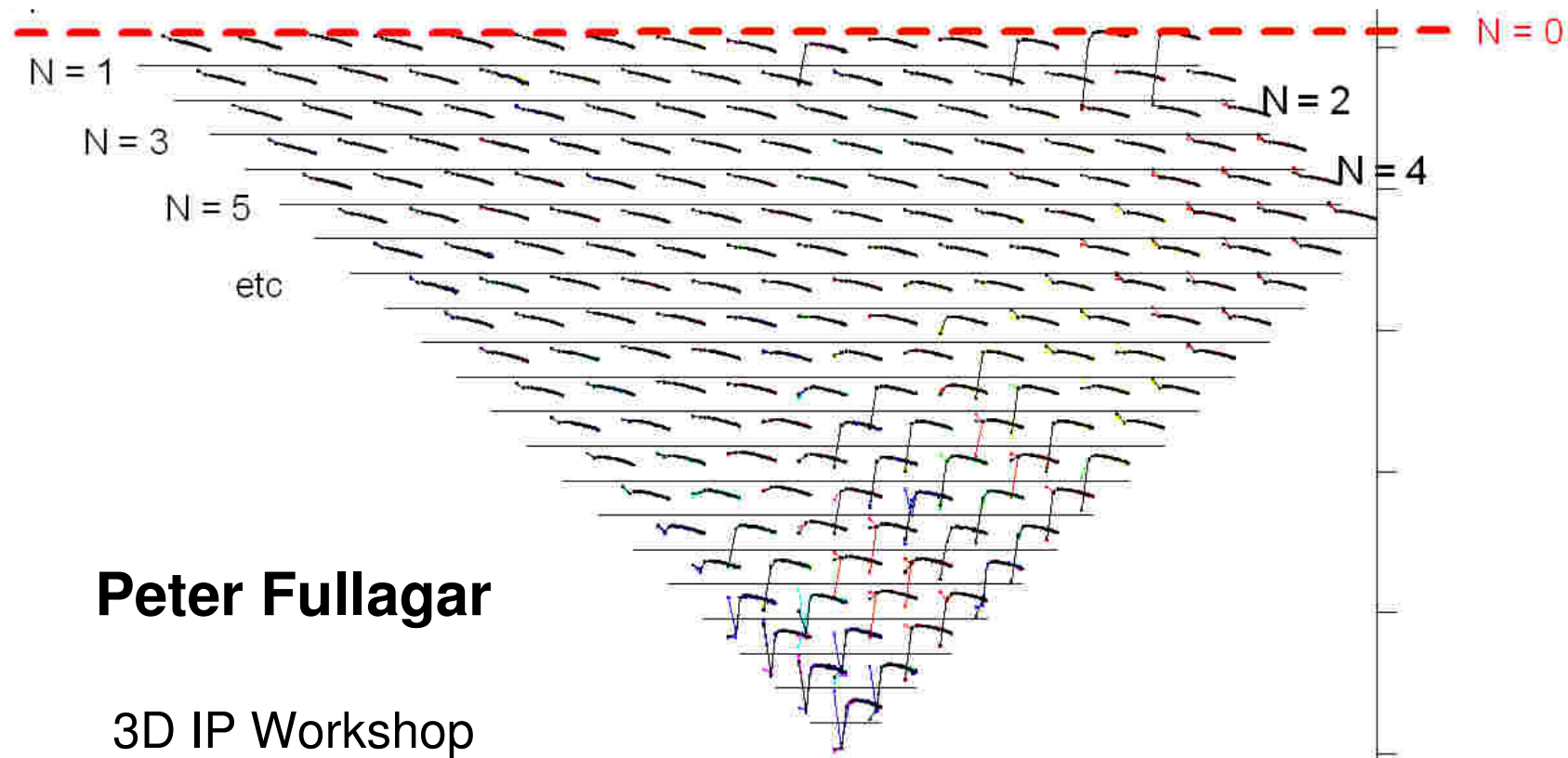


# EM coupling – is it a problem?



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*Geophysics* Pty Ltd

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# Outline

- Introduction
- Coupling and separation of wires
- EM coupling as noise
  - Frequency domain de-coupling
  - Waiting for negligible coupling
  - Time domain de-coupling
- EM coupling as signal
- Conclusions

# Conclusions

1. Yes, EM coupling can be a problem.  
Need to gauge its magnitude for given wire layout & conductivity.
2. “Ideal” solution (long term) is to invert for EM & IP simultaneously
3. Medium term: invert for EM, then IP, sequentially
4. Short term: take wire geometry into account;  
de-couple in TD as well as FD

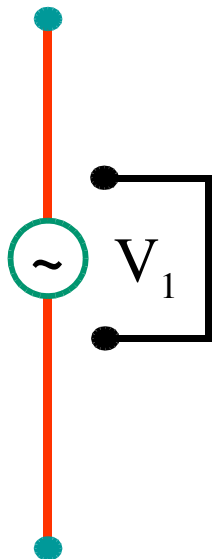
# Introduction

- Implications of time-varying B-field
- Positive coupling
- Negative coupling
- Key considerations

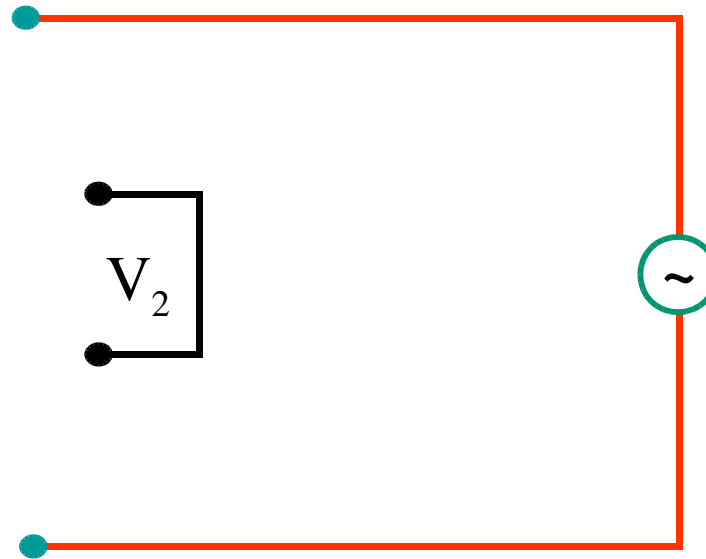
# Implications of time varying B-field

$\mathbf{E}$  is not a potential field

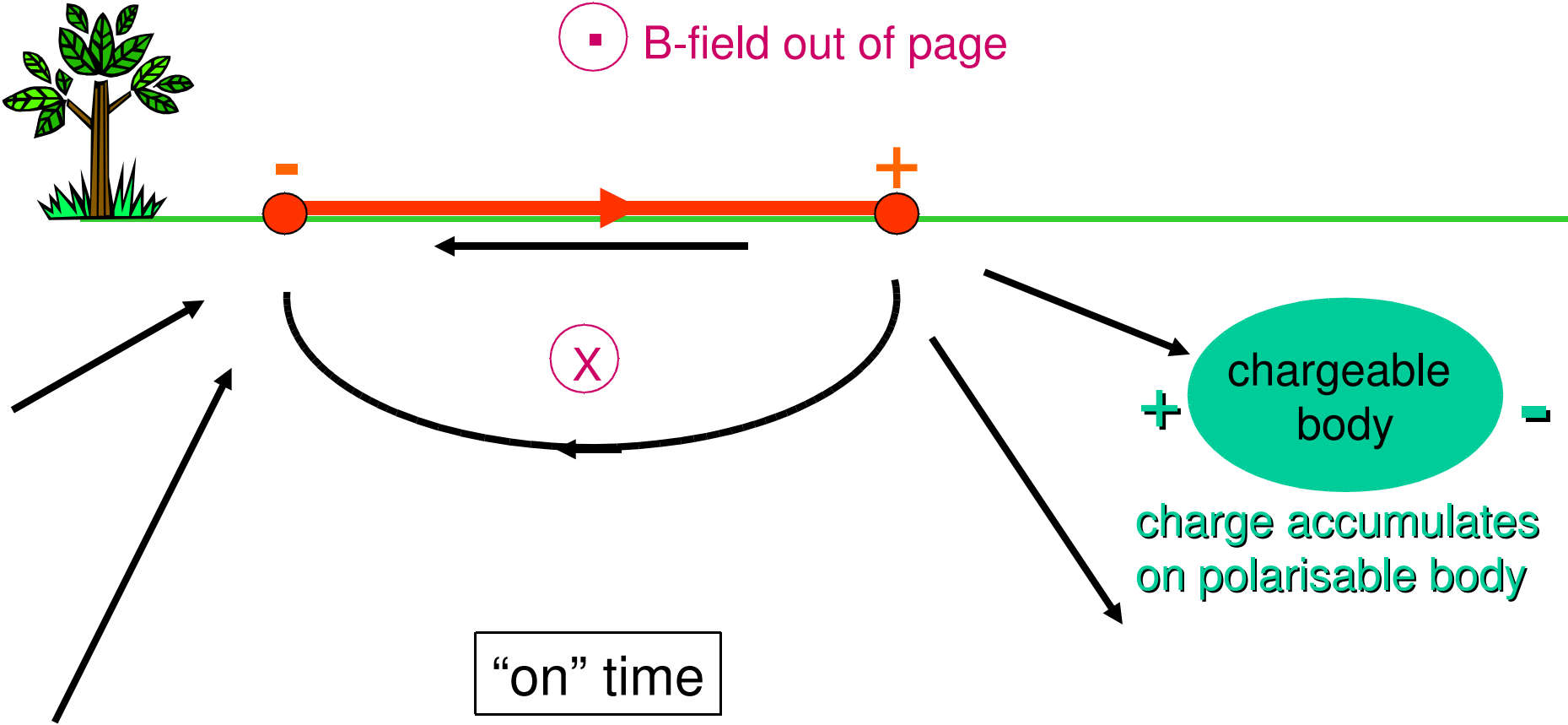
Therefore choice of path between points **does** affect voltage,  
i.e. wire geometry is important



$$V_1 \neq V_2$$

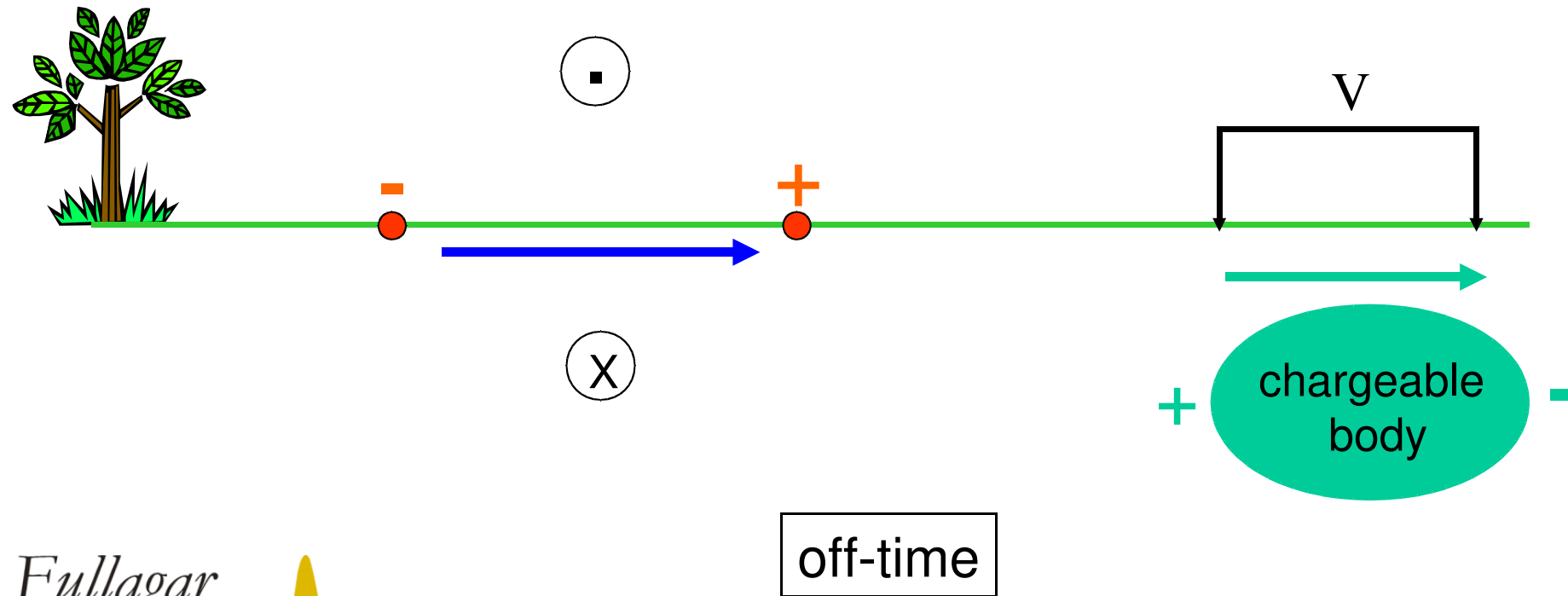


# Galvanic current from a dipole



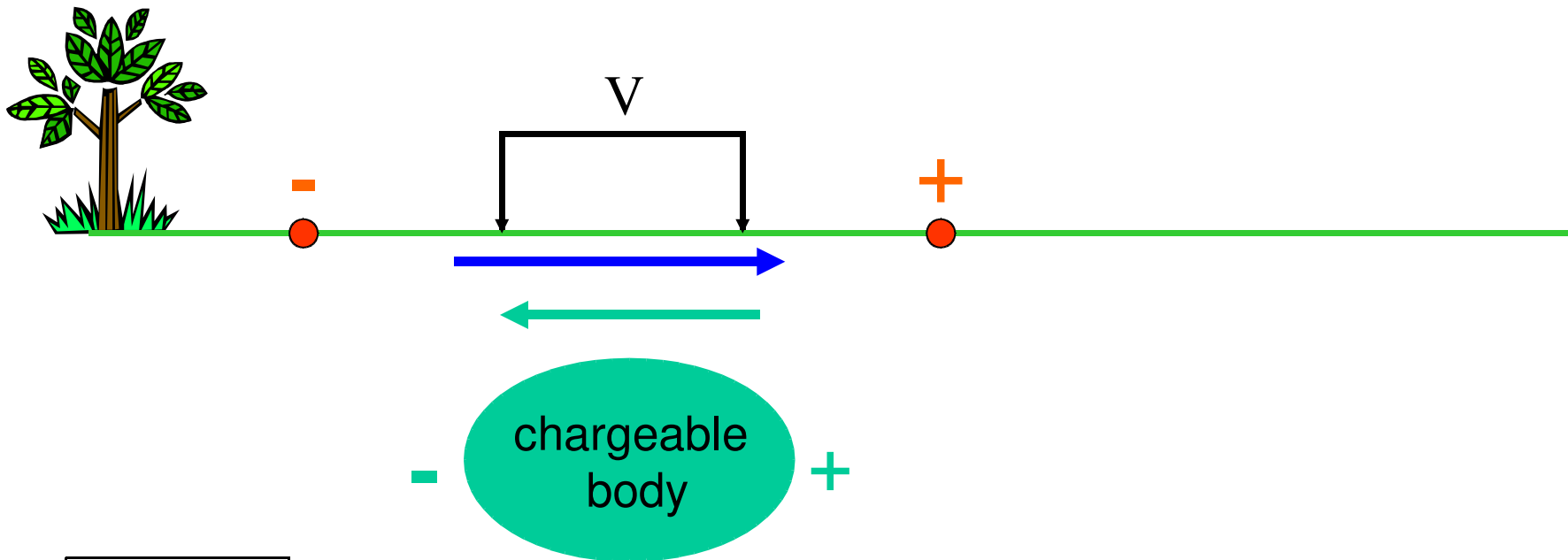
# Positive coupling

**IP discharge** and **induced current** “reinforce”,  
e.g. dipole-dipole array



# Negative coupling

IP discharge and induced current “oppose”,  
e.g. gradient array



off-time

# Key considerations

EM coupling is well understood insofar as it is aggravated by

- increasing conductivity
- higher frequency (or earlier times)
- increasing dipole size
- increasing dipole separation
- parallel wires, and
- any layout of wires which inadvertently couples well with conductors.

# Coupling & separation of wires

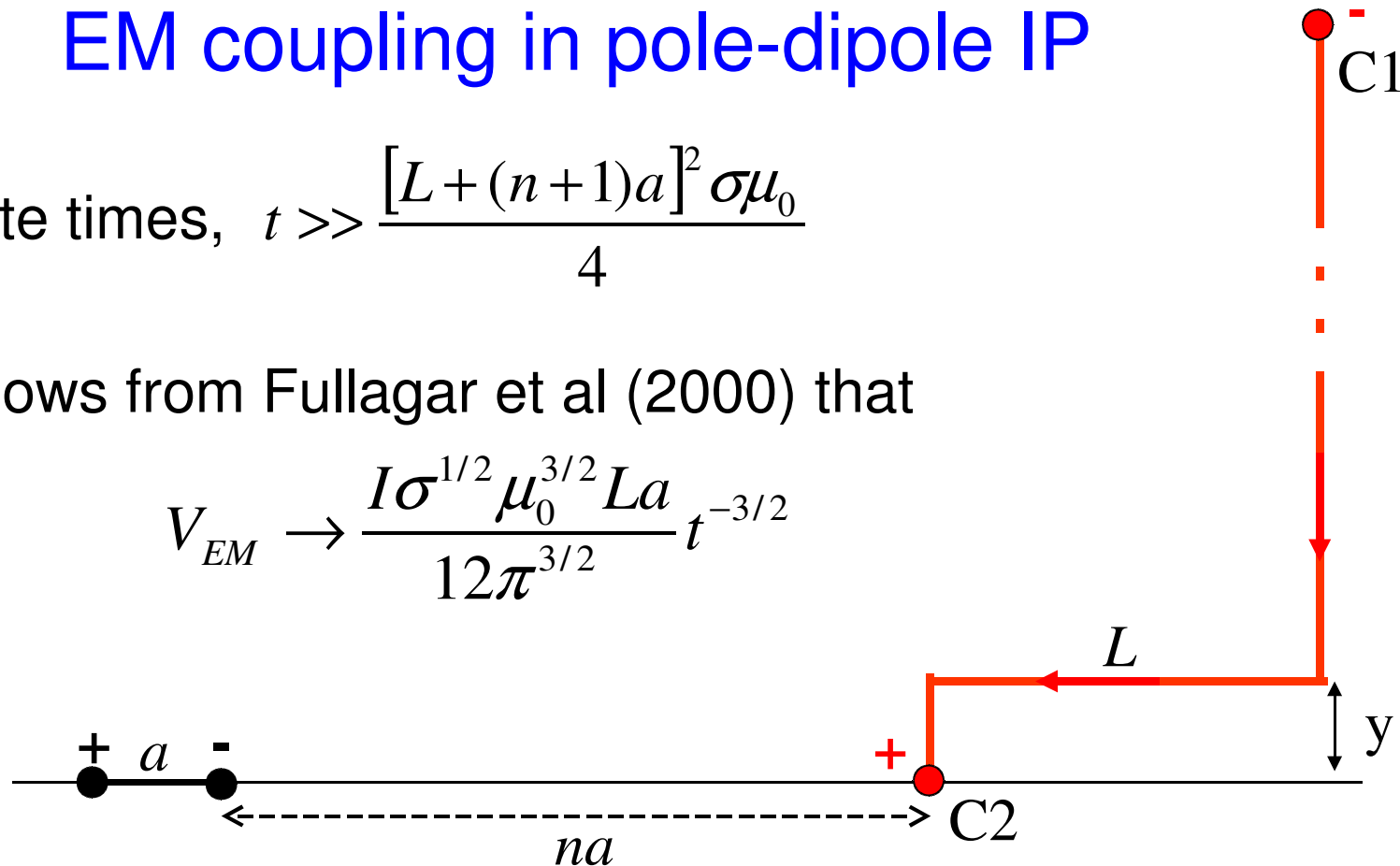
- Half-space coupling decays as  $t^{-3/2}$  at late time
- Coupling more significant at large n-spacings:  
late time  $V_{em}/V_{ip}$  increases as  $\sim n^2$  (P-D)  
or as  $\sim n^3$  (D-D)
- Late time coupling amplitude proportional to dipole size, but not n-spacing dependent
- Early time coupling amplitude higher for wires “broadside” to each other

# Late time formulae for half-space EM coupling in pole-dipole IP

At late times,  $t \gg \frac{[L + (n+1)a]^2 \sigma \mu_0}{4}$

it follows from Fullagar et al (2000) that

$$V_{EM} \rightarrow \frac{I \sigma^{1/2} \mu_0^{3/2} L a}{12 \pi^{3/2}} t^{-3/2}$$



1. Onset of “late time” is  $n$ -spacing dependent, but ...
- 2.... amplitude of late time coupling voltage is not.

# Late time **relative voltage** formulae for EM coupling in pole-dipole IP

At late times after step shut-off,  $t \gg \frac{[L + (n+1)a]^2 \sigma \mu_0}{4}$

amplitude of coupling voltage relative to DC voltage is given by

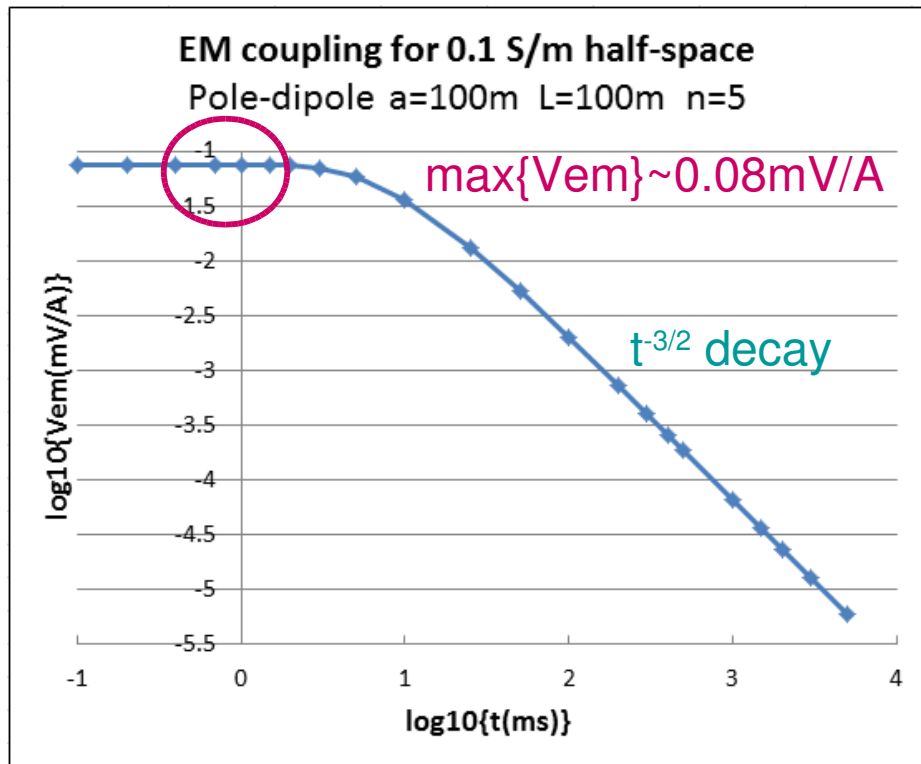
$$\frac{V_{EM}}{V_{DC}} \rightarrow \frac{n(n+1)\mu_0^{3/2} \sigma^{3/2} La^2}{6\sqrt{\pi}} t^{-3/2}$$

on a half-space with conductivity  $\sigma$ .

**Thus late time coupling is much more significant in relative terms at large  $n$ -spacings.**

# EM coupling on conductive half-space

## Pole-dipole Case A: $n=5$



- C1

$V_{em} = 1\%$  of  $V_{dc}$  after 50ms

$V_{ip} = pfe\%$  of  $V_{dc}$  at shut-off

**Positive coupling**

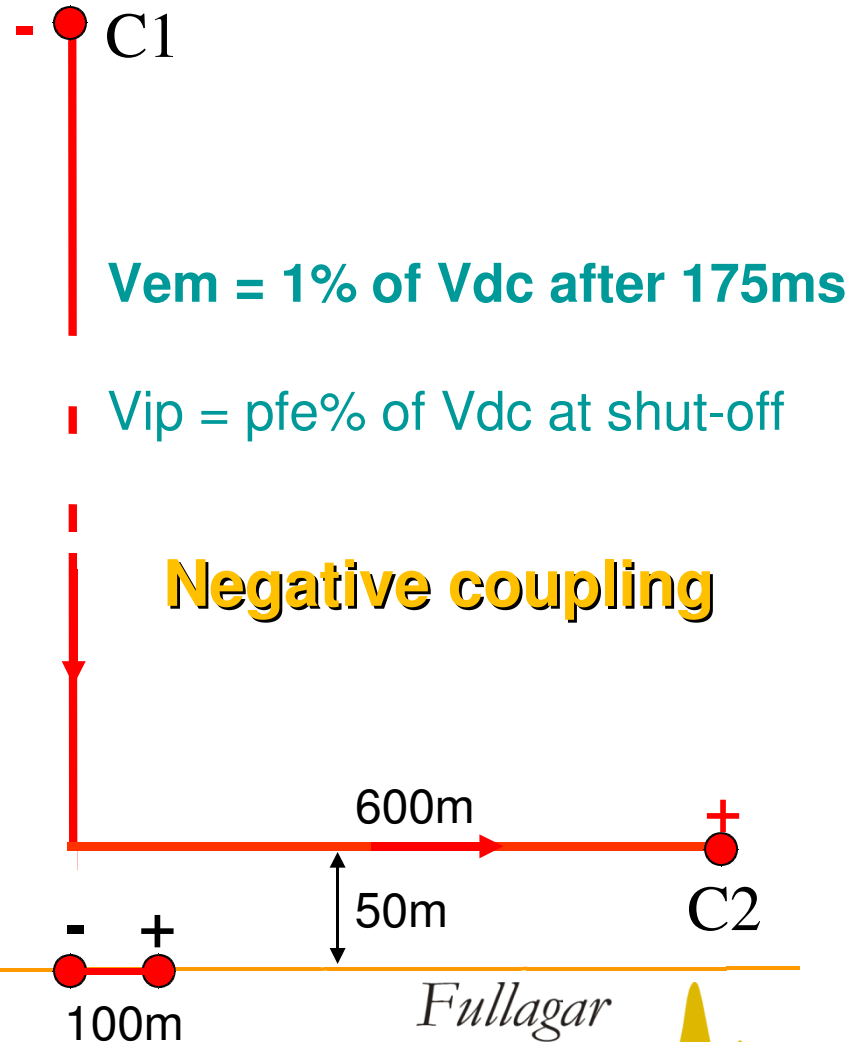
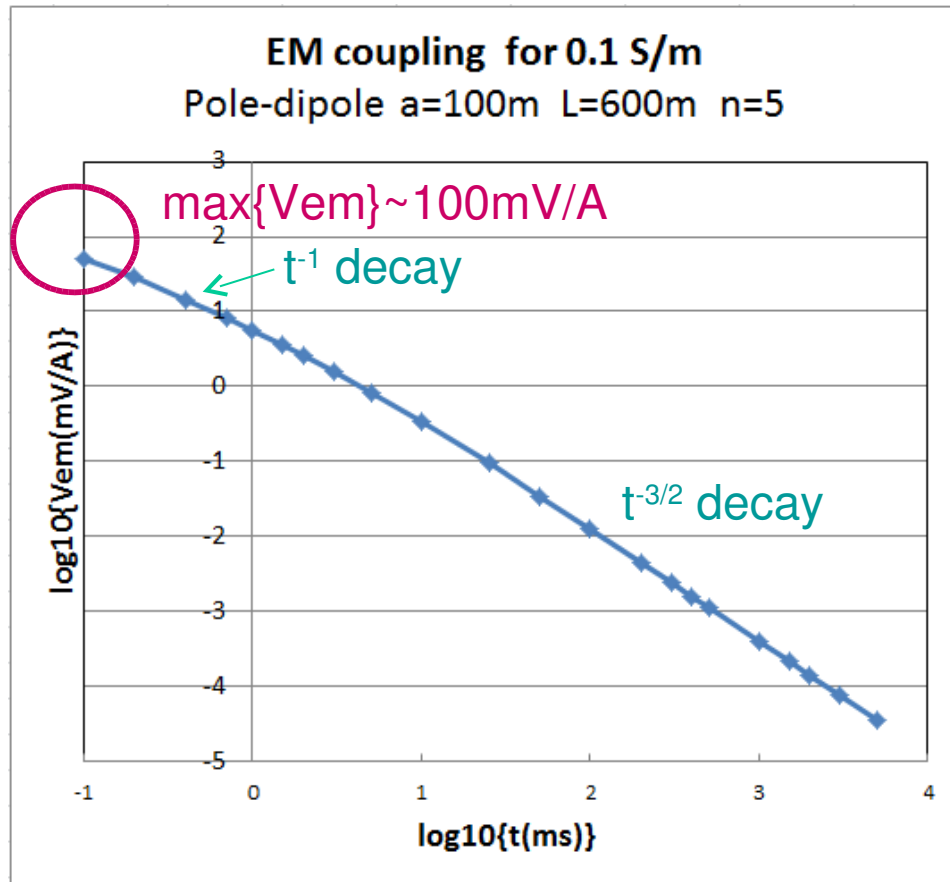
100m  
C2 +  
50m

- +  
100m

500m

# EM coupling on conductive half-space

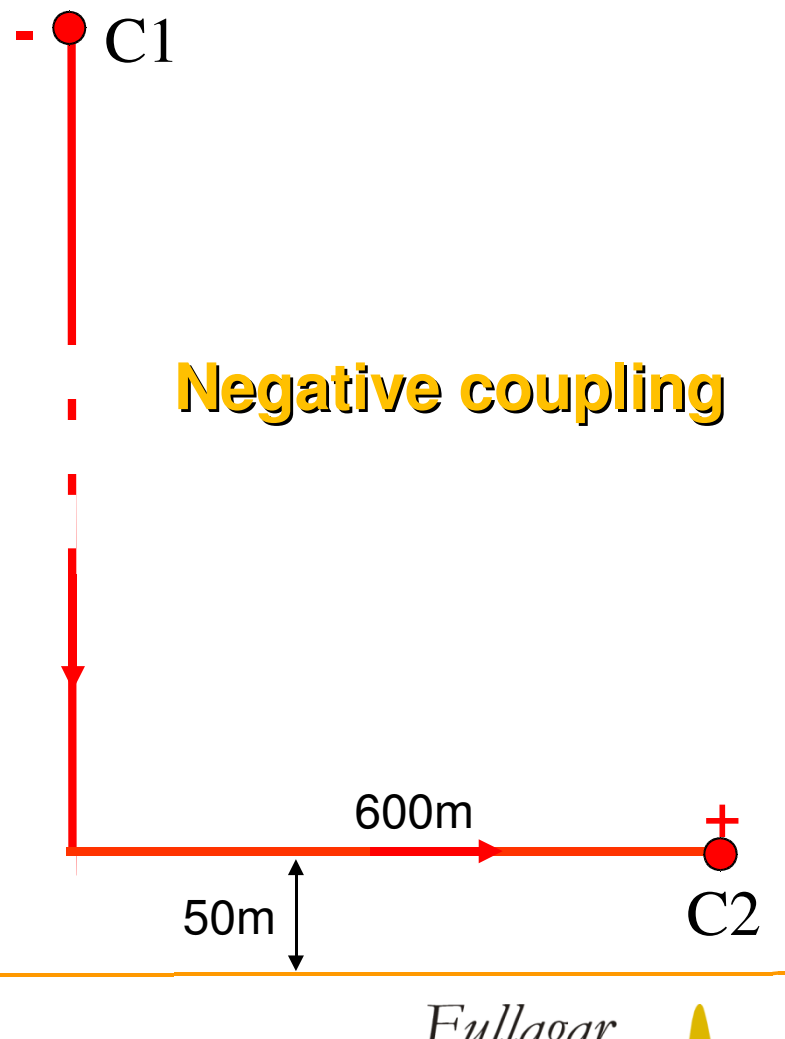
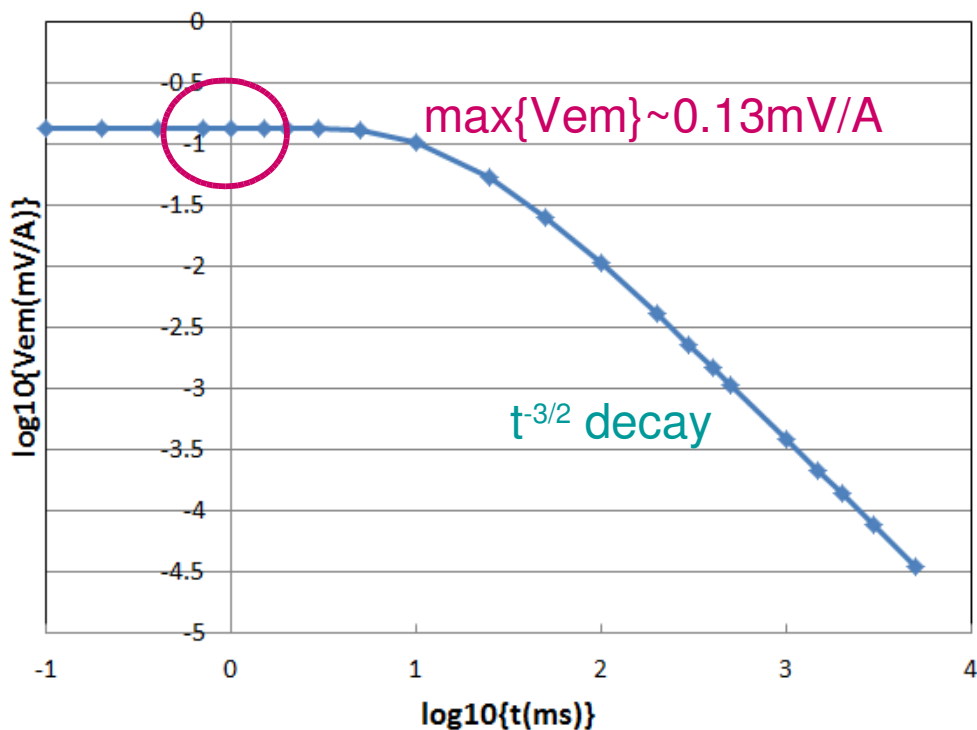
## Pole-dipole Case B: $n=5$



# EM coupling on conductive half-space

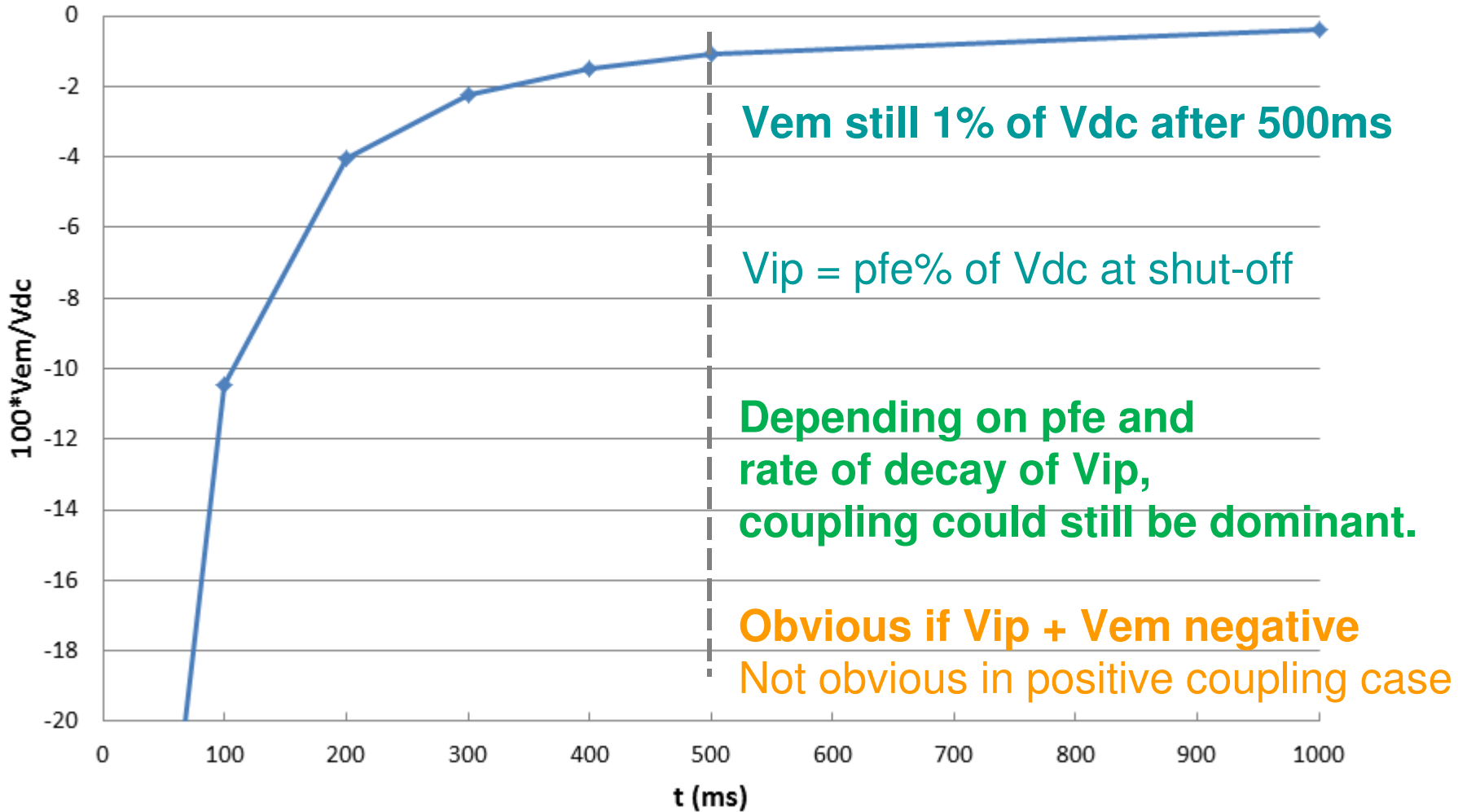
## Pole-dipole Case C: $n=12$

EM coupling for 0.1 S/m half-space  
Pole-dipole  $a=100\text{m}$   $L=600\text{m}$   $n=12$



## EM coupling converted to %Vdc

Pole-dipole  $\sigma=0.1$  S/m  $a=100$ m  $L=600$ m  $n=12$



# EM coupling as noise

- 3-point frequency domain de-coupling:

$$\phi_{IP} = \phi - \phi_{EM}$$

- Waiting in the time domain
- Time domain decoupling – why not?

$$V_{IP} = V - V_{EM}$$

# EM de-coupling in frequency domain via phase extrapolation to DC

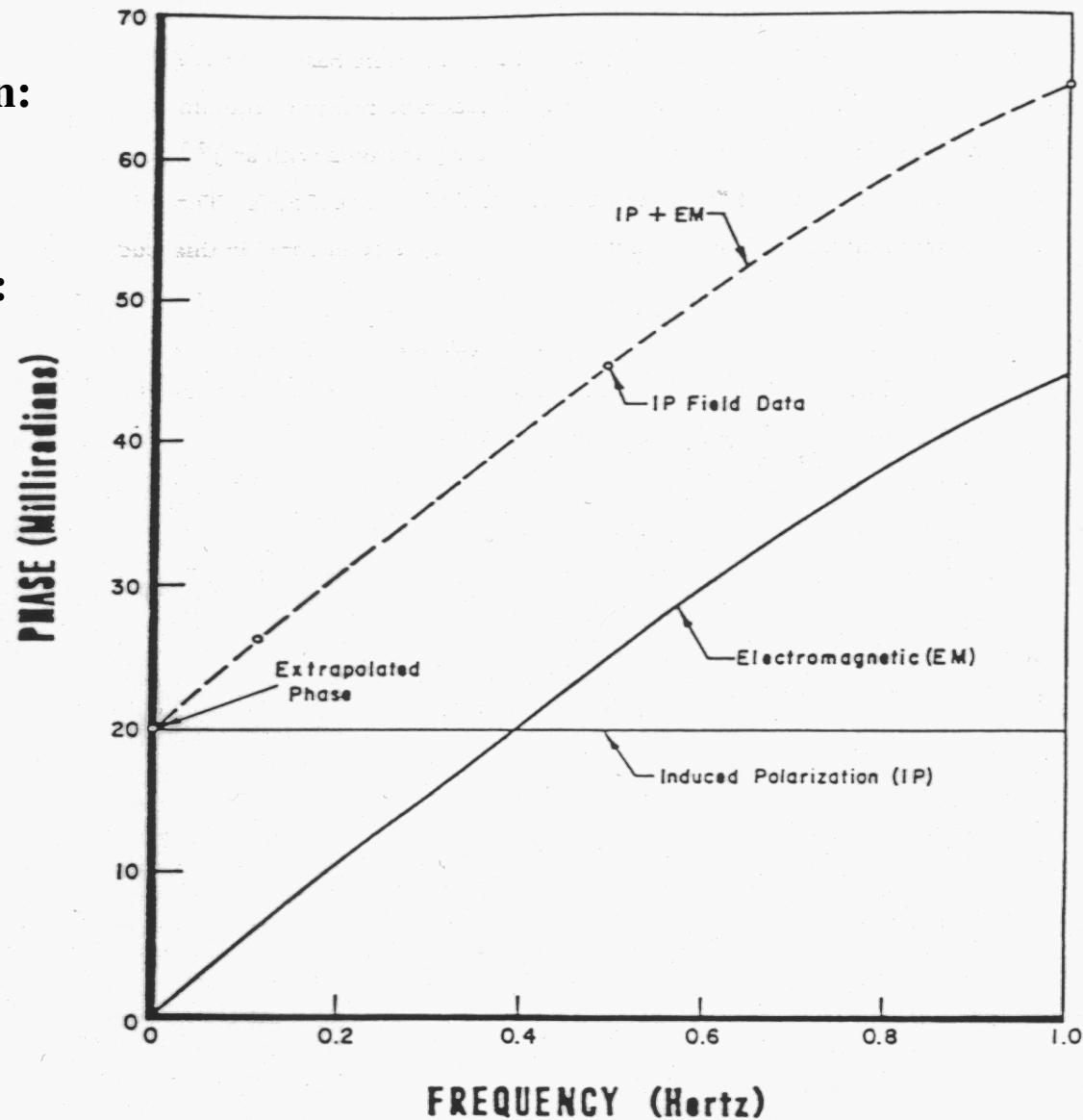
“Conventional” extrapolation:

$$\phi = \phi_{ip} + af + bf^2$$

Coggon (1984) extrapolation:

$$\phi = \phi_{ip} + Af + Bf^{1.5}$$

(after Hohmann, 1990)



# Frequency domain 3-point decoupling

Conventional quadratic approximation: de-coupled phase is

$$\phi_2 = 1.875\phi(1) - 1.250\phi(3) + 0.375\phi(5);$$

Coggon  $f^{3/2}$  approximation: de-coupled phase is

$$\phi_{1.5} = 2.11413\phi(1) - 1.72825\phi(3) + 0.61412\phi(5)$$

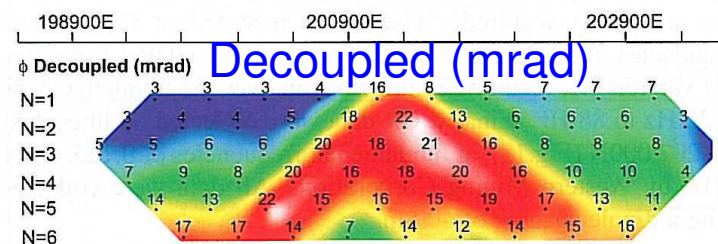
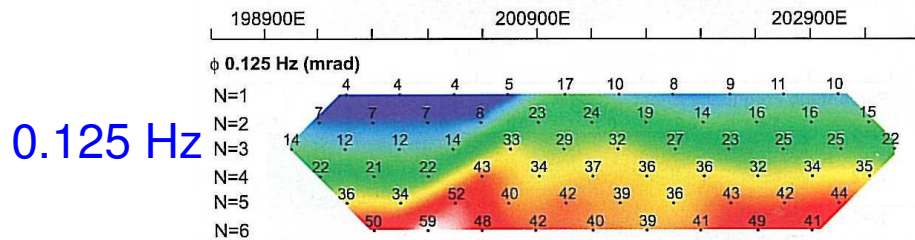
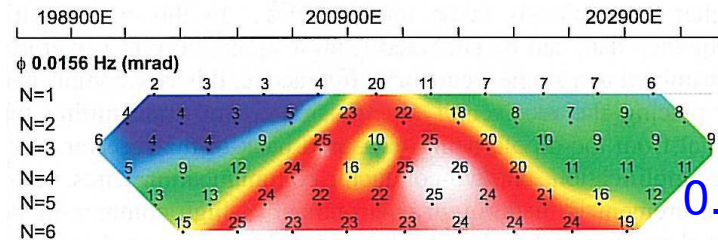
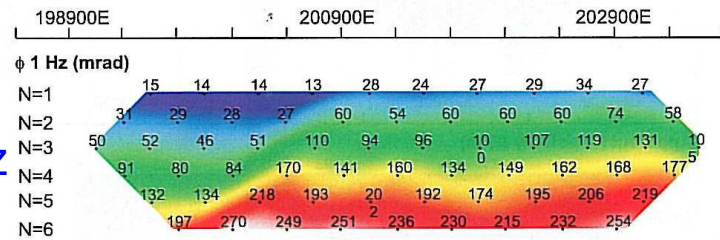
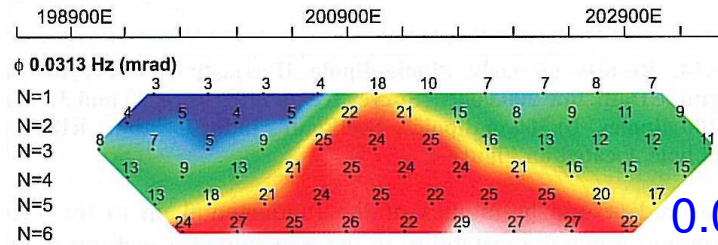
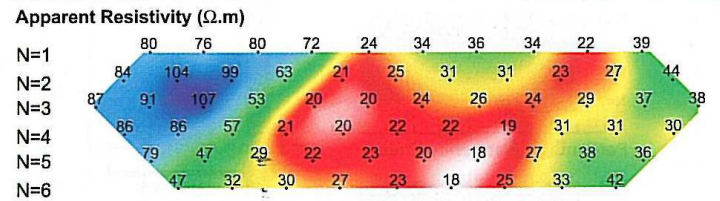
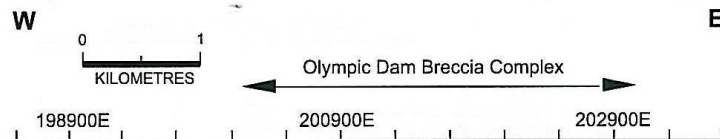
where  $\phi(1)$  is the measured phase at the fundamental,  $f_0$

$\phi(2)$  is the measured phase at  $3f_0$

$\phi(3)$  is the measured phase at  $5f_0$

# Multi-frequency IP

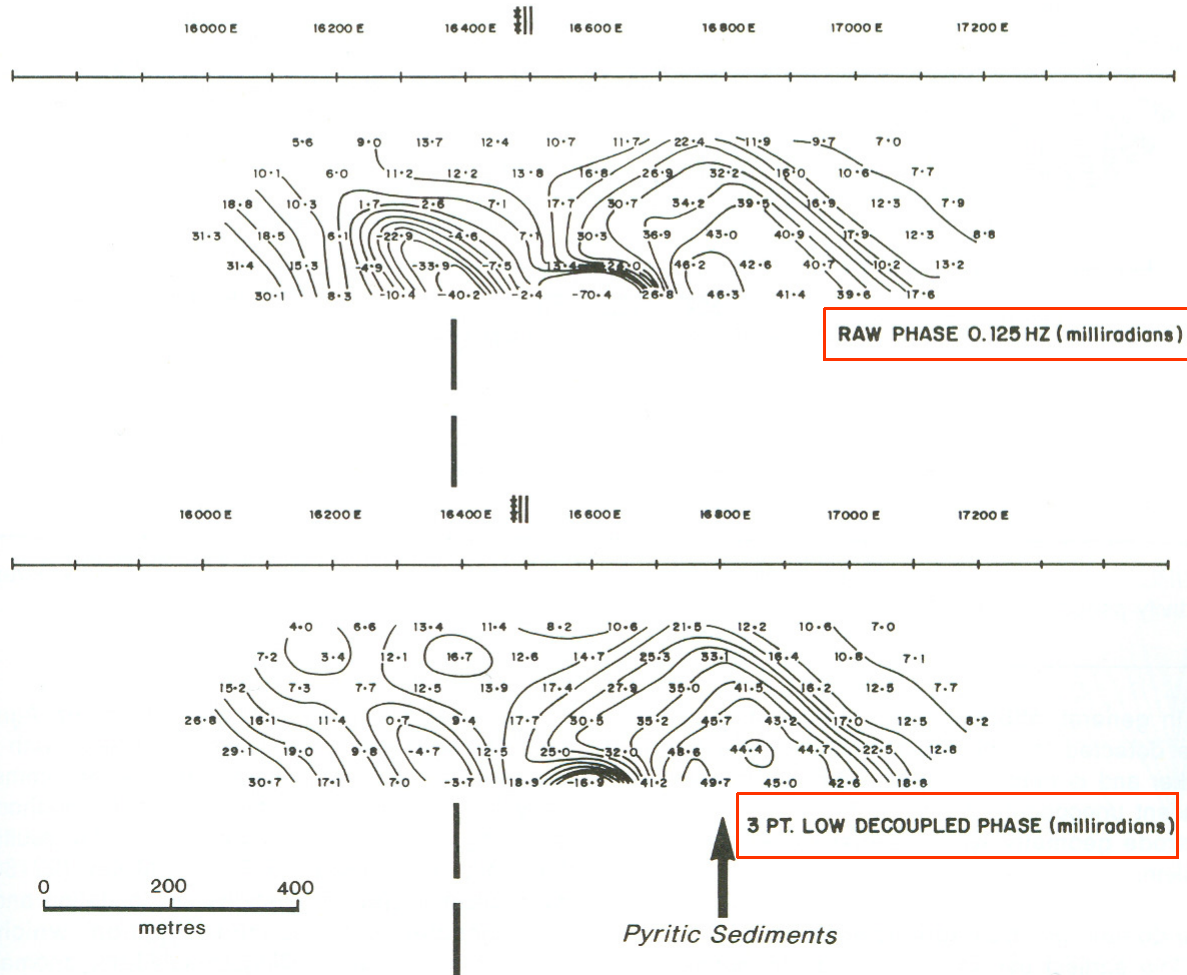
Olympic Dam, SA Dipole-dipole array,  $a = 400$  m



Note decreasing effect of EM coupling as frequency is decreased

(Dentith, 2003)

# De-coupling sometimes fails ... ... but still benign?

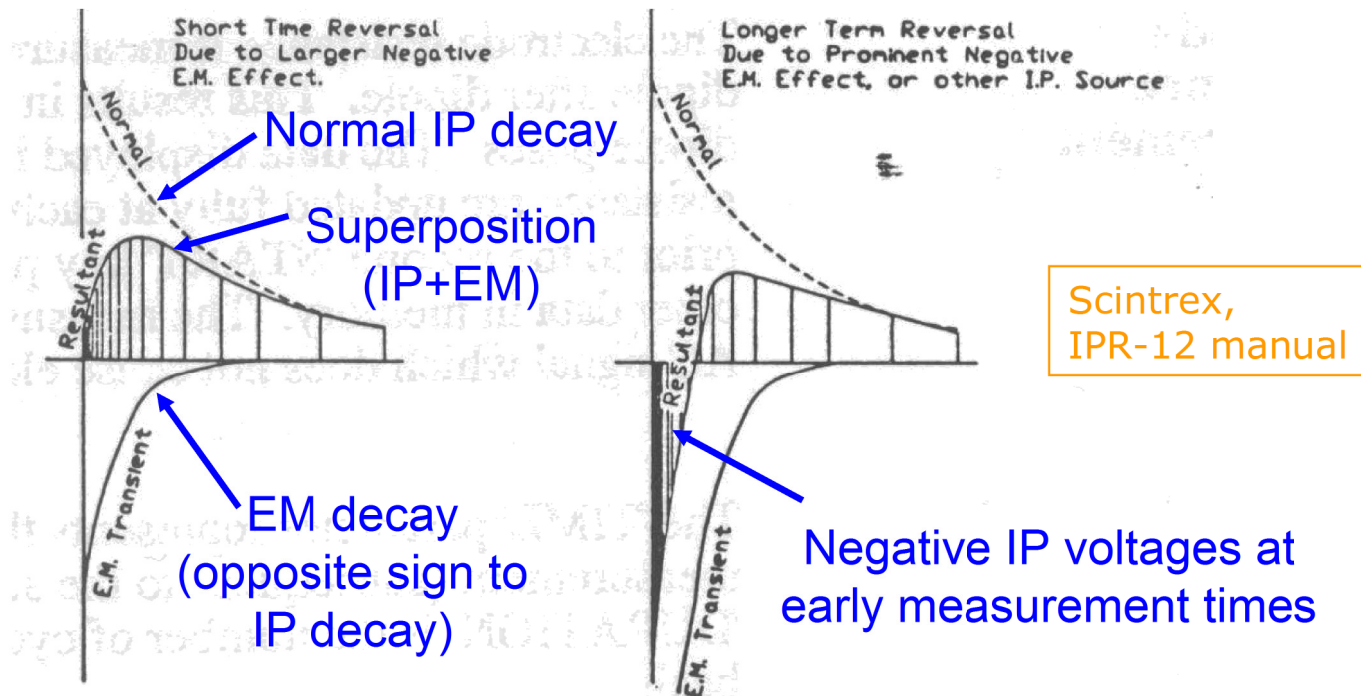


Rocky's  
Reward, WA  
(NiS)

100 m dipole-  
dipole array

(Mutton and Williams, 1994)

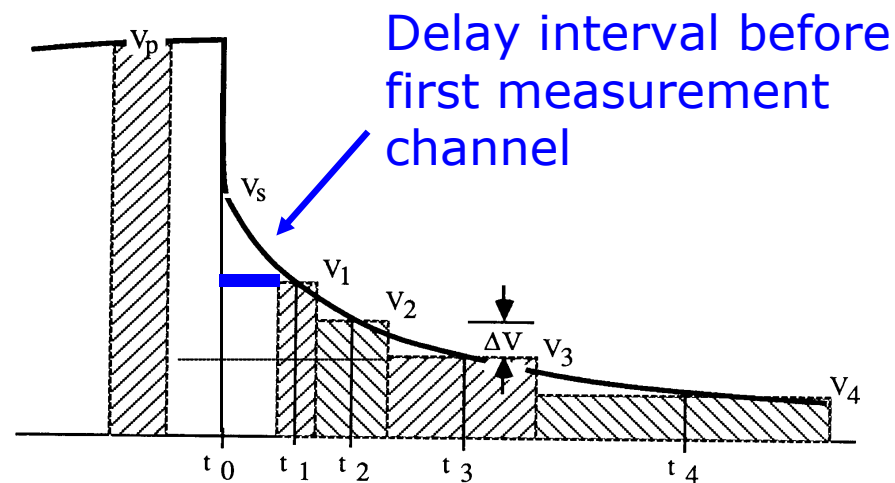
# EM Coupling in time domain IP data



- Weak to moderate negative EM coupling may suppress the voltages at early measurement times, without actually causing them to become negative => EM coupling can be difficult to recognise in these cases

# Waiting versus de-coupling of time domain IP data

- In time-domain data, it is often assumed that EM effects can be avoided by increasing the delay time between current switch-off and the first measurement channel, i.e. **wait a while**
- The increased delay time allows the EM voltage to decay (to **negligible size**) before the IP voltages are measured
- The length of the decay interval must be **carefully chosen** so that EM fields have had time to decay, but the IP decay voltages are still large enough to detect



No need to de-couple?  
**Wishful thinking?**

## 5-star time domain de-coupling

- Determine the 3D conductivity distribution, via inversion of early time data
- Compute TEM response
- Subtract TEM decay from measured transient
- Interpret residual “pure IP” decay estimate

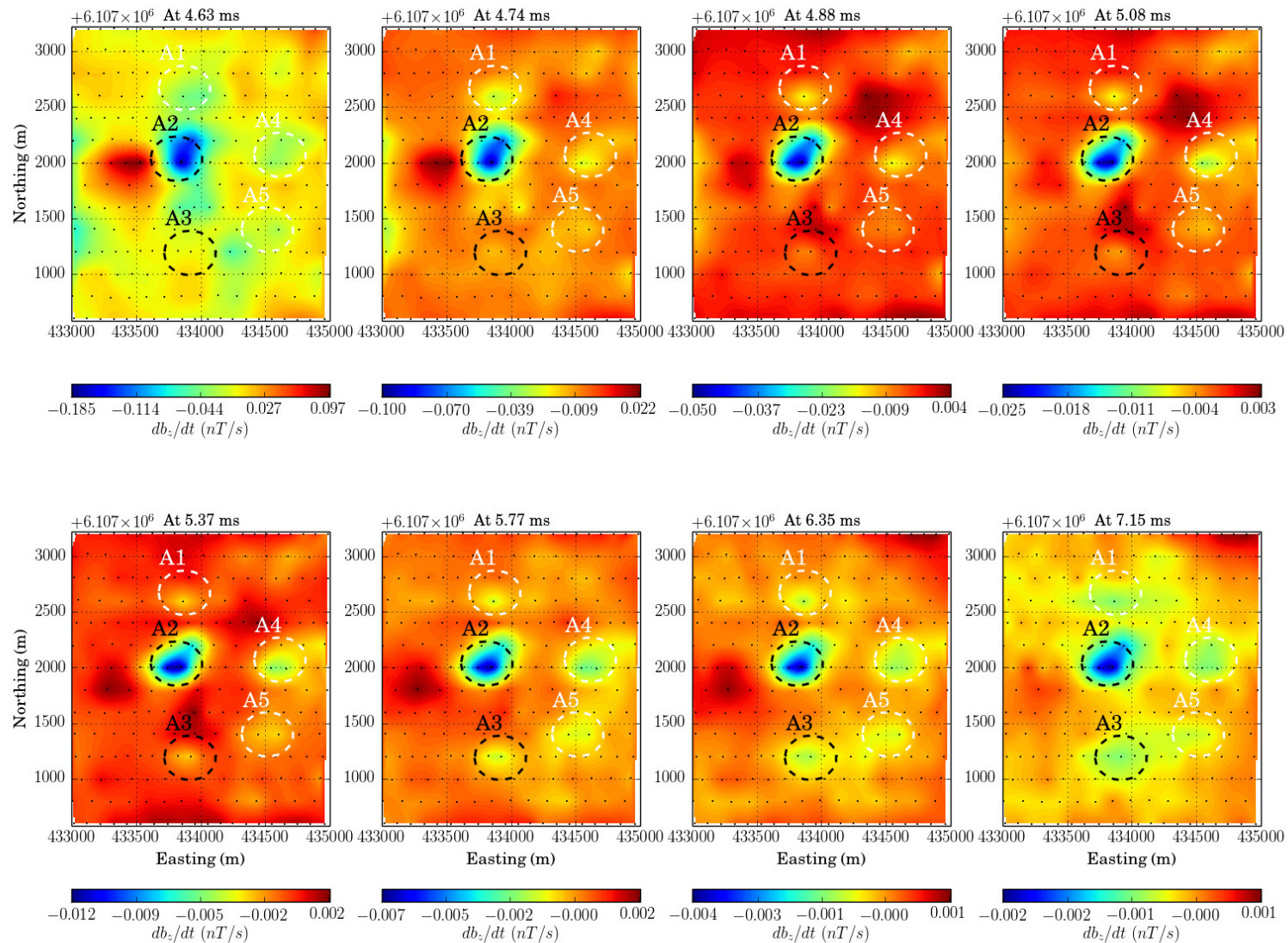
Applied in 2D by Routh & Oldenburg (1996)

Applied in 3D to VTEM by Kang

# “De-coupling” of VTEM data (Kang, UBC)

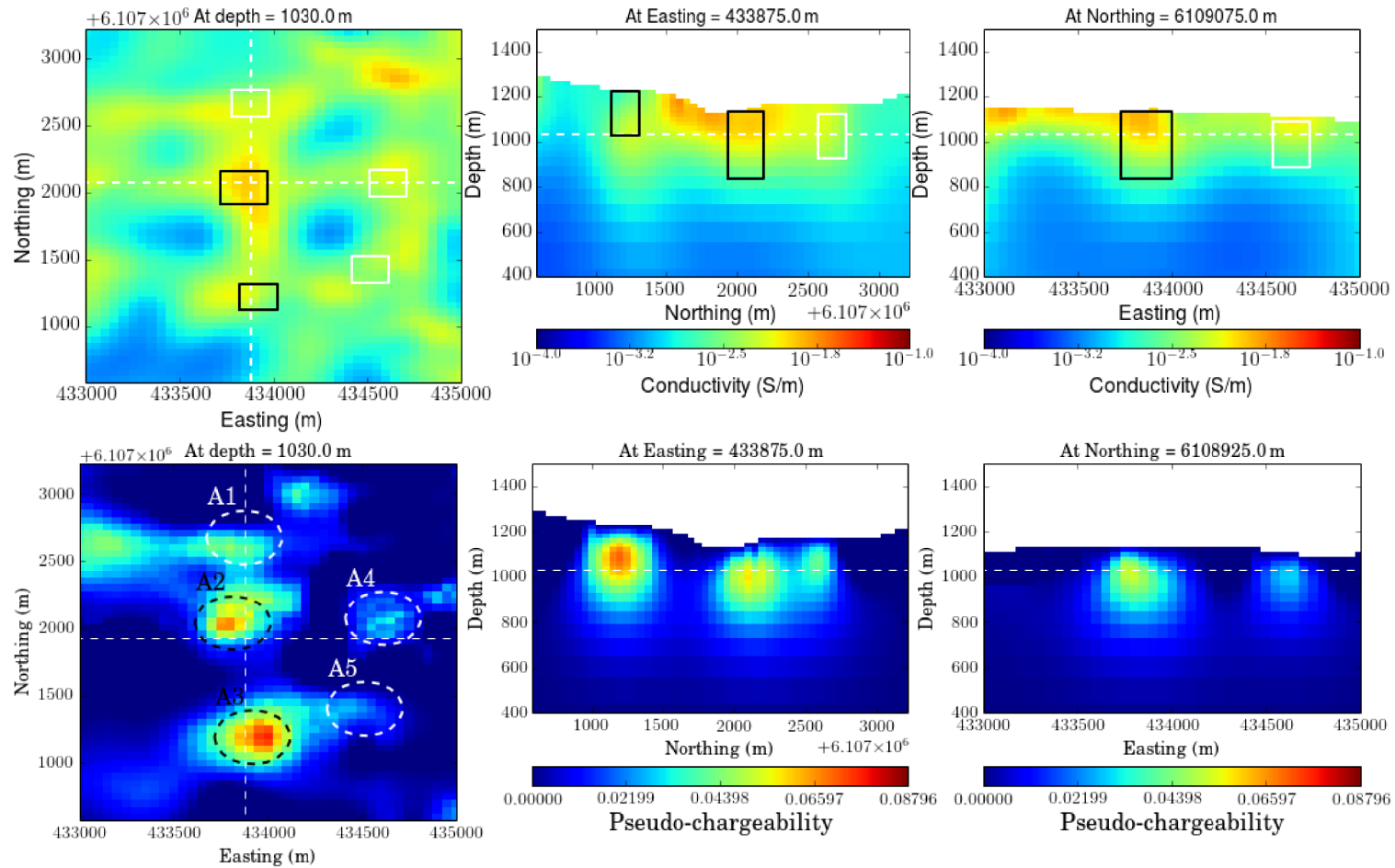
## Invert early time VTEM

Residual (observed - calculated) is estimate of IP response



# IP inversion of VTEM residual

(Kang, UBC)



# 3-star time domain de-coupling

(Fullagar et al, 2000)

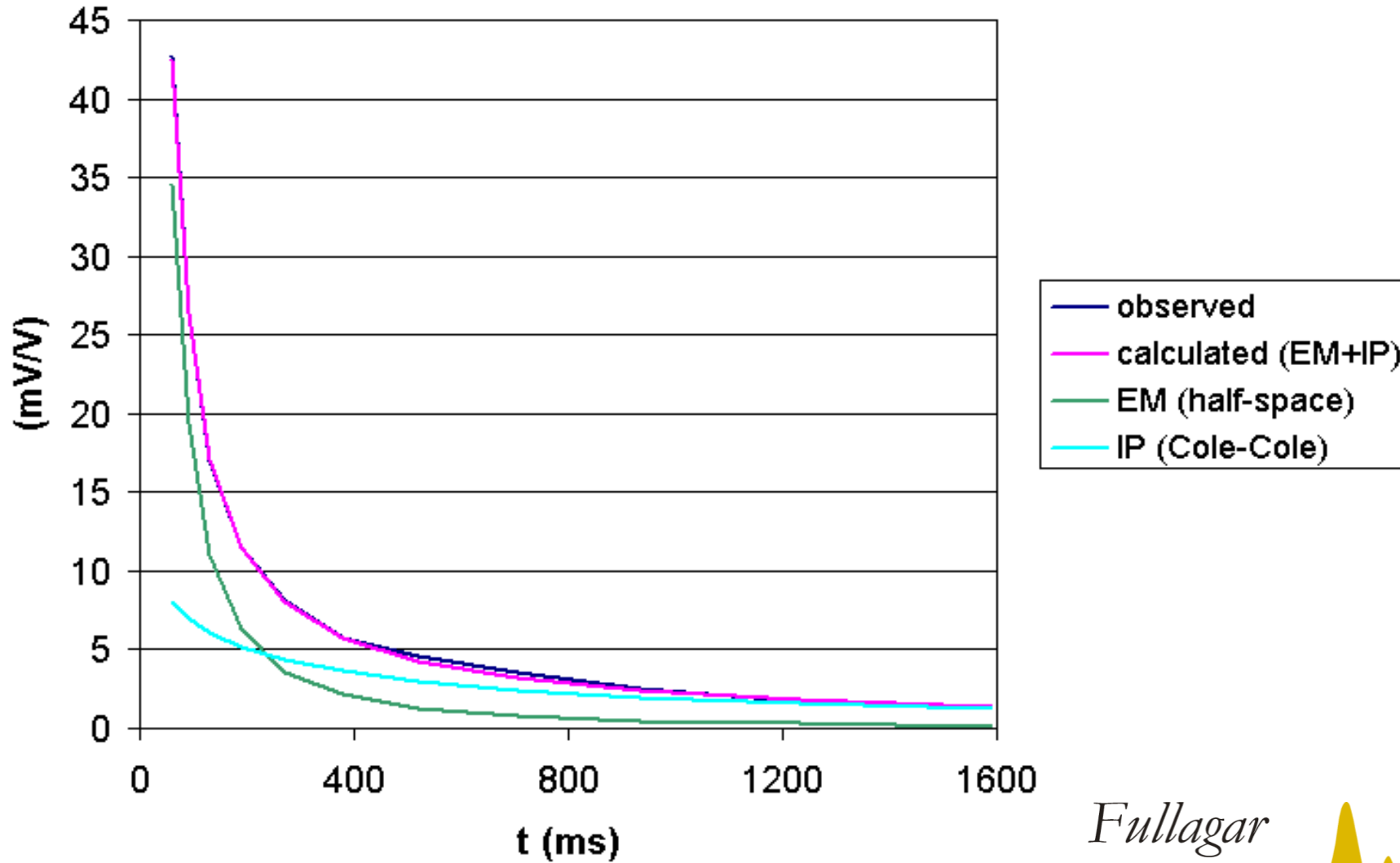
## Removal of TEM half-space decay

- Determine apparent EM resistivity,  $\rho_{EM}$ , for the appropriate wire layout
- Compute TEM half-space decay for  $\rho_{EM}$
- Subtract half-space decay from data
- Interpret “pure IP” de-coupled decay estimate, e.g. determine Cole-Cole parameters
- {Or solve for  $V = V_{em} + V_{ip}$  instead of for  
 $V_{ip} = V - V_{em}$ }

## Cole-Cole inversion of transient

300m DD data n-level=1

res=19.7ohm.m charge=58mV/V tau=107ms c=0.18



# EM coupling as signal

## Ideal is joint EM/IP interpretation

- Requires knowledge of complex conductivity spectra
- Requires 3D software
- Computer intensive
- Not currently feasible
- Not always warranted

# Conclusions

1. Yes, EM coupling can be a problem.  
Need to gauge its magnitude for given wire layout & conductivity.
2. “Ideal” solution (long term) is to invert for EM & IP simultaneously
3. Medium term: invert for EM, then IP, sequentially
4. Short term: take wire geometry into account;  
de-couple in TD as well as FD

# References

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