LIGHTNING STRIKES TO TALL TOWERS, WITH IMPLICATIONS TO ELECTROMAGNETIC INTERFERENCE

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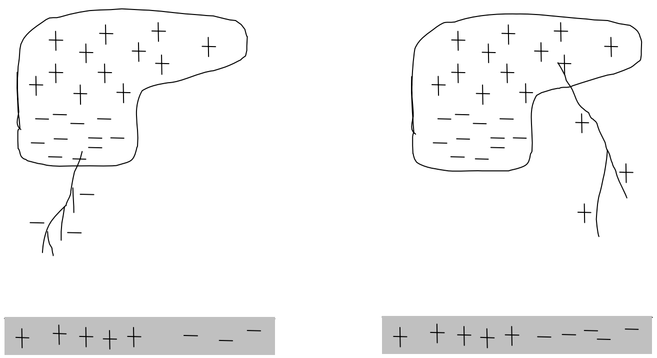
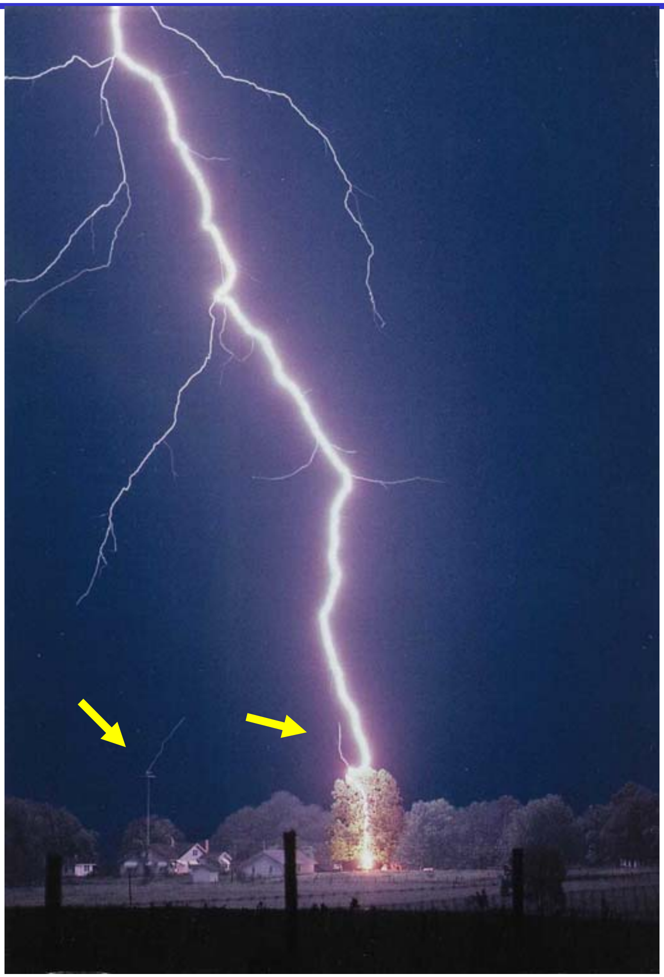
Objective

- Can tall towers influence the incidence of lightning?
- Are the parameters of the lightning, influenced by the presence of the tower?
- What would be the current distribution along the tower?
- What would be the electric and magnetic field environment for tower lightning?
- Are lightning protection methods for protecting communication equipments sufficient to prevent lightning surge transfer to near by local networks?

Can tall towers influence the incidence of lightning?

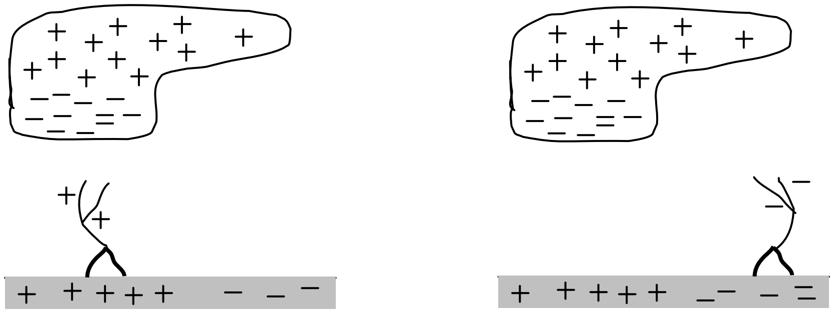


Downward lightning



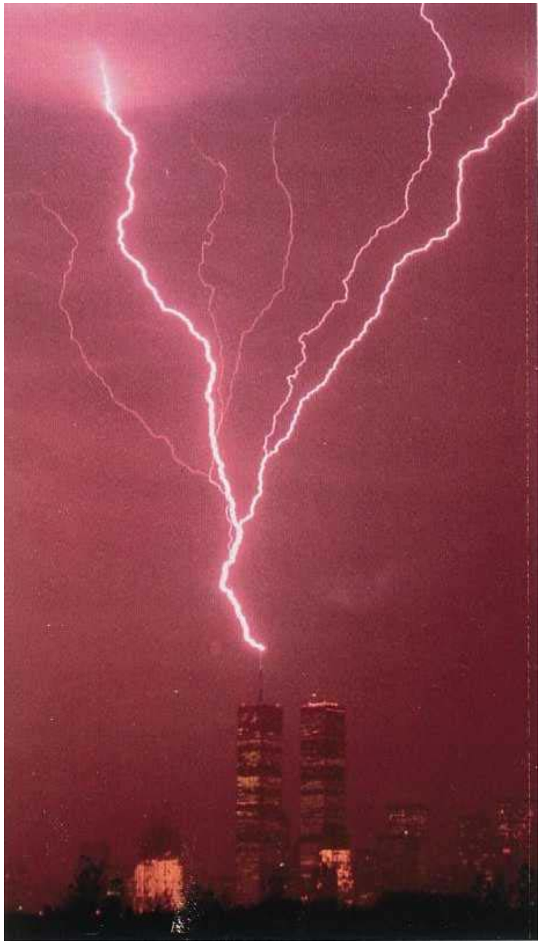
Tower intercepts lightning that would have happened in any case

Can tall towers influence the incidence of lightning?



Upward lightning

Tower initiates lightning that would not be there in the absence of tower



Height of tower and percentage of upward lightning flashes

$$P_u = 68.2\, ln(H_s) - 315.5$$

Empirical relationship from observation. Tower on flat ground [Eriksson, 1978]

> 450 m → 100%

200 m → 46%

< 100 m → 0%

Exception – tower on high hills (increased ambient electric field)

Example – Probability of lightning incidence to a 200 m tower

Flat terrain

In Sweden average 1 flash/km^2/year

Attractive radius ~410 m $$R = 16.3\,H_s^{0.61}$$

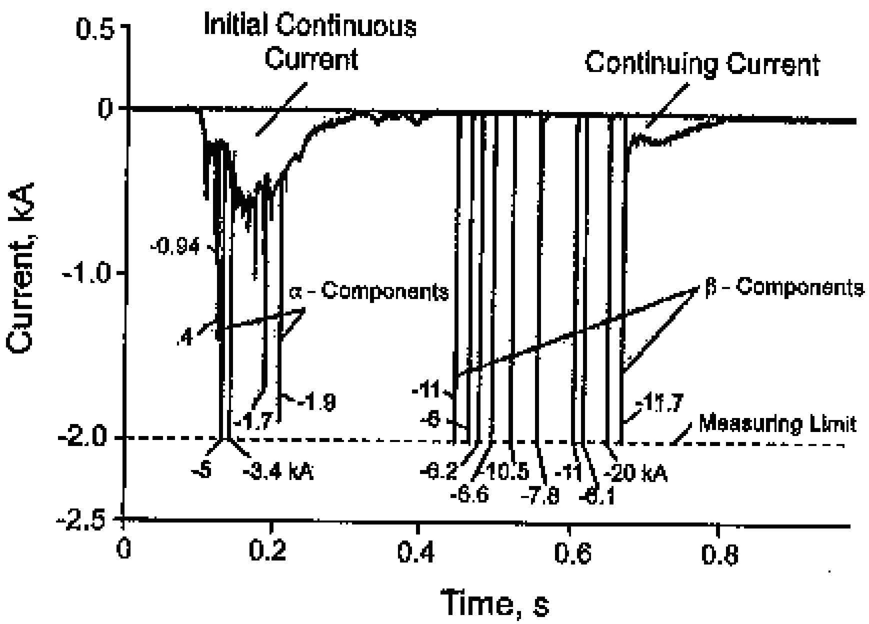
Prob. of downward lightning ~ 1 flash in 2 years

Prob. of upward lightning ~ 1 flash in 2 years

Prob. Of lightning incidence ~ 1 flash/year

(much higher in tropical countries)

Are the parameters of the lightning, influenced by the presence of the tower?



Peissenberg tower in Germany - from Fuchs et al. (1998)

- Average peak currents in upward negative lightning about 3 times smaller
- In tall towers, peak currents at the top and bottom of tower are different

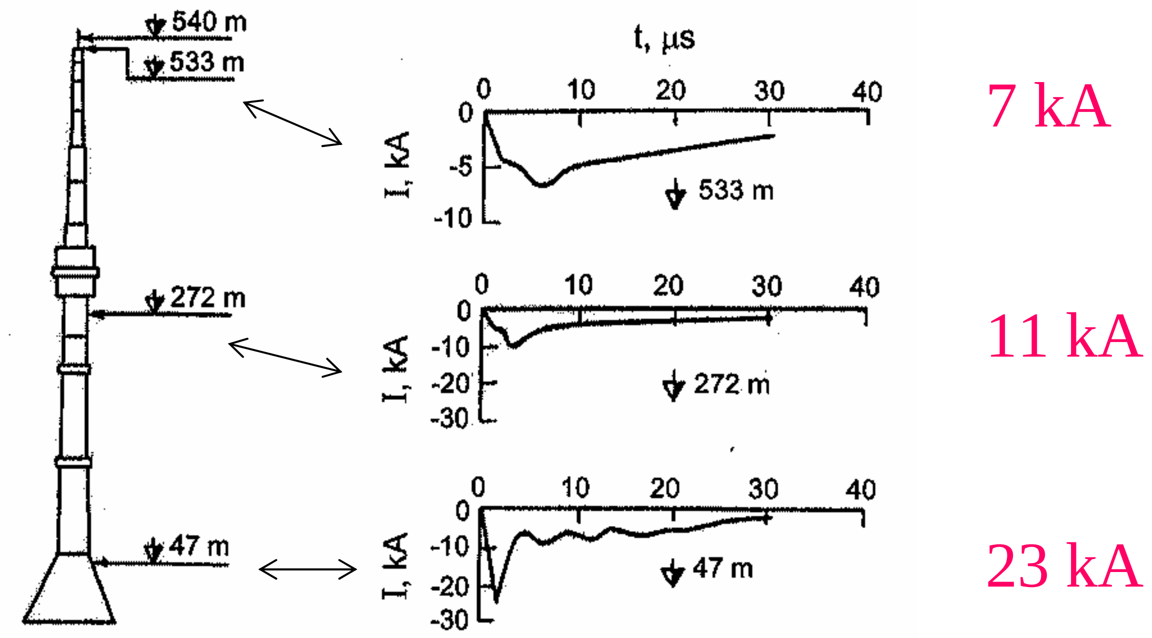
Comparison of peak currents in upward and downward lightning to towers

Reference	**Description**	**Median**	**Extreme**
Fuchs et al. (1998). 160 m tower at Peissenberg, Germany on a 288 m mountain at 933 m above msl.	Negative return strokes in tower initiated flashes	8.5 kA	21 kA
Berger (1978), 70 m tower on Mount San Salvatore 640 m high above lake Lugano in Switzerland at 912 m above msl	Negative return strokes in tower initiated flashes	**10 kA**	**25 kA** (10% exceeds)
Berger (1975) same tower as above.	Negative return strokes in normal downward flashes to tower - first stroke - subsequent	 **30 kA** 12 kA	 **80 kA** 30 kA

(Adapted from Rakov and Uman (2003))

Current distribution along the tower

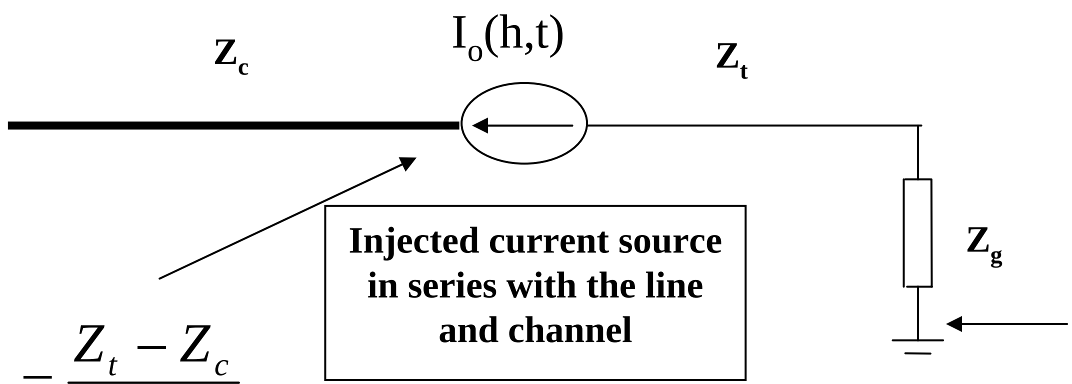
Lightning strike to Ostankino tower in Moscow



Typical impulsive current waveforms of upward negative lightning recorded near the top, in the middle, and near the bottom showing **evidence of current reflections at the tower bottom and tower top**

Adapted from Gorin and Shkilev (1984)

Model for lightning interaction to tower



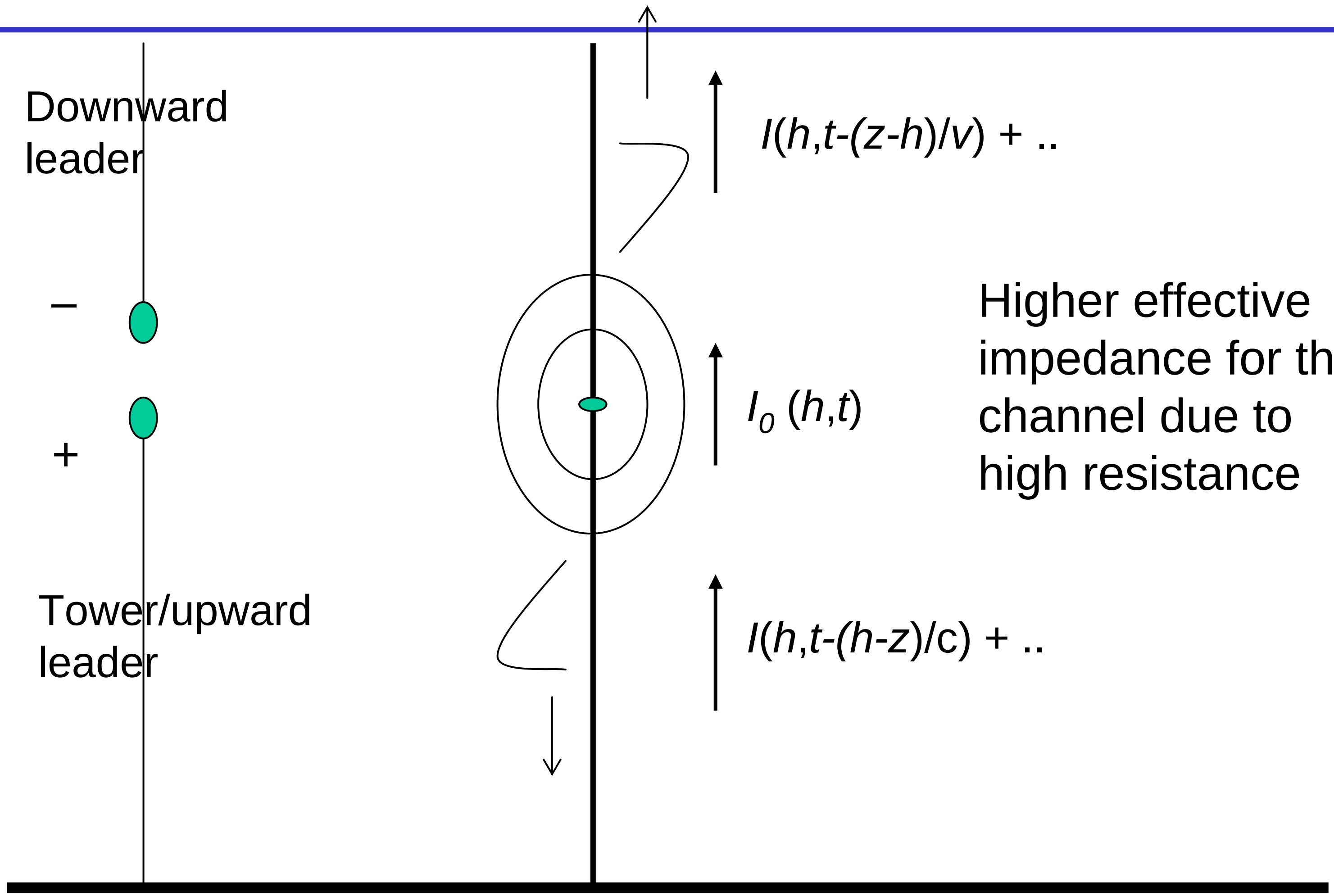
$$\rho_t = \frac{Z_t - Z_c}{Z_t + Z_c}$$

$$\rho_g = \frac{Z_t - Z_g}{Z_t + Z_g}$$

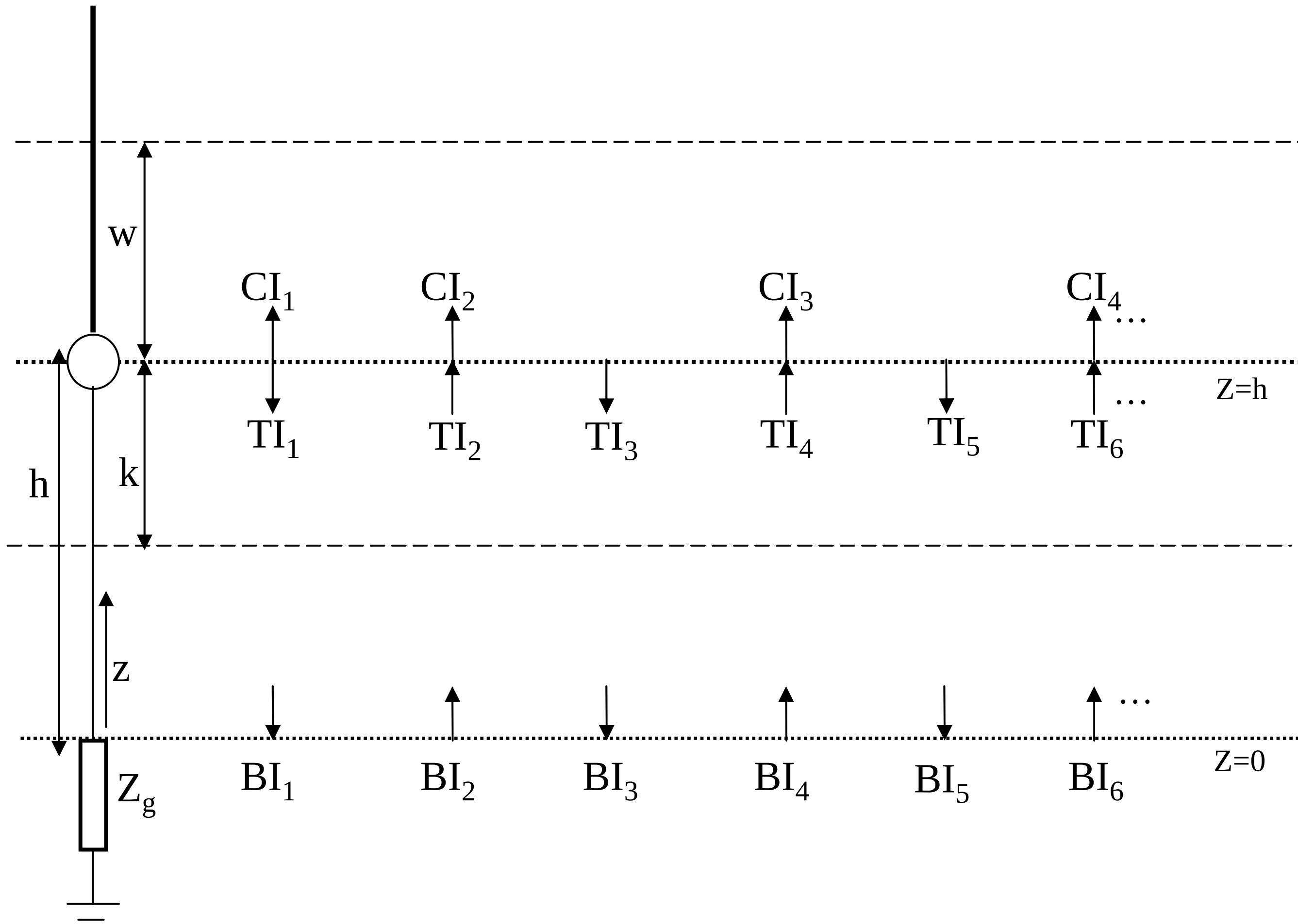
Same injected current in channel and tower

Thottappillil and Theethayi (2006)

Series source model
-the process



Current distribution along tower and channel



Current distribution along tower and channel

The current at the bottom of the tower:

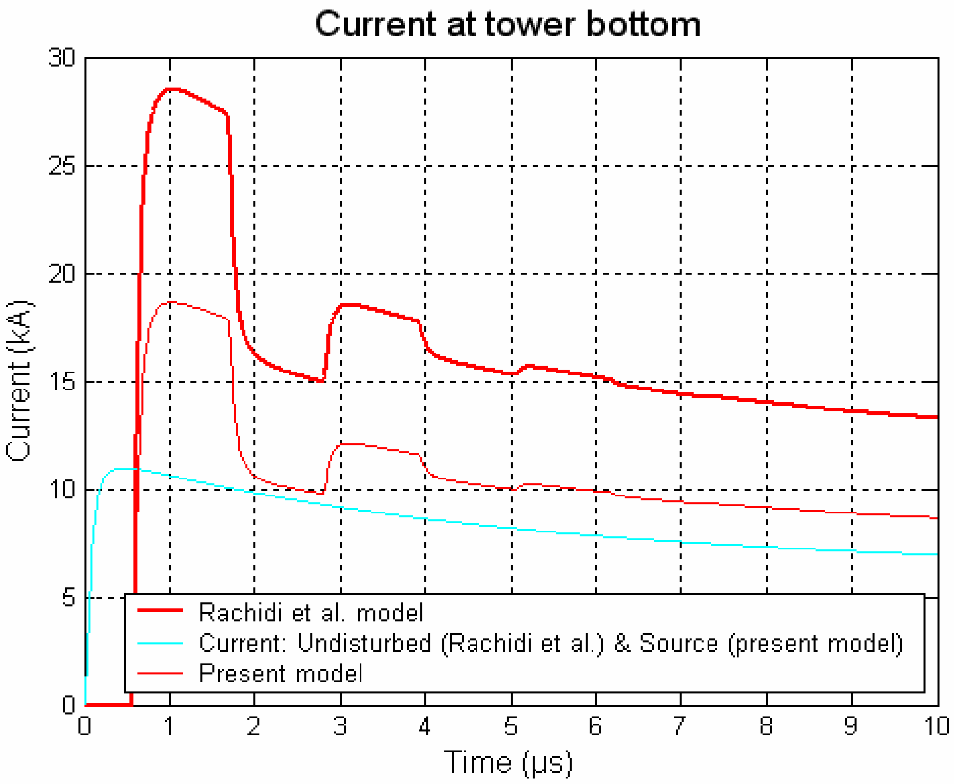
$$i(0,t) = BI_1 + BI_2 + BI_3 + BI_4 + BI_5 + BI_6 + \dots$$

$$= I_0\left(h, t - \frac{h}{c}\right) + \rho_g I_0\left(h, t - \frac{h}{c}\right) + \rho_t \rho_g I_0\left(h, t - \frac{3h}{c}\right) + \rho_t \rho_g^2 I_0\left(h, t - \frac{3h}{c}\right) +$$

$$\rho_t^2 \rho_g^2 I_0\left(h, t - \frac{5h}{c}\right) + \rho_t^2 \rho_g^3 I_0\left(h, t - \frac{5h}{c}\right) + \rho_t^3 \rho_g^3 I_0\left(h, t - \frac{7h}{c}\right) + \rho_t^3 \rho_g^4 I_0\left(h, t - \frac{7h}{c}\right) + \dots$$

$$= \sum_{n=0}^{\infty} \rho_t^n \rho_g^n \left(1 + \rho_g\right) \cdot I_0\left(h, t - \frac{(2n+1)h}{c}\right)$$

Current at tower bottom



ρt = -0.53,

ρg = 0.7

V= 3.0x10^{8}m/s in tower

V= 1.0x10^{8}m/s in channel.

Reflection coefficients

- Determined from the experimental observation of lightning currents at the top and bottom of the tower

	ρ_{gr}	ρ_{to}	**Ref.**
Peissenberg tower	+0.64 to +0.81 (+0.7)	-0.39 to -0.68 (-0.53)	Fuchs (1998)
Ostankino tower	+1	-	Gorin and Shkilev (1984)
CN tower	+0.34 to +0.43 (+0.4)	-0.27 to -0.49 (-0.37)	Janischewskyj et al. (1996)

Surge impedances

Lightning channel, Z_{ch}	570 Ω	Rakov (1998)	10 kHz to 10MHz
Tower, Z_{to}	100 – 300 Ω	Rakov (2001) Gavric (2002)	
Ground, Z_{gr}	< 50 Ω	(for ρ_{gr}=0.7)	

$$Z_{gr} < Z_{to} < Z_{ch}$$

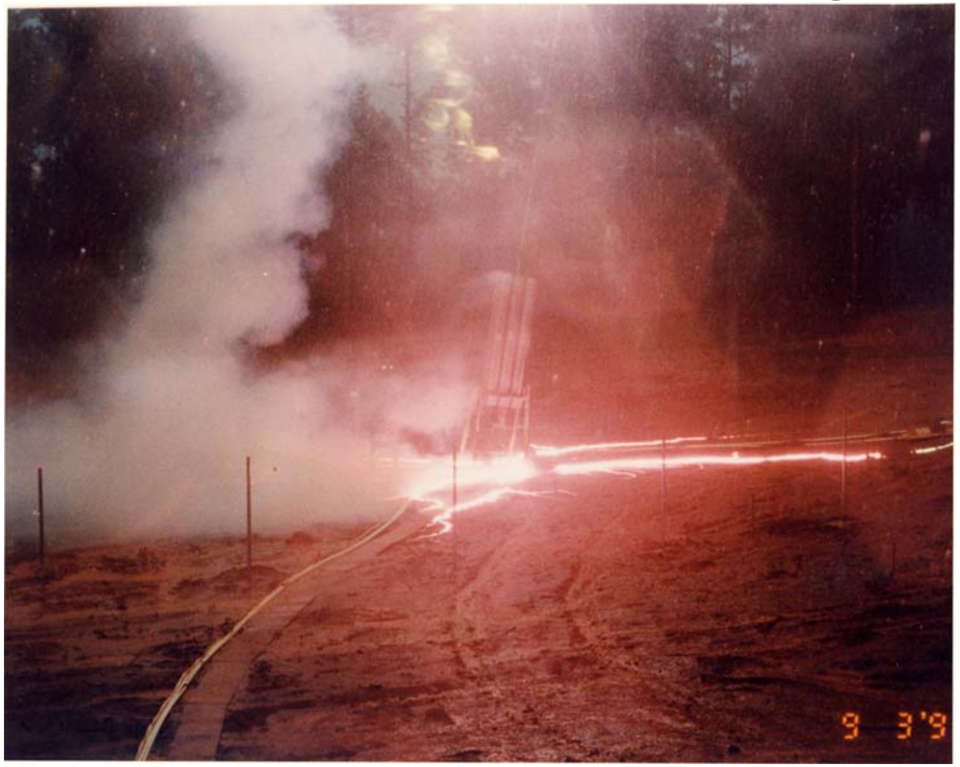
$Z_{ch}=3Z_{to}$ (ρ_{to}=-0.5) $Z_{to}=5Z_{gr}$ (ρ_{gr}=0.7)

What would be the electric and magnetic field environment for tower lightning?

- Not enough measured data
- Theory shows that in the shadow of the tower, E and dE/dt at ground substantially **reduced.** B and dB/dt not substantially affected.
- Far from the tower, E (B) and dE/dt (dB/dt) substantially **increased** (2 to 3 times)

Preventing Lightning Surge Transfer to Nearby Local Networks

Arcing inside soil and on surface
90% of RS above 15 kA produce surface arcing in 500 Ωm clay



Fischer, Sandia National Labs

The problem

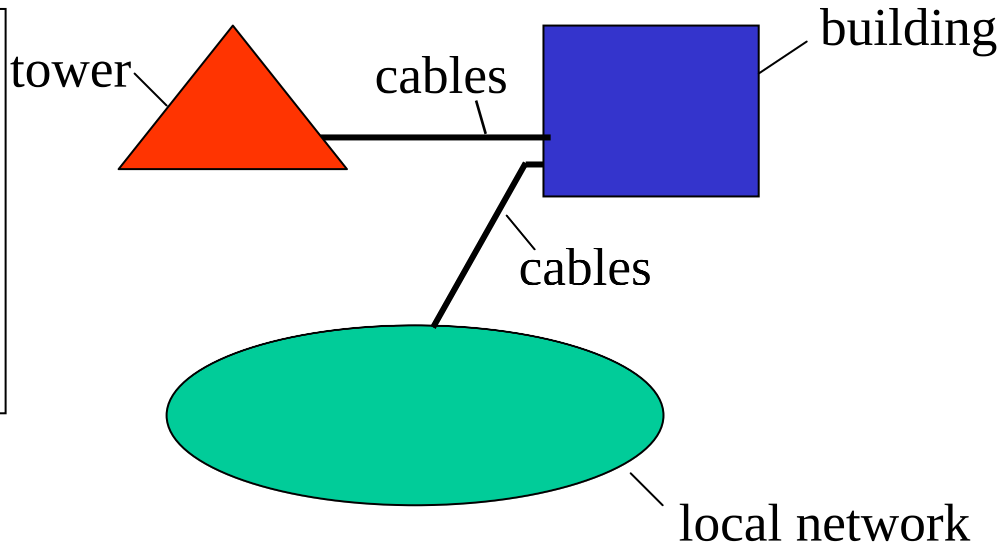
Tower: 20-200 m high

Tower-building: 0 to 20 m

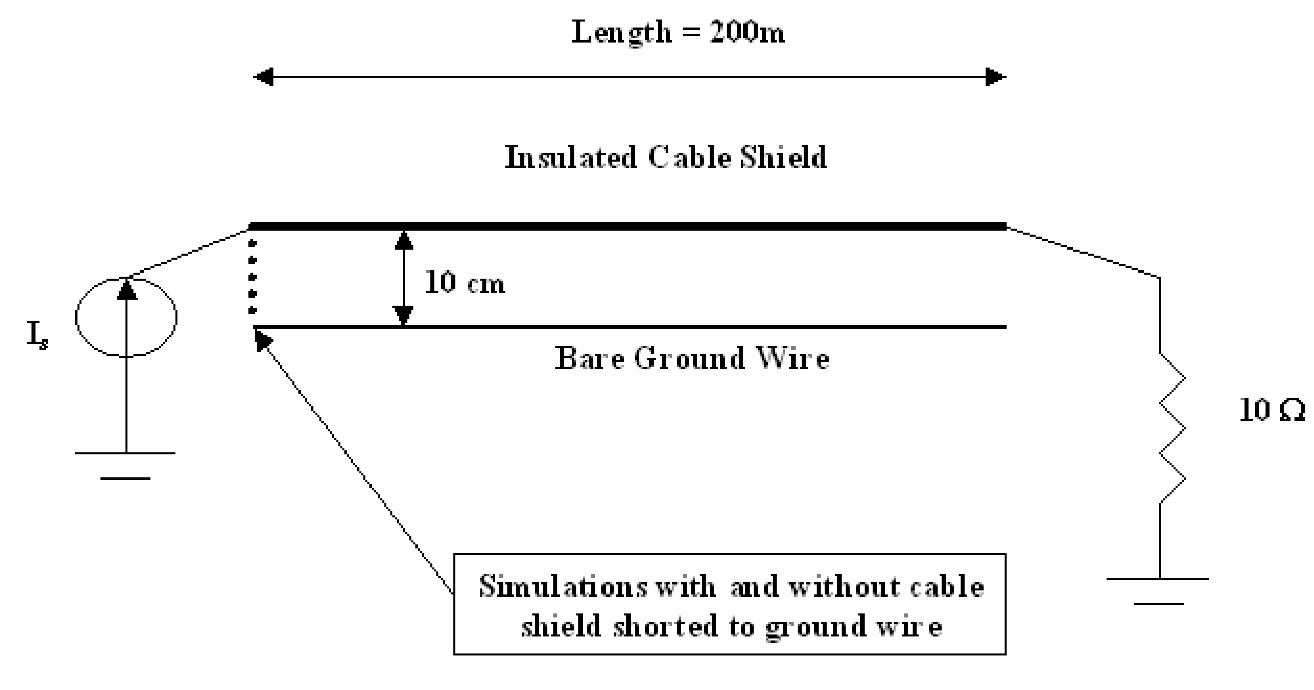
Building-local network: 10 to 1000 m

High resistivity soil: ~5000 Ωm

Potential rise at the tower-building complex may drive large currents via cable shields to local power network



Reduction of service cable shield current - modelling



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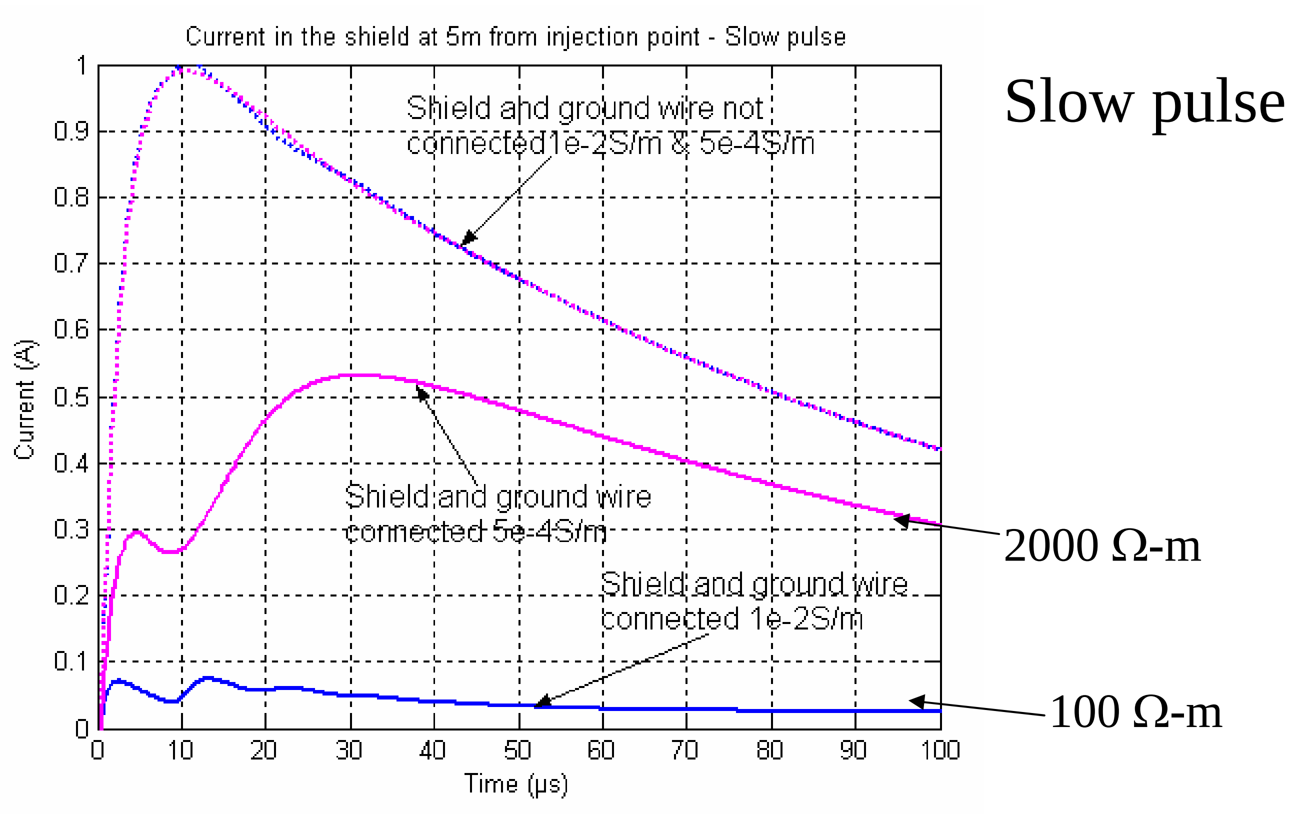

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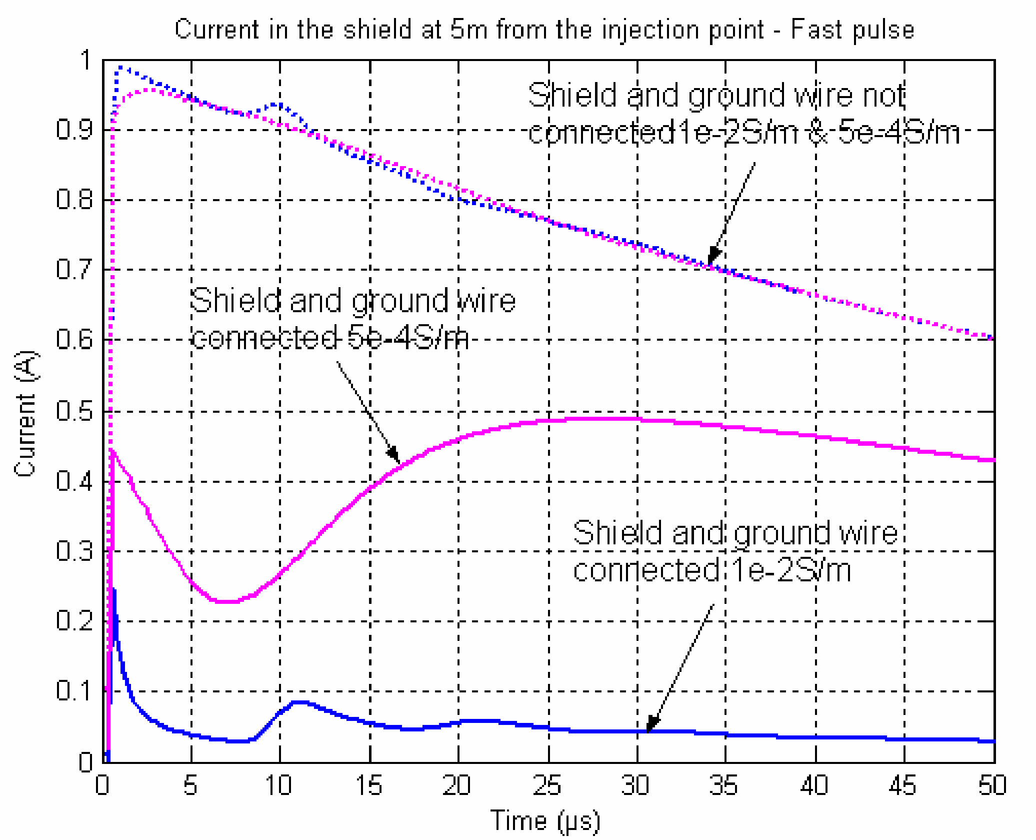
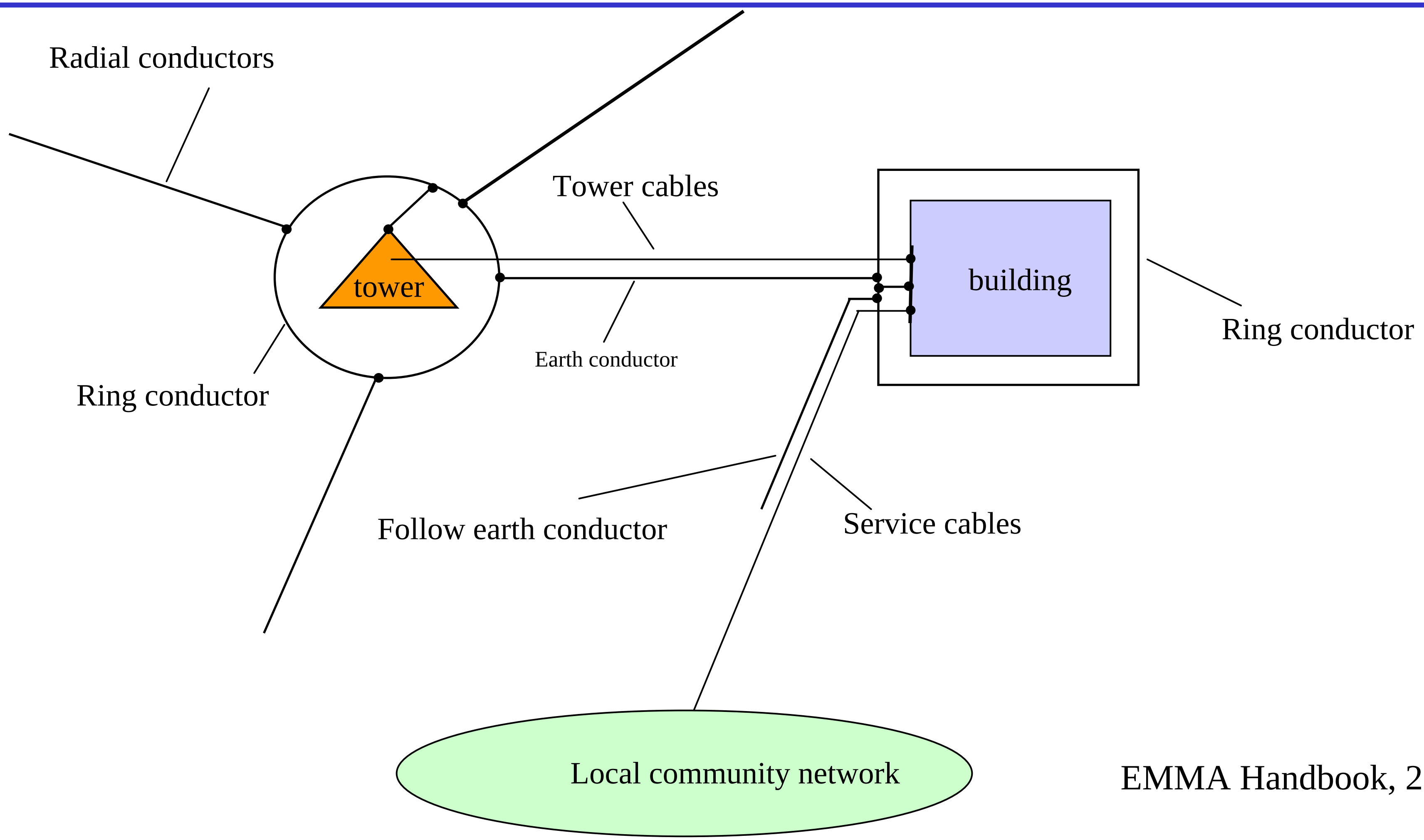


Fast pulse

Schematic of one grounding design



EMMA Handbook, 2002

Conclusions

- Usually towers higher than 100 m initiate upward lightning
- However, for towers on high hills, required height is less
- Electric and magnetic fields from lightning strike to tower different compared to lightning strike to ground
- Protecting tower complex equipments and preventing surge transfer to local community are not necessarily the same.
- Lack of good measurement data and proven models