

# Multiphysics and Electromagnetic Modelling, Optimization and Simulation

## Electromagnetic Compatibility

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# **Multiphysics and Electromagnetic Modelling, Optimization and Simulation**

# A cosa serve la modellistica numerica?

- Progettazione e ottimizzazione di sistemi e dispositivi elettromagnetici
- Analisi di sistemi e dispositivi esistenti
- Generazione di modelli per il controllo avanzato di sistemi e dispositivi
- Studio e analisi di fenomeni fisici complessi

# Come Funziona?

Equazioni PDE

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

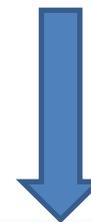
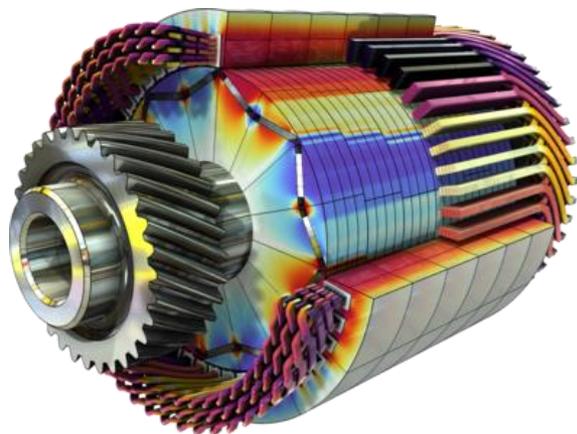
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$



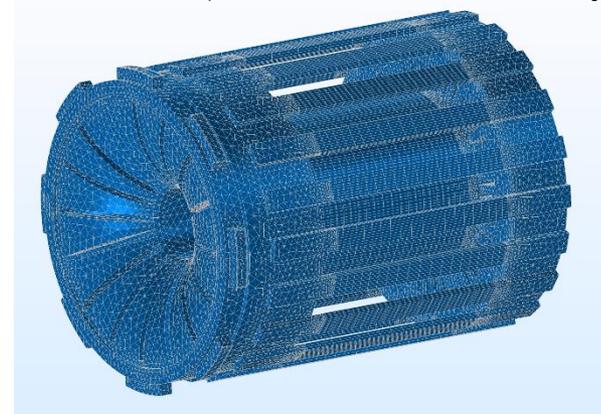
Scelta e riformulazione delle equazioni

Regime	Electro-QuasiStatic (EQS)	Magneto-QuasiStatic (MQS)	EM-QuasiStatic (EMQS)
Ordering	$\mathcal{O}\left(\frac{\hat{E}}{B}, \frac{c\hat{\rho}}{J}\right) \sim \frac{1}{\beta}$	$\mathcal{O}\left(\frac{\hat{E}}{B}, \frac{c\hat{\rho}}{J}\right) \sim \beta$	$\mathcal{O}\left(\frac{\hat{E}_T}{B}\right) \sim \beta, \mathcal{O}\left(\frac{\hat{E}_L}{B}, \frac{c\hat{\rho}}{J}\right) \sim \frac{1}{\beta}$
Maxwell Eqns.	$\nabla \cdot \mathbf{E} = \hat{\alpha}\rho$ $\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{E} = 0$ $\nabla \times \mathbf{B} = \frac{\partial \mathbf{E}}{\partial t} + \hat{\alpha}\mathbf{J}$	$\nabla \cdot \mathbf{E} = \hat{\alpha}\rho$ $\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ $\nabla \times \mathbf{B} = \hat{\alpha}\mathbf{J}$	$\nabla \cdot \mathbf{E} = \hat{\alpha}\rho$ $\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ $\nabla \times \mathbf{B} = \frac{\partial \mathbf{E}_L}{\partial t} + \hat{\alpha}\mathbf{J}$
Continuity Eqn.	$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{J} = 0$	$\nabla \cdot \mathbf{J} = 0$	$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{J} = 0$
Fields from Potentials	$\mathbf{E} = -\nabla\phi$ $\mathbf{B} = \nabla \times \mathbf{A}$	$\mathbf{E} = -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t}$ $\mathbf{B} = \nabla \times \mathbf{A}$	$\mathbf{E} = -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t}$ $\mathbf{B} = \nabla \times \mathbf{A}$

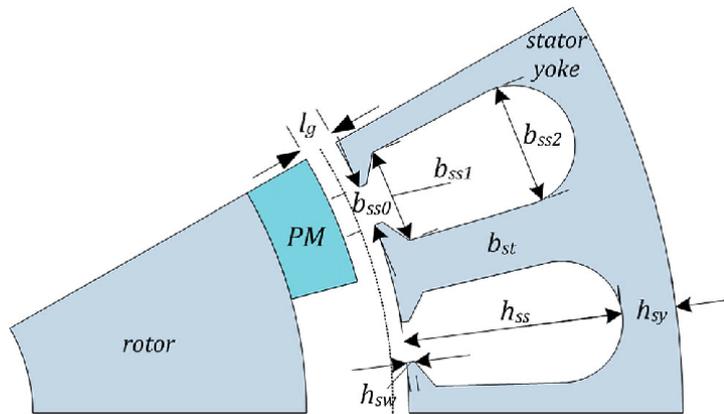
Post Processing – Valutazione delle quantità di interesse



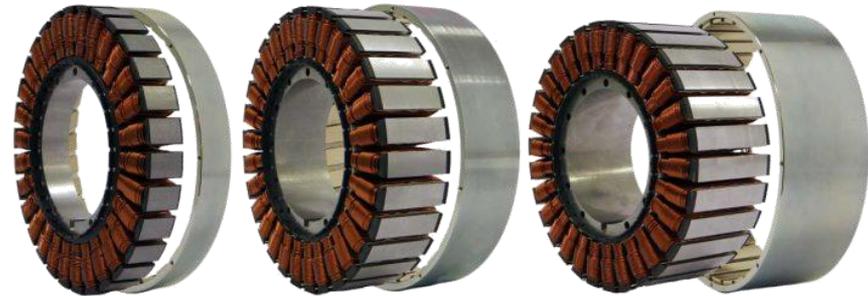
Trasformazione del problema PDE in Sistema di Equazioni (FEM)



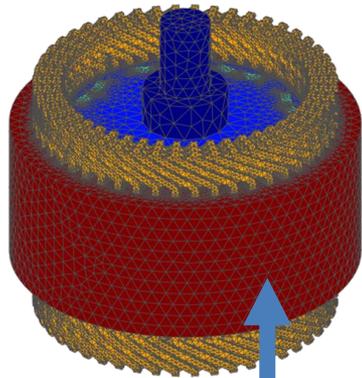
# Simulazione per la progettazione e ottimizzazione



Qual è la geometria “migliore”?



Scelgo la geometria e costruisco il modello



Risolvero il problema (simulo) e valuto le quantità di interesse

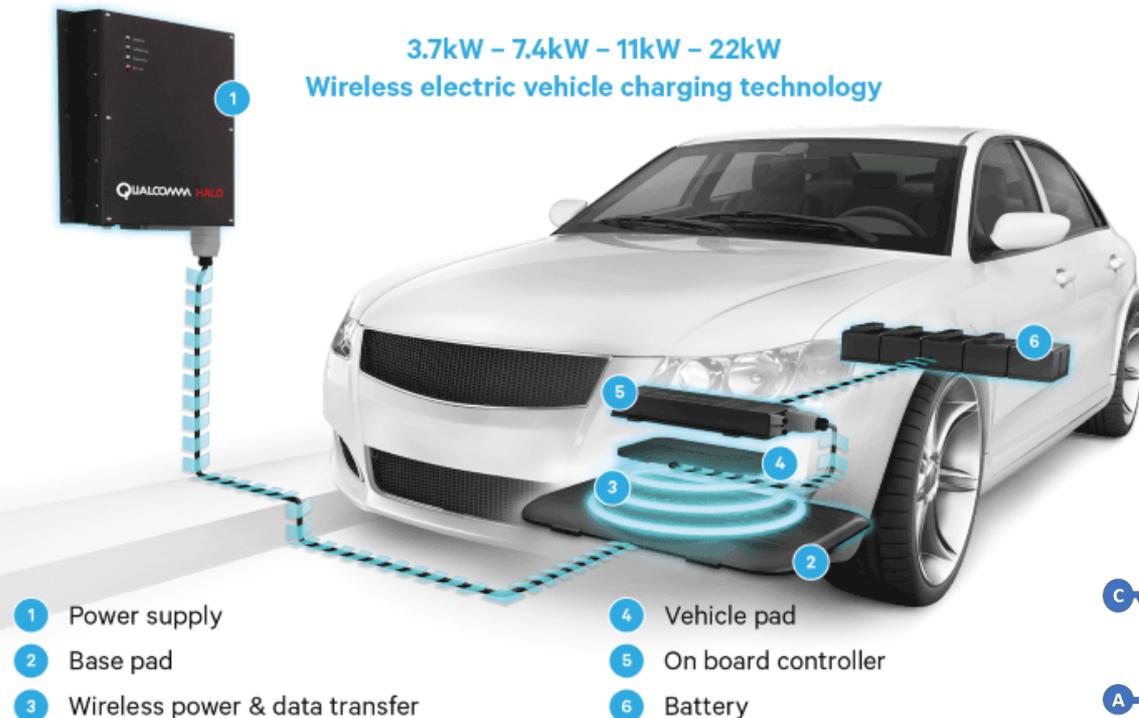


Soddisfatto?

No

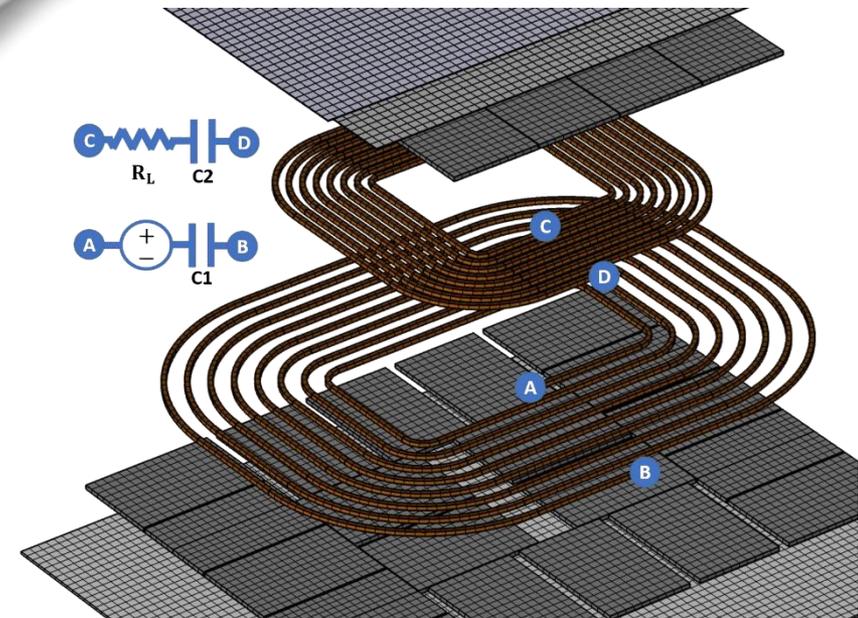
Modifico la geometria

# Progettazione e ottimizzazione di sistemi e dispositivi elettromagnetici



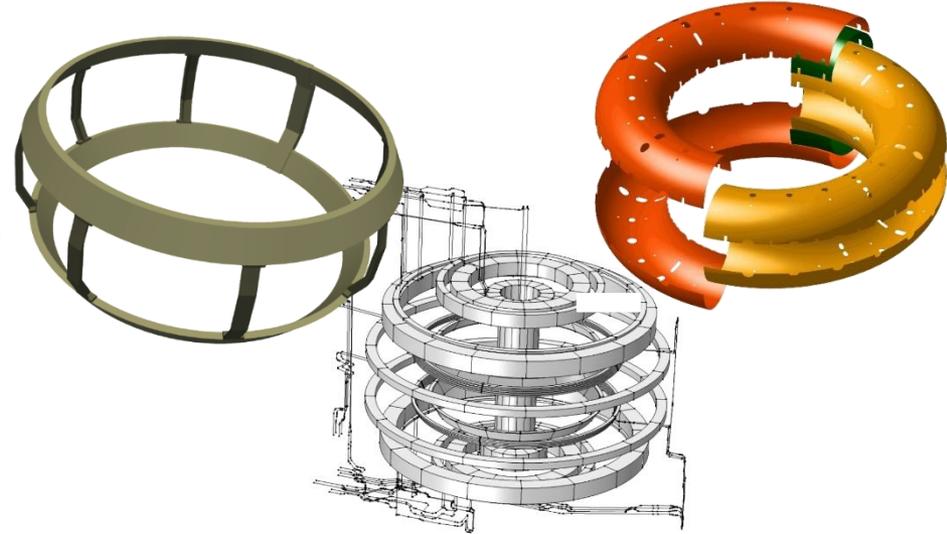
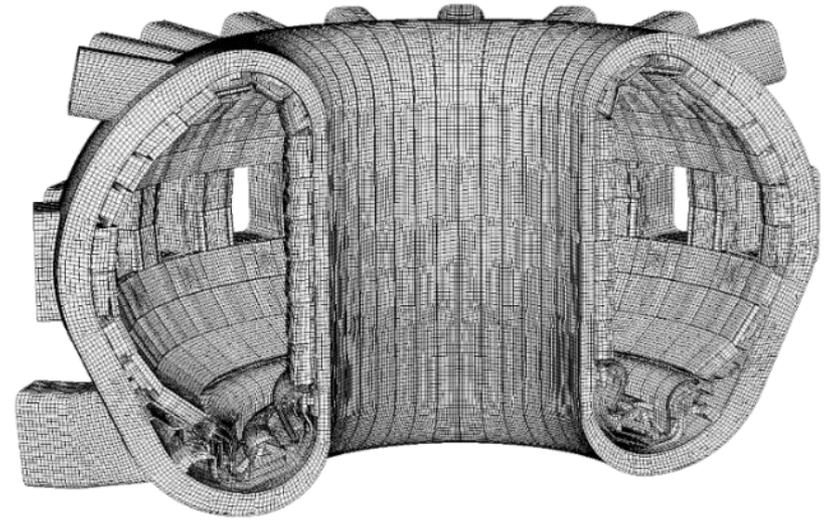
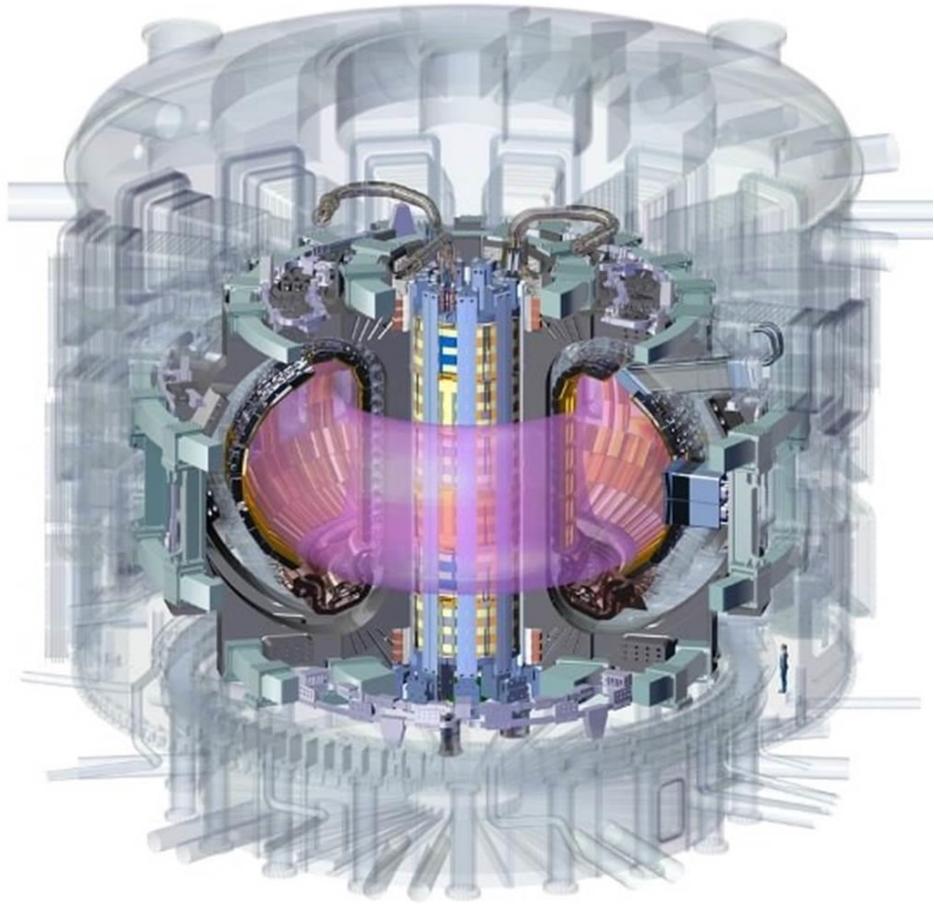
Frequenza: 85 KHz

Magneto-Quasistatic  
Equations



# 7

## Progettazione e ottimizzazione di sistemi e dispositivi elettromagnetici



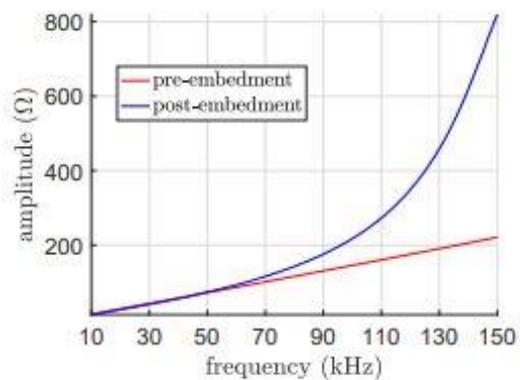
# Progettazione e ottimizzazione di sistemi e dispositivi elettromagnetici



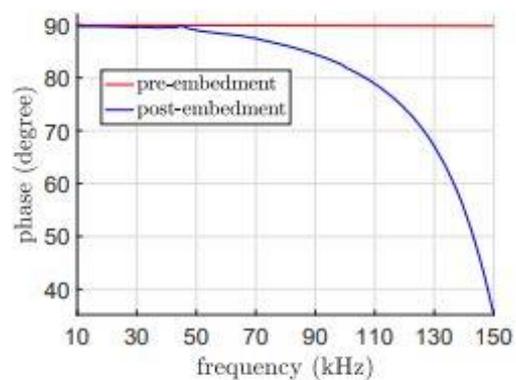
# Progettazione e ottimizzazione di sistemi e dispositivi elettromagnetici



# Analisi di sistemi e dispositivi esistenti

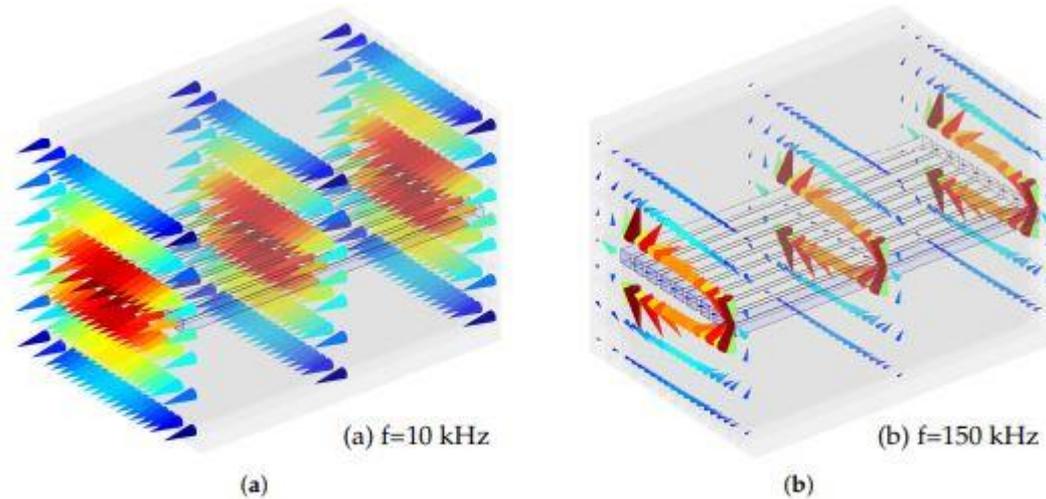


(a)

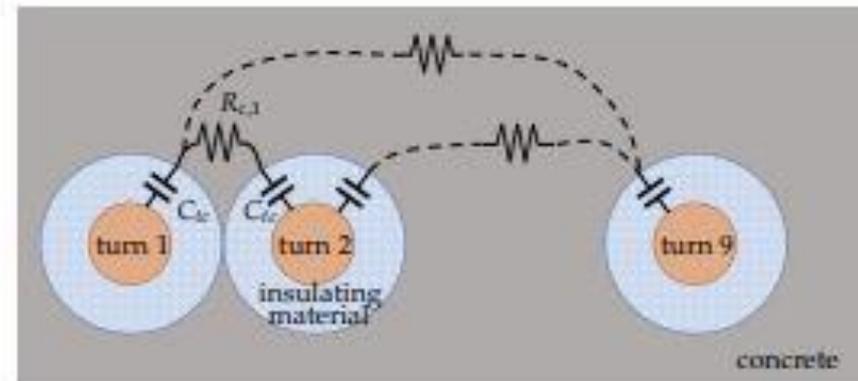
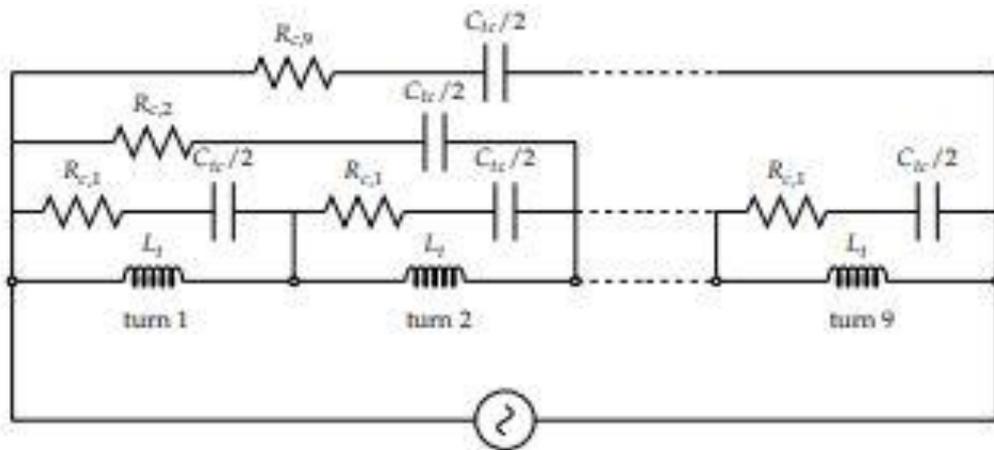


(b)

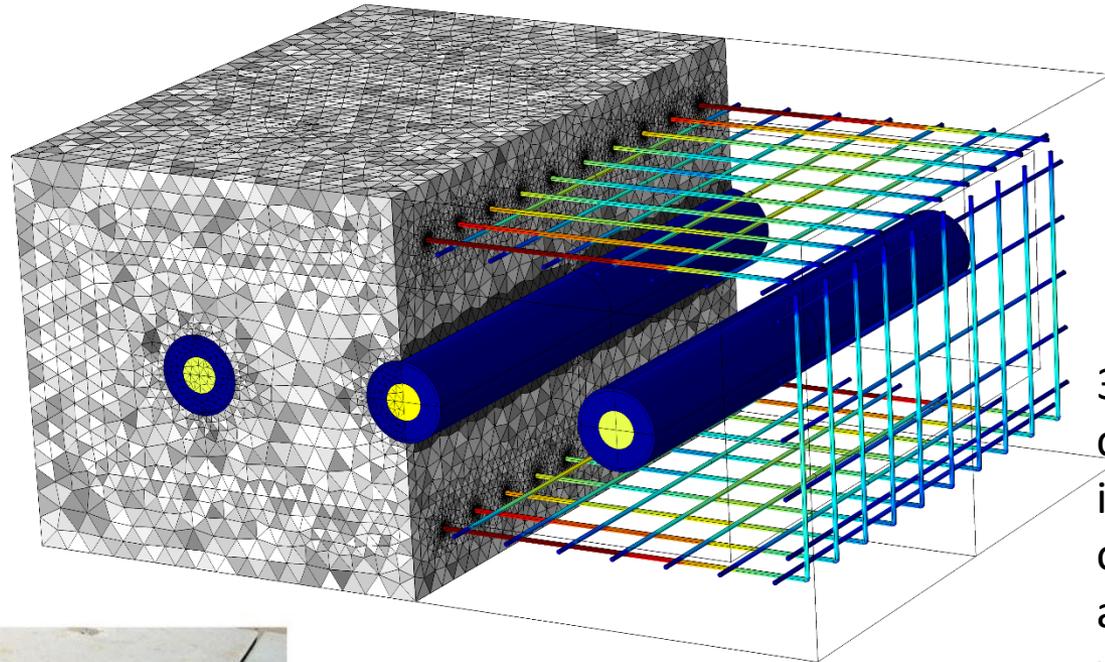
# Analisi di sistemi e dispositivi esistenti



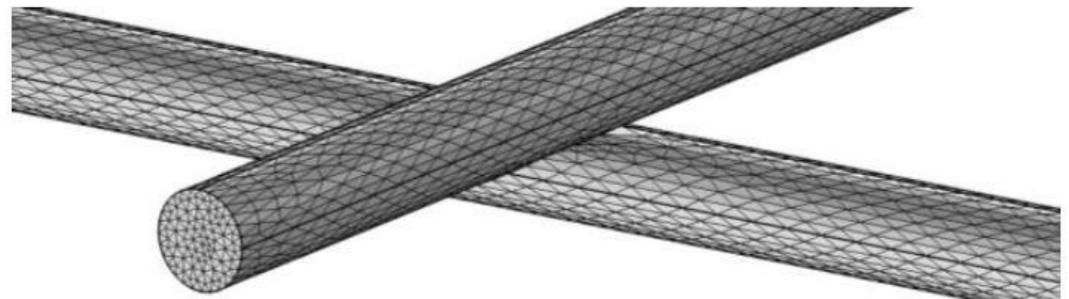
**Figure 12.** PEEC model simulation: distribution of  $J_e$  in the concrete. Inductive component predominant (a); capacitive component predominant (b). (a) and (b) not in the same scale.



# Analisi di sistemi e dispositivi esistenti



380 kV double  
circuit XLPE  
insulated cable,  
operated at 50 Hz  
and enclosed  
within a reinforced  
concrete structure

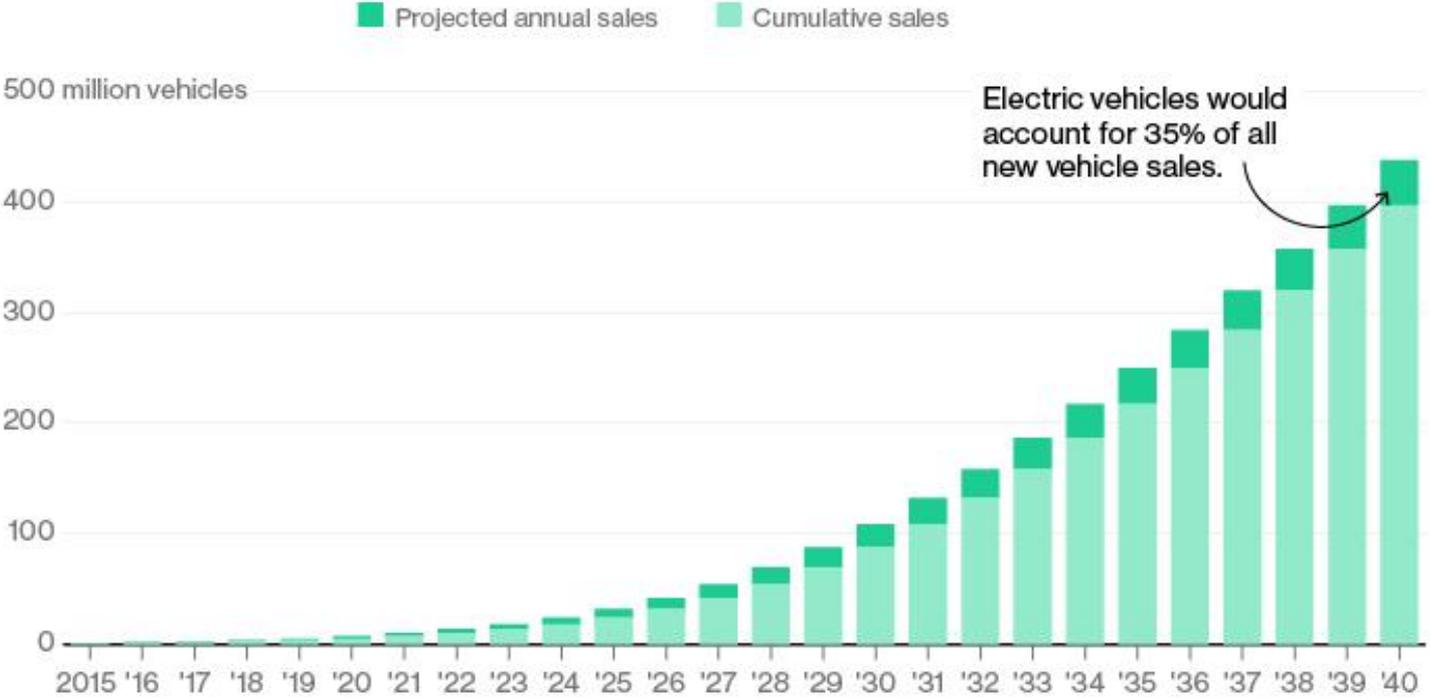


# Electromagnetic Compatibility

# Il numero e la densità di dispositivi elettrici è cresciuta enormemente negli ultimi anni e continuerà ad aumentare

## The Rise of Electric Cars

By 2022 electric vehicles will cost the same as their internal-combustion counterparts. That's the point of liftoff for sales.

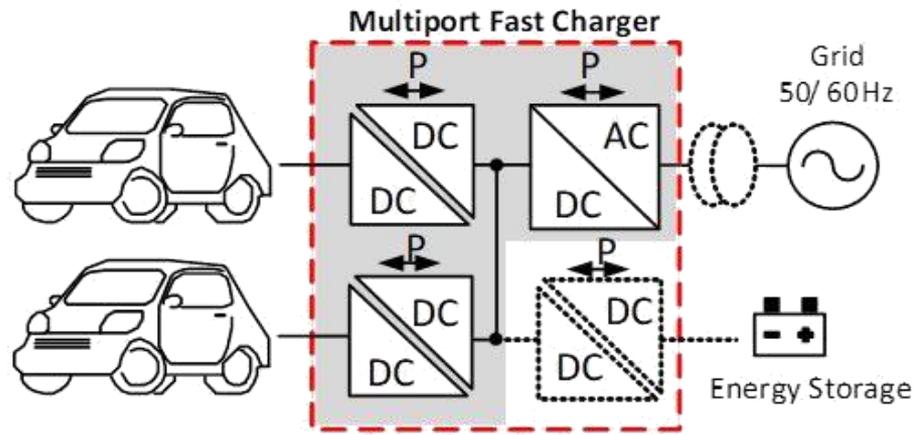
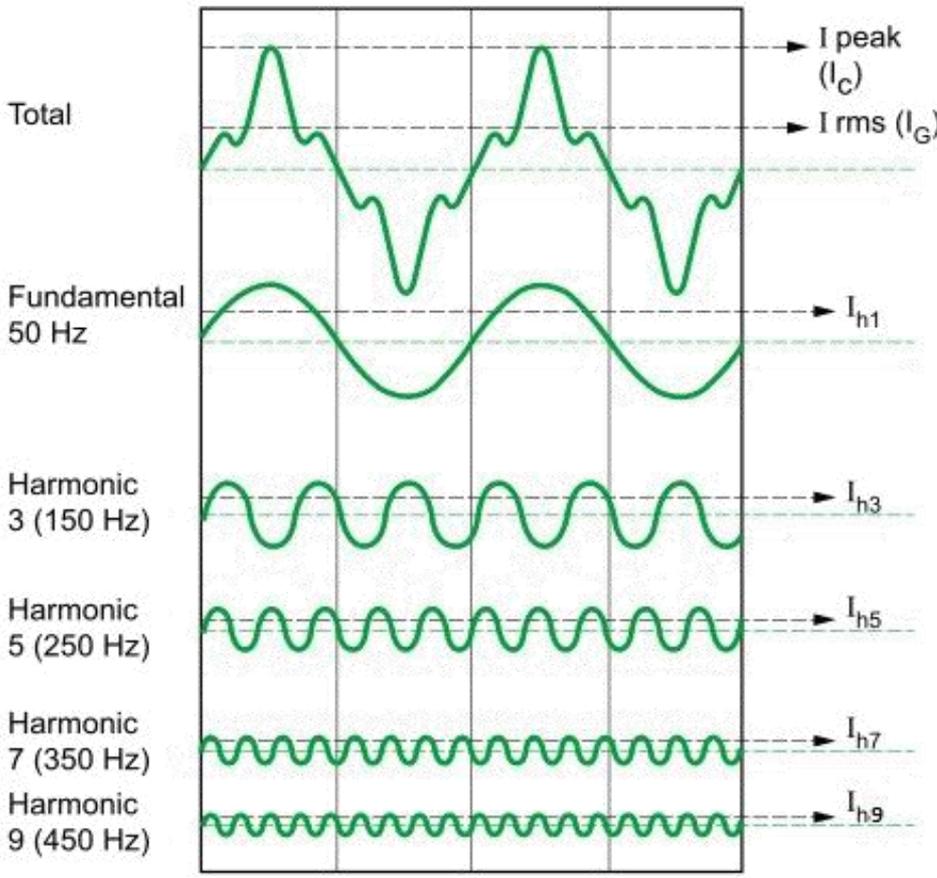


Sources: Data compiled by Bloomberg New Energy Finance, Marklines

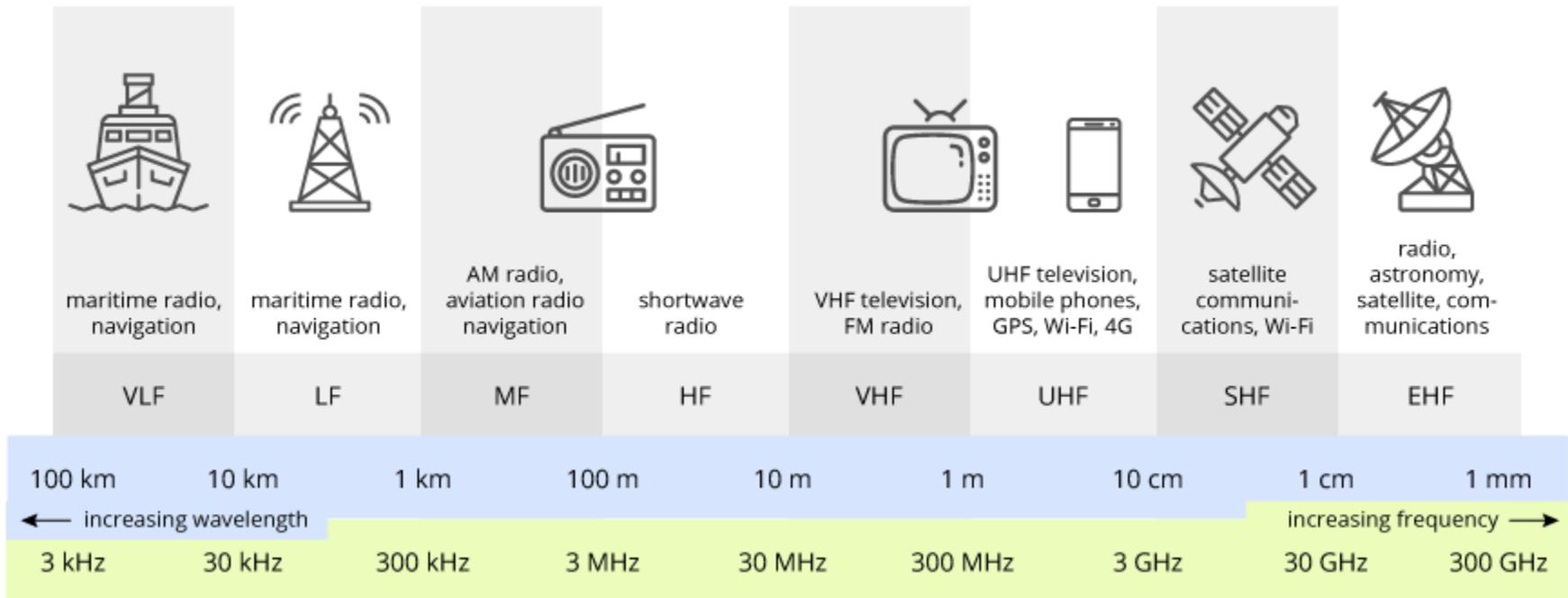




# La compatibilità elettromagnetica regola la coesistenza di dispositivi e sistemi elettrici ed elettronici in uno specifico ambiente elettromagnetico



## La compatibilità elettromagnetica studia (soprattutto) fenomeni che avvengono tra i 150 KHz e 6 GHz



# Esempio



Lunghezza cavo: 1 m

Componente DC: 10 A

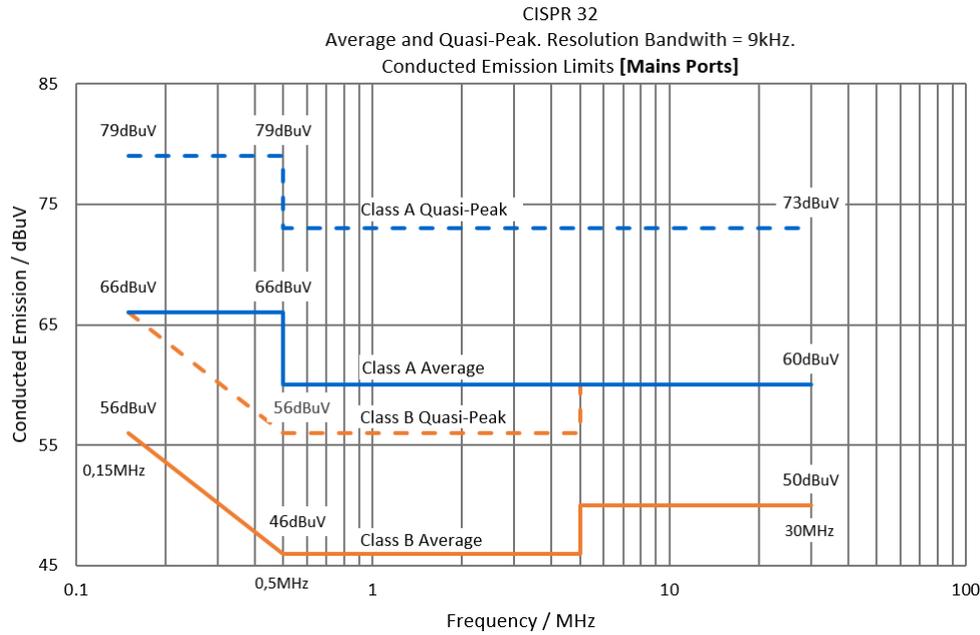
Armonica Corrente a MHz:  $10^{-6}$  A

**NON  
ELECTROMAGNETICAMENTE  
COMPATIBILE**

**=**

**NON PUO' ESSERE MESSO  
SUL MERCATO**

# Ogni dispositivo prima di essere messo sul mercato deve passare dei test di compatibilità stabiliti da normative internazionali



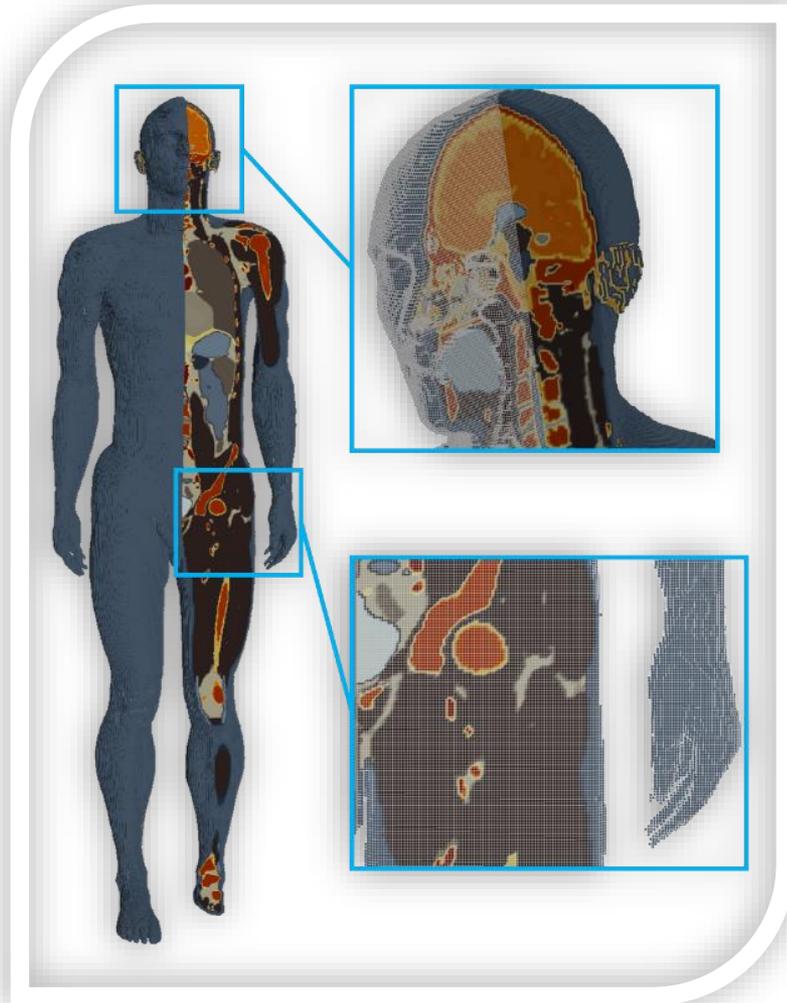
I test a cui viene sottoposto ogni dispositivo misurano I disturbi da esso prodotti, in termini di **tensione elettrica e campi elettromagnetici**

# I dispositivi devono anche essere elettromagneticamente robusti

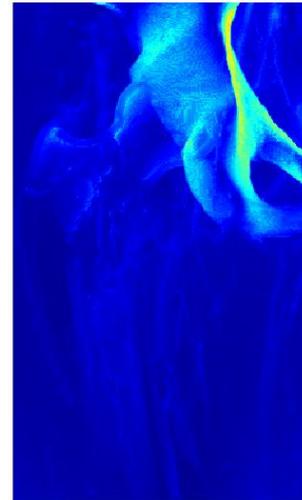


# Corpo umano e compatibilità elettromagnetica

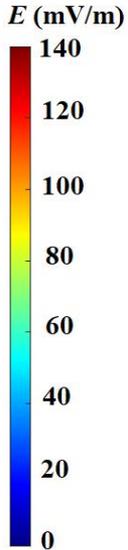
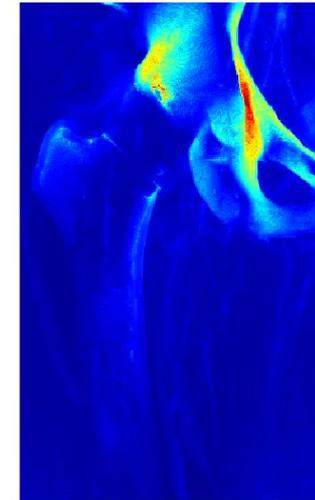
Anche la compatibilità elettromagnetica utilizza strumenti di simulazione



Human model without implant

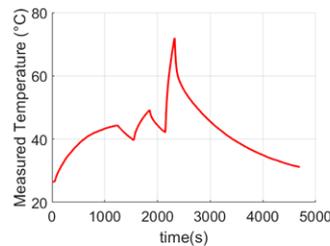
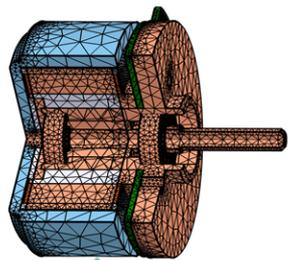


Human model with implant





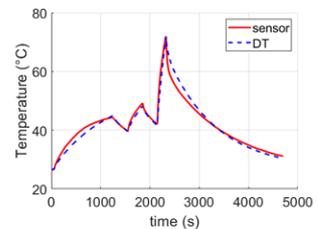
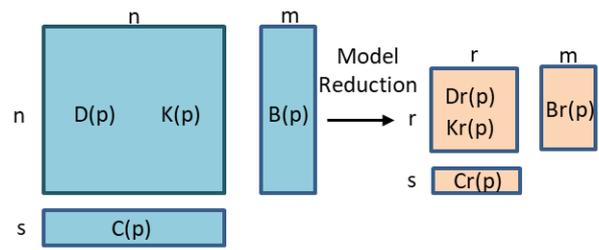
# Generazione di modelli per il controllo avanzato di sistemi e dispositivi



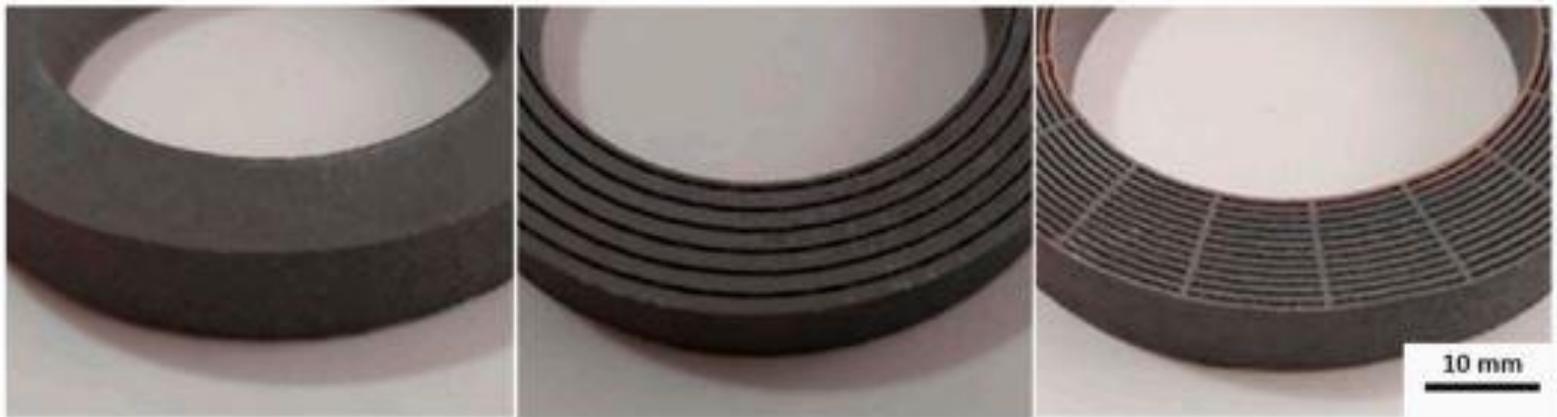
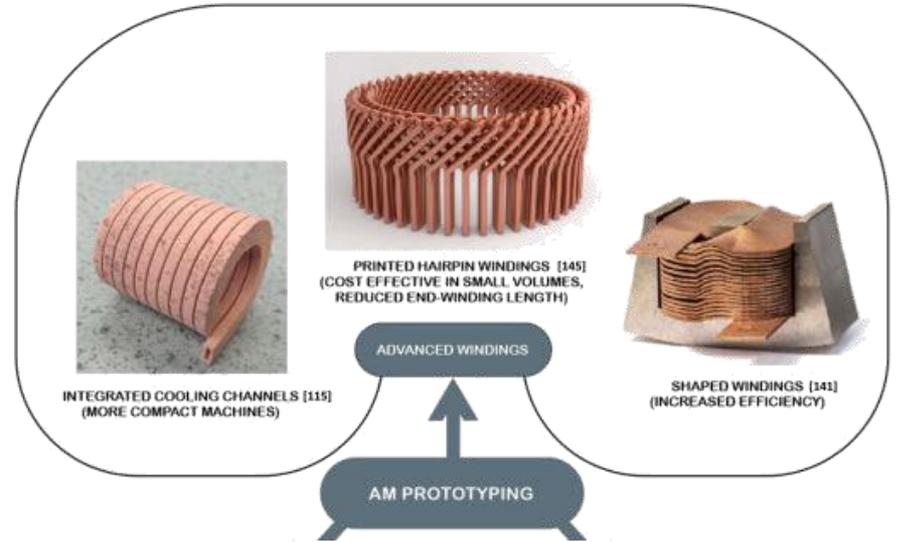
```

source
├── CDT
│   ├── include
│   │   ├── DigitalTwinParams.h
│   │   ├── DT_TemperatureSensorPrivate.h
│   │   └── interface
│   │       ├── DT_TemperatureSensorClass.h
│   │       └── DT_TemperatureSensorClass.c
│   └── src
│       └── DT_TemperatureSensorClass.c
└── ...

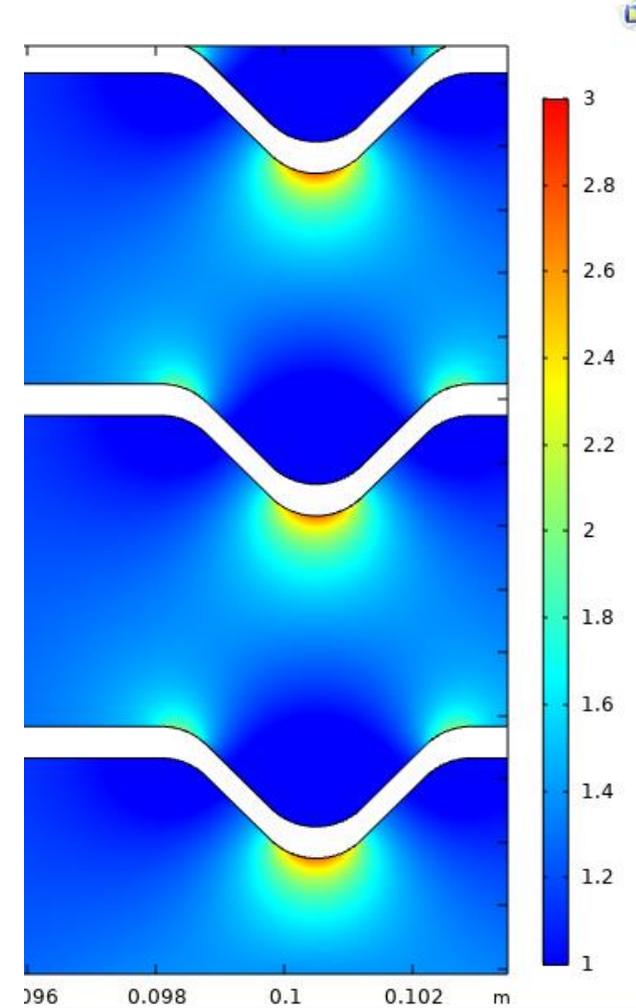
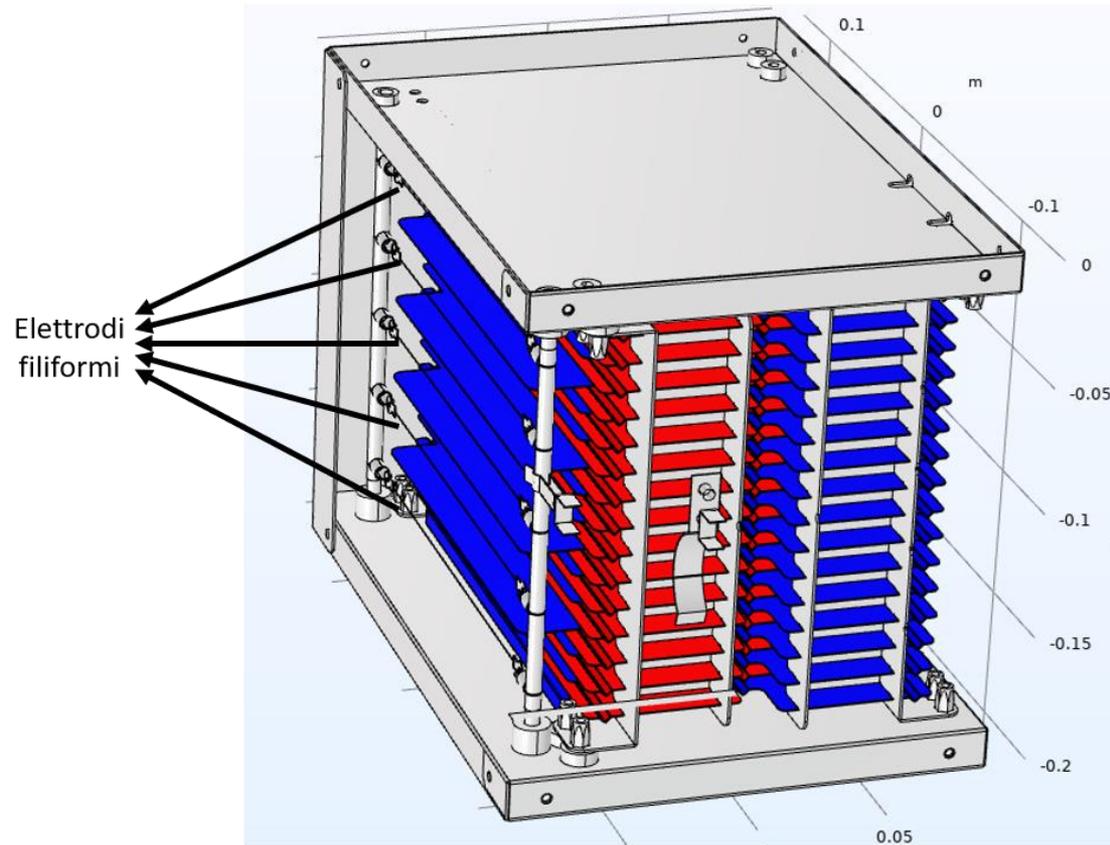
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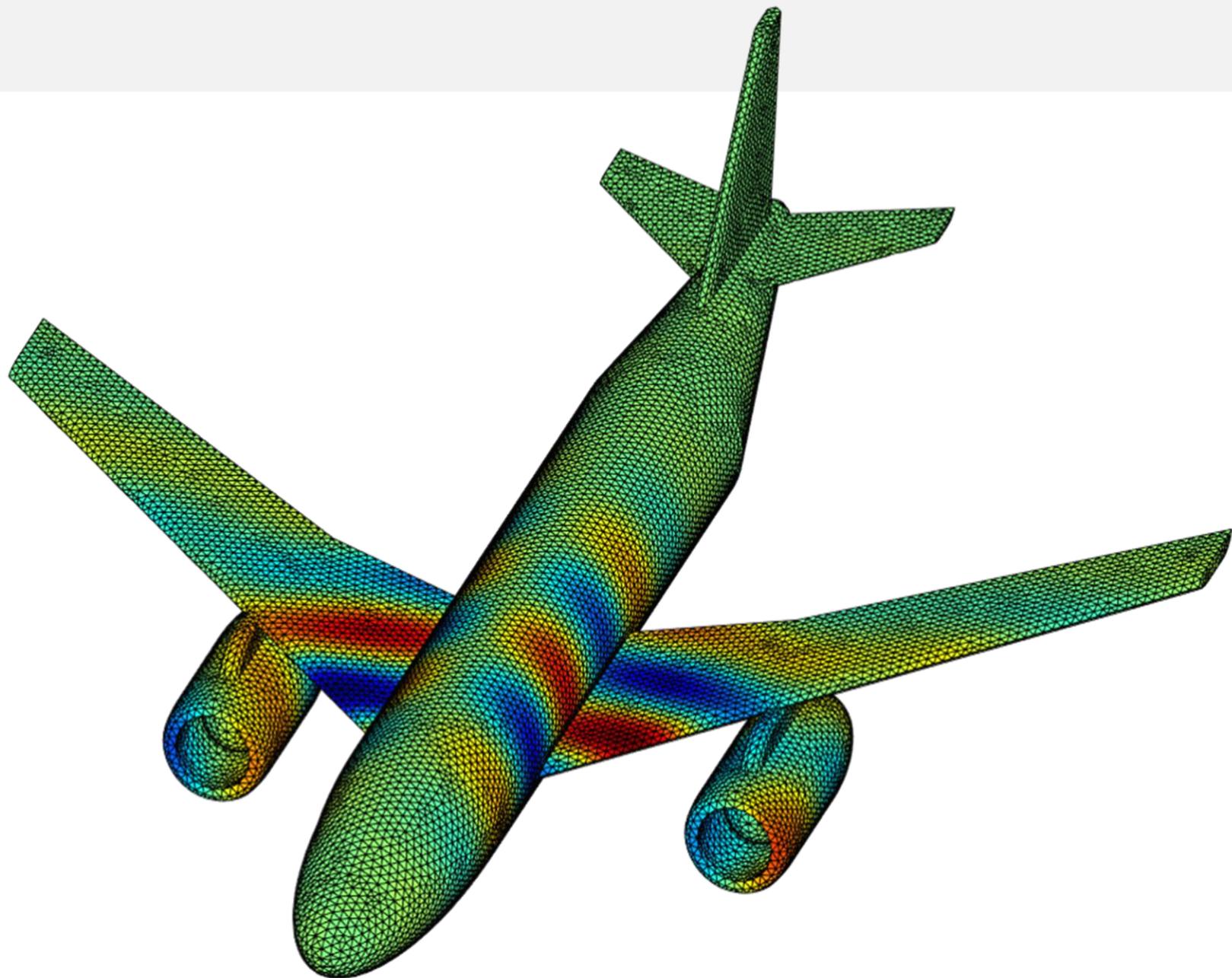


# Progettazione e ottimizzazione di sistemi e dispositivi elettromagnetici



# Progettazione e ottimizzazione + Analisi di sistemi e dispositivi elettromagnetici





# Analisi di sistemi e dispositivi esistenti

