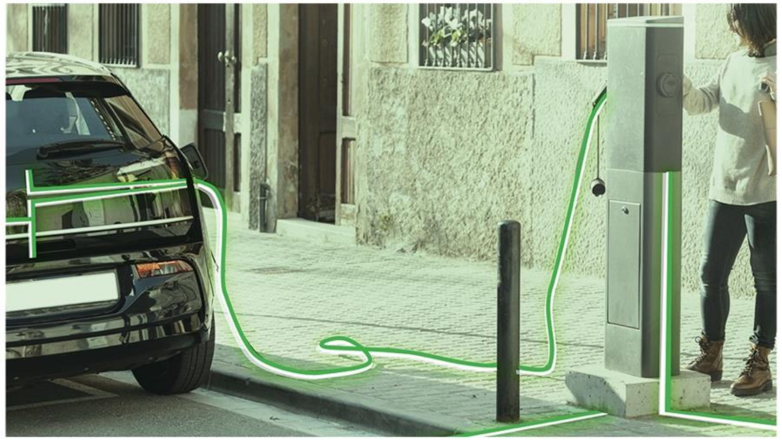
FlatEMF - Technical part

Mr Karatsivos, Europacable TTWG
1 October 2025

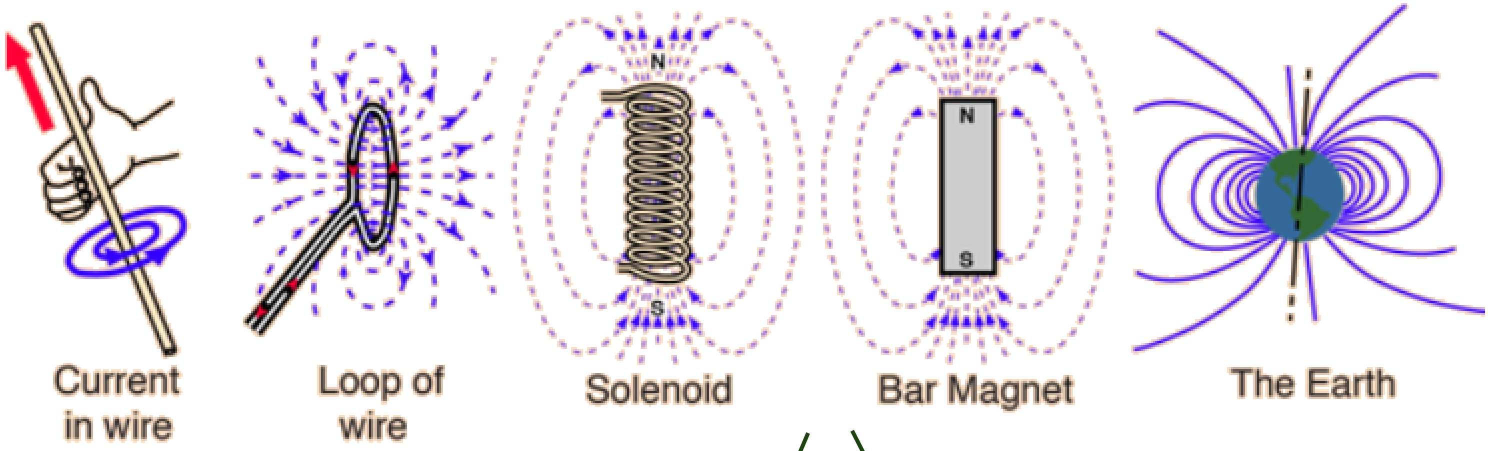






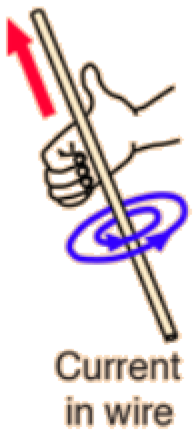

Electromagnetism

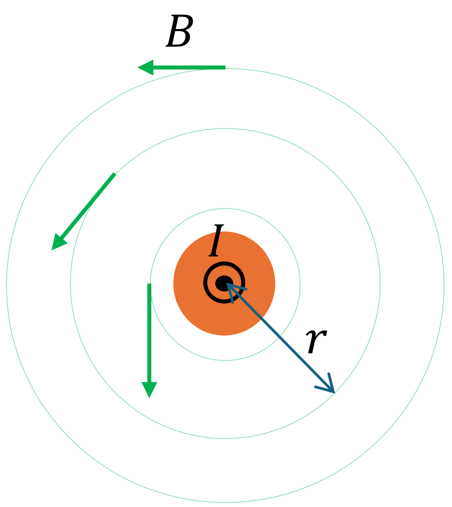
One of the fundamental forces in physics



Generated by the drift of electrons under an electric field

Occuring naturally due to the orientation of the magnetic dipoles in the atomic structure of the material





$$B = \frac{\mu_0 I}{2\pi r}$$

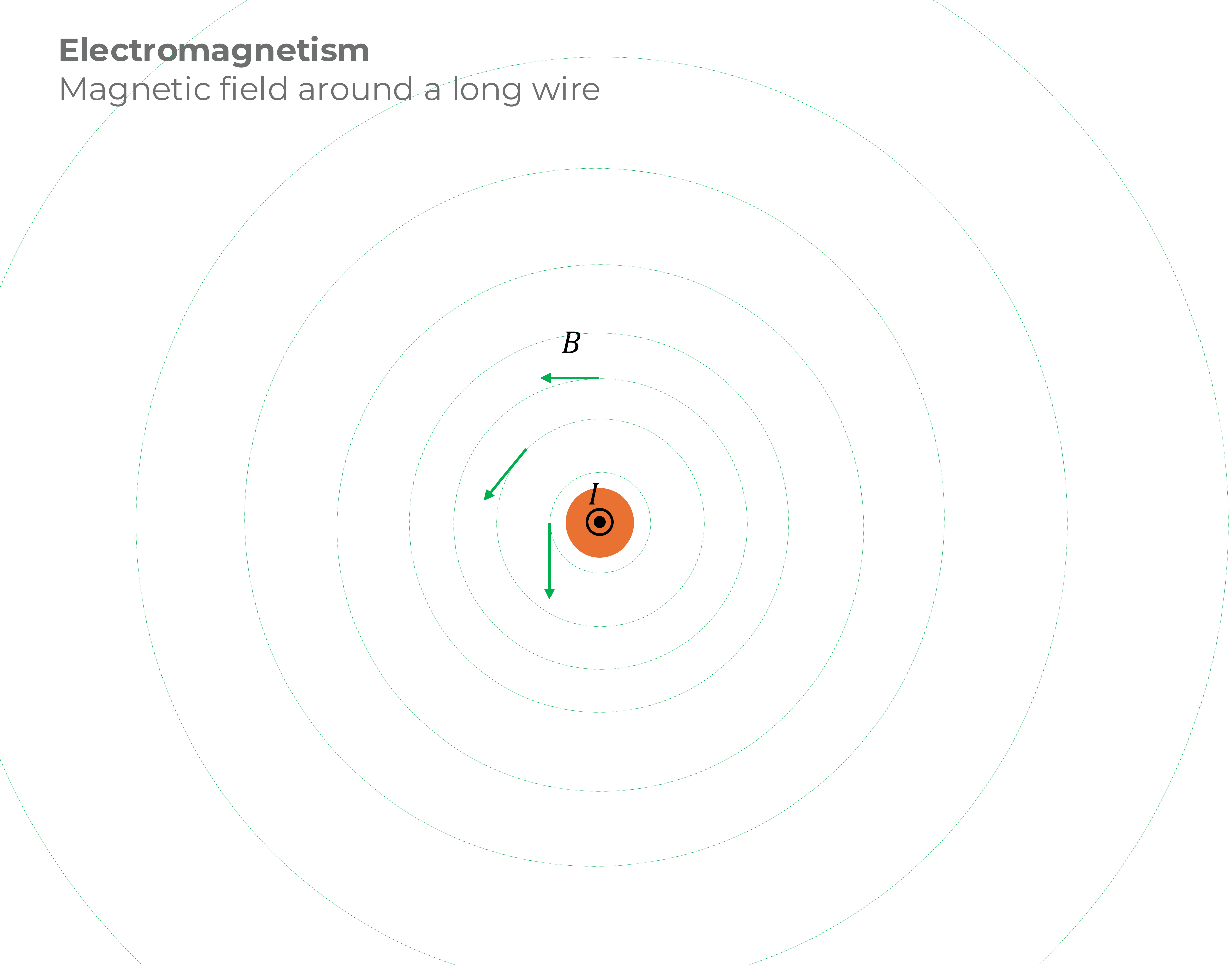
$B: Magnetic\ field\ density\ (T)$
$I: Current\ (A)$
$r: Distance\ (m)$

$B \propto I, B \propto 1/r$

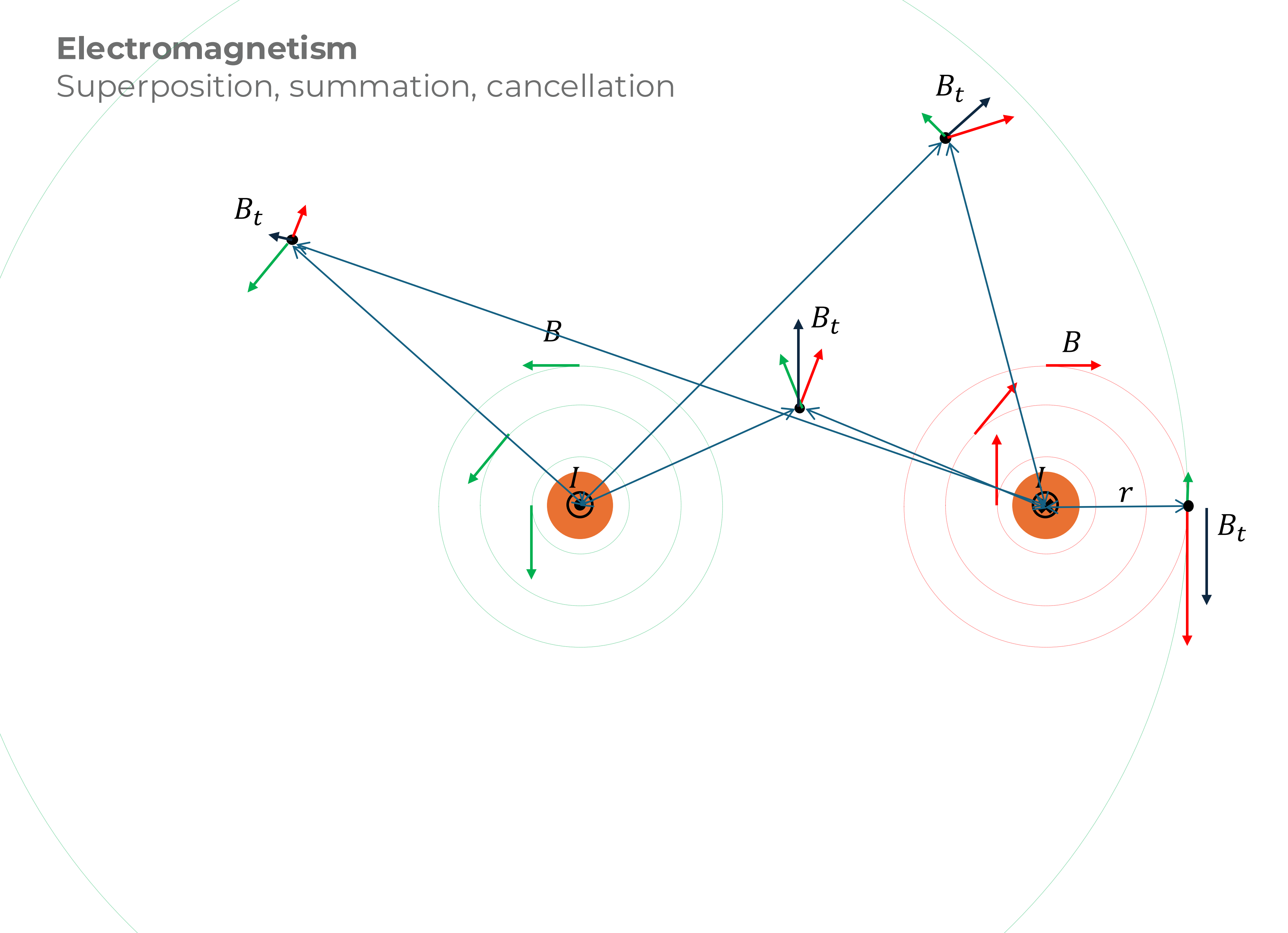
The magnetic field is proportional to the current and inversely proportional to the distance

Electromagnetism

Magnetic field around a long wire

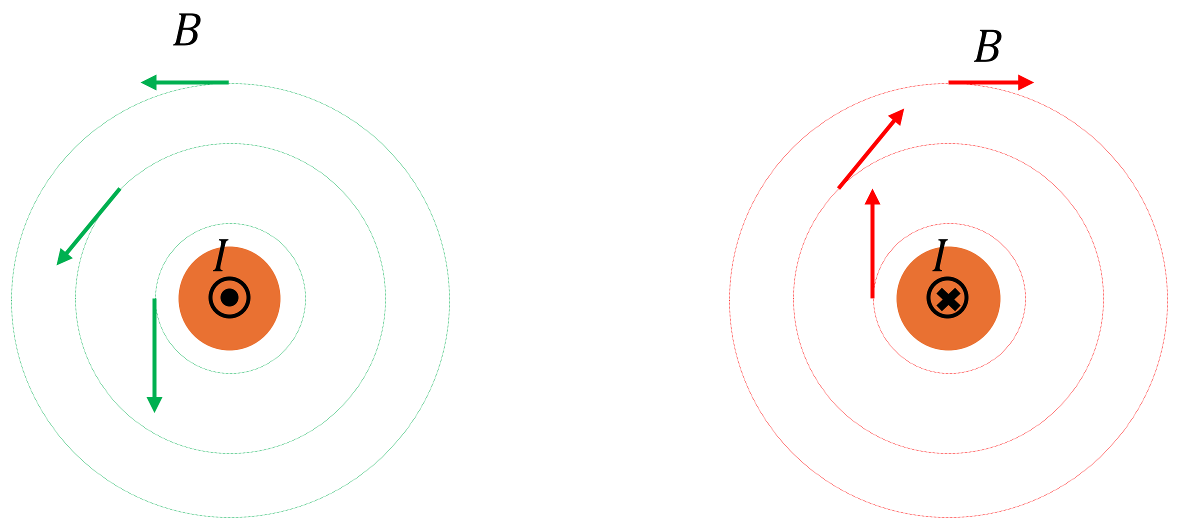


Electromagnetism
Superposition, summation, cancellation

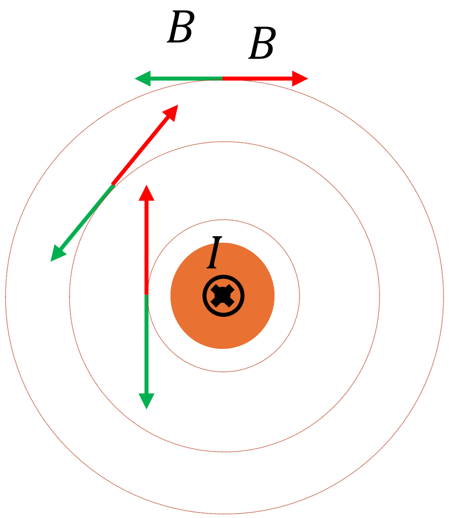


Electromagnetism

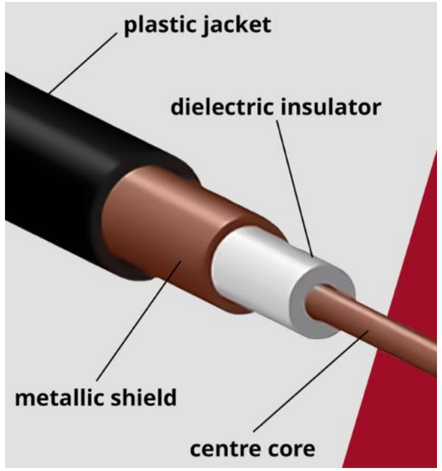
Superposition, summation, cancellation



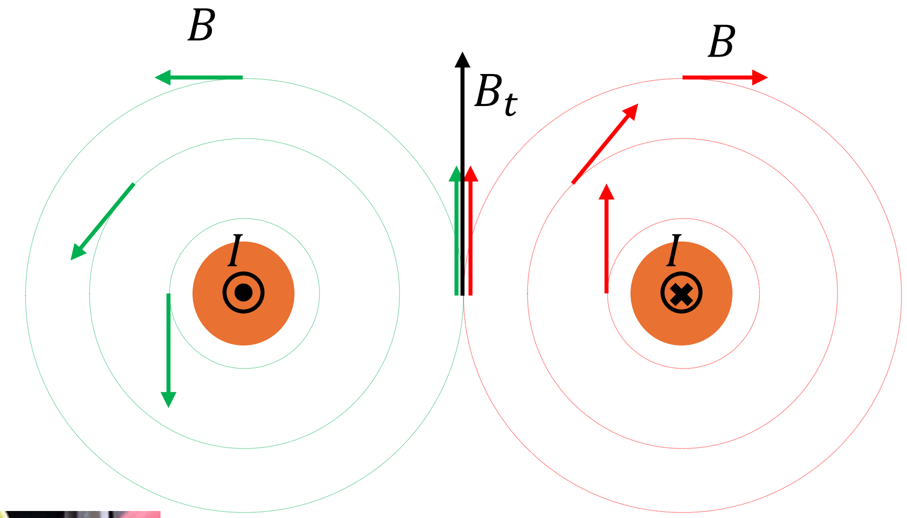
Electromagnetism
DC cables



- Voltage: ~2kV
- Current: ~ mA
- Weight: ~ 30 gr/m
- Diameter: ~10 mm



- Voltage: 525 kV
- Current: ~2kA
- Weight: ~ 60 kg/m
- Diameter: ~150 mm



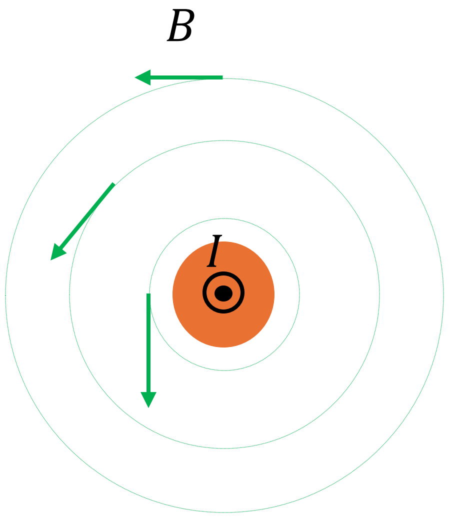
$$I = const$$
$$B = const$$

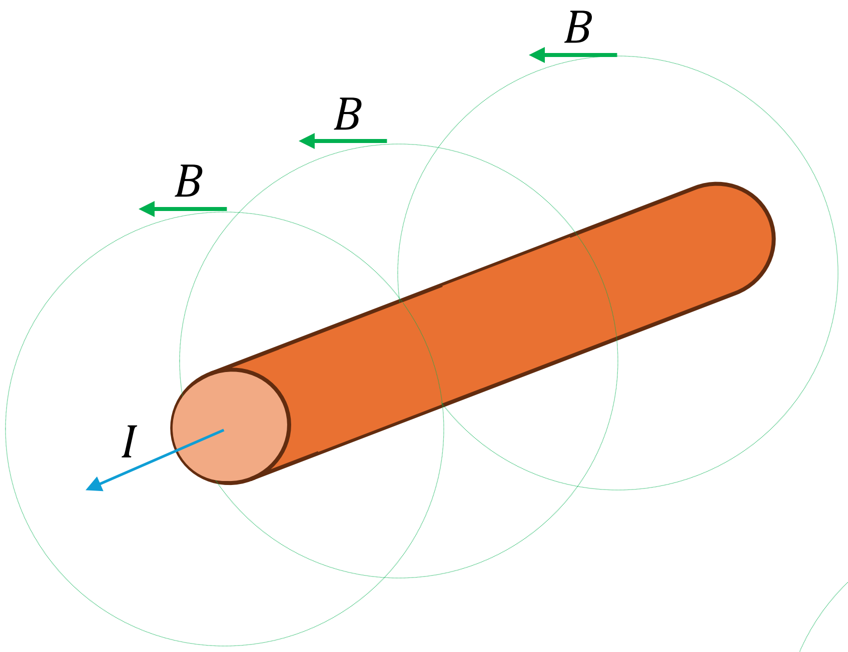
$$B = \frac{\mu_0 I}{2\pi r}$$

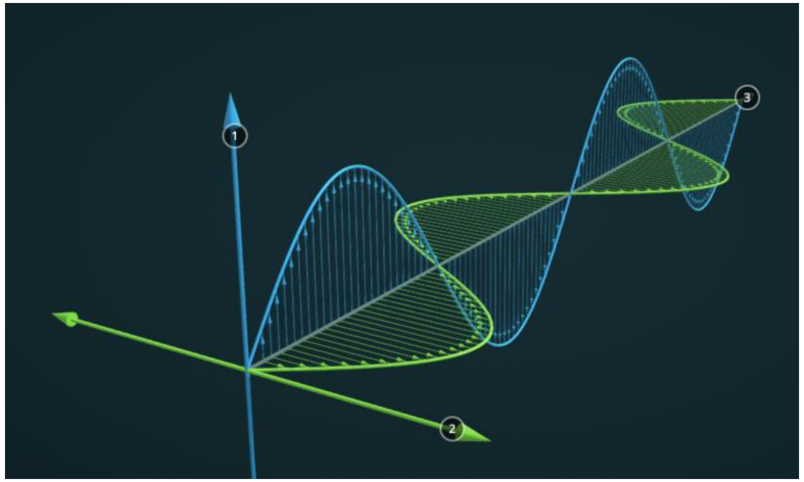
- Voltage: 525 kV
- Current: ~2kA
- Weight: ~ 60 kg/m
- Diameter: ~150 mm

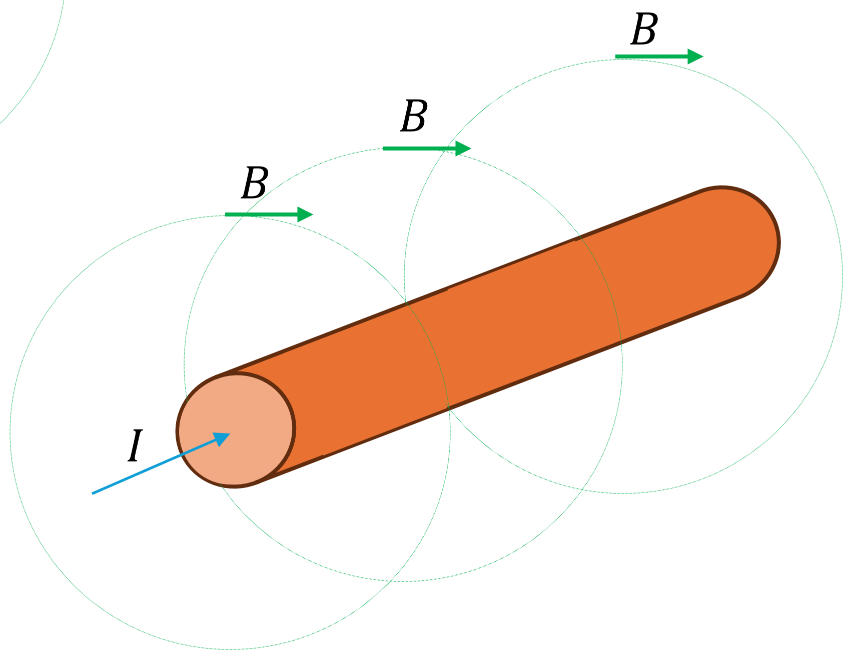
Electromagnetism

Alternate currents, alternate magnetic fields





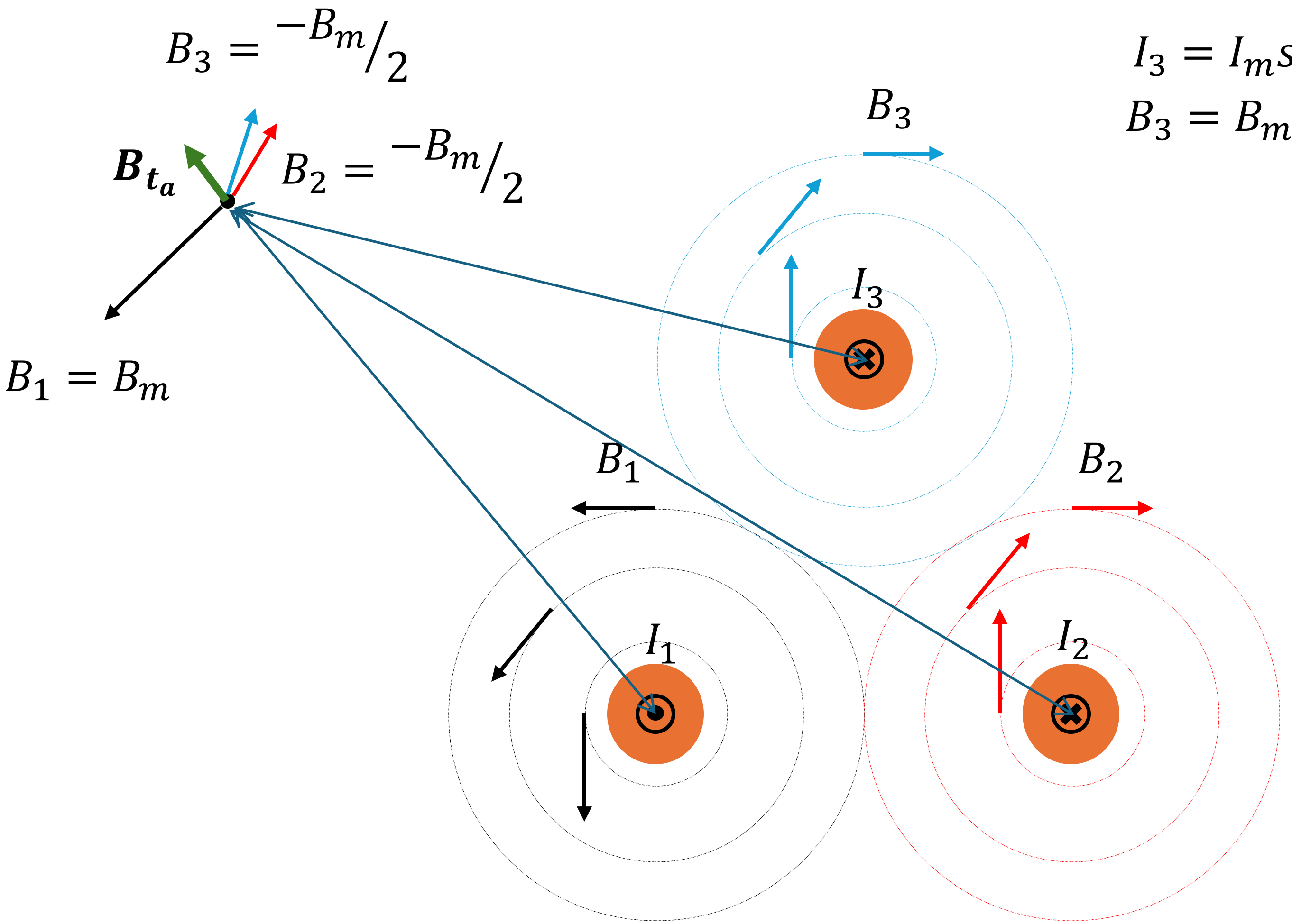




$$I = I_m sin\theta$$

$$B = B_m sin\theta$$

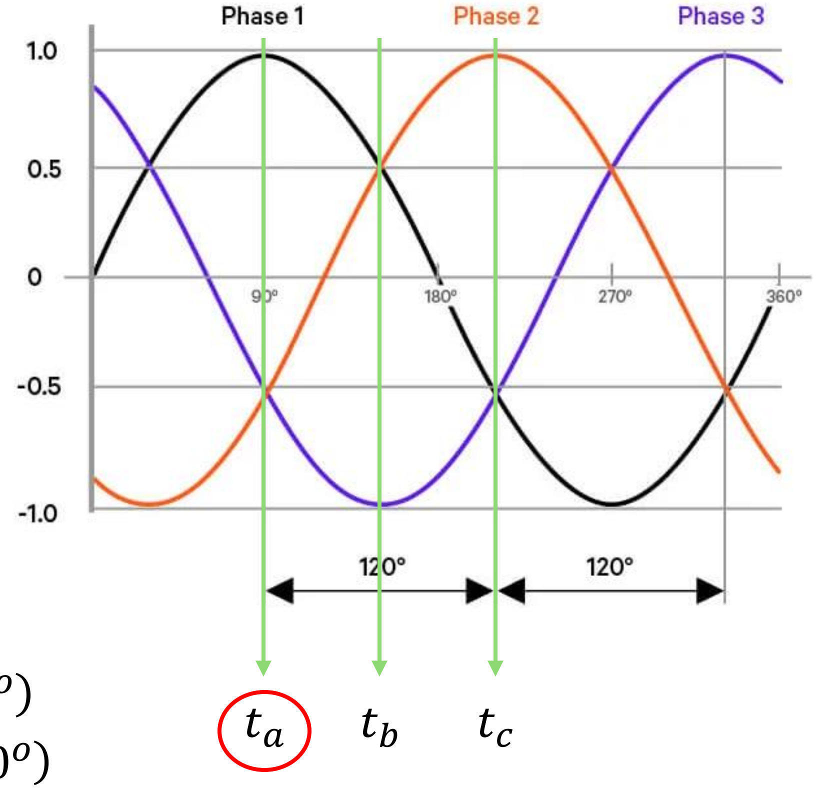
Electromagnetism
Magnetic fields in 3-phase systems



$I_3 = I_m sin(\theta + 240^o)$
$B_3 = B_m sin(\theta + 240^o)$

$I_1 = I_m sin\theta$
$B_1 = B_m sin\theta$

$I_2 = I_m sin(\theta + 120^o)$
$B_2 = B_m sin(\theta + 120^o)$



Electromagnetism
Magnetic fields in 3-phase systems

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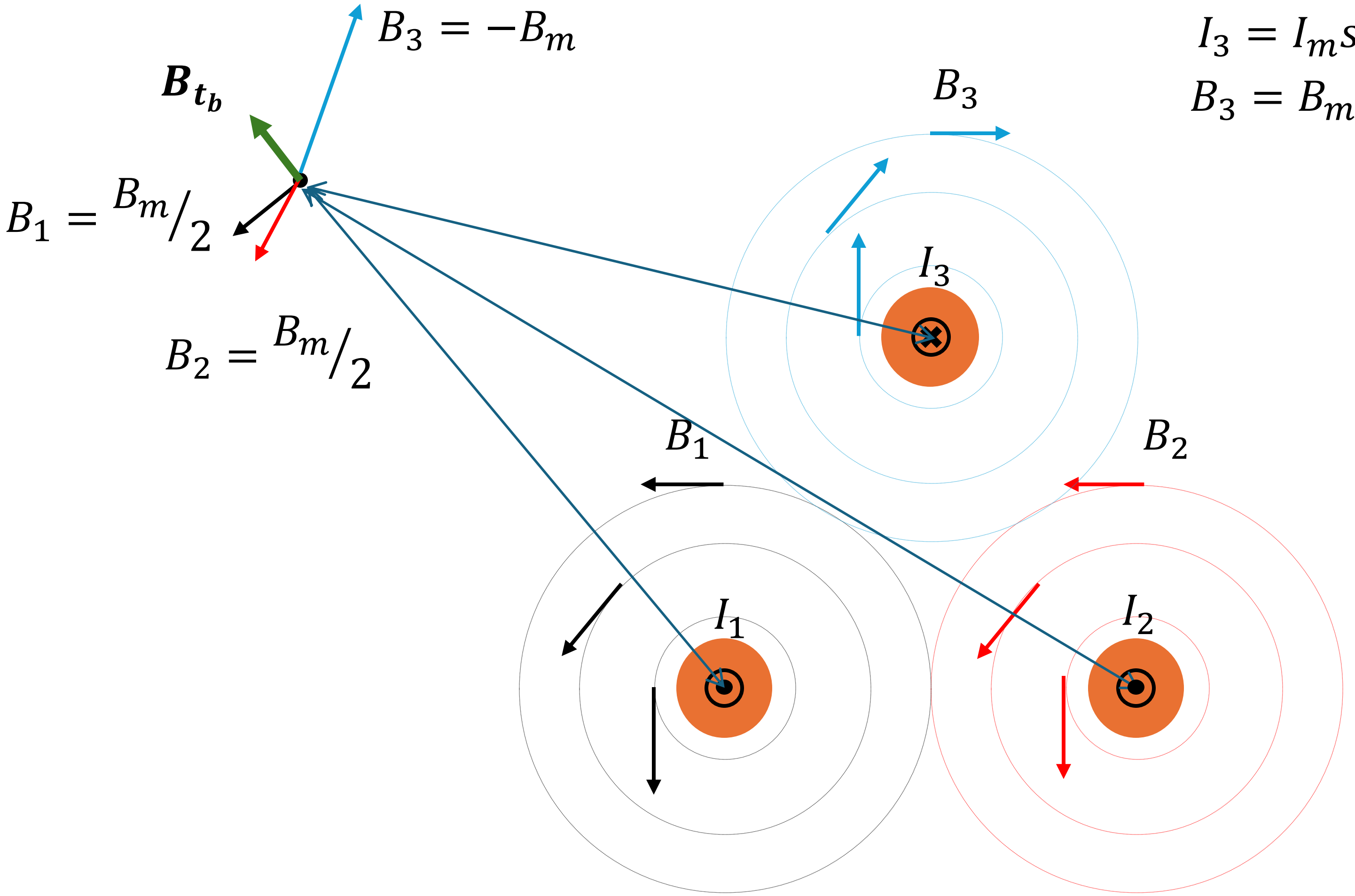
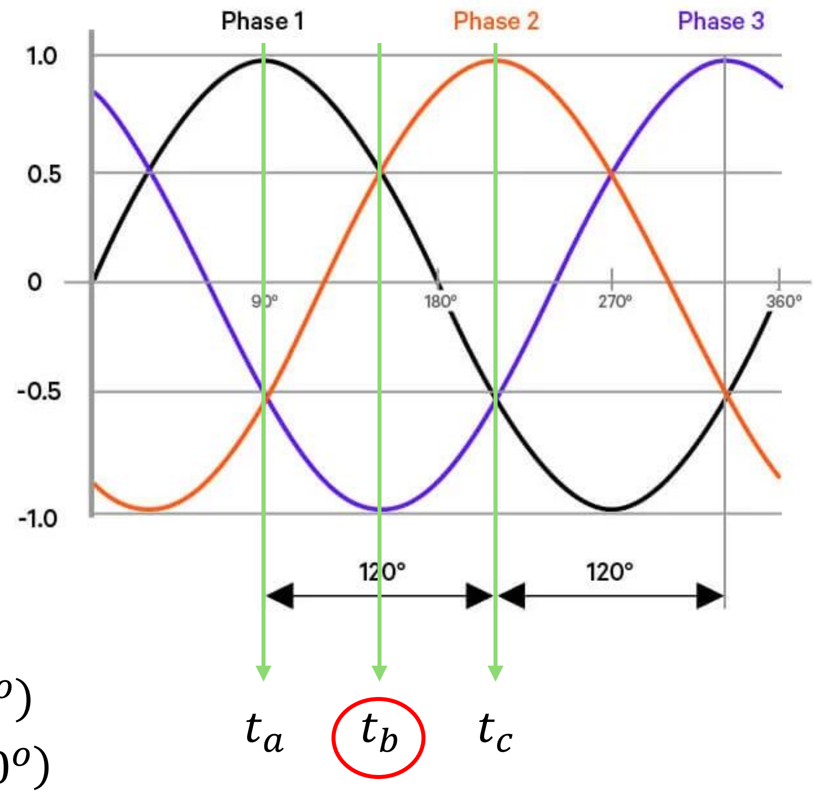
$$I_3 = I_m sin(\theta + 240^o)$$
$$B_3 = B_m sin(\theta + 240^o)$$





$$I_1 = I_m sin\theta$$
$$B_1 = B_m sin\theta$$

$$I_2 = I_m sin(\theta + 120^o)$$
$$B_2 = B_m sin(\theta + 120^o)$$

Electromagnetism

Magnetic fields in 3-phase systems

$$I_3 = I_m sin(\theta + 240^o)$$
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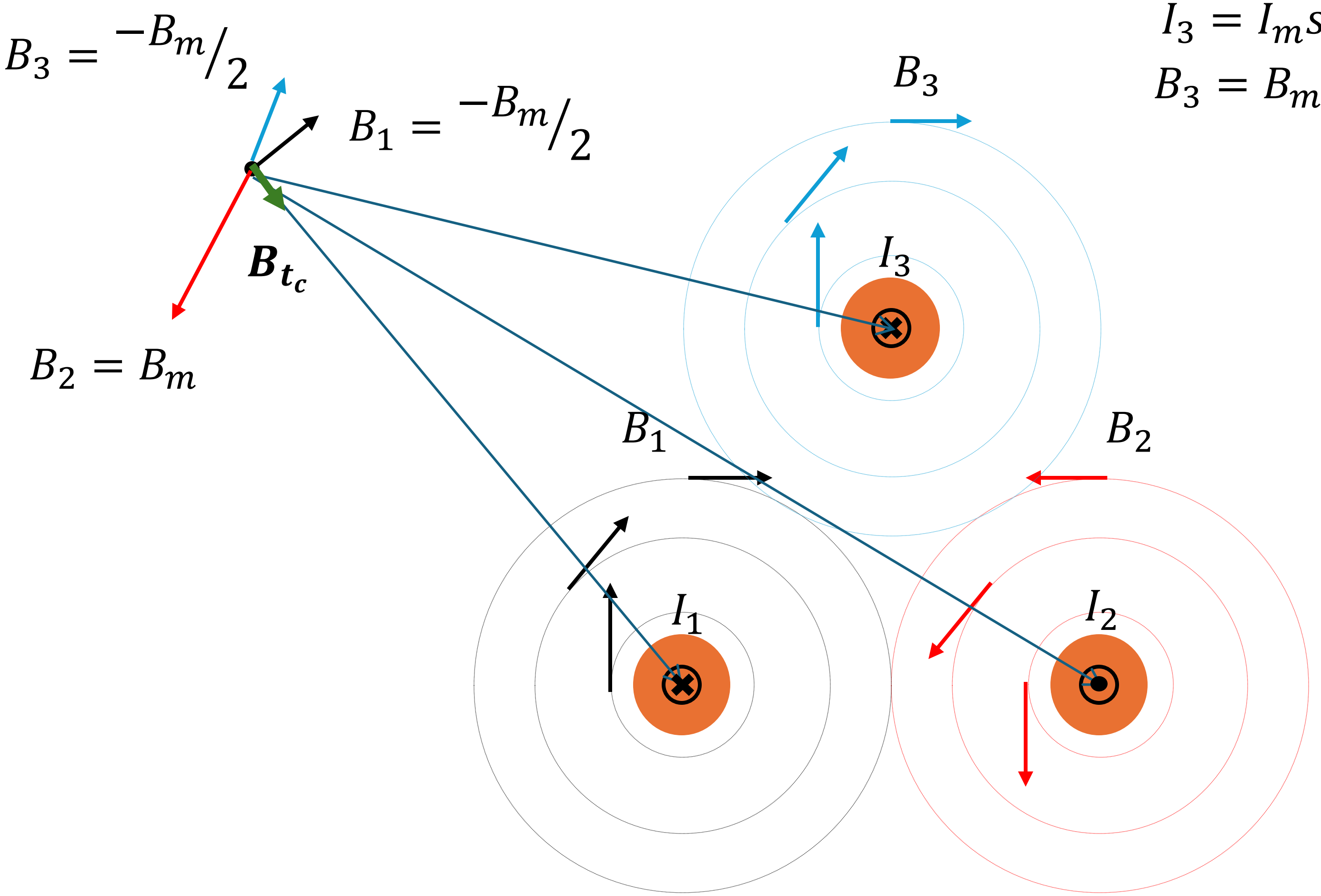

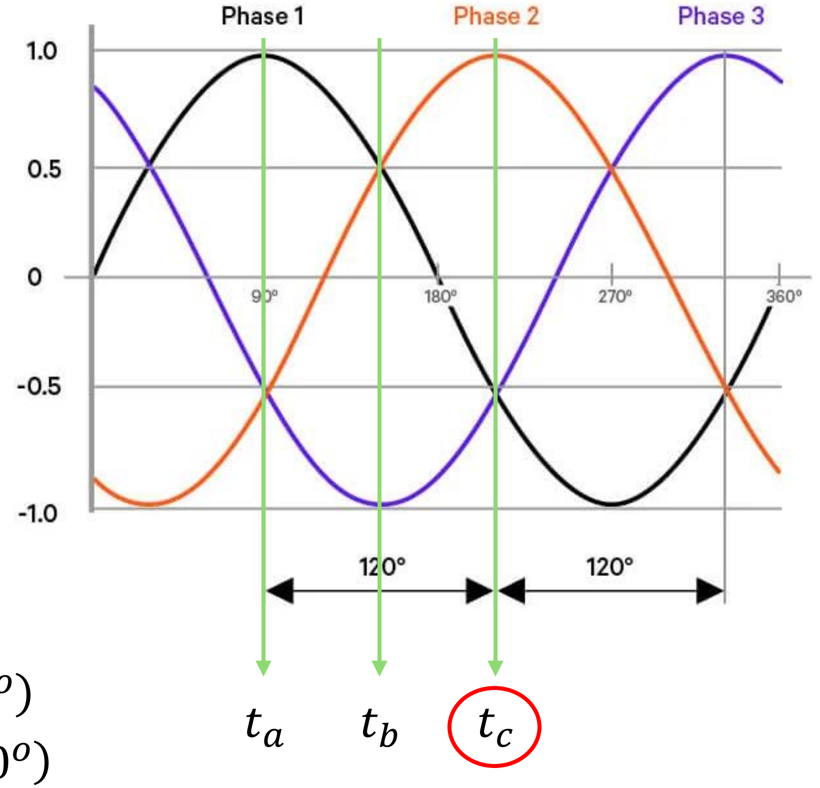

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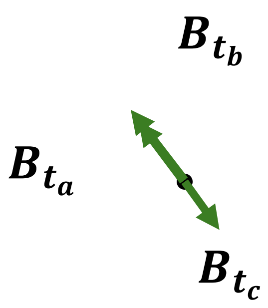
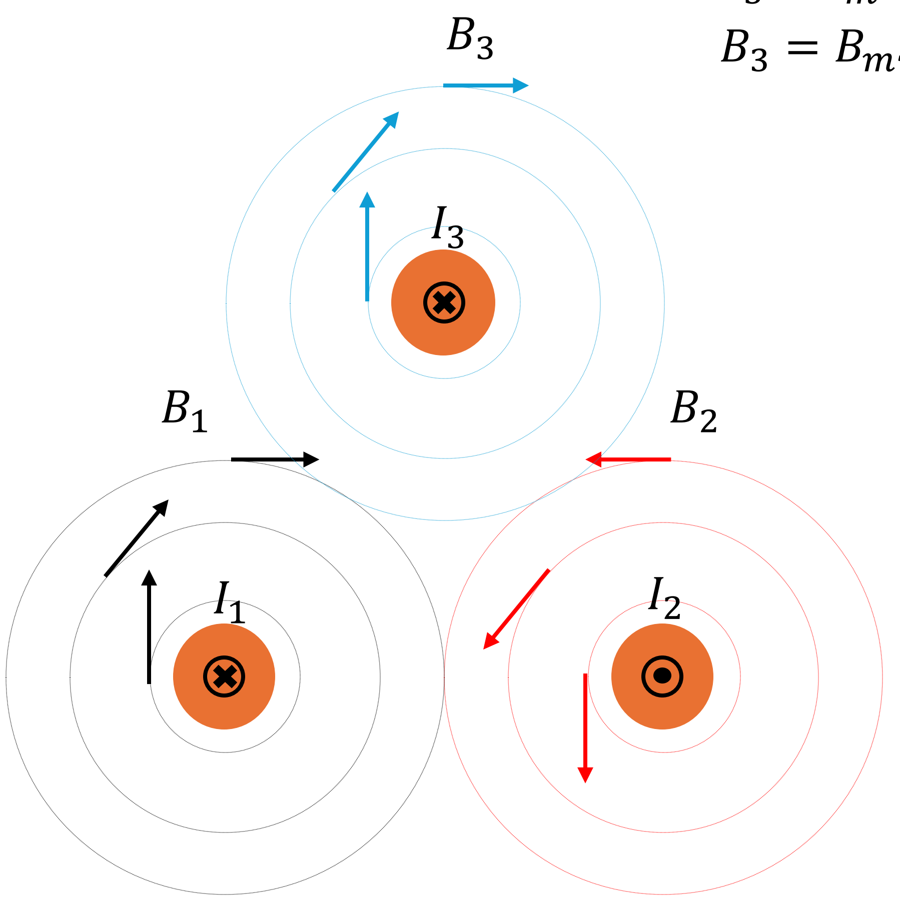
Electromagnetism

Magnetic fields in 3-phase systems



$$I_3 = I_m sin(\theta + 240^o)$$
$$B_3 = B_m sin(\theta + 240^o)$$



$$I_1 = I_m sin\theta$$
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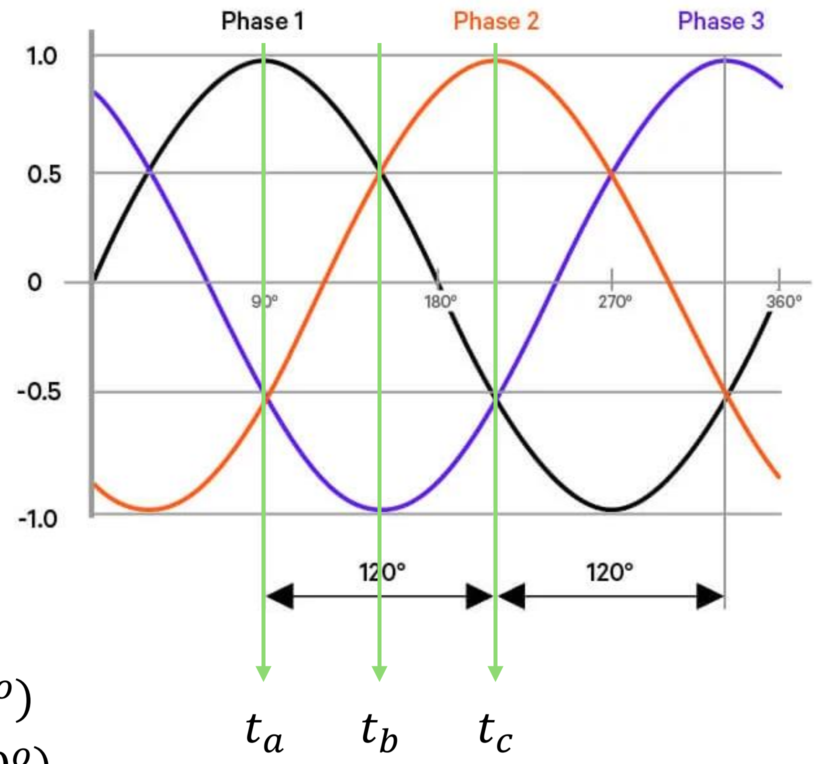
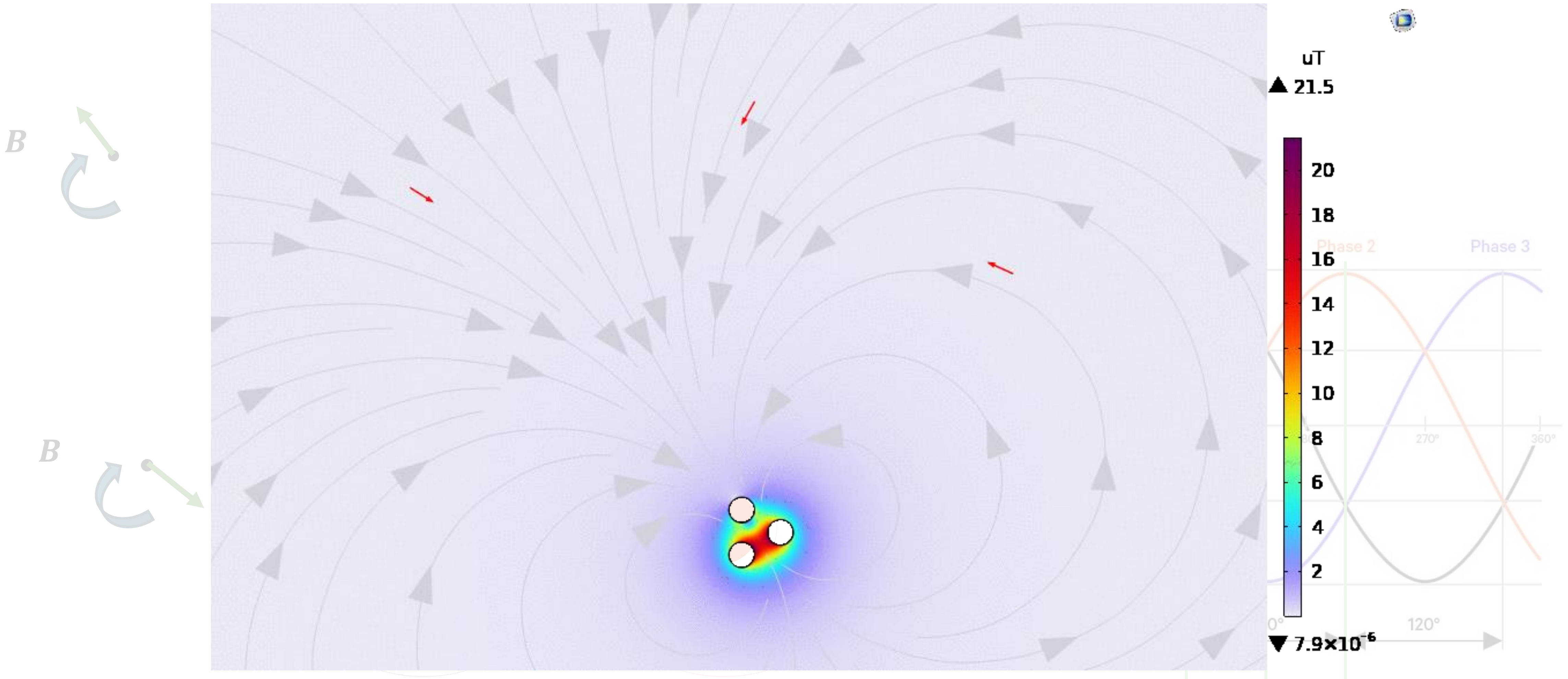


Electromagnetism
Rotating magnetic field



t_a t_b t_c

$I_1 = I_m sin\theta$

$B_1 = B_m sin\theta$

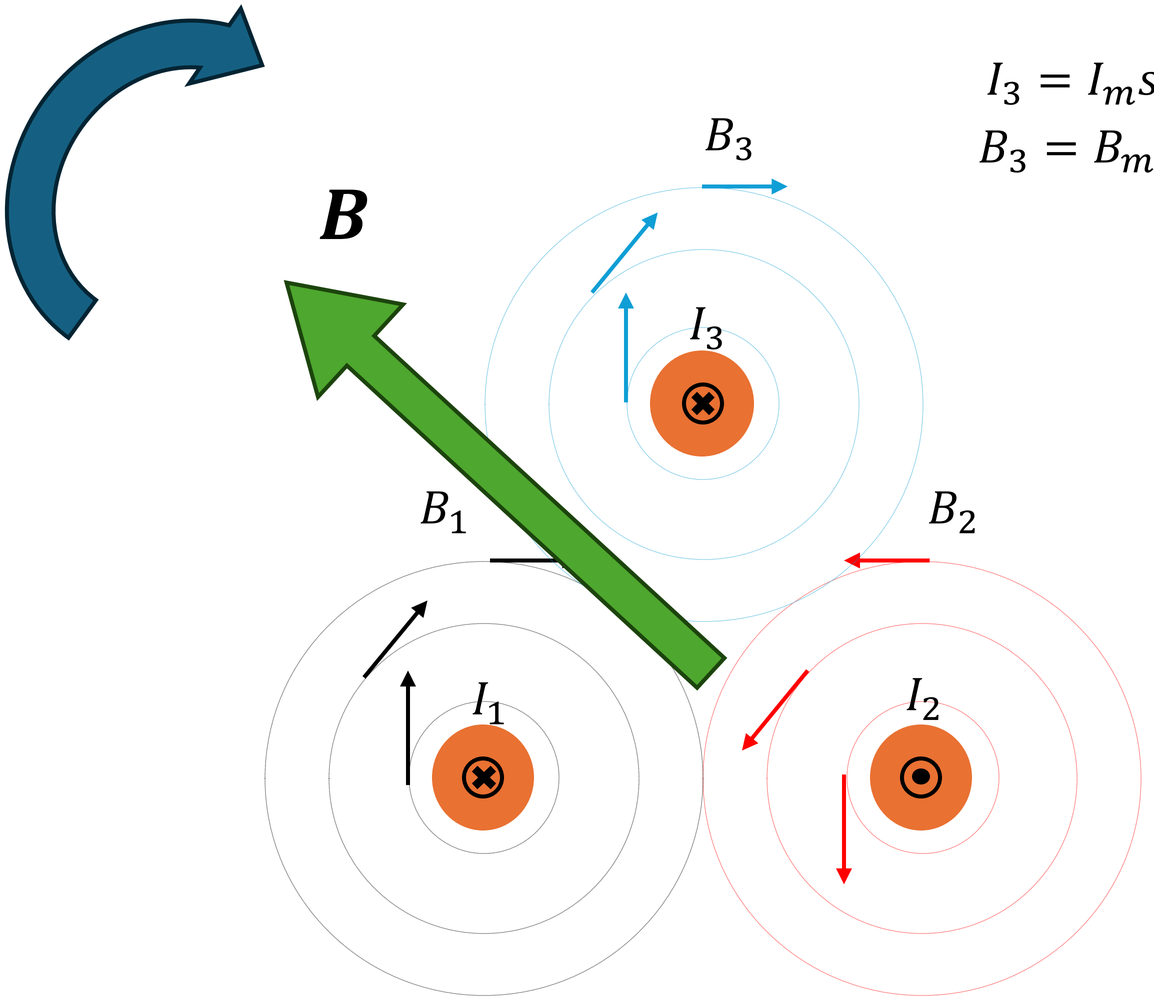
$I_2 = I_m sin(\theta + 120^o)$

$B_2 = B_m sin(\theta + 120^o)$

Electromagnetism

The rotating magnetic field around 3-core submarine cables

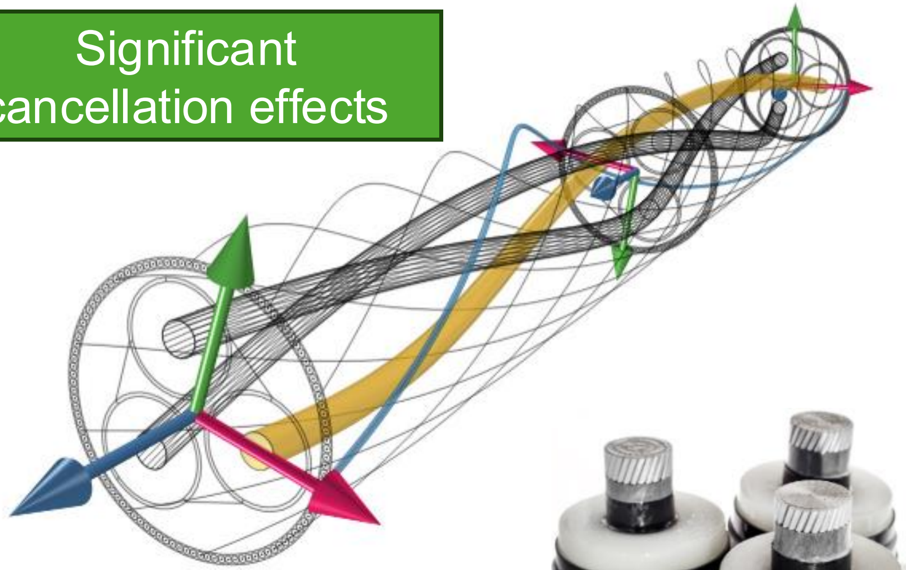
$$I_3 = I_m sin(\theta + 240^o)$$
$$B_3 = B_m sin(\theta + 240^o)$$

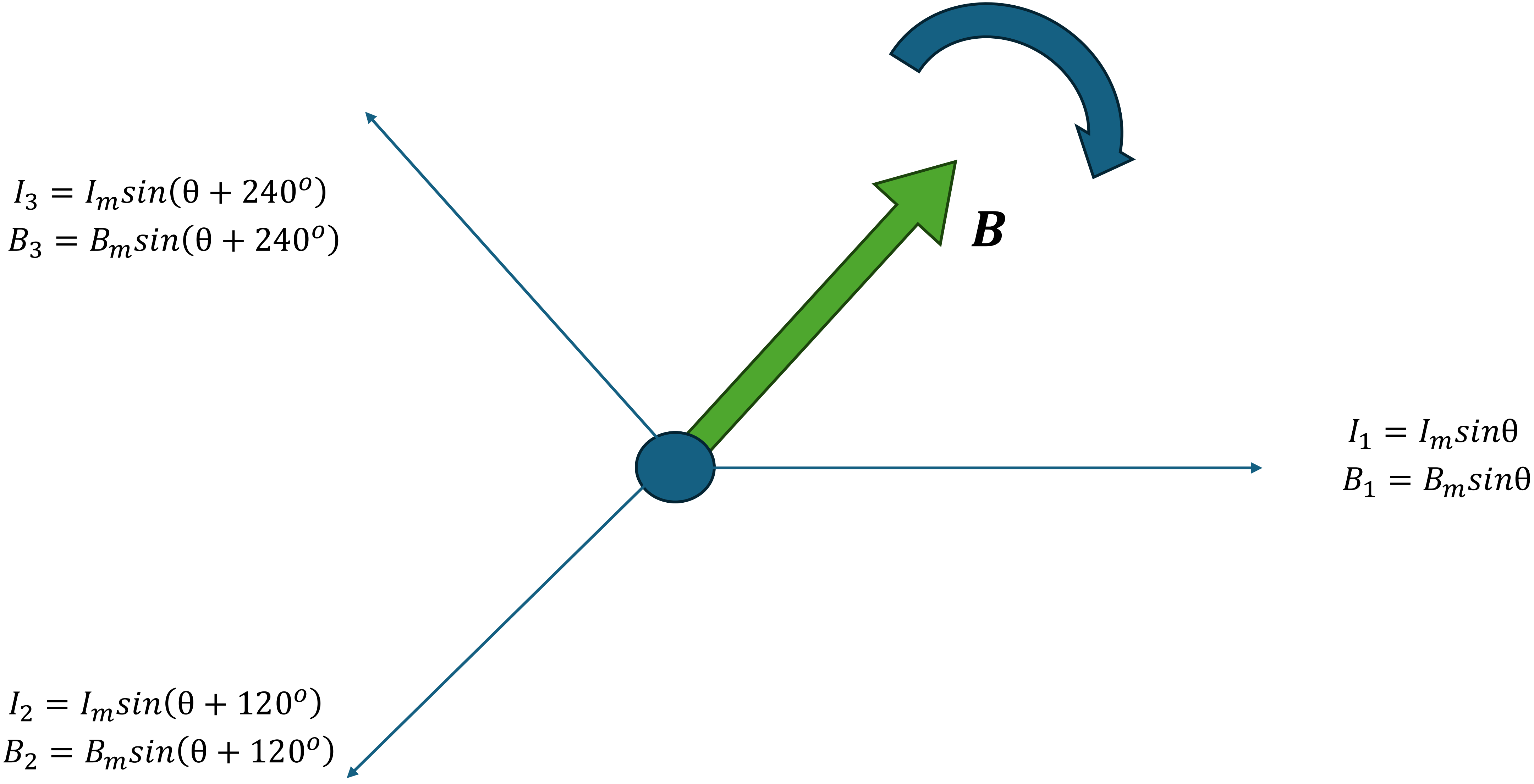


$$I_1 = I_m sin\theta$$
$$B_1 = B_m sin\theta$$

$$I_2 = I_m sin(\theta + 120^o)$$
$$B_2 = B_m sin(\theta + 120^o)$$

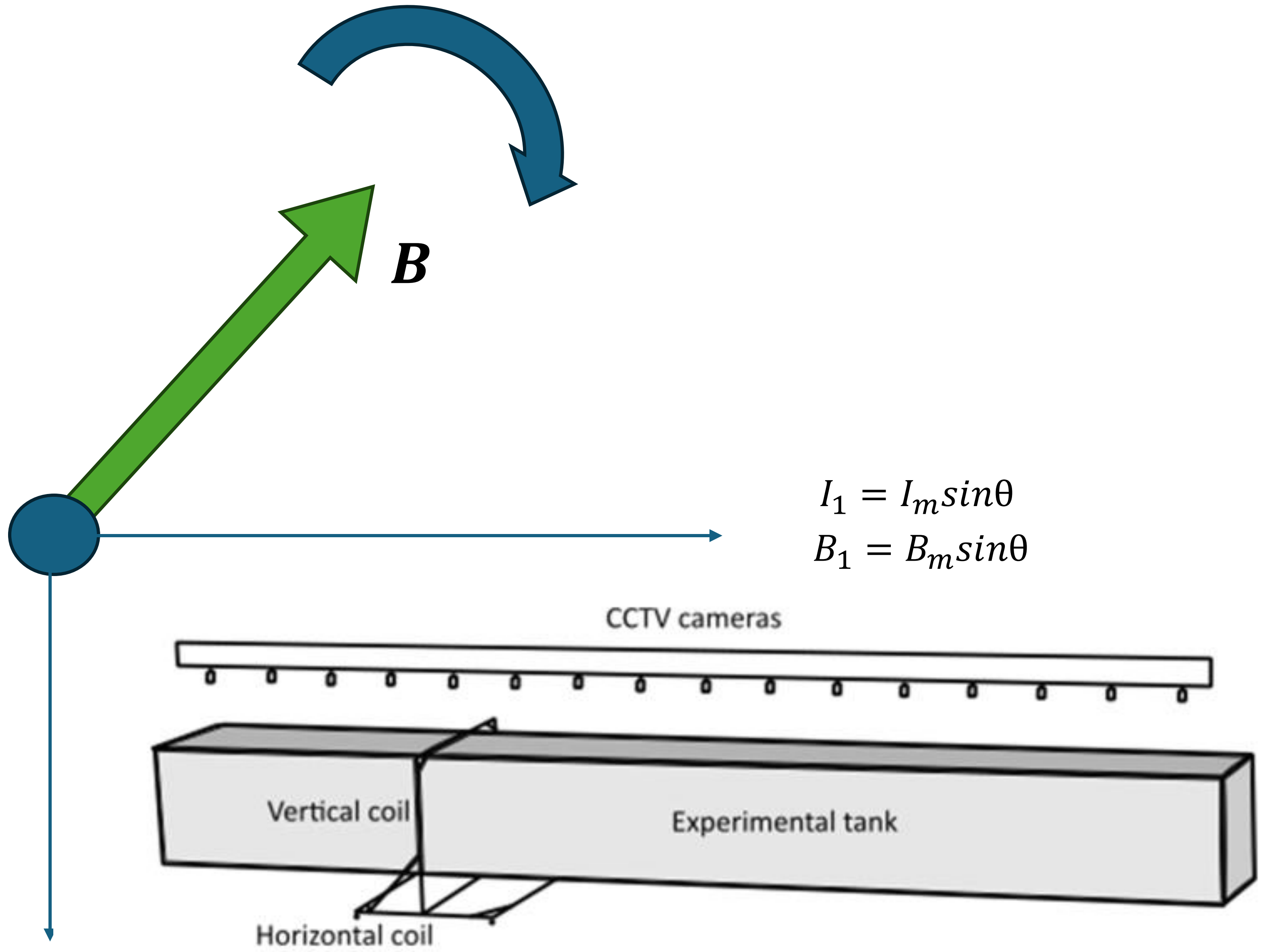
Significant cancellation effects




$I_3 = I_m sin(θ + 240^o)$
$B_3 = B_m sin(θ + 240^o)$
B
$I_1 = I_m sinθ$
$B_1 = B_m sinθ$
$I_2 = I_m sin(θ + 120^o)$
$B_2 = B_m sin(θ + 120^o)$

Electromagnetism

Changing reference system – laboratory implementation



Work Structure

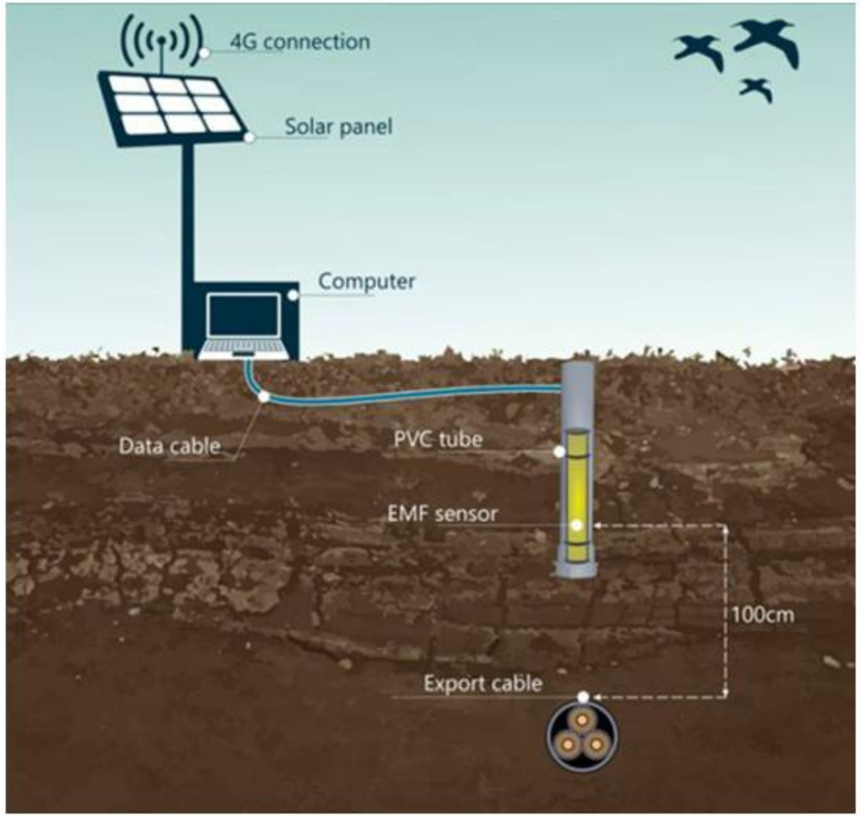


Figure 1: Installation condition of reference cable

Real Systems

+

Real Data

+

Real Expertise

=

Representative Experiment

Reference systems:
- AC: Borselle 220kV 3-core
- DC: NorNed 450kV bipolar

Field measurements:
- Current
- Magnetic flux

Europacable members:
- Independent analysis
- Analytical & numerical
- Consolidated guidelines

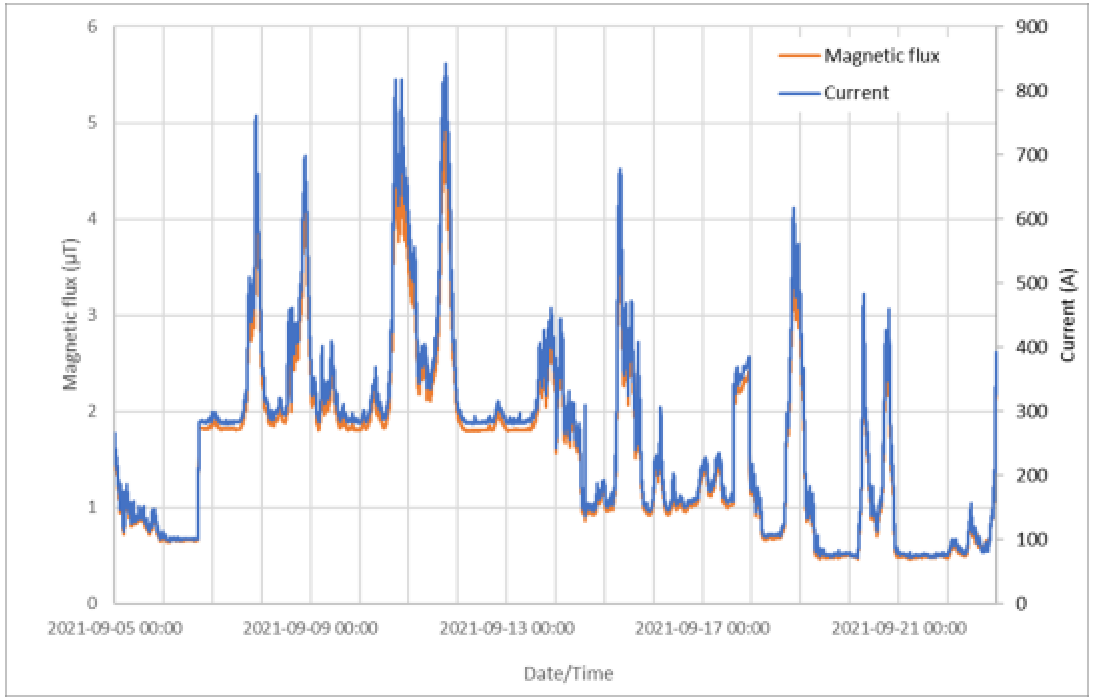
Experimental set up:
- Recreation of real conditions

Modelling of AC cables
Input data

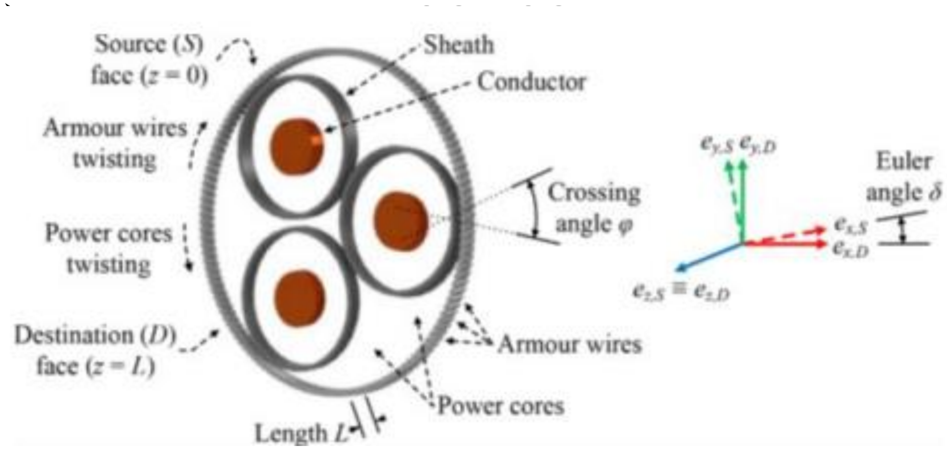
Cable structural parameters

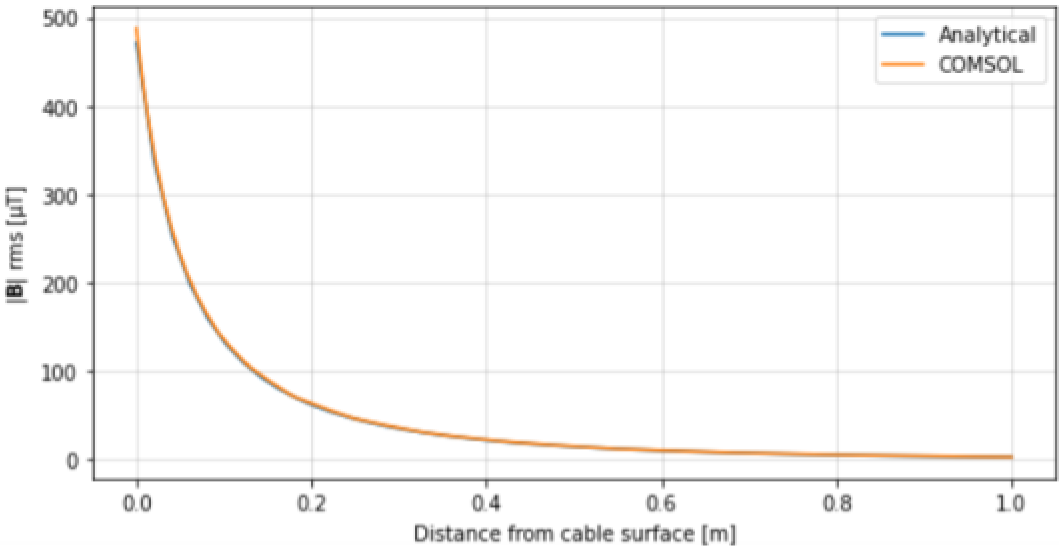
Cable type	3core armoured cable
Conductor material	Aluminium
Conductor outer diameter	39 mm
Diameter below sheath	90 mm
Diameter over sheath	95 mm
Core diameter	99 mm
Core lay length	3000 mm
Armour material type	galvanised steel grade 34
Armour average diameter	225 mm
Armour lay length	3500 mm
Armour wire diameter	7.5 mm
Number of armour wires	62
Outer diameter	245 mm

Measured current and magnetic flux



- Analytical method – based on Cigre TB908:
  - $$|\boldsymbol{b}(\rho,\varphi,z,t)| = \mu_r\mu_0\sqrt{2}\sqrt{|H_\rho|^2\cos^2(\omega t+\theta_x)+|H_y|^2\cos^2(\omega t+\theta_y)+|H_z|^2\cos^2(\omega t+\theta_y)}$$
- Numerical method – based on Finite Element Method:



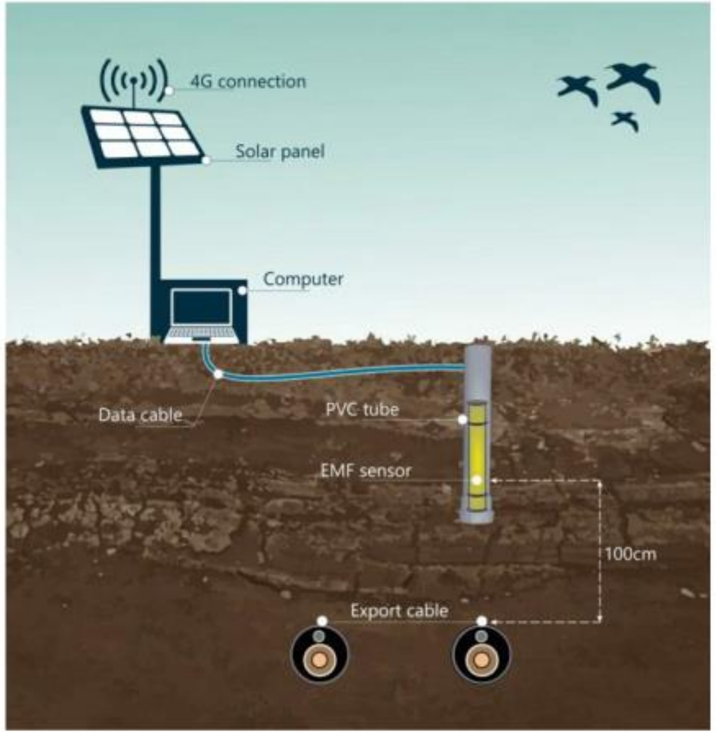


Estimation deviation:
→0.3%
→1.3%

→ ***The models were initially evaluated on a conductor current of 500A, which corresponds to 3.08 uT***

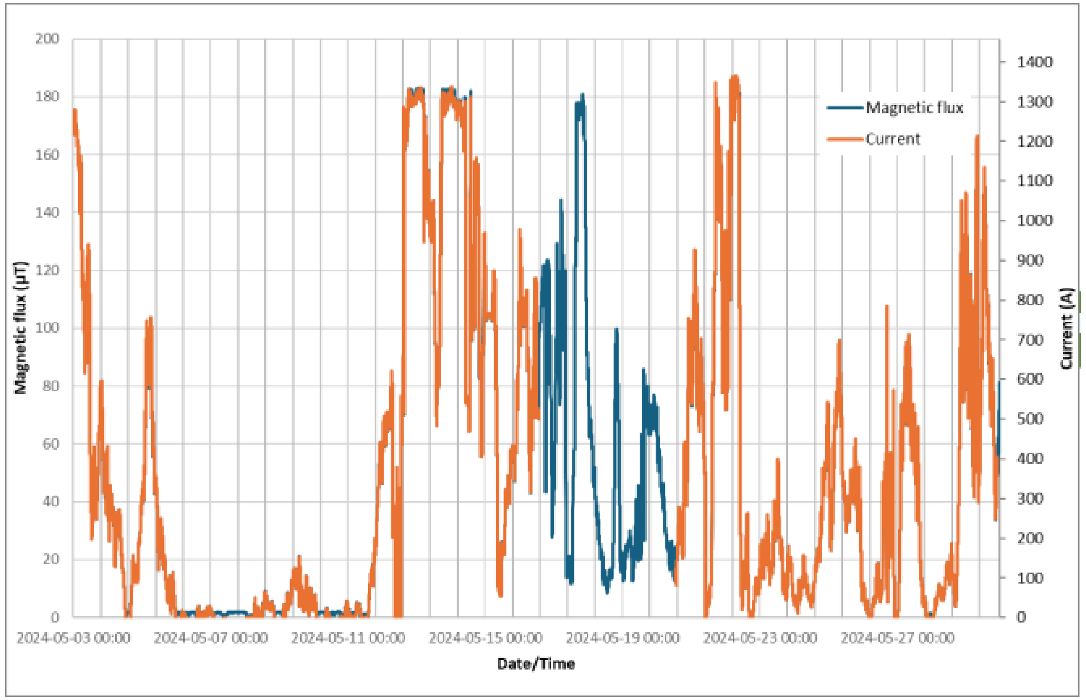
Modelling of DC cables
Input data

Reference installation configuration



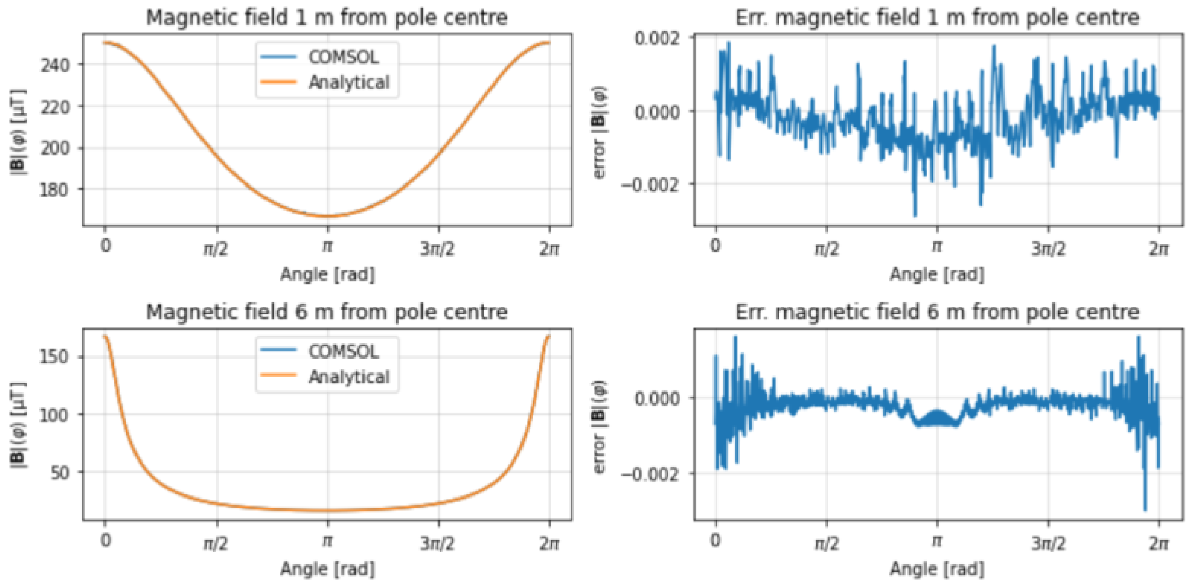
Cable type	Single core DC cable
Location of cable one (x,y)	(-0.4, 0)
Location of cable two (x,y)	(0.4, 0)
Location of for measurement/calculation (x,y)	(0.1, 1)

Measured current and magnetic flux



*adjusted for the influence of the earth magnetic field

- Analytical method:
  - $$|\boldsymbol{B}(\rho,\varphi)| = \frac{\mu_0 I_c}{2\pi}\frac{s}{\rho}\frac{1}{\sqrt{\rho^2 - 2s\rho\cos\varphi + s^2}} \qquad (2.1)$$
- Numerical method – based on Finite Element Method:
  - 2D FEA model in COMSOL Multiphysics



Estimation deviation
→1.0%

→ The models were initially evaluated on a conductor current of 1000A and separation of 1m and 6m.

Summary

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- Field measurements, current and magnetic flux, used as input
- Measurement configuration on land, used as input
- Verification of analytical and numerical models against field measurements
  - Reliable models: estimation error 0.3-1.3%
- Modelling guidelines to model the seabed configuration of interest