Extending the Inductor Operating Frequency for Optimally-coupled Wireless Power Transfer Systems

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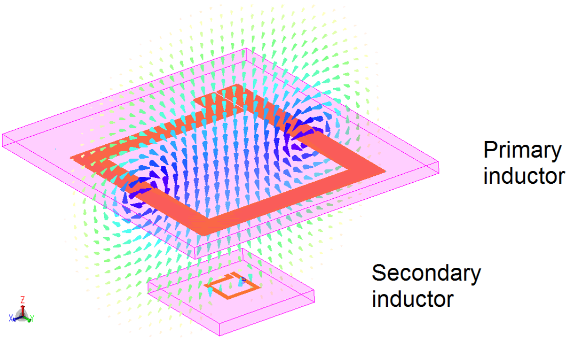

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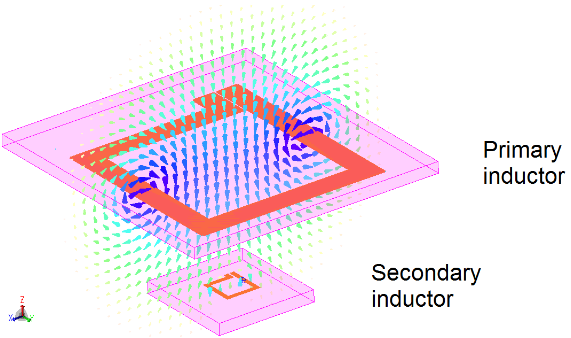

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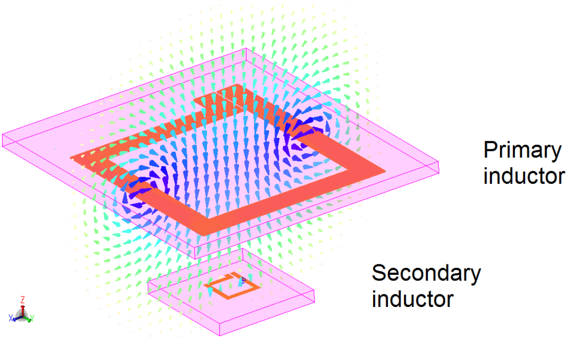
- The primary size constraints are more relaxed.



Efficiency must be maximized

$$\frac{1}{\eta} = \frac{1}{k^2} \cdot \frac{1}{Q_1} \cdot \frac{1}{Q_2} \cdot \underbrace{(p + 2 + \frac{1}{p}) + p + 1}$$

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- First Inductor quality factor

Power transfer efficiency

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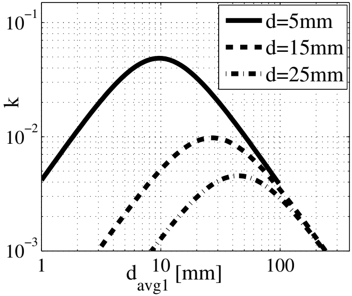
- Coupling factor squared
- First Inductor quality factor
- Second Inductor quality factor
- Load matching dependence

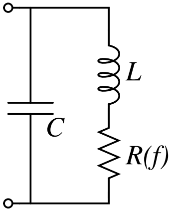
$k = M/\sqrt{L_1 L_2}$

$$M = \mu\sqrt{\frac{d_{avg1}d_{avg2}}{\pi}}\left[\left(\frac{2}{\gamma}-\gamma\right)K(\gamma)-\frac{2}{\gamma}E(\gamma)\right] \quad (1)$$

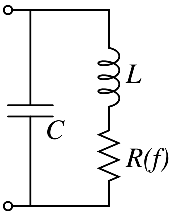
$$\gamma = \sqrt{\frac{4d_{avg1}d_{avg2}}{(d_{avg1}+d_{avg2})^2+\pi d^2}}, \quad (2)$$

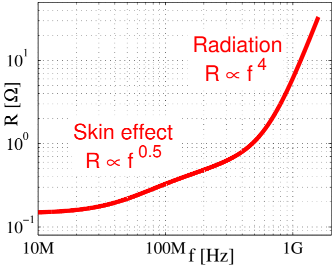


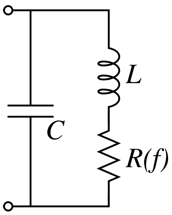
Magnetic coupling factor when $d_{avg2} = 4\,\text{mm}$.

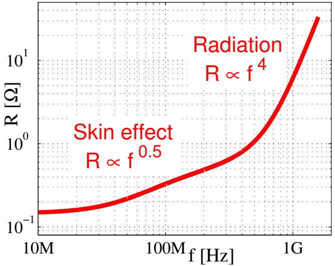

L
C
R(f)

Quality factor model



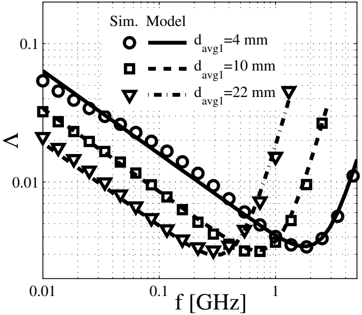






Loss factor

$$\Lambda = \frac{1}{Q} = \frac{R}{2\pi f\ L}$$



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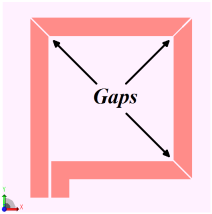
- Therefore, the smaller inductor does not operate in its optimal frequency.
- We can extend the operating frequency of the link using a segmented inductor.

Segmented inductor



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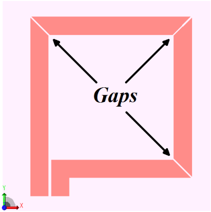
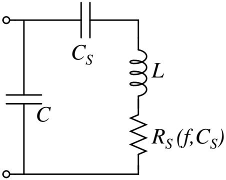


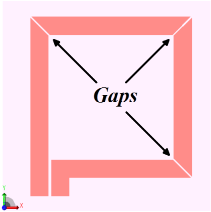


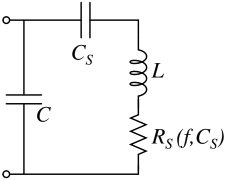
$$C_S = \frac{C_G + C_D}{N - 1}$$

C_G *Gap capacitance*

C_D *Discrete capacitor*

N *Number of segments*





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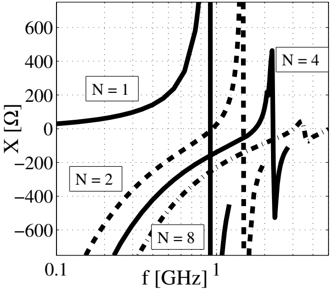
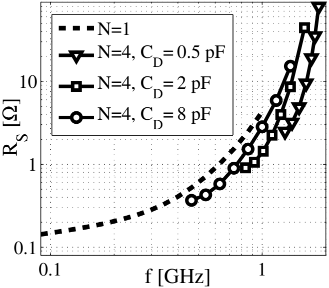
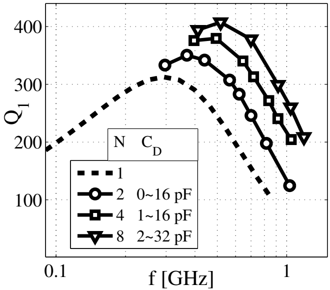
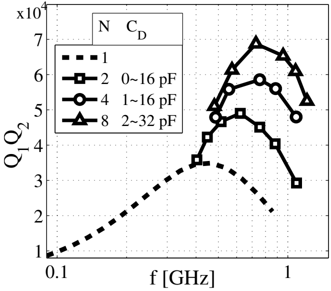


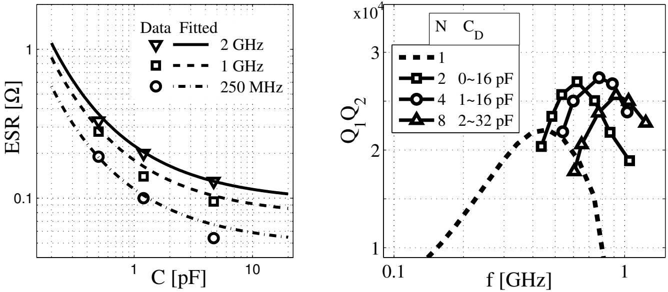


(a) Equivalent reactance when C_D=0. (b) Segmented inductor losses.

Segmented inductor quality factor

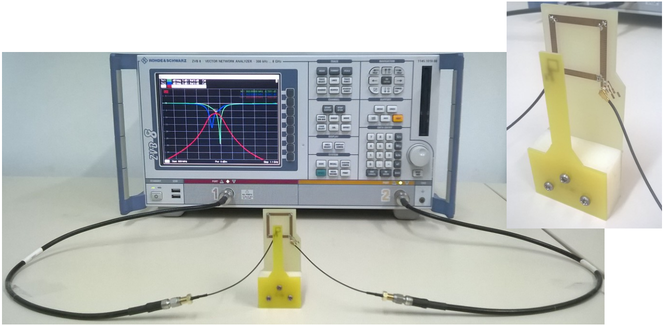






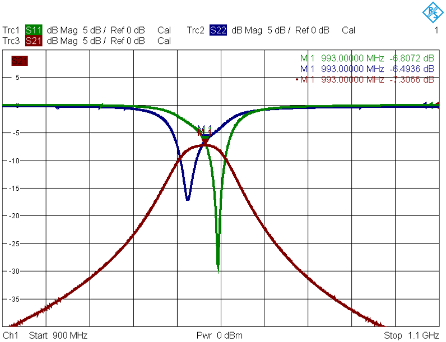
(a) Equivalent series resistance for discrete capacitors. (b) Quality factors product accounting the capacitors ESR.

- Performance is no longer improved for higher values of *N* because of the capacitor losses.



d_{avg2} [mm]	d_{avg1} [mm]	N	C_D [pF]	d [mm]
4	22	4	3	15

Experimental results



N	C_D [pF]	η_{max} [%]	$f_{\eta max}$ [MHz]	
1	–	30	415	Meas. [3]
4	3	38	735	Sim.
4	1.5	37	990	Sim.
4	1.5	30	980	Meas.

[3] Fabian L. Cabrera and F. Rangel de Sousa, “Optimal Design of Energy Efficient Inductive Links for Powering Implanted Devices,”in BioWireleSS 2014.

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- The extension of the operating frequency was achieved by dividing the primary inductor into four segments.
- The technique presented offers potential improvements on the link efficienncy, however that improvements are limited by the capacitor losses.
- The extension of the primary inductor frequency offers flexibility to the inductive link design.