

Vezeték nélküli energiaátvitel



Dr. Gyimóthy Szabolcs

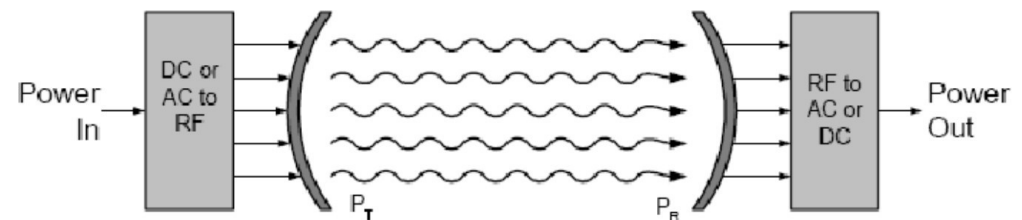
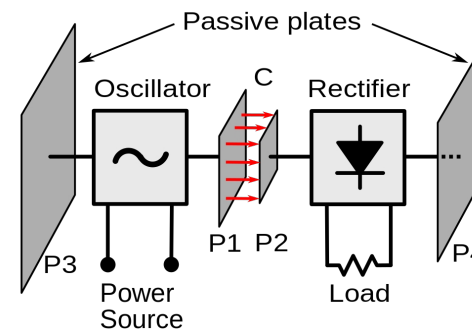
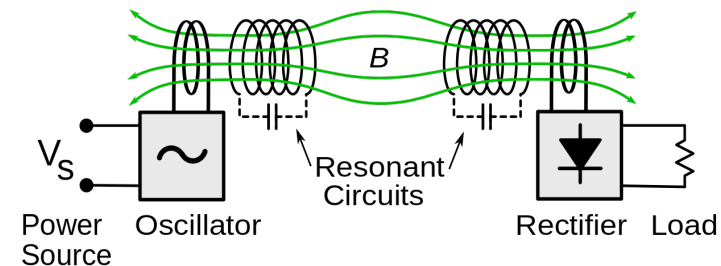
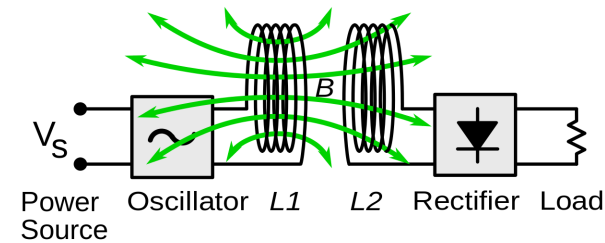
BME Szélessávú Hírközlés és Villamosságtan Tanszék

2017. február 16.

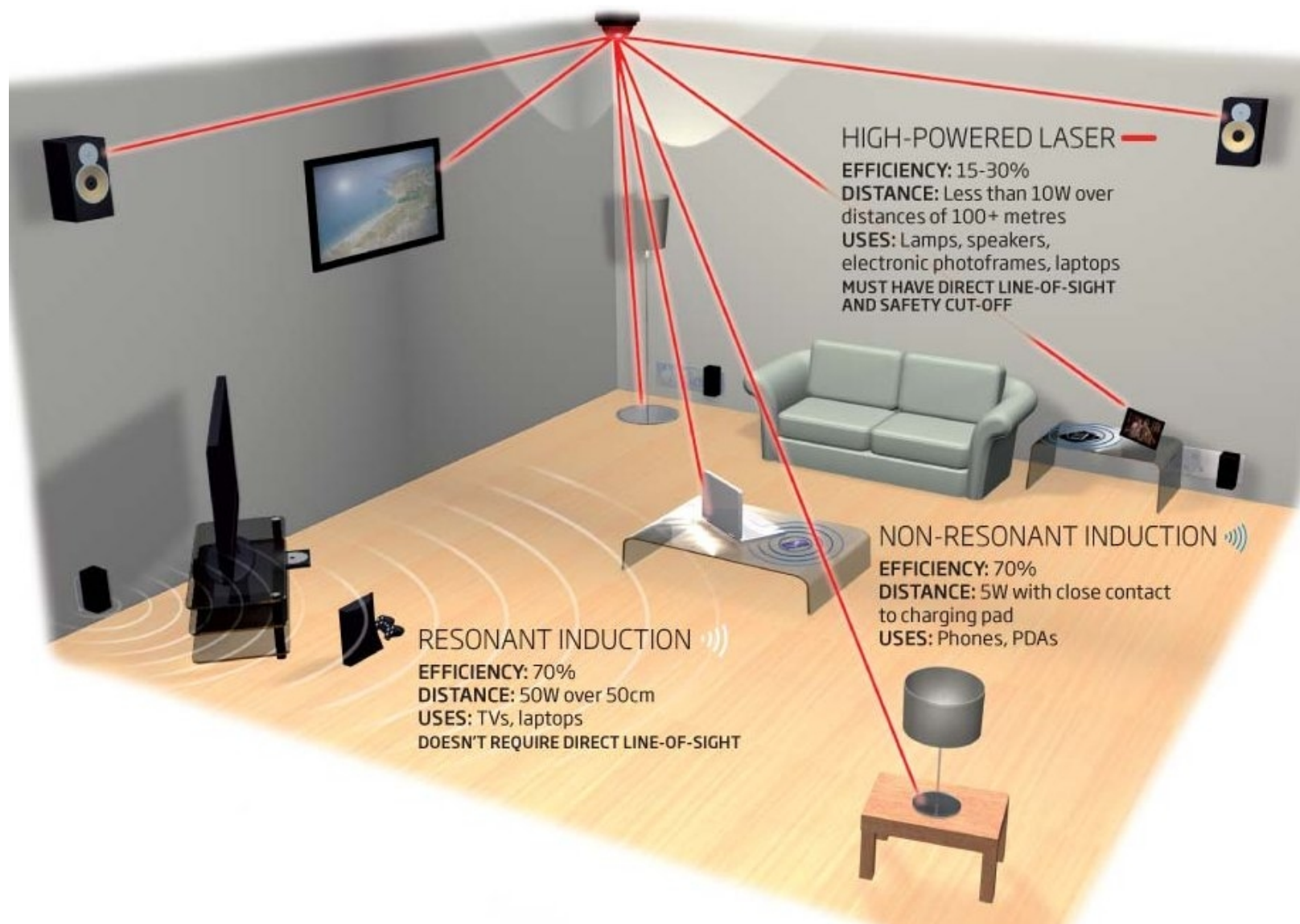
- Bevezető
- A csatolt rezonancián alapuló átvitel elve
- Az átvitel matematikai leírása
- Alkalmazási területek
- A fejlődés fő irányvonalai



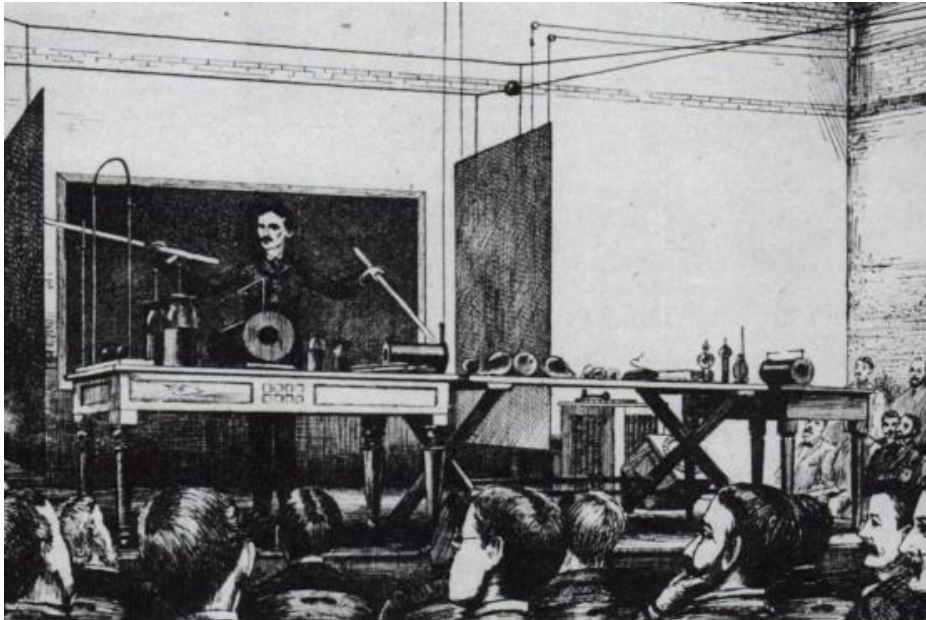
- Közeltéri (nem sugárzó)
 - Induktív (nem rezonáns)
 - Rezonancián alapuló
 - Induktív csatolással
 - Kapacitív csatolással
- Távoltéri (sugárzó)
 - mikrohullámú
 - lézeres



A képek forrása: Wikipedia, Jenshan Lin



forrás: NewScientist

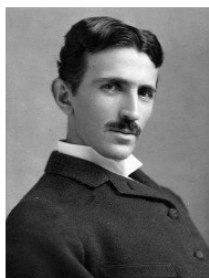


Tesla előadása 1891-ben



A Wardenclyffe-torony

A képek forrása: [Wikipedia](#)



Nicola Tesla



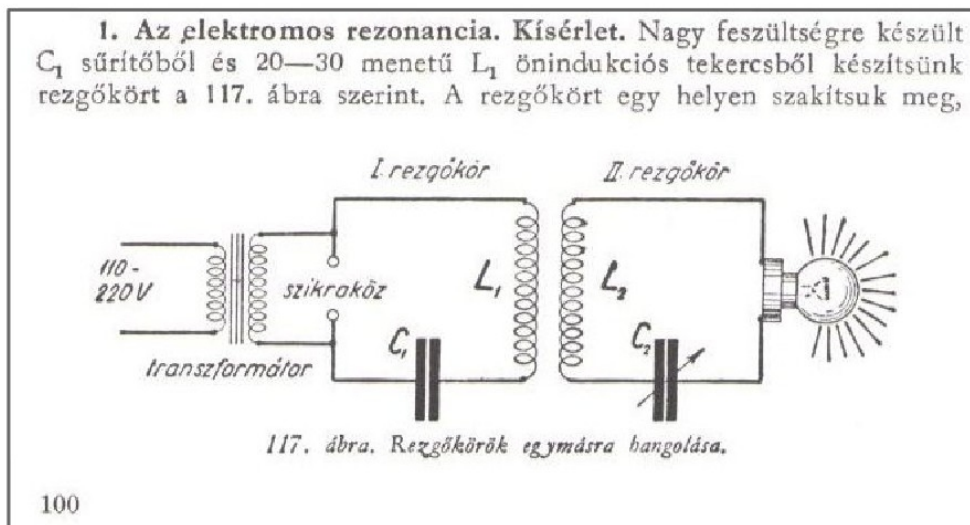
Soljacic et al.

1894

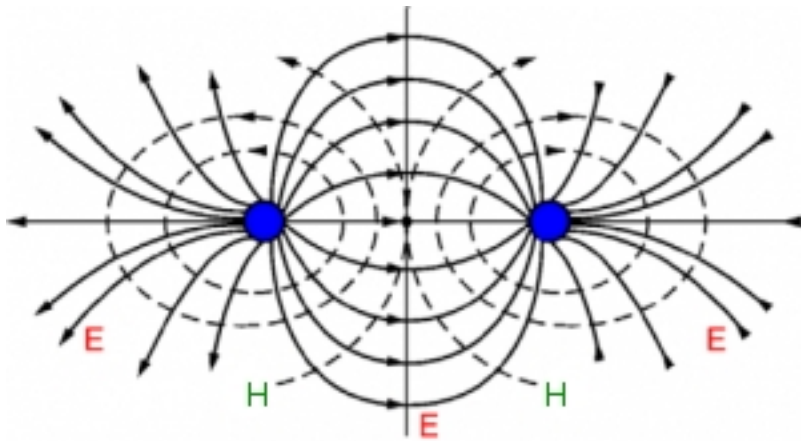
1954

2007

... egy tankönyv a
“vasfüggönyön” innen...

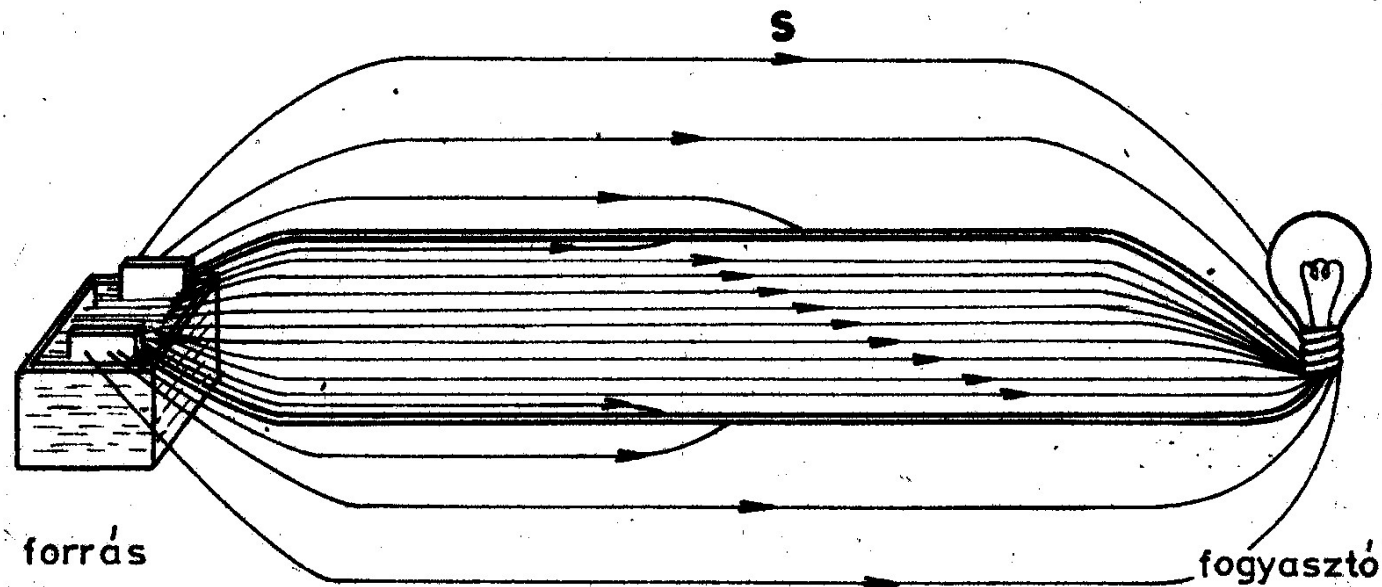


A rezonancia alapú vezeték nélküli energiaátvitel alapjai

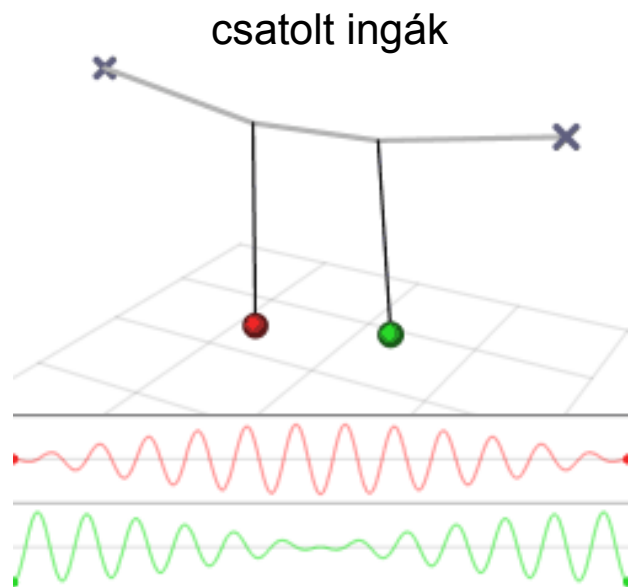


Poynting-vektor

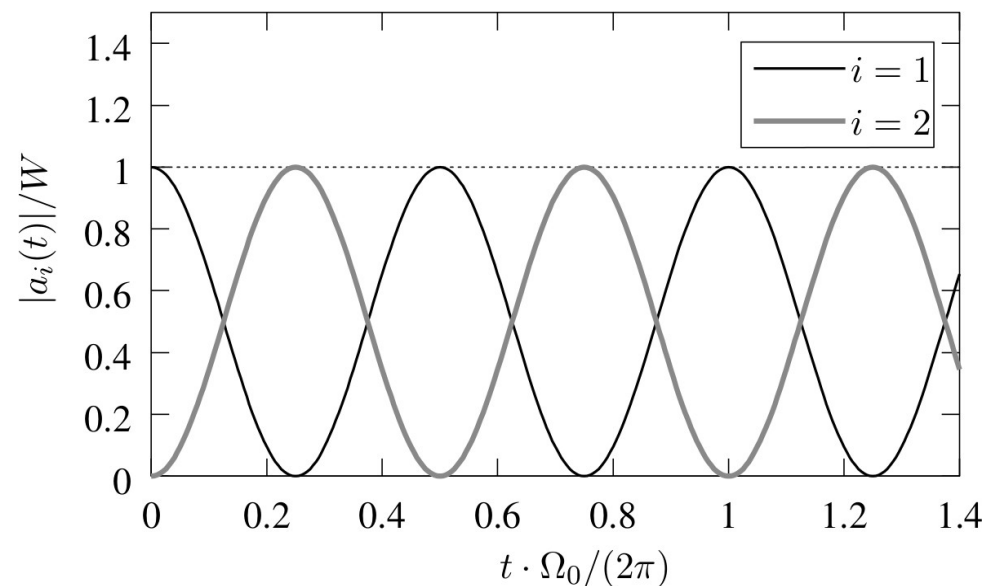
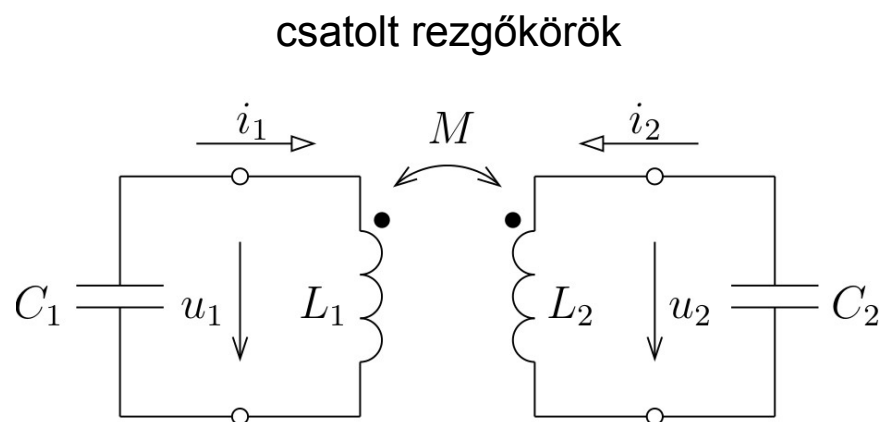
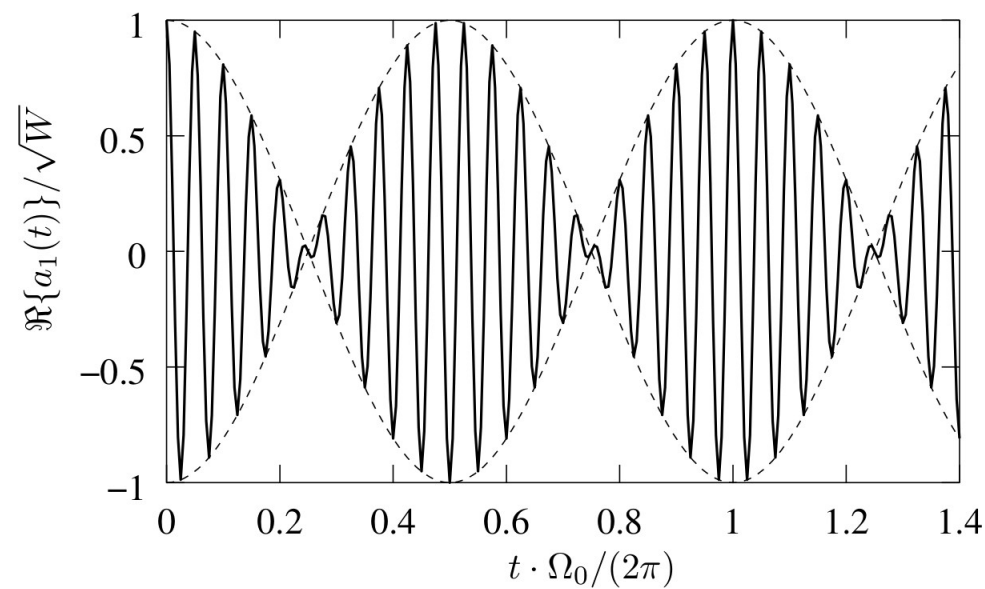
$$\vec{S} = \vec{E} \times \vec{H}$$

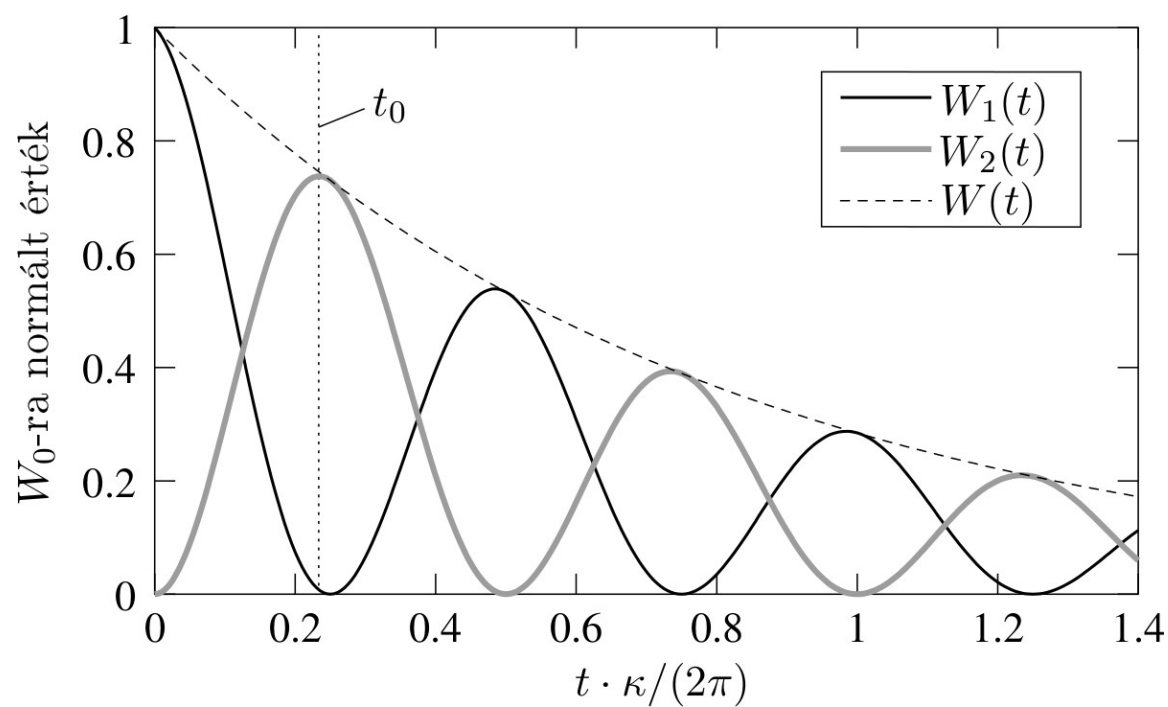
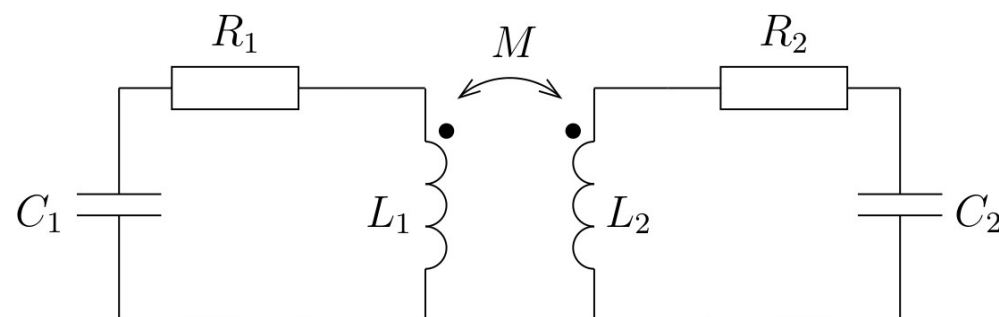


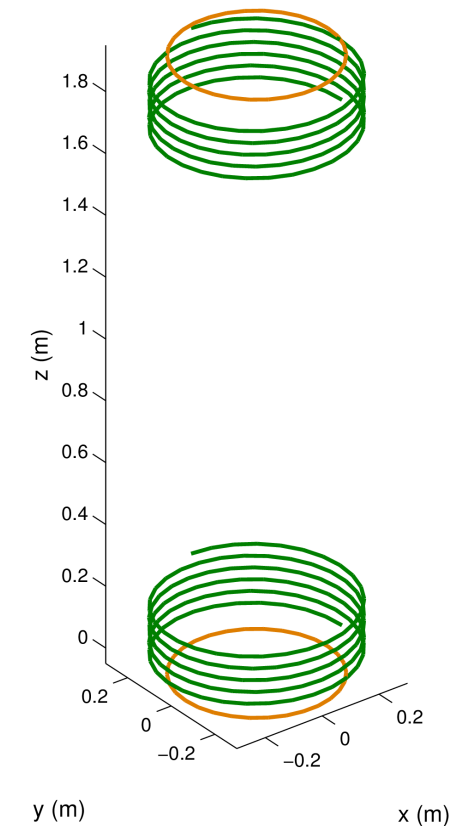
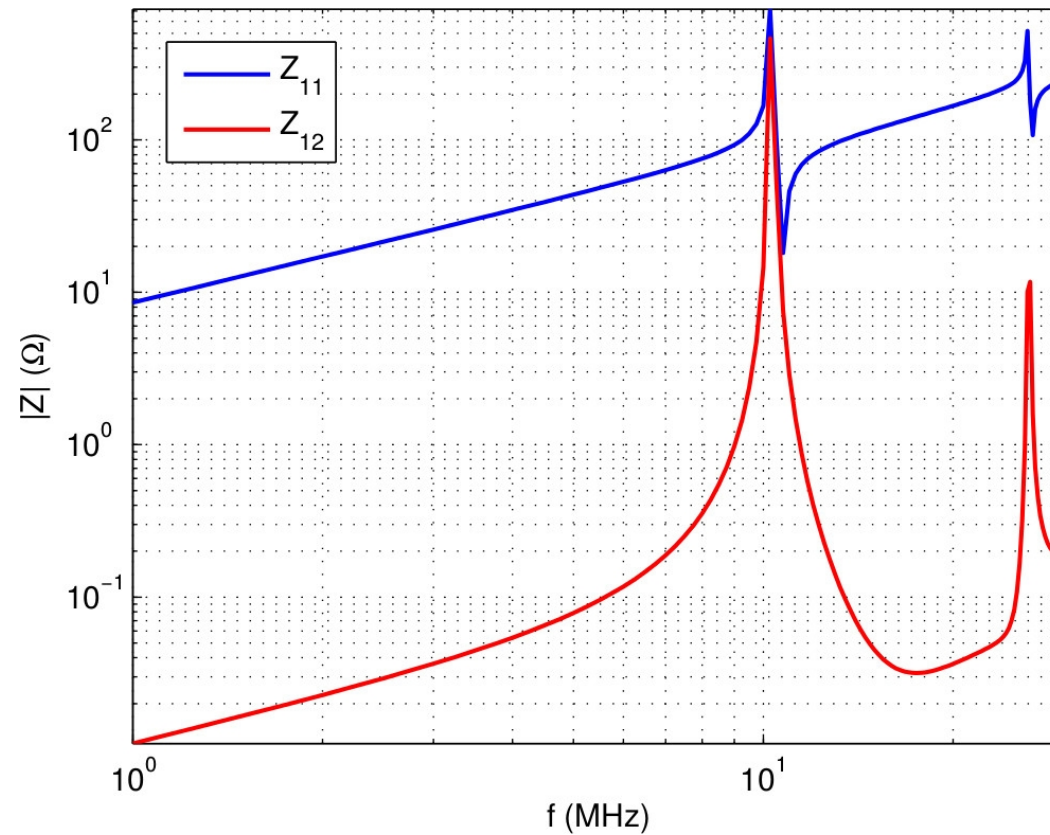
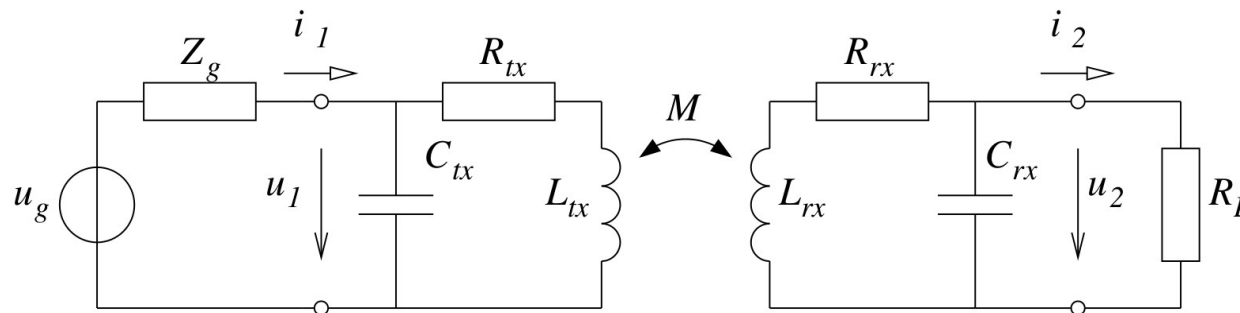
A képek forrása: www.emfrf.com, Vágó I. Villamosságtan II.

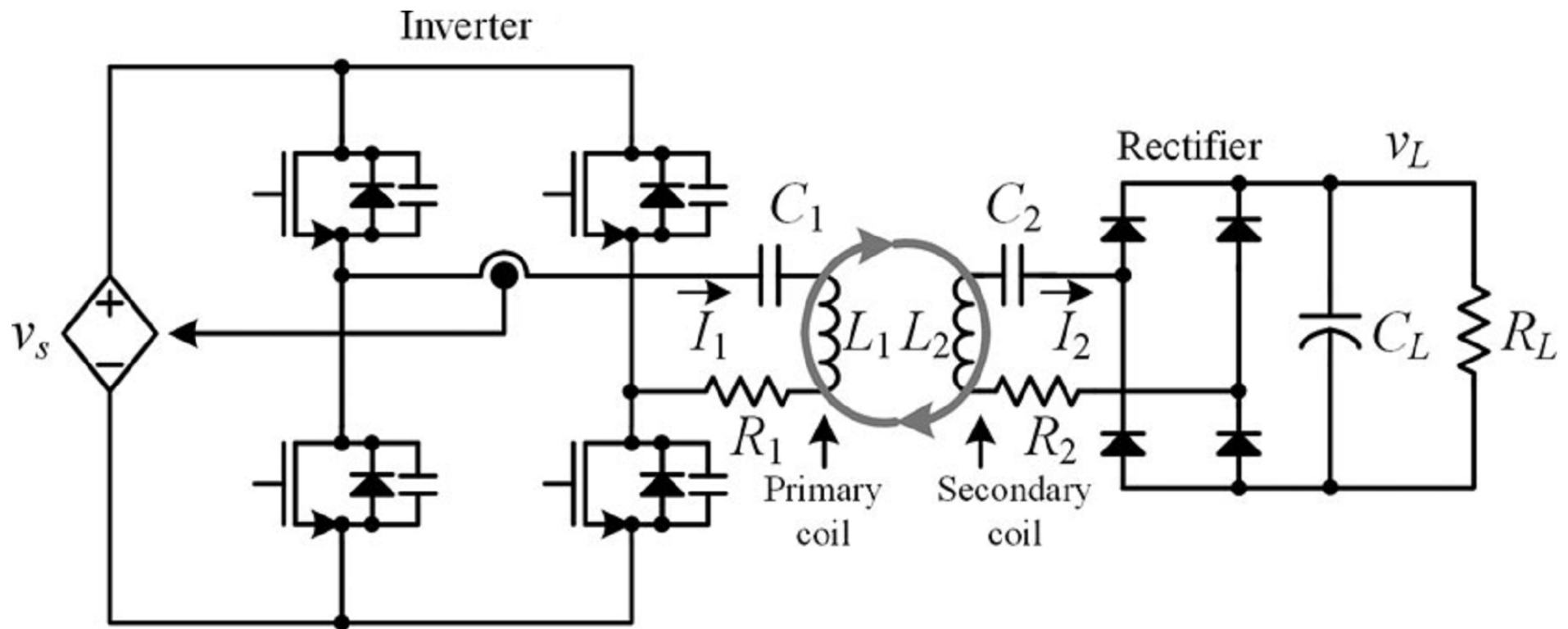


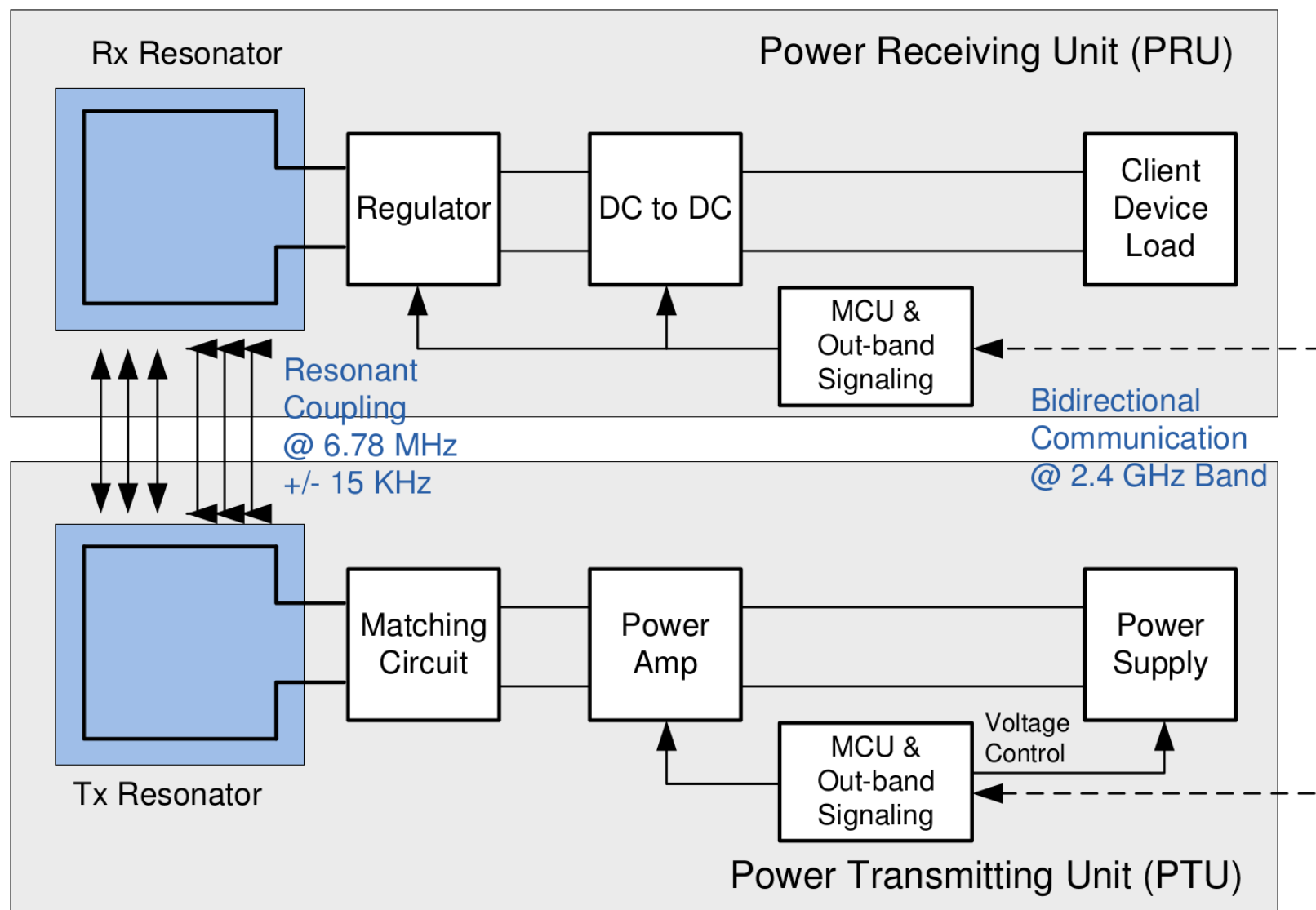
(wikipedia.org)



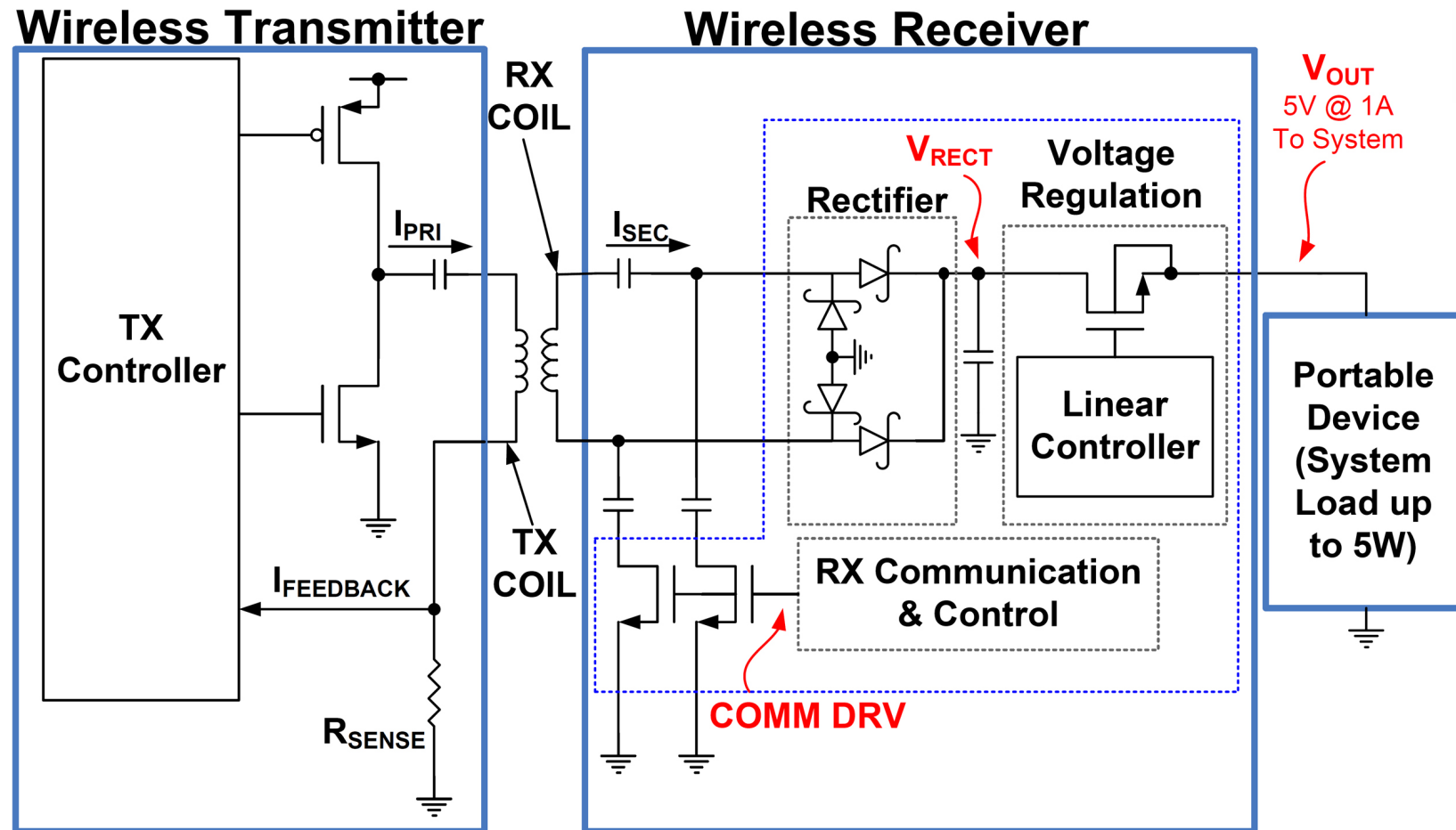




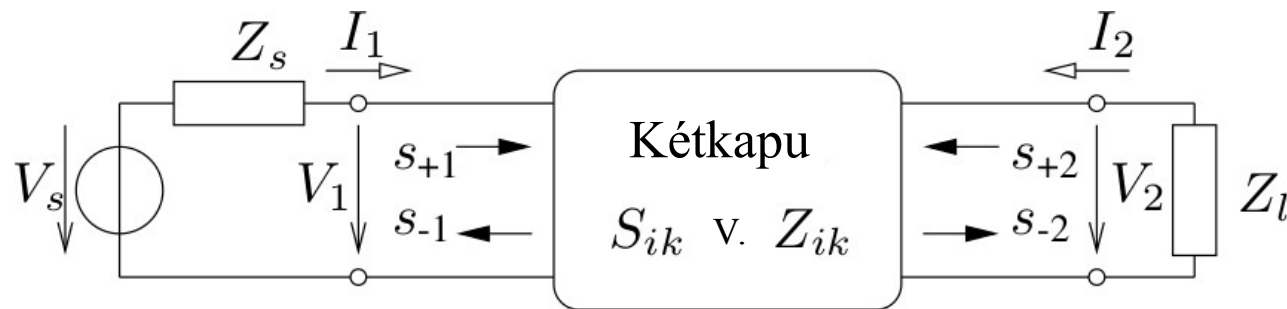




Forrás: Rezence™ Specification



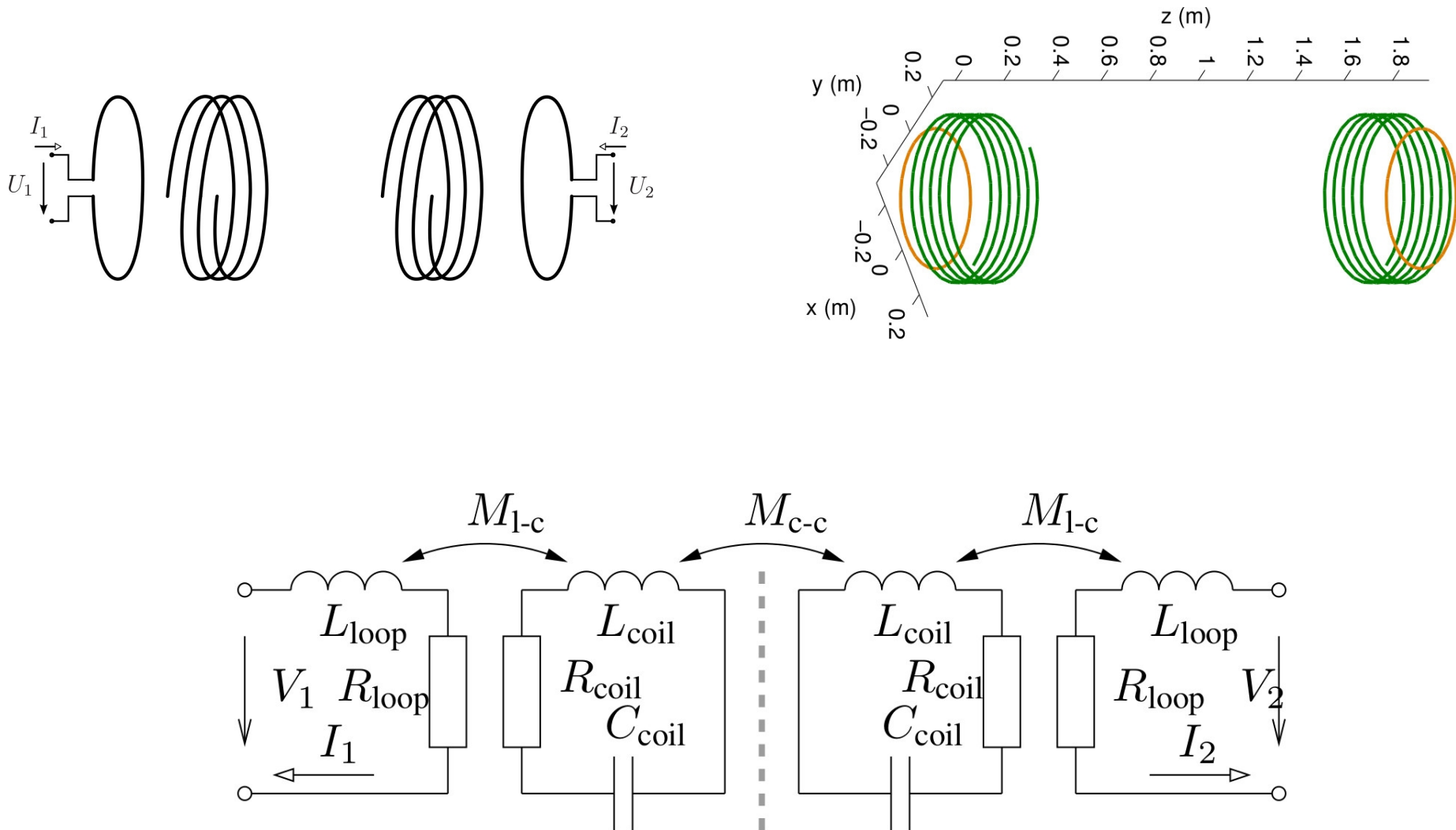
Az átvitel matematikai leírása

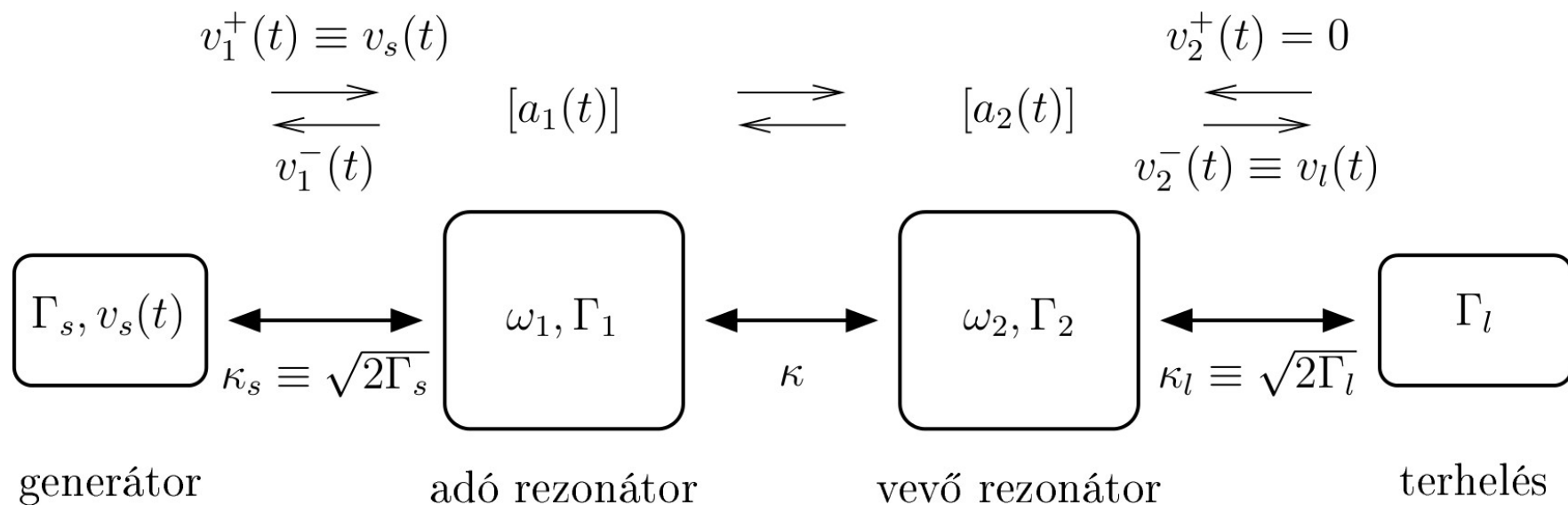


$$\begin{bmatrix} s_{-1} \\ s_{-2} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} s_{+1} \\ s_{+2} \end{bmatrix} \quad \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

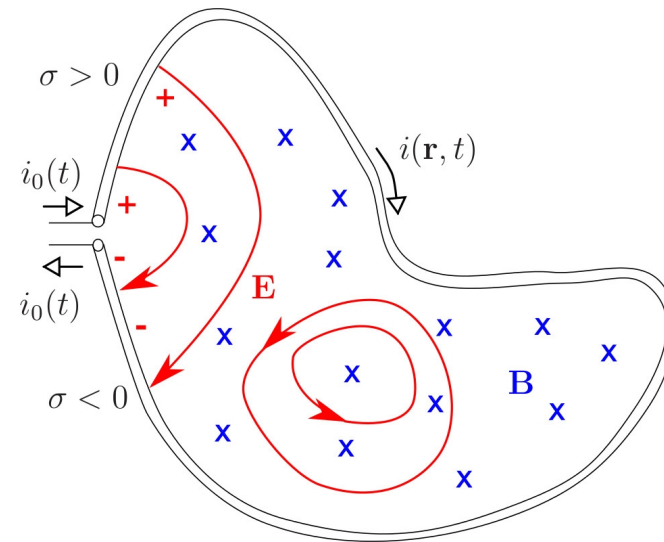
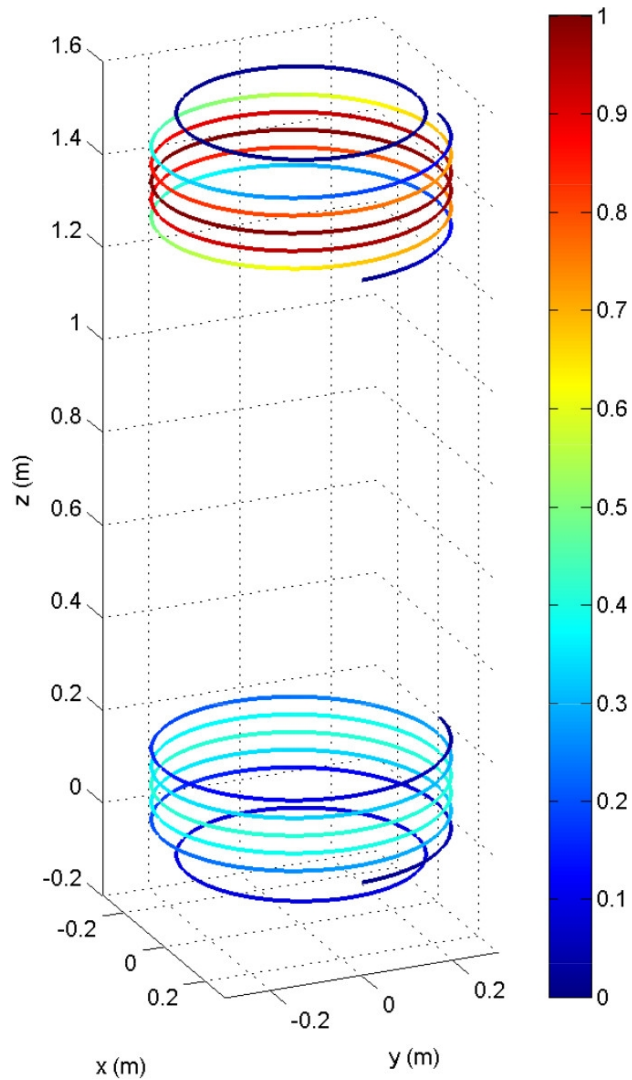
Mi van a „dobozban” ?

- Koncentrált paraméterű hálózat
- Csatolt módusok elméletén alapuló modell
- Direkt térszámítási modell

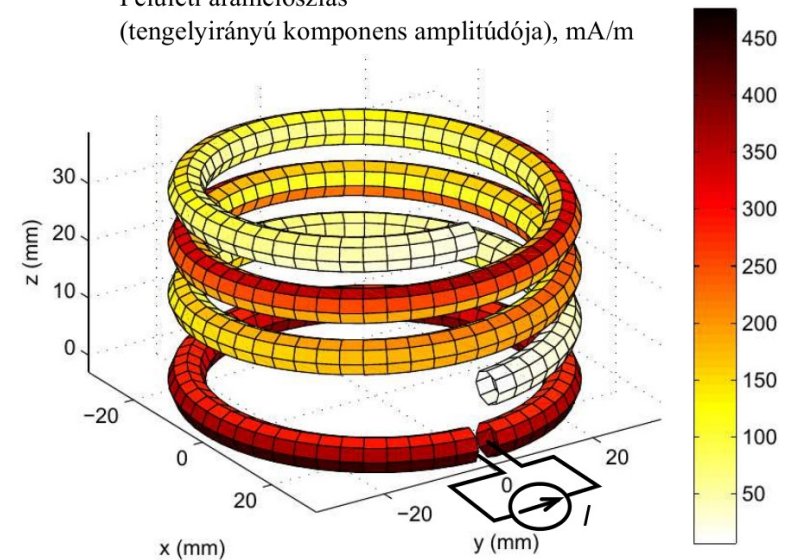


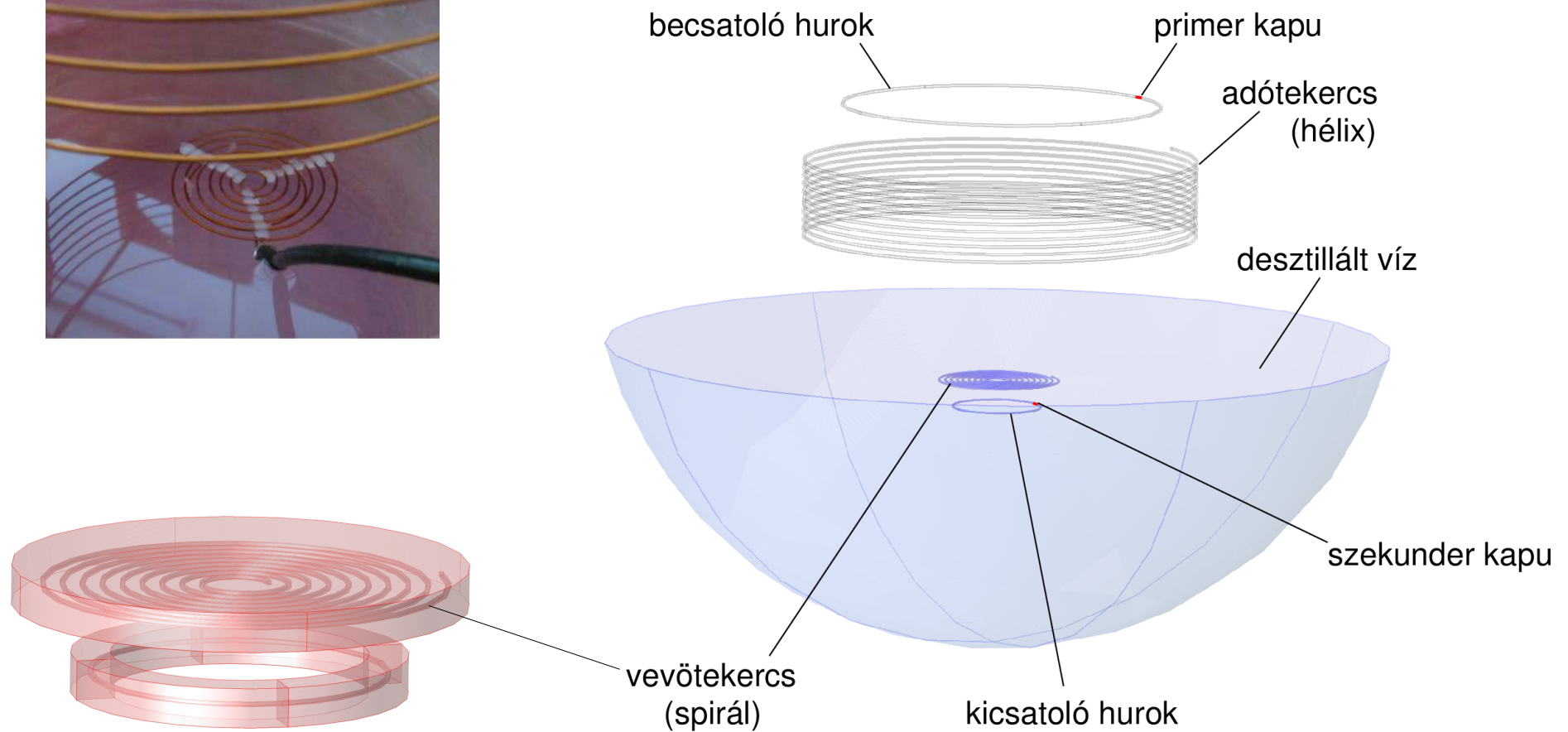
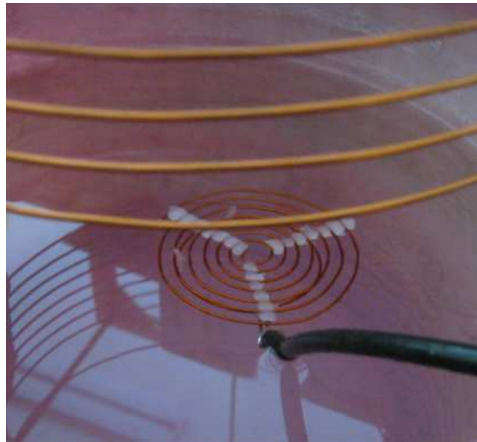


$$\begin{aligned}\frac{da_1}{dt} &= j\omega_1 a_1 - (\Gamma_1 + \Gamma_s) a_1 + j\kappa a_2 + \sqrt{2\Gamma_s} v_1^+ \\ \frac{da_2}{dt} &= j\omega_2 a_2 - (\Gamma_2 + \Gamma_l) a_2 + j\kappa a_1 \\ v_1^- &= -v_1^+ + \sqrt{2\Gamma_s} a_1 \\ v_2^- &= \sqrt{2\Gamma_l} a_2\end{aligned}$$

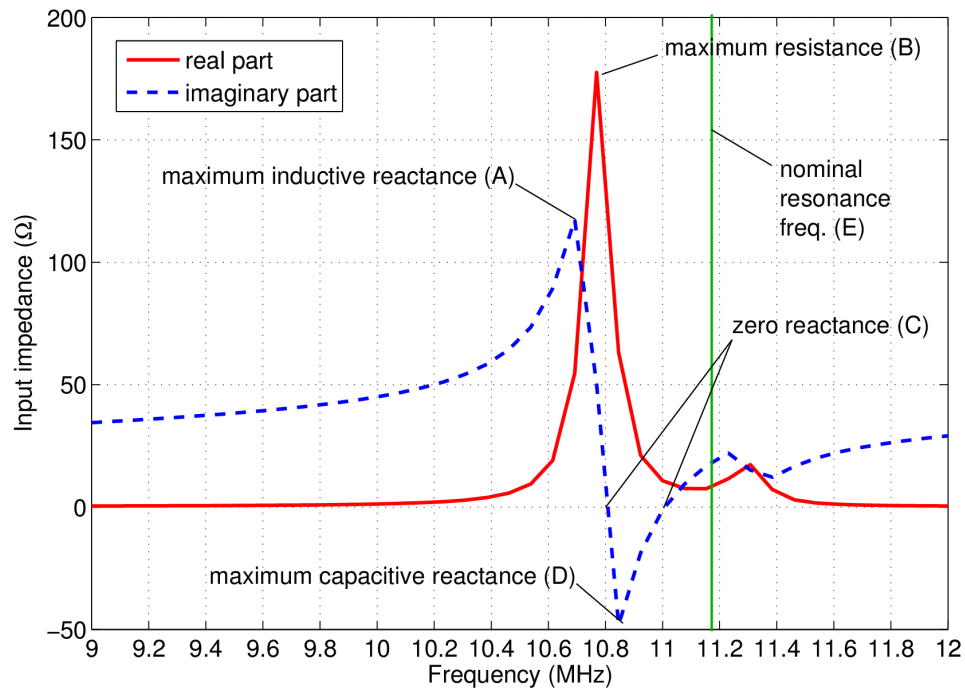


Felületi árameloszlás
(tengelyirányú komponens amplitúdója), mA/m

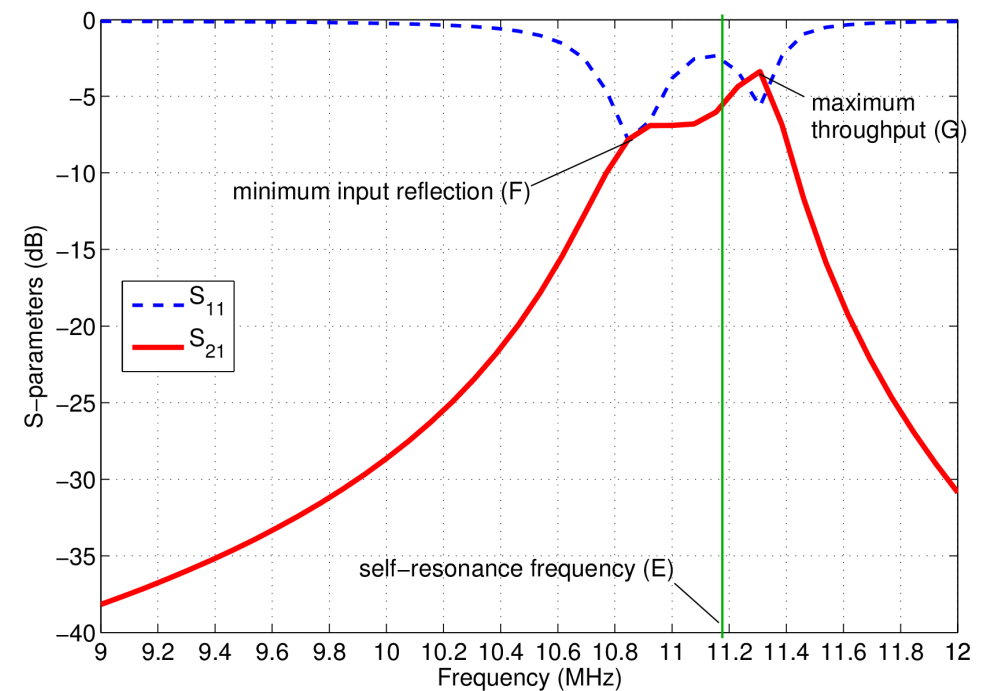




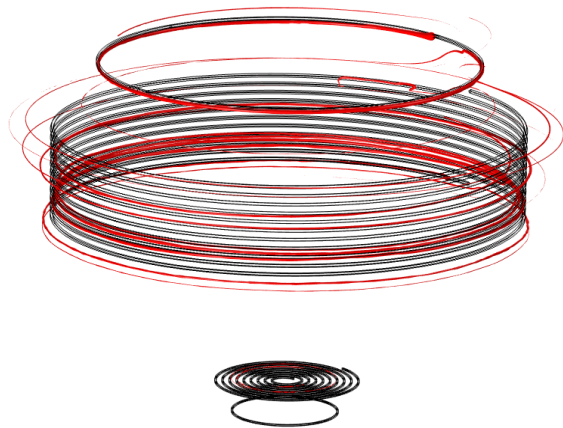
Bemeneti impedancia



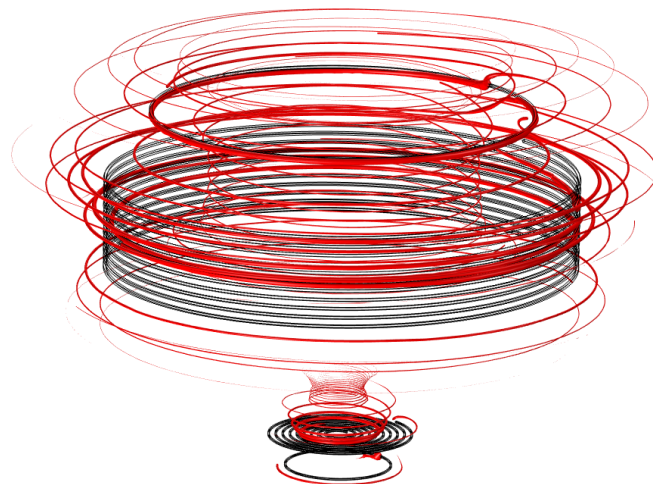
Szórási paraméterek



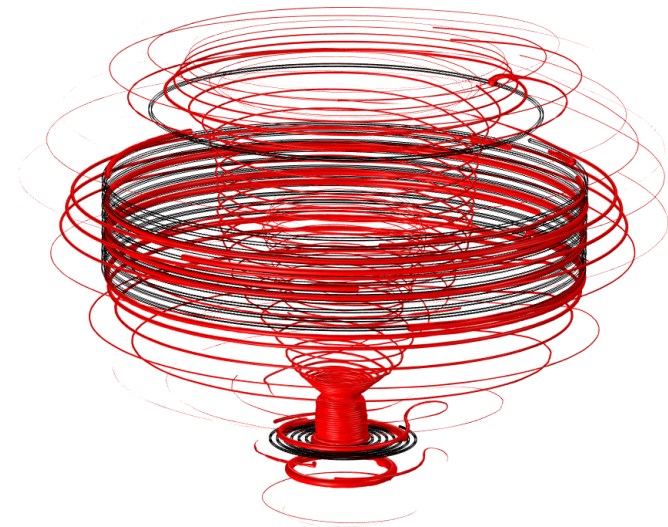
Teljesítményáramlás
(a komplex Poynting-vektor valós részének trajektóriái)



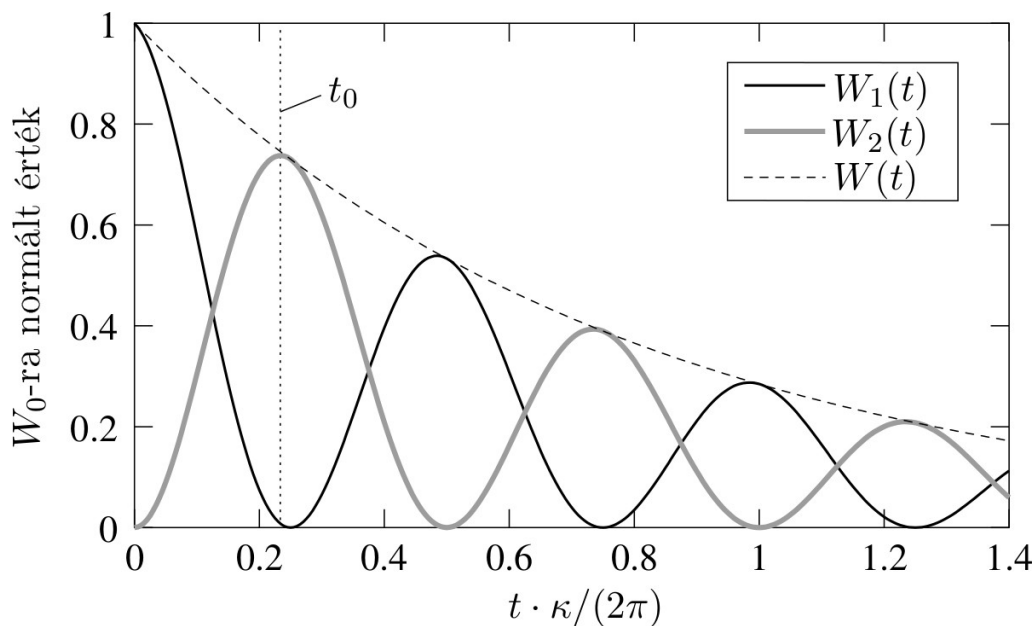
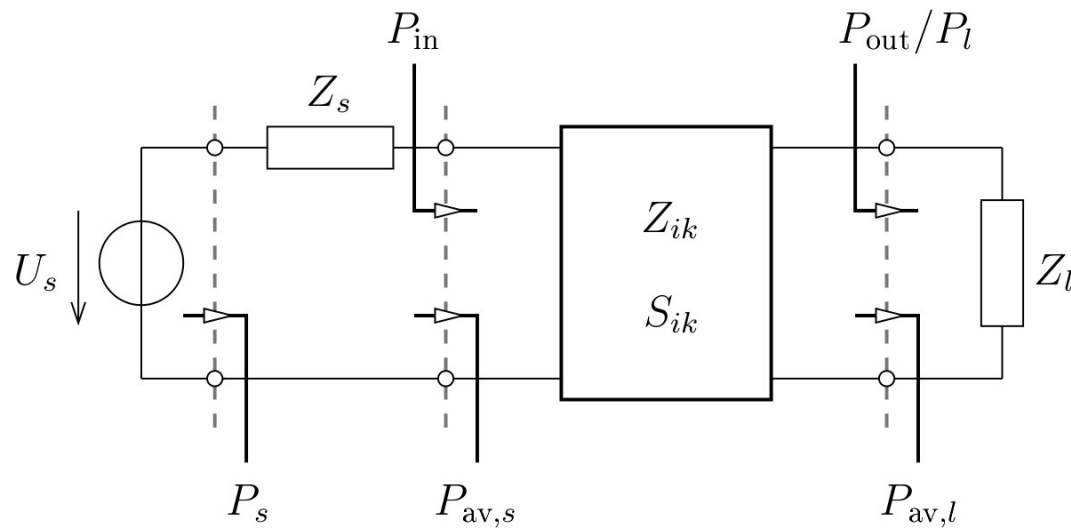
10,5 MHz



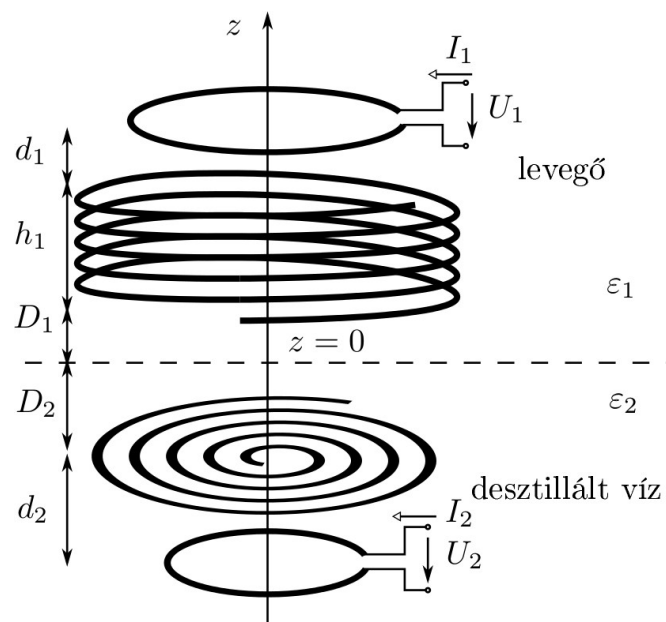
10,75 MHz



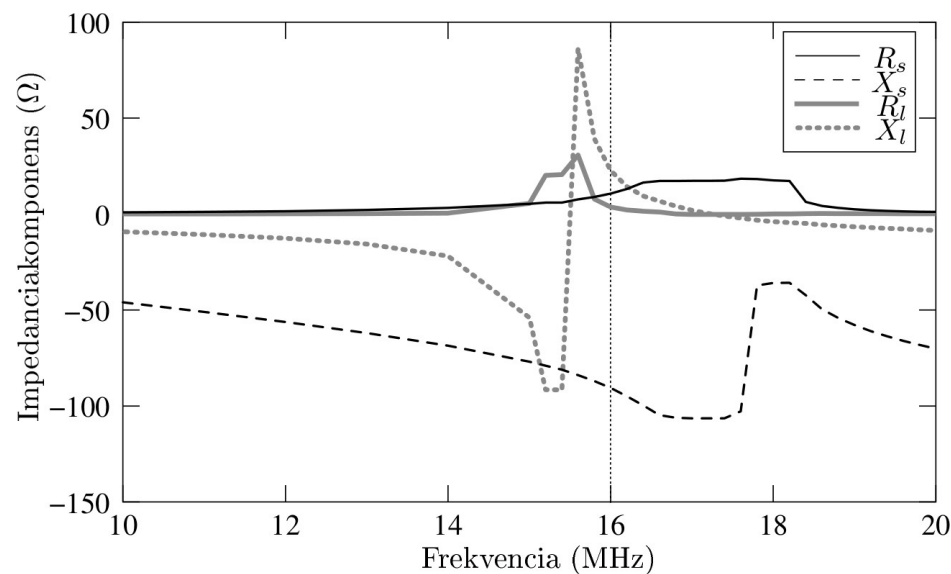
11,3 MHz



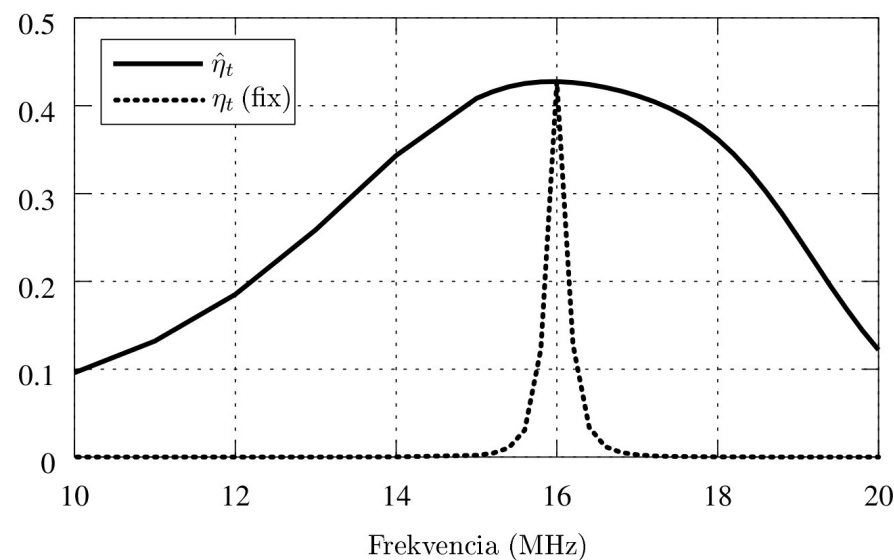
- Üzemi hatásfok $\eta_p = \frac{P_l}{P_{in}}$
- Átviteli hatásfok $\eta_t = \frac{P_l}{P_{av,s}}$
- Elérhető hatásfok $\eta_a = \frac{P_{av,l}}{P_{av,s}}$
- Teljes hatásfok $\eta = \frac{P_l}{P_s}$
- Tranziens hatásfok $\eta_0 = \frac{W_2(t_0)}{W_1(0)}$



Konjugált illesztést megvalósító impedanciák



Hatásfok adaptív és fix illesztés mellett



Adó	h_1	90 mm
	$\varnothing$ hélix	222 mm
	$\varnothing$ drót	1,5 mm
	$\varnothing$ hurok	222 mm
	d_1	30 mm
	D_1	100 mm
Vevő	$\varnothing$ spirál	4...78 mm
	$\varnothing$ drót	1 mm
	$\varnothing$ hurok	52 mm
	d_2	7 mm
	D_2	10 mm

- Csatolási tényező

$$k_L = \frac{M}{\sqrt{L_1 L_2}}$$

- Jósági tényezők

$$Q_1 = \frac{\omega_0 L_1}{R_1}, \quad Q_2 = \frac{\omega_0 L_2}{R_2}$$

- Jósági szám (figure of merit)

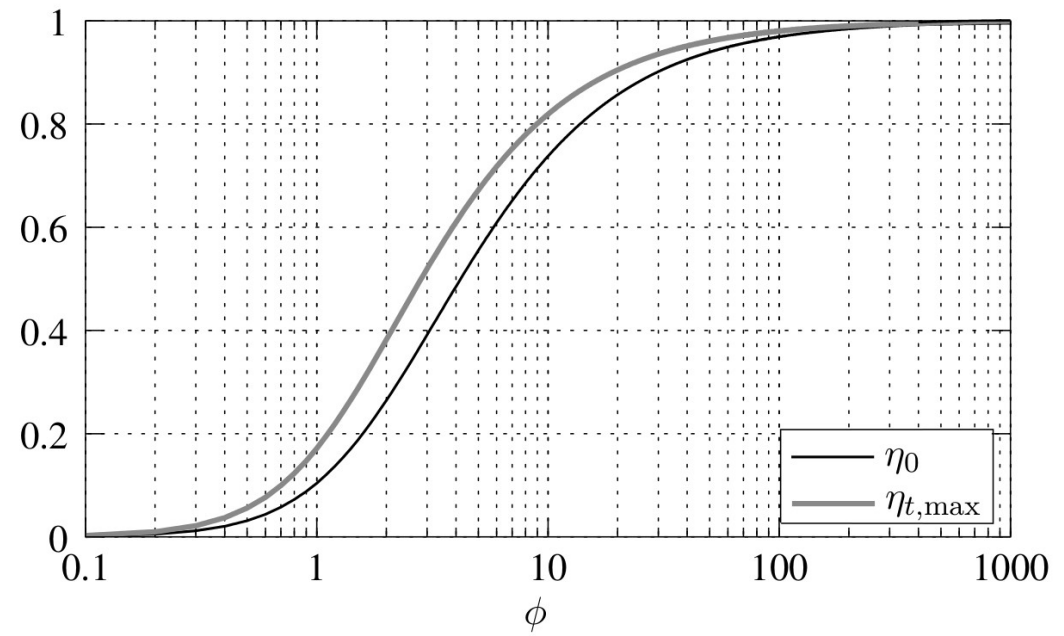
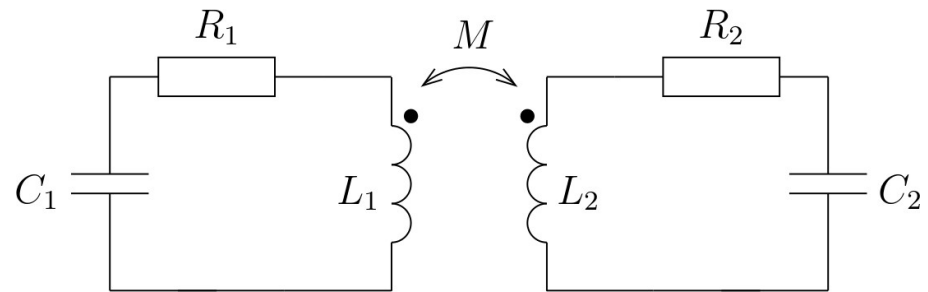
$$\phi = 2k\sqrt{Q_1 Q_2}$$

- Hatásfok

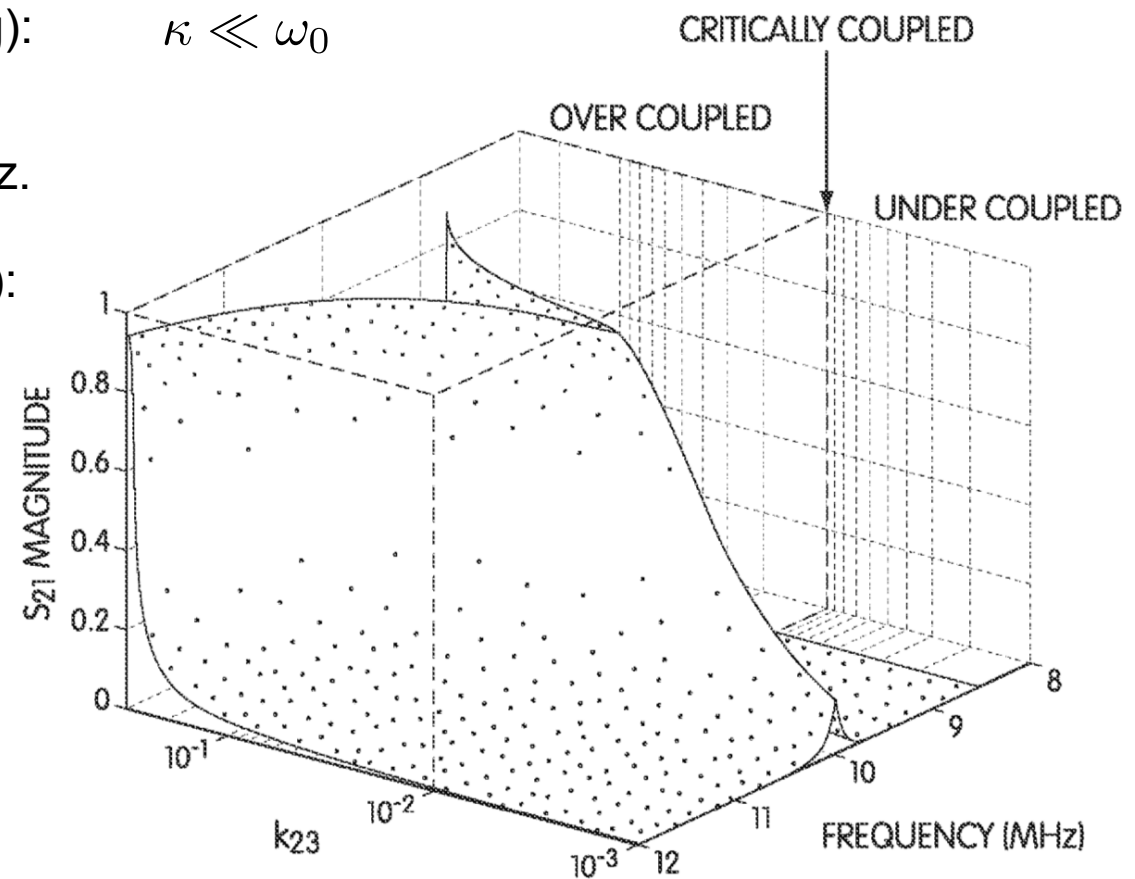
$$\eta_{t,\max} = 1 + 2 \frac{1 - \sqrt{\phi^2 + 1}}{\phi^2}$$

$$\eta_0 = \frac{\phi^2}{1 + \phi^2} \cdot \exp\left(-2 \frac{\arctan \phi}{\phi}\right)$$

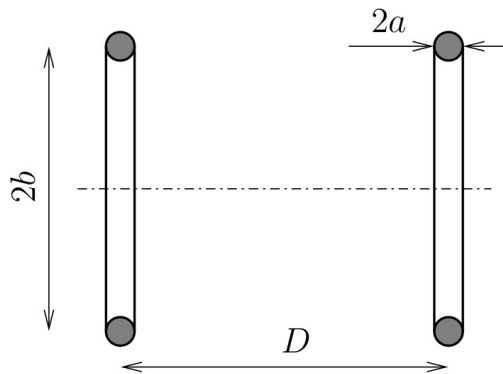
$$|S_{21}|^2 = \left[\frac{\phi}{1 + \sqrt{1 + \phi^2}} \right]^2$$



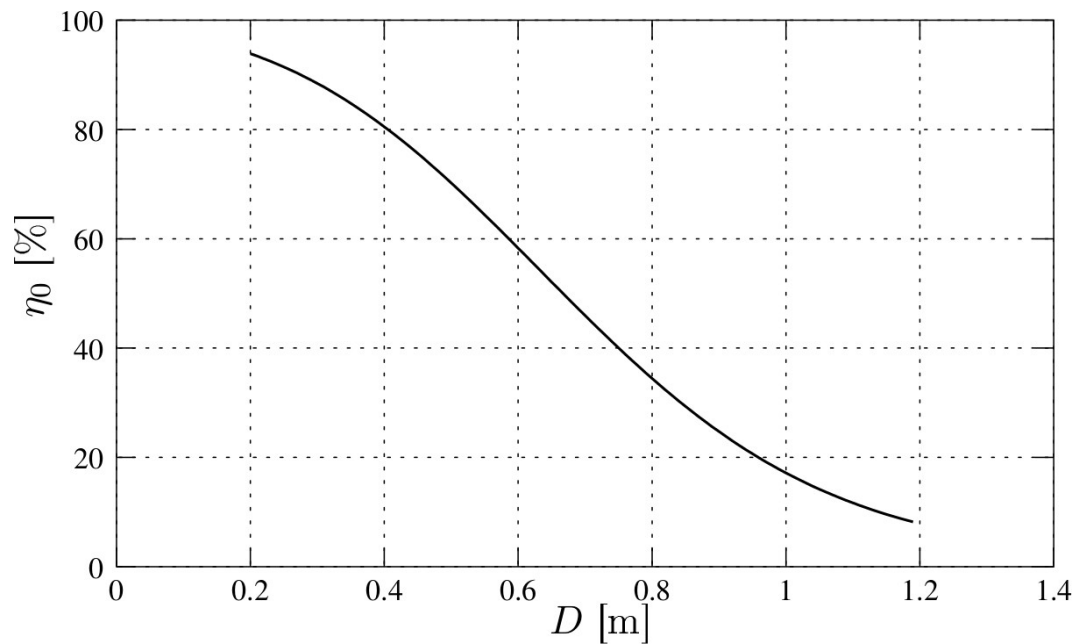
- szoros csatolás (tight coupling): $k \approx 1$
- laza csatolás (loose coupling): $k \ll 1$
- gyenge csatolás (weak coupling): $\kappa \ll \omega_0$
- túl-, alul- és kritikusan csatolt rsz.
(over / under / critically coupled):



forrás: WO 2012/045050



a	2 mm
b	20 cm
D	20 – 120 cm
σ_{Cu}	57 MS/m
C	470 pF
Q_C	3000



Jellemző	Érték	Megnevezés
L	1,18 μH	hurok önindukciós együtthatója
C	470 pF	kondenzátor kapacitása
M	98,8 nH	kölcsönös indukciós együttható
R	68,5 m Ω	vezeték ellenállása (egy hurokra)
R_s	0,13 m Ω	sugárzási ellenállás (egy hurokra)
f	6,78 MHz	rezonanciafrekvencia
ω_0	42,6 Mrad/s	rezonancia-körfrekvencia
λ	44,2 m	szabadtéri hullámhossz
δ	25,6 μm	behatolási mélység rézben
k_{ind}	0,084	hurkok csatolási tényezője
κ	1,79 Mrad/s	CMT csatolási együttható
Q_L	730	hurok jósági tényezője
Q_C	3000	kondenzátor jósági tényezője
Q_0	587	eredő „belső” jósági tényező
Γ_0	0,036 Mrad/s	CMT „belső” csillapítási együttható
ϕ	49,3	CMT jósági szám (figure of merit)
η_0	94 %	transziens hatásfok

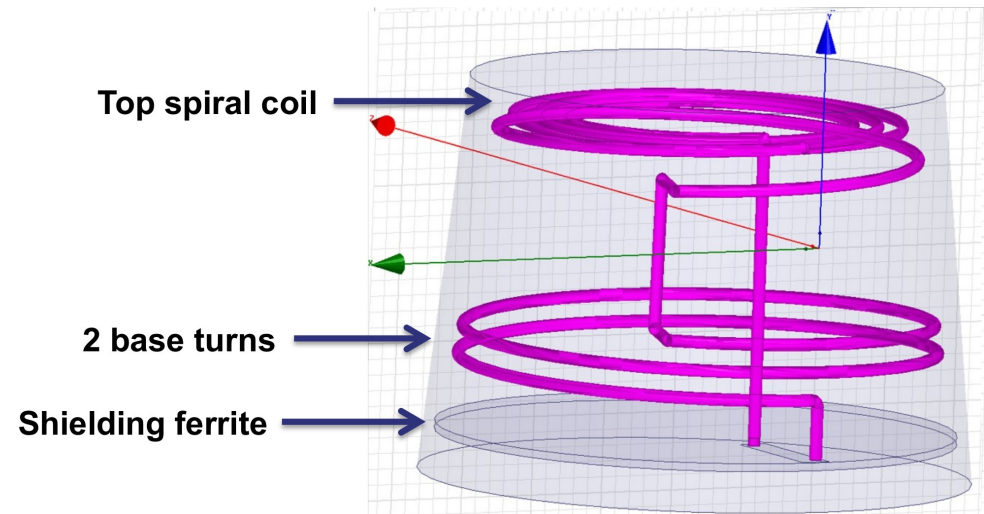
Alkalmazások



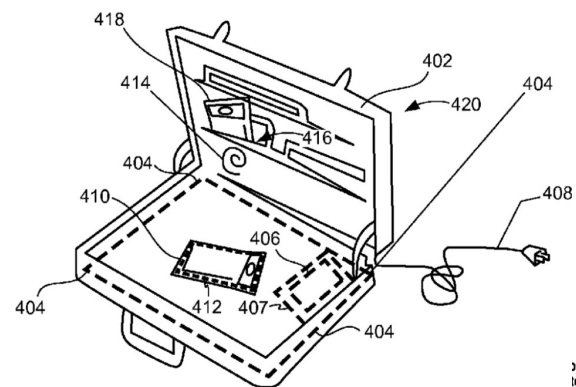
napipiac.unas.hu



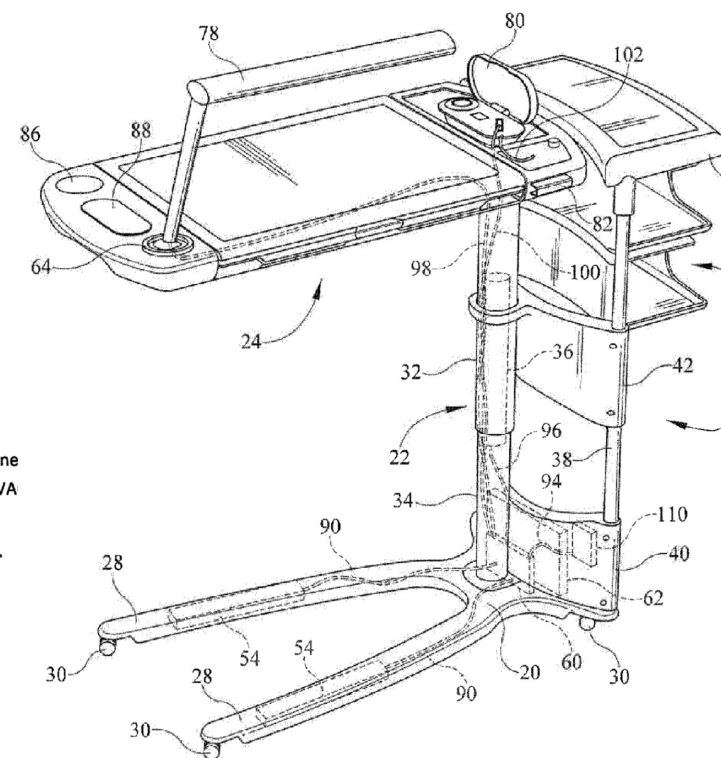
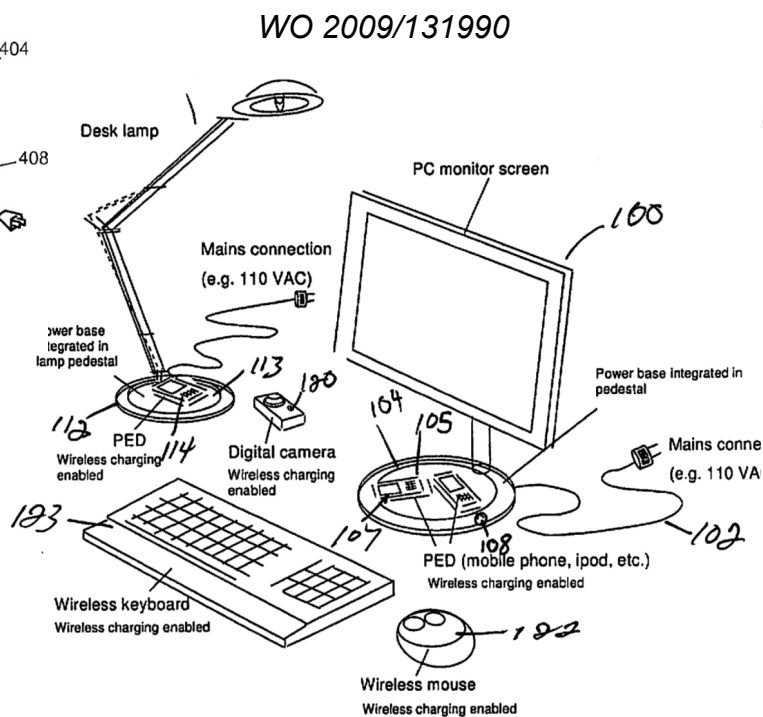
www.tylt.com



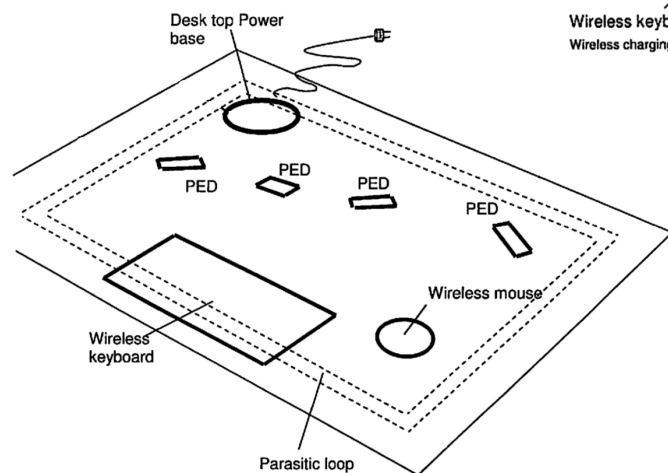
forrás: Jenshan Lin: "A Perspective on Far-Field and Near-Field Wireless Power Transfer"



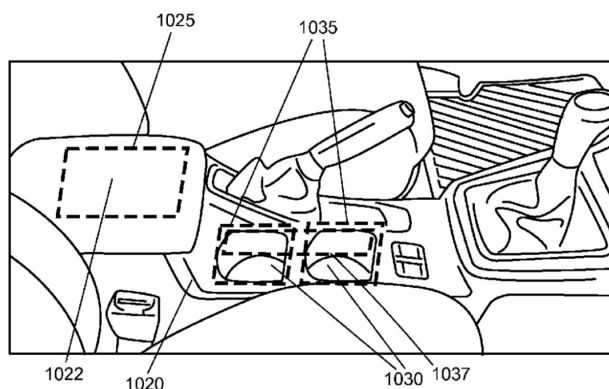
WO 2010/093728



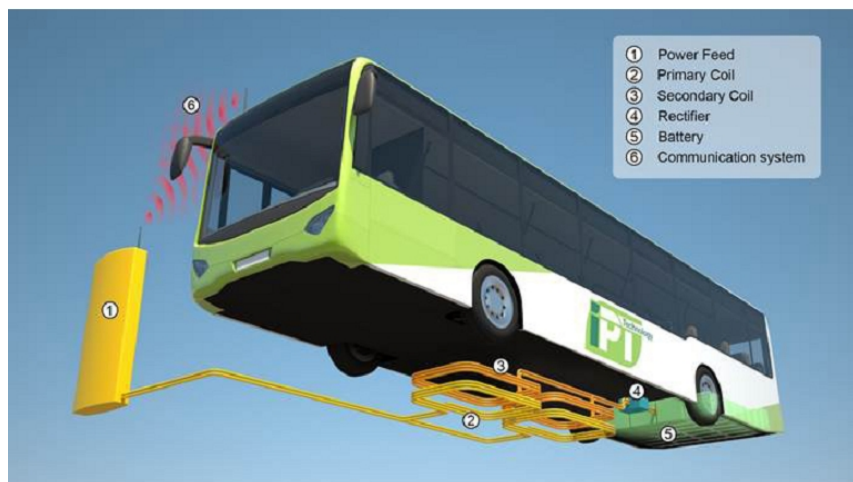
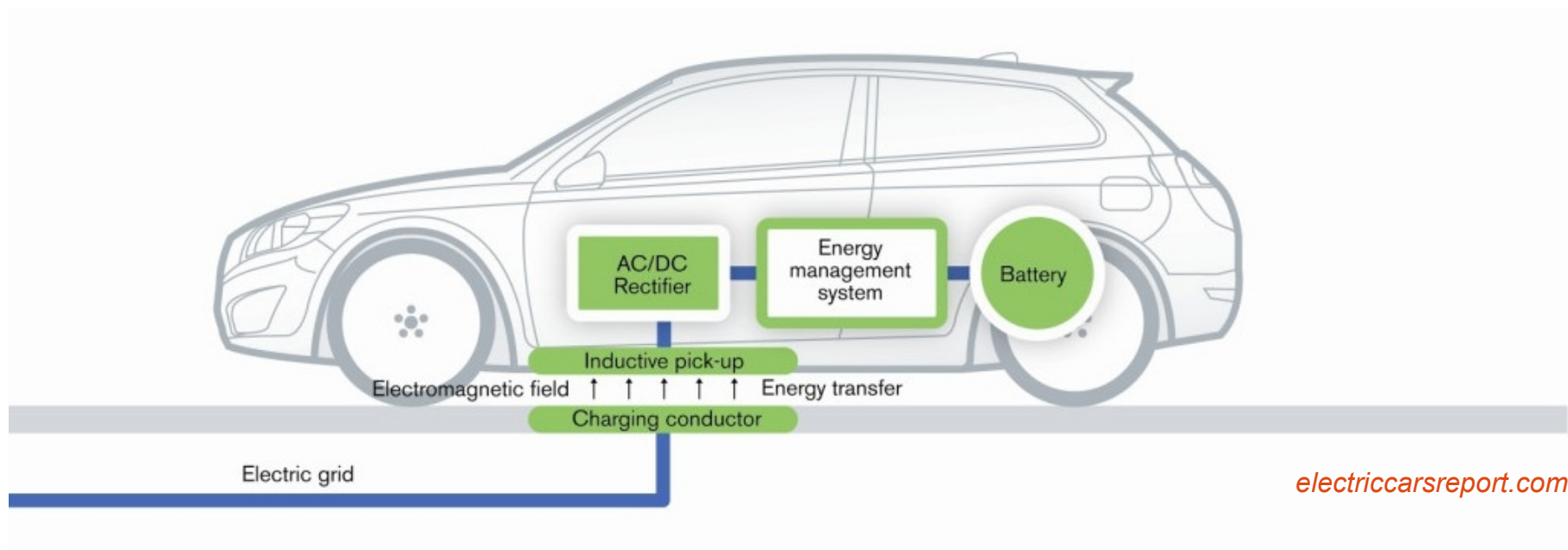
EP 2 533 394



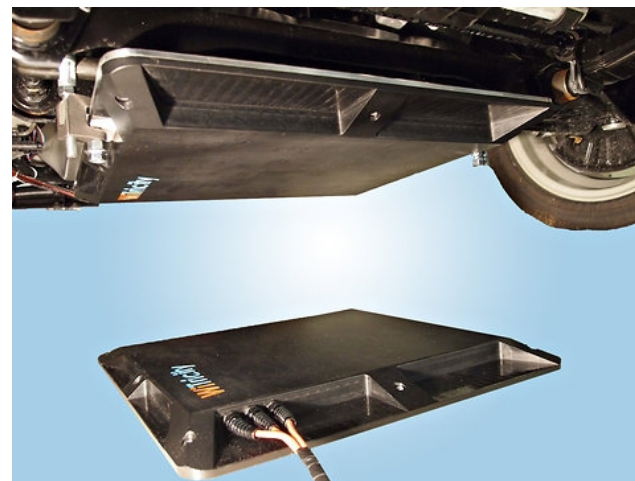
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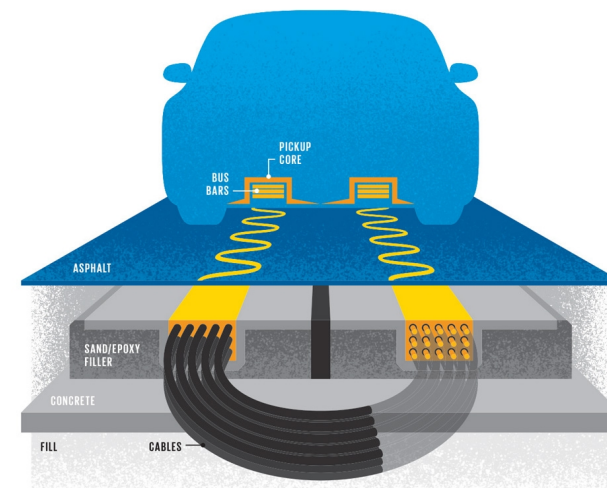
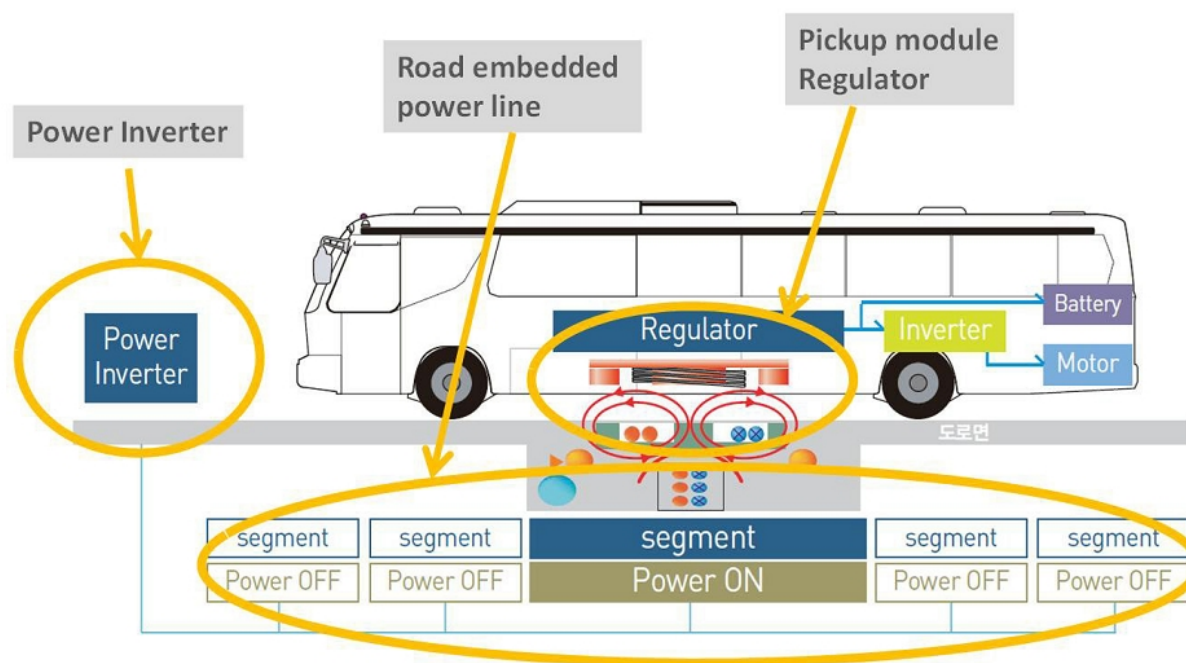
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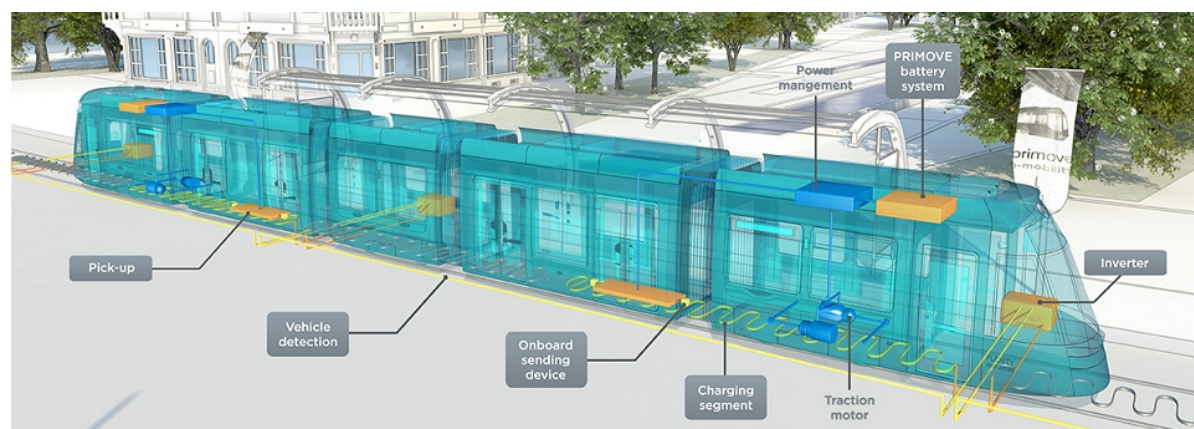
Conductix-Wampfler



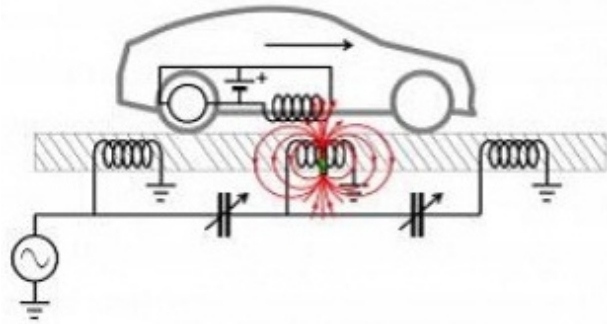
WiTricity



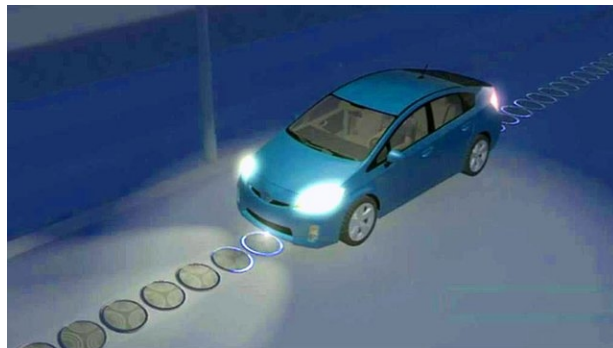
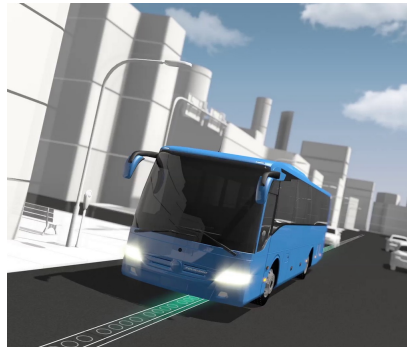
KAIST – OLEV



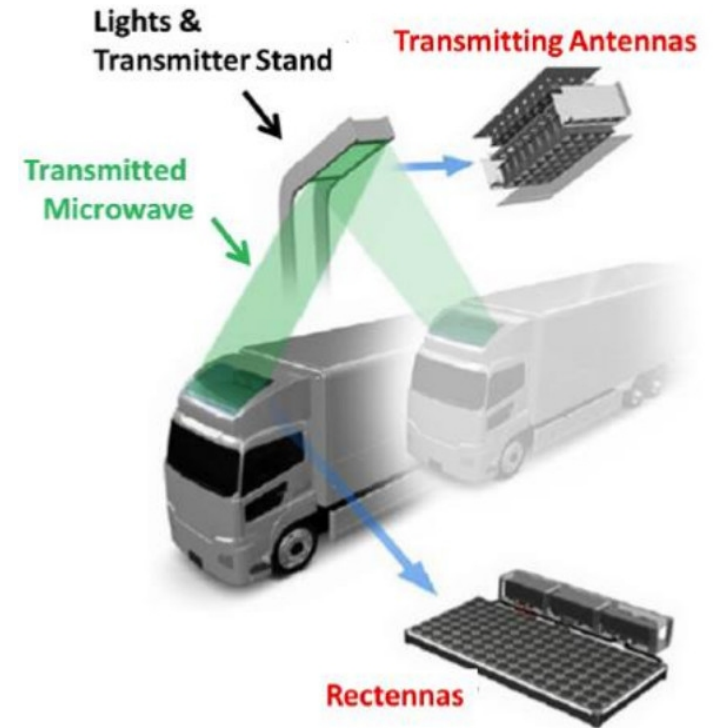
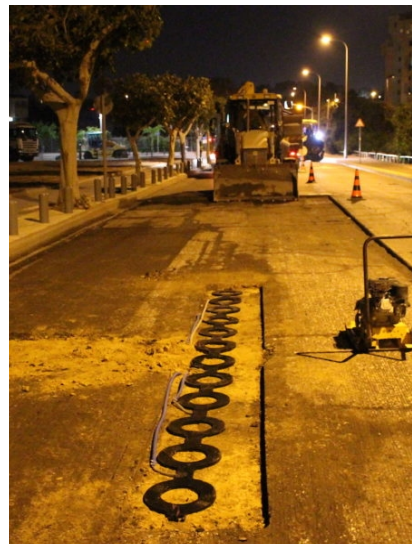
Bombardier – Primove



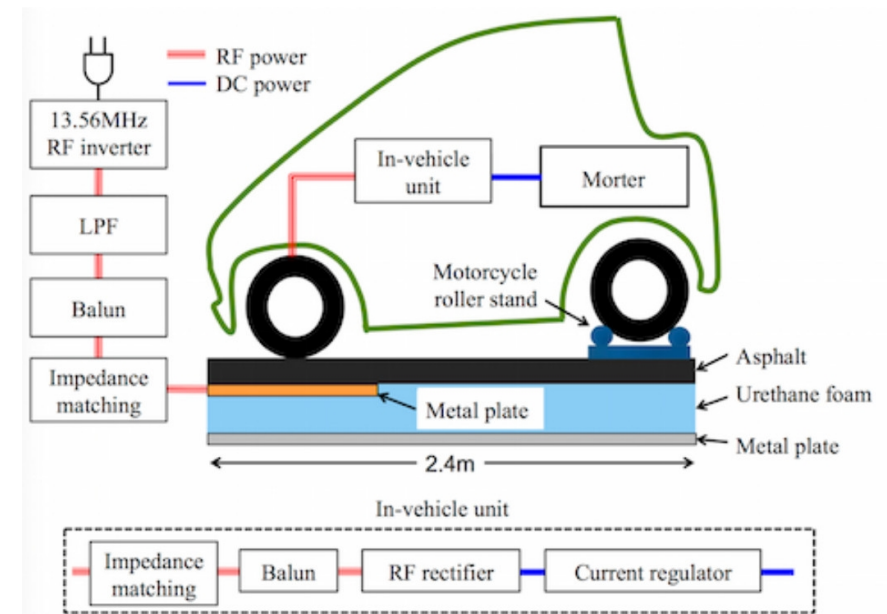
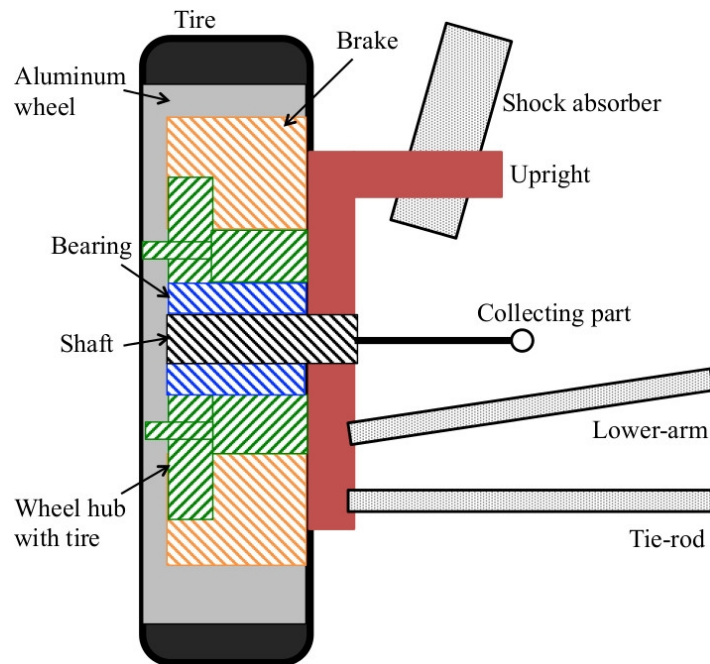
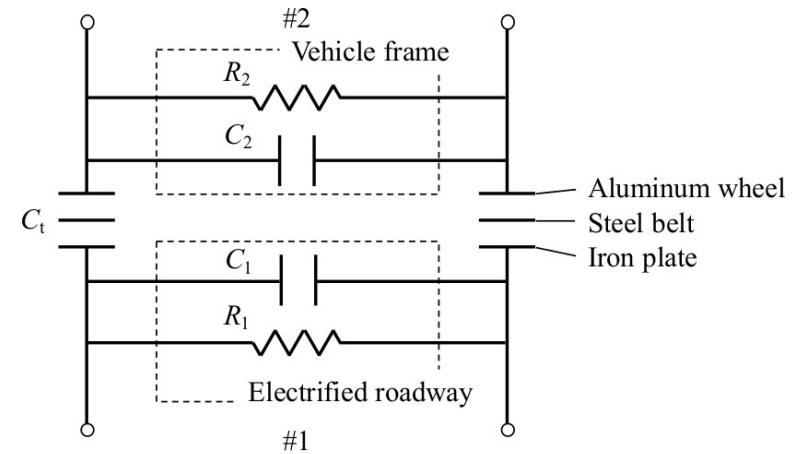
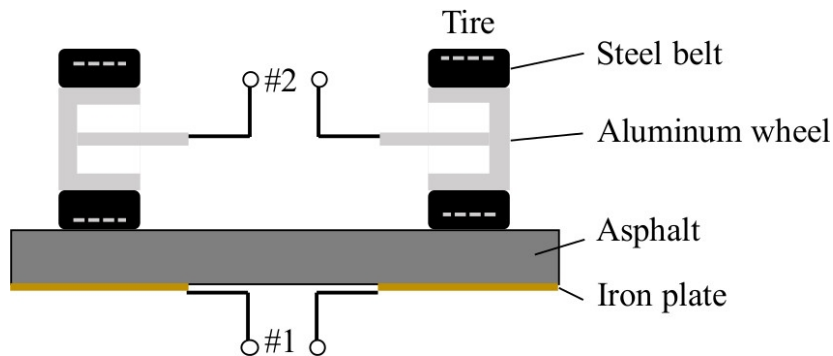
Electroad DWPT



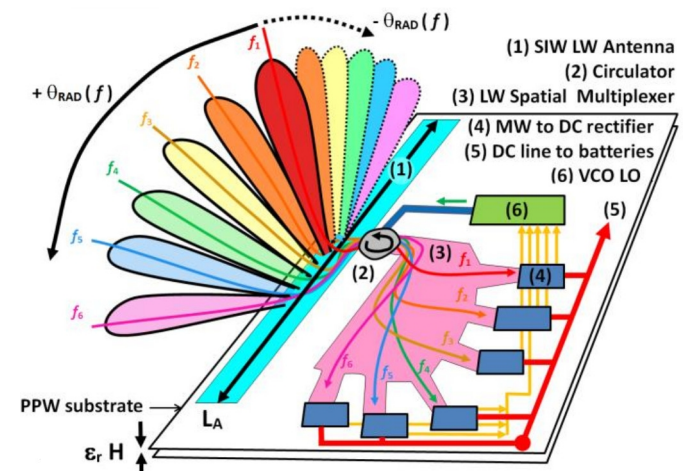
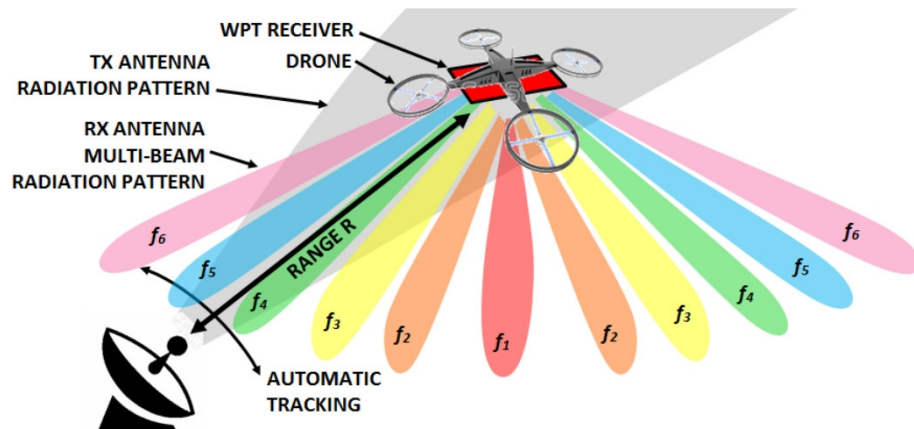
Stanford University



Kyoto University, ATR

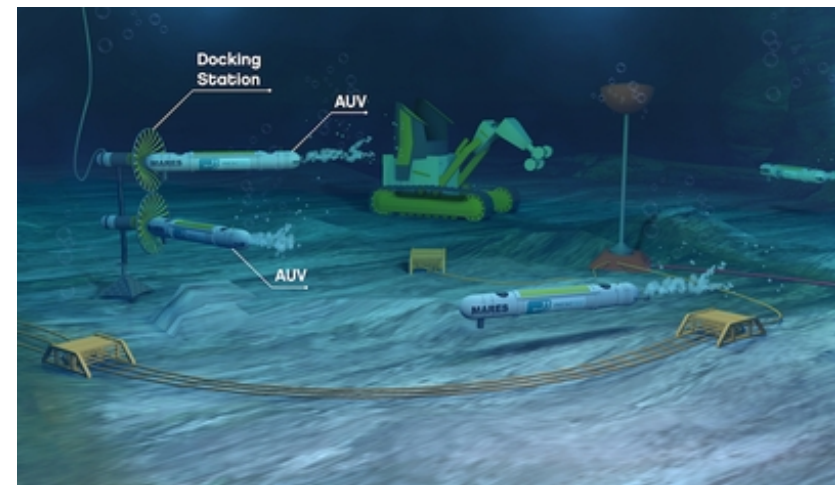
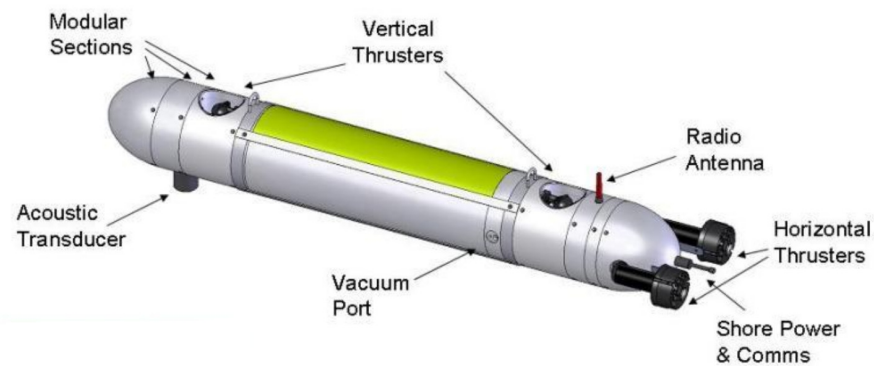


Toyohashi University of Technology (kapacitív)

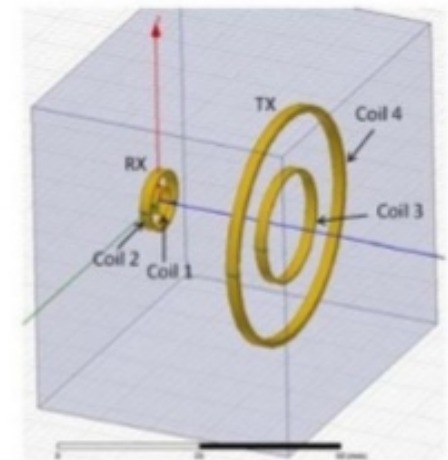
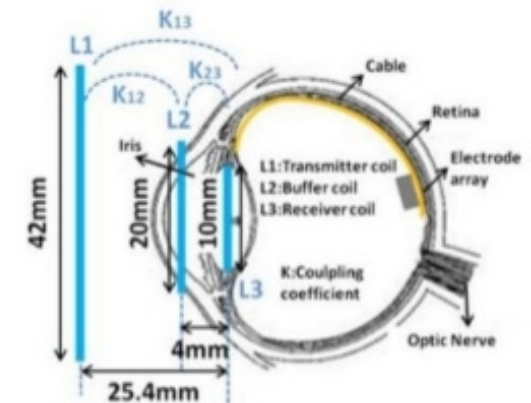
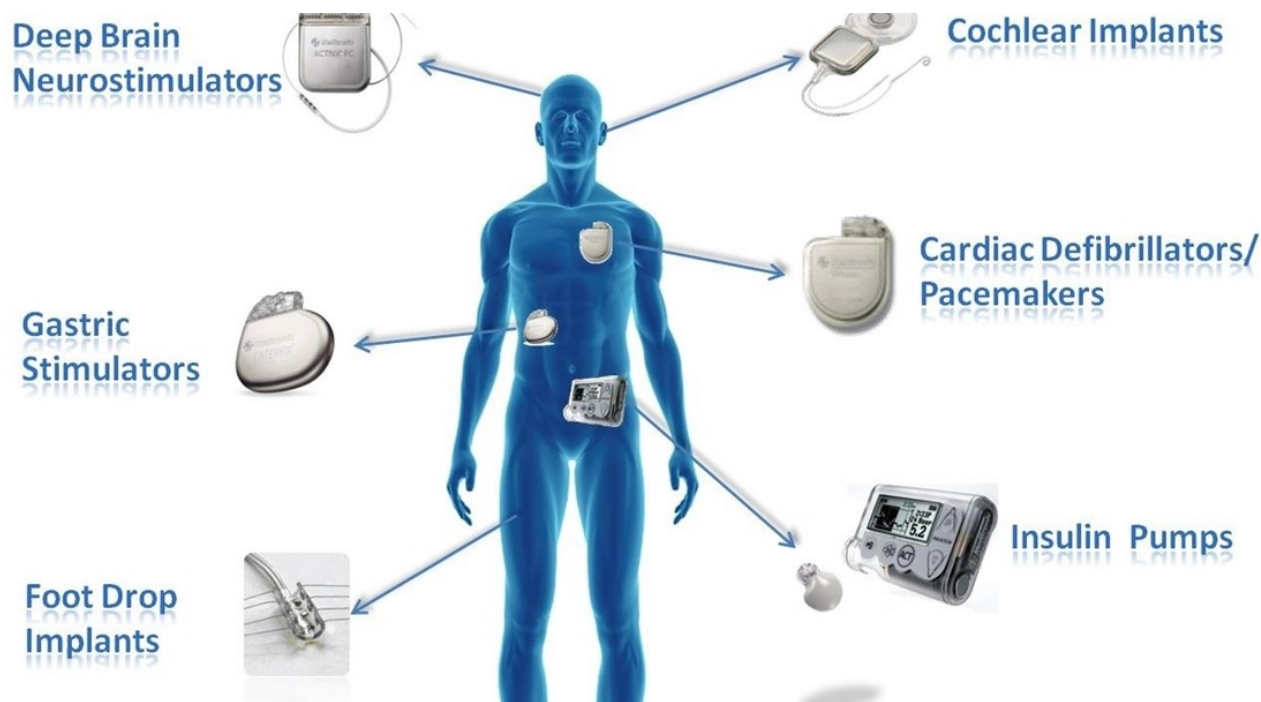


Technical University of Cartagena

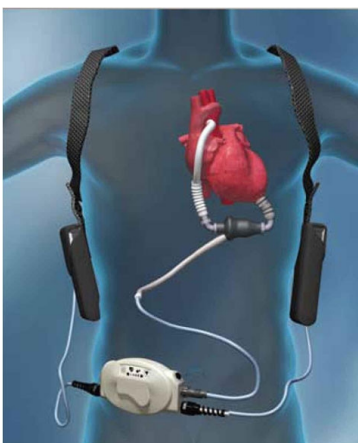
MARES Autonomous Underwater Vehicle



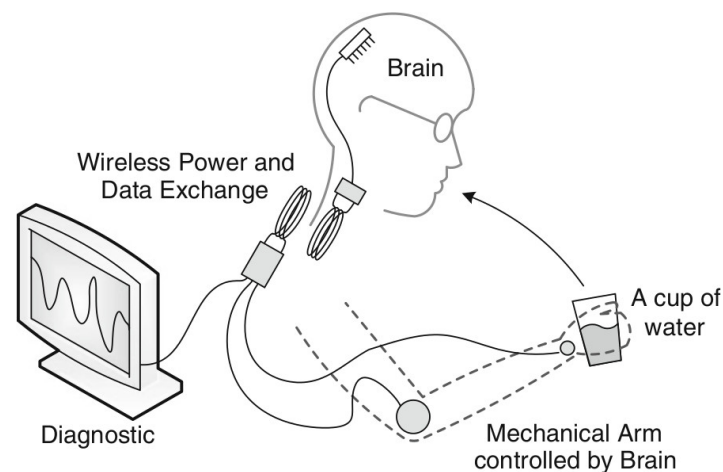
INESTEC

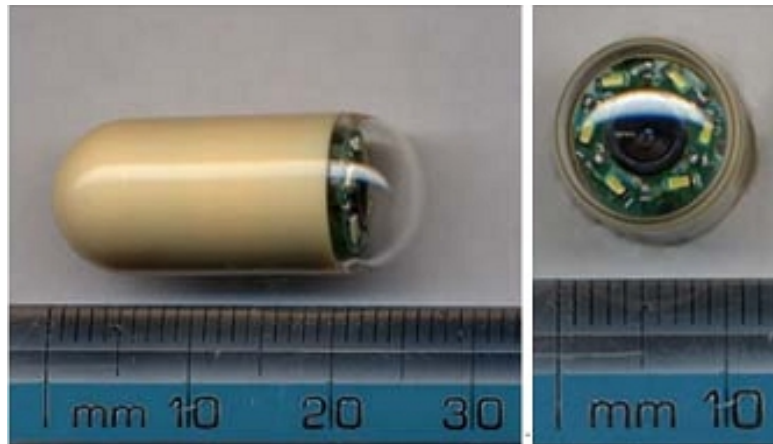


Jai Han, Chieh Chan 2012

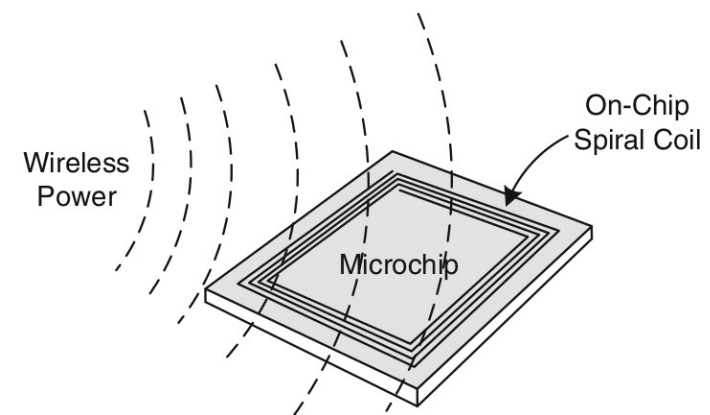
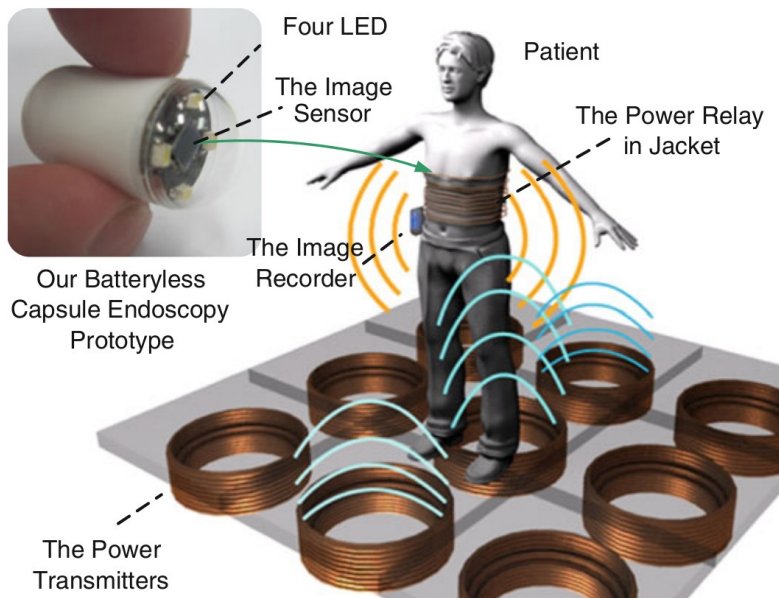
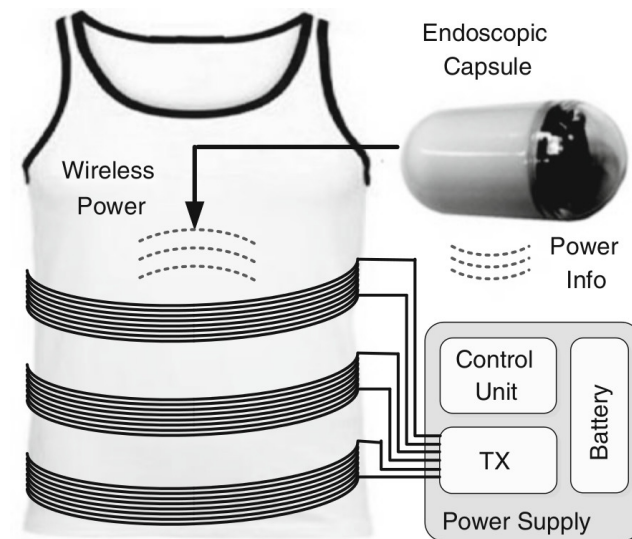


heartmateii.com





endoszkóp-kapszula



lab-on-a-chip koncepció

A képek forrása: T. Sun, X. Xie, Z. Wang, *Wireless Power Transfer for Medical Microsystems*, Springer, 2013

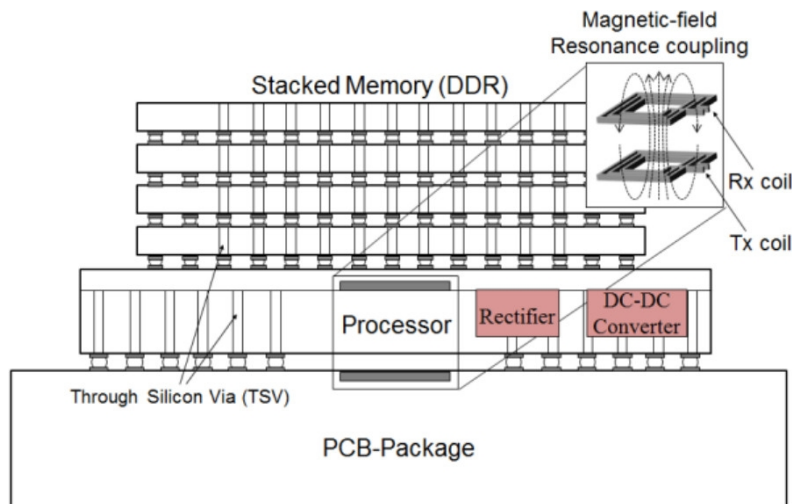


<http://www.cerdec.army.mil>



mil-embedded.com

PCB és chip közötti energiaátvitel

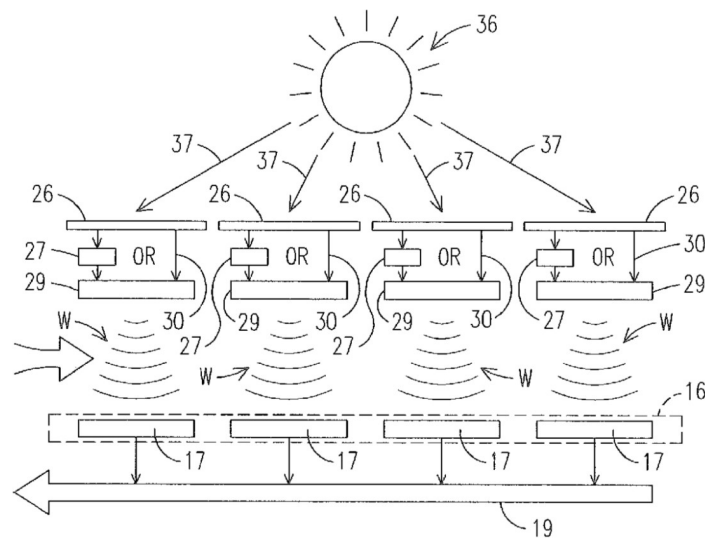


J. Song et al, KAIST

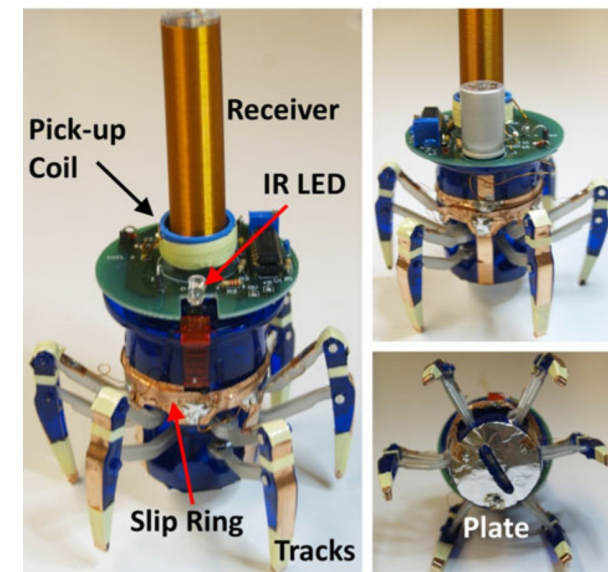
robotok táplálása



napelemes tetőcserép energiacseréje

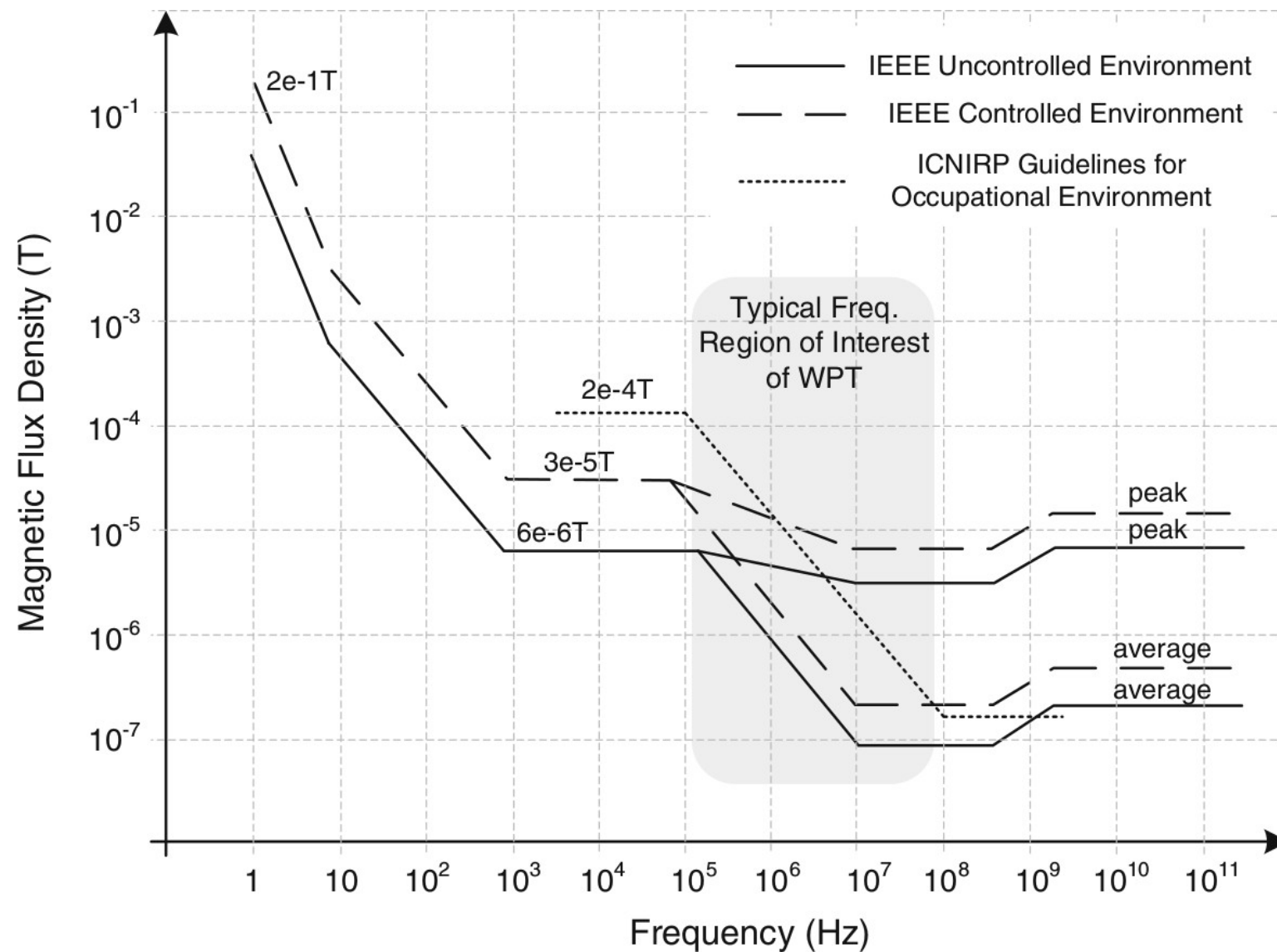


WO 2013/112248

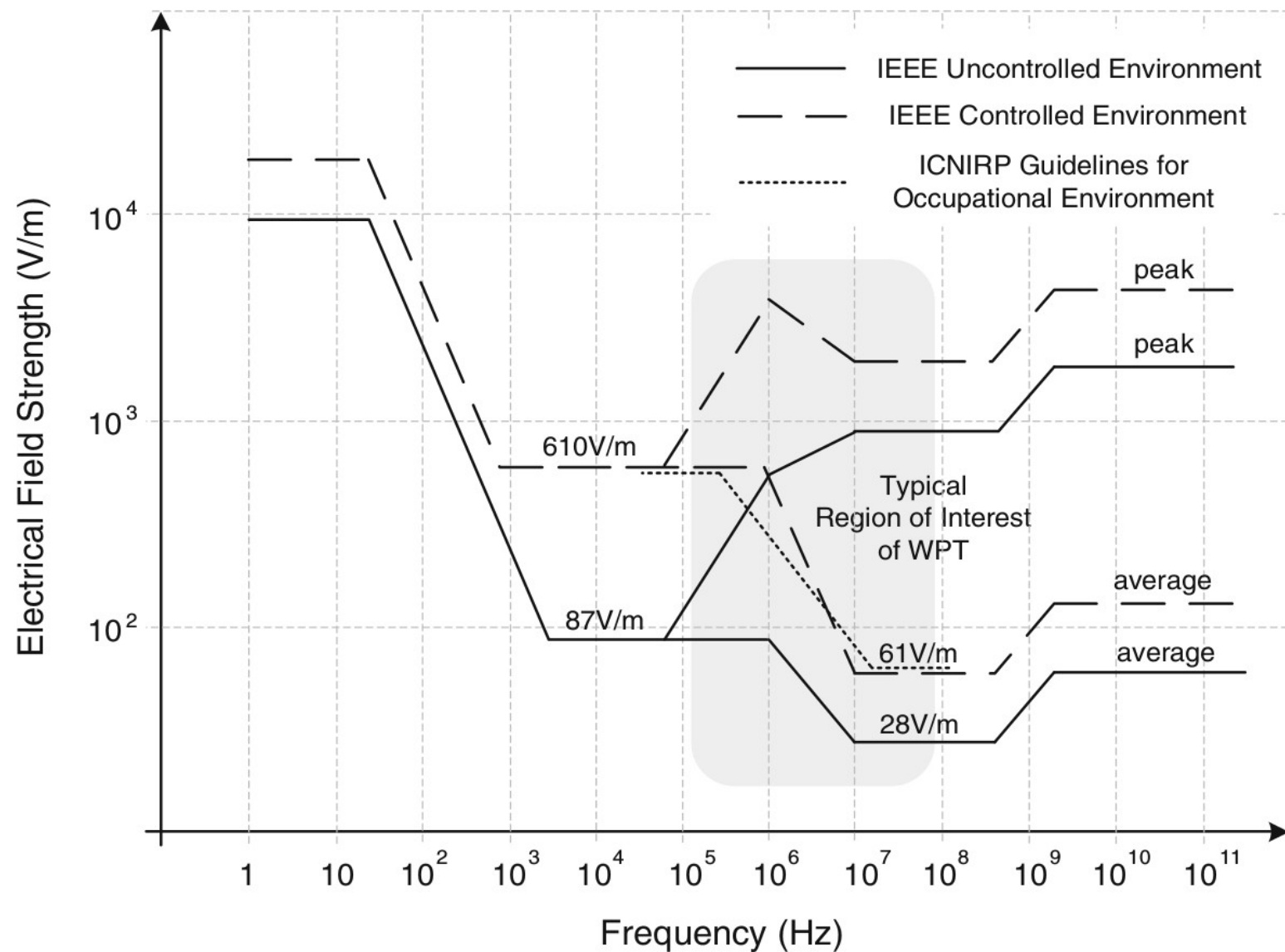


Van Neste et al, University of Alberta

Kockázatok és korlátok

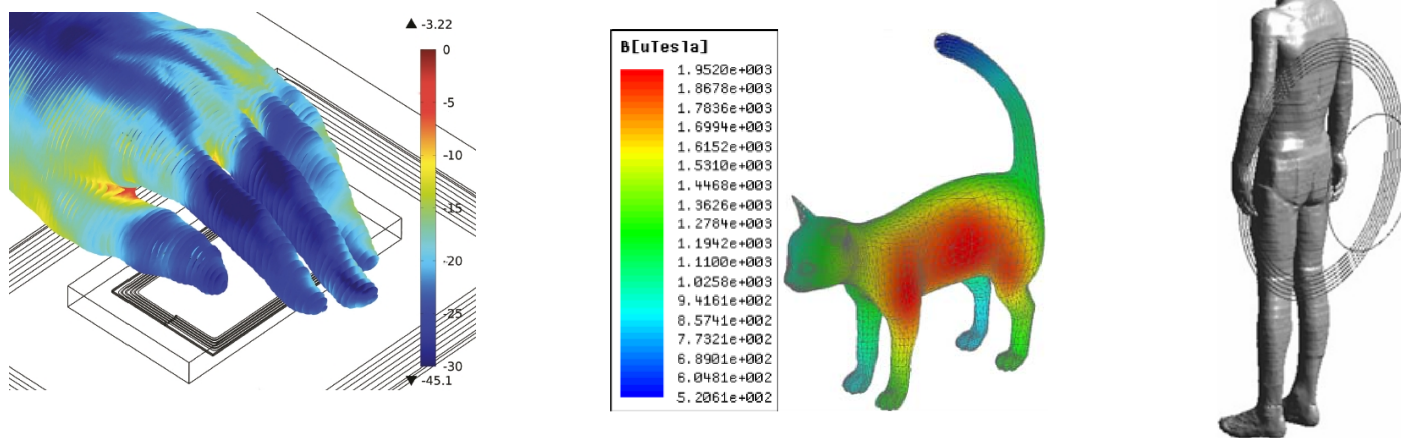
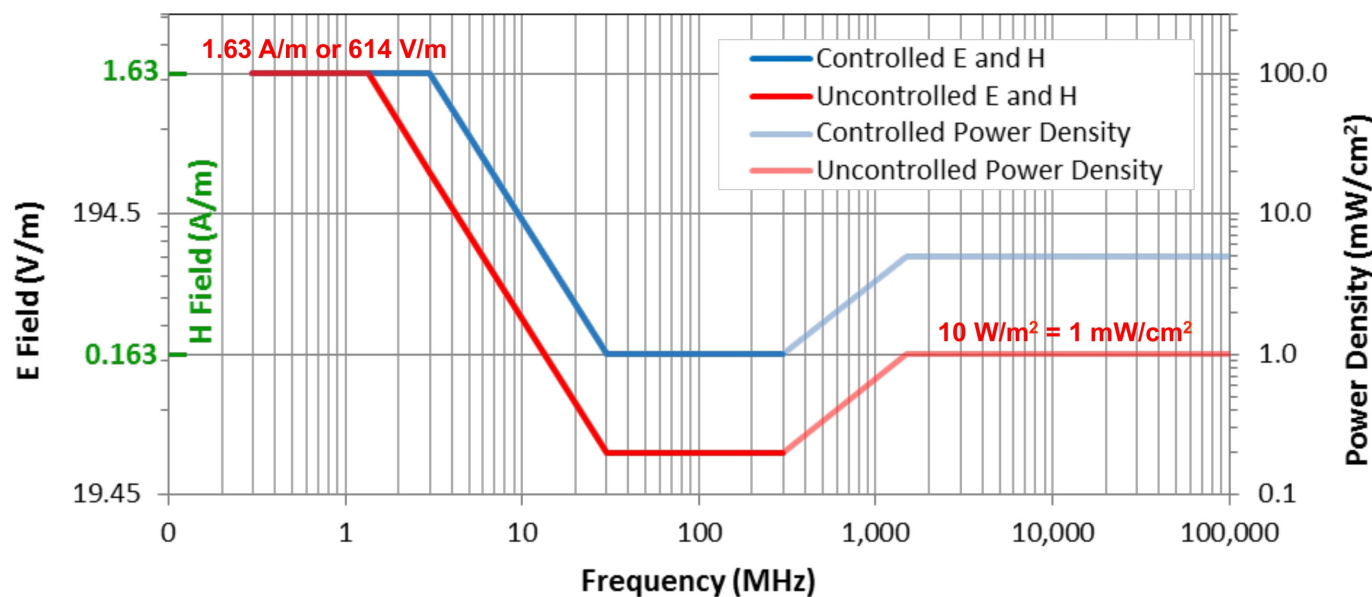


Forrás: T. Sun, X. Xie, Z. Wang, *Wireless Power Transfer for Medical Microsystems*, Springer, 2013



Forrás: T. Sun, X. Xie, Z. Wang, *Wireless Power Transfer for Medical Microsystems*, Springer, 2013

RF Safety 2013 (FCC 13-39)



A képek forrásai: Jenshan Lin; Comsol; A. Christ et al IEEE T Electromagn Compat 2013

ISM frekvencia sáv MHz	sávközépi frekvencia MHz	megj.
6,765 – 6,795	6,780	b
13,553 – 13,567	13,560	a
26,957 – 27,283	27,120	a
40,66 – 40,70	40,68	a
433,05 – 434,79	433,92	b
2400 – 2500	2450	a
5725 – 5875	5800	a
24 000 – 24 250	24 125	a
61 000 – 61 500	61 250	b
122 000 – 123 000	122 500	b
244 000 – 246 000	245 000	b

Standard	Operating frequency
Qi	110-300 kHz
AirFuel/Rezence/A4WP	6.78 MHz

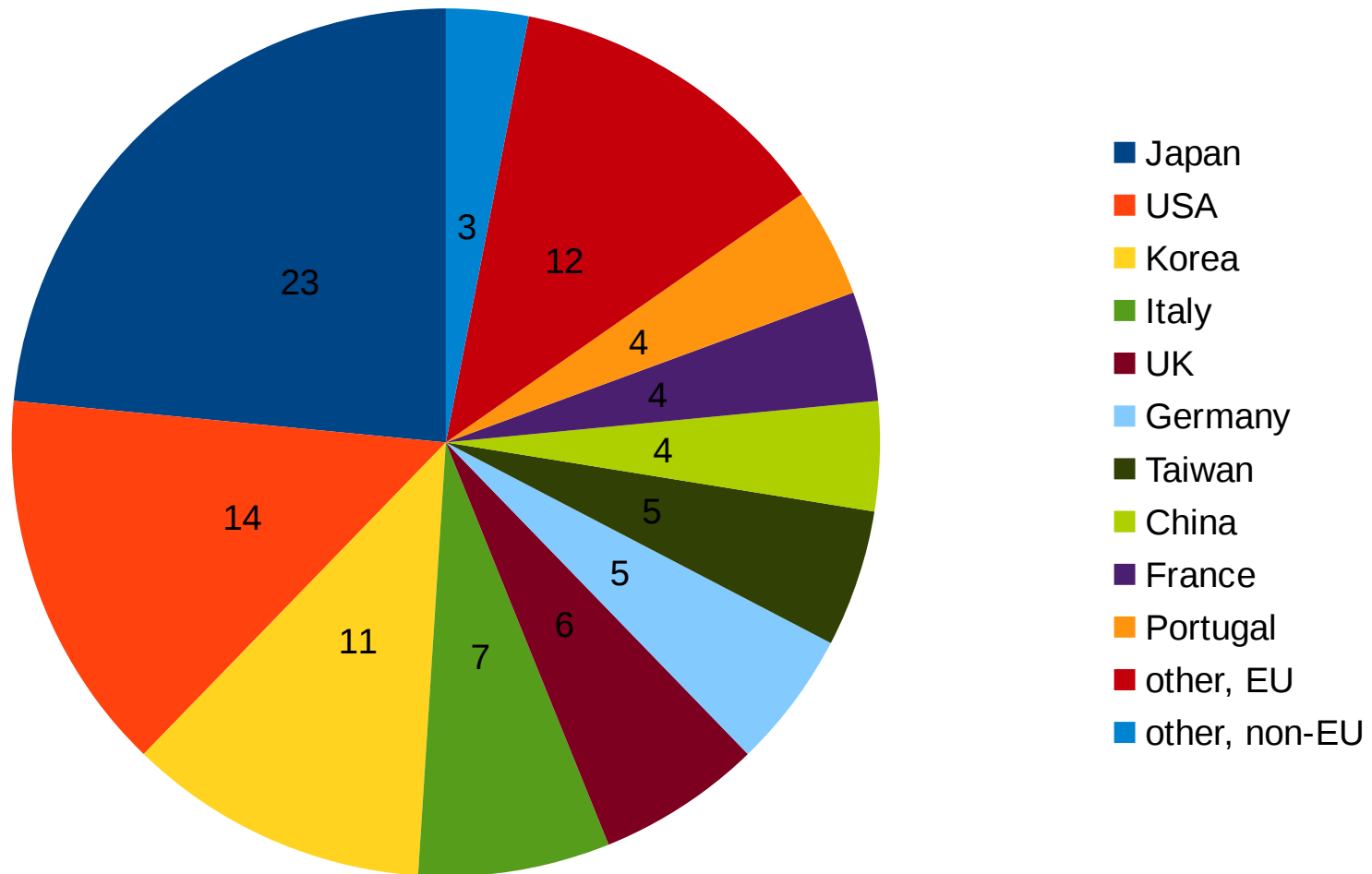
Company	Operating frequency
WiTricity [15, 16]	145 kHz
Qualcomm Halo [9, 21]	20 kHz
Conductix-Wampfler [23]	N/A
Bombardier [25, 32]	N/A
Momentum Dynamics [15, 29]	N/A
HEVO Power [30, 31]	85 kHz

University/Institution	Operating frequency
KAIST [10]	20 kHz
Utah State University (WAVE) [15, 40]	N/A
ORNL [41]	N/A
University of Auckland [42]	N/A
Setsunan University [43]	1.20–2.45 GHz
Tokohu University [44]	360 kHz
Utah State University [45]	N/A
University of Tokyo/WiTricity [6, 46–48]	13.56 MHz
Saitama University [52]	30 kHz
University of British Columbia [53]	150 Hz

Források: Máta G. Magyar Tudomány 2002; T.M. Fisher et al, Wireless Power Transfer 2014.

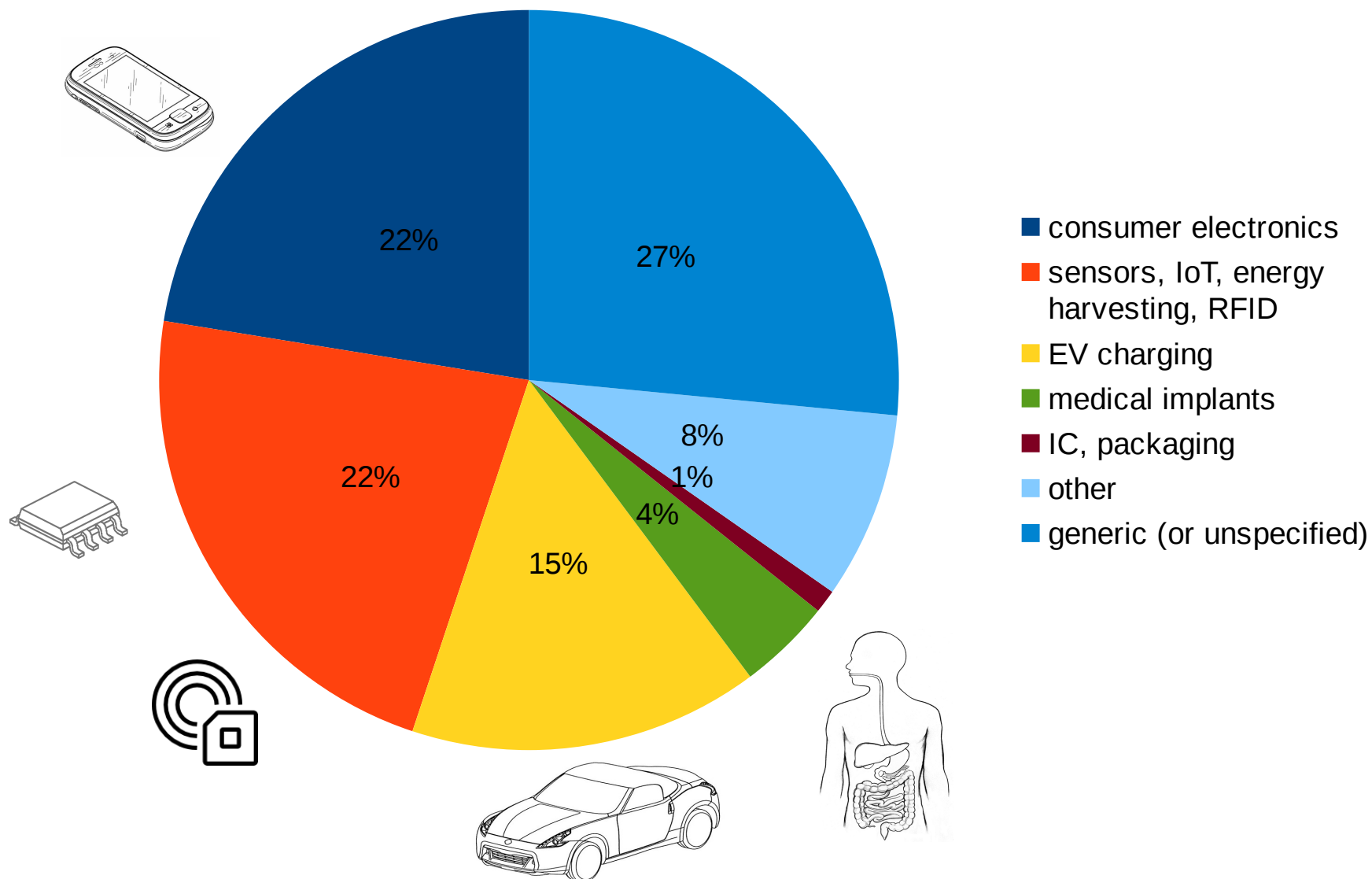
A fejlődés fő irányvonalai

A kutatás földrajzi megoszlása*



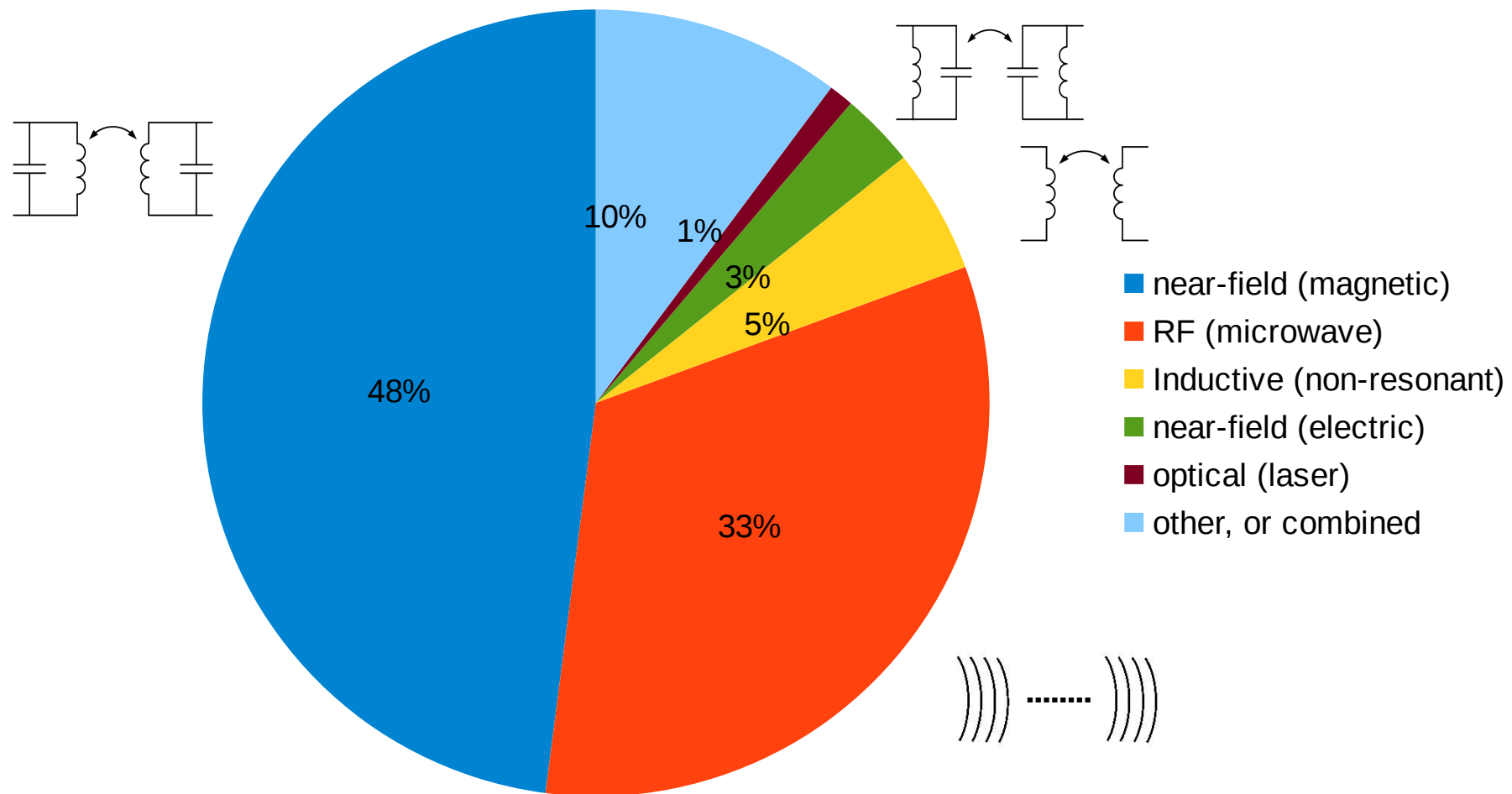
* a WPTC 2016 konferencia statisztikája

A kutatás intenzitása alkalmazási terület szerint*



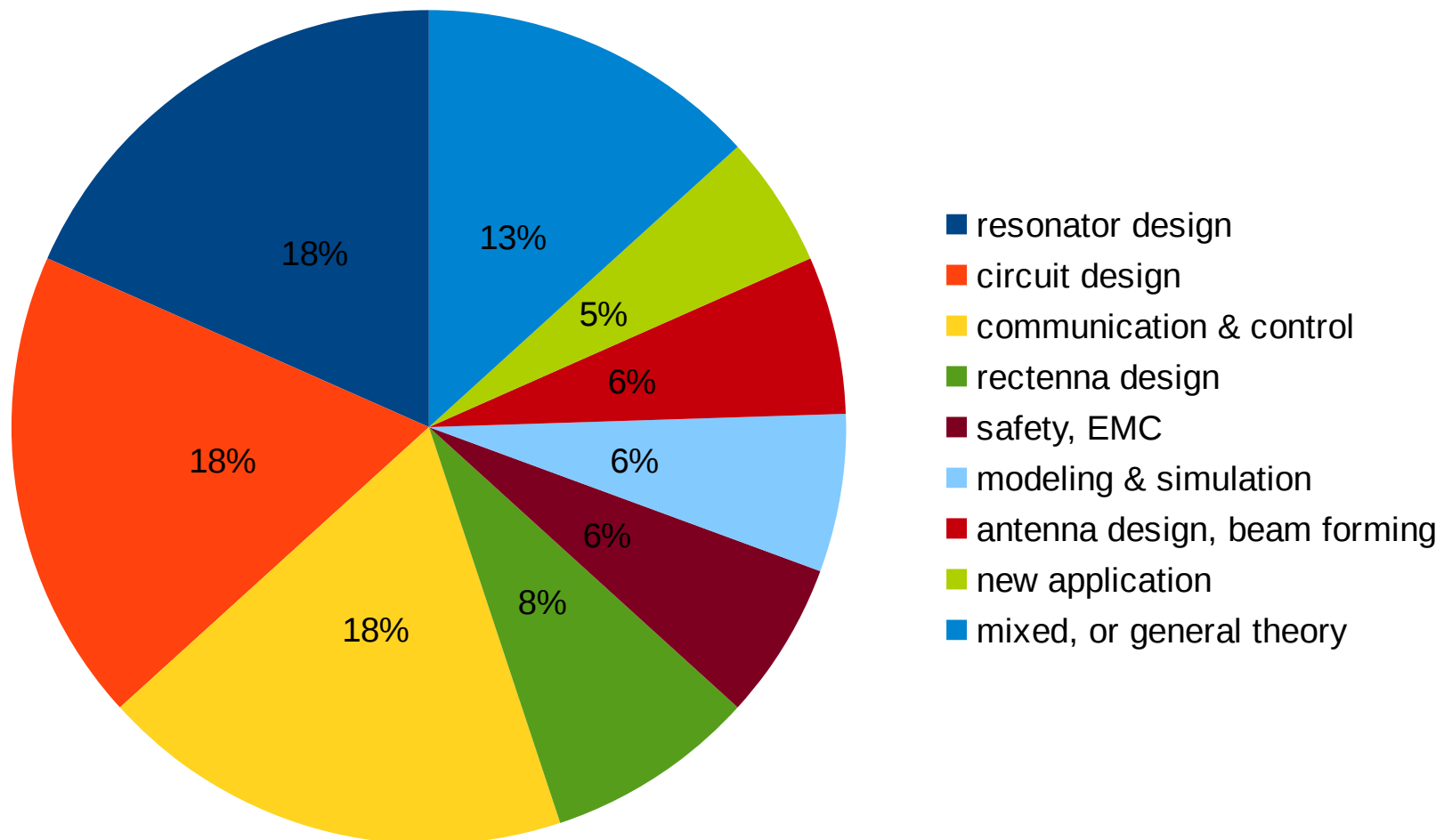
* a WPTC 2016 konferencia statisztikája

WPT technológiák részesedése a kutatásban*



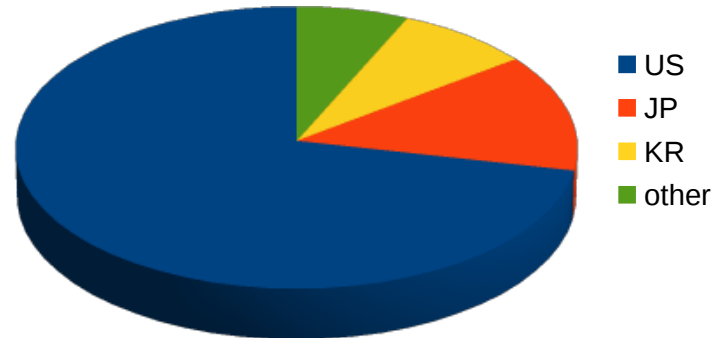
* a WPTC 2016 konferencia statisztikája

Az egyes részproblémákra fordított kutatómunka aránya*

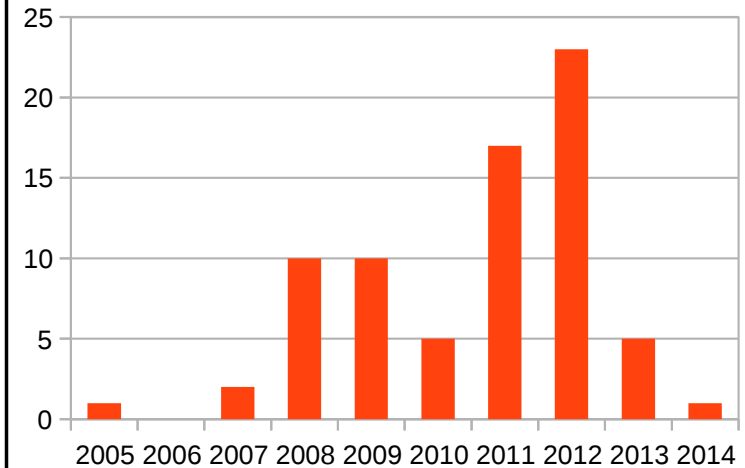


* a WPTC 2016 konferencia statisztikája

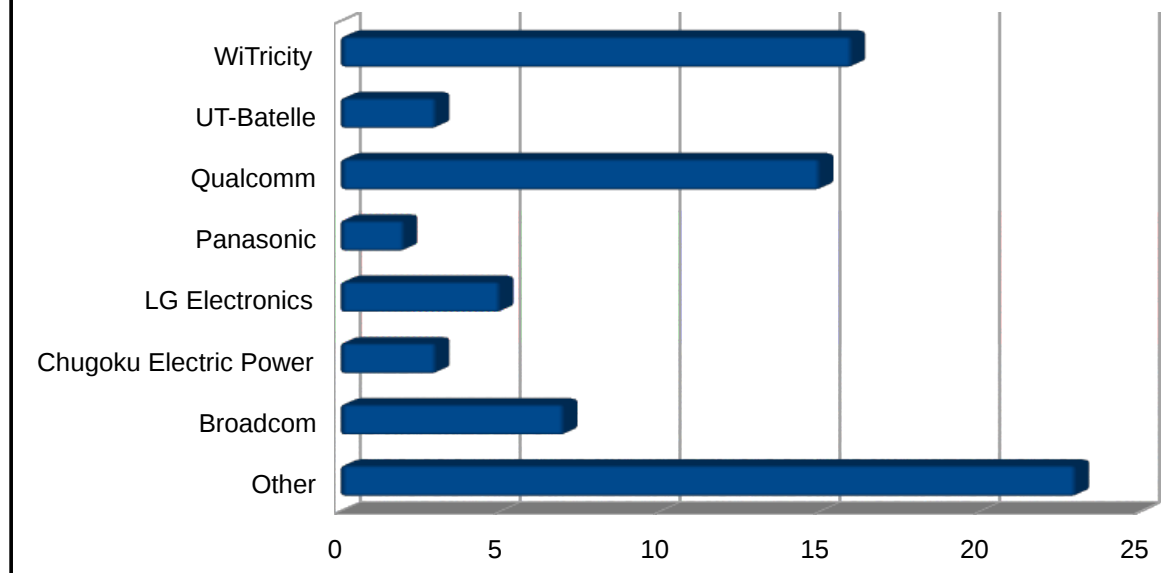
Country of Origination

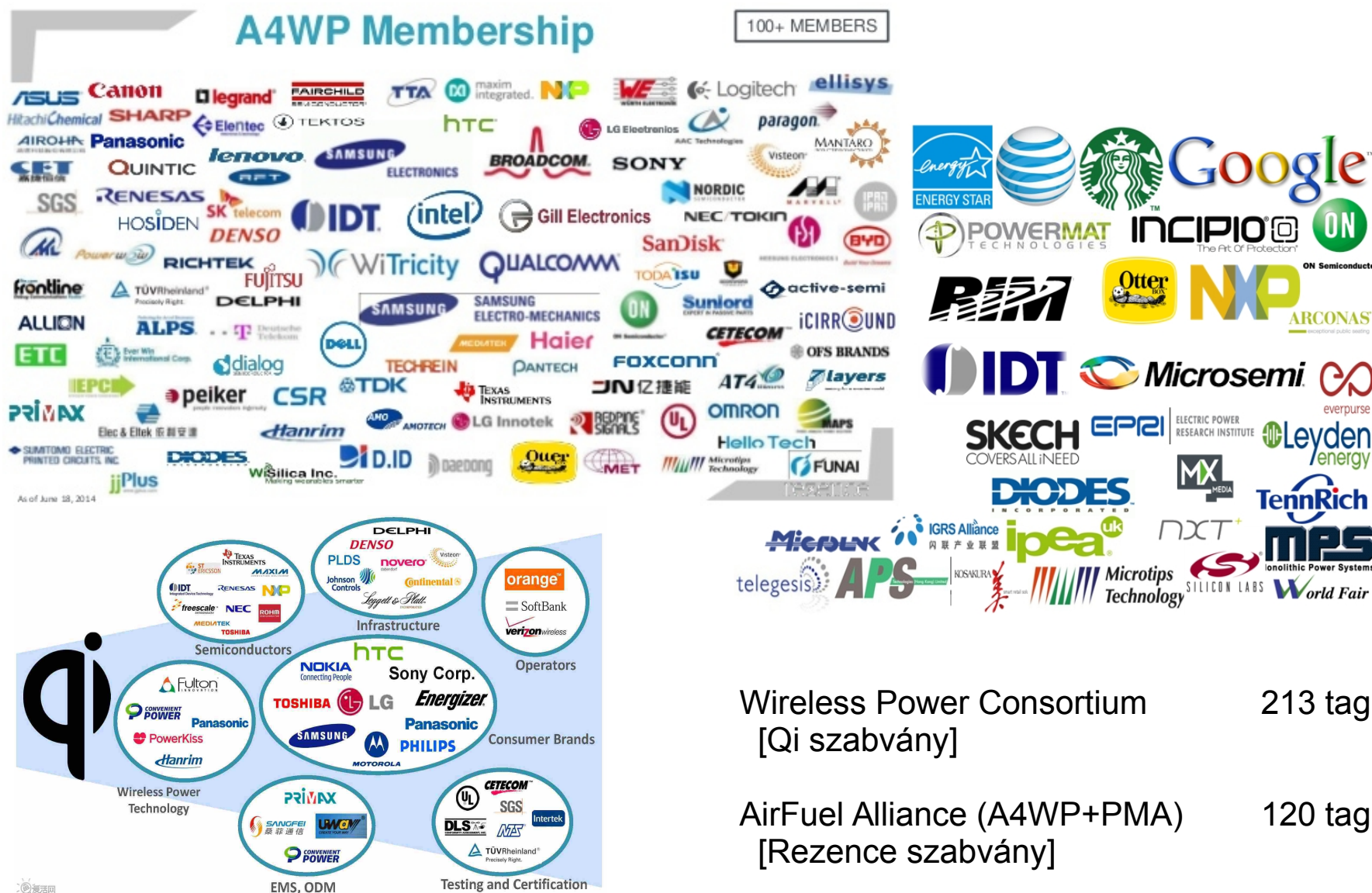


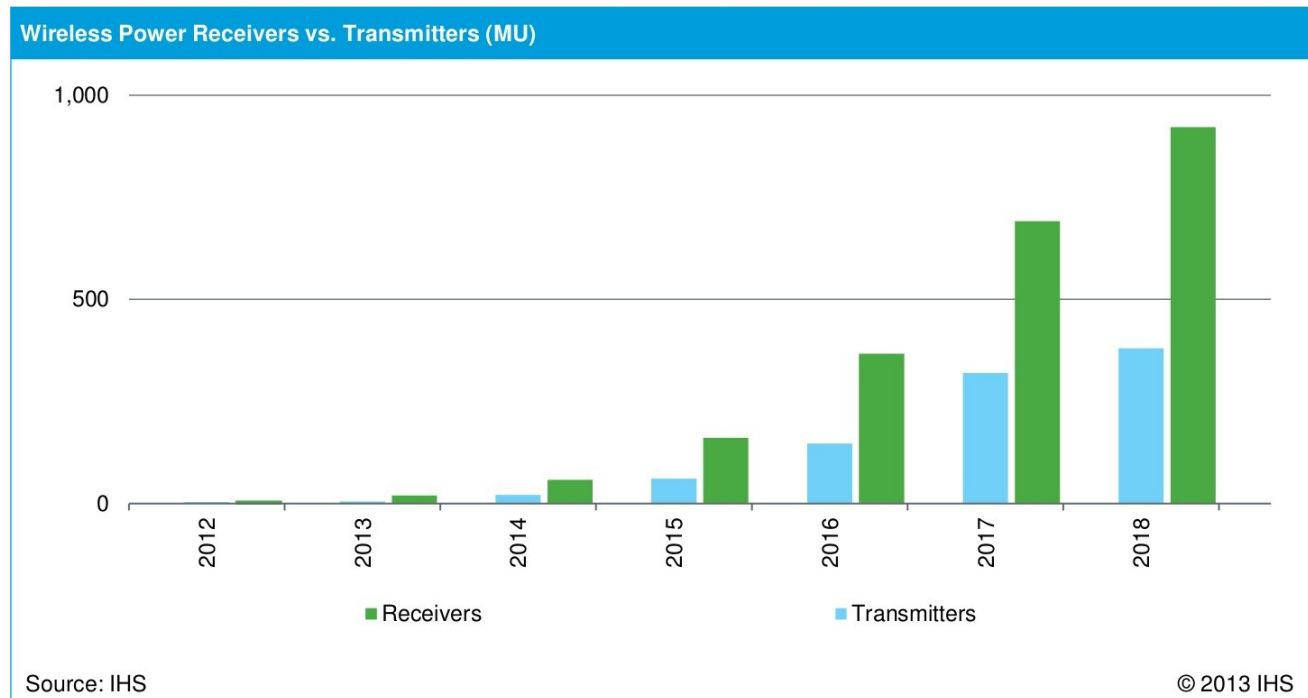
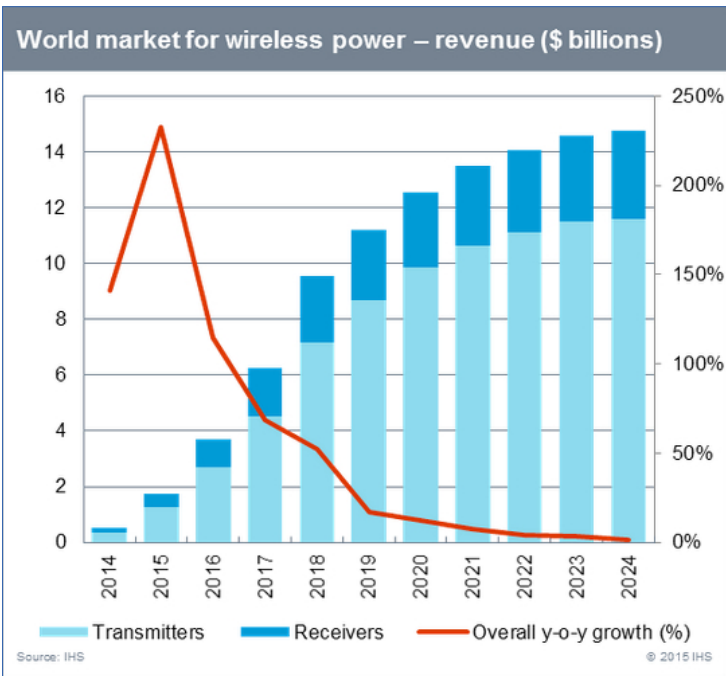
Priority Date (Year)



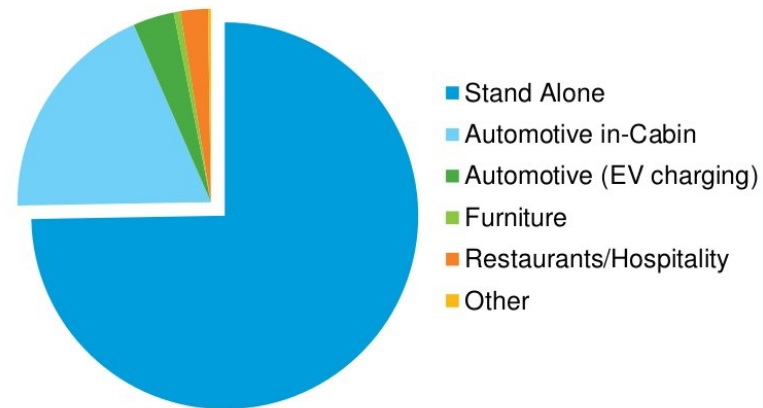
Patent Owner







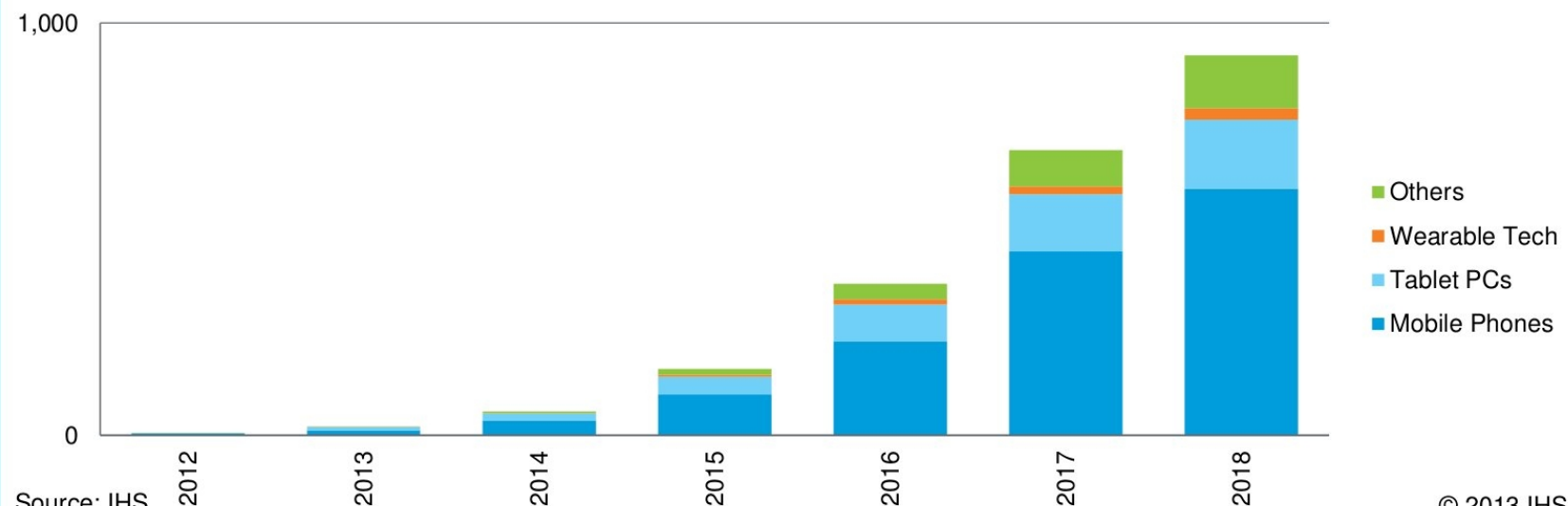
Deployment of Wireless Power Transmitters in 2018 (% of Units Shipped)



Source: IHS

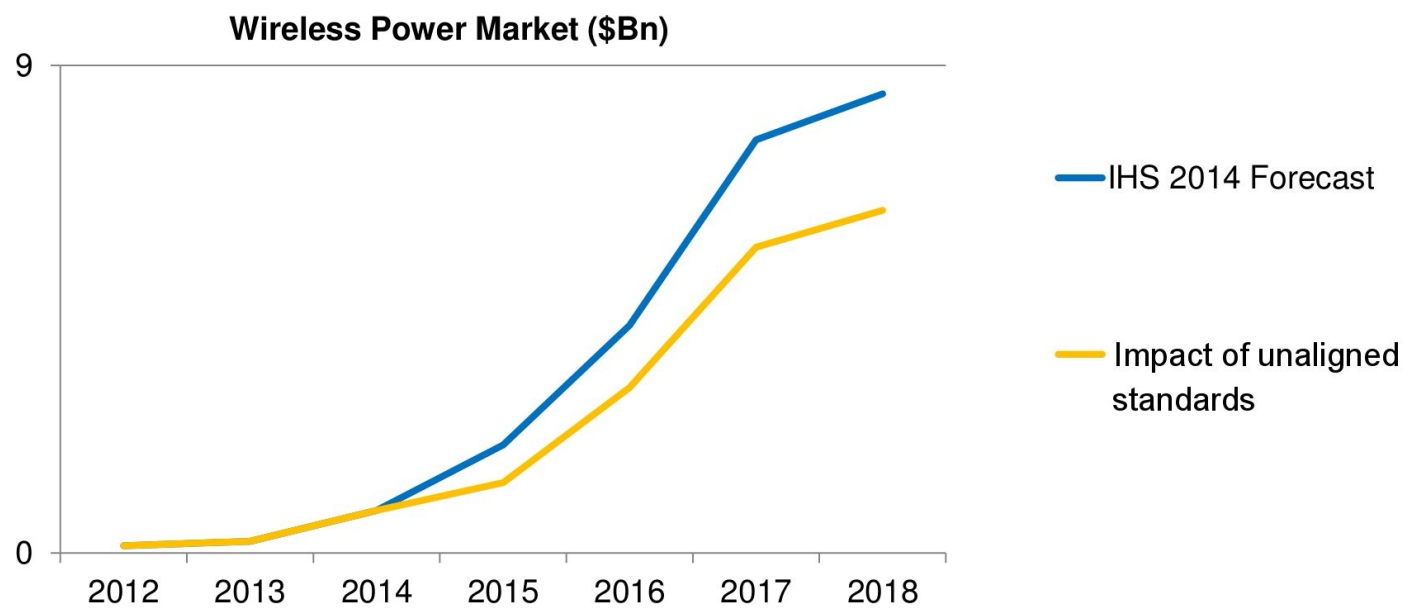
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The World Market for Wireless Power Receivers - ByMajor Application (MU)

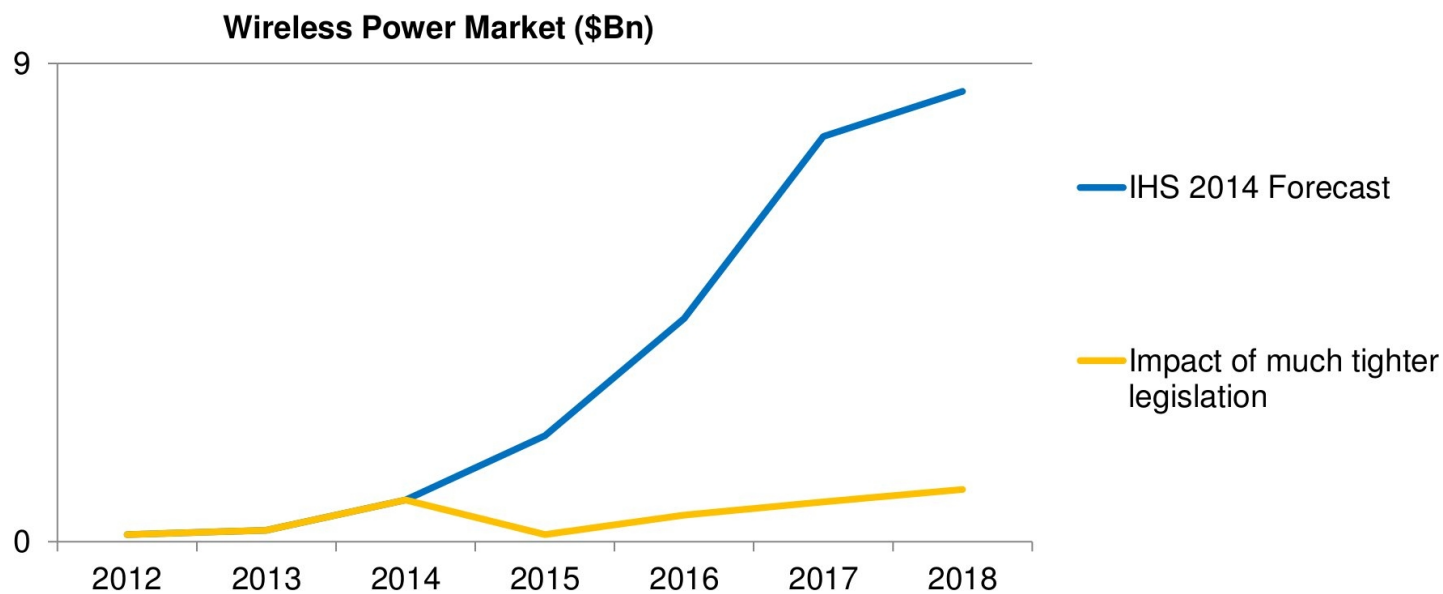


Source: IHS

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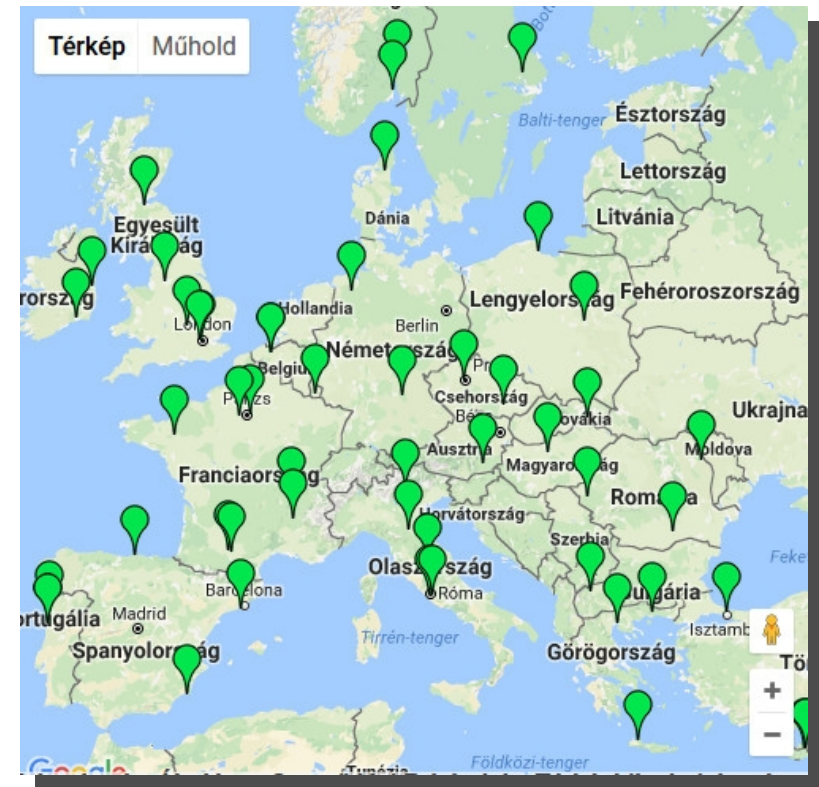
Source: IHS



Source: IHS



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TECHNOLÓGIAI INTÉZET



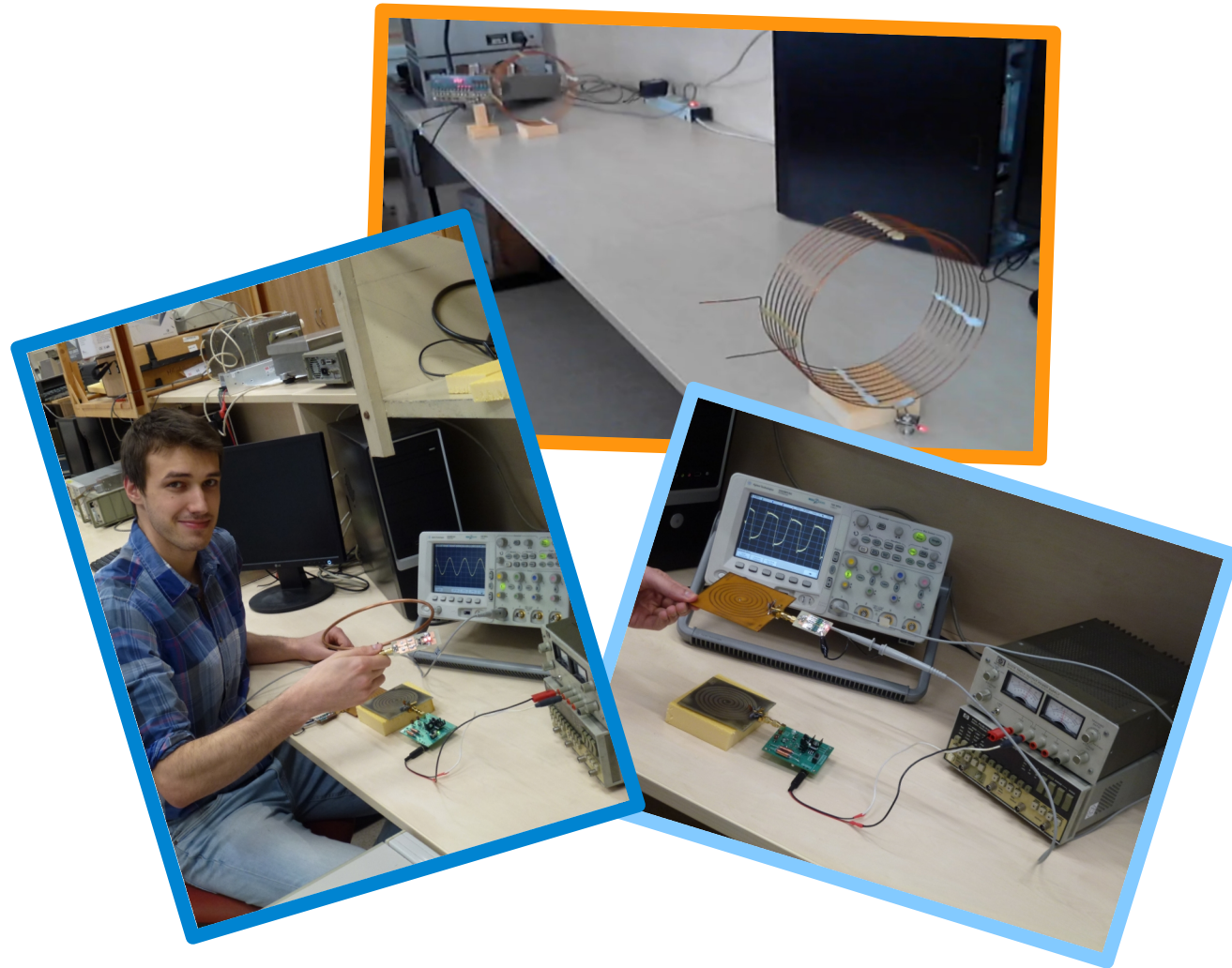
www.hirado.hu



www.micropross.com

Munkatársak:

- Bilicz Sándor
- Farkas Csaba (VET)
- Horváth Péter
- Lénárt Ferenc
- Pávó József
- Szalay Zoltán
- Szűcs László
- Tóth László Levente



Vezeték nélküli energiaátvitel (BMEVIHVAV25)

Köszönöm a figyelmet!