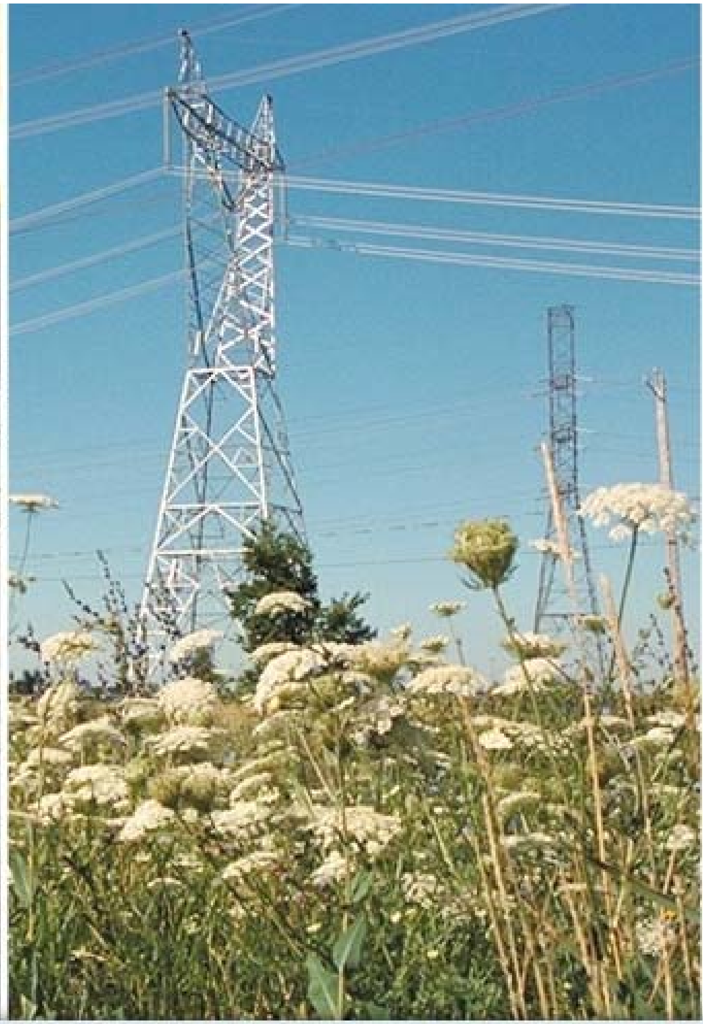

Level of confidentiality: PUBLIC

GROUNDING AND BONDING
An overview of recent success stories

James Crook, Eng.
Standards and Engineering Support

Hydro Québec

Biography: James Crook, Eng.

- **1985:** **Graduate of the Joncquière Technical College (Electronics)**
- **1989:** **Graduate of the Université du Québec à Trois-Rivières (Bachelor of Electrical Engineering)**
- **1990:** **Professional Field Engineer for Captel (Turnkey microwave and fibre-optic integration project)**
- **1992:** **Joined Hydro-Québec (Telephony expert in generating stations and substations)**
- **1998:** **Joined Intrawest – Mont Tremblant Resort (Telecom project management & expertise)**
- **2001:** **Established a professional engineering firm − Consulting work for Hydro-Québec & Intrawest (Telecom infrastructure, project expertise & operations)**
- **2009:** **Returned to Hydro-Québec (Technical expertise division, grounding and protection)**
- **2011:** **Transferred to Standards and Engineering Support**

Today's Agenda

Objective: Present some of the more recent best practices used in telecommunication grounding and bonding at Hydro-Québec.

Three parts:

- Why worry about grounding?
- Where are the risks?
- How grounding models compare?

Why worry about grounding?
General issues

- Our technical problems
  - Propagation of impulse noise
  - Unexplained service downtime/interruption
  - Deficient immunization against power faults (SPDs)
  - Insufficient fault energy dissipation (lightning protection)
  - Doubtful grounding practices (among professionals)
  - Lack of standards for hardware and installation techniques (among contractors)

CSA Standards

10-002 Object

(1) The object of bonding metal parts and metal systems together and to the grounded system conductor is to reduce the danger of electric shock or property damage by providing a low impedance path for fault current back to the source and to establish an equipotential plane such that the possibility of a potential difference between metal parts is minimized.

(2) The object of grounding the electrical system and non-current-carrying metal parts is to connect the earth to the equipotential plane, thereby minimizing any potential difference to earth.

(3) The object of using an ungrounded system or a system incorporating neutral grounding devices is to provide an alternative to a solidly grounded system, thereby limiting the magnitude of fault current and minimizing the damage resulting from a single fault.

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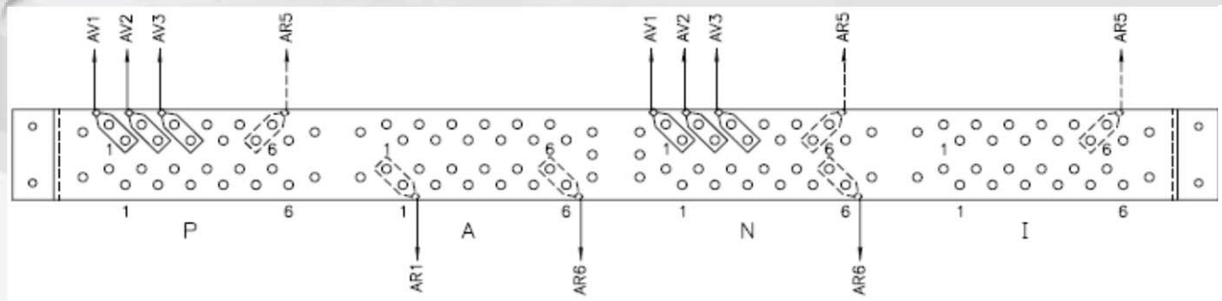
Why worry about grounding?
General philosophies(MTGB) T1.313-2003

Standards Committee T1 Telecommunications



P	A	N	I
1 -Week			
Current line radio	Outside building ground (peripheral, web)	DC power plant (return bar)	DC Level I equipment frame or cabinet
Gas tube protector	Main building ground (water pipe)	Equipment grid	DC Level II (switches and routers)
Metallic conduits (ingress/egress)	Main building ground (electrical, structural)	DC converter (return bar)	DC Level III (routers)
	Secondary telecom room	DC equipment frame or cabinet (general)	
		DC PABX	
2 – Medium			
Metallic sheath cables box			
AC distribution panel box			
Fire alarm box			
AC equipment box			
Heating unit			
Air conditioning unit			
Out plant cables			
Electric motors			
Cable dispatching frame			
PAGA system			
AC frame or cabinet (routers and/or switches)			
3- Strong			
Antistatic floor (local)			
Raised floor (local)			
UPS system			
Inverter			
Generator			
Tower obstacle lights			

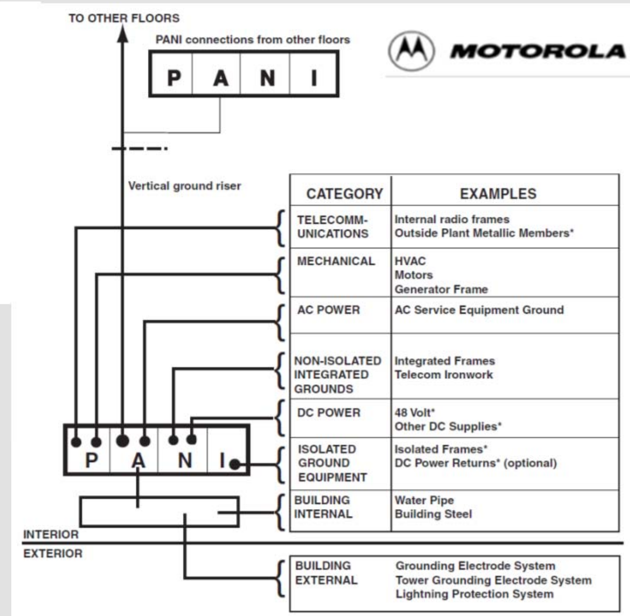


FIGURE 5-23 PANI GROUNDING SYSTEM SEQUENCE

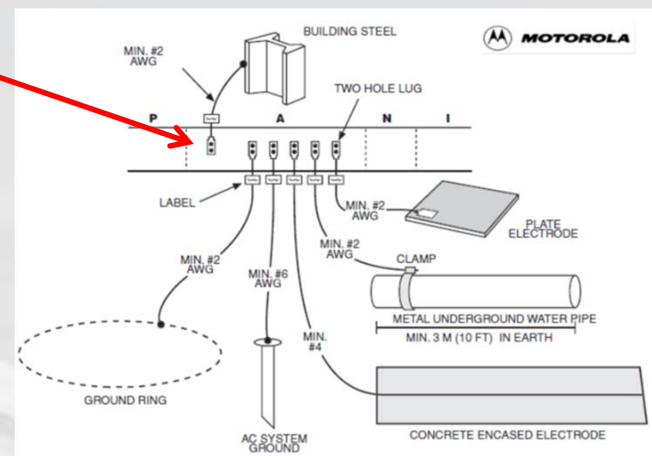
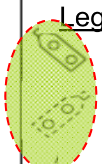


FIGURE 5-10 TYPES OF ACCEPTABLE GROUNDING ELECTRODE SYSTEMS



Legend:

Lug termination on front

Lug termination on back

NOTE: angled hole array allows to add or remove lugs while maintaining lug contact on opposit side of MTGB

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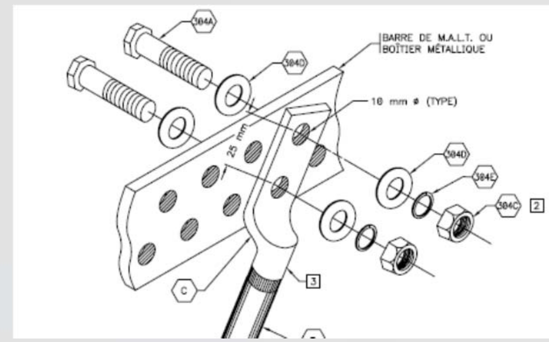
Why worry about grounding?
General hardware (torque efficiency)

Boulon (diamètre)			INSTALLATION		MAINTENANCE	
(po)	(/ 64po)	(mm)	N-m	lb-pce	N-m	lb-pce
1/8	8	3,2	2,3	20	2,0	18,0
9/64	9	3,6	2,8	25	2,5	22,5
5/32	10	4,0	3,4	30	3,1	27,0
11/64	11	4,4	4,0	35	3,6	31,5
3/16 #10	12	4,8	4,5	40	4,1	36,0
13/64	13	5,2	5,1	45	4,6	40,5
7/32	14	5,6	6,2	55	5,6	49,5
15/64	15	6,0	7,3	65	6,6	58,5
1/4	16	6,4	7,9	70	7,1	63,0
5/16	20	7,9	12,4	110	11,2	99,0
3/8	24	9,5	18,1	160	16,3	144,0
7/16	28	11,1	24,9	220	22,4	198,0
1/2	32	12,7	31,6	280	28,5	252,0

Copper (bronze–silica)

Nuts & bolts assembly



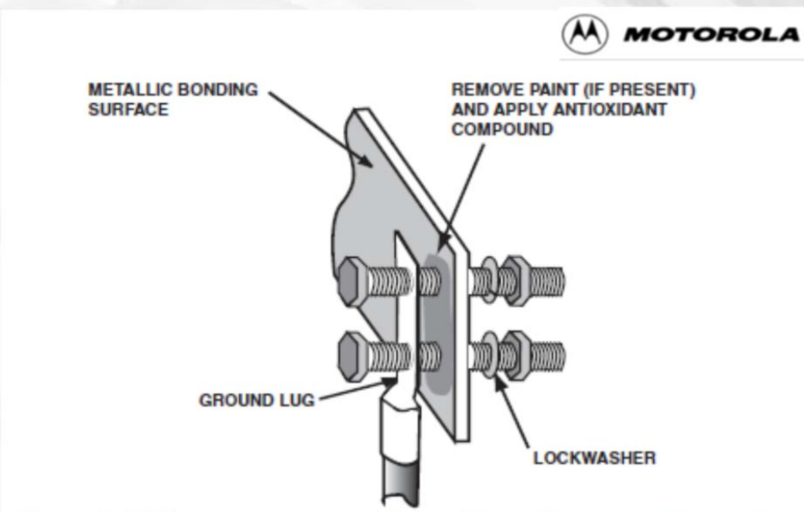
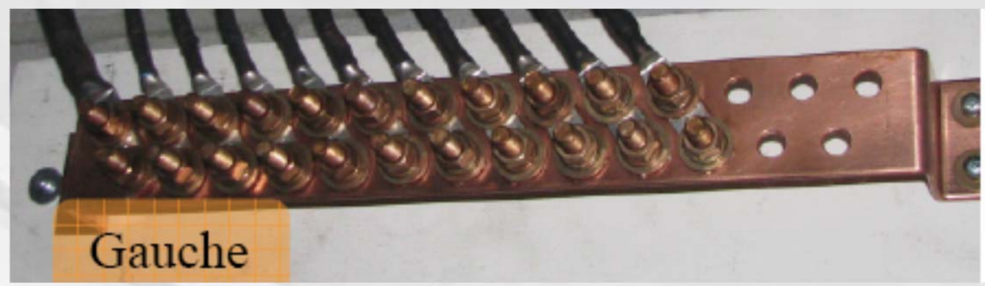
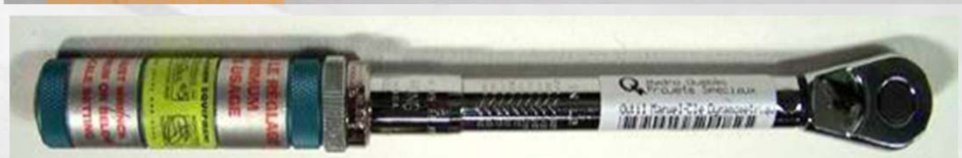


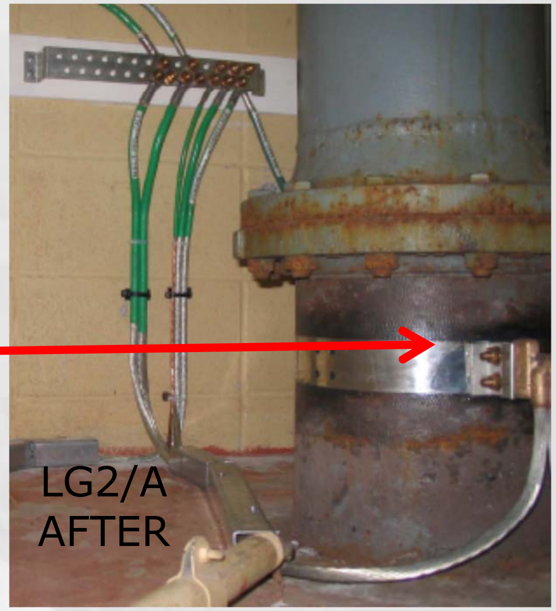
FIGURE 5-19 PROPER LOCATION OF WASHER WHEN CONNECTING GROUND LUG

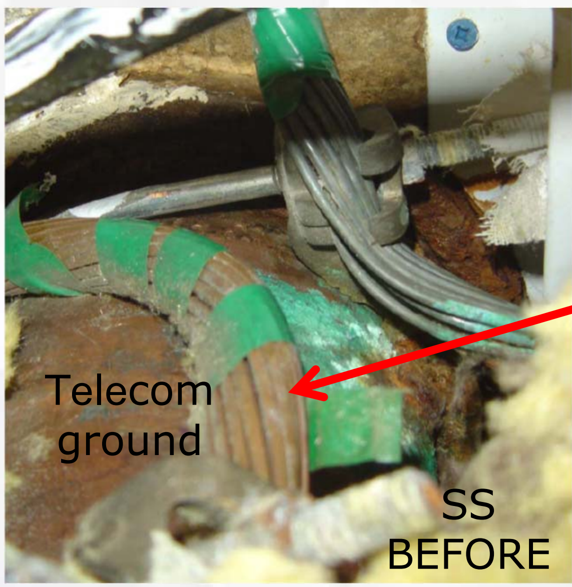


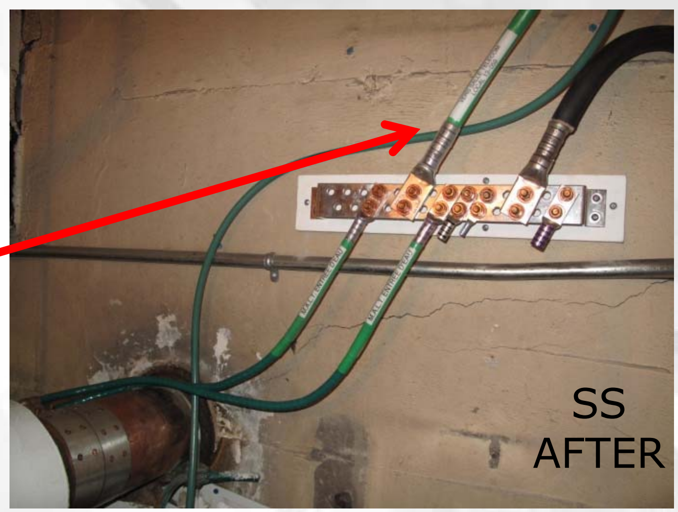


Why worry about grounding?

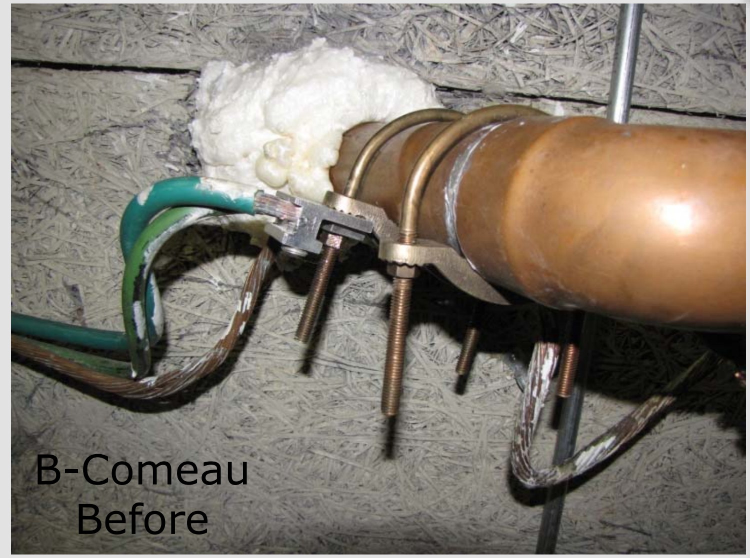
General improvement

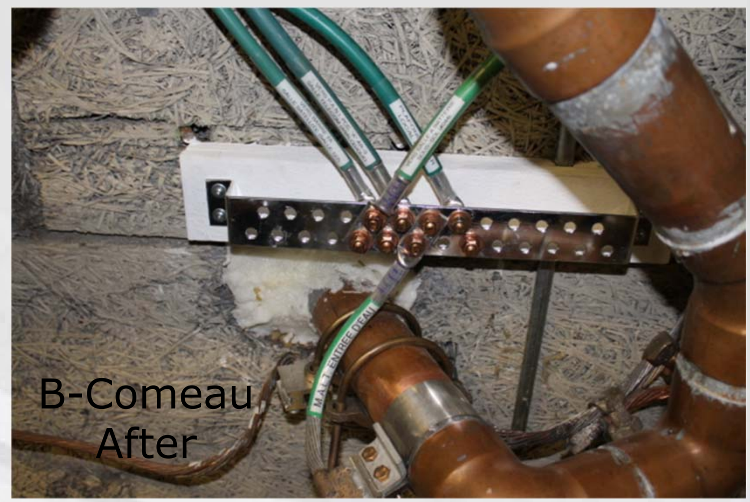






Quality of building ground





Where are the risks?
Grounding: Electric vs telecom

IEEE Std 1692™-2011
IEEE Guide for the Protection of Communication Installations from Lightning Effects

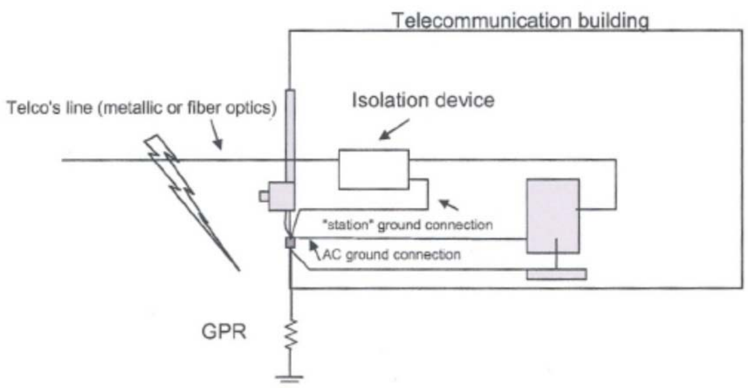


Figure 3—Example of an acceptable and proper installation. Power, equipment, and protection device grounds are at the same reference.

10-208 Grounding connections for two or more buildings or structures supplied from a single service

Where two or more buildings or structures are supplied from a single service,
(a) the grounded circuit conductor at each of the buildings or structures shall be connected to a grounding electrode and bonded to the non-current-carrying metal parts of the electrical equipment; or
(b) except for buildings housing livestock, the non-current-carrying metal parts of the electrical equipment in or on the building or structure shall be permitted to be bonded to ground by a bonding conductor run with the feeder or branch circuit conductors.

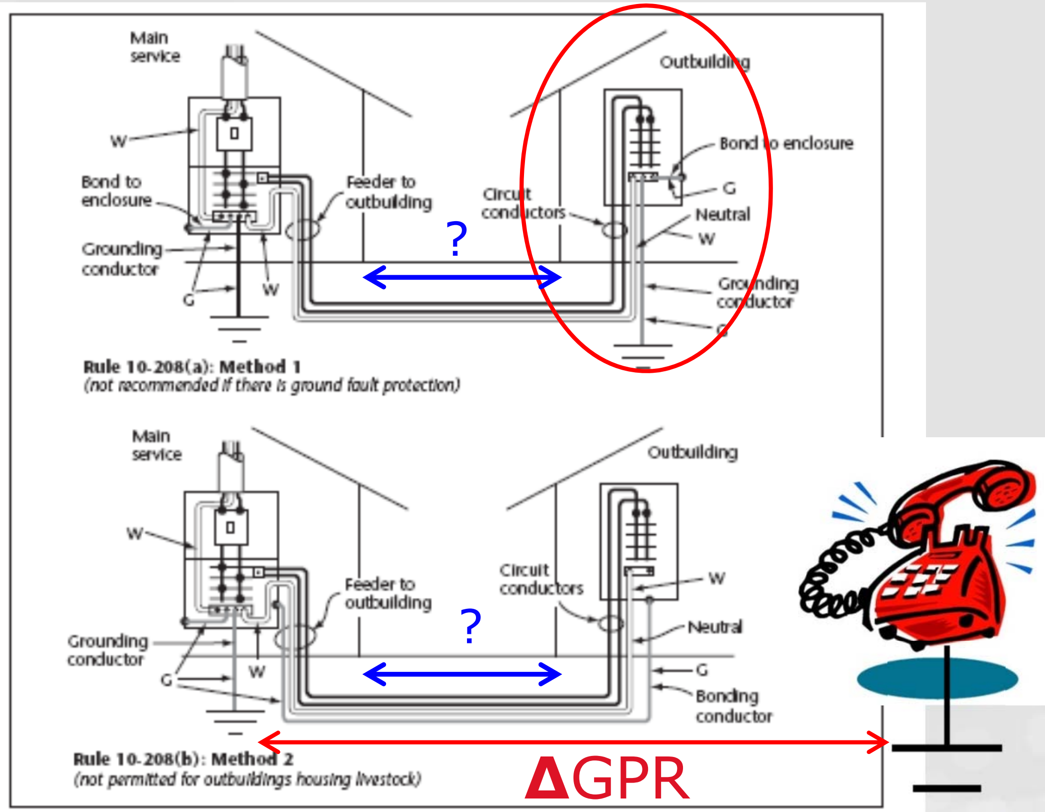
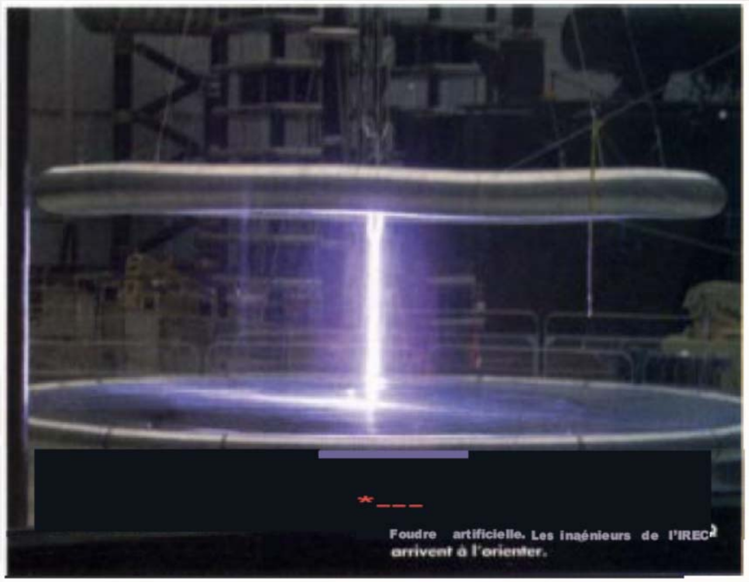
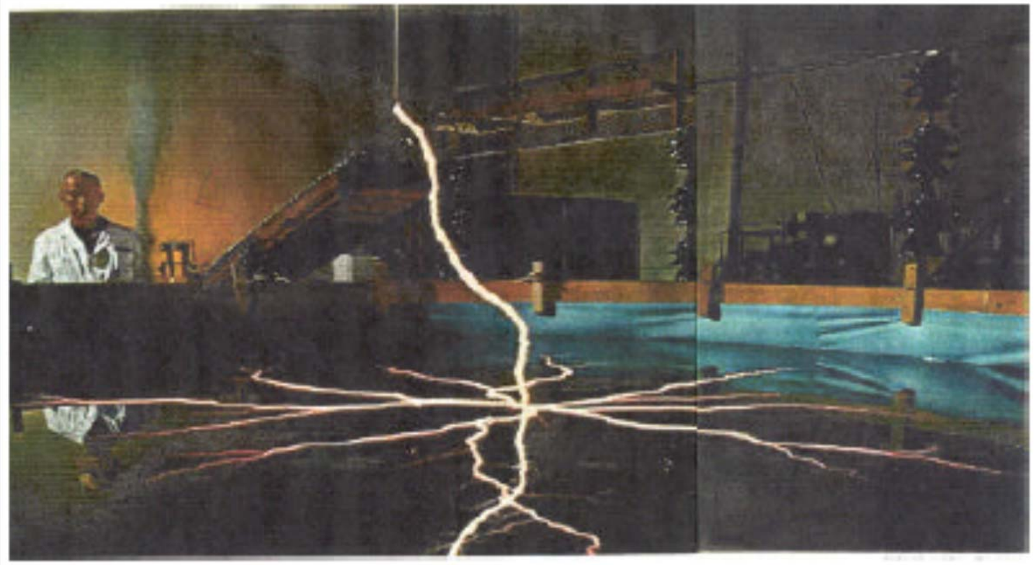


Figure 10-17
Grounding for two or more buildings

Where are the risks?
Our concern: Lightning



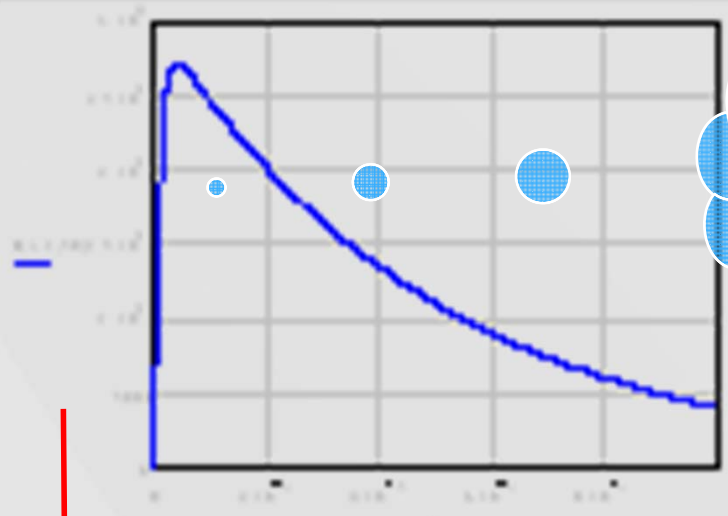
Québec-Science / Février 1999 23



(This photograph appeared in the August, 1969 issue of The National Geographic Magazine.)

Lightning strikes at Lake Macquarie, Peter Kenelly

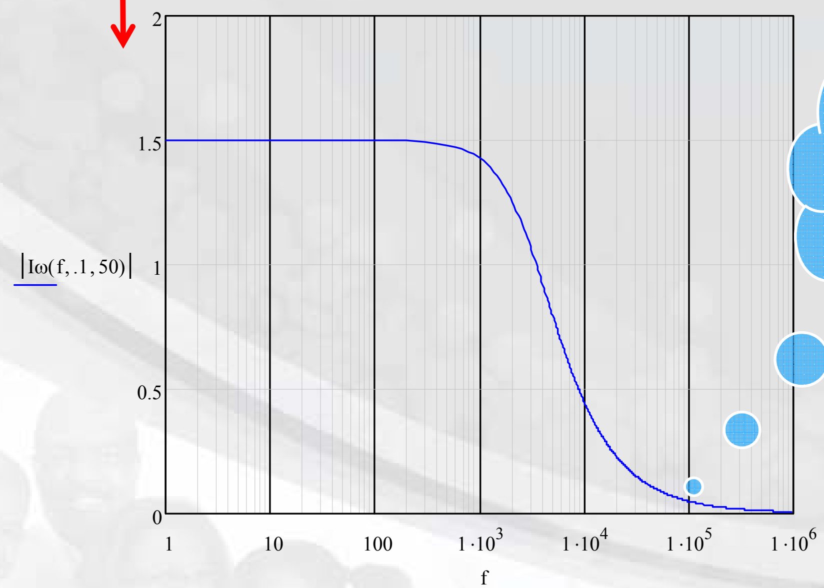
Where are the risks?
Voltage dissipation below 100 kHz



di/dt can cause arc flashes and dielectric breakdown

Current vs time

Fourier transformation

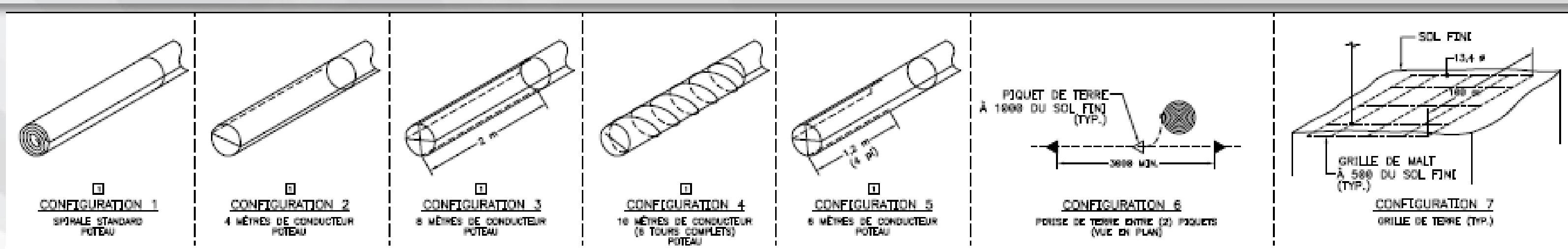


Grounding configuration must be efficient up to 100 kHz.

Frequency vs time

Equipotentiality at lower frequencies

Where are the risks?
Ground configurations

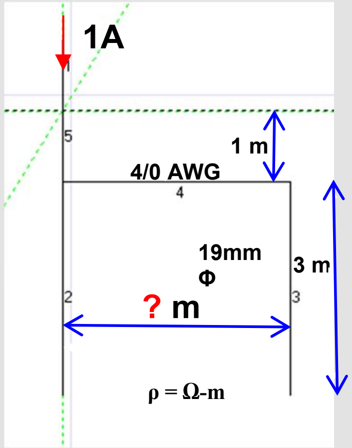


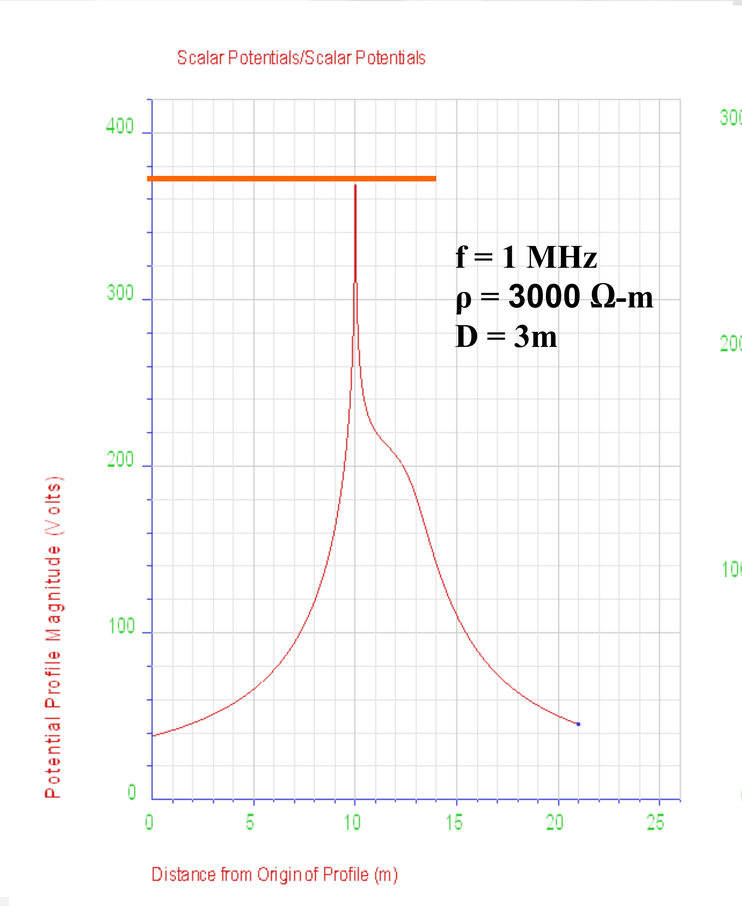
Where are the risks?
Models : 2 rod electrodes

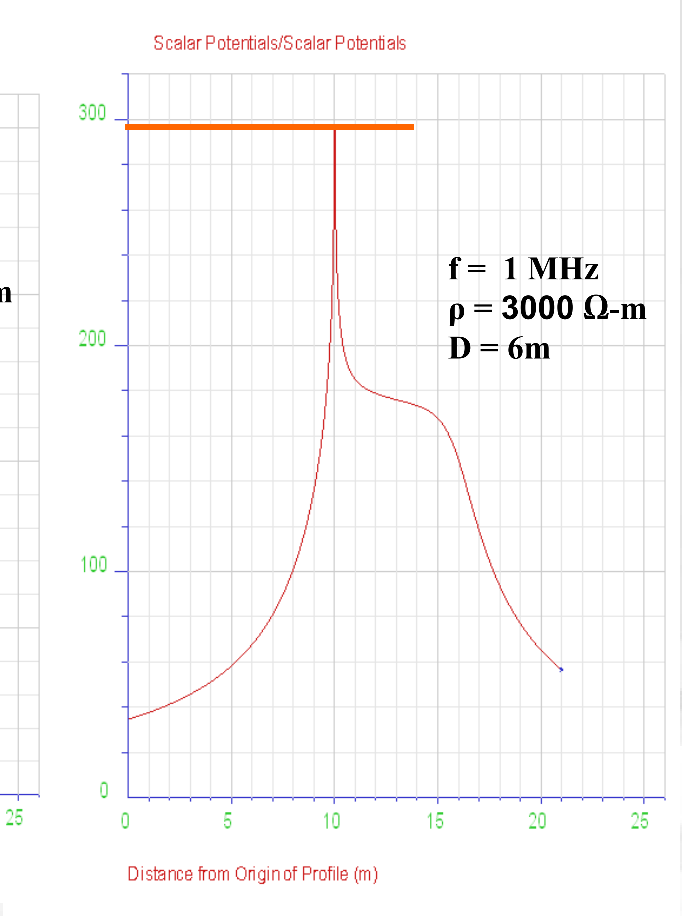
10-700 Grounding electrodes (see Appendix B)

(1) Grounding electrodes shall consist of
- (a) manufactured grounding electrodes;
- (b) field-assembled grounding electrodes installed in accordance with this Rule; or
- (c) in-situ grounding electrodes forming part of existing infrastructure as defined in this Rule.

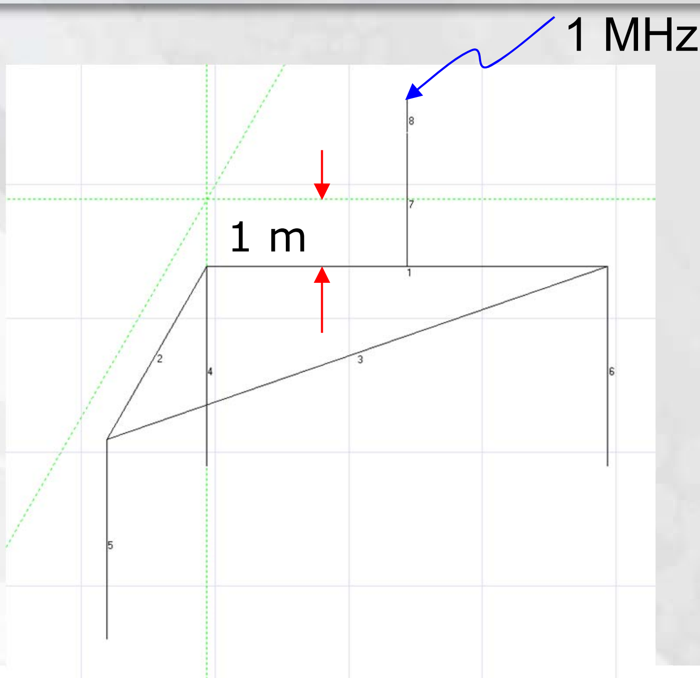
(2) Manufactured grounding electrodes shall
- (a) in the case of a rod grounding electrode, consist of 2 rod electrodes (except for a chemically charged rod electrode where only one need be installed) spaced no less than 3 m apart,
  - (i) bonded together with a grounding conductor sized in accordance with Rule 10-812; and
  - (ii) driven to the full length of the rod; or





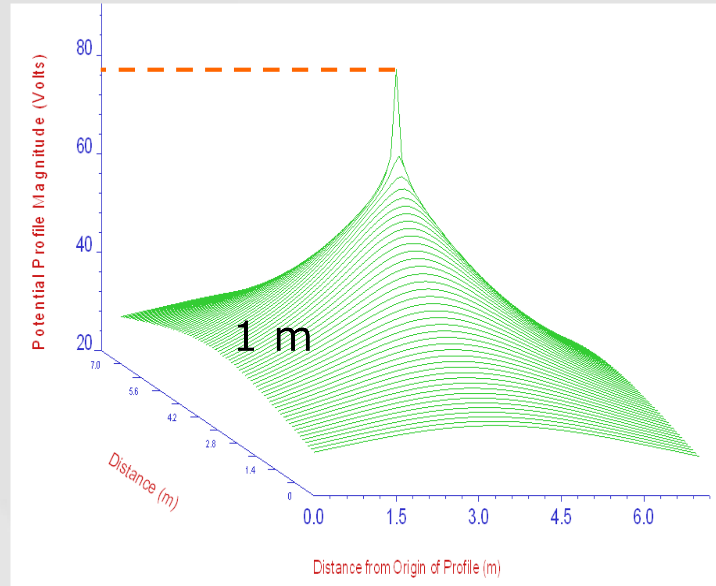


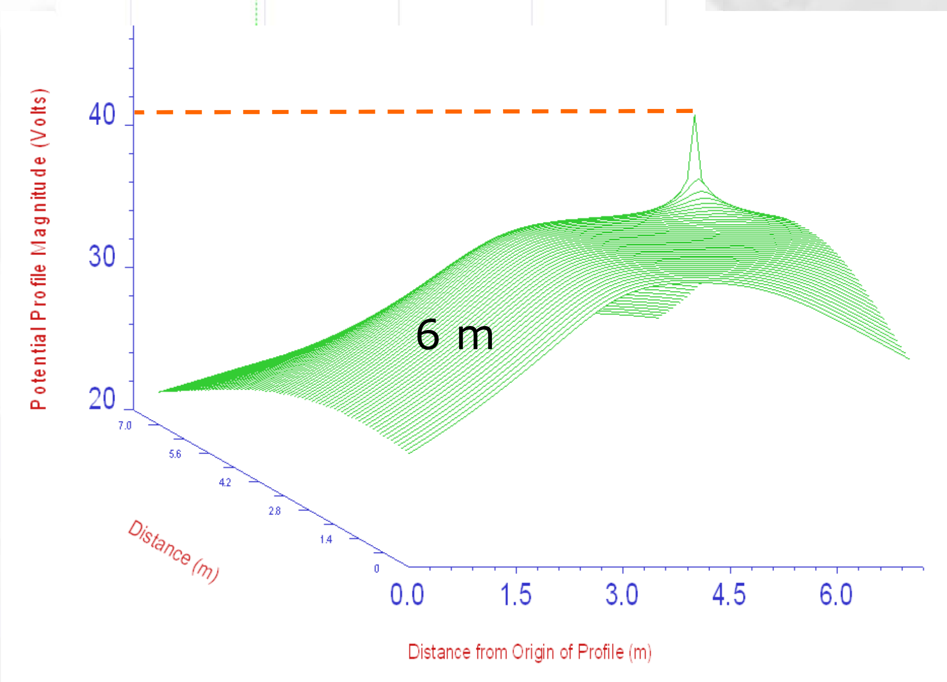
Where are the risks?
Models: Equilateral triangle configuration

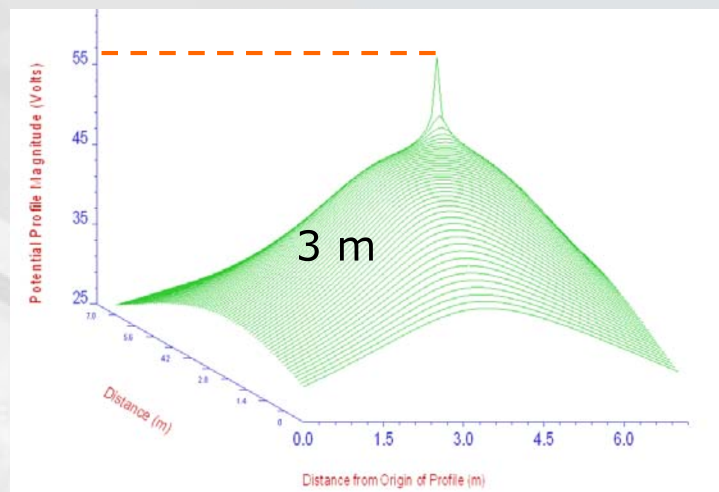


3 m
19 mm Φ

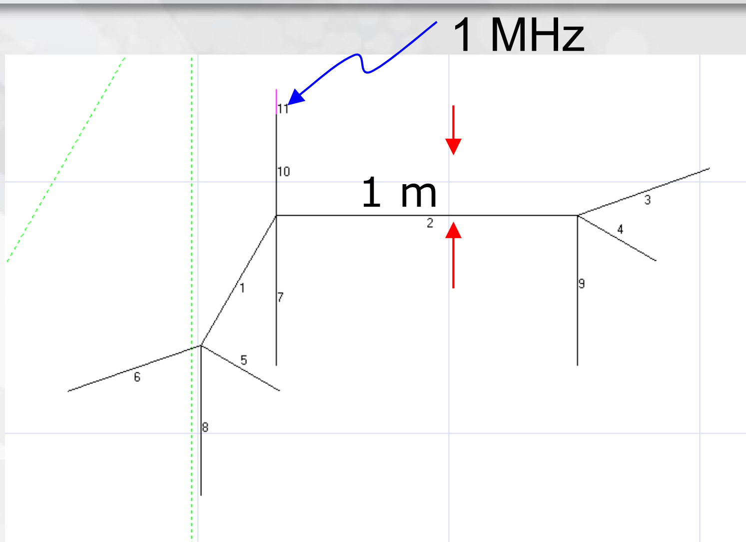
ρ = 300/3000 Ω





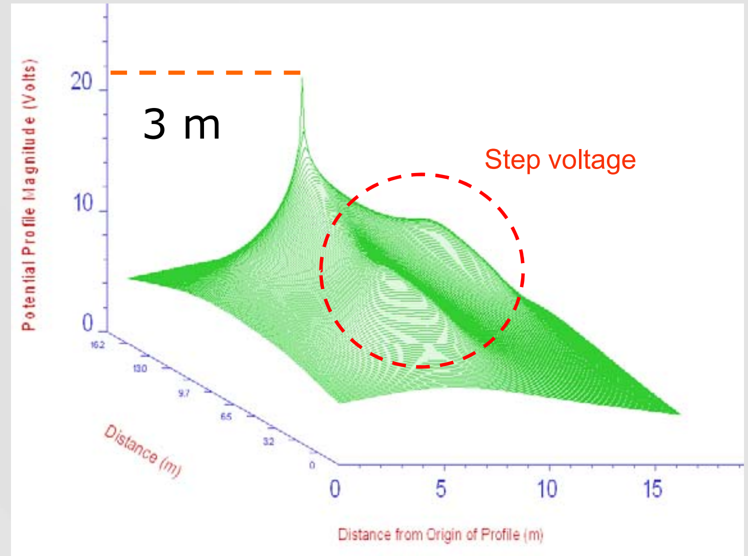


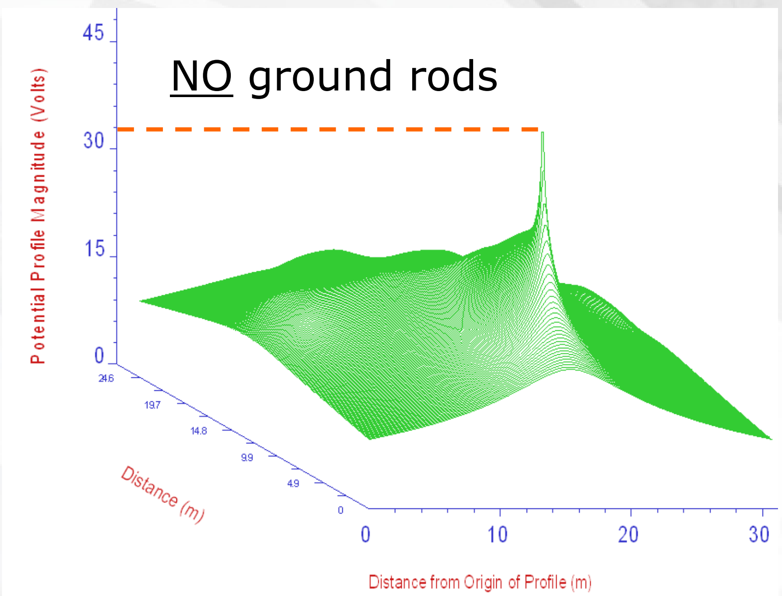
Where are the risks?
Models: Web configuration

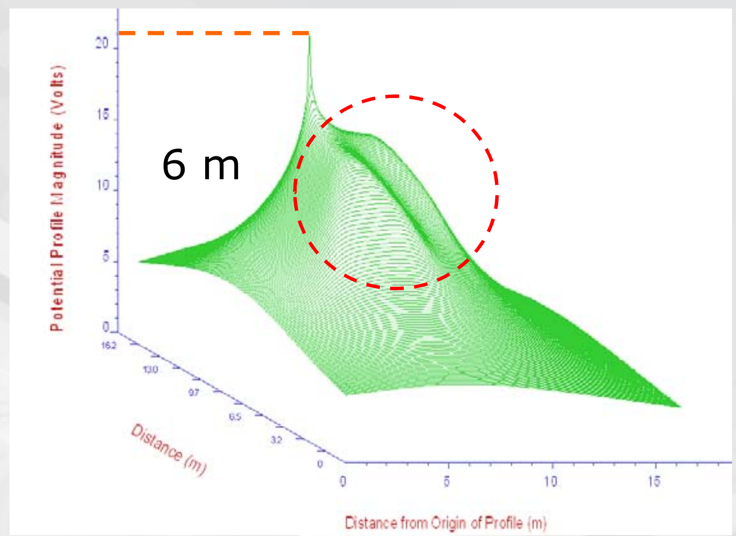


3 m
19 mm Φ

ρ = 300/3000 Ω







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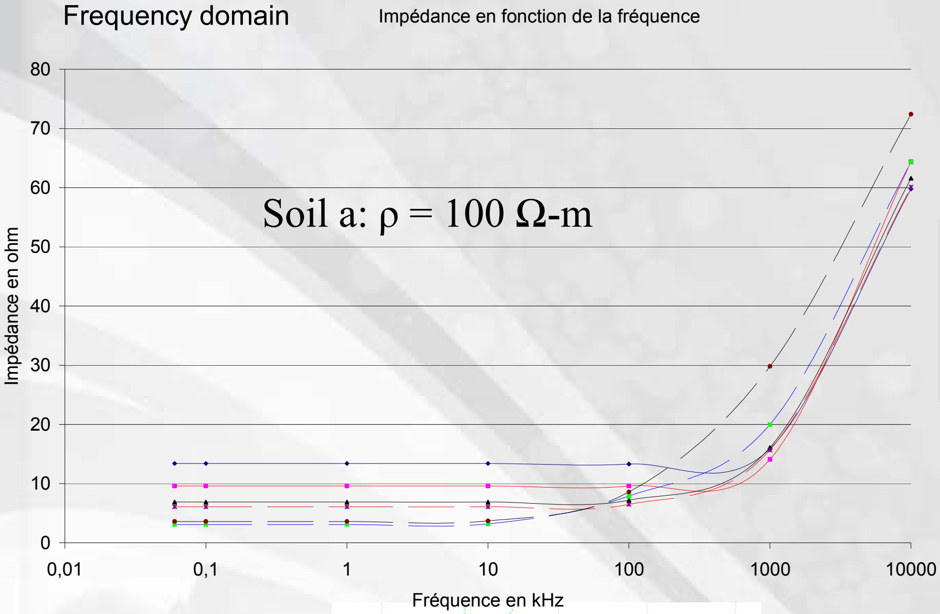
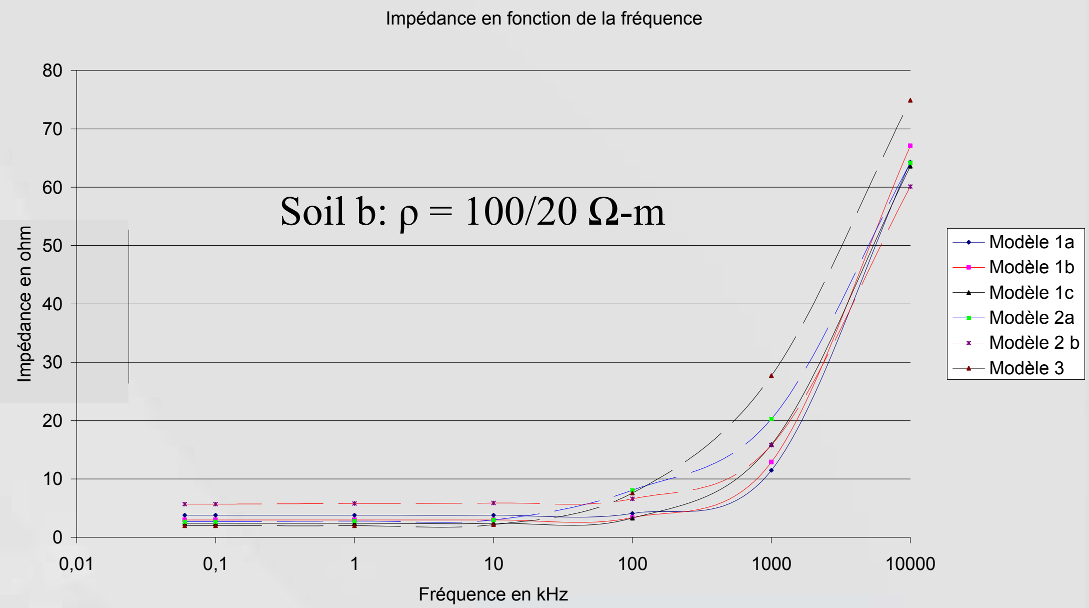
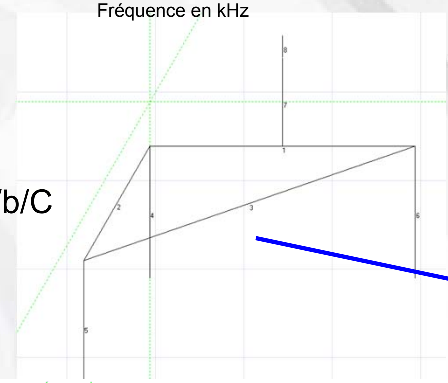
Where are the risks?
Models: Overall performance Y vs. Δ

Impulse of 1 X 50 µs
Frequency domain

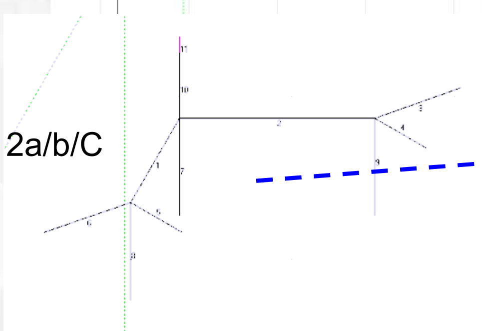


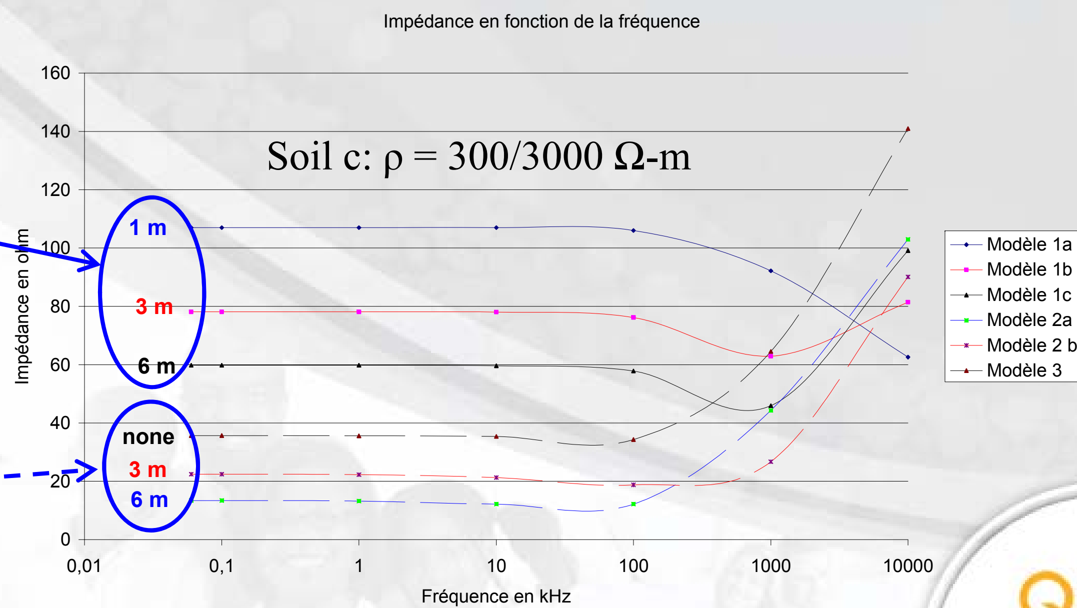


Model 1a/b/C



Model 2a/b/C





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Where are the risks?
Models: Tower grounding

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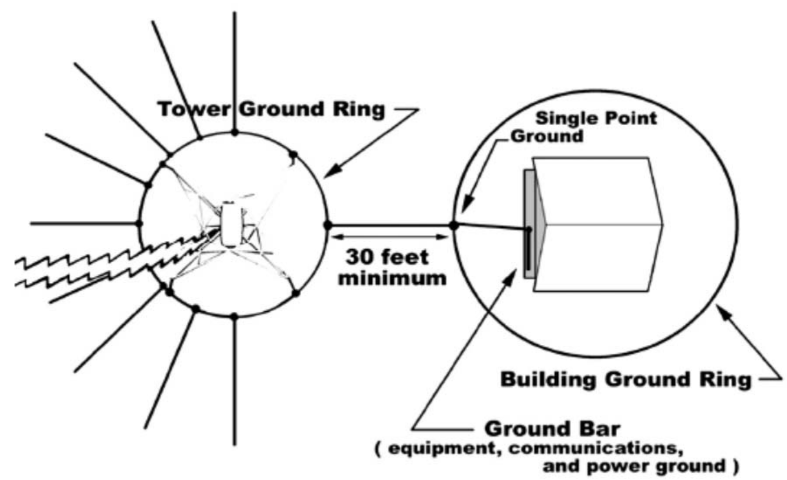
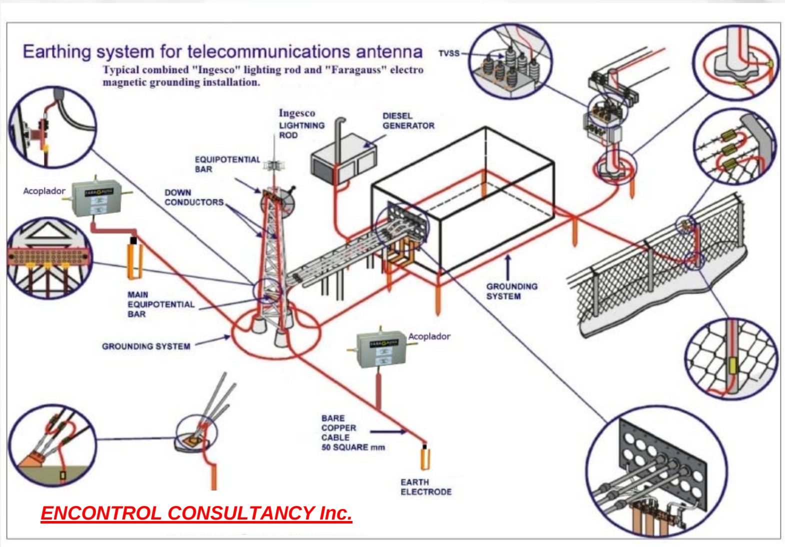


The ideal number of radial counterpoises recommended is ten (see Block [B5]. The maximum effective length of each radial counterpoises (see Block [B5]) is 24 m (80 feet) each. Longer length radial counterpoises will offer little dissipation improvement because the lightning strike current will not remain on the radial counterpoises for much over 24 m (80 feet).

In sites with limited space (i.e., real estate limitations or restrictions), the recommended grounding system is, at a minimum, 60 m (200 feet) of grounding conductors. This includes a ring ground of 12 m (40 feet) and four radial counterpoises, each 12 m (40 feet) in length.



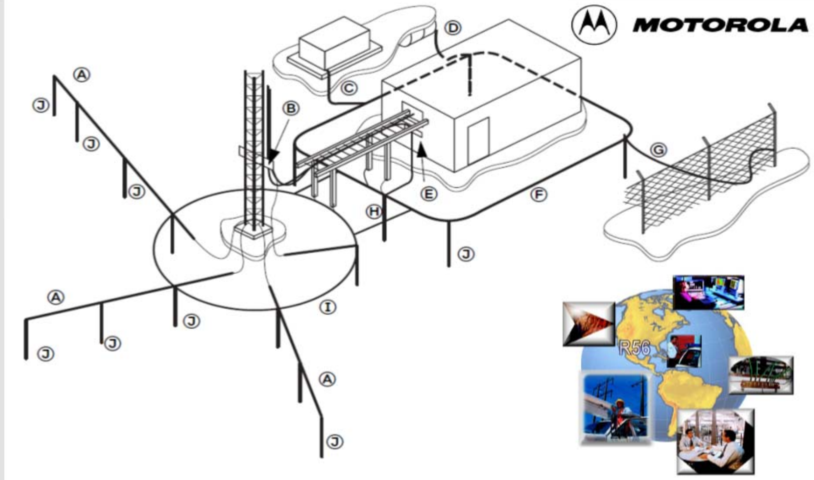


FIGURE 4-4 TYPICAL EXTERNAL GROUNDING ELECTRODE SYSTEM

T1.313-2003

Standards Committee T1 Telecommunications

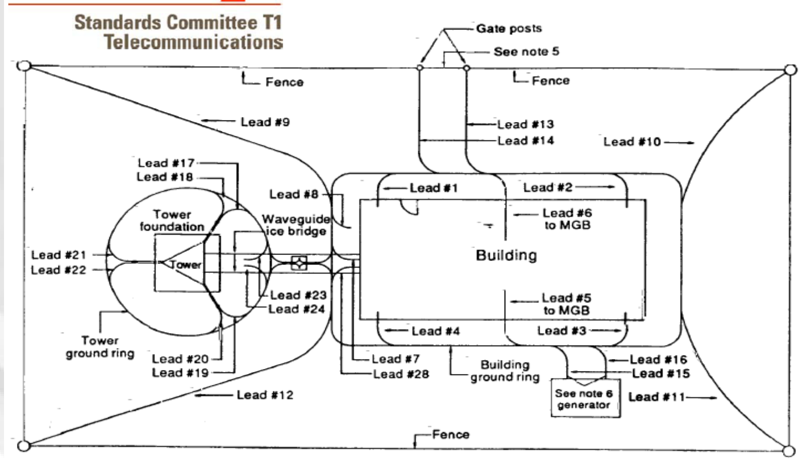
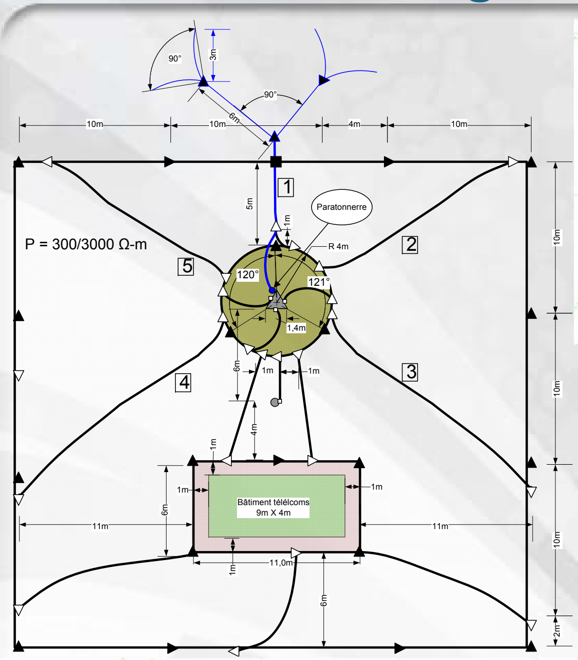
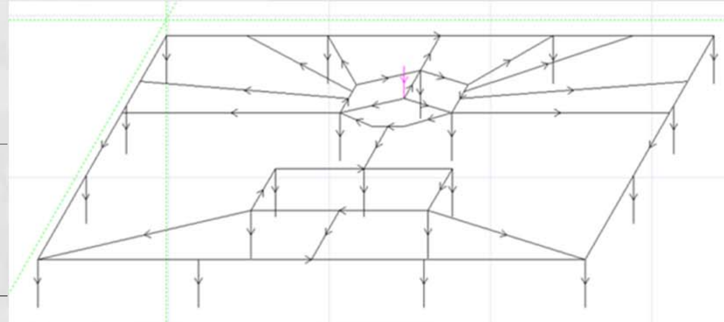


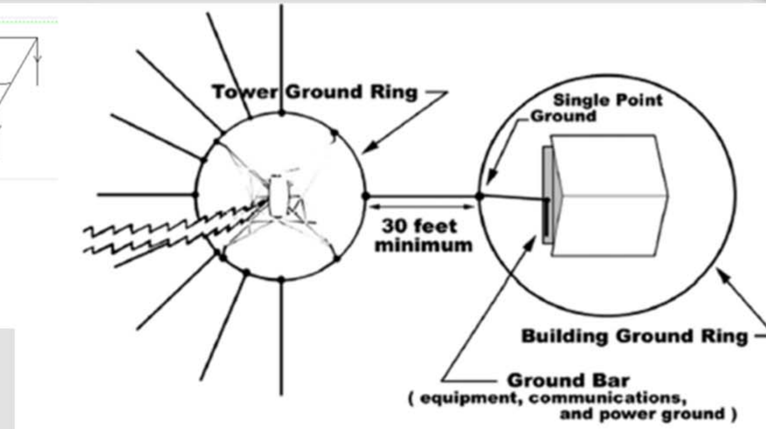
Figure 3(a) - Supplemental radio microwave tower site grounding

Where are the risks?
Models: Tower grounding



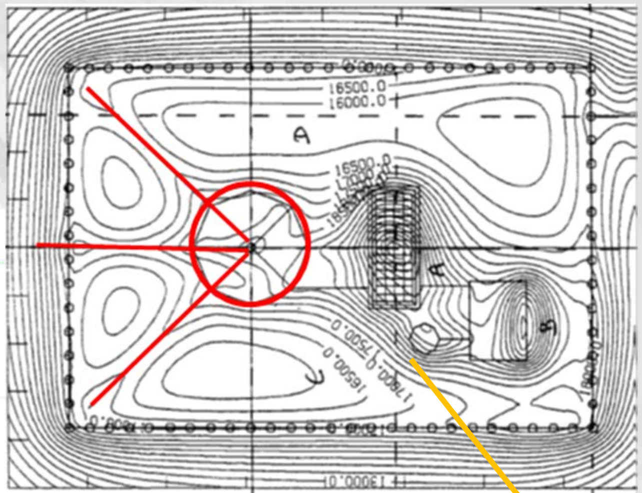


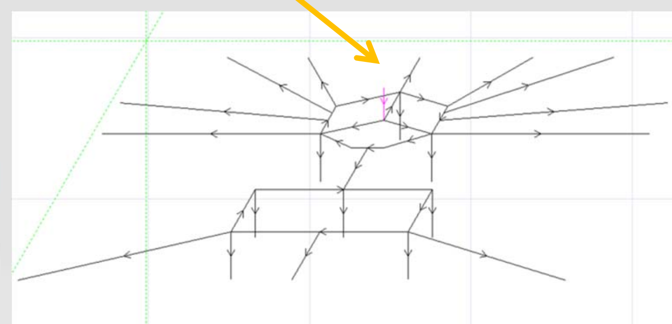
10 radials with a fence GND



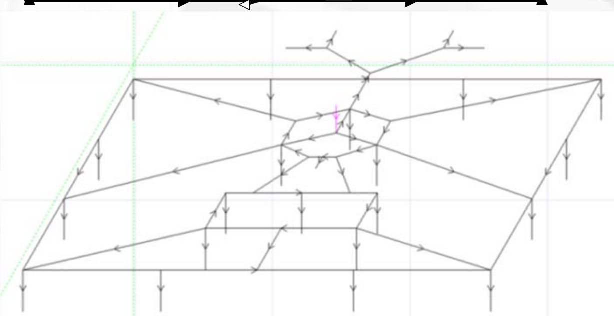
NOTE—Reprinted with permission from Duckworth et al.[B10]

Figure 7—Example of a grounding system

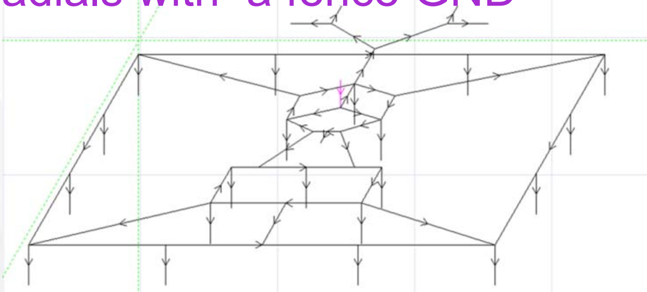




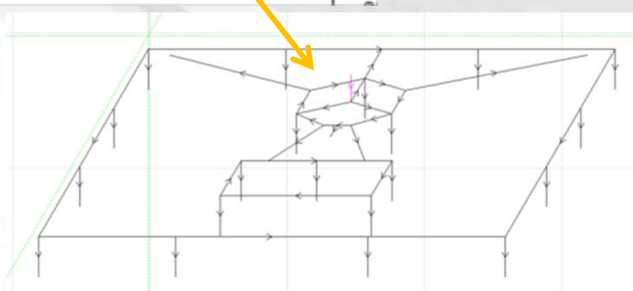
10 radials without a fence GND



5 radials with a fence GND

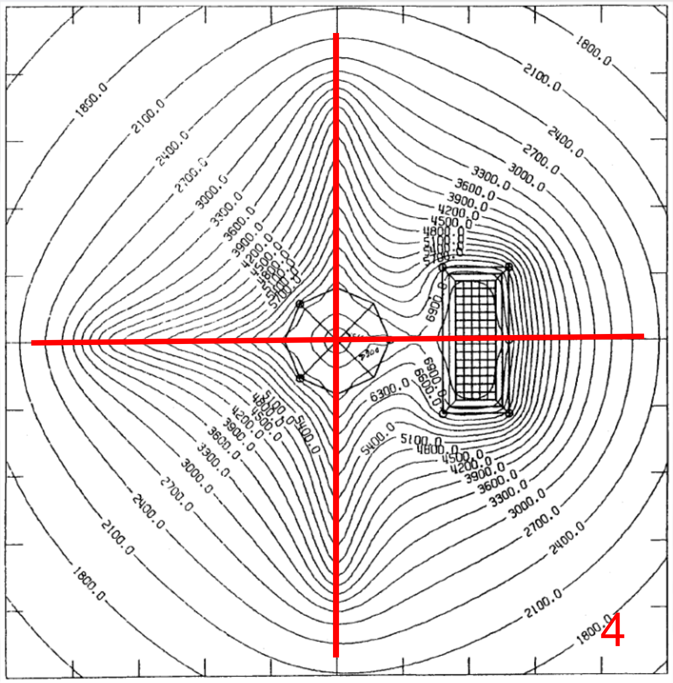


3 radials with a fence GND

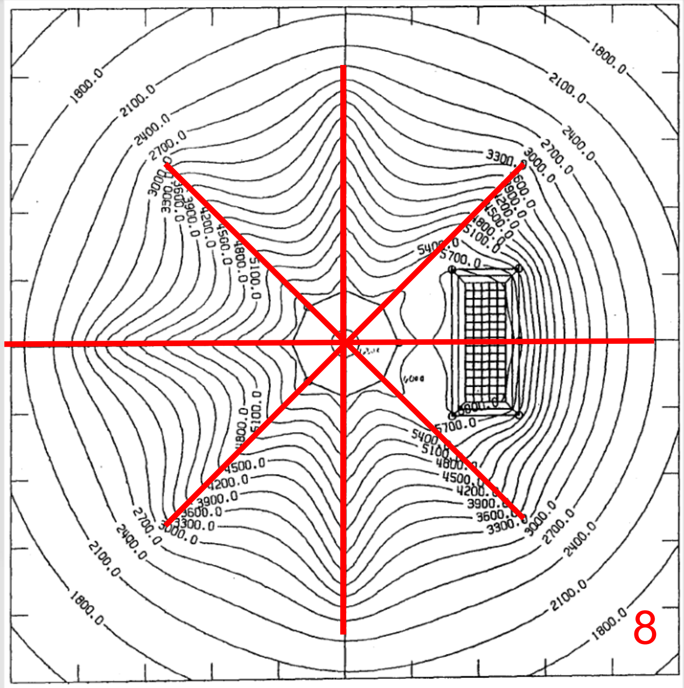


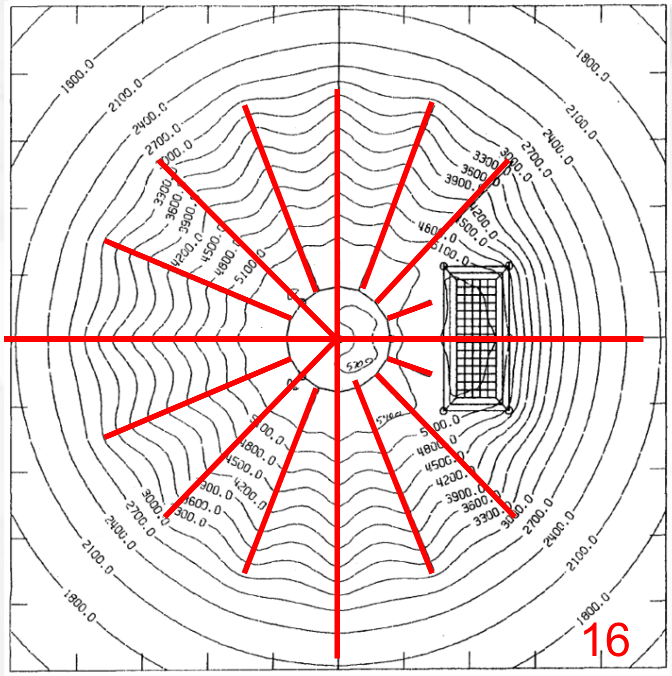
3 radial not connected to the fence GND

How do grounding models compare?
HQ-CG-PT-CEM601-1, 1994



CYMGRD - 1992
P = 10 Ω-m
F = 60 Hz





- Uniform step voltage within the tower ground loop
- Increasing number of ground rods above 3 has no significant effect
- Number of radials has no influence on ground potential level
- Increasing the number of radials decreases ΔV in the area (step voltage)
- Adding a 300-mm layer of crushed rock on top of local soil improves touch voltage tolerance values

CG-PT-CEM601-1

MARS 1994

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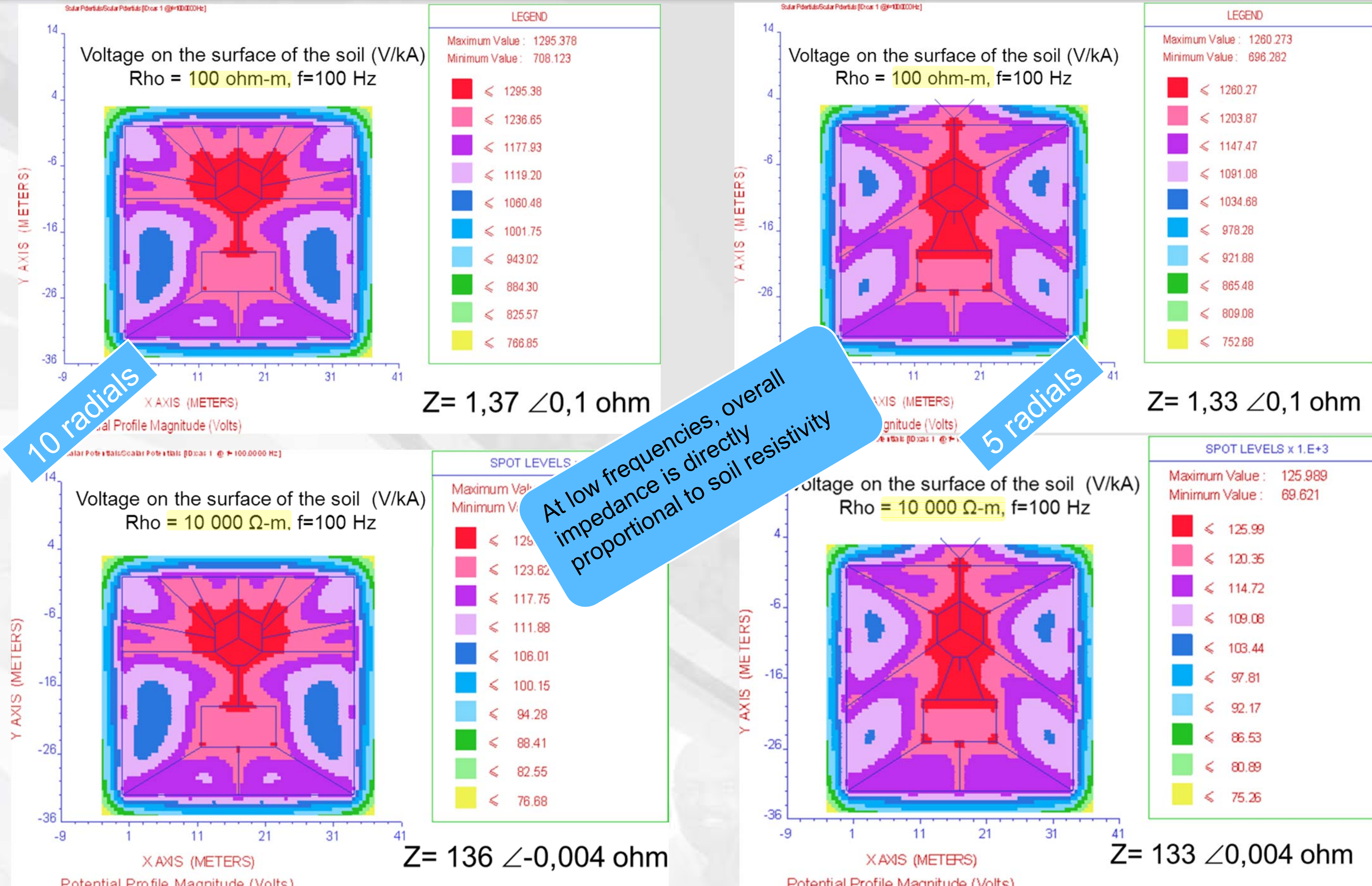
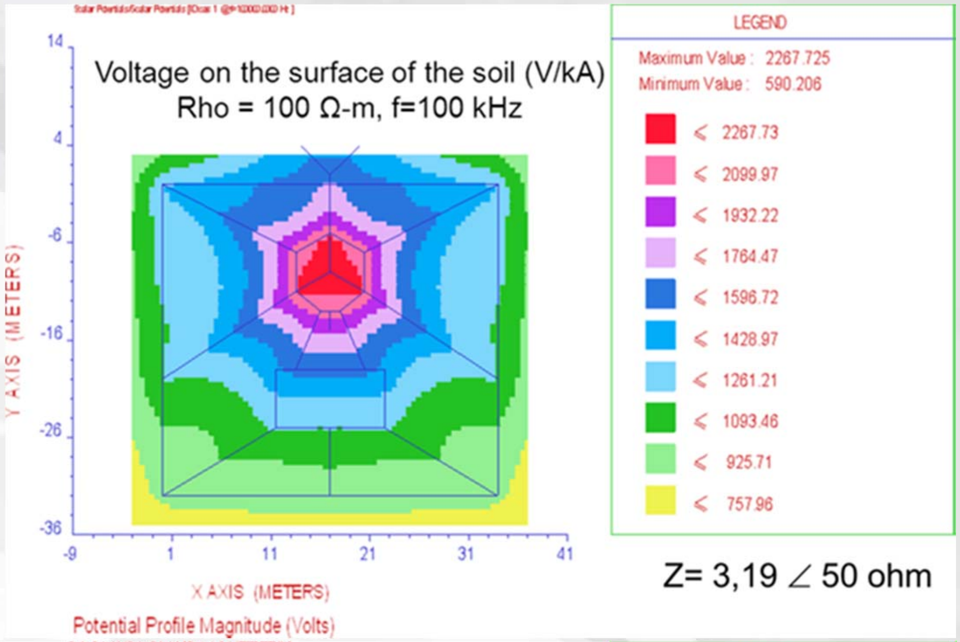
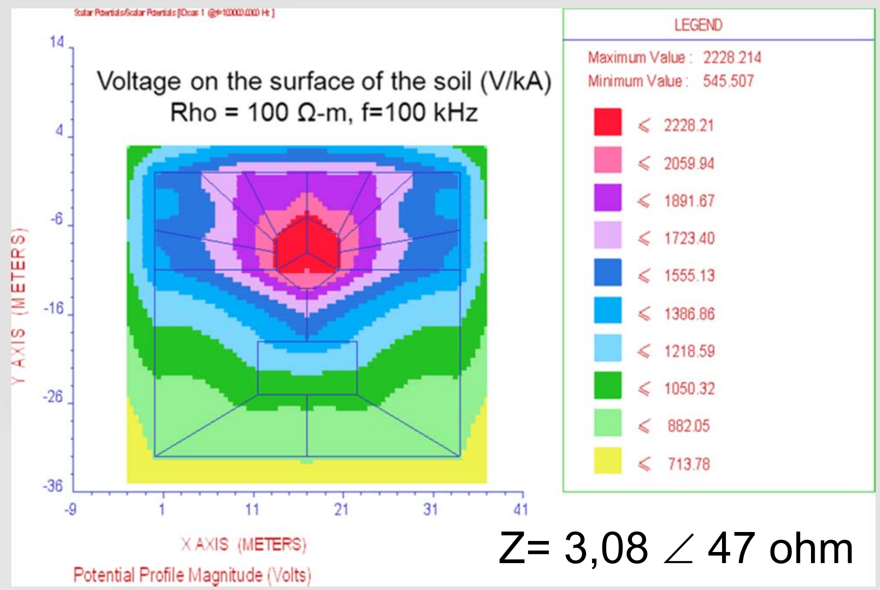
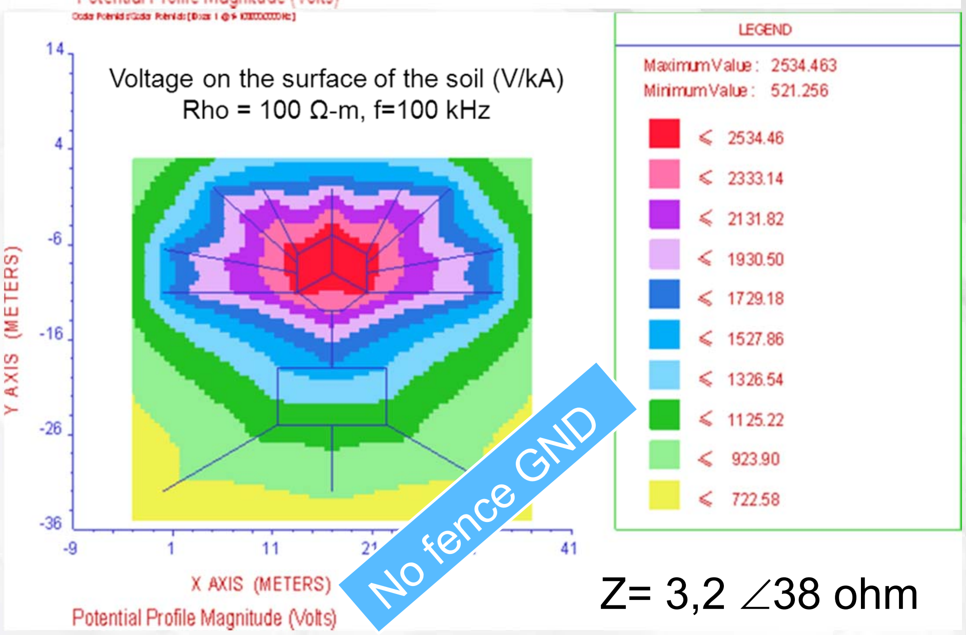
How do grounding models compare?
Rho = 100 Ω-m & 10,000 Ω-m, f = 100 Hz

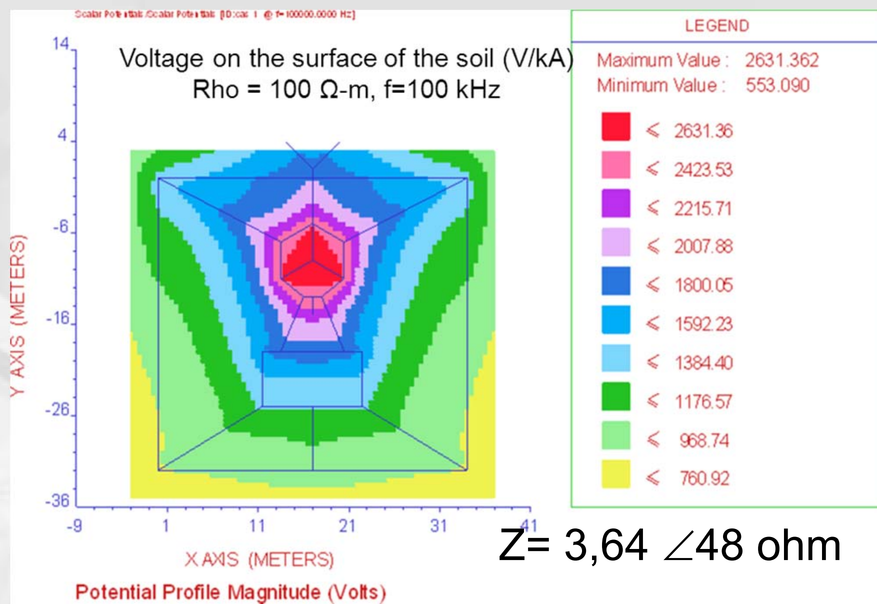


How do grounding models compare?
Rho = 100 Ω-m, f = 100 kHz









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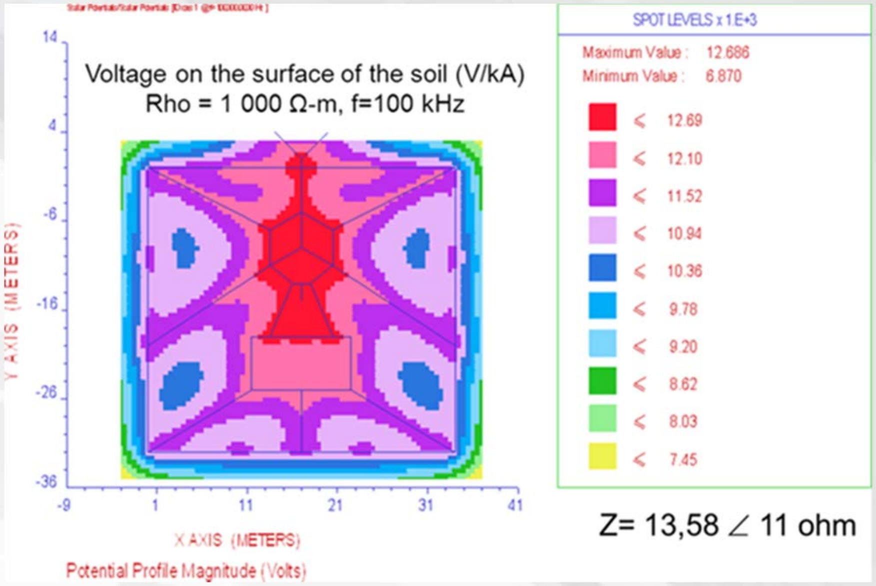
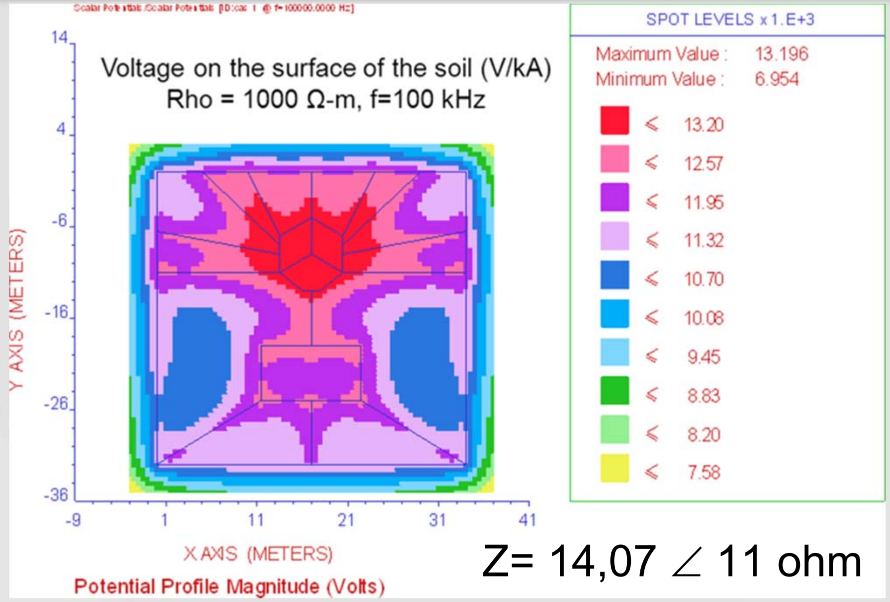
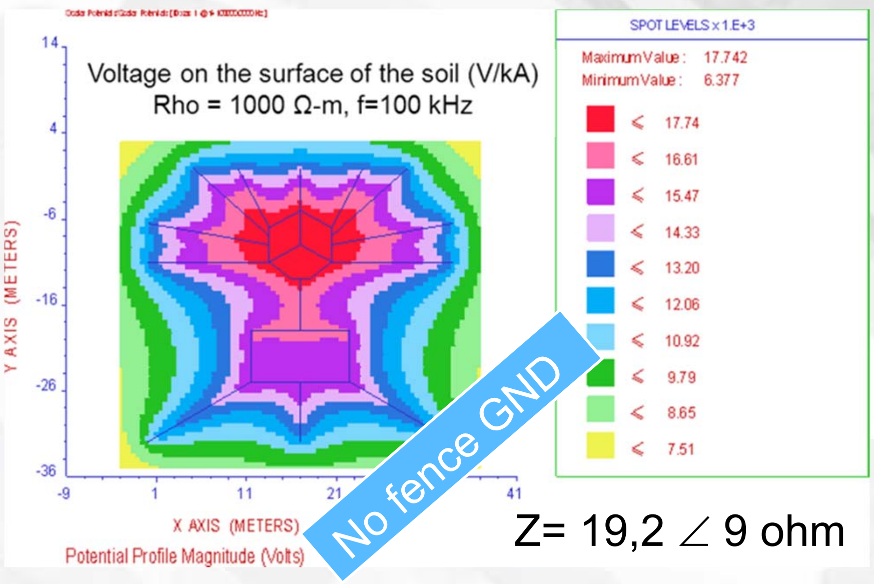
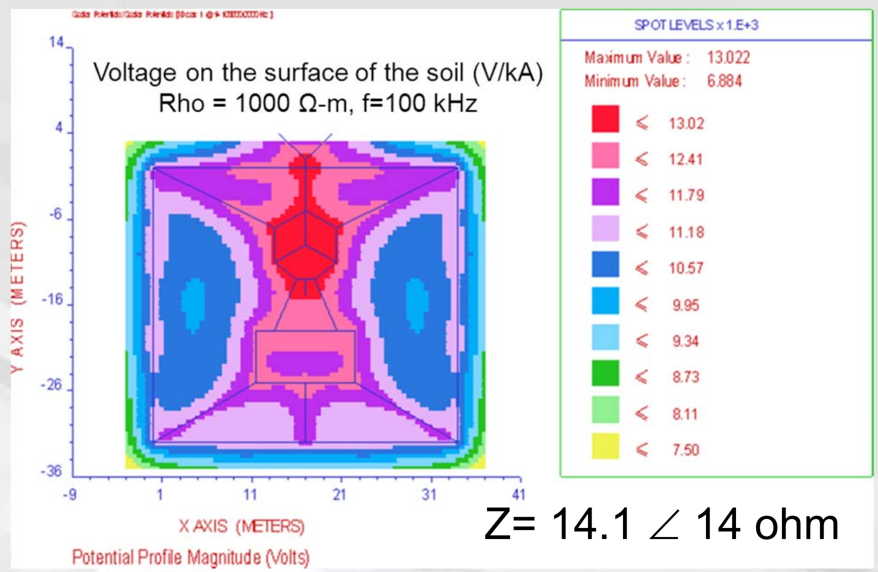
How do grounding models compare?
Rho = 1,000 Ω-m, F = 100 kHz

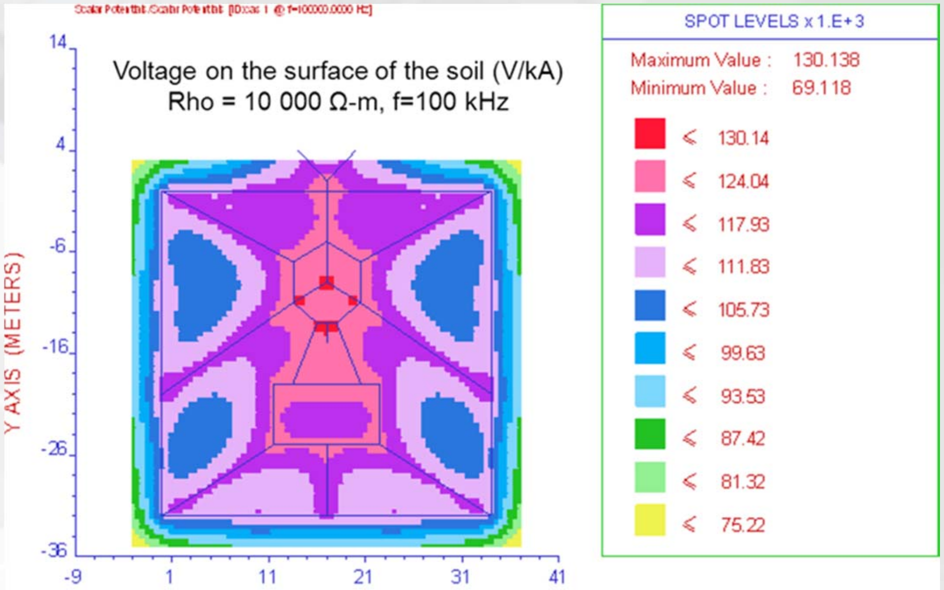




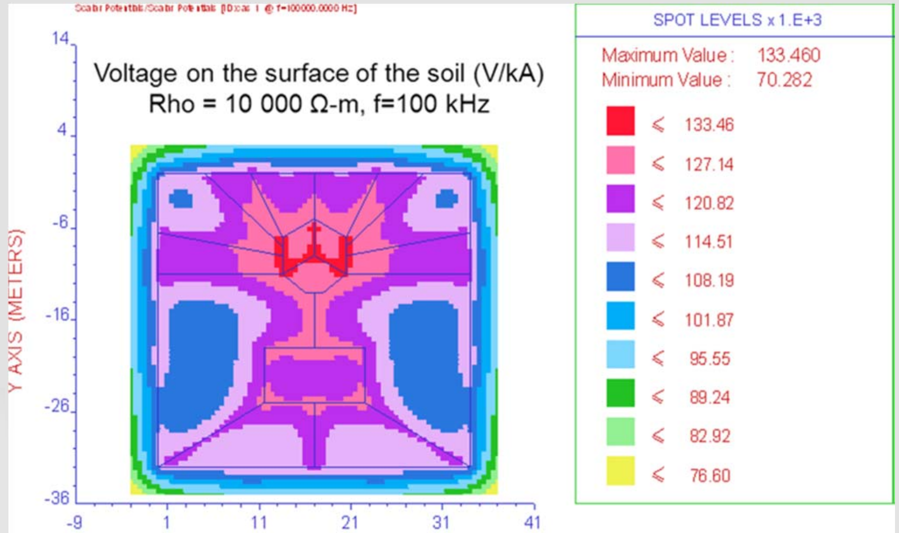




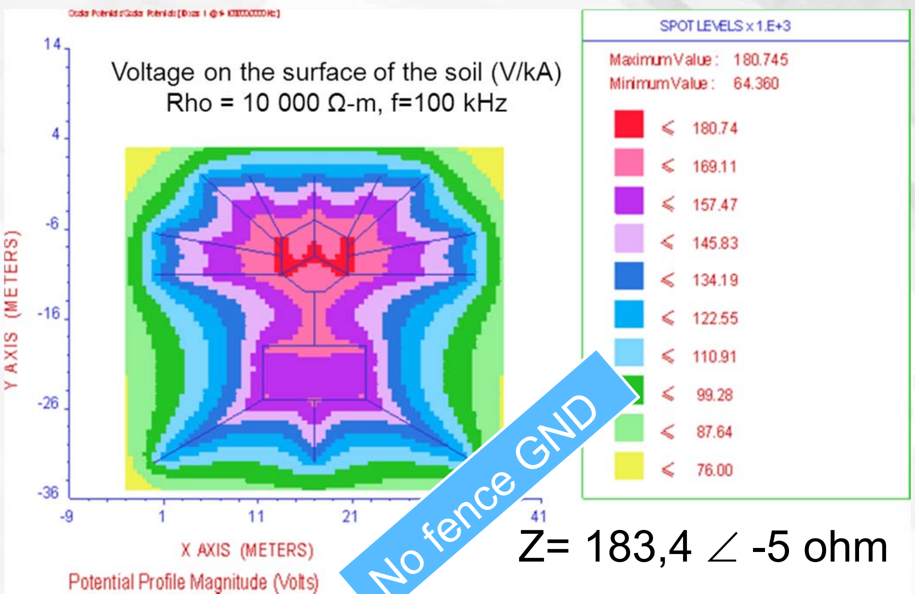
How do grounding models compare?
Rho = 10,000 Ω-m, f = 100 kHz



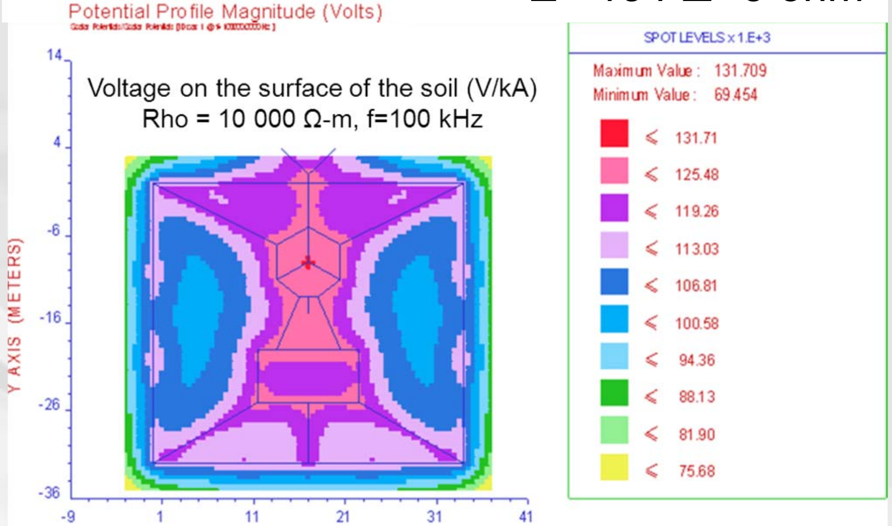
Z= 131 ∠ -5 ohm



Z= 134 ∠ -5 ohm



Z= 183,4 ∠ -5 ohm



Z= 133 ∠ -5 ohm

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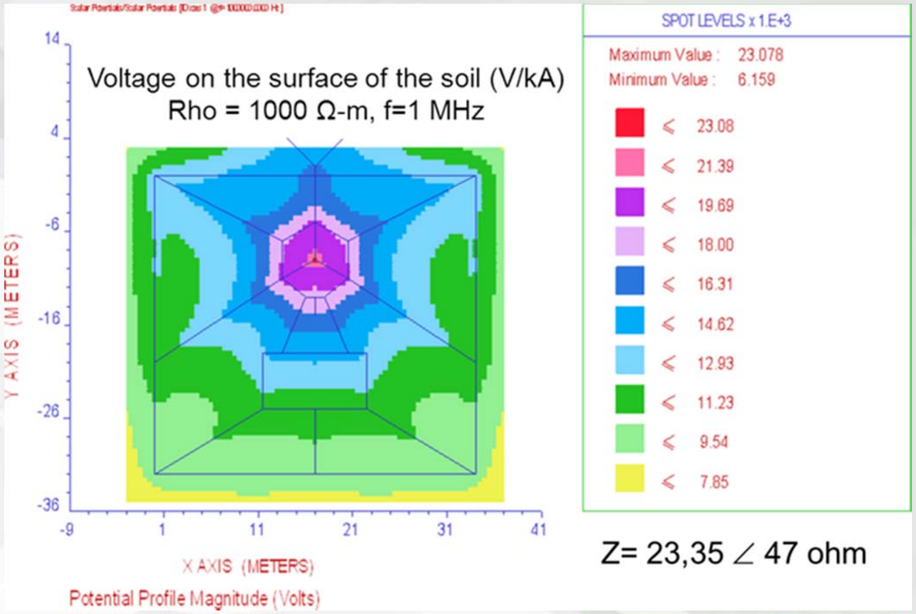
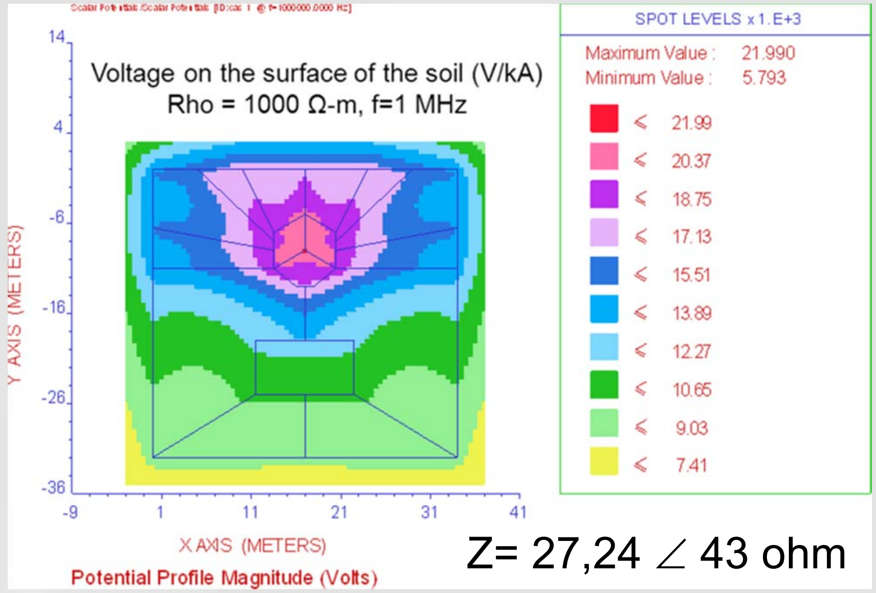
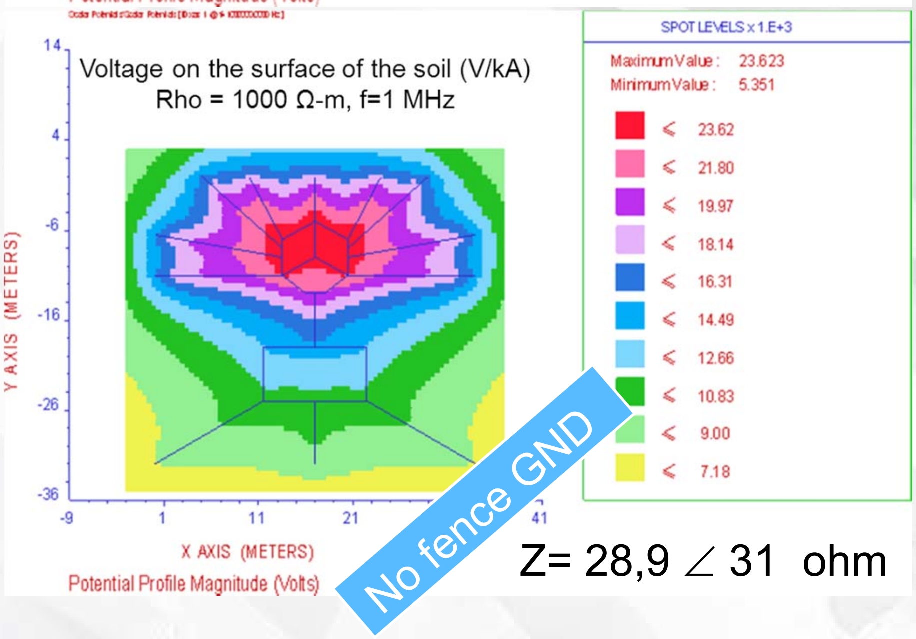
How do grounding models compare?
Rho = 1,000 Ω-m, f = 1 MHz



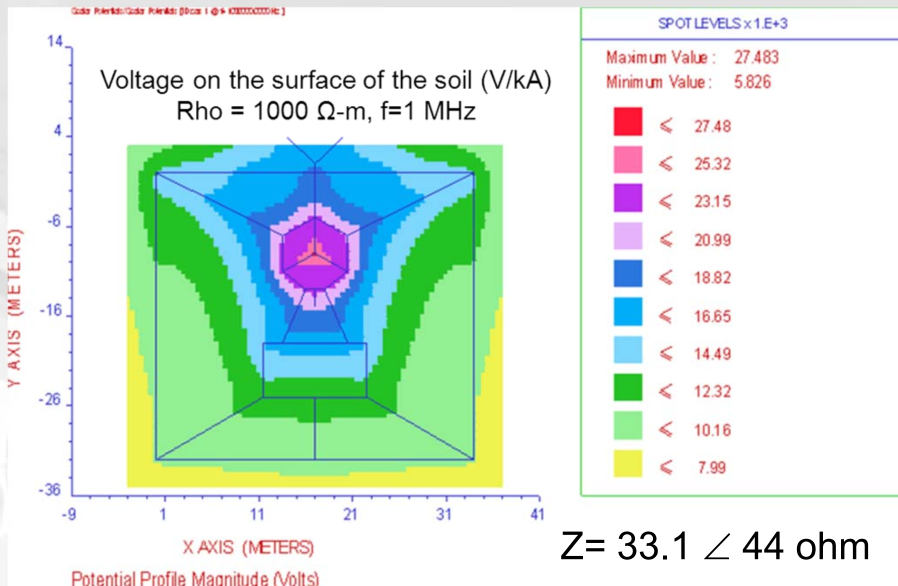
Z= 23,35 ∠ 47 ohm



Z= 27,24 ∠ 43 ohm



Z= 28,9 ∠ 31 ohm



Z= 33.1 ∠ 44 ohm

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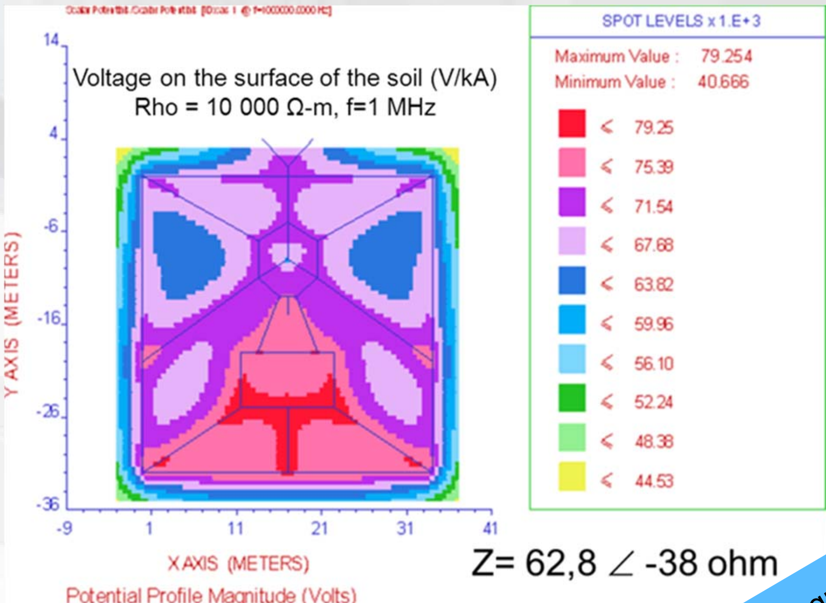
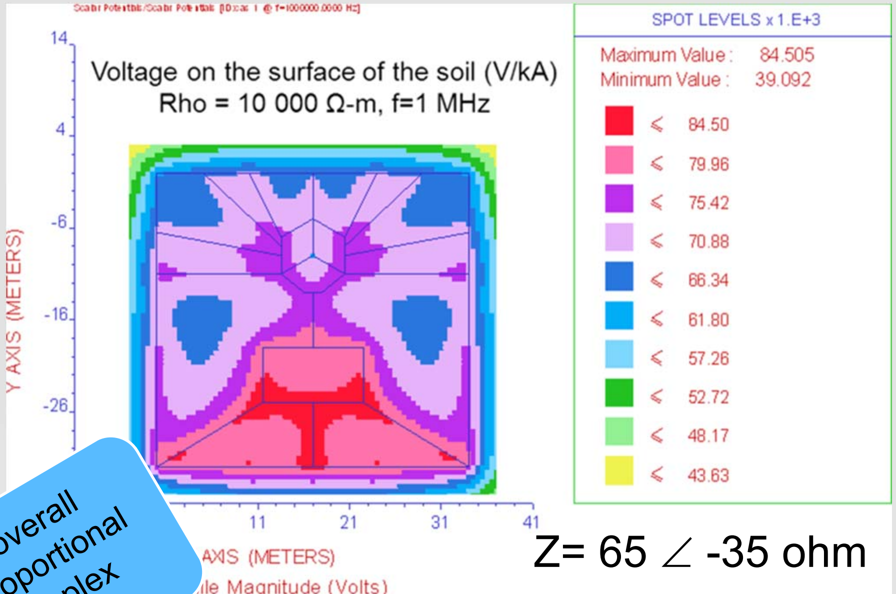
How do grounding models compare?
Rho = 10,000 Ω-m, f = 1 MHz

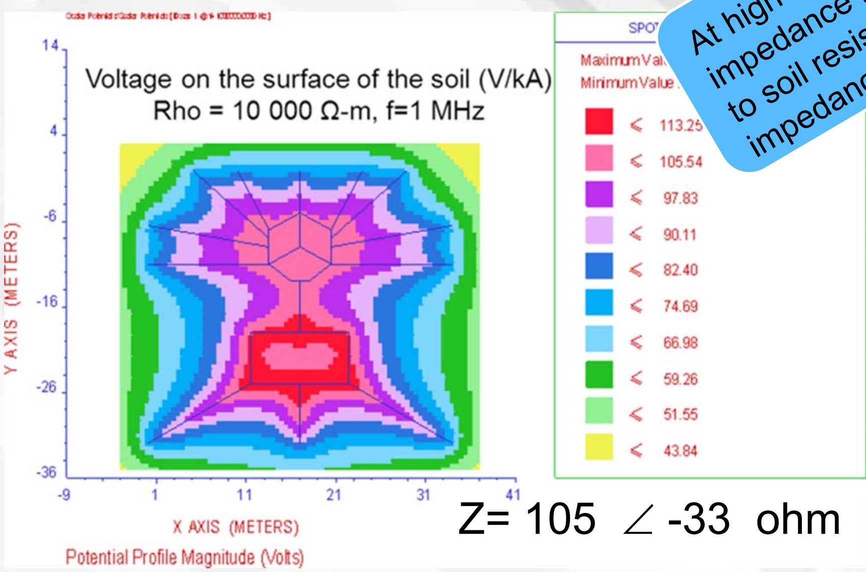


Z= 62,8 ∠ -38 ohm

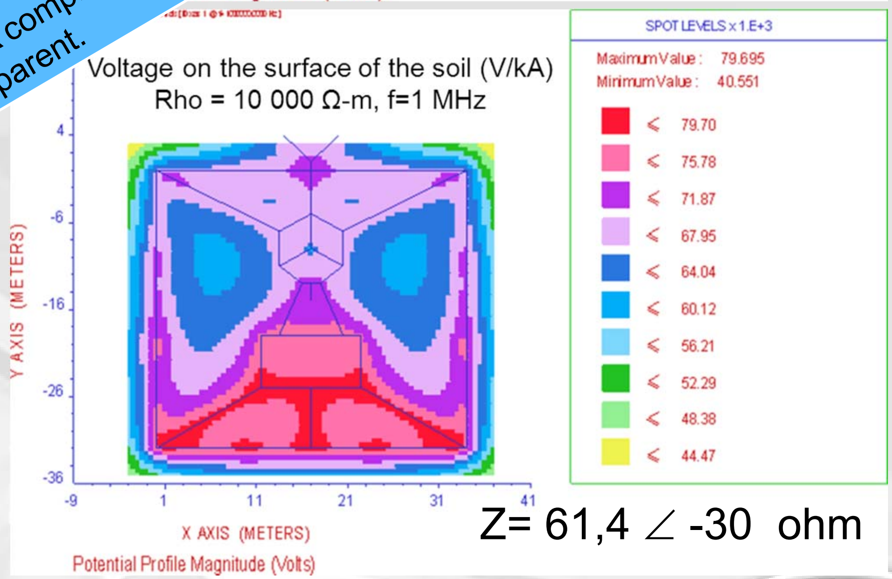


Z= 65 ∠ -35 ohm

At high frequencies, overall impedance is not proportional to soil resistivity. A complex impedance is apparent.

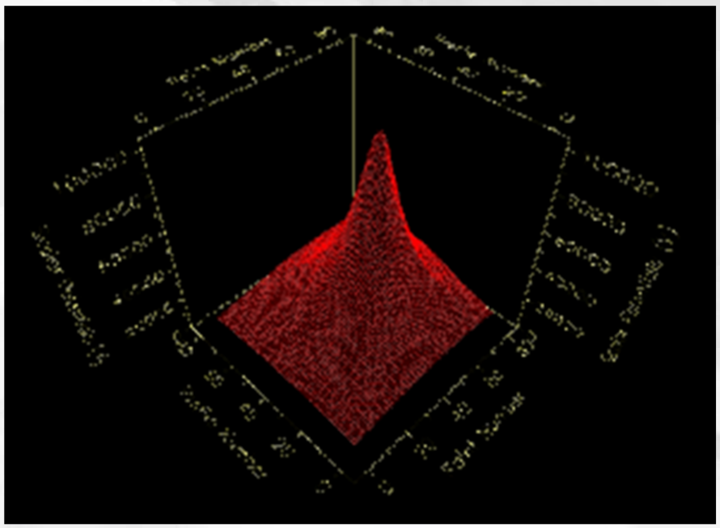


Z= 105 ∠ -33 ohm

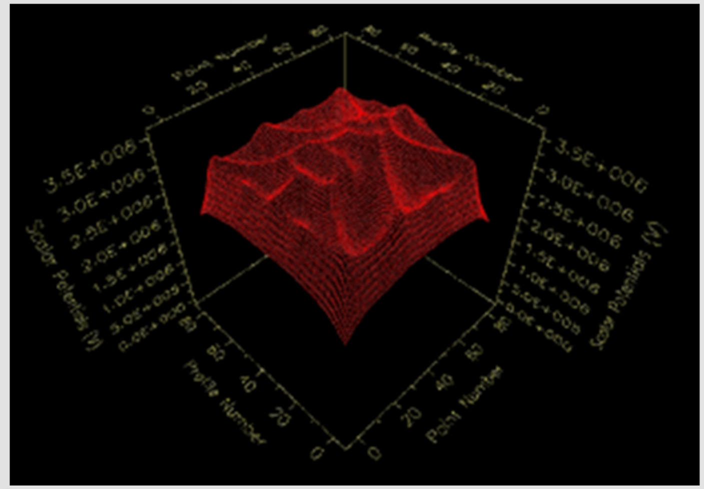


Z= 61,4 ∠ -30 ohm

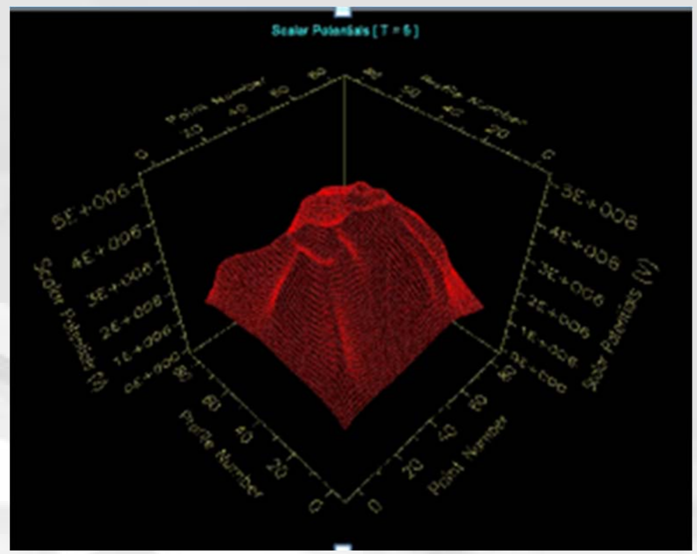
How do grounding models compare?
3D models



5 radials, 100Ω-m, 100kHz
With a fence

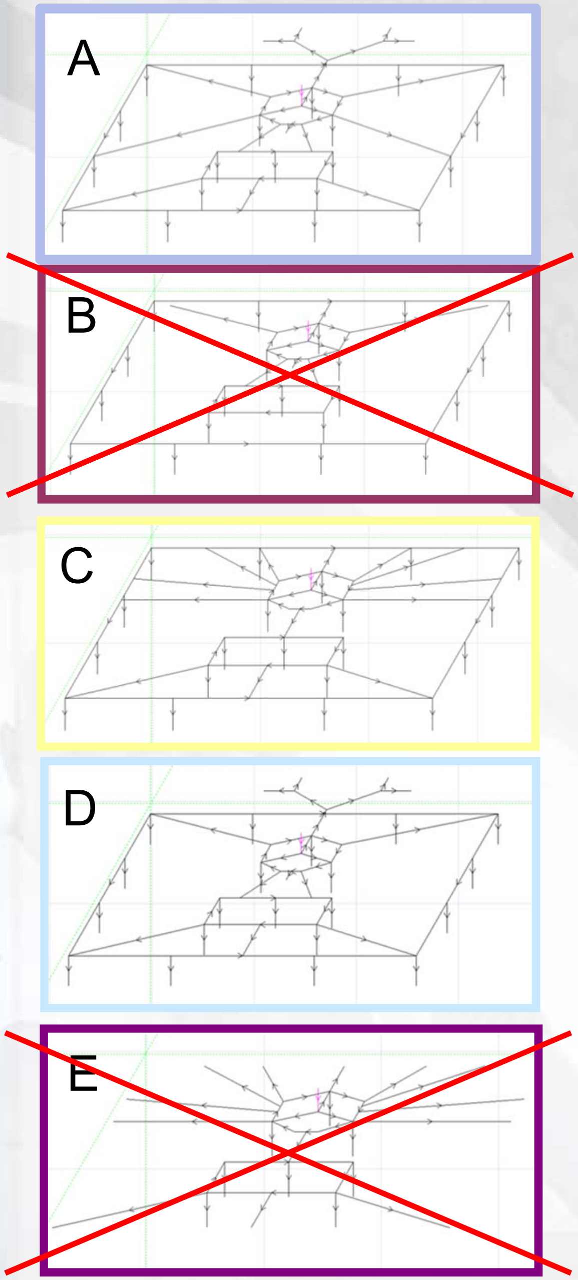


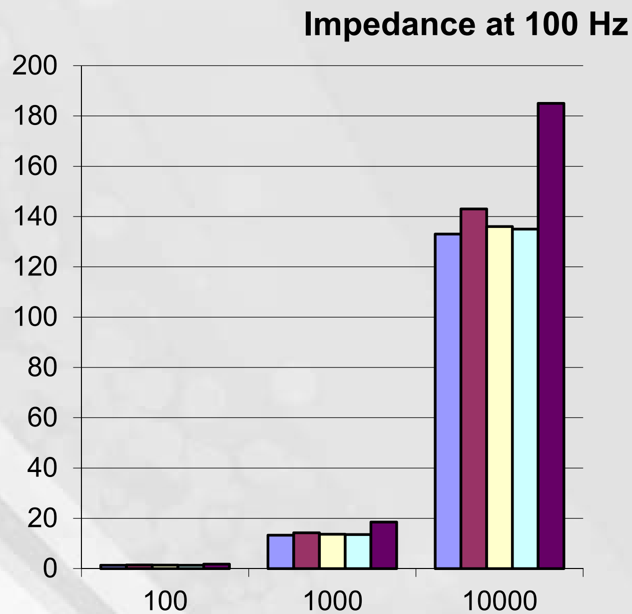
5 radials, 10 000Ω-m, 100kHz
With a fence

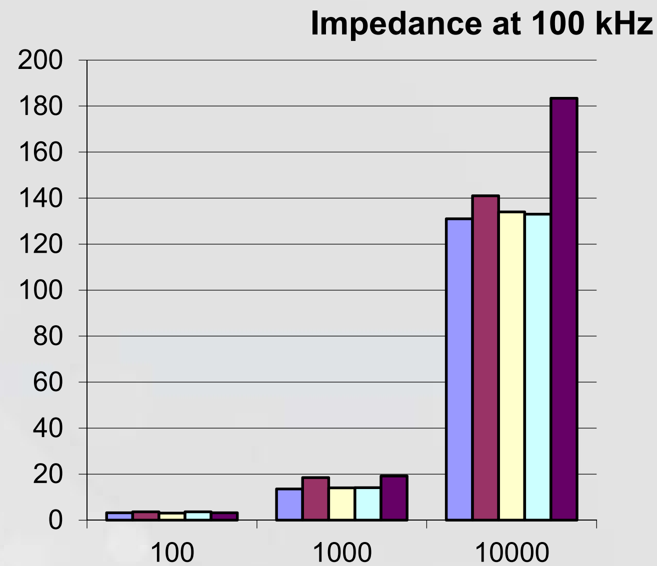


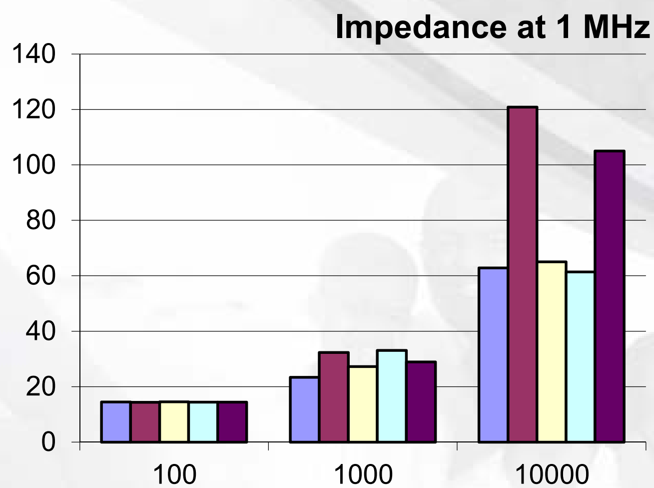
5 radials, 10 000Ω-m, 100kHz
Without a fence

How do grounding models compare?
Few or many radials – For what soil type?



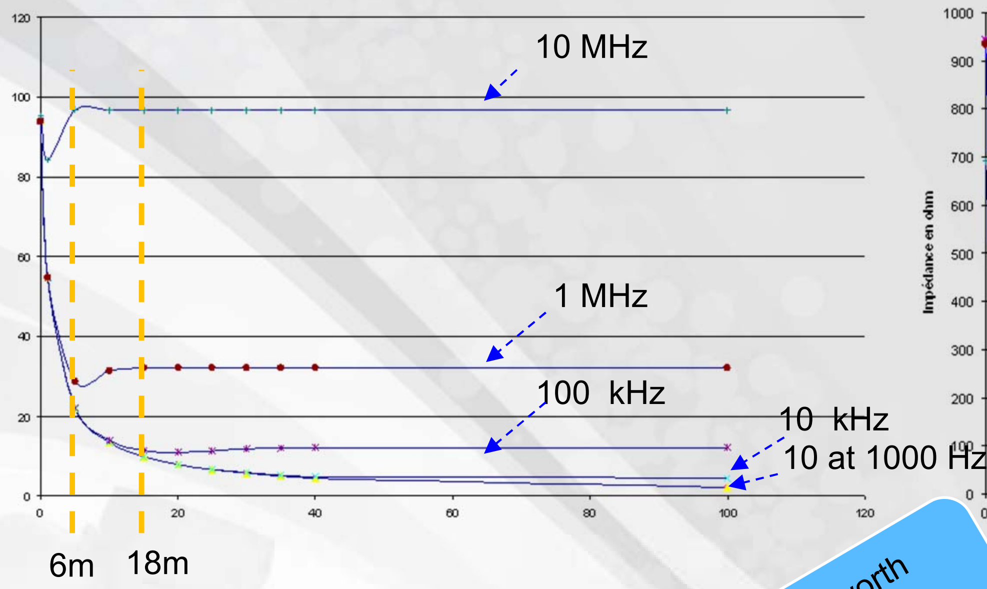




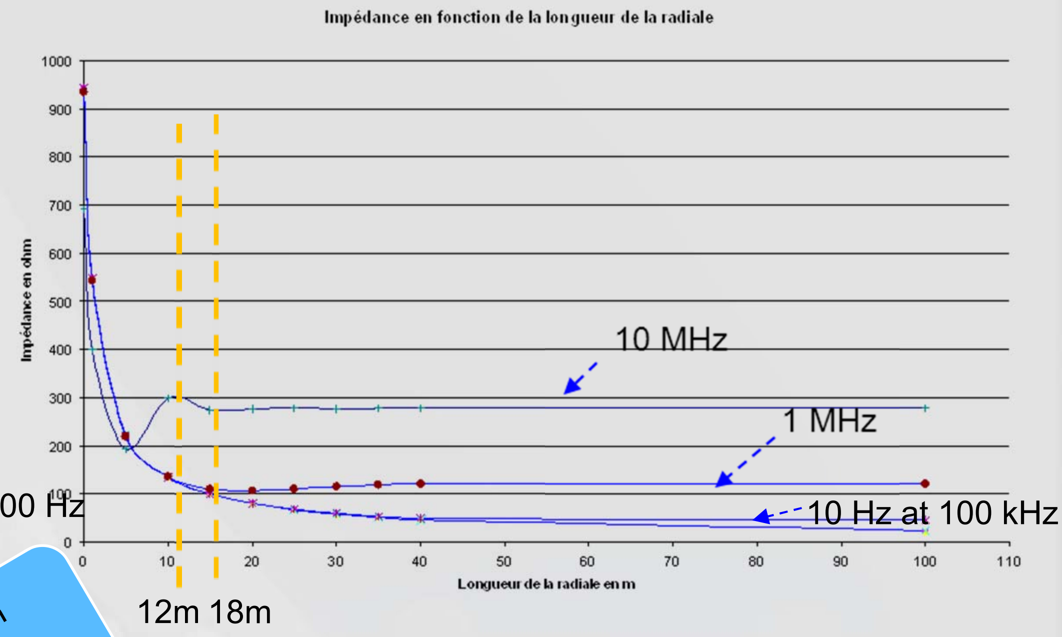


How do grounding models compare?
Conductor length – How long is enough?

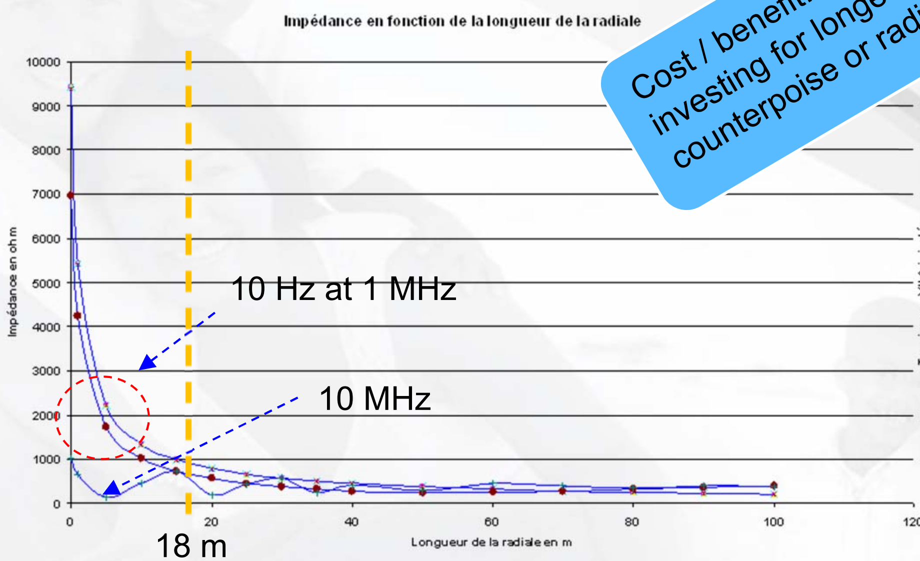
Effective length as a function of the frequency
Rho 100 Ω-m



Effective length as a function of the frequency
Rho 1,000 Ω-m

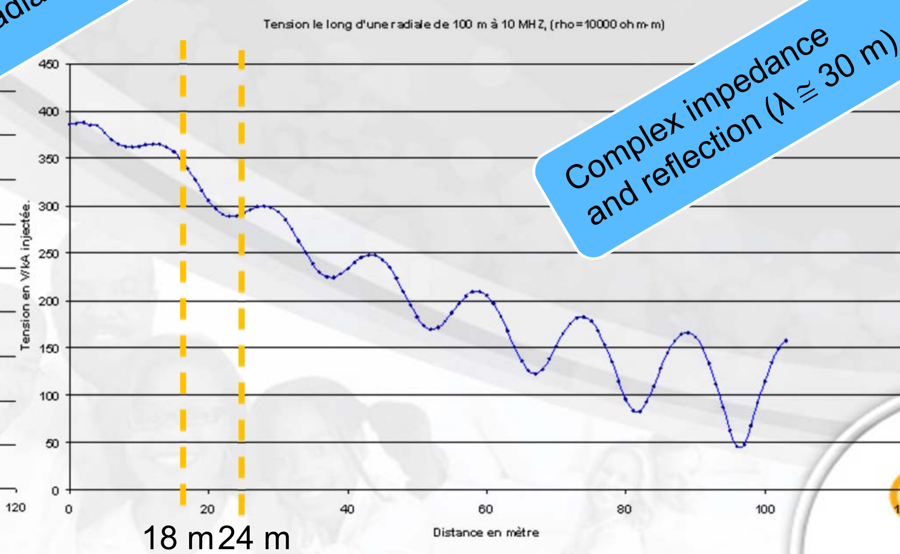


Effective length as a function of the frequency
Rho 10 000 Ω-m



Cost / benefit: Not worth investing for longer counterpoise or radial

Voltage along a radial of 100 m
f=10 MHz, Rho 10 000 Ω-m



Complex impedance and reflection (λ ≅ 30 m)

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How do grounding models compare?
Cost effectiveness!

- Equipotentiallity is not observed above 100 kHz
- 5 radials are better than 3
  - especially above 100 kHz
  - offers backup in case of conductor theft
  - less expensive than 10
- Connecting the radials to the grounding conductor around the fence improves overall performance when fence is within 18−24 m
- Ground resistivity affects the length of the buried conductor
  - 6 m (min.), in 6 m increments, maximum of 18 m.
- Complex impedance observed at higher frequencies (ex: 61.4 $\angle$-30 Ω)

How do grounding models compare?
Other views! (As presented by Al Martin, ATIS-PEG-2013)

- IEC 61312-1 (Protection against lightning electromagnetic impulse – Part 1, General principles
  - Generally ground rods are expected to behave like resistors.
- V. Rakov and M. Uman (ICLRT – Camp Blanding (Fl), USA)
  - Concluded that ground rods (systems') also have reactive element that may change the rise time of a surge at high frequencies.
    - Short rods (≤ 3m) resemble a parallel RC circuit (lossy capacitors) influenced by p;
    - Long rods (≈ 30m) resemble a series RL circuit influenced by p.
  - A long ground rod contributes to decrease the specific energy (I^2t) of a surge by directing the high amplitude low-frequency content to ground.
    - At higher frequencies (fast rising surges), ground rod length can lead to potentially damaging voltage spikes.

How grounding models compare
Safety: There is no safe place outdoors during a thunderstorm!

Environment Canada

- Do not use the tower structure as a shelter;
- Do not touch or be close to the fence during a storm;
- If caught outside do not stand near tall objects or anything made of metal;
- Avoid using a telephone that is connected to a landline;
- Once in a safe location, remain there for 30 minutes after the last rumble of thunder is heard before resuming your outdoor activities.

Hydro Québec

Conclusion

- Being aware ≈ Better grounding
- Modeling ≈ Standards
- Addressing risks ≈ Security for all

Questions?

Bibliography

- QUÉBEC CONSTRUCTION CODE, Chapter V – Electricity – 2012
- Utilisation du code électrique, Polytechnique – Montréal - 2010
- Hydro-Québec − SN-12.3b (Réalisation et contrôle de la qualité des connexions dans les réseaux de terre)
- Hydro-Québec − SN-T-12.01.01.B (Mise à la terre, Installations de télécommunications)
- Hydro-Québec − GT-T-12.01.03.D (Mise à la terre, Installations de télécommunications)
- Hydro-Québec − La foudre: Sa génération, ses effets et notre protection, Eugène Lambert, Eng. – 2006
- T1-313-2003 (Electrical Protection for Telecommunications COs and Similar Facilities)
- EDSPIC:340 (Étude des risques de défaillance d'un réseau de télécommunications soumis aux effets directs ou indirects de la foudre, José Ribeiro)
- Wikipedia – Lightning
- Thor vs. la Masse, VA2J0T-2008
- Lightning & Transients, R. Briët, Ph.D. – ITEM, 2000
- Électrotechnique – Mesures 735, 2001
- Foudre et tension de pas, Frédéric Elie, 2005
- Earthing Fundamentals: Lightning & Surge Technologies
- Transient response of shielded substation hit directly by a lightning strike (Dawalibi, Fortin, Li – SES Tech)
- Motorola R56-2005
- IEC 61312-1 (Protection against lightning electromagnetic impulse – part 1 – general principles)

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