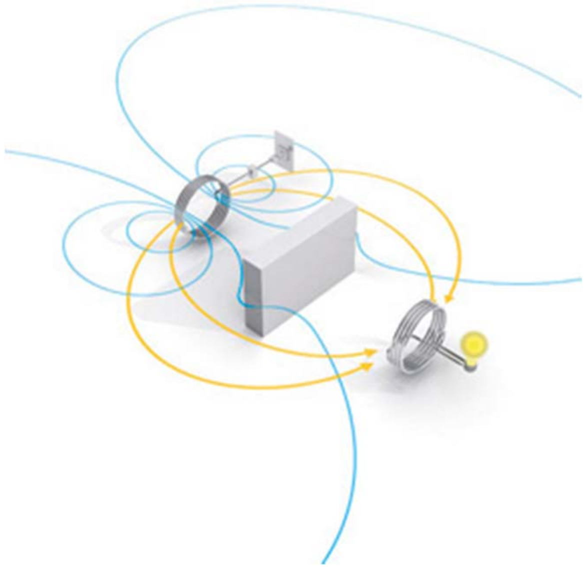
Resonant Inductive Coupling Wireless Power Transfer

Elisenda Bou Balust



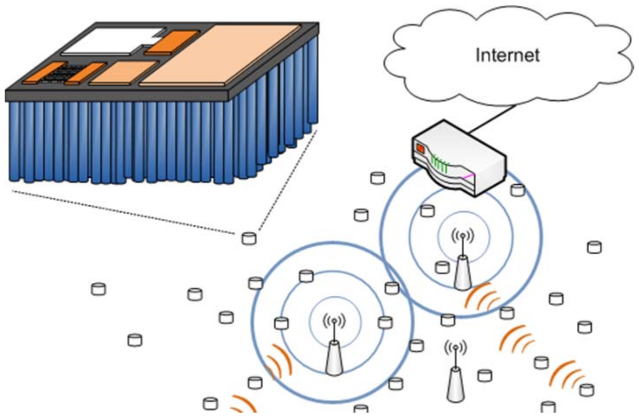
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
Departament d'Enginyeria Electrònica

Outline

- Introduction
    - Energy Challenges in Nanotechnology
    - Resonant Inductive Coupling
    - RIC Scalability
- WPT-Based Active Energy Harvesting
- New Nano-Applications
    - Wireless Nano Sensor Networks
    - Claytronics
    - Nano-materials

Energy Challenges in Nanotechnology Enabled Wireless Comm.

WNSN



Claytronics

All nodes need to be individually powered

Ambient Energy is not enough

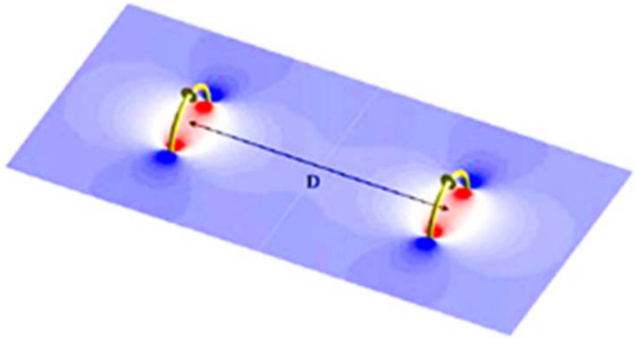
ACTIVE energy harvesting

Resonant Inductive Coupling

Graphene Inductors

Introduction – Overview

Resonant Inductive Coupling is a type of Electromagnetic WPT



- Very **promising efficiencies** → Above 80% PTEff.
- Relative **large distances** → 3 times the tx/rx diameters.

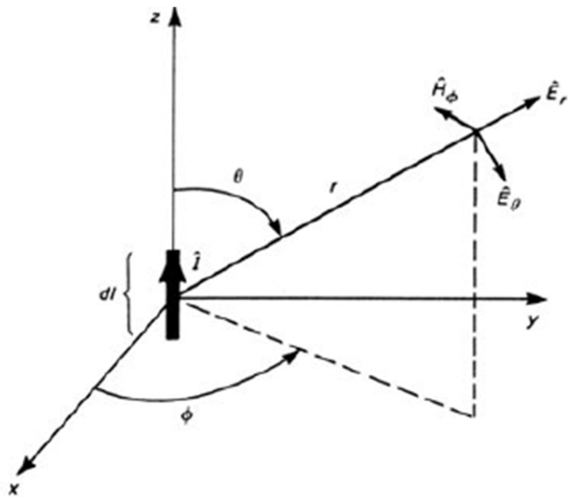
Potential applications

- Electric vehicle charging
- Sensor networks
- Biomedical Implants
- Commercial electronic devices

- RIC is a **very novel technology** (< 4y)

Introduction – Radiative & Non-Radiative behaviors

- Electromagnetic WPT is the **transmission of EM fields**
- **Dual composition** of EM fields → a WPT system can **behave differently depending on the separation** between Tx and Rx
  - **Non-Radiative** (Near Field Region) → changes in current/charge distrib.
  - **Radiative** (Far Field Region) → changes in Magnetic/Electric fields.
- Where is the limit? ➡ Maxwell's equations for an **Infinitesimal Dipole**



Quasi-stationary term

Radiative term

$$E_{e,\theta} = \frac{jZ_0 I_e dl \pi}{\lambda^2} \sin\theta \left[-\left(\frac{\lambda}{2\pi r}\right)^3 - j\left(\frac{\lambda}{2\pi r}\right)^2 + \left(\frac{\lambda}{2\pi r}\right) \right] e^{-j\frac{2\pi r}{\lambda}}$$

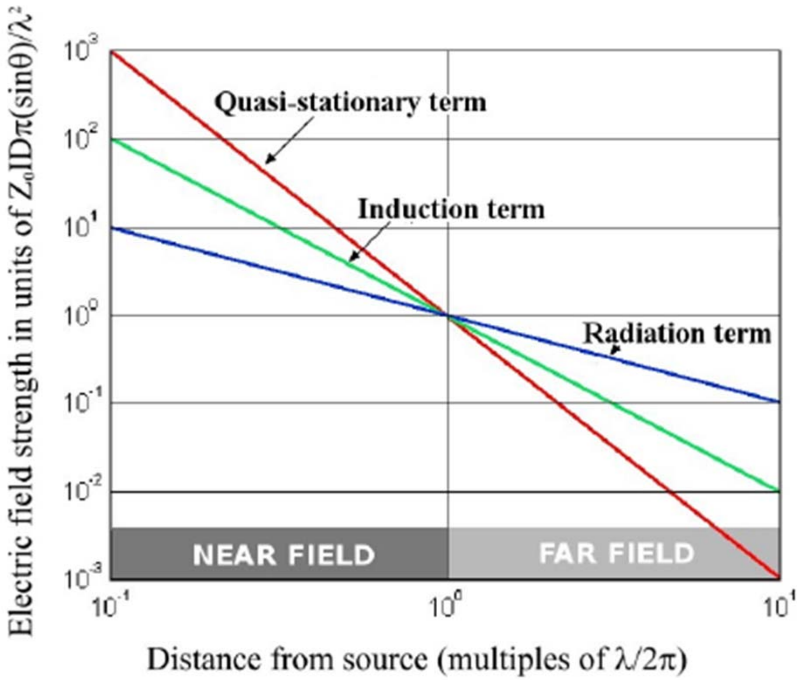
$$E_{e,r} = \frac{2\pi Z_0 I_e dl}{\lambda^2} \cos\theta \left[-j\left(\frac{\lambda}{2\pi r}\right)^3 + \left(\frac{\lambda}{2\pi r}\right)^2 \right] e^{-j\frac{2\pi r}{\lambda}}$$

$$E_{e,\phi} = 0$$

Induction term

Introduction – Radiative & Non-Radiative behaviors

- The region where all the contributions are **equal** is the **boundary region between near and far-field.**
- Separation not sharp → **mid-range zone** where radiative and non-radiative fields coexist.



- If **r << λ/2π** Electrostatic & induction terms → non-radiative (reactive) **near-field zone**
- If **λ/2π < r < λ** Induction & Radiation terms→ **mid-range**
- If **r >> λ/2π** Radiation term dominates → **far-field zone**

Introduction – EM. Inductive WPT

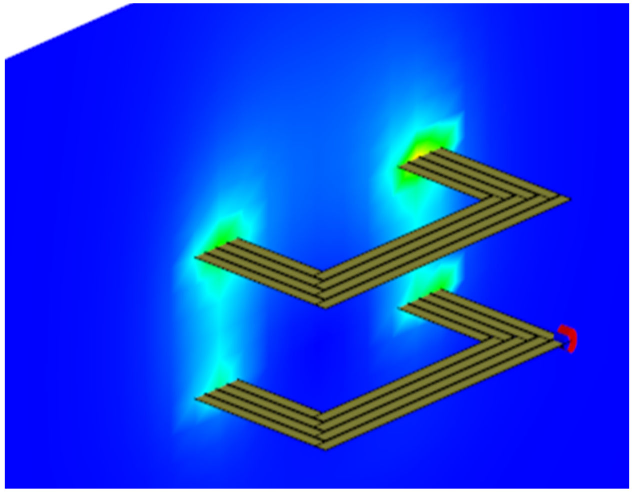
- First demonstrated in the **early 20th century** by Nikola Tesla, but thought impractical due to the undesirably large electric fields.

- In 1960 WPT EMI was reintroduced for biomedical applications (artificial hearts).

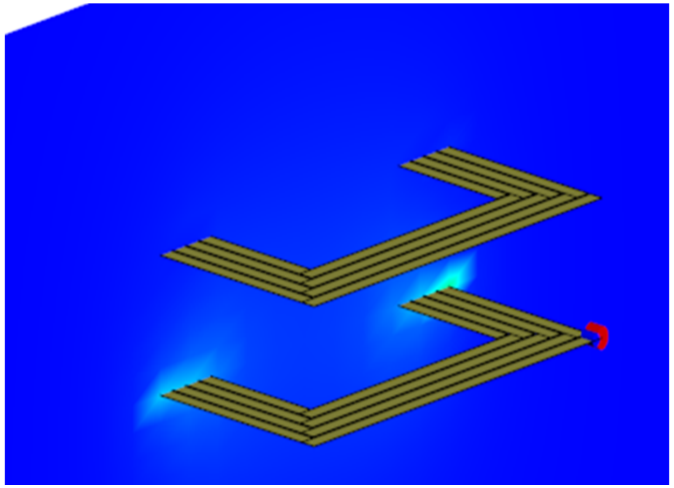
  - Since then, commonly used in **implantable devices.**
  - These inductors, such as typical transformers, required a **very short distance** between transmitter and receiver (**centimeters range**).

Introduction – Radiative & Non-Radiative behaviors

- **Later systems** implemented **resonant** transmitter coils
  - Each coil capacitively loaded forming a **tuned LC resonating circuit** at a common frequency.
  - Inductive links used in medical and consumer applications, but **limited to the near-range** (less than the dimensions of the coils).



Resonant



Non-Resonant

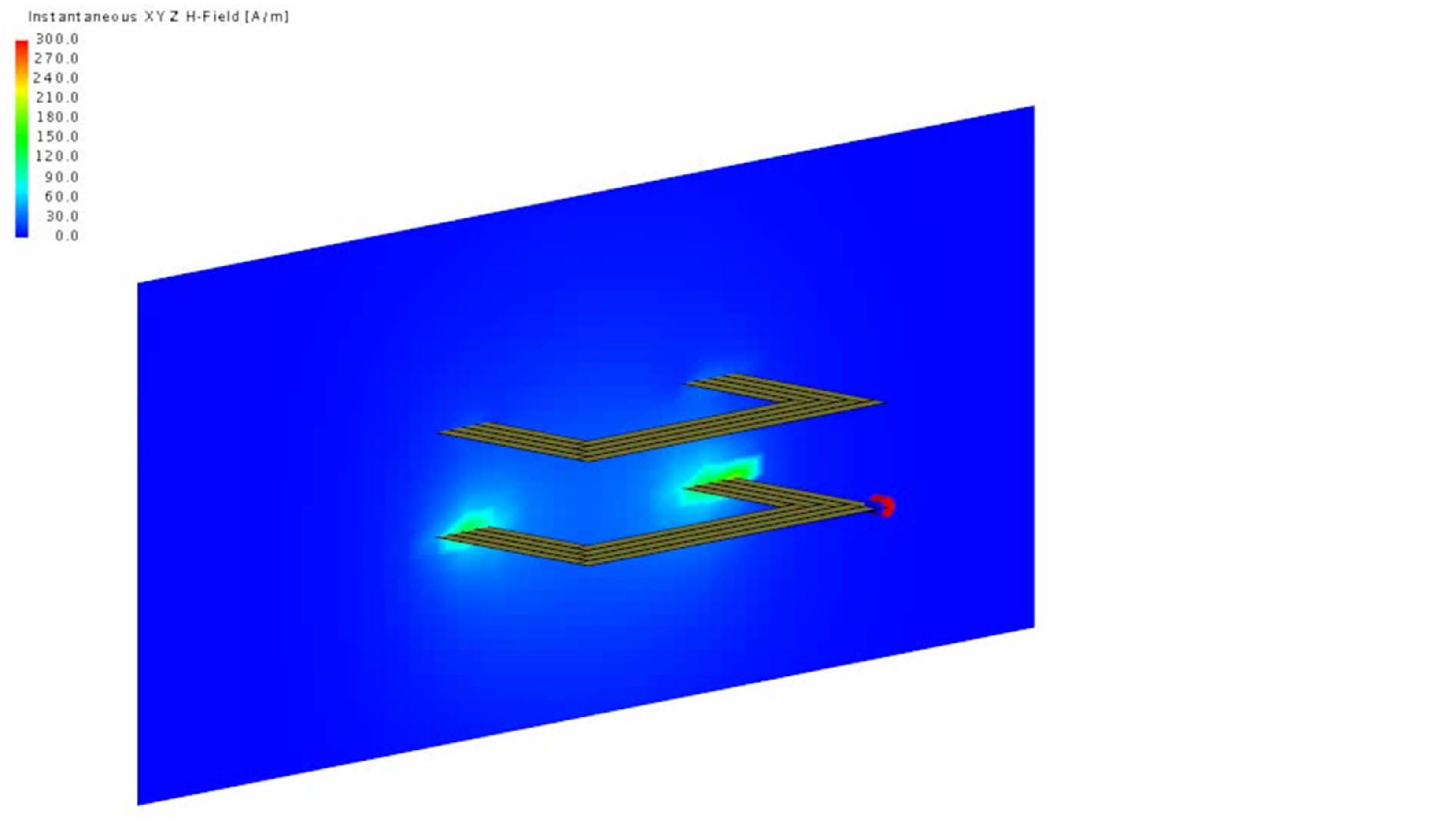
Introduction – Radiative & Non-Radiative behaviors

- In **2007**, EMI links extended to larger ranges (several times the diameter of the antennas) stretching RIC in **strong-coupling regime.**
  - Demonstrated lighting a bulb at 2m with 40% Efficiency

- Strong coupled RIC attracted lot of attention
  - **Harmless** to humans (non-radiative).
  - **No direct line-of-sight needed**
  - Good efficiencies at **several meters.**

- **RIC** is foreseen as a **key enabling technology** for **wireless power transfer** in the following years.

Introduction – Radiative & Non-Radiative behaviors



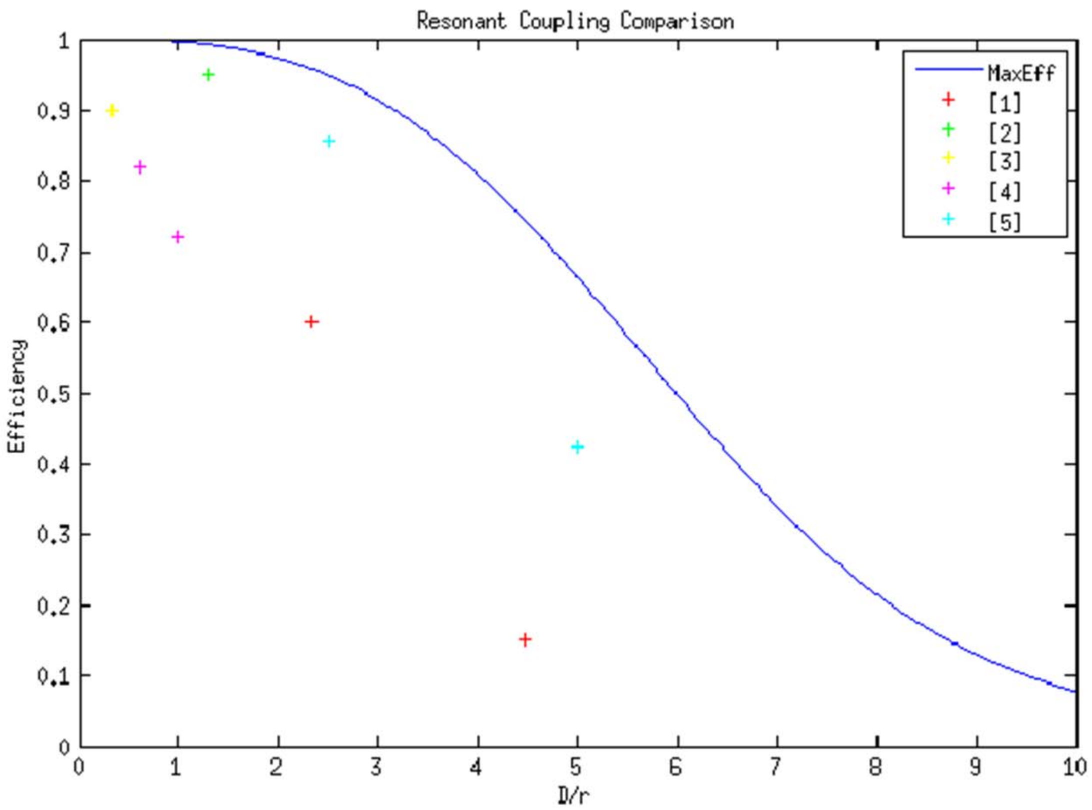
Exploring RIC Scalability

- There are scattered examples of RIC for different frequencies/sizes of the coils

Coil Diam. [cm]	f[MHz]	Turns	d/r_m	Eff[%]	P_{out}[W]	Ref	Year	Comments
(2.56,2.56)	10.38	20	2.34	60	1.21	[51]	2009	4 Coils
(2.56,2.56)	10.38	20	4.37	15	0.20	[51]	2009	4 Coils
(32,32)	10	5	25	1.3	-	[52]	2008	2 Coils
(4.6,4.6)	3.7	1	1.3	95	3000	[53]	2011	
(3.0,3.0)	19.22	4	0.33	90	-	[54]	2010	Optimum Load
(6.4,2.2)	0.7	40	1.07	82	0.1	[31]	2011	AWG44 Litz Wire
(6.4,2.2)	0.7	40	1.73	72	0.08	[31]	2011	AWG44 Litz Wire
(100,100)	0.2	1	200	50	80	[44]	2010	Superconducting
(6,6)	10	1	2.5	85.7	200	[55]	2010	Optimum Load
(6,6)	10	1	5	42.3	70	[55]	2010	Optimum Load
(6,2)	0.7	-	1.73	36	0.05	[56]	2004	Non Resonant
(2.4,2)	2	32	1	40	-	[57]	2010	

Exploring RIC Scalability

RIC efficiency as a function up to 10 times the radii of the antennas.



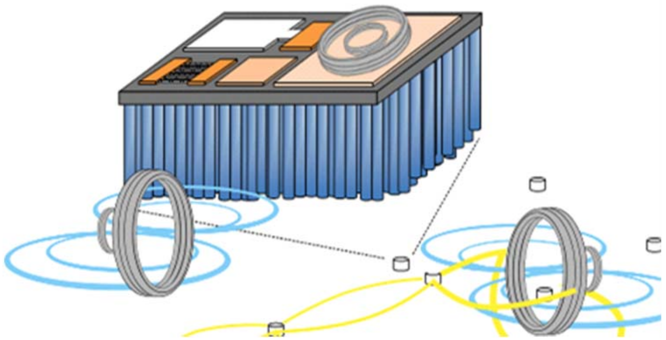
WPT-Based Active Energy Harvesting

- EH would allow successful deployment of battery-less self-powered **Wireless sensor networks** (WSN) nodes, biomedical implants and body area networks

- Despise EH is already successful in niche applications, the most ubiquitous source of energy, **EM harvesting**, is **still not feasible.**

- To circumvent the current short and mid-terms limits of EH technologies

  → artificially **increase ambient energy** → **active** radiation of a single energy source (**energy broadcast**).



- The high-efficiency WPT RIC systems become of strong interest as an **enabler** of **active electromagnetic WPT based energy harvesting.**

Nano-Materials: Graphene-Based coils

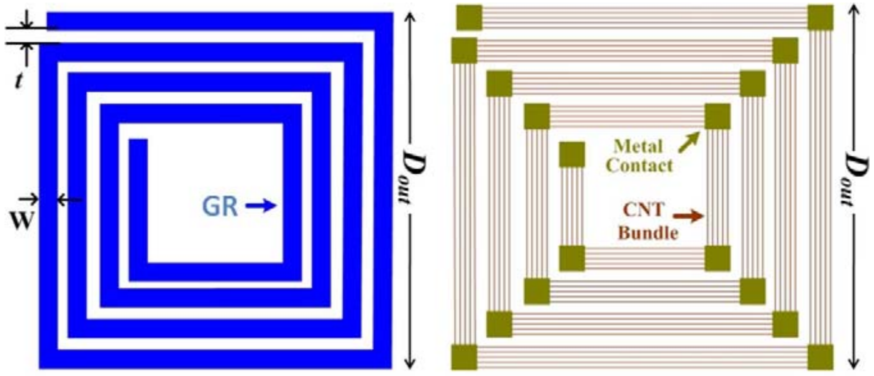
- How to increase the range of the system?
  - Decrease losses (improve Q)
- To reduce losses, several technologies have been proposed:
  - Superconducting dielectric-less coils
    - ohmic losses negligible
    - More complexity
  - Litz-Wire Coils
    - minimize skin & proximity effects
    - Low frequencies 1-2MHz.

- Because high frequency/low loss coils are necessary in Wireless Power and Data Systems, we propose to use new materials such as **graphene-based nano-coils** for the design and implementation of active energy harvesting systems.

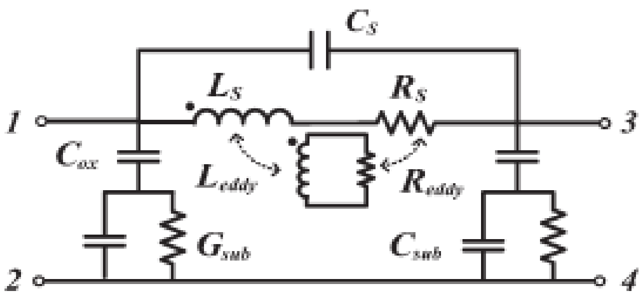
Nano-Materials: Graphene-Based coils

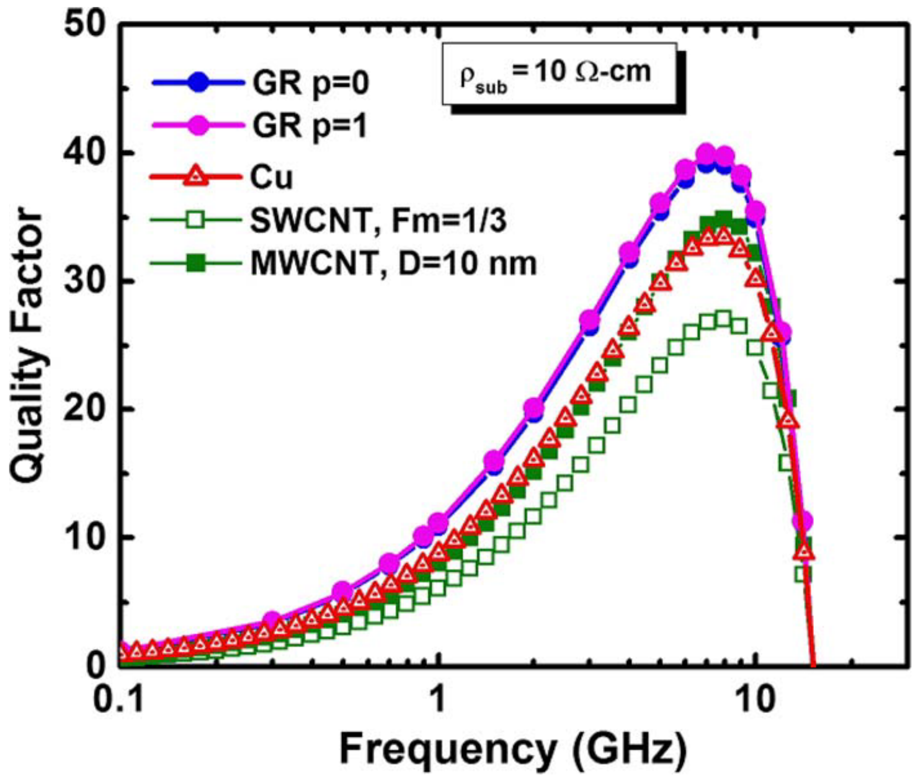
"High-Frequency Behavior of Graphene-Based Interconnects—Part II: Impedance Analysis and Implications for Inductor Design" Deblina Sarkar, *Student Member, IEEE*, Chuan Xu, *Student Member, IEEE*, Hong Li, *Student Member, IEEE*, and Kaustav Banerjee, *Senior Member, IEEE*

Diameter = 200 μm, N=4, Wire width= 8 μm, Wire thickness H = 2 μm



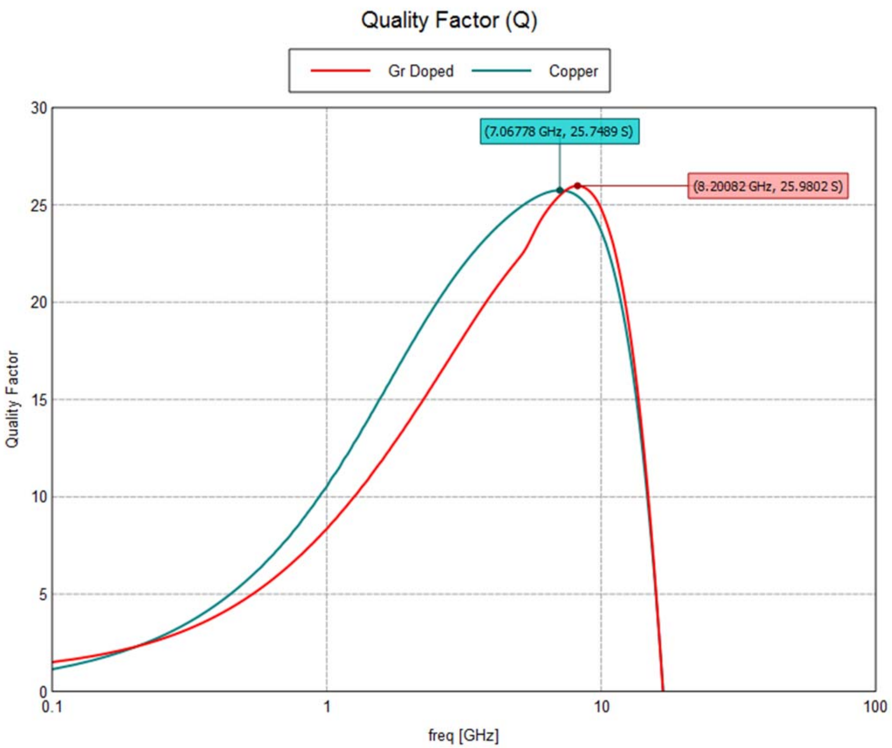
(a) (b)

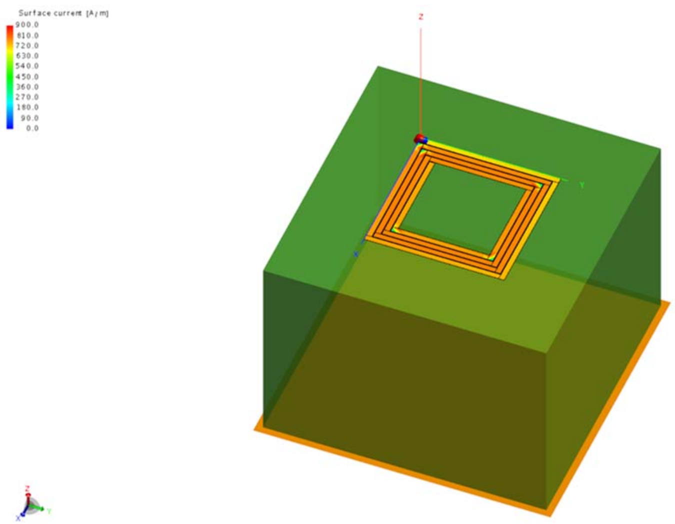




Nano-Materials: Graphene-Based coils

Same graphene-doped coils simulated with Finite Element Field-Solver FEKO

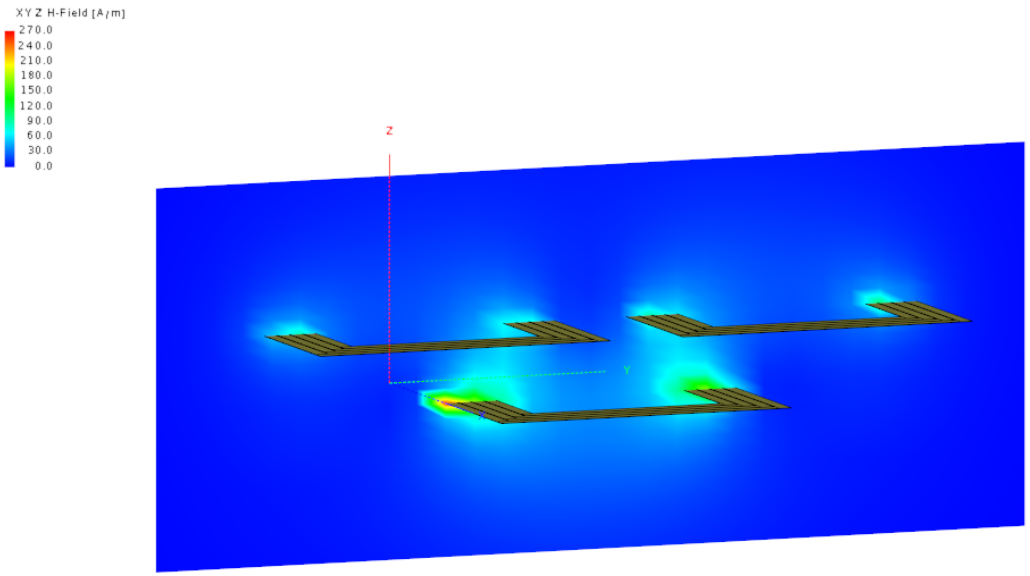




Differences with previous results due to the non-ideal dielectric substrate used.

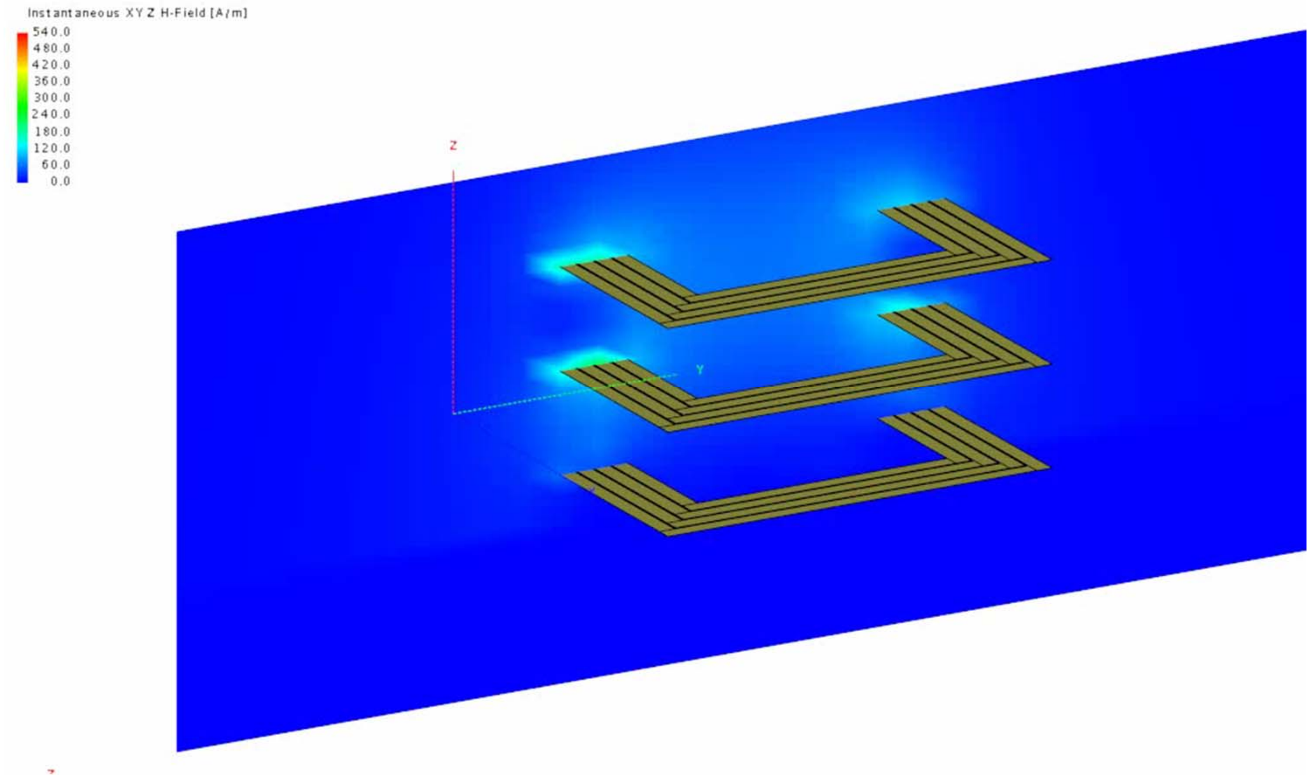
Wireless Nano-Sensor Networks

- One of the potential applications of RIC systems is **WPT networks.**
- Due to the behavior of RIC systems, this WPT method is **very suitable for broadcast applications** where coils could **be active (resonant) or inactive (non-resonating) without** inquiring in **significant losses** to the transmitter's power.
- Because in RIC systems, antennas act as transmitter and receiver at the same time, **WPT meshed networks could be implemented** and **miniaturized.**



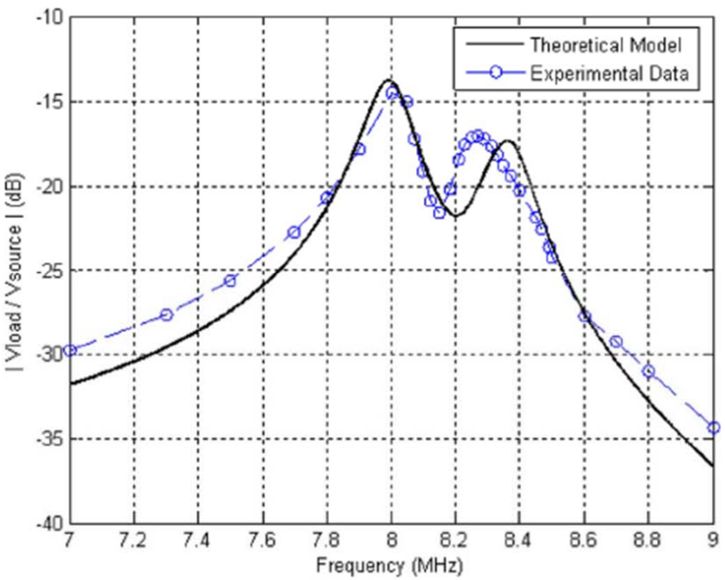
Wireless Nano-Sensor Networks

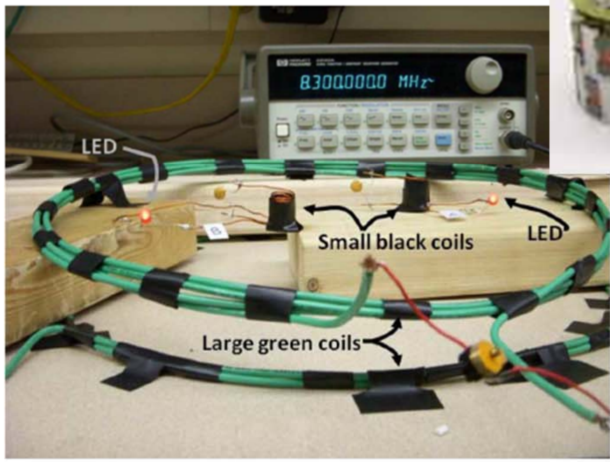
- RIC inductors can operate as transmitter and receiver at the same time
- Increase in distance range by using the different nodes as repeaters.



Claytronics – Inteligent Matter

- RIC can be used as a potential means for providing power to catoms without using electrical connections.
- WPT to multiple small receivers has been demonstrated by Prof. Goldstein.





Magnetic Resonant Coupling As a Potential Means for Wireless Power Transfer to Multiple Small Receivers" Benjamin L. Cannon, James F. Hoburg, Daniel D. Stancil and Seth Copen Goldstein

Conclusions

- In WNSN and claytronics, every node needs to be **powered individually.**
- The challenge to power this nodes using **energy harvesting** is still unsolved.
- We propose to use **Active Energy Harvesting** to circumvent the energy requirements.
- Because of its scalability in frequency and size, **Resonant Inductive Coupling** is proposed as a method to perform Active Energy Harvesting in the nano-scale.
- **Graphene based inductor antennas** have been simulated to act as the transmitters and receivers of such a RIC system.