NON-CONVENTIONAL LIGHTNING PROTECTION SYSTEMS - AN UPDATE

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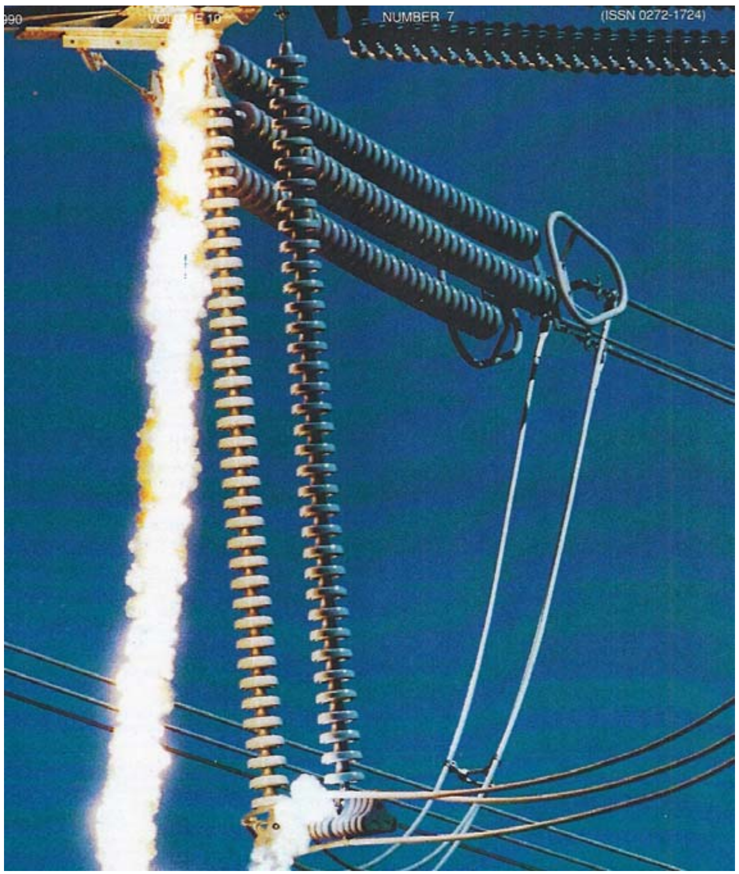
Abbreviations

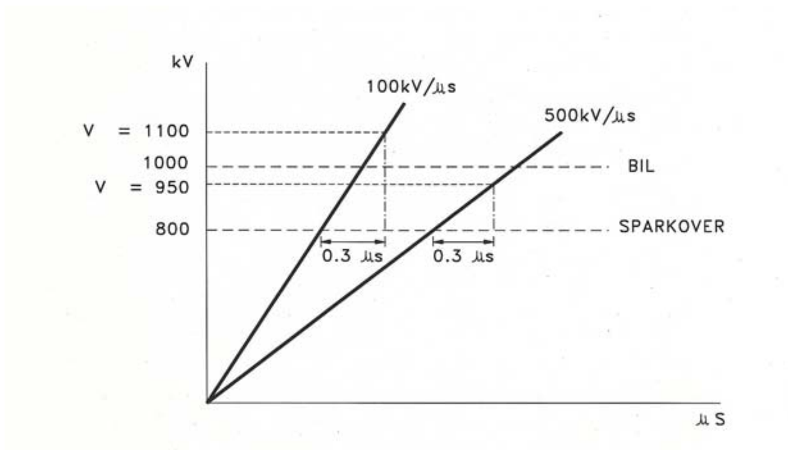
- EGM: Electrogeometric Model. Rolling Sphere Method is a simplified version.
- DAS^{TM}: Dissipation Array System.
- CTS: Charge Transfer System, generic name for DAS
- ESE: Early Streamer Emission.
- CVM: Collection Volume Method.

Why protect against Lightning?



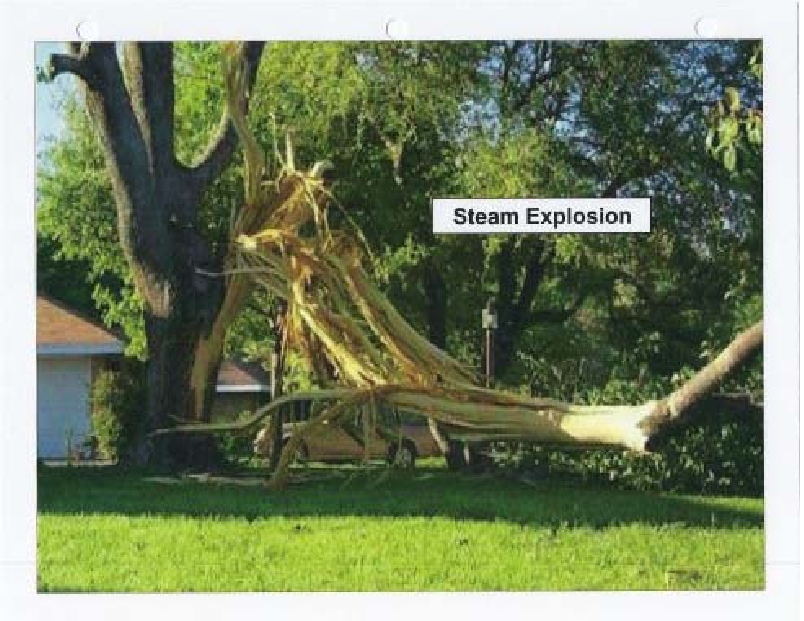
- Concern in power systems is flashovers.
- Most serious in case of substations:
- Damage to equipment.
- Extensive blackout.
- System stability concern.

Would Surge Arresters help?



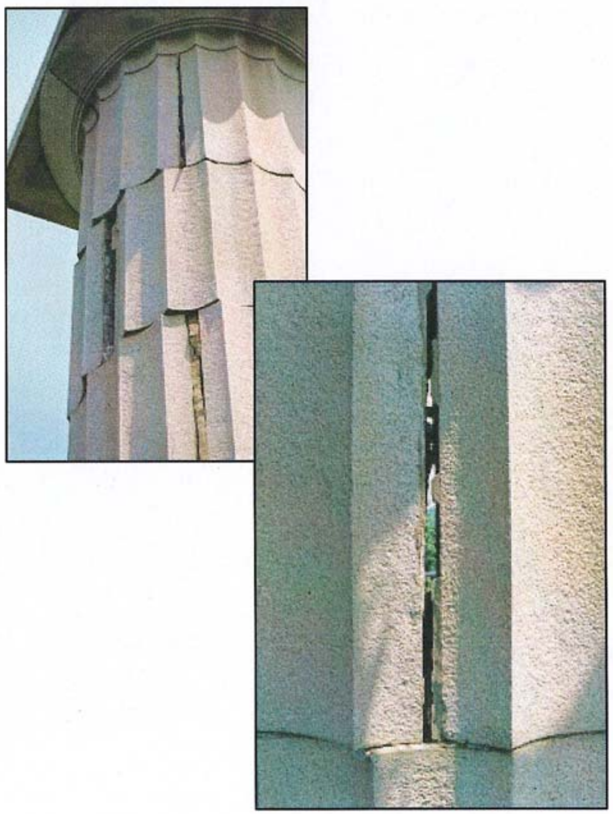
- Surge arresters may fail to protect against direct strokes because:
- Rate-of-rise is too steep.
- Discharge capability may be exceeded.

Lightning Damage to Structures



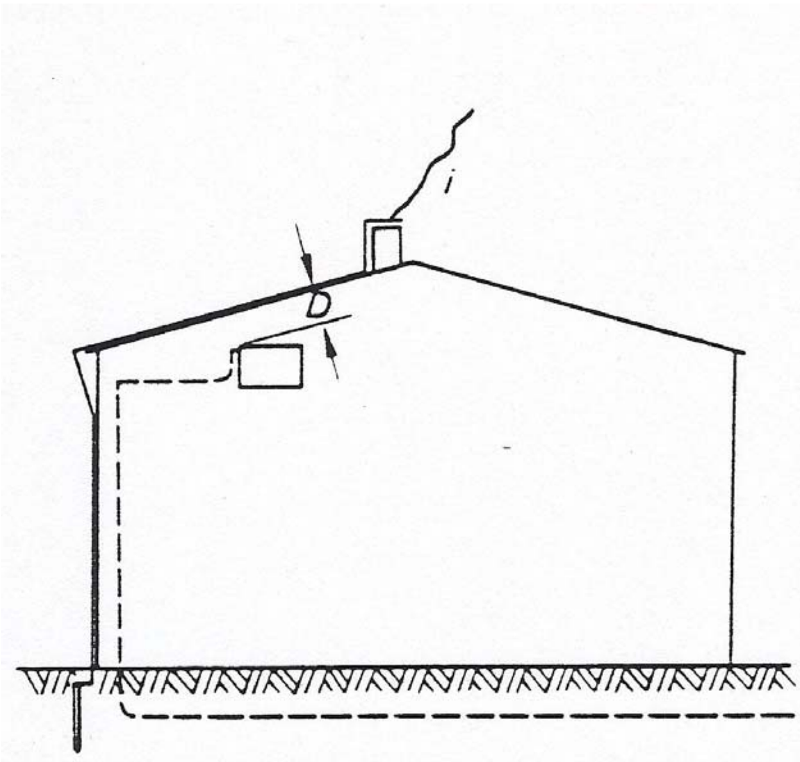
- The Sudden heating to moisture converts it to high pressure steam, leads to explosion.
- Example of case of a strike to a tree.

Lightning Damage to Structures



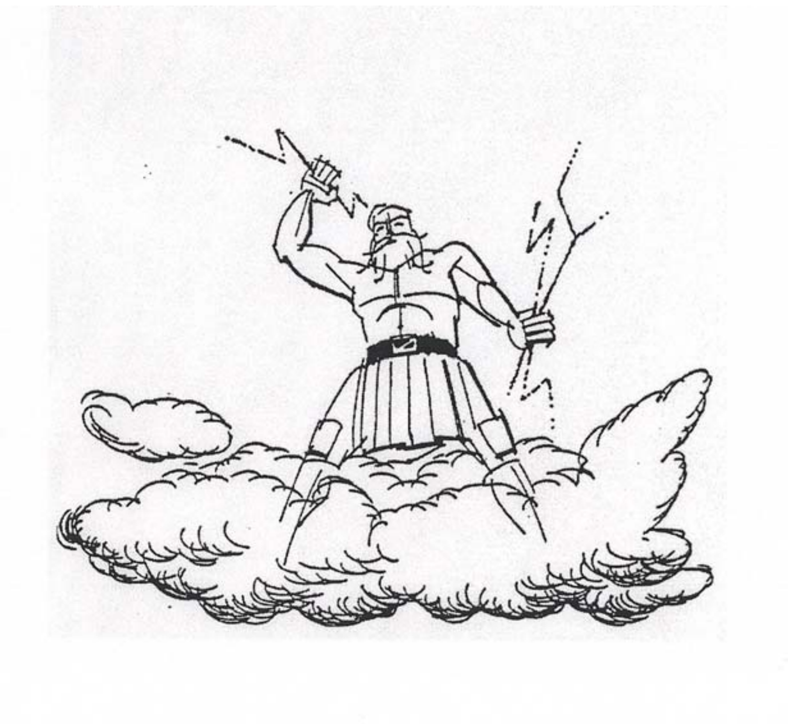
- Even the little moisture n stone can cause it to explode or fracture when struck by lightning.

Fire-initiated Lightning



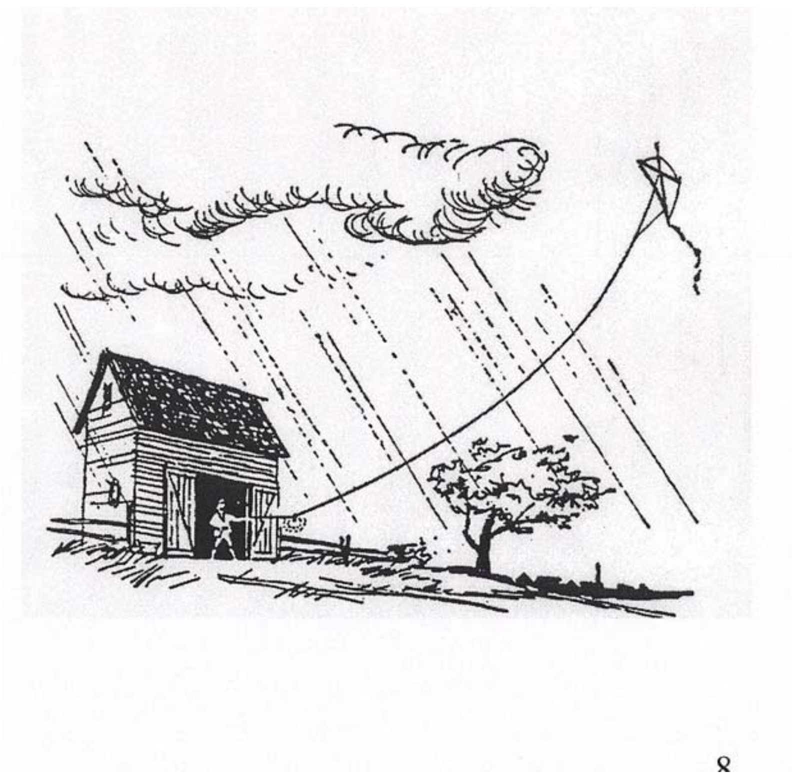
- The arcing between two adjacent metallic components can ignite flammable materials.
- Damage from resulting fire can be devastating.

Lightning in History



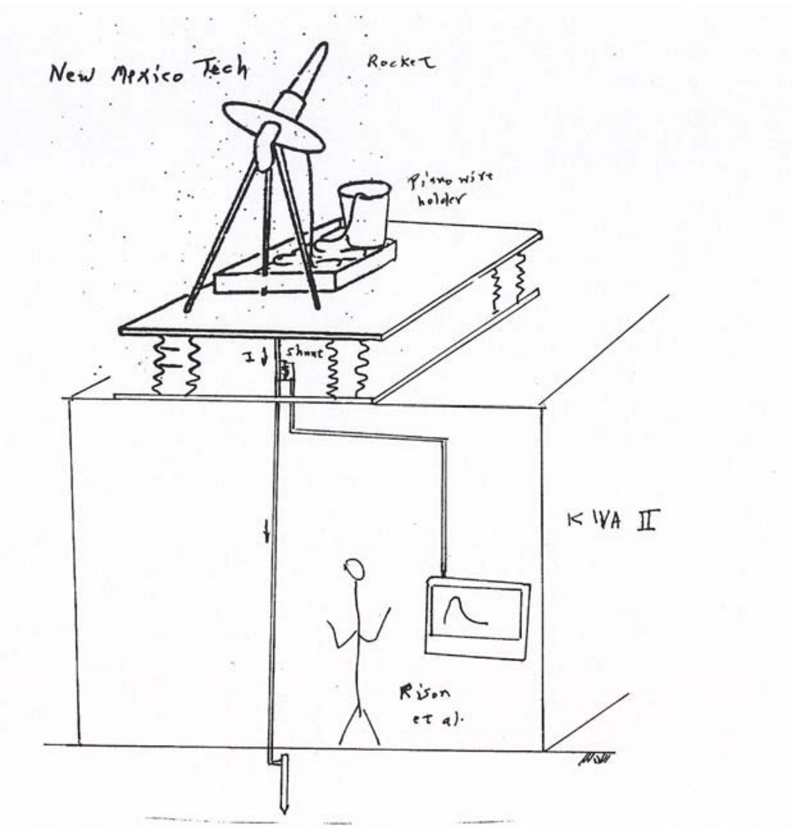
- Punishment from the Gods.
- Solution: pray, ring church bells, ..
- But temples were largest structures around, got struck more often than other buildings.

Conventional Lightning Protection



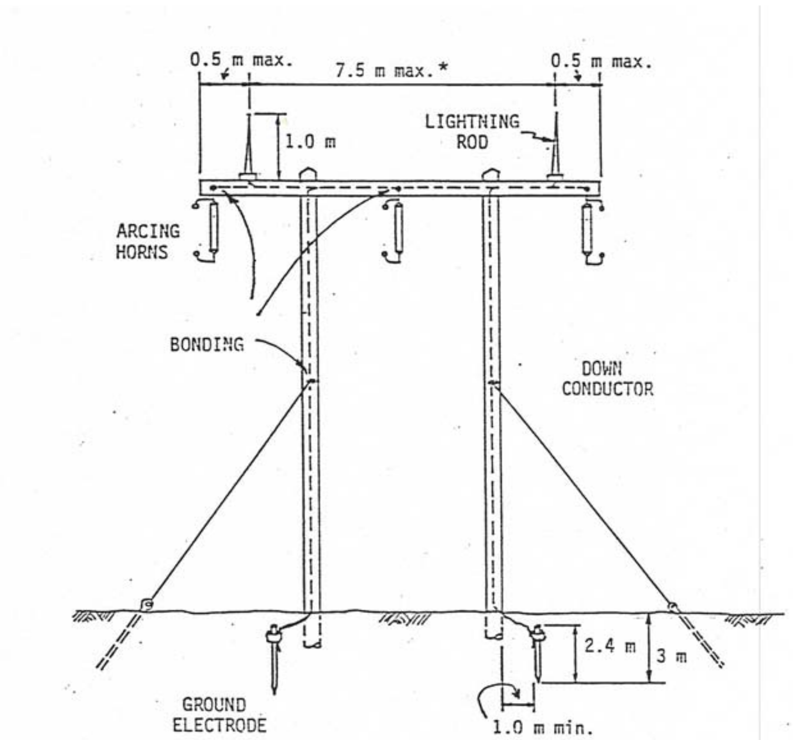
- About 250 years ago, Franklin discovered that lightning was a form of electricity.
- Franklin invented the Franklin rod.
- The shield wire is the equivalent in case of power lines.

Conventional protection works!



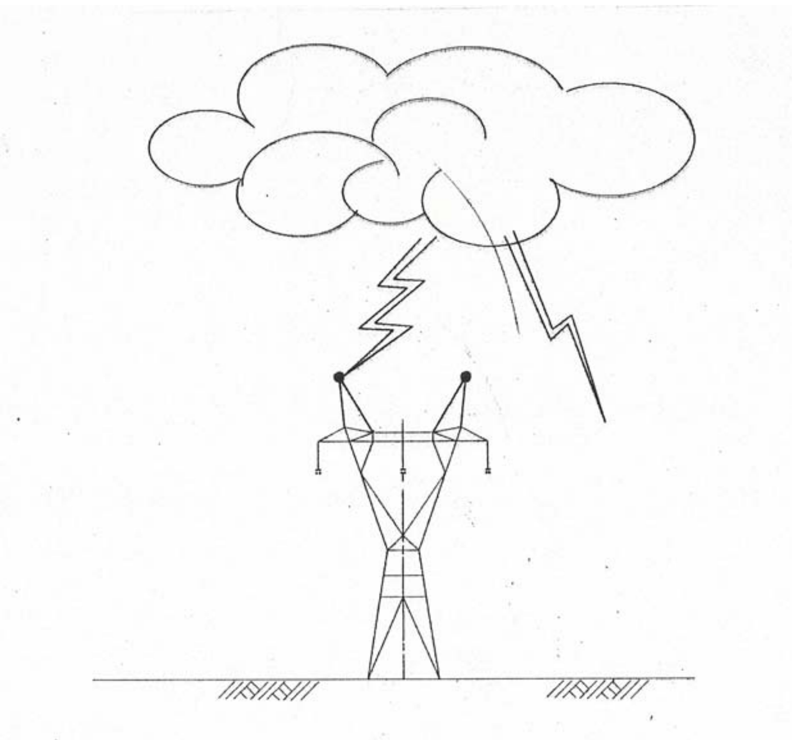
- Persons and equipment were proven safe in a structure below a platform in triggered lightning tests, New Mexico Institute of Mining & Technology.

Components of a Lightning Protection System



- “Air terminal” to collect the stroke.
- Ground rod to dissipate it.
- Down wires to connect the above.
- Bonding to prevent side flashes.

Components of a Lightning Protection System



- In case of metallic structures / steel towers, down wires are not needed.
- Depending on soil resistivity, tower footings may provide adequate grounding.

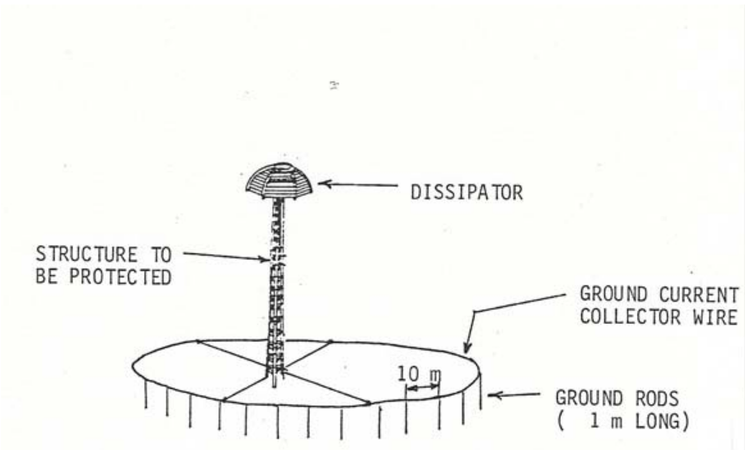
Surge Protection

- Lightning rods were only intended to protect the structure against damage, fire.
- Surges can enter the building over the wires, even if not directly struck.
- Surge protection is required regardless of whether lightning rods are used, especially for susceptible electronic systems.

Non-conventional Lightning Protection Systems

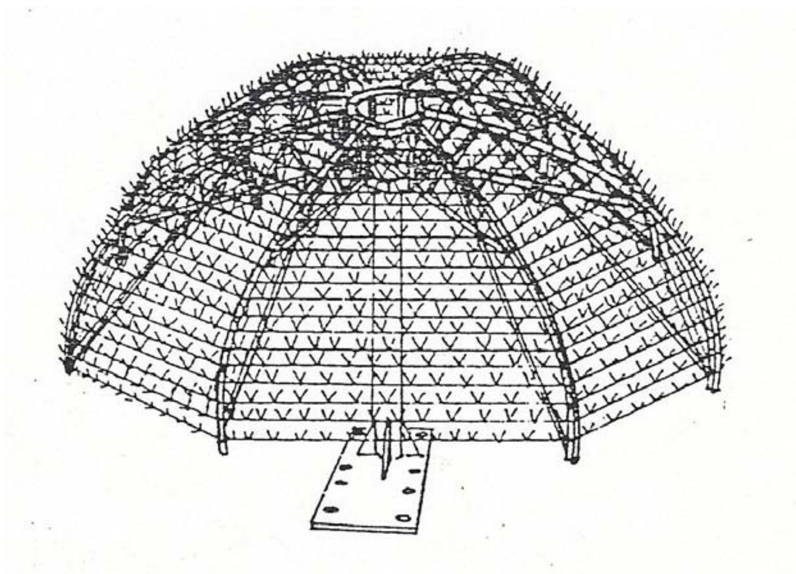
- Two main categories:
- Devices that seek to eliminate lightning strikes - Charge Transfer Systems (CTS).
- Devices that seek to enhance the protective range of the lightning rod: radio-active lightning rods and Early Streamer Emission (ESE) lightning rods.

Lightning Elimination Devices



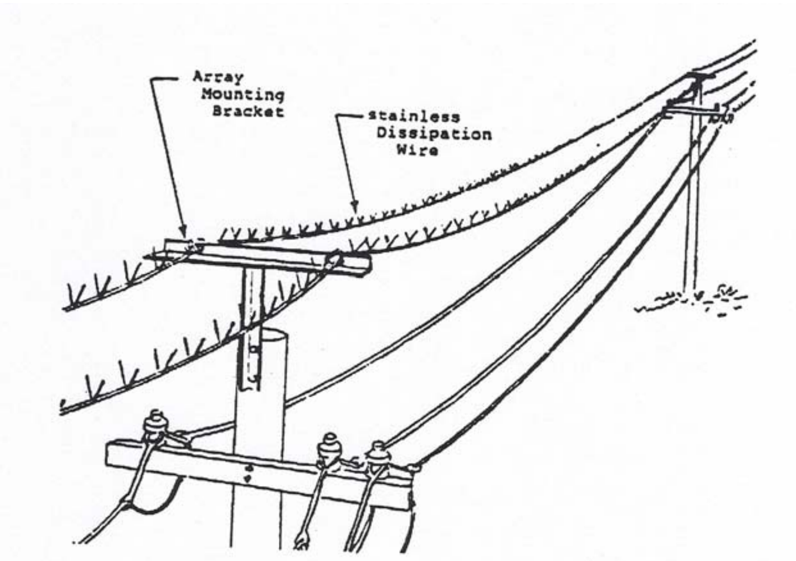
- The most common device is the hemispherical Dissipation Array.
- Requires extensive grounding, as well as use of surge arresters on the electrical facilities of structure.

Dissipation Array



- Consists of barbed wire installed on a frame to produce corona.
- Initial theory: neutralizes the clouds.
- Current theory: corona reduces electric field, inhibits streamers.

Form of CTS for Power Lines

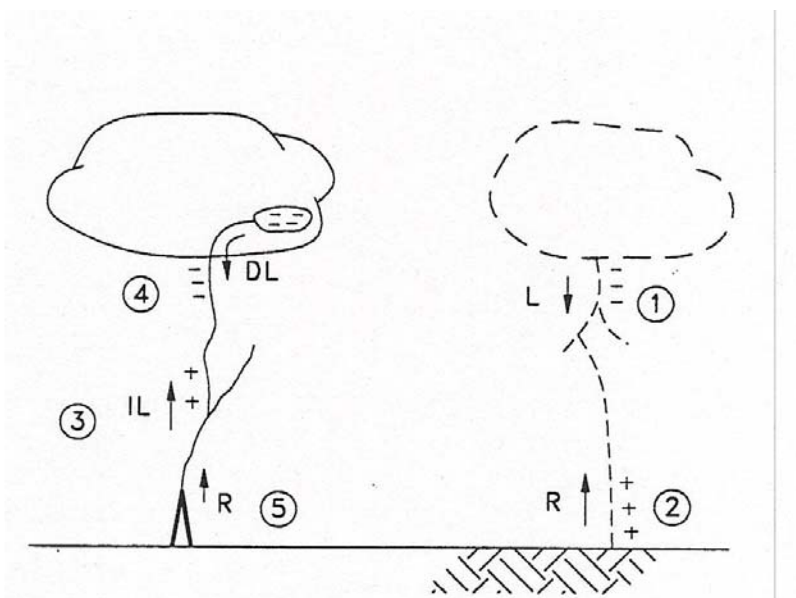


- Shield wires are replaced by barbed wires.
- Rarely used.

Invalidity of the Lightning Elimination Claim

- Soon after DAS was introduced in the early 1970's, it was found to be ineffective and photos showed lightning striking DAS.
- CTS succeeded in preventing damage for two reasons: it intercepted the strokes, same like a Franklin rod (though a very expensive one), and the extensive grounding and surge protection protected the electronics.

Inadvertent Success of DAS in High Altitude Areas



- **A nearby strike within clouds or to ground induces an upward discharge from tall towers. This may reach base of the cloud and draw subsequent strokes. This only occurs if altitude of tower tip exceeds 300 m.**

Case of Induction from a 12 km away Lightning Strike

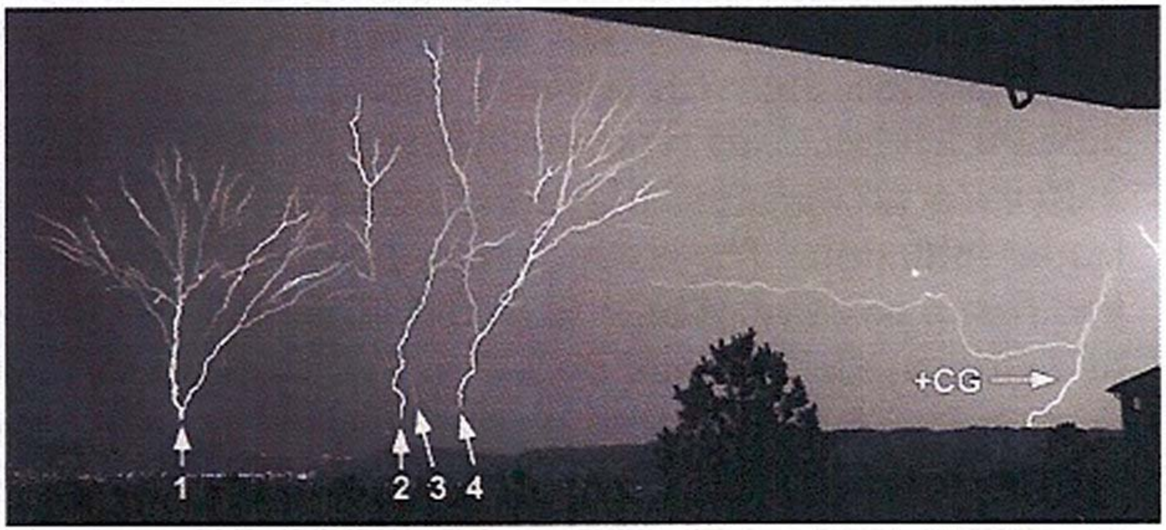
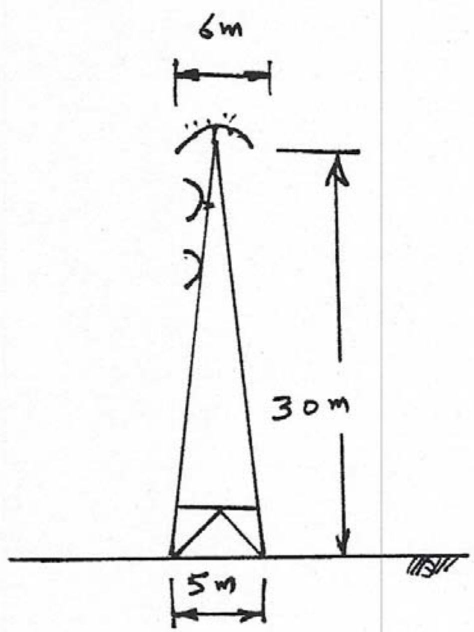


Figure 4. High-definition video image (60 ips) showing the preceding +CG return stroke channel and self-propagating upward leaders developed from all four towers.

Inadvertent Success of DAS - Example



- H= 30 m
- 40 thunderstorm days/year
- Ratio of cloud / ground flashes= 4/1
- Assume radius of influence zone to be just 500 m.

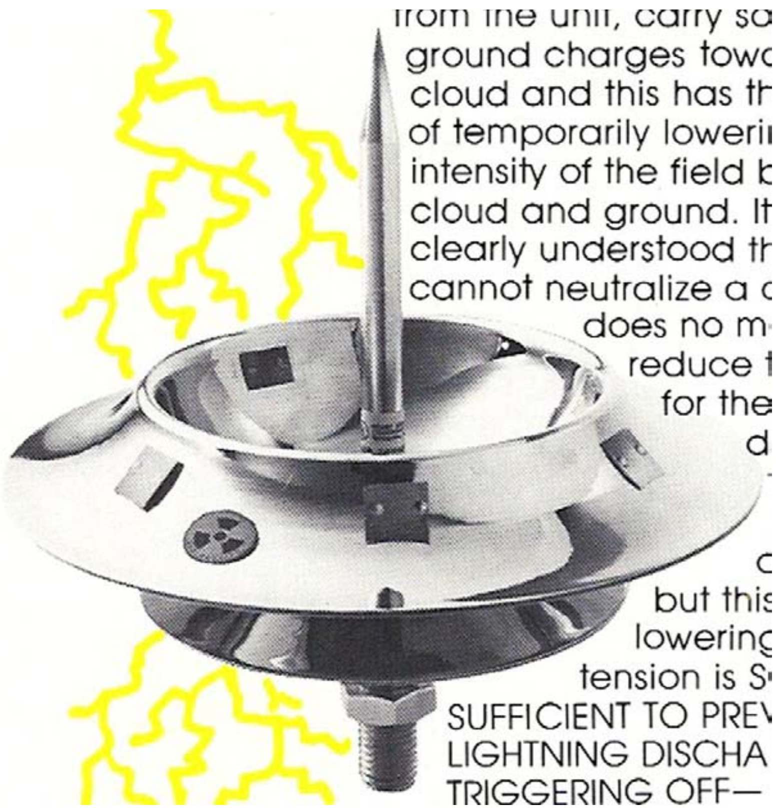
Inadvertent Success of DAS - Example (Continued)

- No. of Downward flashes: 1 every 22 years.
- Upward discharges if altitude is high: 16 strikes/year.
- DAS changes the needle-like geometry of the structure, makes it less susceptible to induction, eliminates the 16 upward discharges, but not the downward strokes.

CTS in Standards?

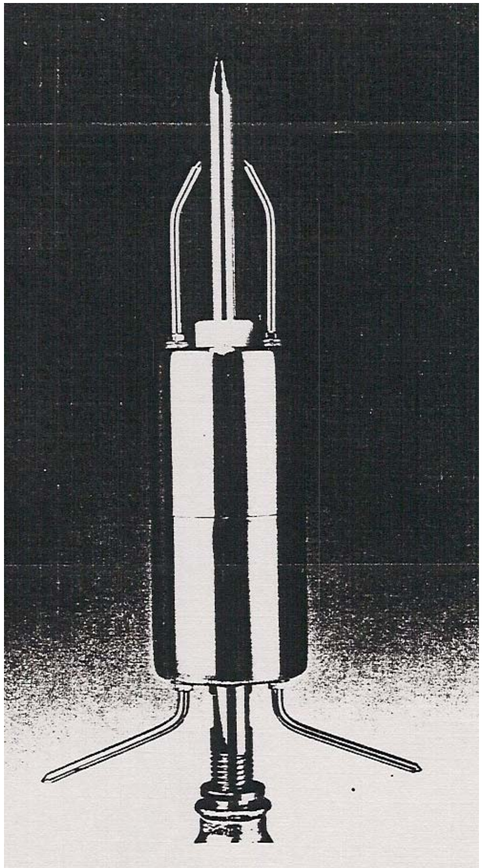
- CTS was the subject of failed aggressive campaigns to introduce it in NFPA and IEEE Standards.

Radio-active Lightning Rods



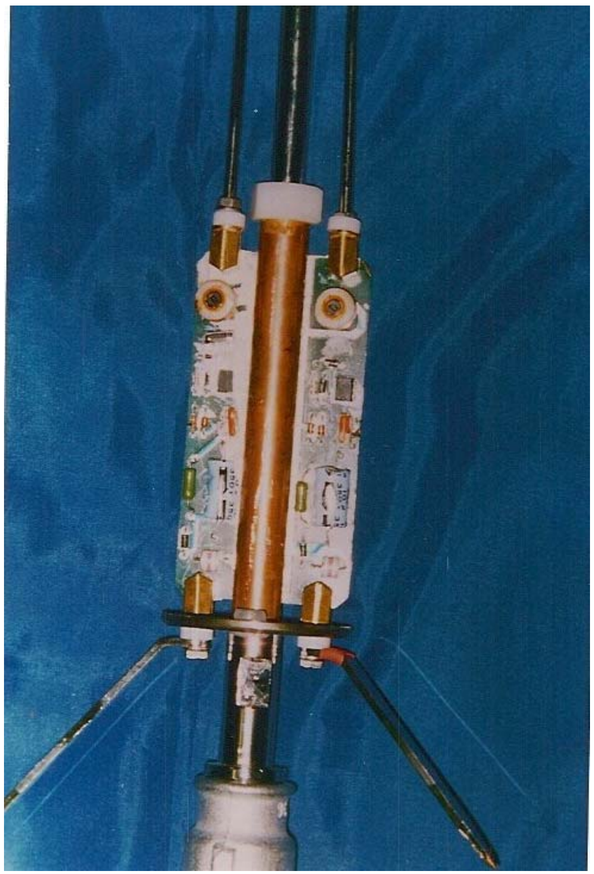
- Radiation near tip of the device ionizes the air, and this is claimed to extend its stroke collection range.
- Were banned, and have since been replaced by ESE devices.

ESE Lightning Rods



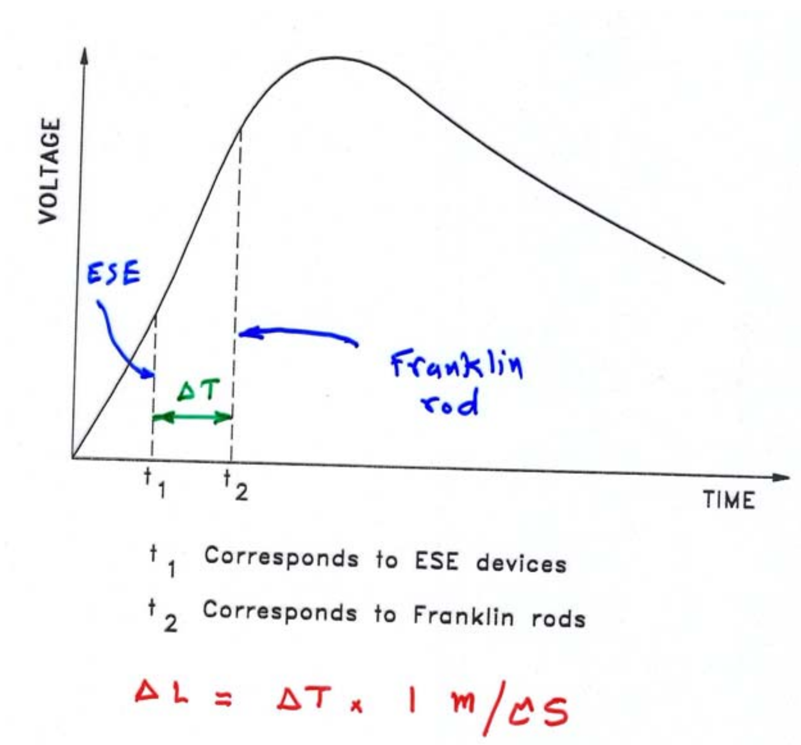
- Center rod is grounded to collect the stroke, insulated tips around it spark to ionize the air when thundercloud is overhead, powered by induction from electric field that charges a capacitor inside it.

Charging Circuits of ESE Device



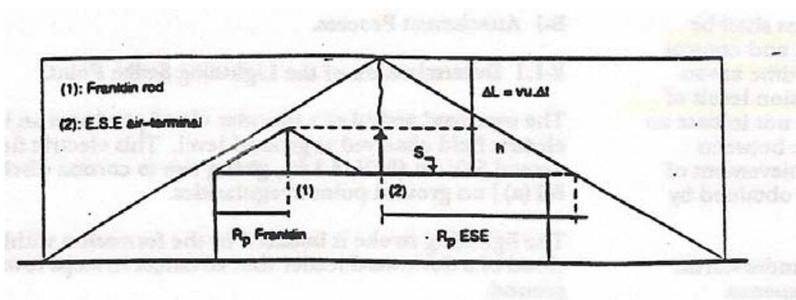
- Photo shows circuits and capacitors inside an ESE device, arcing occurs at the upper rods, lower vanes and enclosure collect the charges induced by the electric field.

ESE Theory



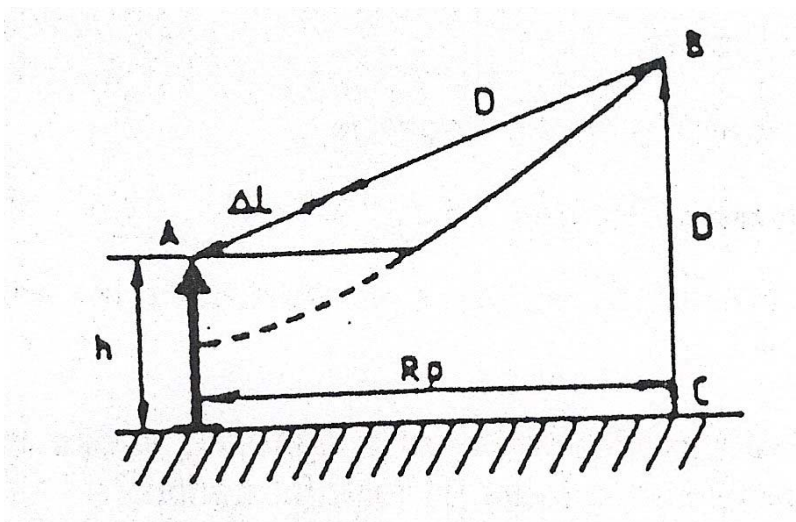
- Because of charge deposited at its tip, when an impulse is applied, corona current starts flowing earlier than case of a Franklin rod. ΔT is measured in the lab.

Claimed Increased Protection Range of ESE Device



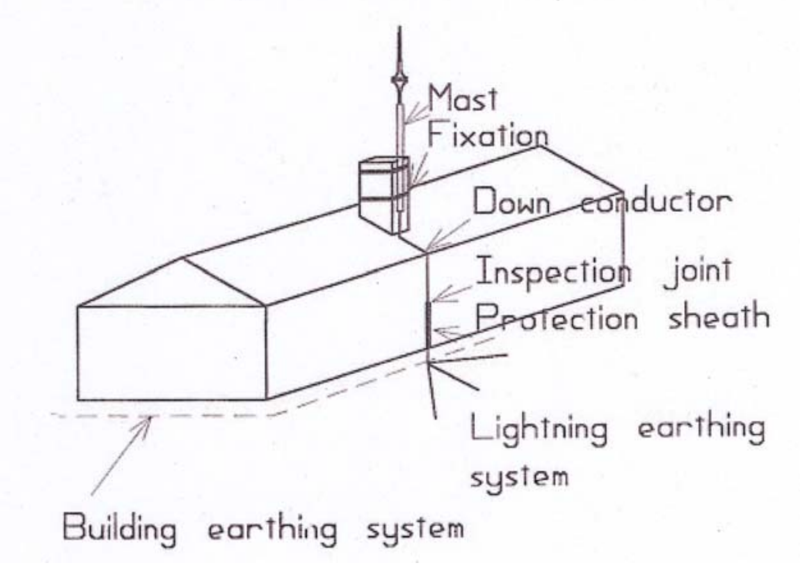
- ΔT is converted to an increase in rod height "ΔL". This is claimed to increase the protection radius, shown here assuming that the Fixed Shielding Angle Method is applied.

Claimed Increased Protection Range of ESE Device



- ESE theory also permits use of EGM to calculate the increase in the protection range. This is done by adding ΔL to the striking distance to the ESE rod.

One ESE Device for a Whole Building?



- The crux of the ESE claim is that only one ESE device, with only one down wire, would protect a whole building. In contrast, the conventional method requires many Franklin rods.

ESE Lightning Rods

- Vendors were challenged to produce photos of their claimed giant early streamers. They did not.
- Instead, photos showed that no streamers existed.

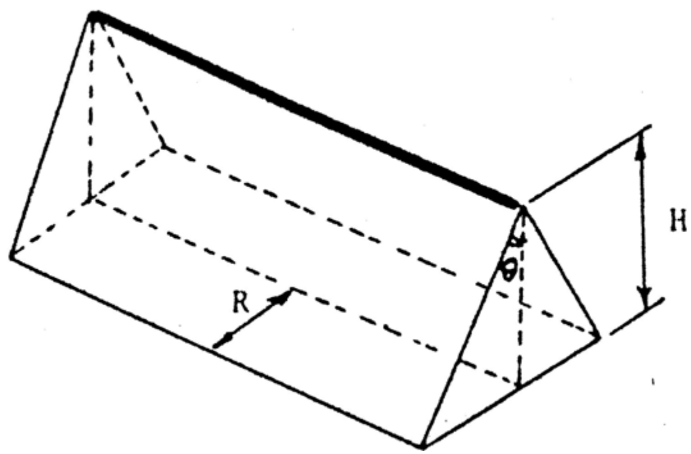
ESE Controversy

- ESE devices were the subject of a bitter decade-long battle to get them in NFPA Standards.
- Vendors failed and since then tried to find other methods to promote their gadgets.
- Their new tactic is promoting the Collection Volume Method (CVM) for rod placement.

Placement of Air Terminals

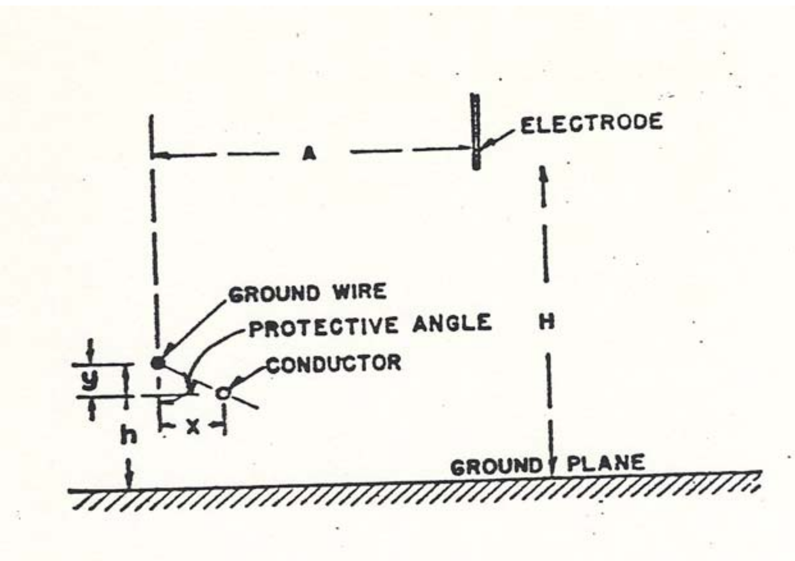
- To be effective, an air terminal must be correctly placed relative to the protected object.
- Placement theories were initially based on geometrical considerations alone.
- Geometrical methods include the Fixed Angle Method and Wagner's 1942 method.

The Fixed Angle Method



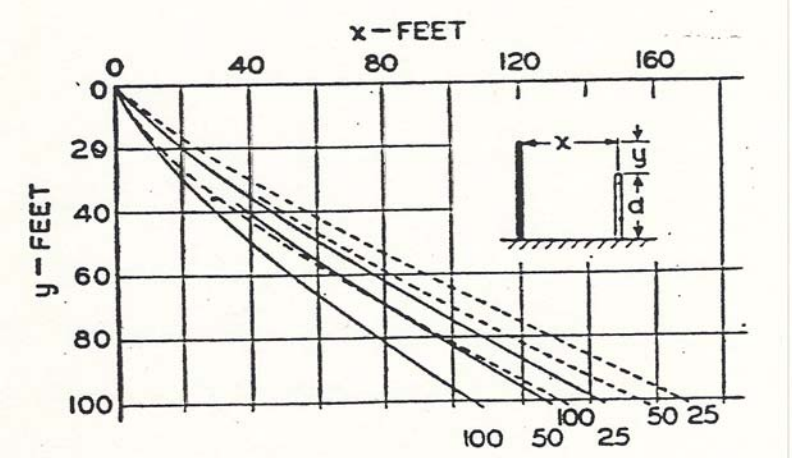
- Diagram shows the Fixed Shielding Angle in case of a Shield wire.
- The angle often used is 30 degrees.

Wagner's 1942 Method



- Repeated impulses were applied to a scale model to see whether arcing would occur to shield wire, live wire, or ground plane. Electrode is moved horizontally to cover the range of interest.

Wagner's 1942 Method



(a) · One shielding mast:

- This is an example of Wagner's curves.
- Based on theoretical grounds, Golde (1941) showed that tests on scale models give invalid results, but utilities still applied Wagner's Method.

Electrogeomteric Model (EGM)

- In the 1950's, the geometrical methods were found to be invalid when they were applied to 345 kV T/L's.
- By 1963, this led to development of the EGM which recognizes that effectiveness of the shielding also depends on electrical characteristics of the protected object.

Air Terminal Placement Methods

- The Rolling Sphere Method is a simplified version of the EGM. The EGM continues to be used to date in IEC and NFPA Standards.
- The Collection Volume Method was introduced by A.J. Eriksson in the 1970's as he incorrectly thought that EGM was flawed.

Development of Revised EGM

- In 1983, Mousa sought to study lightning performance of unshielded power lines. He could not use the classic EGM because Eriksson discredited it. But he also found that the CVM was invalid. Hence a revised EGM was developed and it addressed Eriksson's criticism against the EGM.

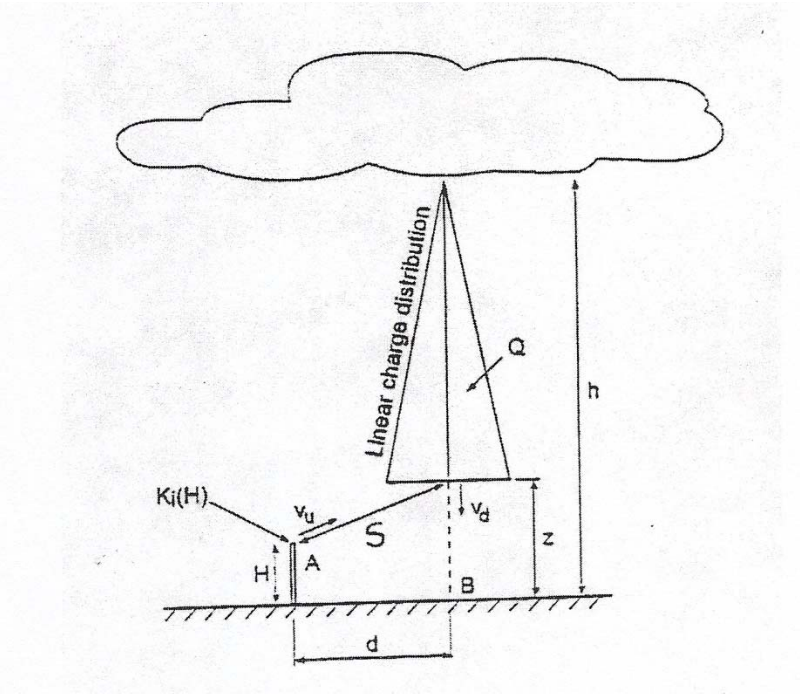
Review of the CVM

- Eriksson erred in interpreting data of others.
- Eriksson erred in designing his field test, and got incorrect results.
- It was a result of this double error that Eriksson thought that predictions of the EGM did not agree with field observations, which is completely false!

Review of the CVM

- So Eriksson developed the CVM in his attempt to save us from what he thought were shortcomings of the EGM, but he ended producing an invalid method.
- The biggest irony is that the CVM suffers from the same "shortcomings" which Eriksson thought existed in the EGM!

Eriksson's Model



- He rounded top of the structure to the "Critical Radius" based on the concept of Carrara & Thione.
- Assumed the final jump condition to be reached when electric field = 30 kV/cm.

Eriksson’s Model (Continued)

- Eriksson calculates the electric field by multiplying the unperturbed value by an intensification factor, and those factors are huge.
- For example, for Eriksson’s mast which is 60 m tall, he used a factor of 60.

Eriksson's Model (Continued)

- This means that Eriksson declares that the final jump condition has been reached when the unperturbed field reaches just 0.5 kV/cm!
- This would occur while the leader is still far away. As a result, the CVM exaggerates the attractive radius of a ground object or an air terminal.

Same false proposition, different flawed justification:

- Consider this: one ESE gadget costs $1250, one Franklin rod costs $10.
- Hence the need to claim that one ESE rod can protect a whole building.
- **1) ESE theory: gadget has magic powers!**
- **2) CVM: gadget can protect whole building by virtue of its height and shape (being a pointed object).**

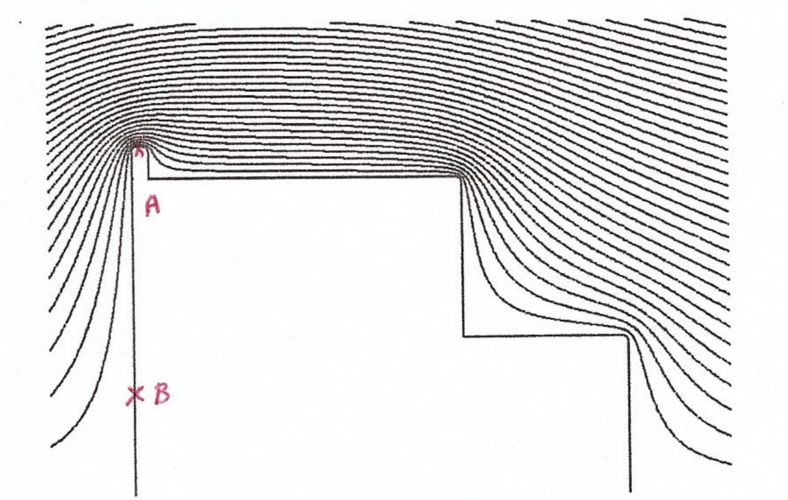
Vendors’ Deception

- According to Vendor’s proposition, the CVM should also apply to Franklin rods, but they do not apply it to these.
- That is why Hartono called these gadgets: “ESE/CVM devices”.

Rebutting the CVM

- CVM is invalid as it contradicts field observations regarding the following:
- a) its predictions;
- b) the assumptions upon which it is based;
- c) its basis for eliminating the ground plane from the model, and;
- d) its estimates of the striking distances.

Strikes below top contradict the CVM



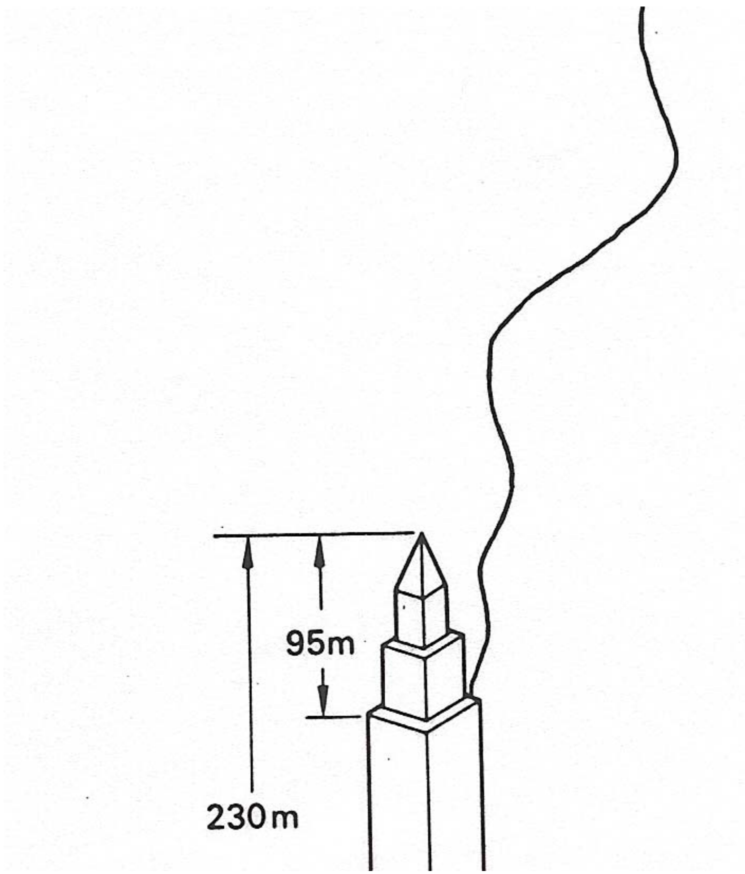
- CVM predicts that strikes should not occur below top of the structure because of the large difference in intensification factor due to both height and shape of the object.

A lightning strike to the Washington Monument

- Photo by Kevin Ambrose, 2005
- Monument height: 169.3 m. Built of marble & granite.
- Struck point at least 40 m below the top.

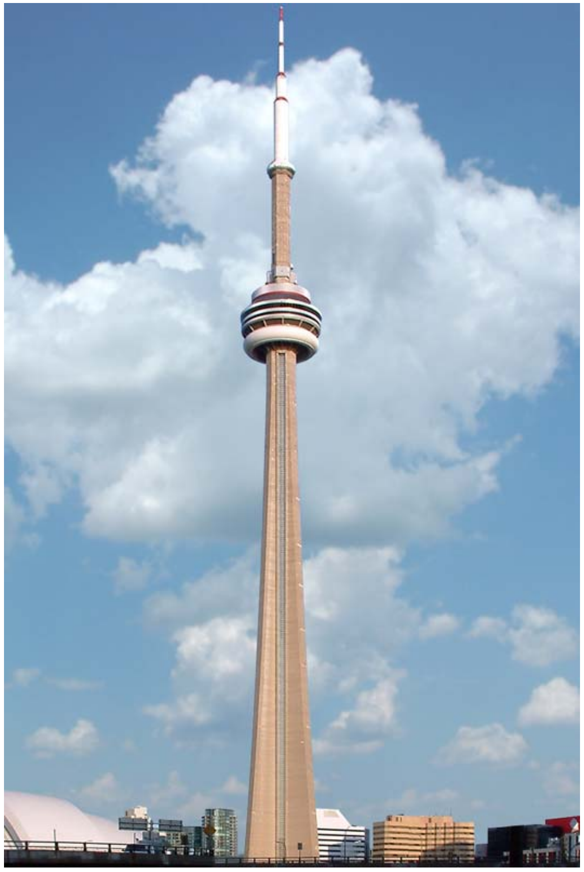
Palace of Culture

A lightning strike to the Palace of Culture, Warsaw, Poland



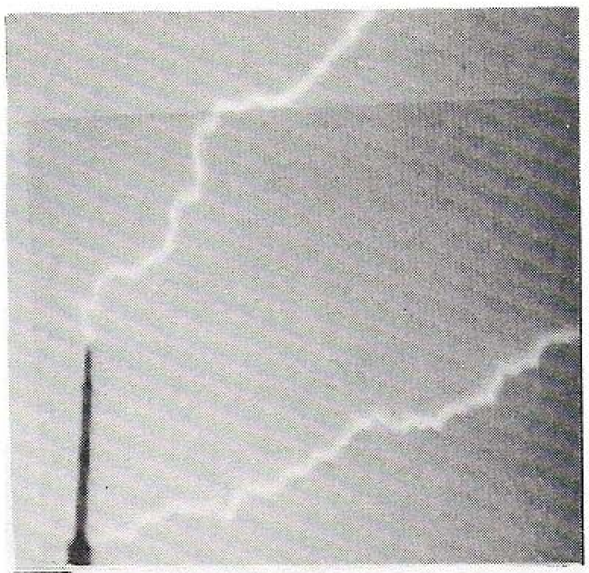
- Palace is 230 m high.
- Strike to a platform located 95 m below the top.
- Reference: Golde, 1973.

CN Tower



- 553 m high.

Lightning strikes to the CN Tower, Toronto, Canada



FLASH 780910
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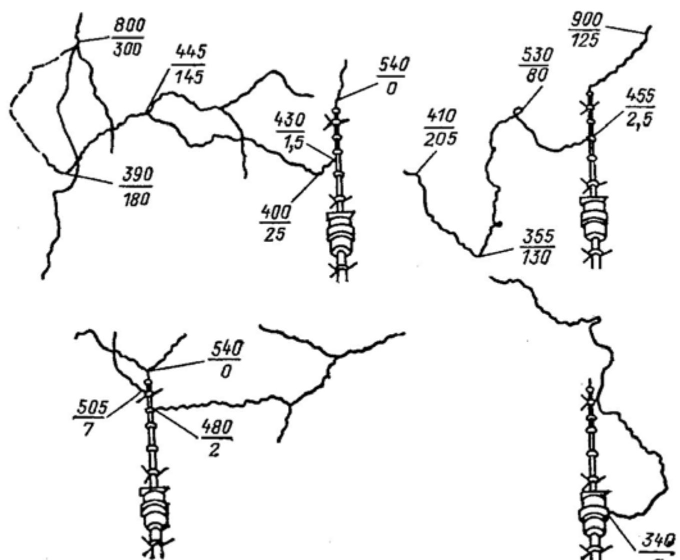
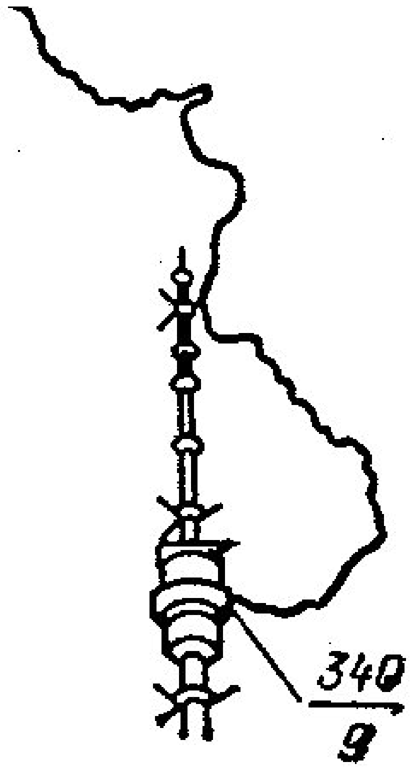
- Ref.: Janischewski et al., 1982, CEA.

540 m Ostankino Tower -1



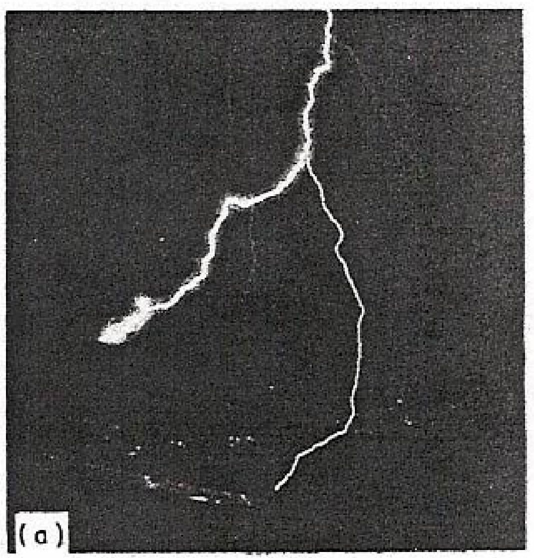
- Many flashes terminated below the top.
- Simultaneous upward discharges often occurring from top.

540 m Ostankino Tower -2



- One flash terminated 200 m below the top, 9 m off the axis.

Strike below top of Berger's mast

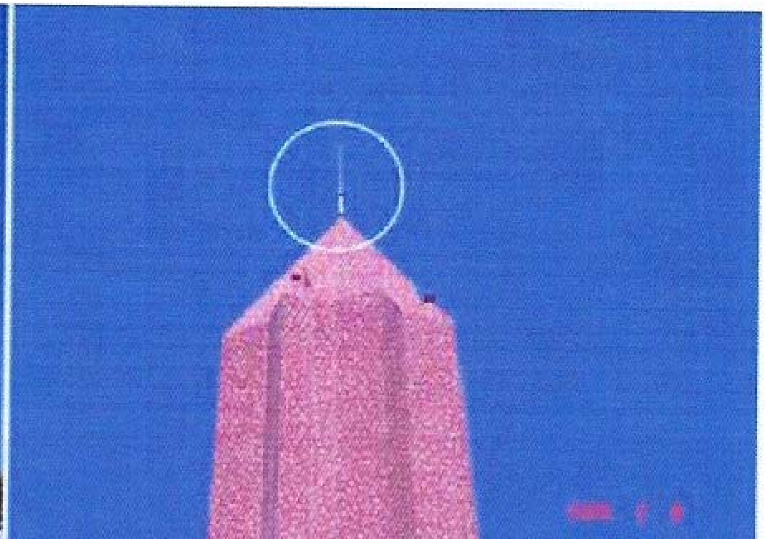


- Mast #2 struck 10 m below the top.
- Ref.: Berger, 1977, Chapter 5 of Golde's Lightning book.

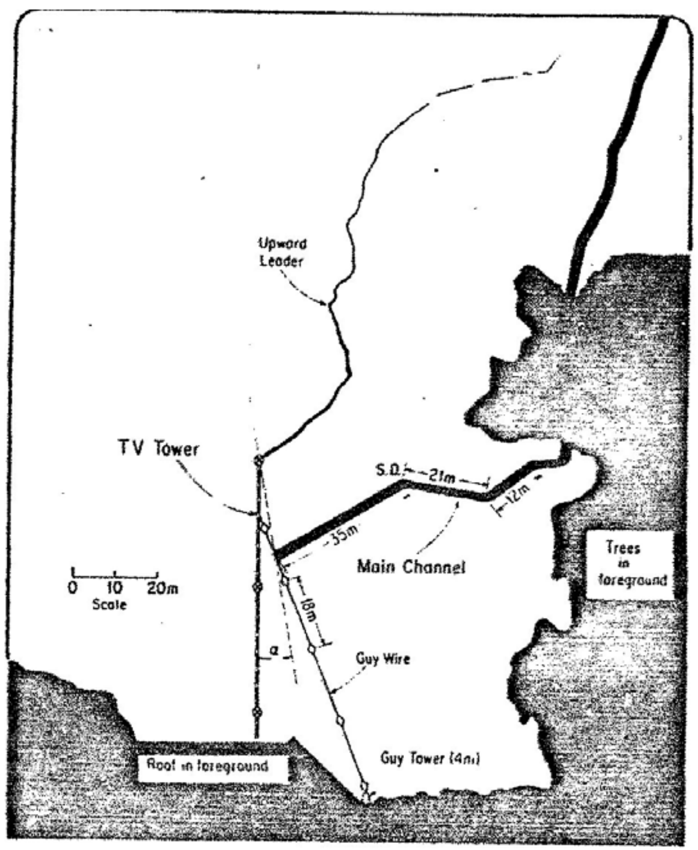
Strike to Empire State Building

- Strike to side elevations.
- 15 m below top.
- Ref.: Golde (1978) after H.M. Towne.

Hartono’s finding (2006)

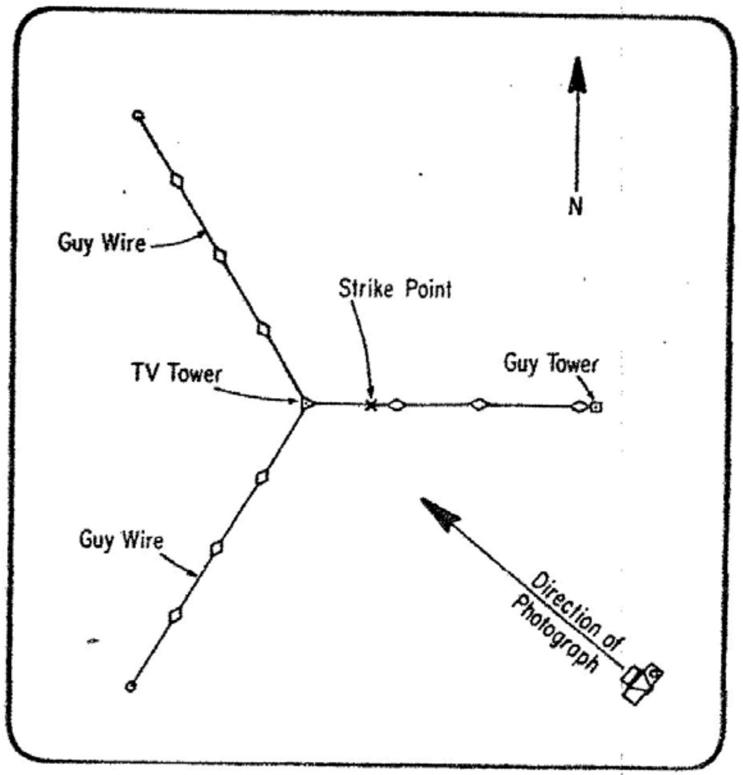



Strike to an 80 m TV Tower
(Krider, 1983)



- Tower in Tucson, Arizona, USA.

Strike to an 80 m TV Tower



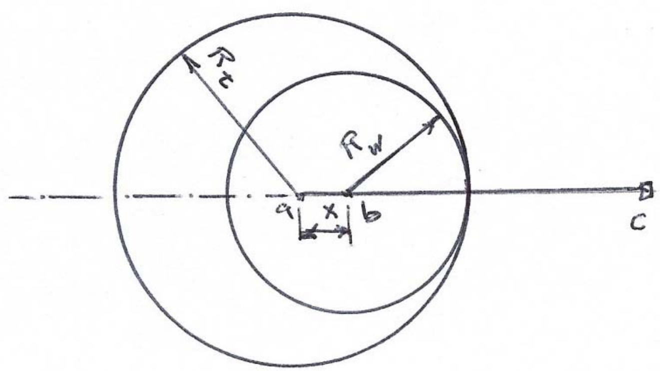
- Guy wire insulators are 18 m apart.

Strike to an 80 m TV Tower

Fig. 6.6 A photograph of lightning to a TV tower guy wire originally published by Krider and Alejandro, *Weatherwise*, **36**:71–75 (1983). Reprinted with permission of the Helen Dwight Reid Educational Foundation. Copyright © 1983 by Heldref Publications, 4000 Albemarle Street, N.W., Washington, D.C. 20016.

- Struck point: 14 m below top, 5 m off axis.

Amplitude of stroke according to CVM



a: axis of TV tower
Tower height = 80 m.
ac: guy wire, struck at point b, 14 m below tower top.
Horizontal distance X = 5 m
R_t = protective radius of tower top.
R_w = protective radius of struck point of guy wire.

- For the critically shielded case:
- $R_t - R_w = 5 \quad \ldots (1)$
- CVM implies that the stroke was less than 1.7 kA

Stroke Amplitude less than 1.7 kA?

- The stroke could not be less than 1.7 kA:
- Based on theory: Cooray (2010) found the minimum first stroke to be 2 kA.
- Based on measurements, Krider et al (2010) found the minimum 1st stroke to be 3 kA.
- Luminosity and branching indicate that amplitude of the stroke was substantial.

Other failed predictions of CVM

- ESE failure incidents prove invalidity of CVM:
- The failure incidents observed by Hartono in building equipped with a single air terminal prove the invalidity of either theory which is claimed to form the basis of the installation.

Other failed predictions of CVM

- Failures of Franklin rod systems prove invalidity of CVM:
- The CVM implies that conventional installations use more air terminals than is necessary. The fact that shielding failures still occasionally occur proves the invalidity of the CVM.

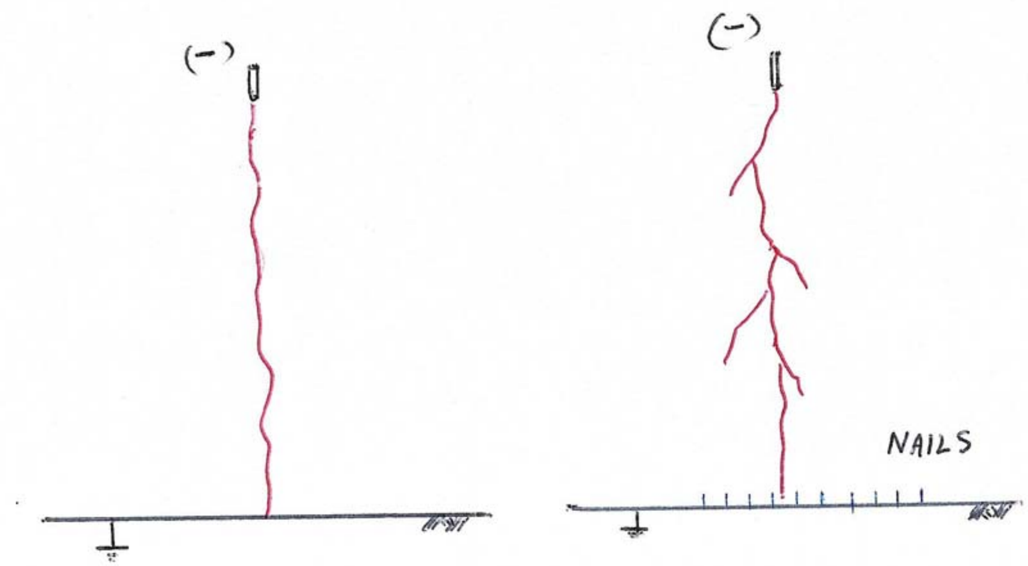
Other failed predictions of CVM

- Radioactive rod installations consisted of one air terminal per building, installed same as done for ESE devices. Hence they complied with the CVM. It follows that their reported failures prove the invalidity of the CVM.

Invalid assumptions of CVM

- Most lightning flashes have (-) polarity, and the channel is branched.
- On the other hand, negative imulses in the lab produce no branches.
- By inserting nails in the ground plane and repeating the imulse test, Schonland proved that space charge caused the branching.

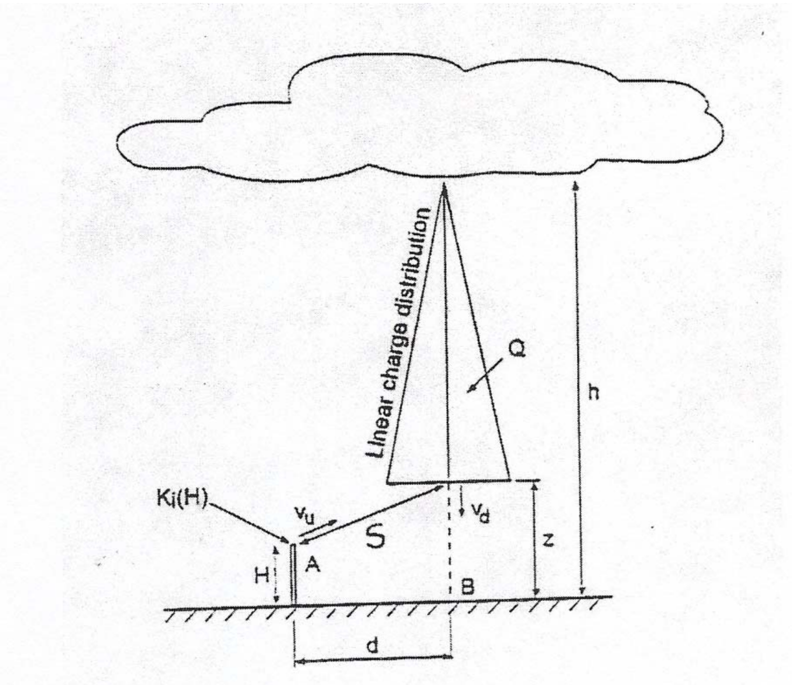
Role of pockets of space charge
(Schonland & Allibone, 1931, Nature)



Corollary:

- Since 1931 we knew that the reason lightning behaves the way it does is because of the existence of pockets of space charge,

CVM fails to account for Effect of the Space Charge



- It is that omission that makes height of the cloud, charges in cloud and charges in the upper part of the cannel appear to be significant, when in fact they are not.

Absurd Implication of CVM

- How would it sound if an engineer was asked to design the lightning protection of a power line and he then replied:
- “Oh, to be able to do that, I need to know the height of the clouds where the line has been built”?

Eriksson's elimination of the ground plane

- Eriksson eliminated the ground plane because he could not assign to it a critical radius, nor an intensification factor.
- Eriksson considers strikes to ground to be a "default condition"!

Eriksson’s elimination of the ground plane (2)

- Eriksson failed to realize that upward leaders can be generated from the ground plane, same as from structures.
- This contradicts field observations.

Upward leaders from ground

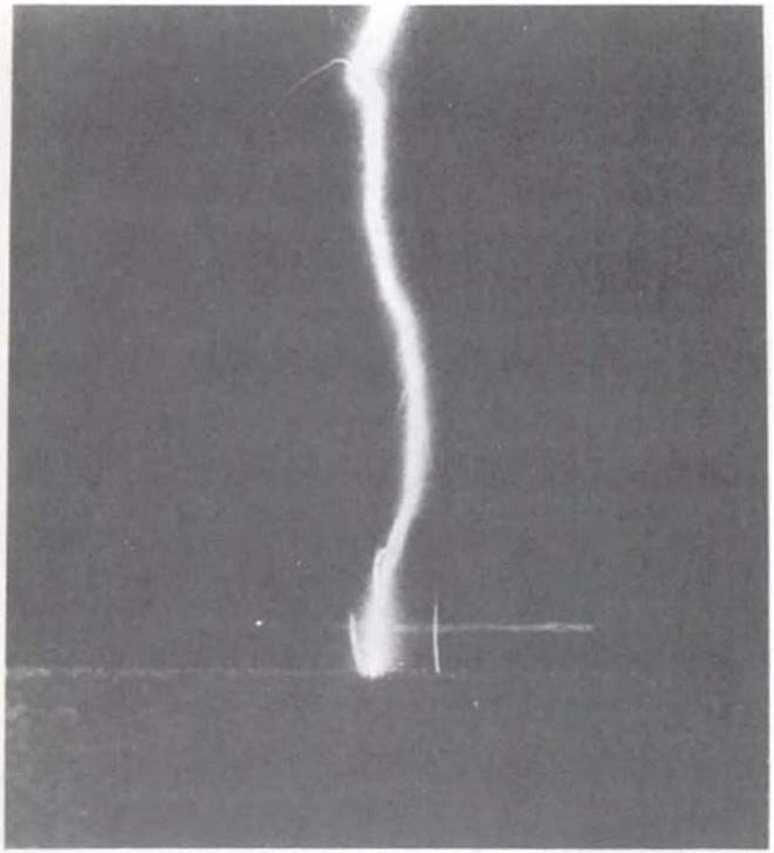
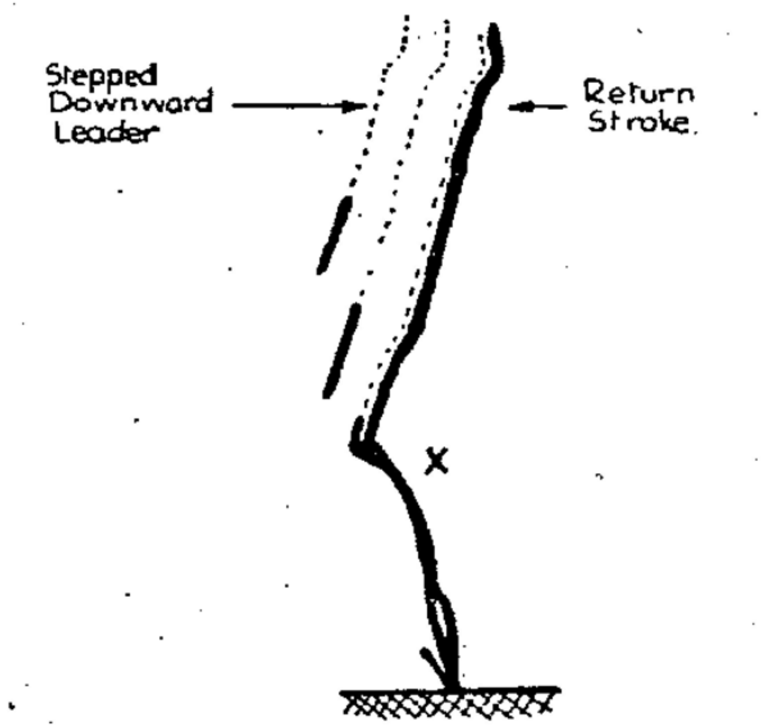


Fig. 6.5 A photograph of lightning to the sand at Manasquan Beach, New Jersey taken in July 1934 from a distance of about 30 m by Robert Edwards. No other information is available. Courtesy, Galloway, New York.

- (Strike to beach in New Jersey, USA, August 1934)

Malan photo (Golde, 1947)

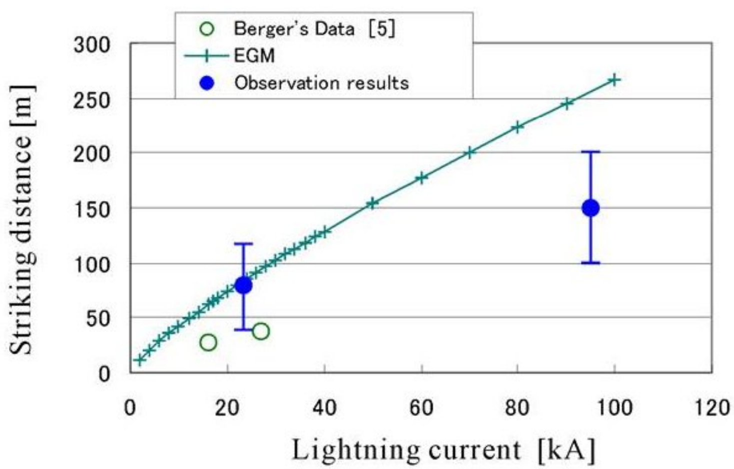


- Boys' camera photo by Malan.
- Reported by Golde, 1947.
- Striking distance: about 50 m.

Upward leaders from ground - 2

- Recent close photo of a strike to ground.

Striking Distance Discrepancy

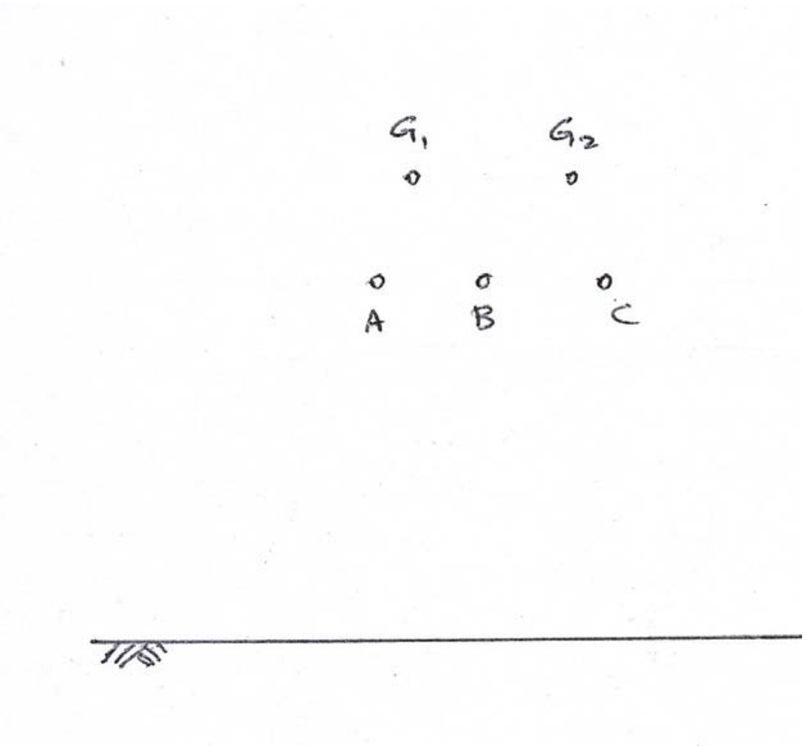


- **CVM implies that the striking distances are larger than used in the EGM. Recent measurements on 80 m high transmission towers in Japan found the striking distances to be not any larger than used in the EGM.**

CVM in Standards?

- ERICO, a manufacturer of ESE devices in North America & Australia, has been attempting to get the CVM in standards to promote the sale of its ESE devices.
- ERICO previously failed to penetrate Standards Australia and NFPA. ERICO is now attacking IEEE Standard 998 which deals with the shielding of substations.

Tricking Substation Designers

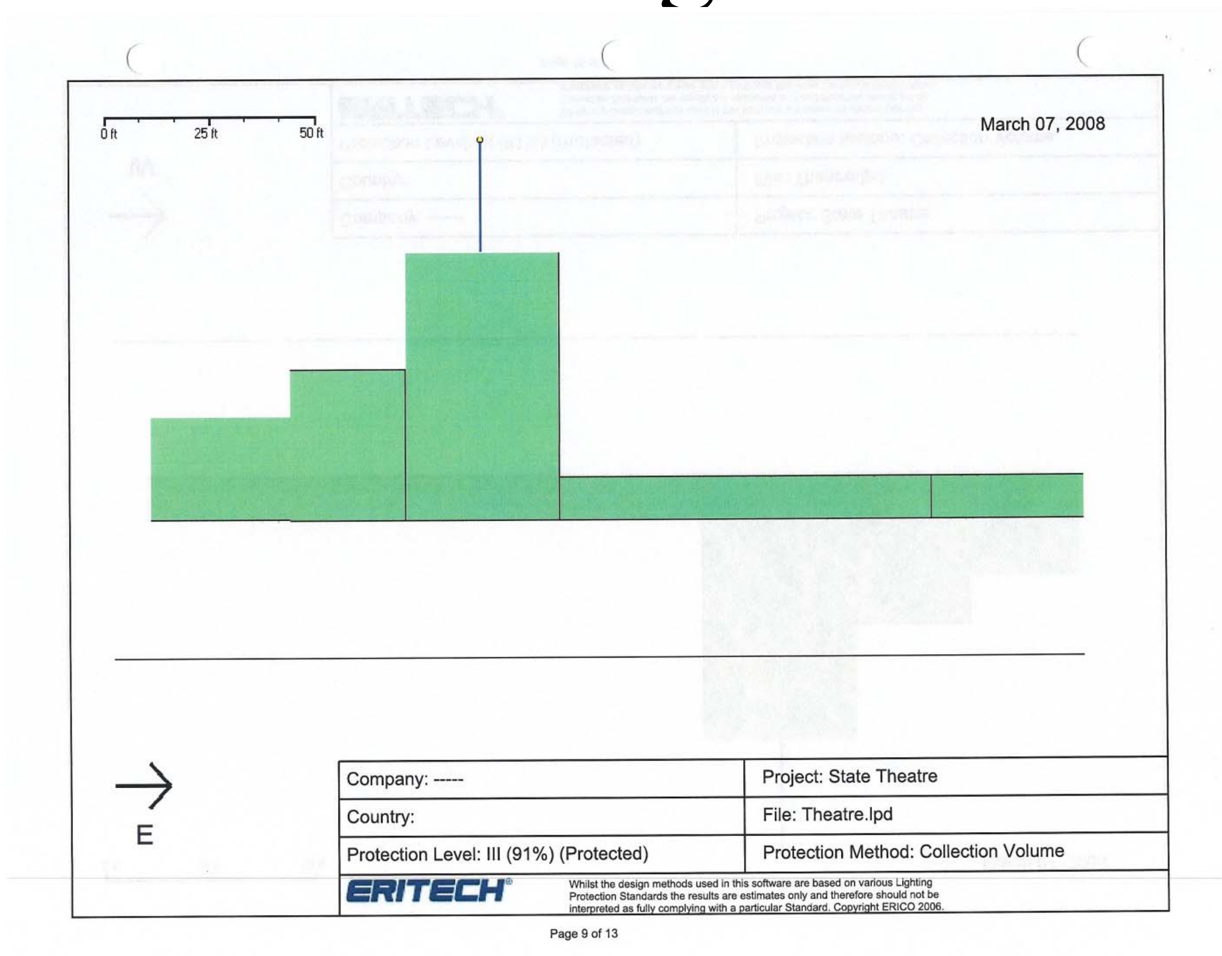


- **In case of power lines and substations, both objects are of the same type (shield wire and live wire), and the difference in height is small. Hence results of CVM and EGM are not far from each other.**

ERICO’s Hidden Agenda

- ERICO is using the above to trick IEEE WG D5 into believing that the CVM is a reasonable method. Once sanctioned by the IEEE, ERICO will then use it to justify the use of one air terminal per building based on vastly different intensification factors to the terminal and to the building.

ERICO's Application of CVM to Buildings



Consequences of corrupting IEEE Standard 998

- Serious damage to power systems if CVM was applied to substations.
- Facilitates sale of grossly inadequate ESE systems, thus exposing more people and property to hazards.
- Enable vendors to evade liability for consequences of their actions.

Conclusions

- By switching to using the CVM as their justification, ESE vendors in Australia and North America have in effect conceded that ESE theory is invalid!!!

Conclusions (2)

- CVM is invalid as it contradicts field observations regarding the following:
- a) its predictions;
- b) its assumptions (no space charge);
- c) its construction (its reason for eliminating the ground plane), and;
- d) its estimates of the striking distances.

Conclusions (3)

- Serious damage to utility facilitates, and consequential damage due to related power outages, if CVM was applied to substations.
- A building with a single air terminal is mostly exposed to lightning strikes.
- Putting CVM/ESE in standards multiplies the risk to life and property, and enables vendors to evade liability.

Concluding Remarks

- WG D5 refused to consider a letter issued by the Scientific Committee of International Conference on Lightning Protection. So the proposed IEEE Standard contradicts the consensus of the scientific community
- We previously defeated ERICO's attacks against Standards Australia & the NFPA.

Concluding Remarks (2)

- We now need your help to repel ERICO’s attack against the IEEE by swinging the vote on draft Standard 998 via the participation of more concerned utility engineers.
- Only members of IEEE-SA are permitted to vote, expected in early 2011.

Concluding Remarks (3)

- Please join the Lightning Protection forum (3,000 members worldwide) to learn of developments. Just send a blank e-mail to: LightningProtection-subscribe@yahoogroups.com
- Please contact me if you need more information: abdul_mousa@hotmail.com
- Thank you.