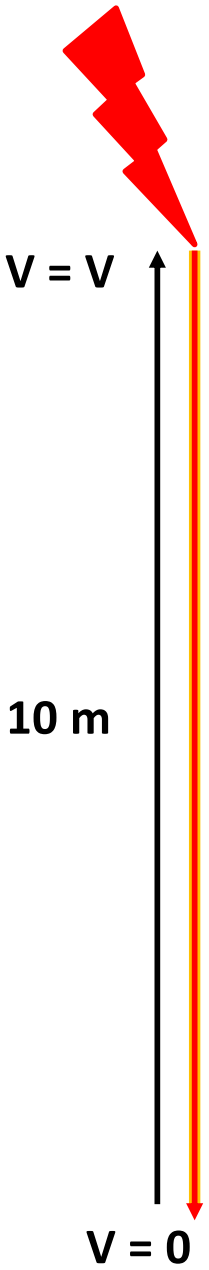
- certain risk of arcing
- certain risk of touch potential
- certain risk of step potential
- strong emission of EM radiation



Therefore, an LPS is **NOT** designed to attract lightning but to intercept with a stepped leader which would have reached the building in the absence of an LPS

Lightning Current





Voltage across an RL circuit due to a time varying current:

$$V = i\,R + L\,di/dt$$

Consider a bad conductor (eg. brick column)

$R = 10^5\ \Omega/m$ $\quad$ $L = 2\ \mu H/m$

Negative subsequent stroke (mean values)

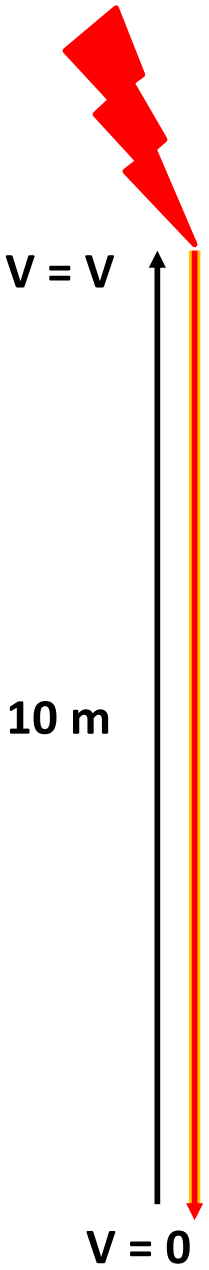
$I_p = 12$ kA $\quad$ $(di/dt)_p = 40$ kA/µs

$$V = 0.8 \times 12 \times 10^3 \times 10^5 \times 10 + 2 \times 10^{-6} \times 10 \times 40 \times 10^3/10^{-6}$$

$$V = \mathbf{9.6\ GV} + \mathbf{800\ kV}$$

Extremely high

Moderately high



Voltage across an RL circuit due to a time varying current:

$$V = i\,R + L\,di/dt$$

Consider a good conductor (eg. copper tape)

$R = 10^{-4}\ \Omega/m$ $\quad$ $L = 2\ \mu H/m$

Negative subsequent stroke (mean values)

$I_p = 12$ kA $\quad$ $(di/dt)_p = 40$ kA/µs

$$V = 0.8 \times 12 \times 10^3 \times 10^{-4} \times 10 + 2 \times 10^{-6} \times 10 \times 40 \times 10^3/10^{-6}$$

$$V = 9.6\ V + 800\ kV$$

Very low

Moderately high

Structural Protection is given under 4 Levels of Protection (Classes of Protection)

(If you do it right)

Class I or Level I : Highest level of Protection

Class II or Level II

Class III or Level III

Class IV or Level IV : Least level of protection

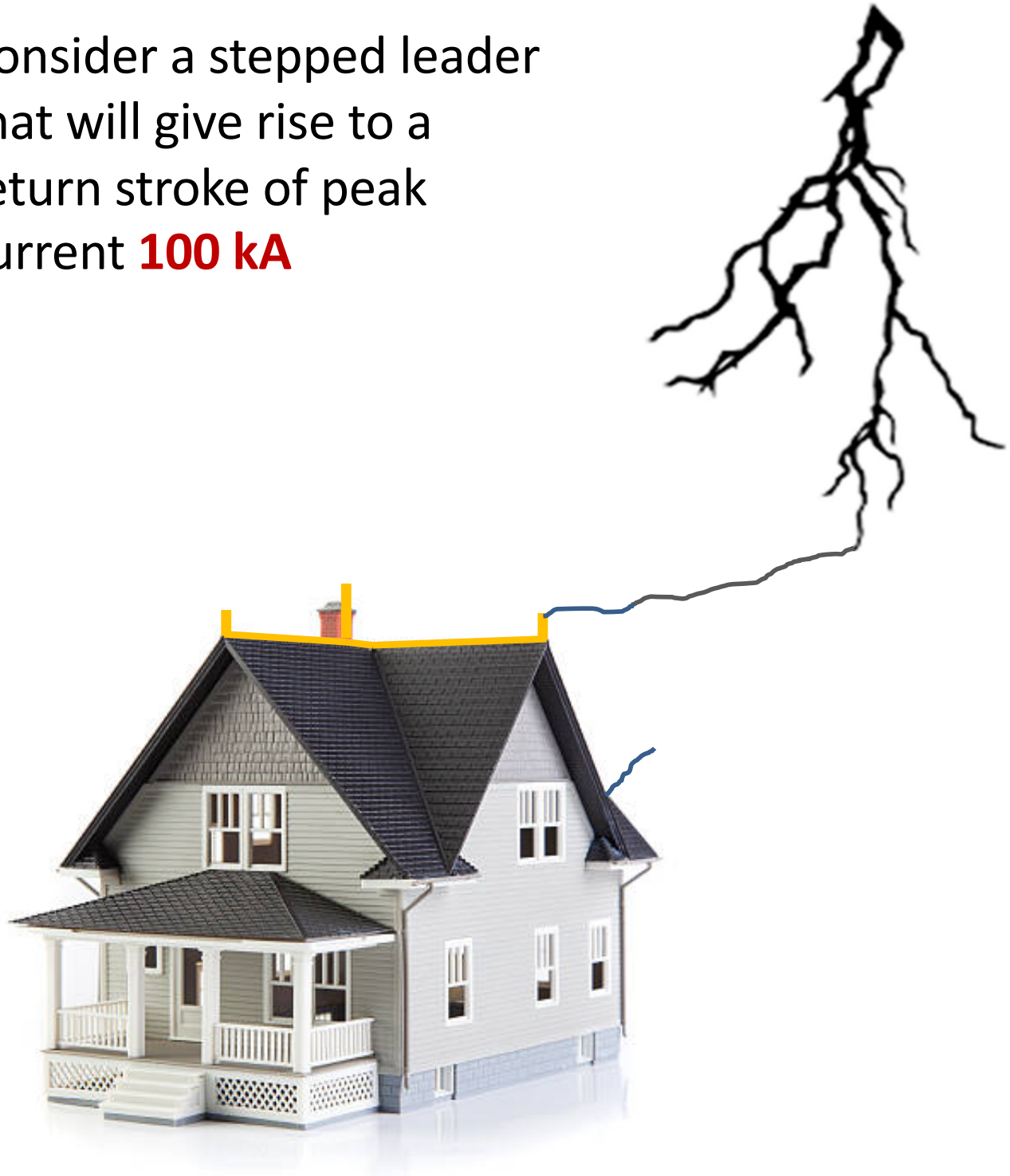
Limiting Currents (kA)	LPL			
	I	II	III	IV
Maximum	200	150	100	100
Minimum	3	5	10	16

Maximum value of current determines the withstanding capacity of the components of LPS

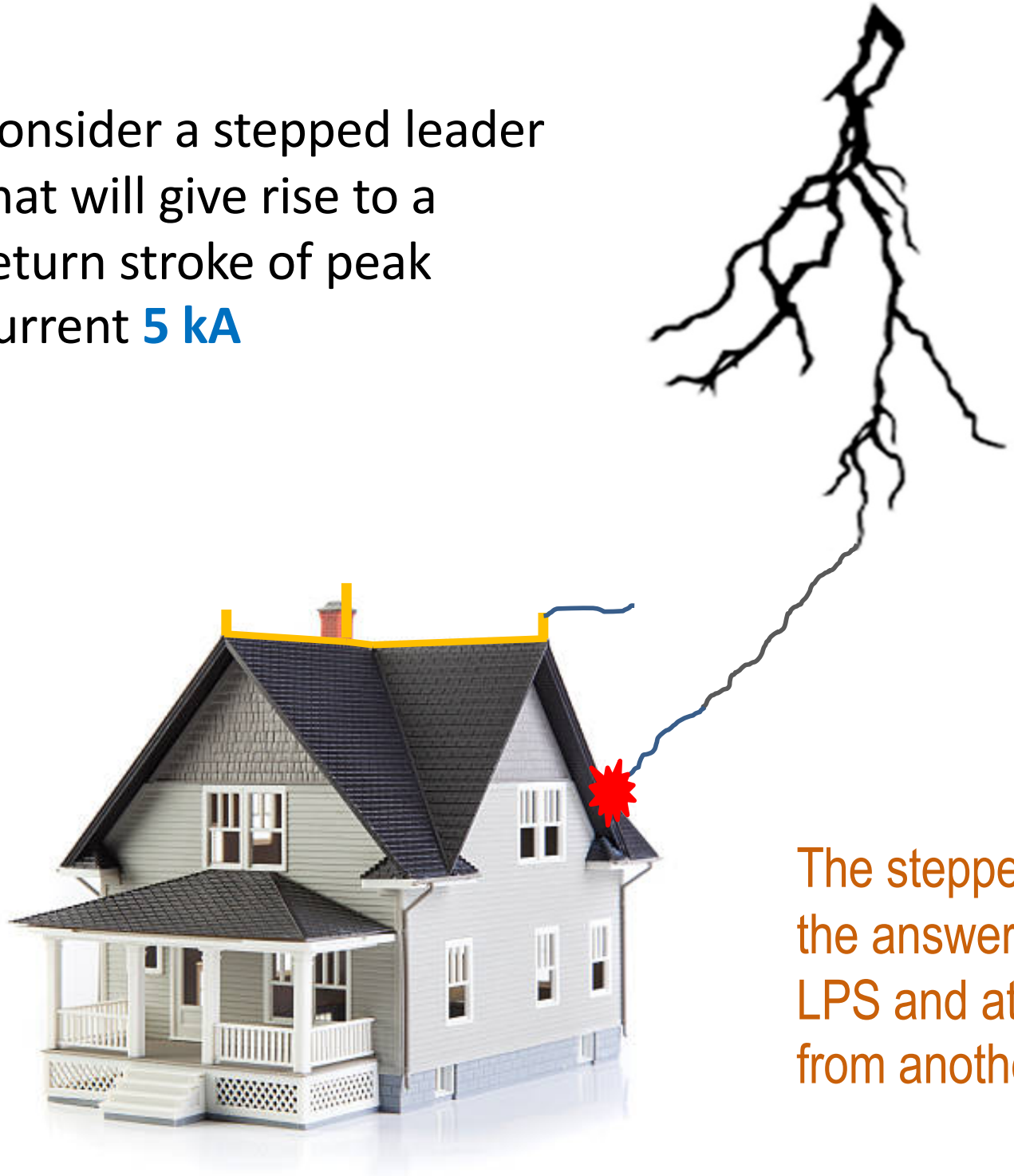
Minimum value of current determines the probability of lightning stepped leader bypassing the LPS

Probability of lightning current parameters;	LPL			
	I	II	III	IV
Smaller than the maximum value defined above	99%	98%	95%	95%
greater than the minimum value defined above	99%	97%	91%	84%

Consider a stepped leader that will give rise to a return stroke of peak current **100 kA**



Consider a stepped leader that will give rise to a return stroke of peak current **5 kA**

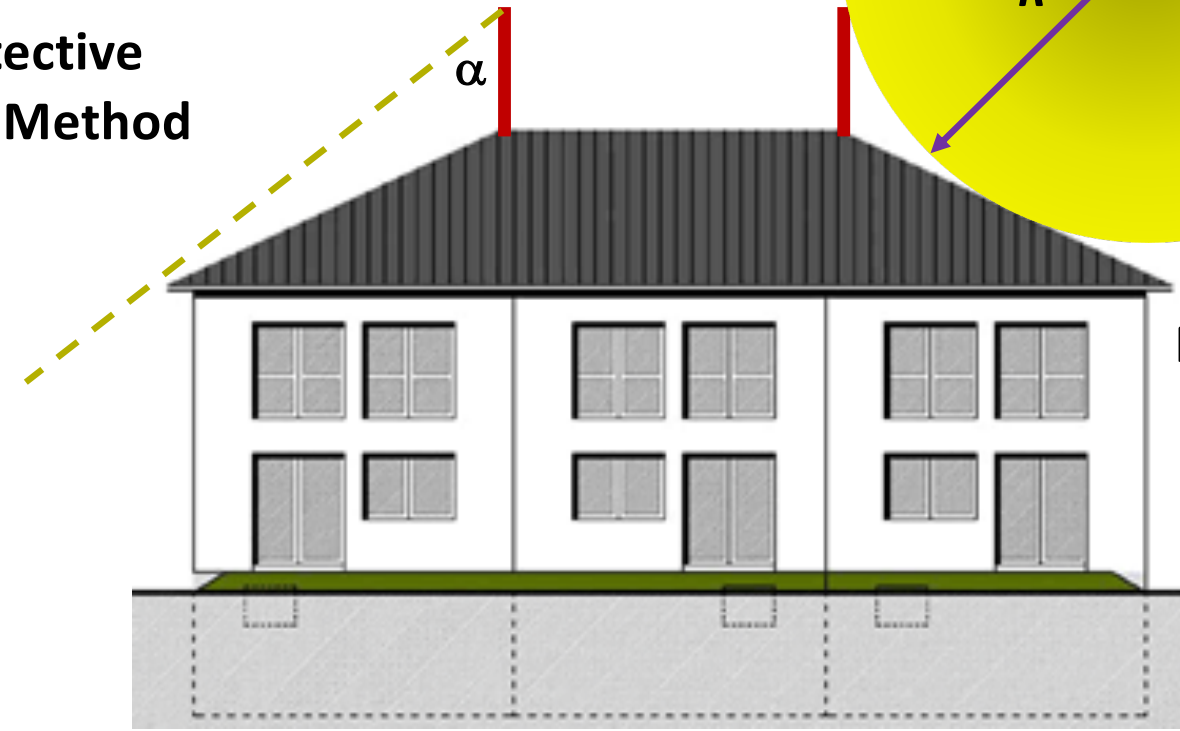


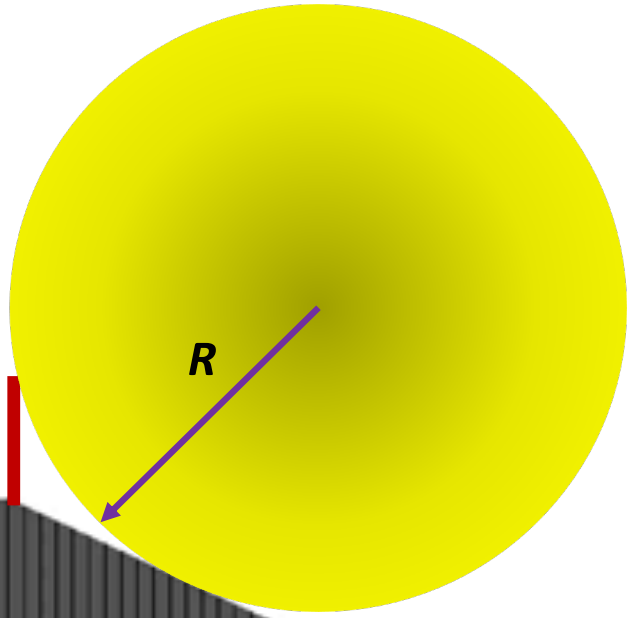
The stepped leader bypasses the answering leader from the LPS and attach with a leader from another part of the building

There are 3 ways of implementing air termination

Mesh Method

Protective Angle Method





Rolling Sphere method

Two concepts of Lightning Protection

(If you do it wrong)

- **Attraction** of downward Lightning Leader with the protection system and safely passing the current into ground

ESE Rod: A virtual height of the rod is considered

Whereas

Franklin rod: Only the physical height of the rod is considered

- Dissipation of the charge of the downward Lightning Leader or repelling of the Lightning Leader away from the protection system

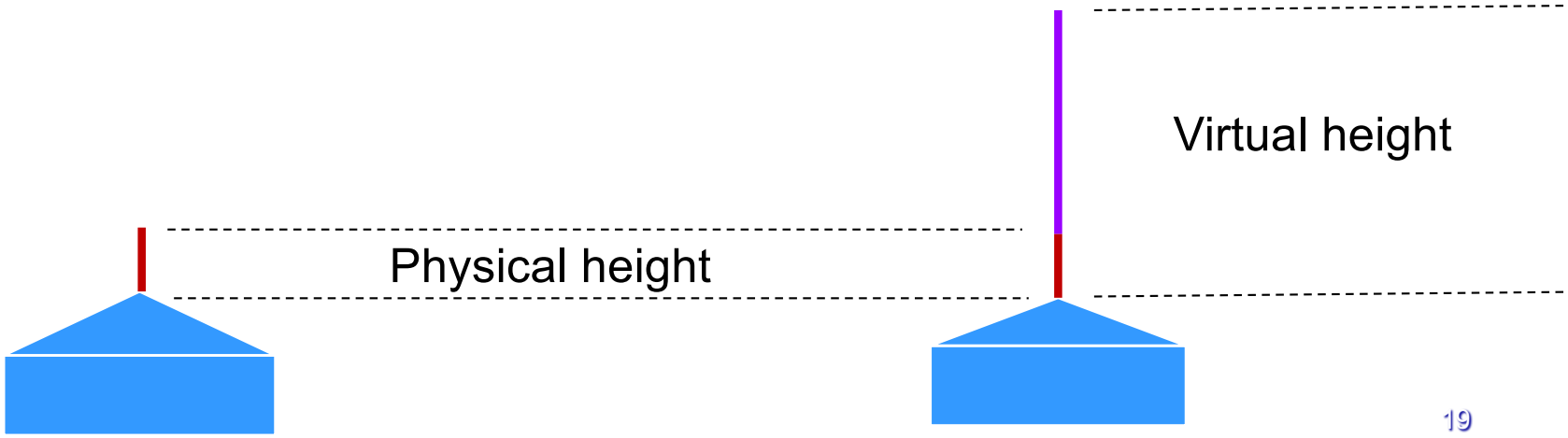
This is not accepted by any standard in the world

Attraction of Lightning Leader – ESE Technology

The inventors attributed the early initiation of the answering leader (rather streamer) of ESE rod to a greater virtual height of the rod

Franklin Rod : Only the physical height of the rod is considered

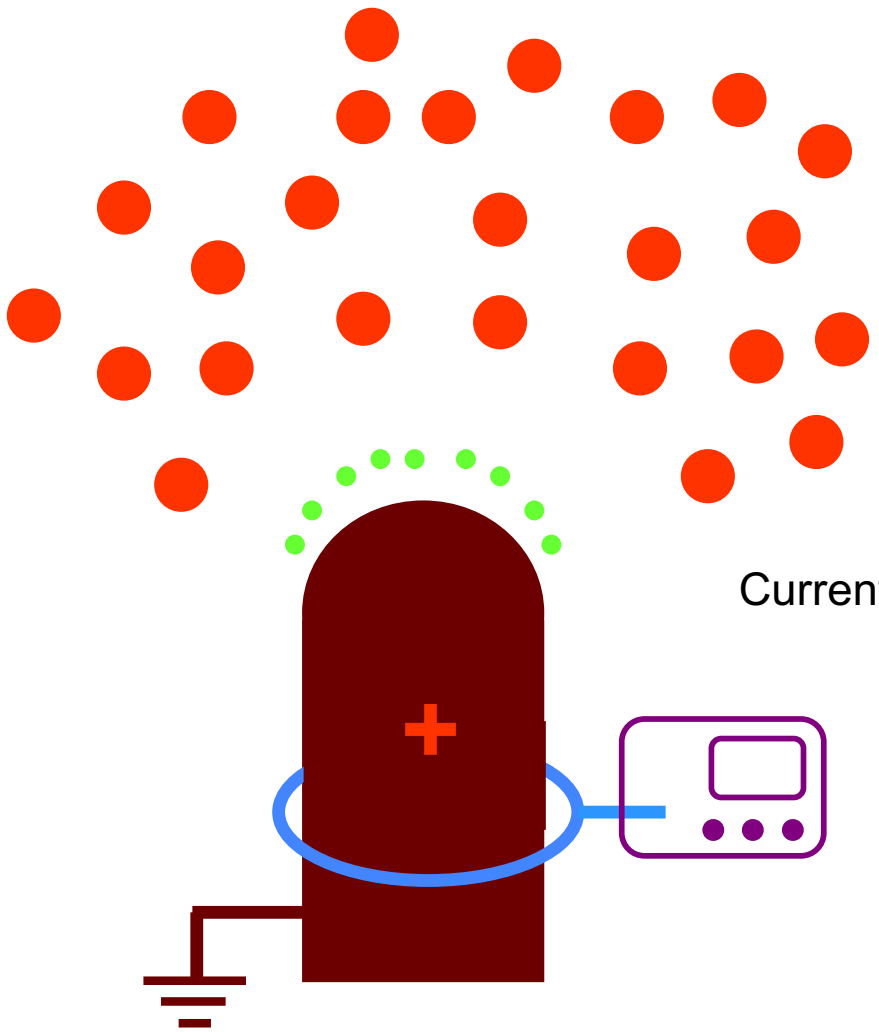
Early Streamer Emitters (ESE): An effective height is considered



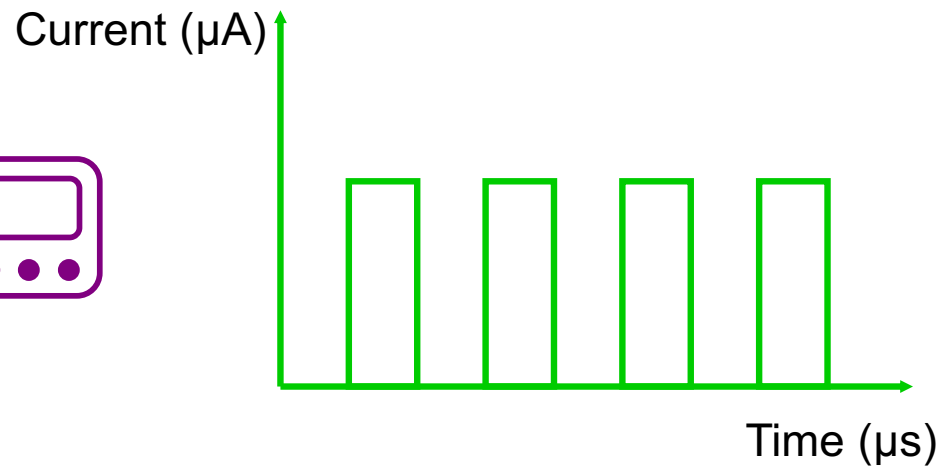
Argument:

In the presence of an enhanced negative electric field, space charges form around the electrode

The space charge leaves behind electrons that will flow into ground



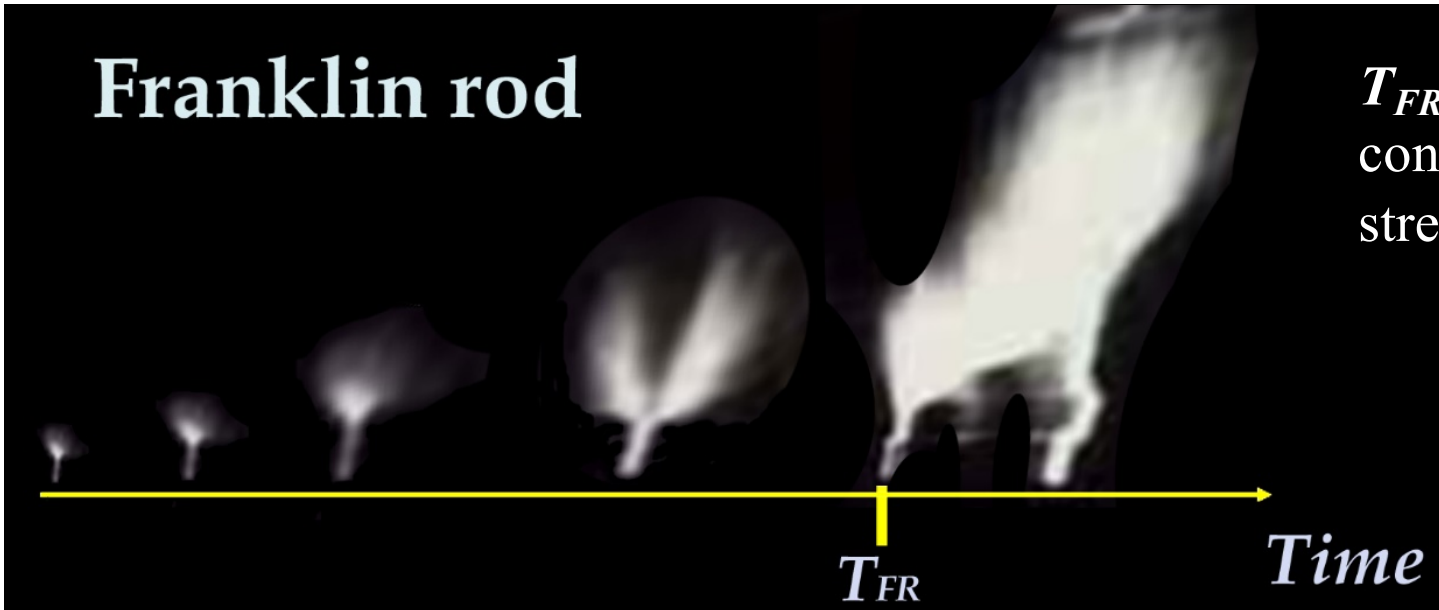
- *The inrush of electrons gives rise to a current pulse in the electrode*
- *The current stops when the space charge fully shields the electrode*
- *After sometime the space charge disappears and another current pulse will be observed*



- It is argued that this delay slows down the streamer initiation process

- The ESE designers claims that they have developed techniques to prevent this space charge accumulation around the electrode, thus the self-propagating streamer is initiated much earlier.

- The term "Early Streamer" comes with this concept



T_{FR} : Time of initiation of continuous propagation of streamer in Franklin rod

T_{ESE} : Time of initiation of continuous propagation of streamer in Franklin rod

Computation of length advantage

$\Delta T = T_{FR} - T_{ESE}$

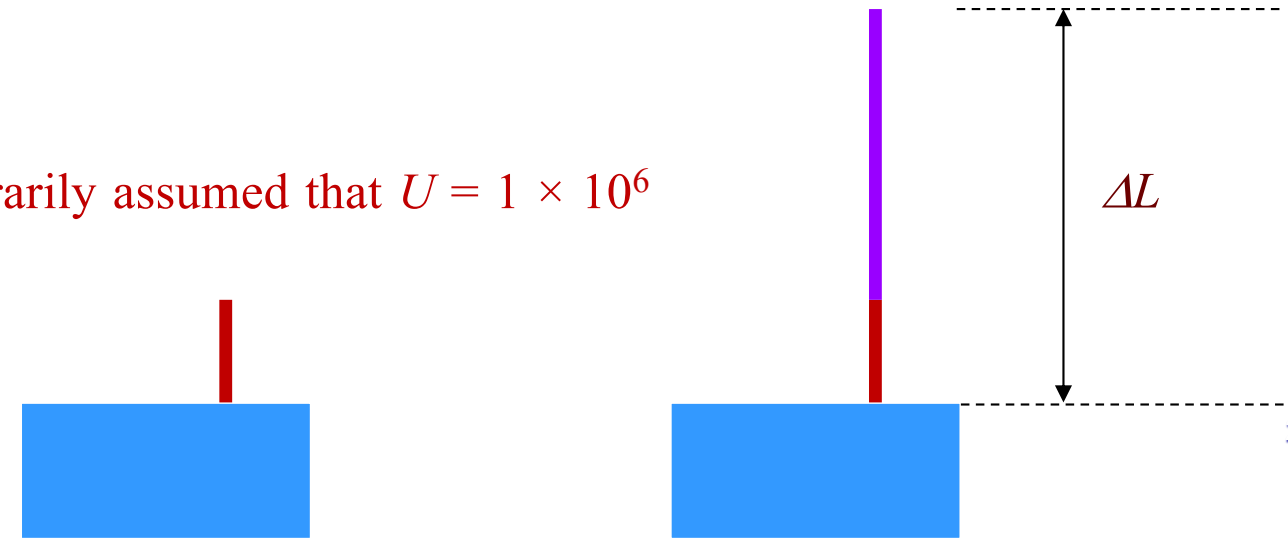
Where ΔT is termed the time advantage of ESE system

Let the streamer velocity be U

Let ΔL be the gain in height of the rod (Length advantage)

Then $\Delta L = \Delta T \times U$

The ESE vendors arbitrarily assumed that $U = 1 \times 10^6$



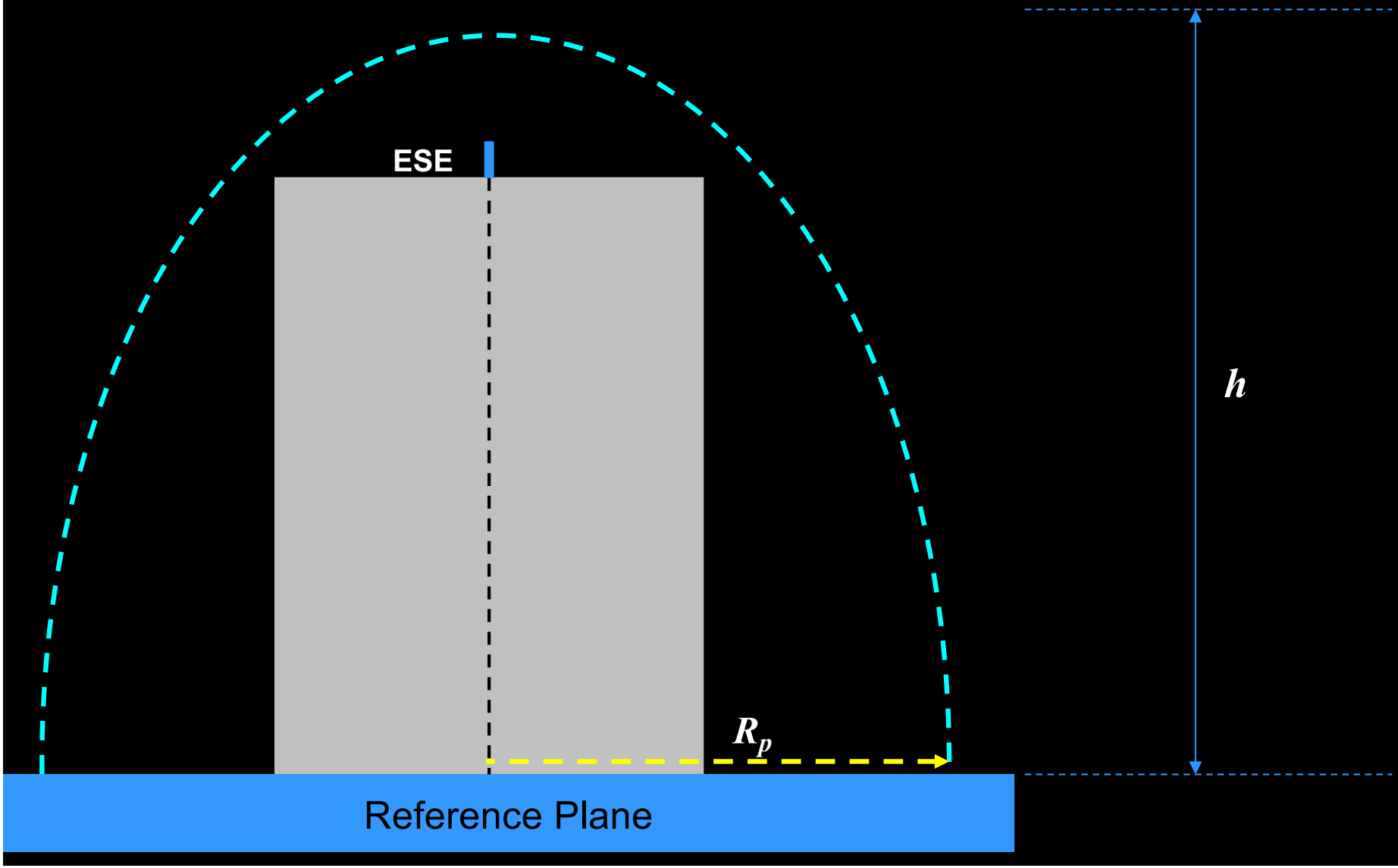
D : Striking distance given by $D = 10 \times I^{2/3}$

I: Peak first return stroke current in kA

h: ESE tip-height above the reference plane

R_p: Radius of Protection at reference plane

$$R_p = \sqrt{h(2D - h) + \Delta L(2D + \Delta L)}$$



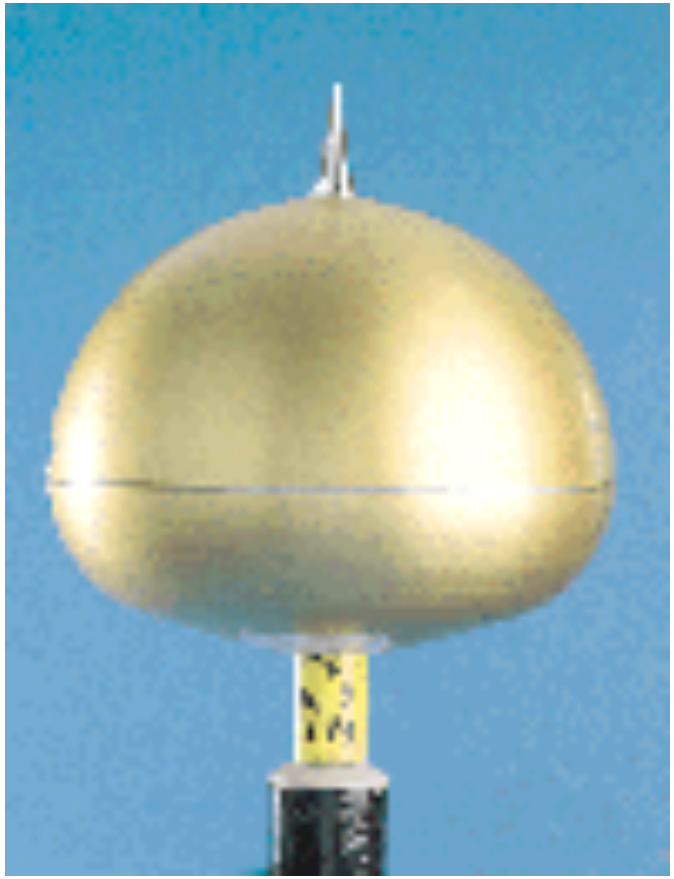
The Origin of the Concept of ESE

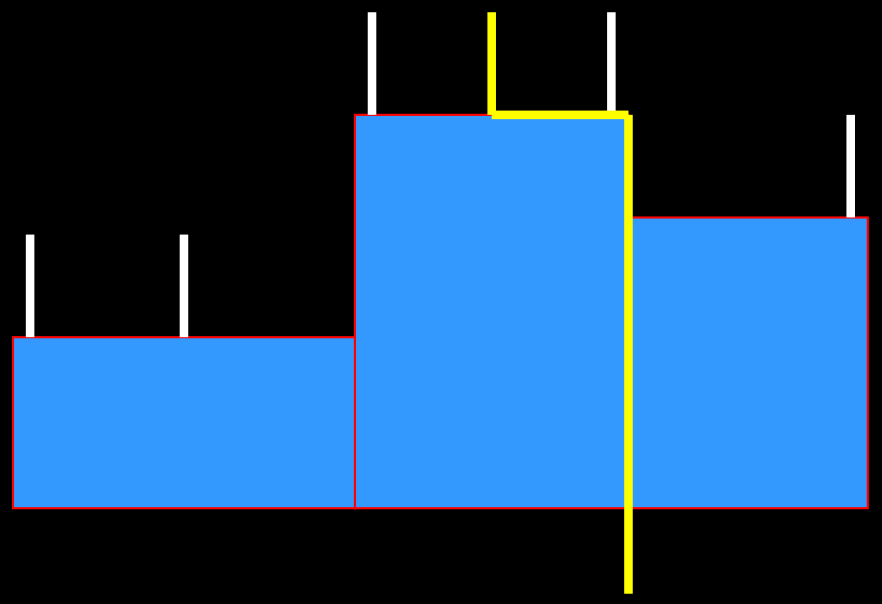
- In the early 70s due to the rapid increase in copper price prompted several scientists to look for an alternative method of protecting structures that could reduce the amount of metal used in the LPS.

- By that time there were several industries that produced an air-termination with a piece of radioactive material such as Americium (Am-241), Caesium (Cs-137), Polonium (Po-210) etc., placed in a small container located at the air terminal which claimed to be enhancing the emission of the upward streamer that intercept with the stepped leader.

- As the streamer inception from these radioactive air-termination occurs earlier than that from an ordinary metal rod of similar dimensions placed at the same location, this system is termed Early Streamer Emission (ESE) air-terminations.

- Later radioactive type ESEs were banned in many countries due to health risk.
- Then various technologies were surfaced.
- The products differ from each other by the secret mechanism that they do not reveal fully, in controlling the streamer initiation
  - Radioactive sources
  - Electronic device that injects voltage pulses
  - Piezo-electric device that generate voltage pulses
  - Complex electrode system that acts as a switch
  - Electric field modified by the shape of the tip





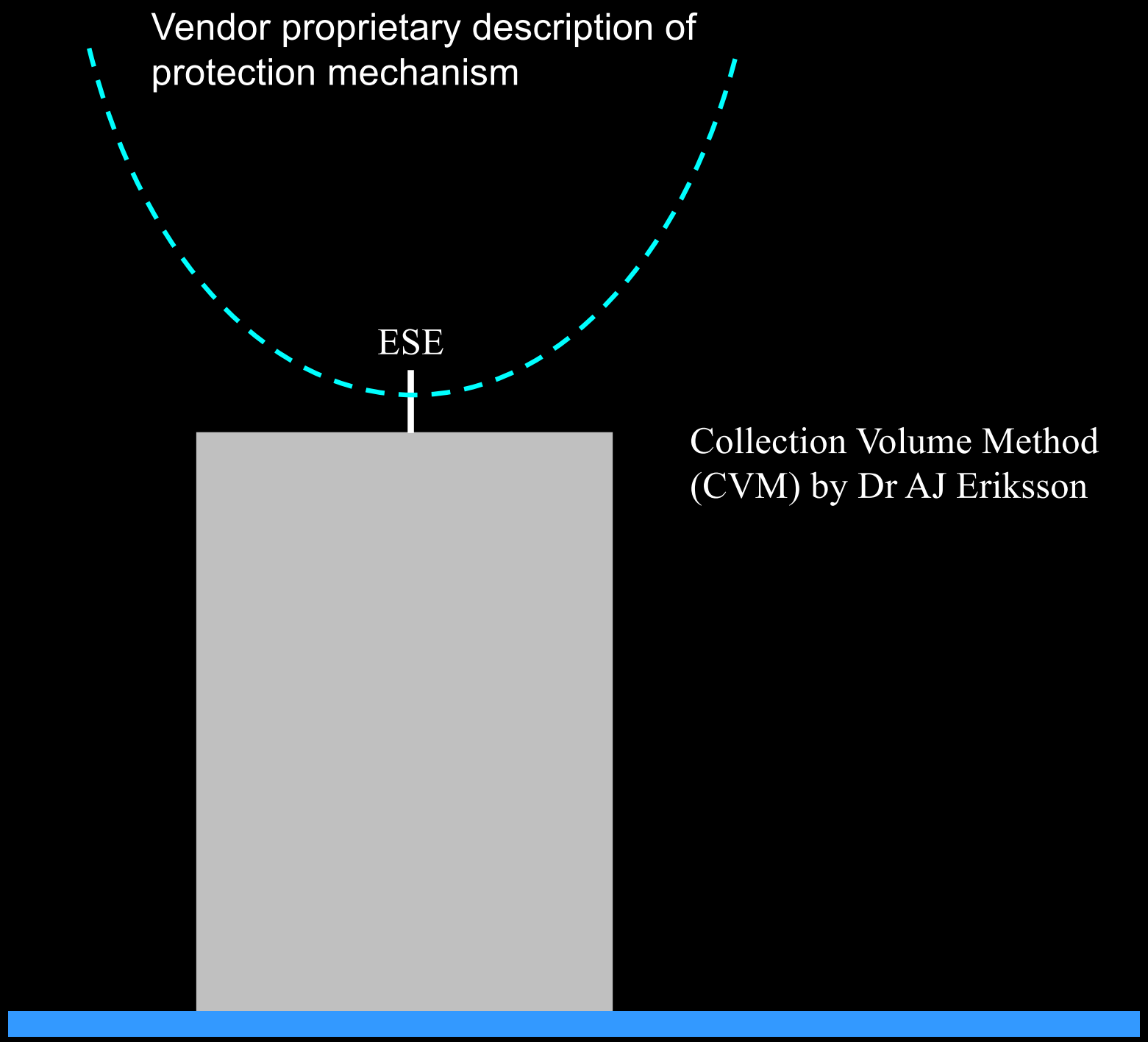
Typically, the ESE rod is installed in the middle of the building to have the maximum gain in coverage

Due to its enhanced streamer initiation capability, ESE manufacturers prescribe a much smaller number of rods to a given building than that is formulated in many international and national standards

- Whereas many national and international standards refused to recommend this so called new technology, citing that there are no theoretical, experimental or statistical proof to justify the claimed height advantage, in 1995 French Standard NF C 17-102 was established.

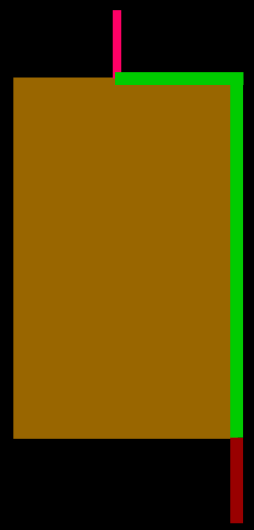
- Spain followed soon establishing a standard for ESE technology coded UNE21186

- Both standards were updated in 2011.



Collection Volume Method (CVM) by Dr AJ Eriksson

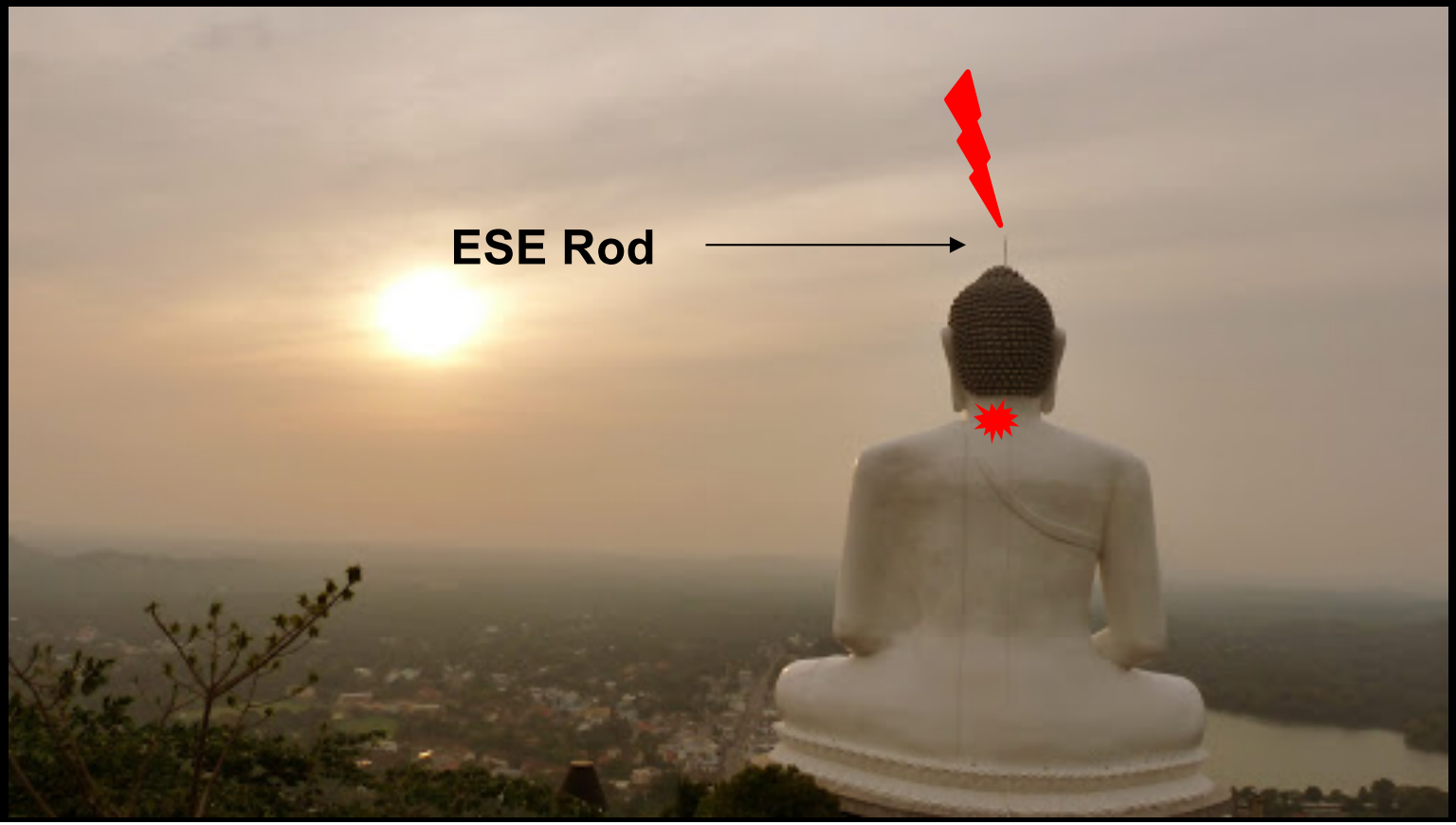
Issue No 1



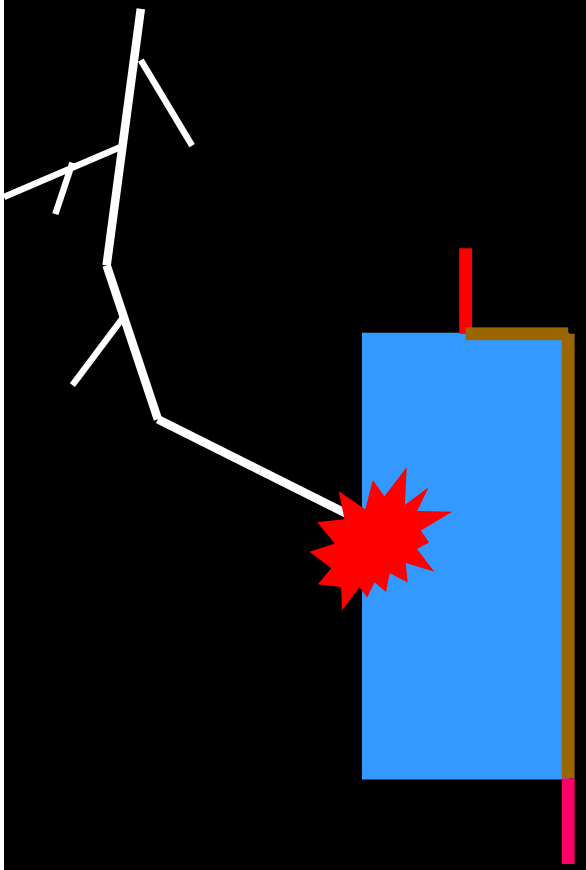
- Let's assume that French Standard is correct, for the time being
- Consider a 20m tall building which is protected by a single ESE device grounded through a single down conductor (A common practice in ESE technology for buildings below height 20 m)
- Typical copper strips used for down conductors have an inductance in the range of 2 **μH/m**. Considering a typical peak lightning current derivative of 50 kA/ **μs** we obtain a potential of about 2 MV close to the top of the building
- Thus, in between the LPS and any grounded object such as part of the reinforcement steel there will be a potential difference of few Mega Volts

Issue No 1

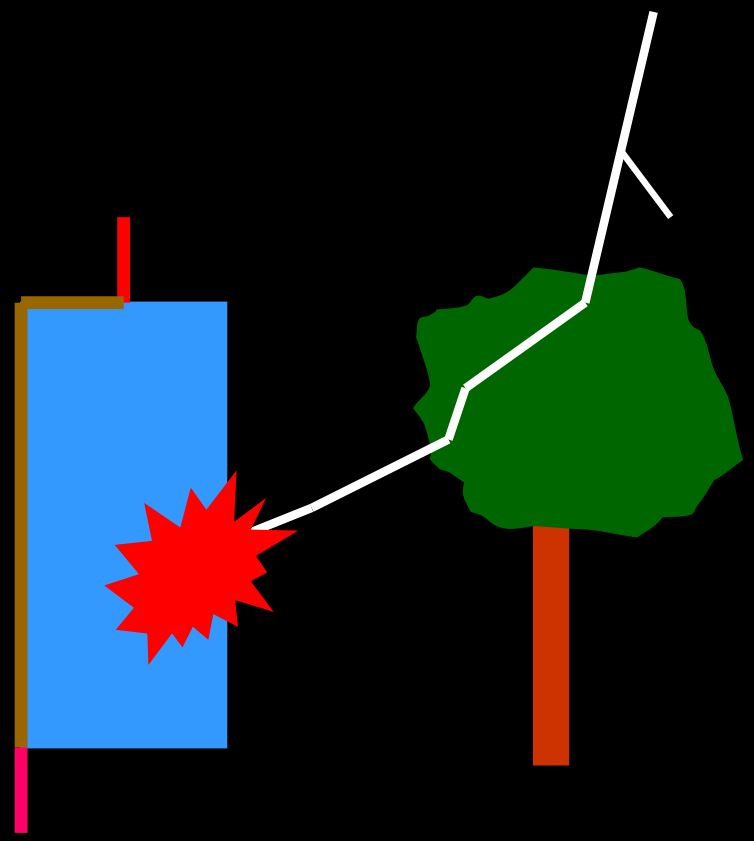
In plain words, even if the air-termination attracts the stepped leader, the building will be damaged due to the arcing of the lightning current from the LPS into other parts of the structure.



Issue No 2



A stepped leader that will produce a low return stroke peak current may by-pass the air termination and hit the side of the building where there are no down conductors



A side flash from a lightning that strikes a nearby object may jump into the side of the building where there are no down conductors

Issue No 3

ESE rods are highly expensive

Note that ESE concept is not a superior Lightning protection technique than the conventional method prescribed in standards

It's sole purpose is to reduce the cost of material which is usually high in the methods specified in the standards

Thus if the cost of installation of ESE system is higher than that of the conventional system, then the primary objective of introducing ESE technology is lost

Now we will come back to our assumption

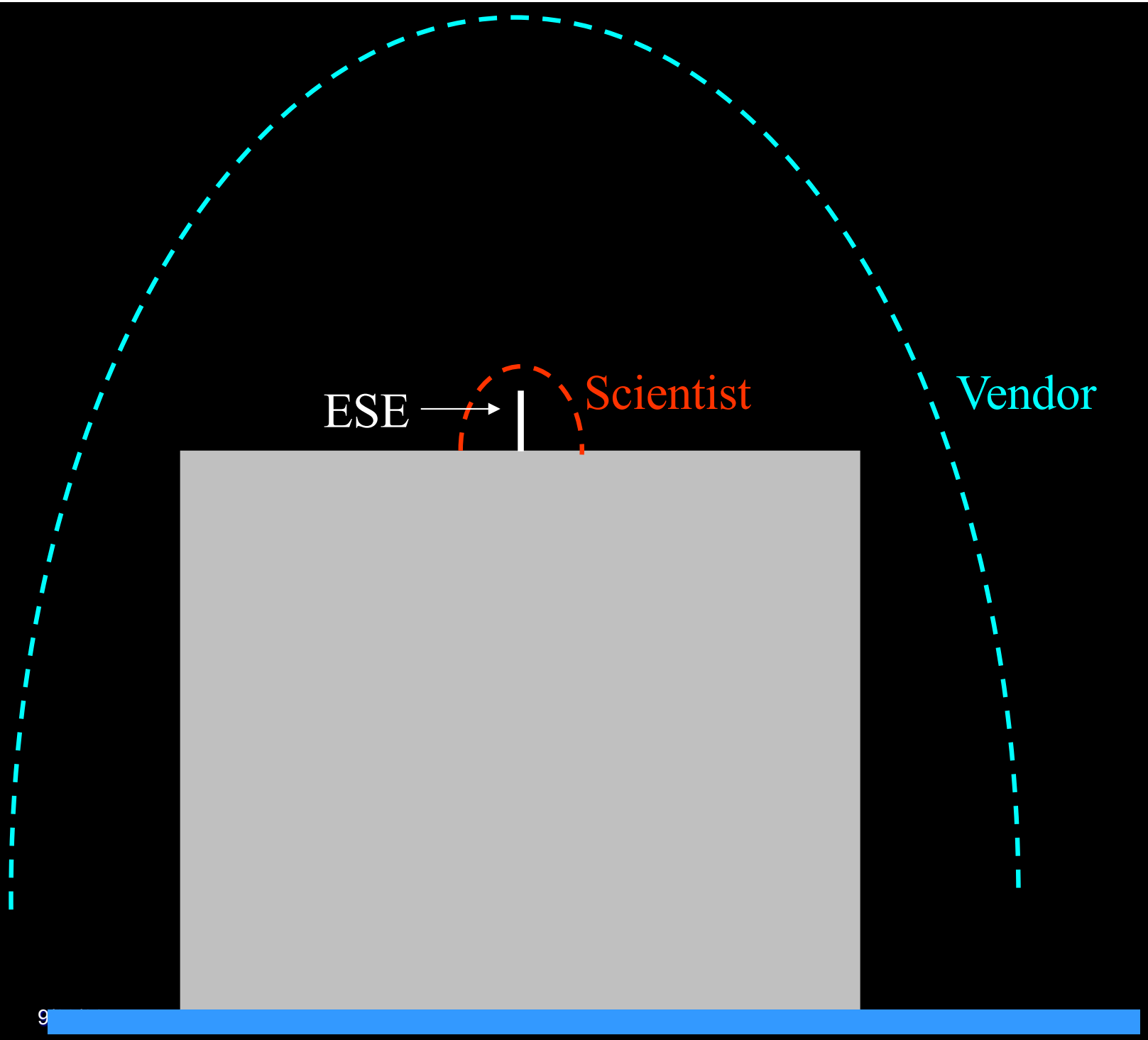
Do French / Spanish Standards have a scientific base?

NF C 17-102

UNE 21186

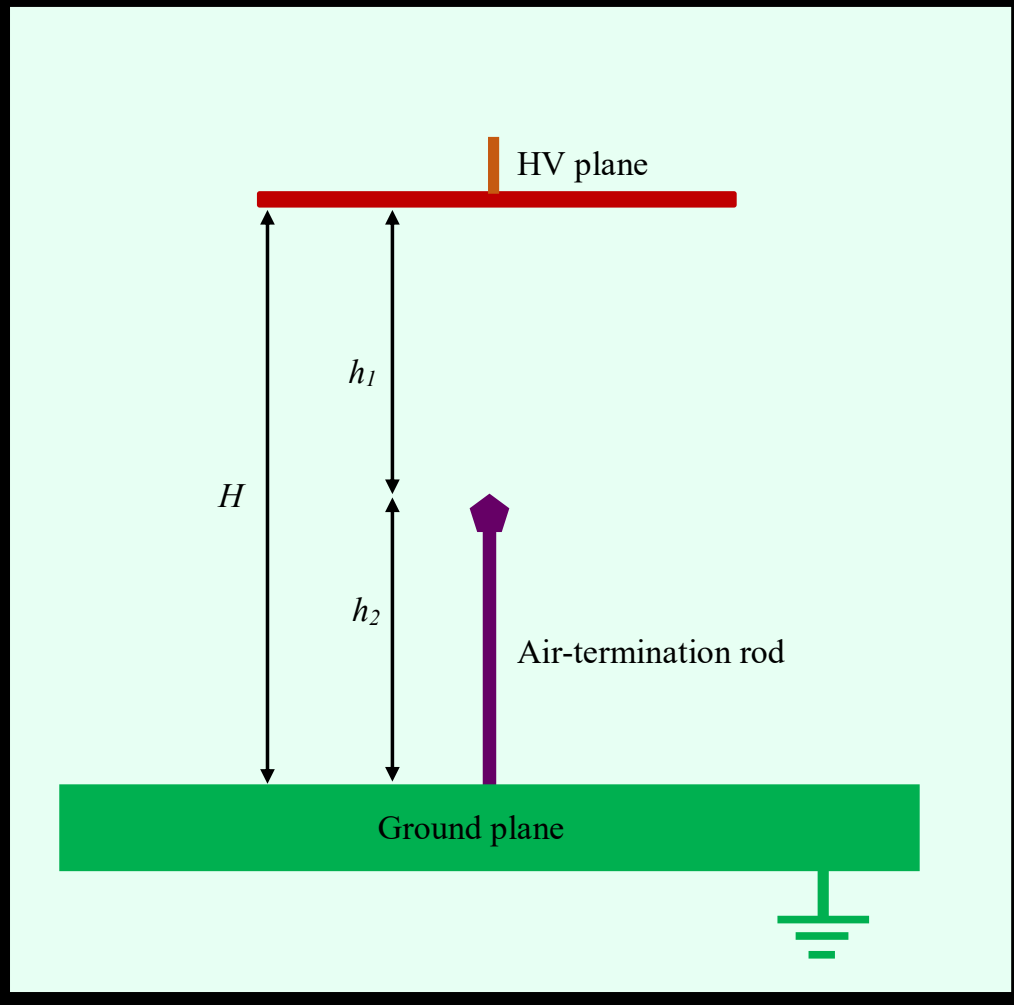
Issue No 4

- The ESE manufacturers adopt an arbitrary value of 10^6 m/s for the speed of the answering leader
- Recent studies reveal that the speed of the answering leader is in the order of **10^4 m/s.**
- Then the effective height, if there is any such phenomenon, would be decreased by 100 fold
- i.e. If the claimed height of the ESE is 150 m, actually the virtual height is 1.5 m above the physical height


ESE
Scientist
Vendor

Issue No 5

- The French standard specifies a test to be performed with a rod-plane gap length of 2m and above
- Can the results obtained be extrapolated to the real lightning phenomenon which occurs in between earth and cloud, several kilometers apart?



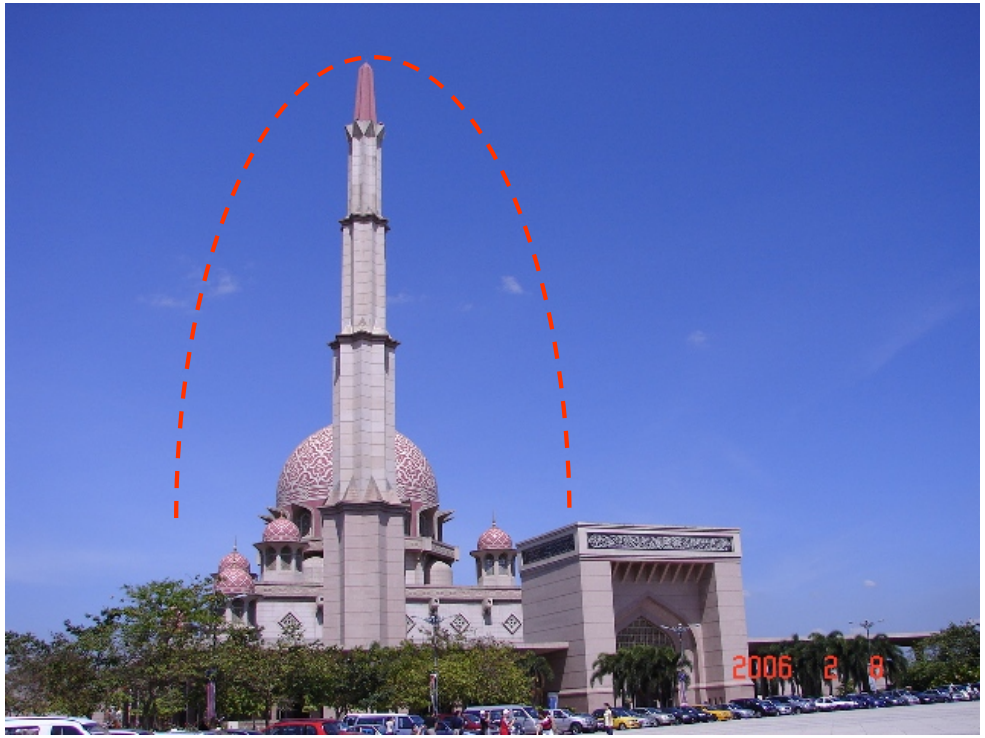
What is the real protection radius of the ESE air terminal?

Lightning struck within few meters!

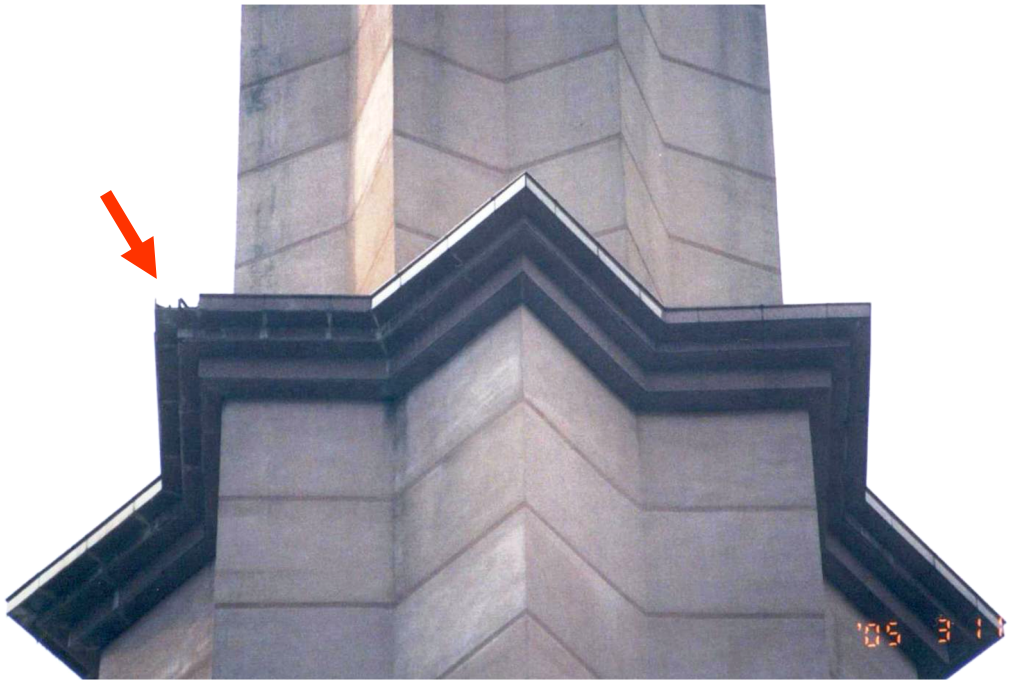
Before lightning strike

After lightning strike

Putrajaya mosque



Putrajaya mosque

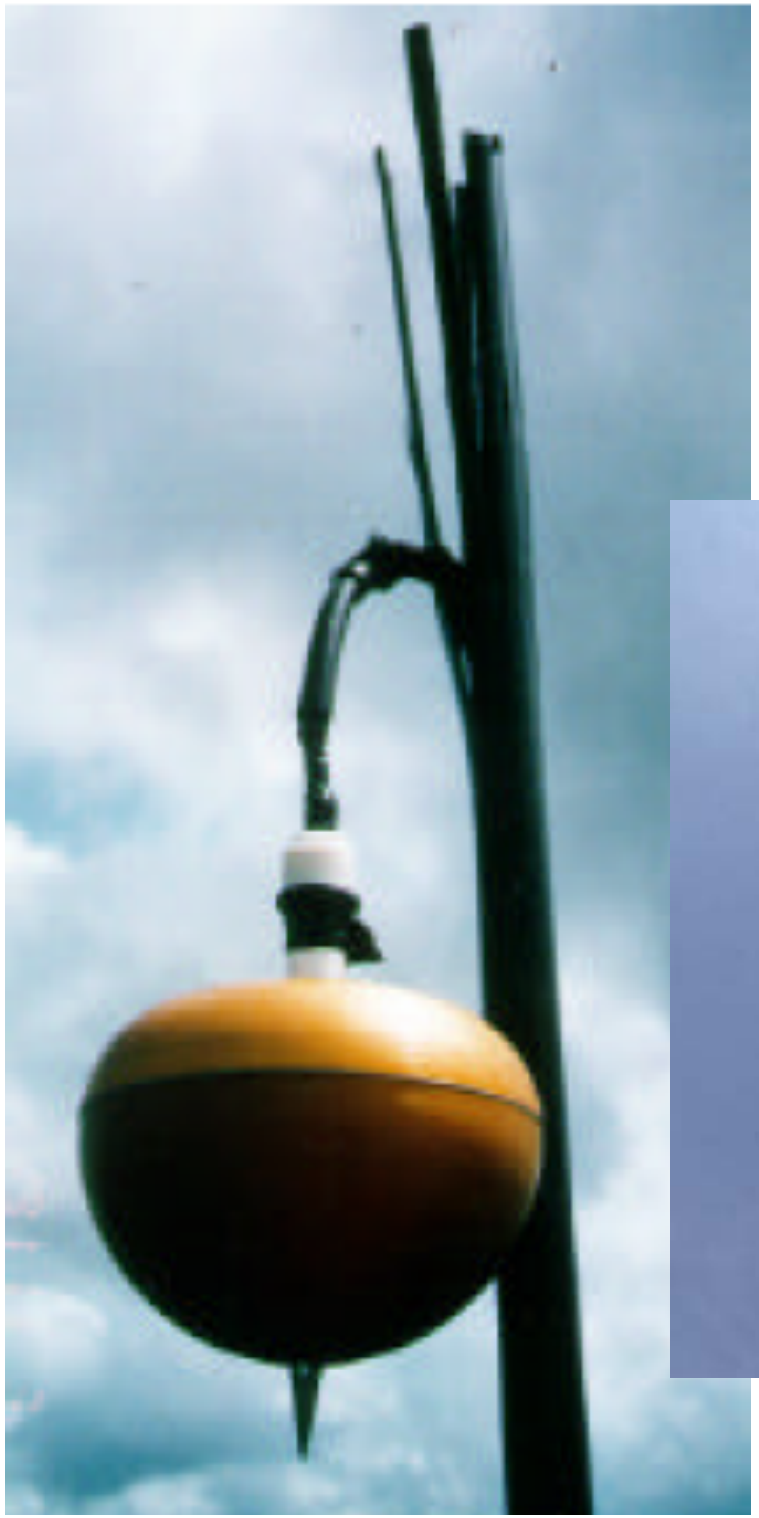


ESE failures

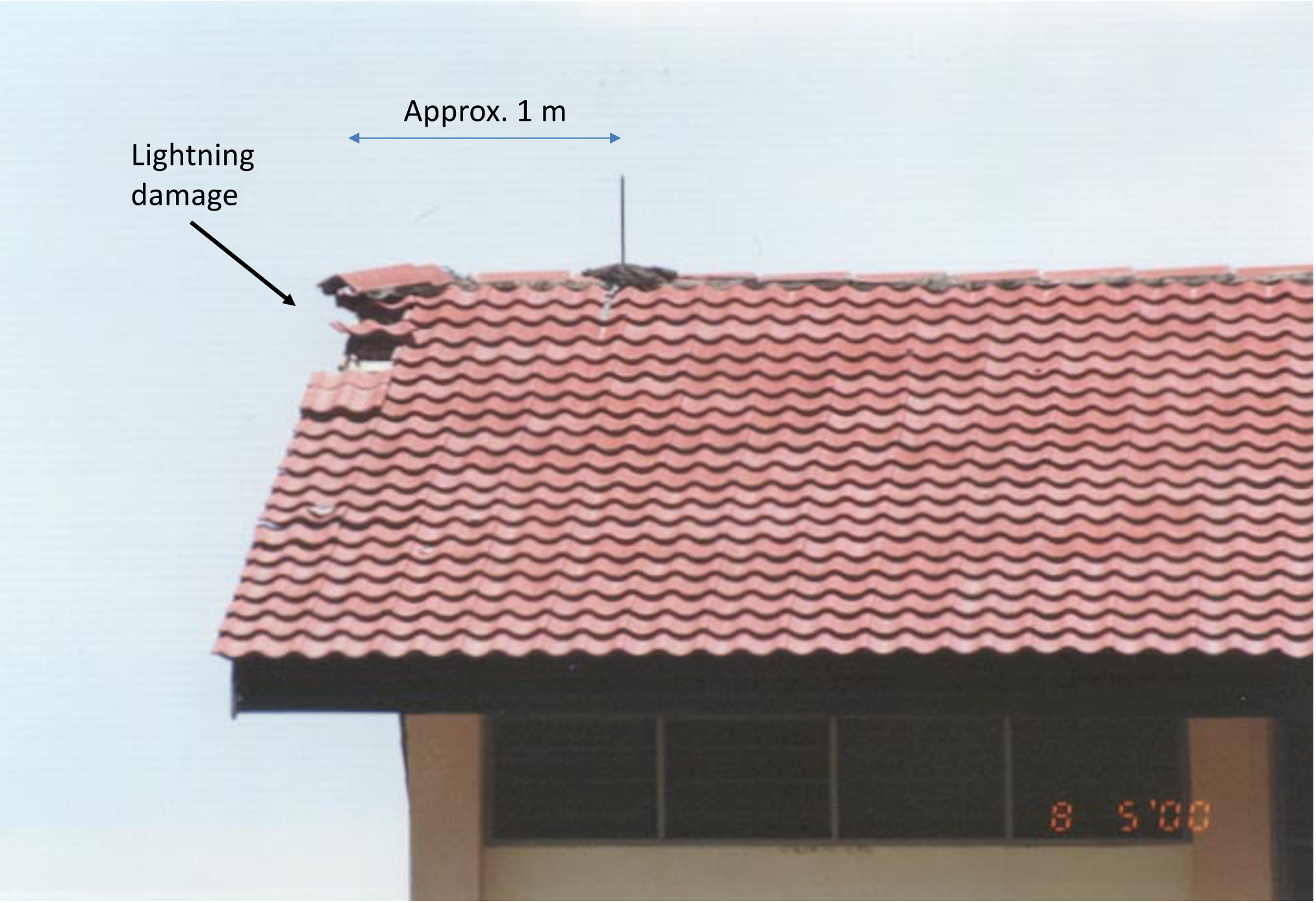
ESE failures


2006 3 10

Mechanical instability



Where does lightning strike most?

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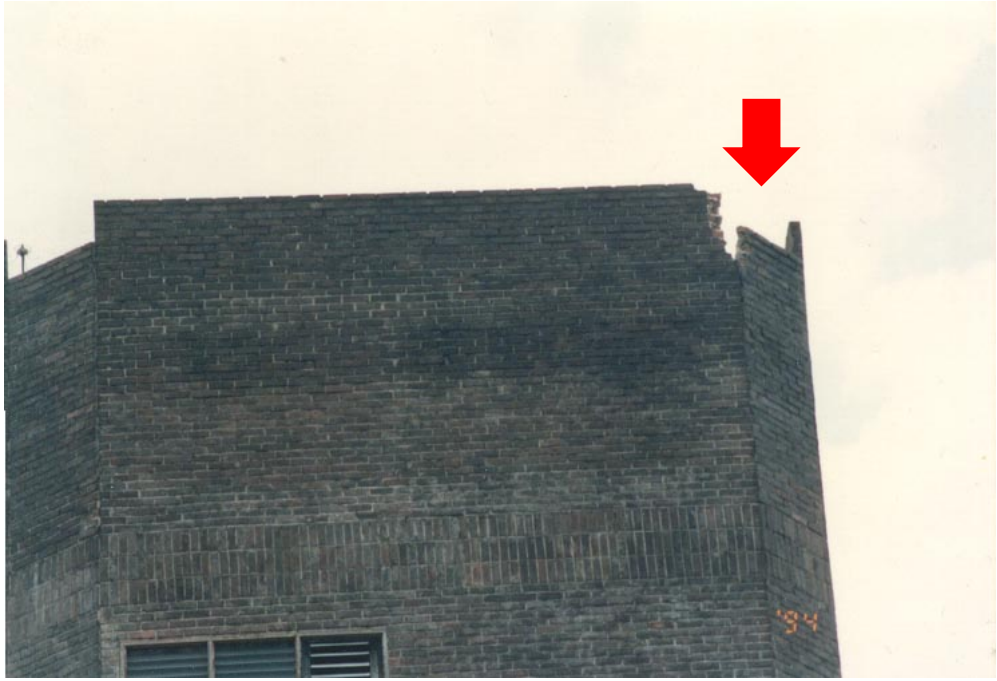
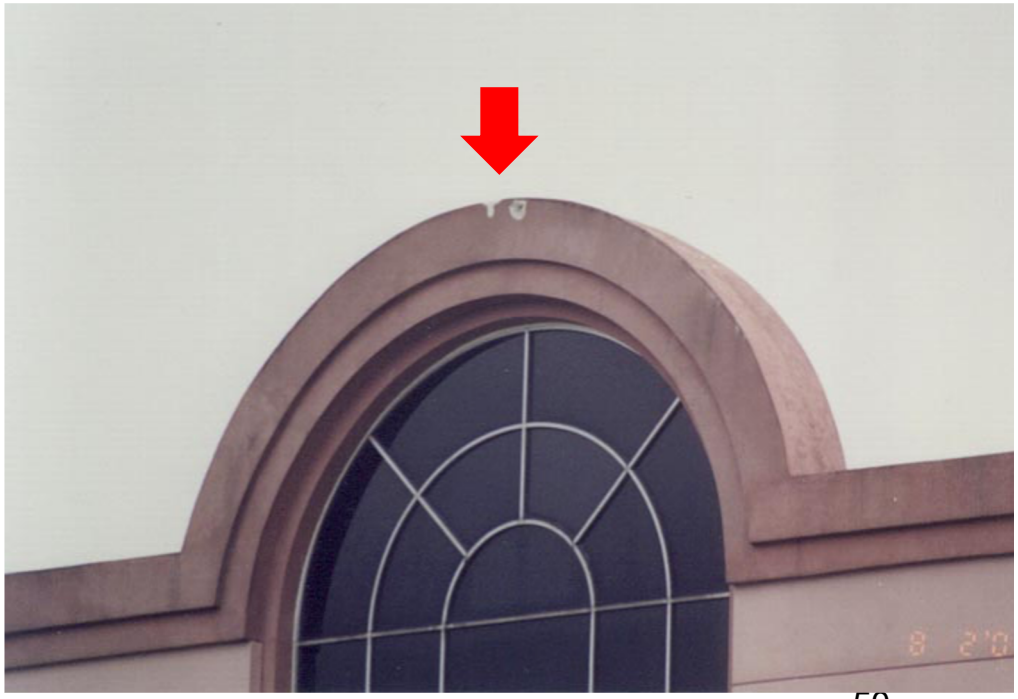
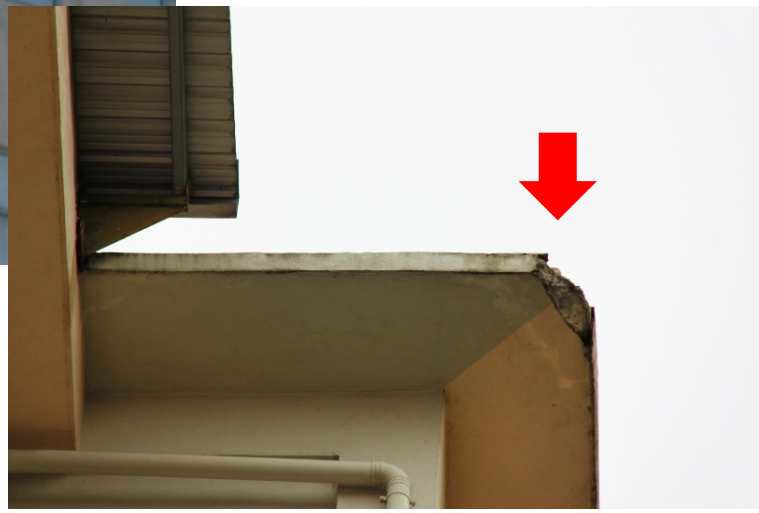




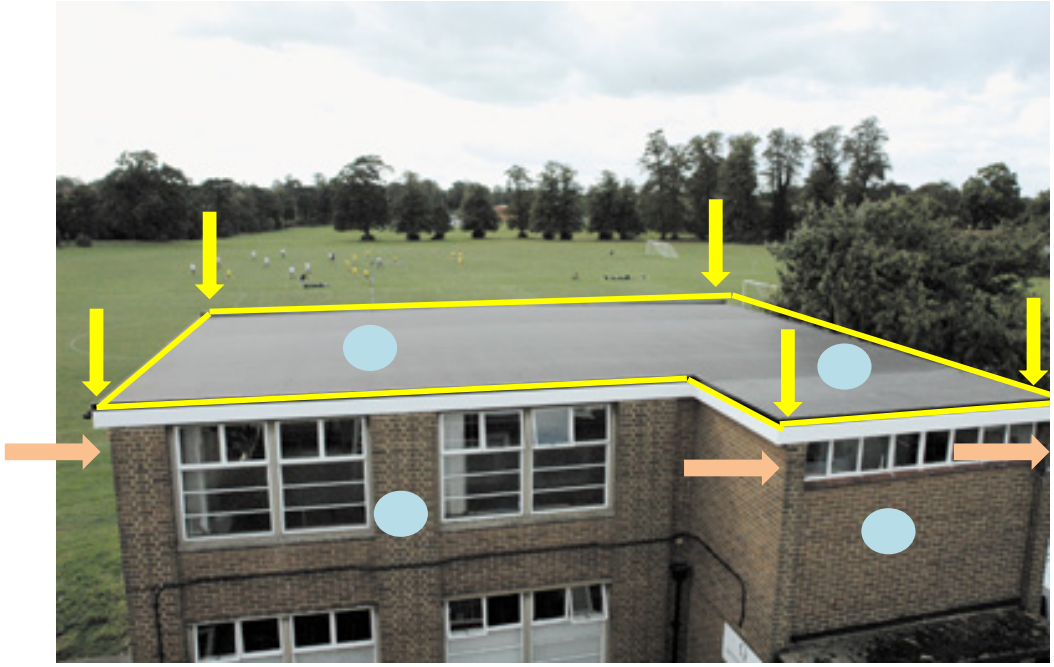



16 4'00

Lightning strike observations

- Analysis of observations
  - More than 90% of lightning strike damages occurred at upper corners, ridge-ends, facades
  - Less than 5% occurred on vertical edges below the top
  - Less than 1% occurred on flat surfaces, either horizontal (even at the top) or vertical

PROTECT EDGES & CORNERS



Lightning Eliminating systems

Lightning Dissipation Arrays

SLE Resistive Air Terminal

Lightning Eliminator

Proponents claim that the device that can repel or neutralise a lightning leader so that it has no harm to the protected site

According to this concept

A device acts as a charge dissipation array is connected to the LPS in the place of the rod

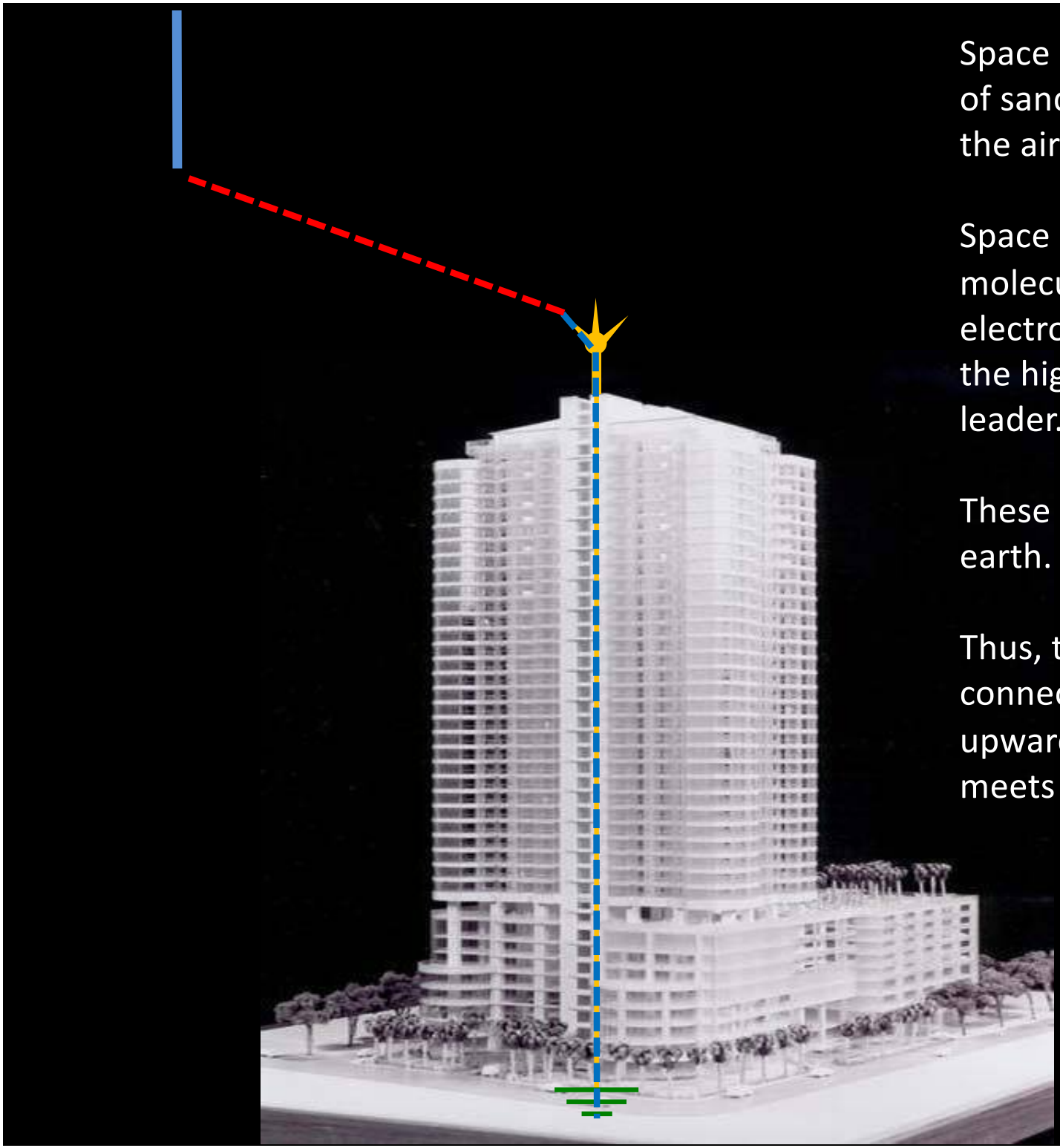
A large amount of space charges are rapidly generated from this array in the presence of the stepped leader

Either these space charges neutralize the opposite charge in the stepped leader
or the large space charge cloud repels the stepped leader?

The concept sounds pretty good for the protection of structures, especially the high risk installations and towers

But

There are some grave doubts about this concept, which totally contradicts with the accepted scientific knowledge



Space charge is not just like a bucket of sand that someone throws up at the air-termination tip.

Space charge is generated when air molecules gain from or give electrons to the air-terminal due to the high field generated by the step leader.

These electrons go to or come from earth.

Thus, there is always a path connected to ground once the upward streamer (space charge) meets the step leader tip.

Thank You