Resonant electrical coupling: circuit model and first experimental results

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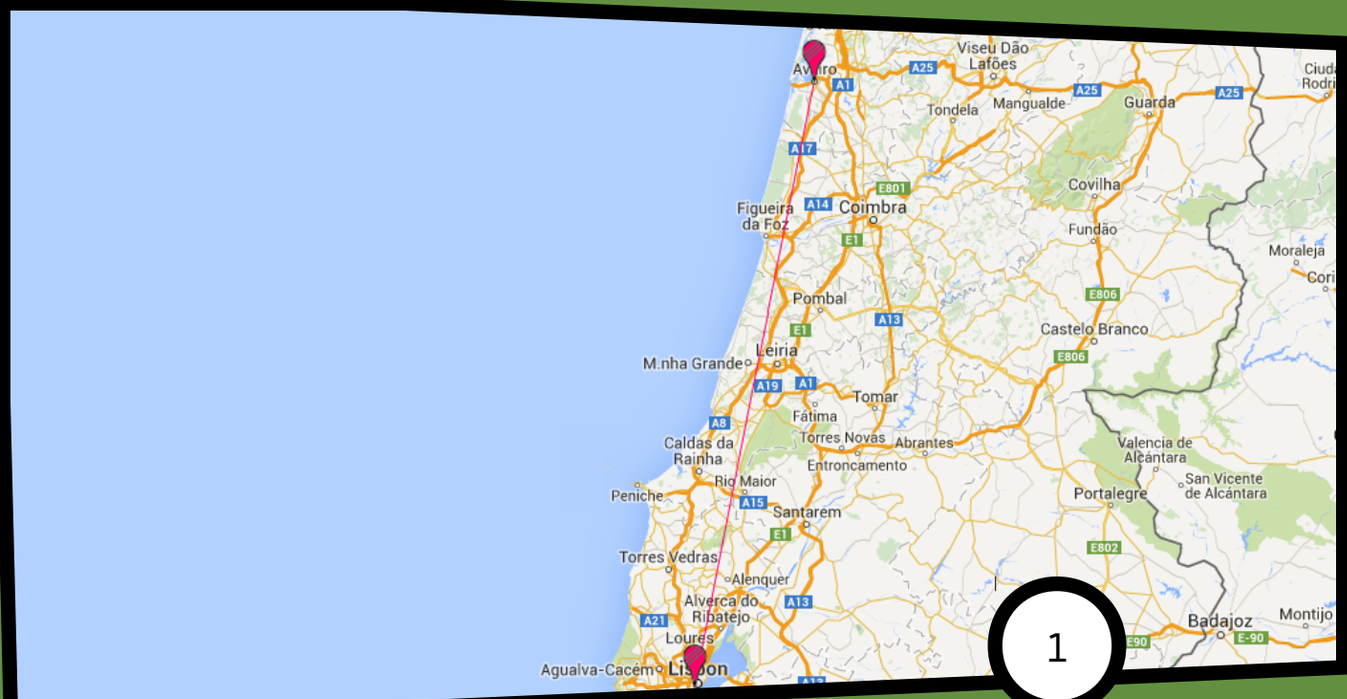
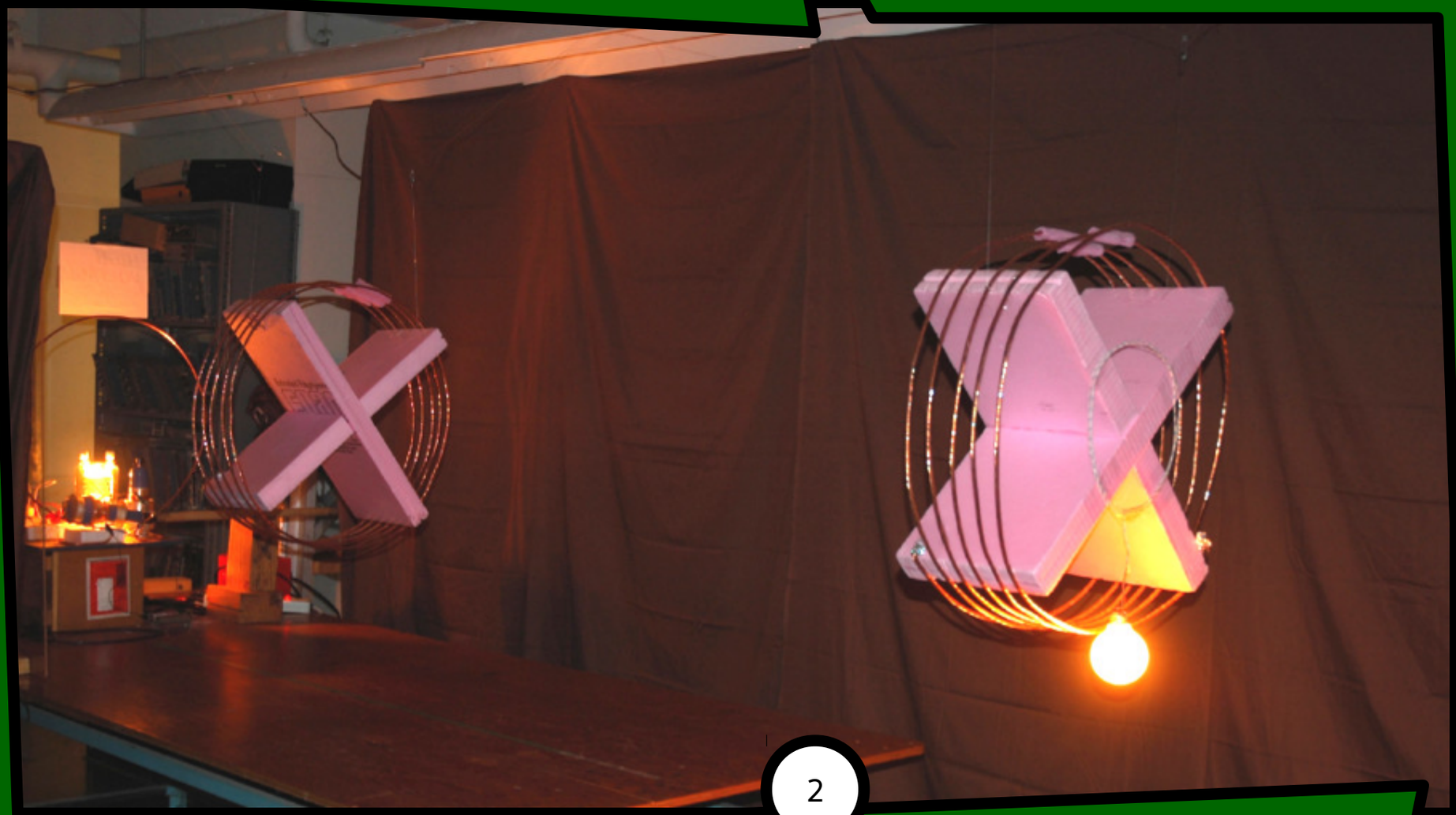
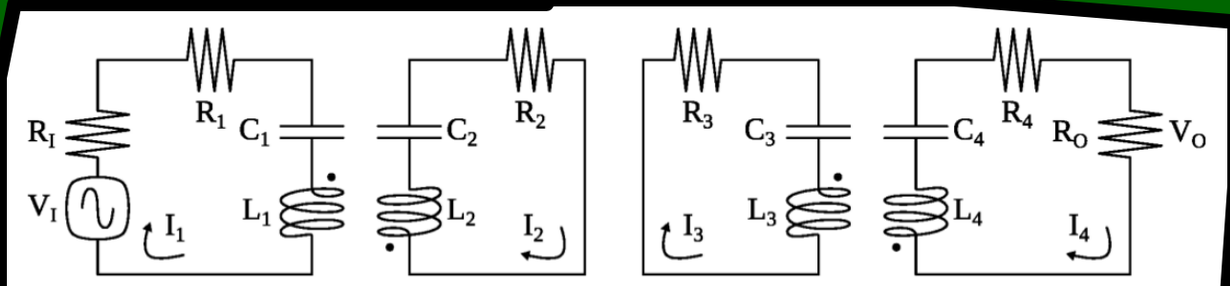


Resonant magnetic coupling (2007): 4 coils (largest diameter of 60 cm, cross-sectional diameter of 6 mm), a 60 W light bulb, distance of 2 m, efficiency of 40%

Balanced trade-off between efficiency, range, simplicity, size and power transfer capability





$$\frac{V_O}{V_I}=\frac{-jw^3M_{12}M_{23}M_{34}R_O}{M_{12}^2M_{34}^2w^4+Z_1Z_2Z_3Z_4+w^2\left(M_{12}^2Z_3Z_4+M_{23}^2Z_1Z_4+M_{34}^2Z_1Z_2\right)}$$

$$Z_1=R_I+R_1-\frac{j}{wC_1}+jwL_1$$

$$Z_2=R_2-\frac{j}{wC_2}+jwL_2$$

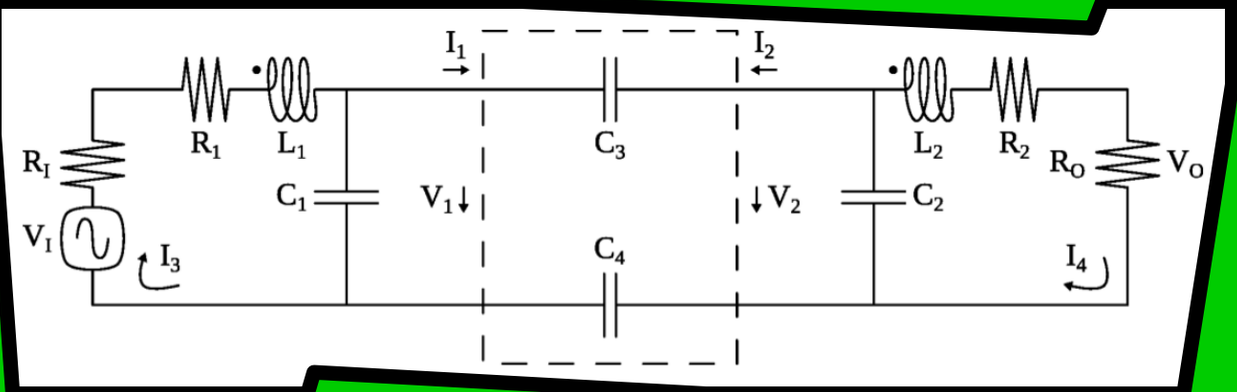
$$Z_3=R_3-\frac{j}{wC_3}+jwL_3$$

$$Z_4=R_O+R_4-\frac{j}{wC_4}+jwL_4$$

$$M_{12}=k_{12}\sqrt{L_1L_2}$$

$$M_{23}=k_{23}\sqrt{L_2L_3}$$

$$M_{34}=k_{34}\sqrt{L_3L_4}$$



$$\frac{V_O}{V_I} = \frac{R_O Y_{21}}{Y_{12} Y_{21} Z_1 Z_2 - (1 + K_1 Z_1)(1 + K_2 Z_2)}$$

$$Z_1 = R_I + R_1 + j w L_1$$

$$Z_2 = R_O + R_2 + j w L_2$$

$$K_1 = Y_{11} + j w C_1$$

$$K_2 = Y_{22} + j w C_2$$

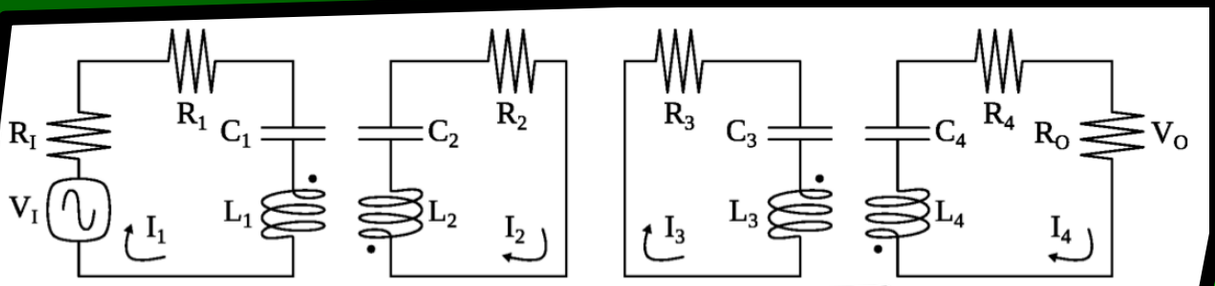
$$Y_{11} = j w \frac{C_3 C_4}{C_3 + C_4}$$

$$Y_{12} = -Y_{11}$$

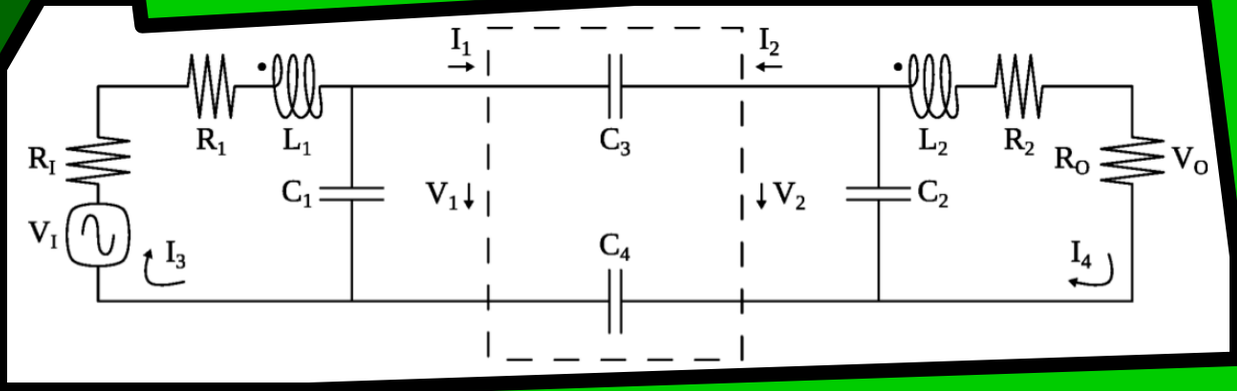
$$Y_{21} = -Y_{11}$$

$$Y_{22} = Y_{11}$$

Available power gain: $\frac{P_O}{P_A} = \frac{4 R_I}{R_O} \left| \frac{V_O}{V_I} \right|^2$

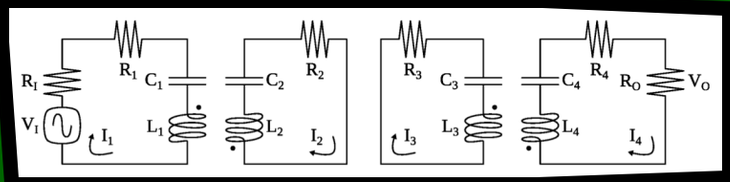


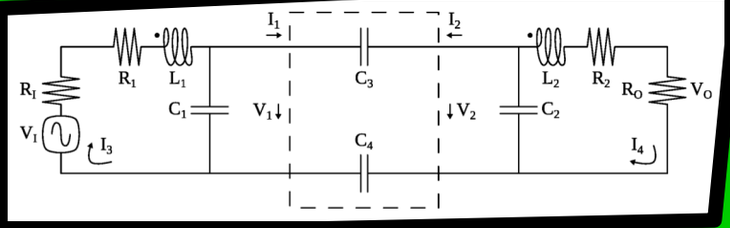
Parameter	Value
R_I, R_O	50 Ω
R_1, R_4	2 Ω
R_2, R_3	10 Ω
L_1, L_4	1 μH
L_2, L_3	28 μH
C_1, C_4	140 pF
C_2, C_3	5 pF
K_{12}, k_{34}	0.1



Parameter	Value
R_I, R_O	50 Ω
R_1, R_2	12 Ω
L_1, L_2	28 μH
C_1, C_2	5 pF

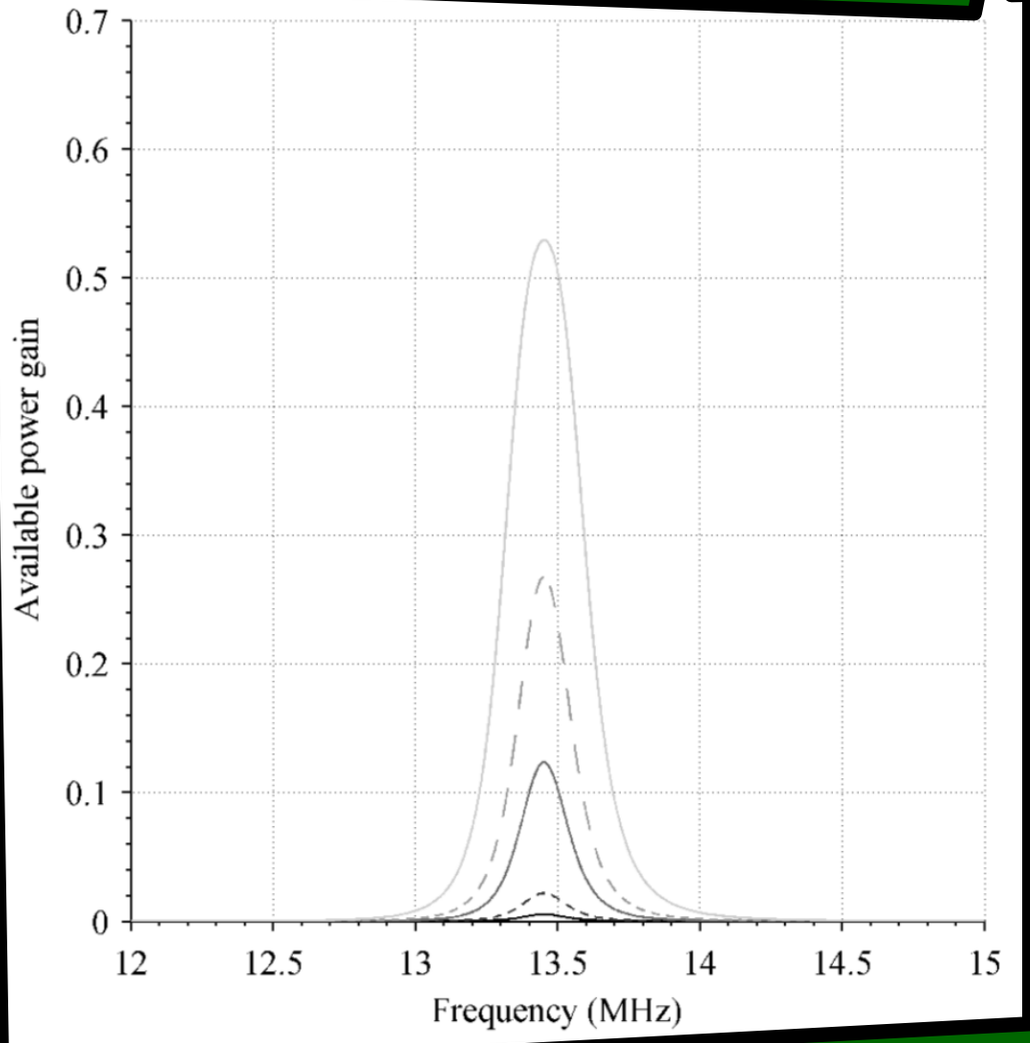
$C_4 = C_3$

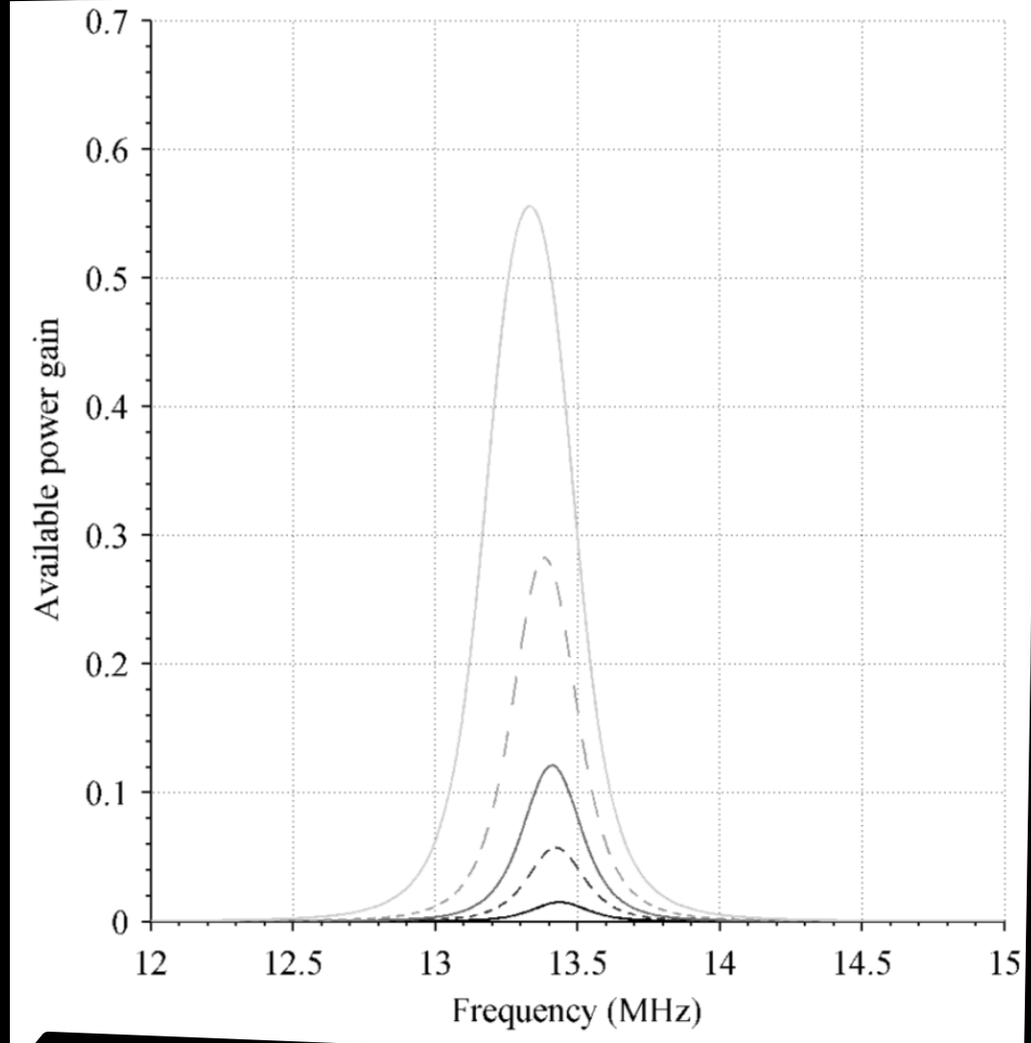


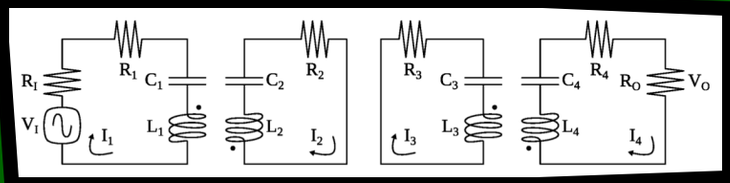


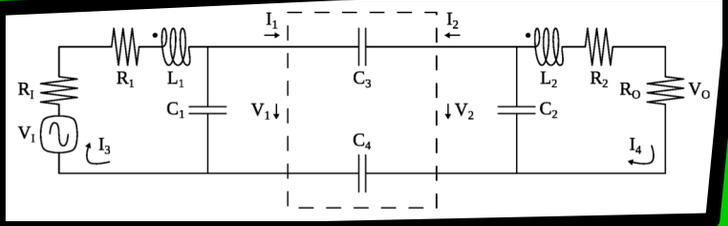
k_{23}	0.001	0.002	0.005	0.008	0.015

C_3 (pF)	0.02	0.04	0.06	0.1	0.18



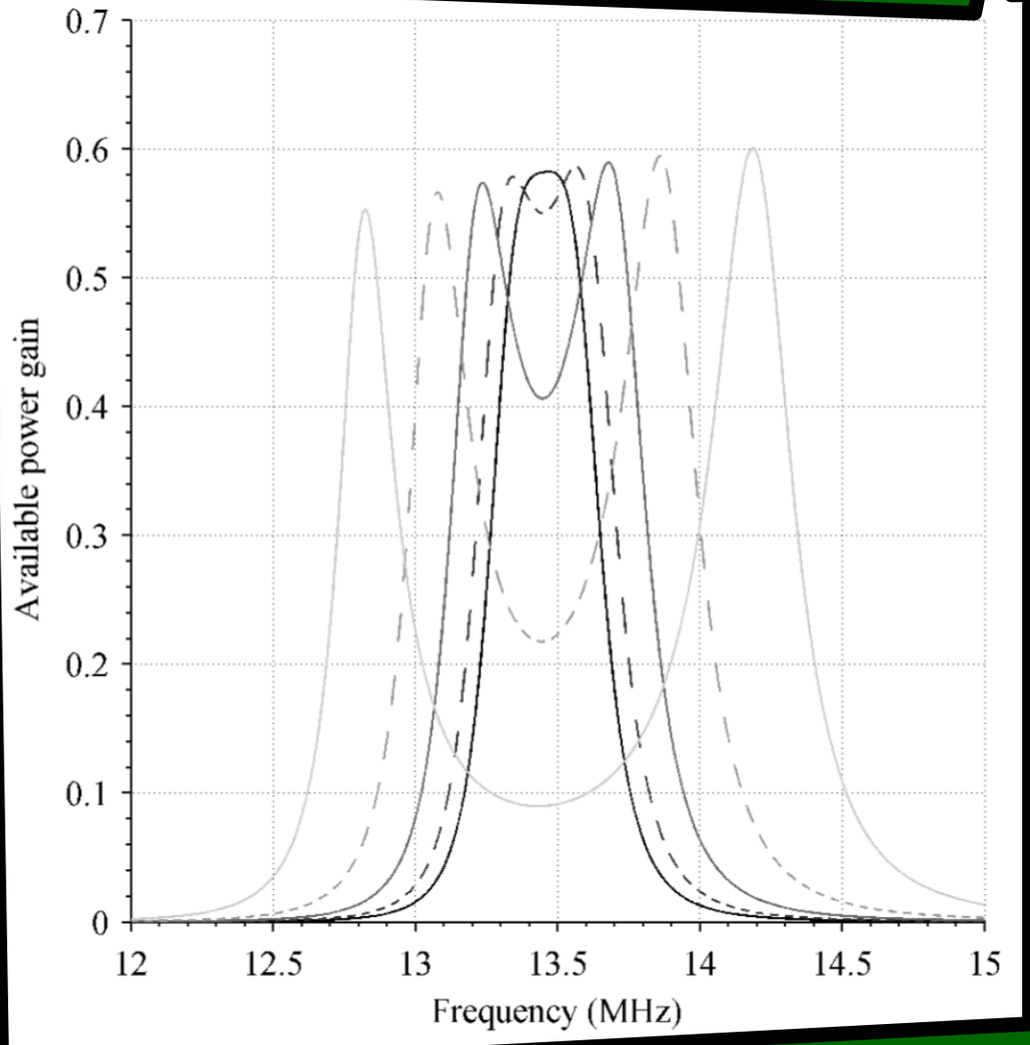


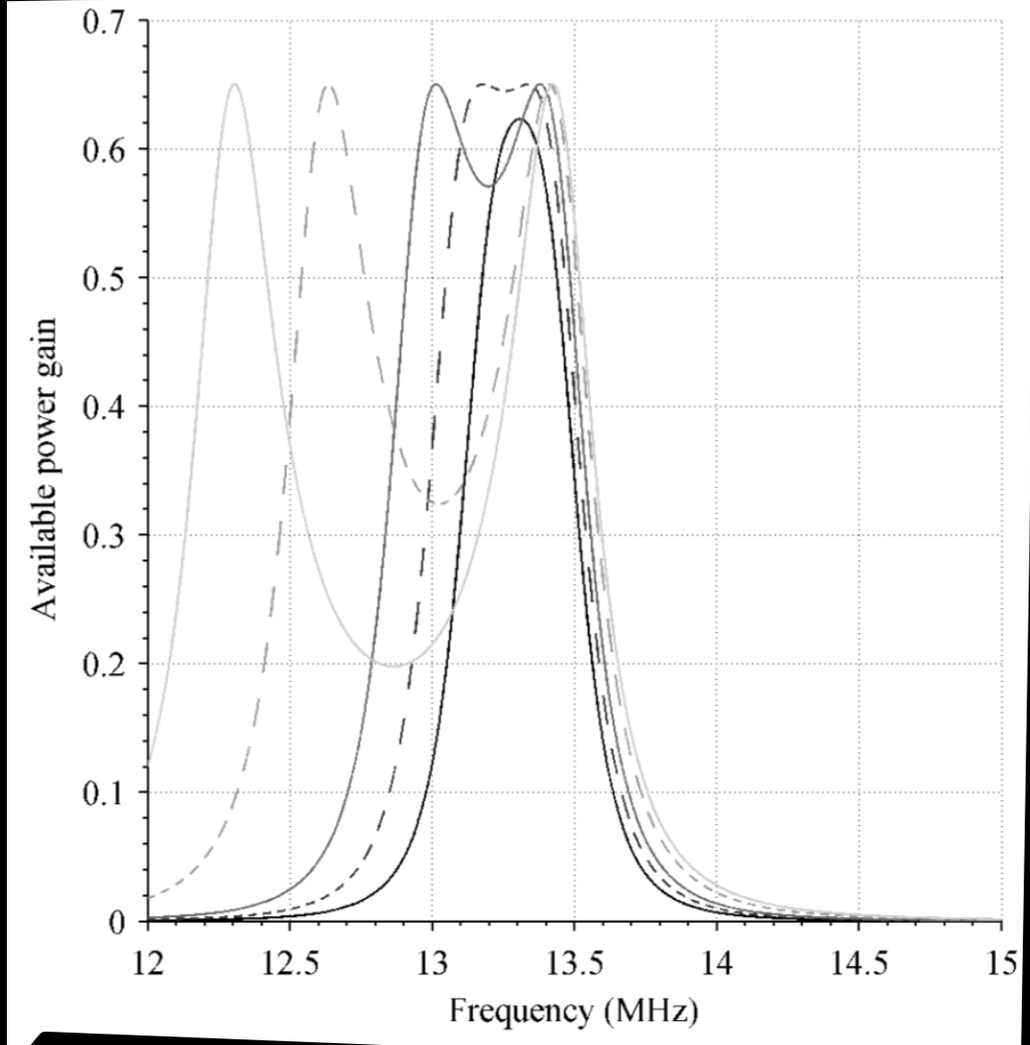


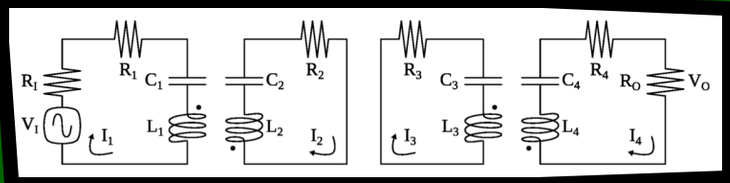


k_{23}	0.02	0.026	0.038	0.06	0.1

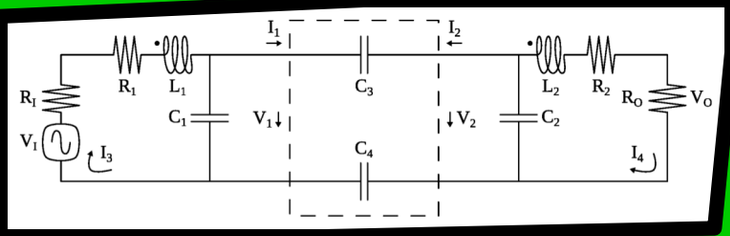
C_3 (pF)	0.22	0.3	0.4	0.7	1







$R_1 = R_2 = R_3 = R_4 = 0$



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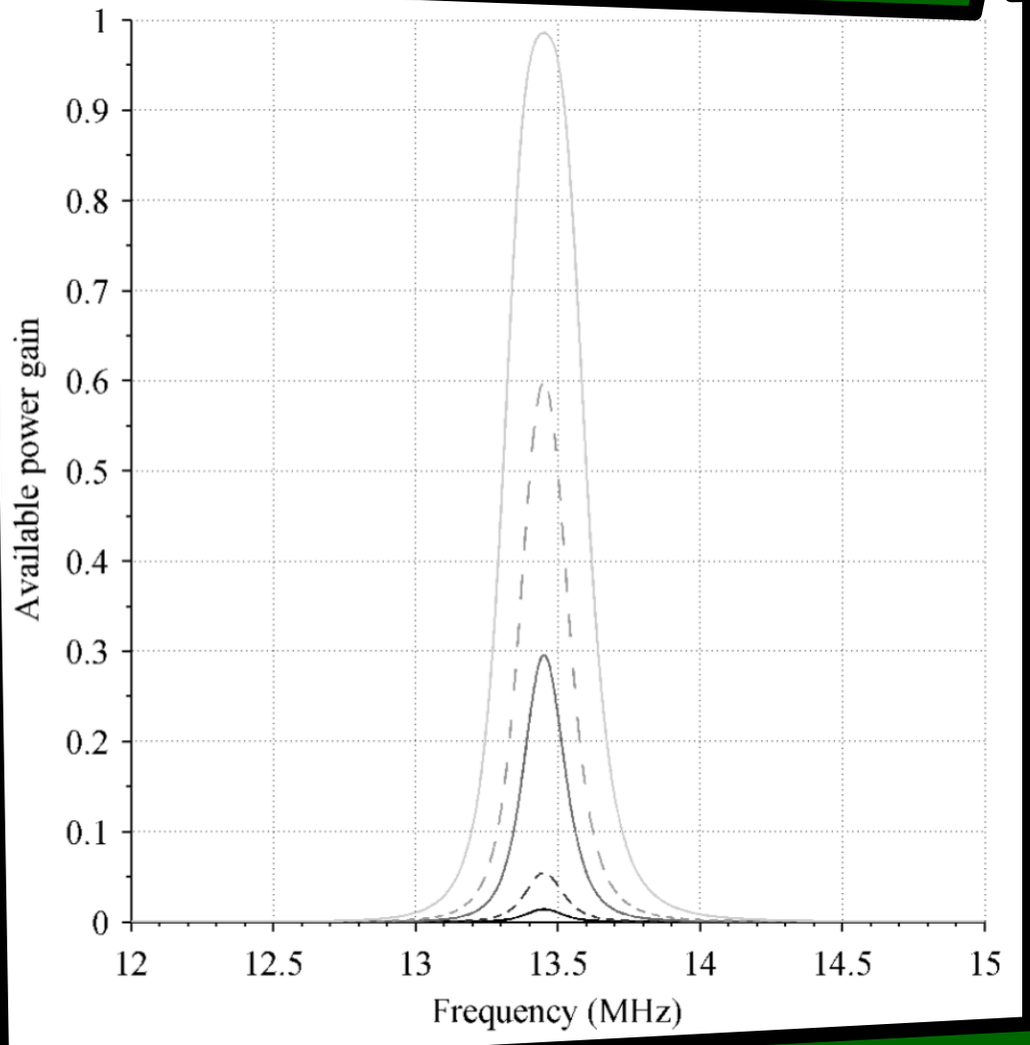

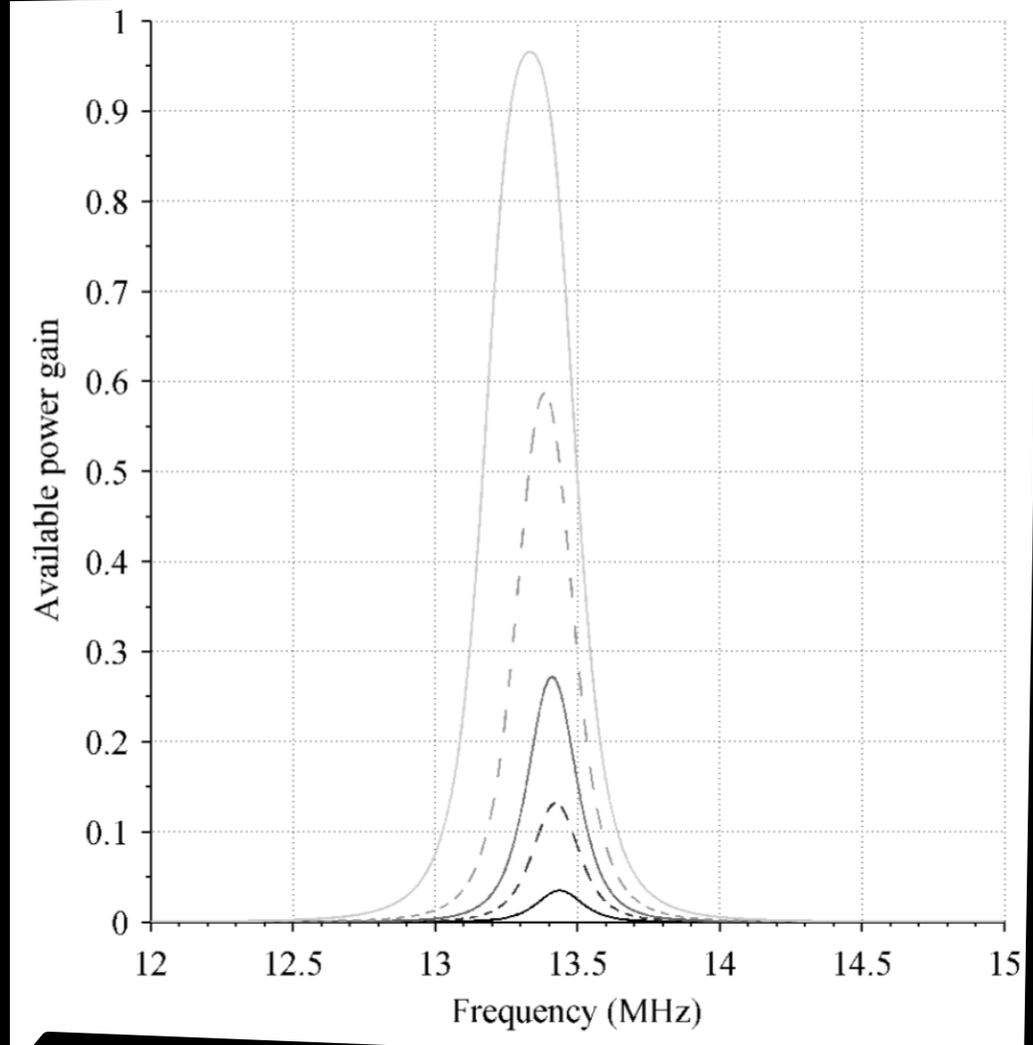

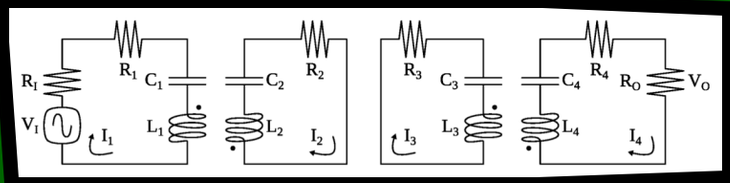

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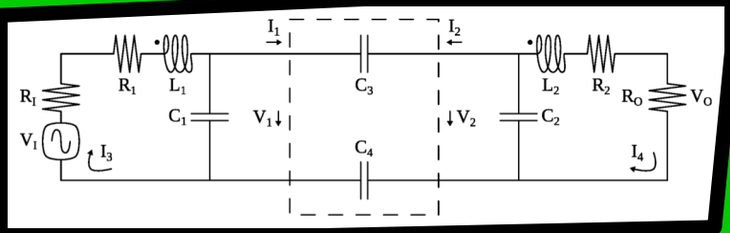

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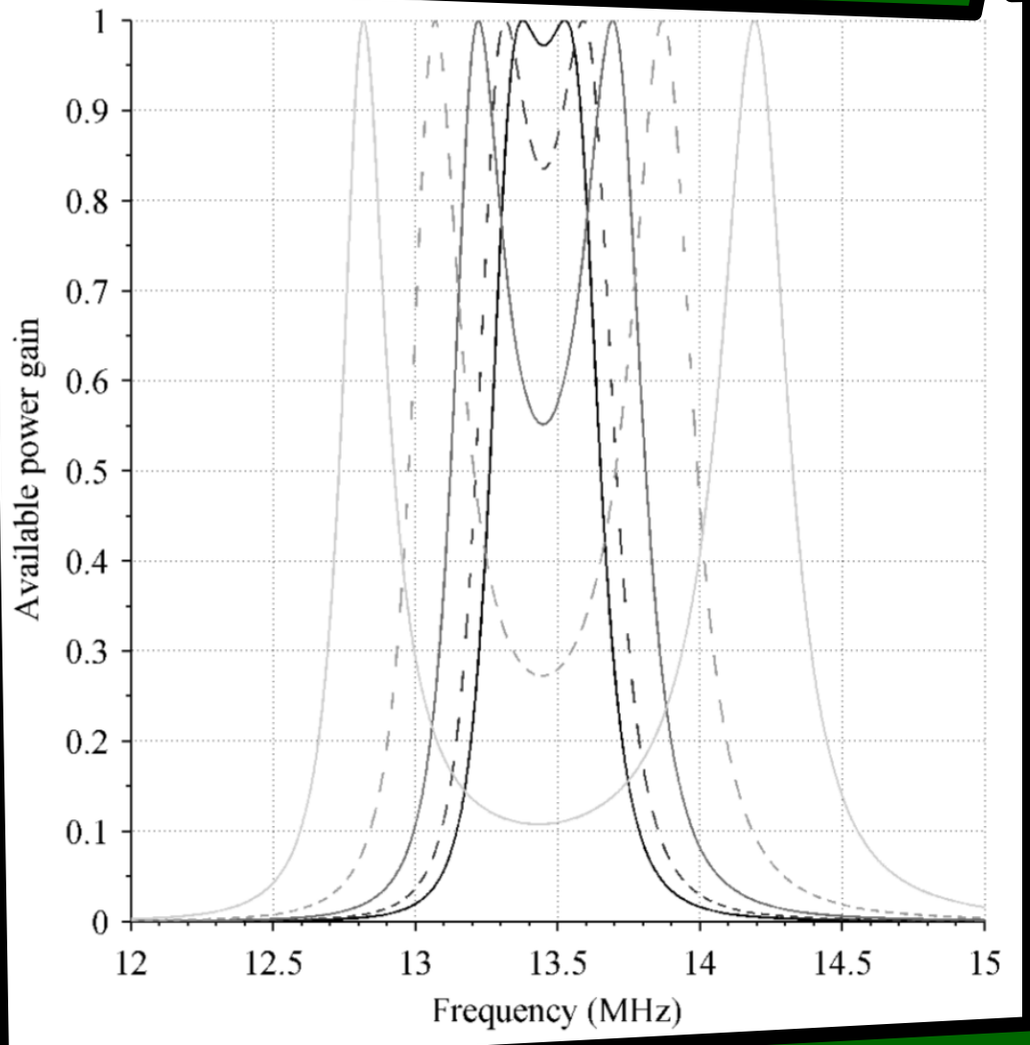
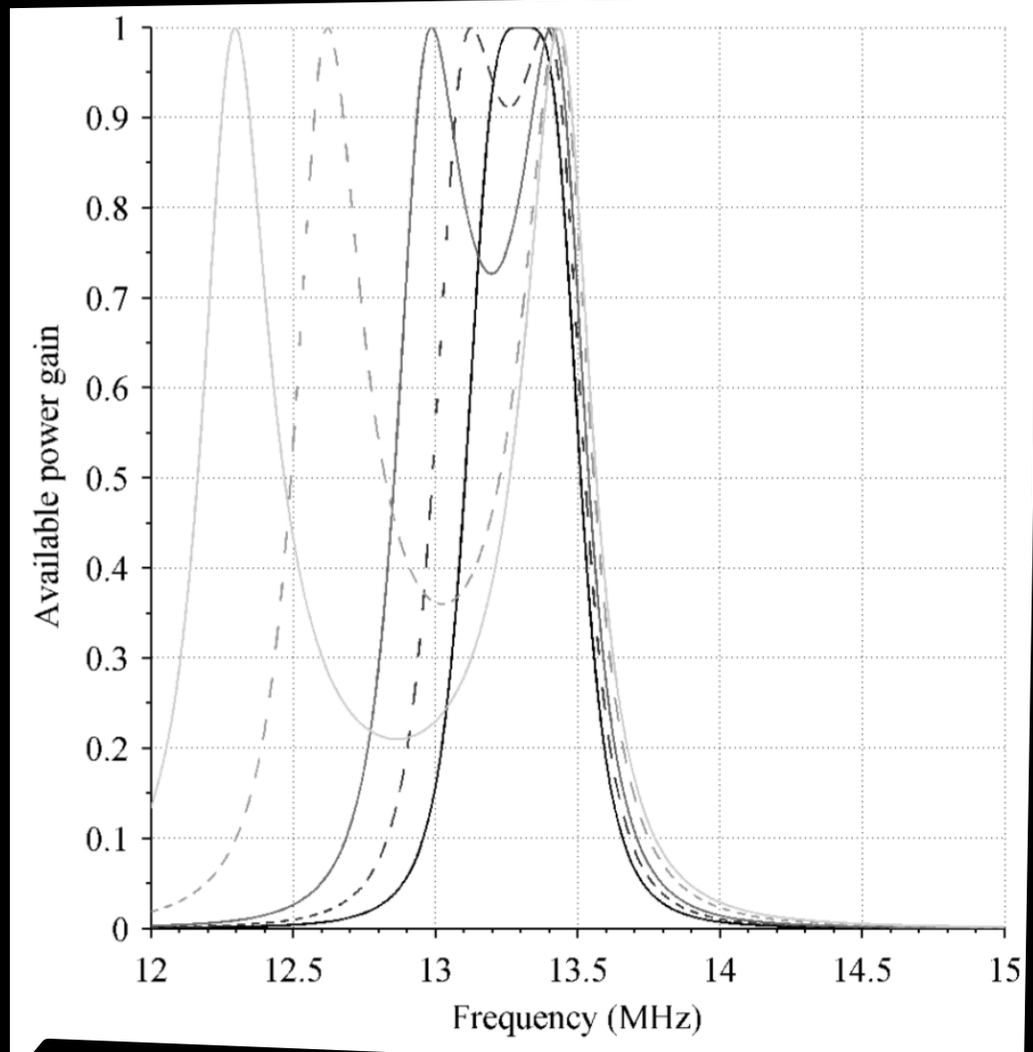
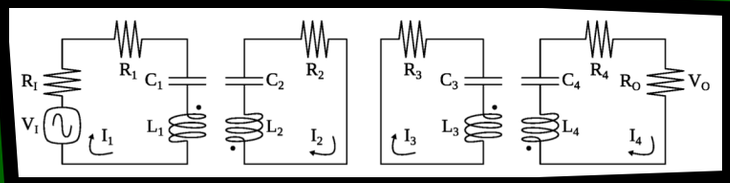
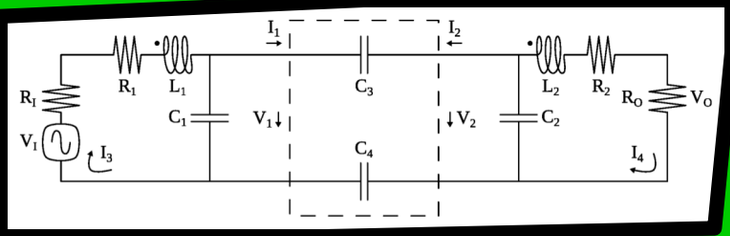






$L_2 = 0.9 L_1$



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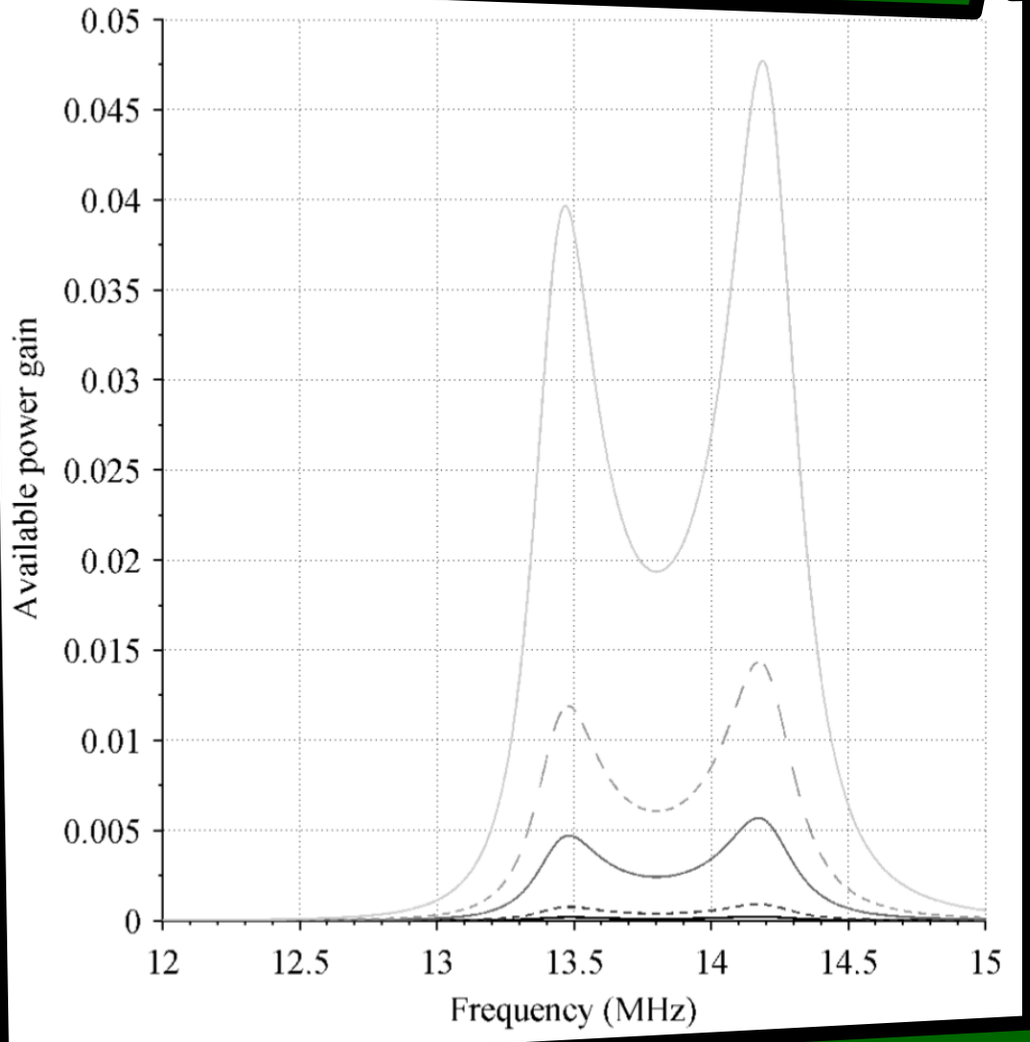

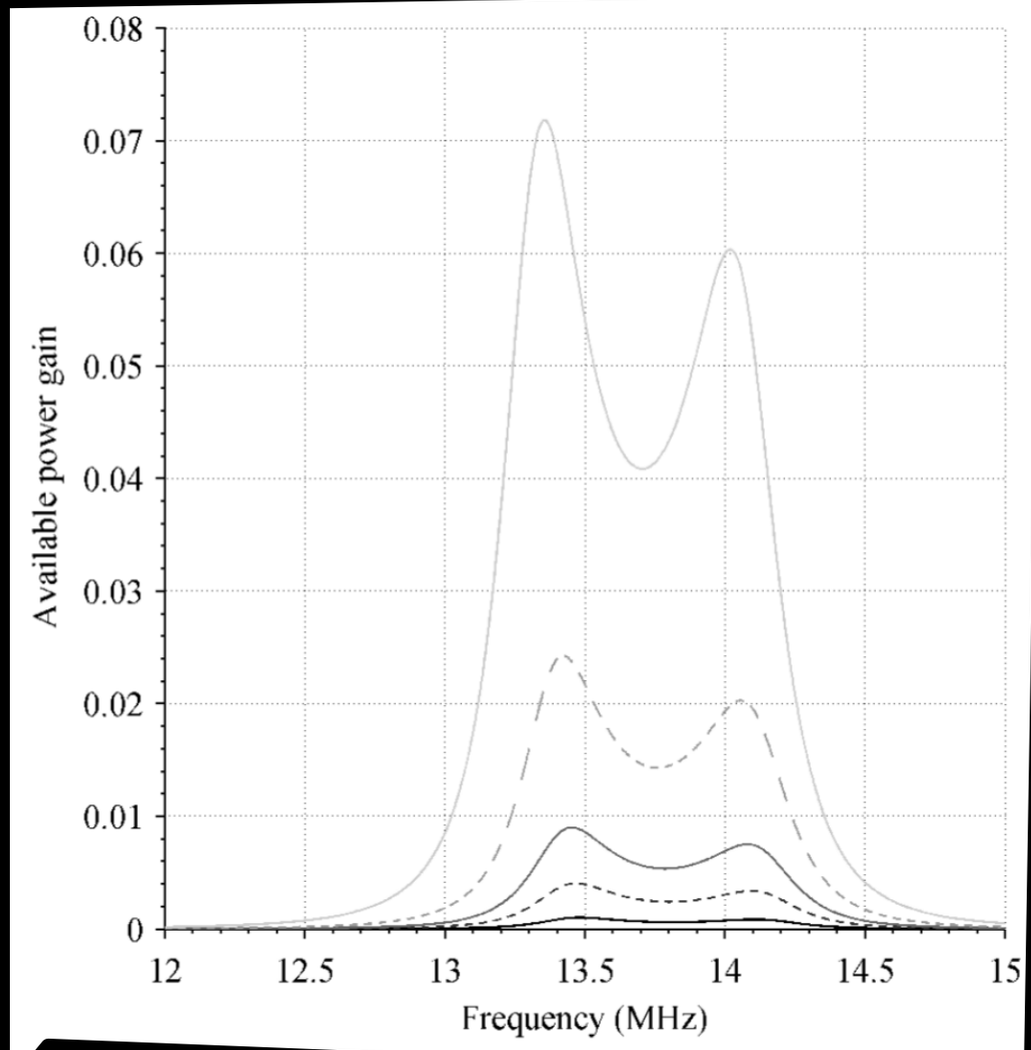

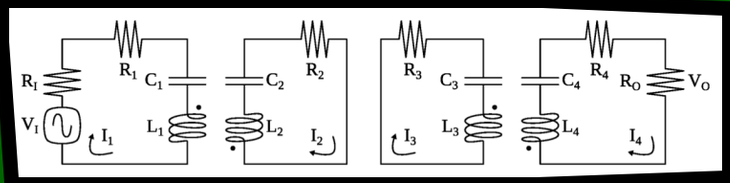

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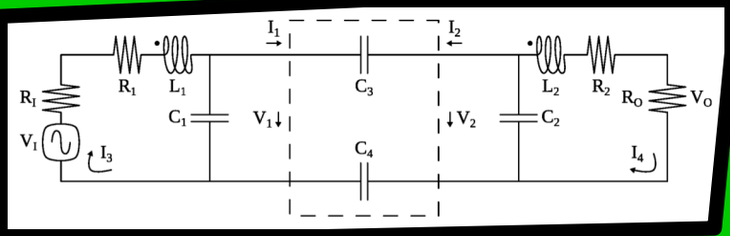

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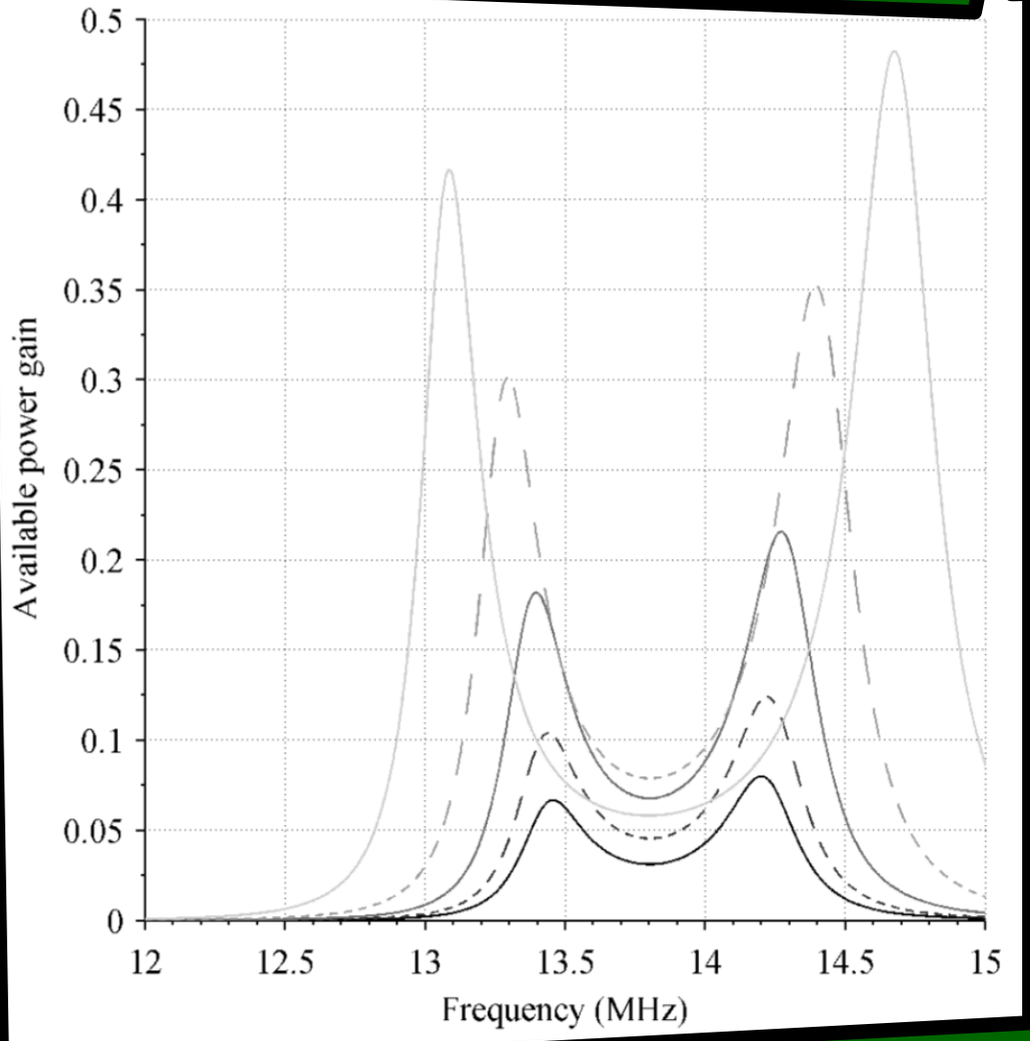

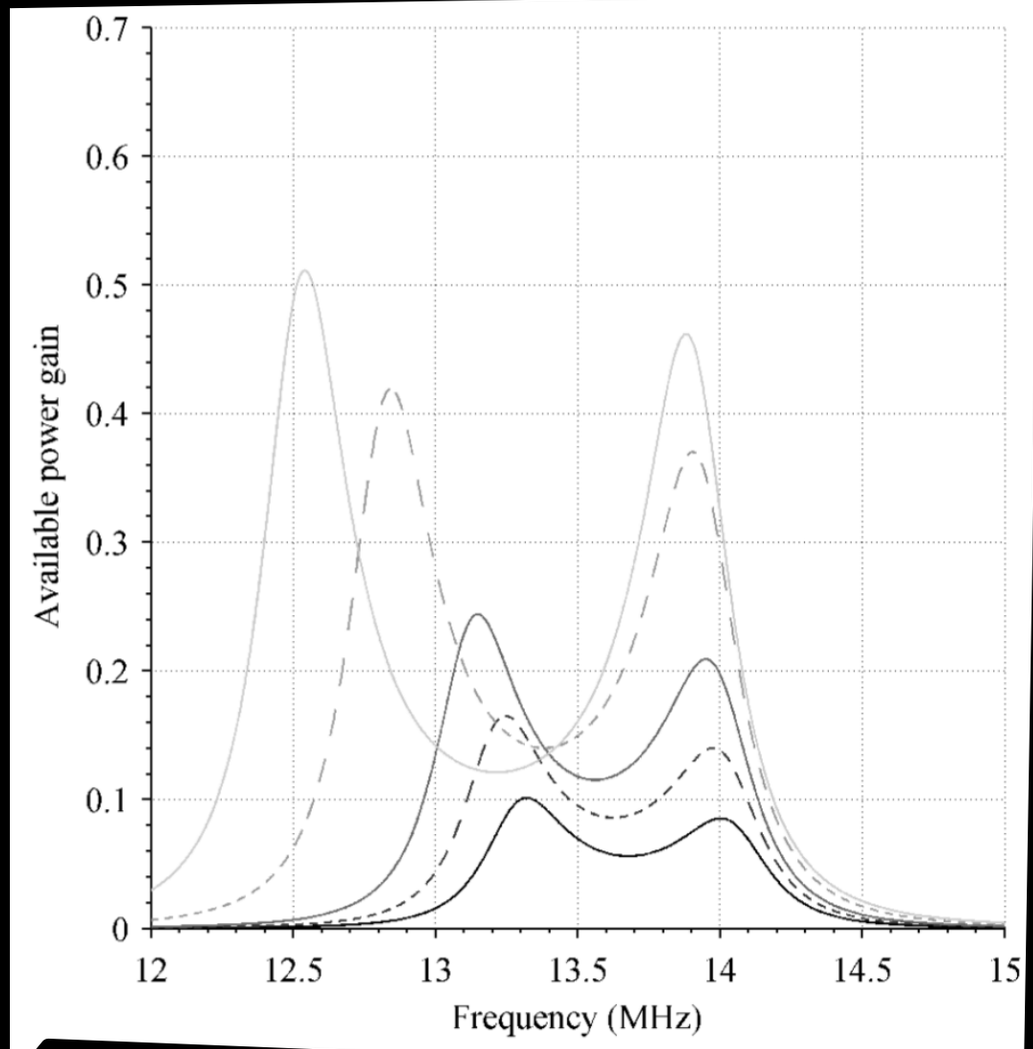

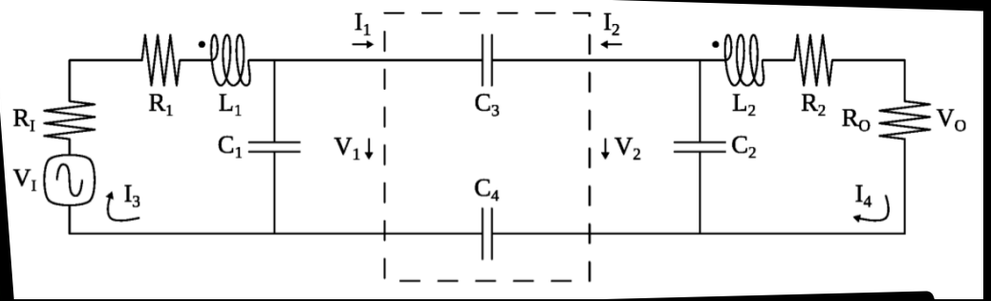
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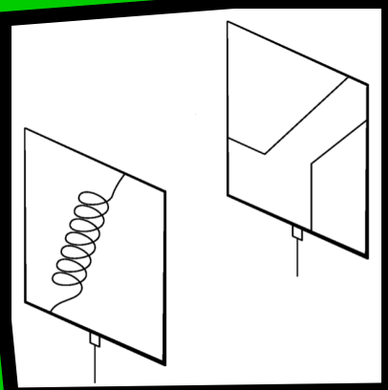
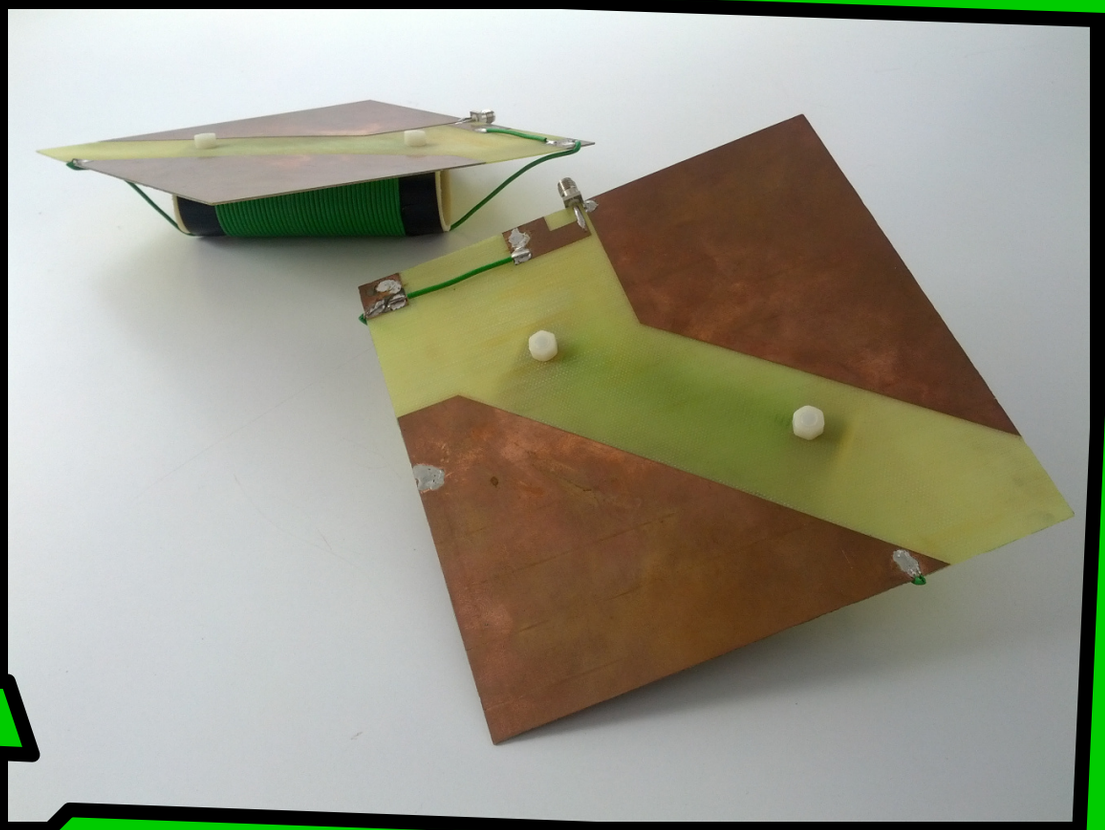
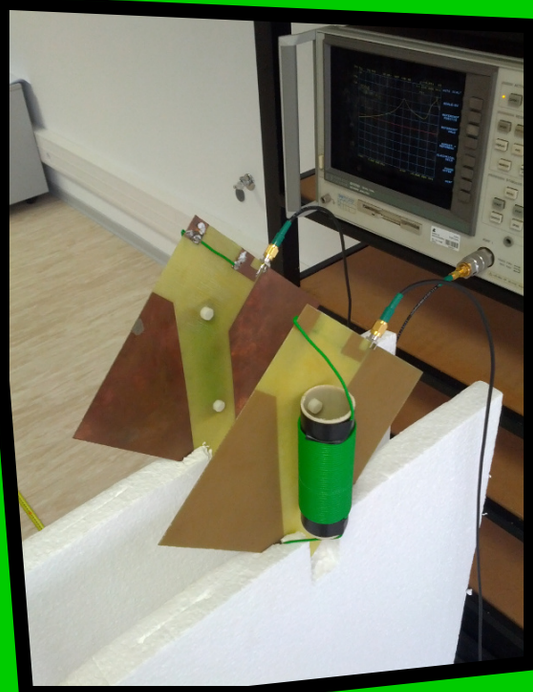
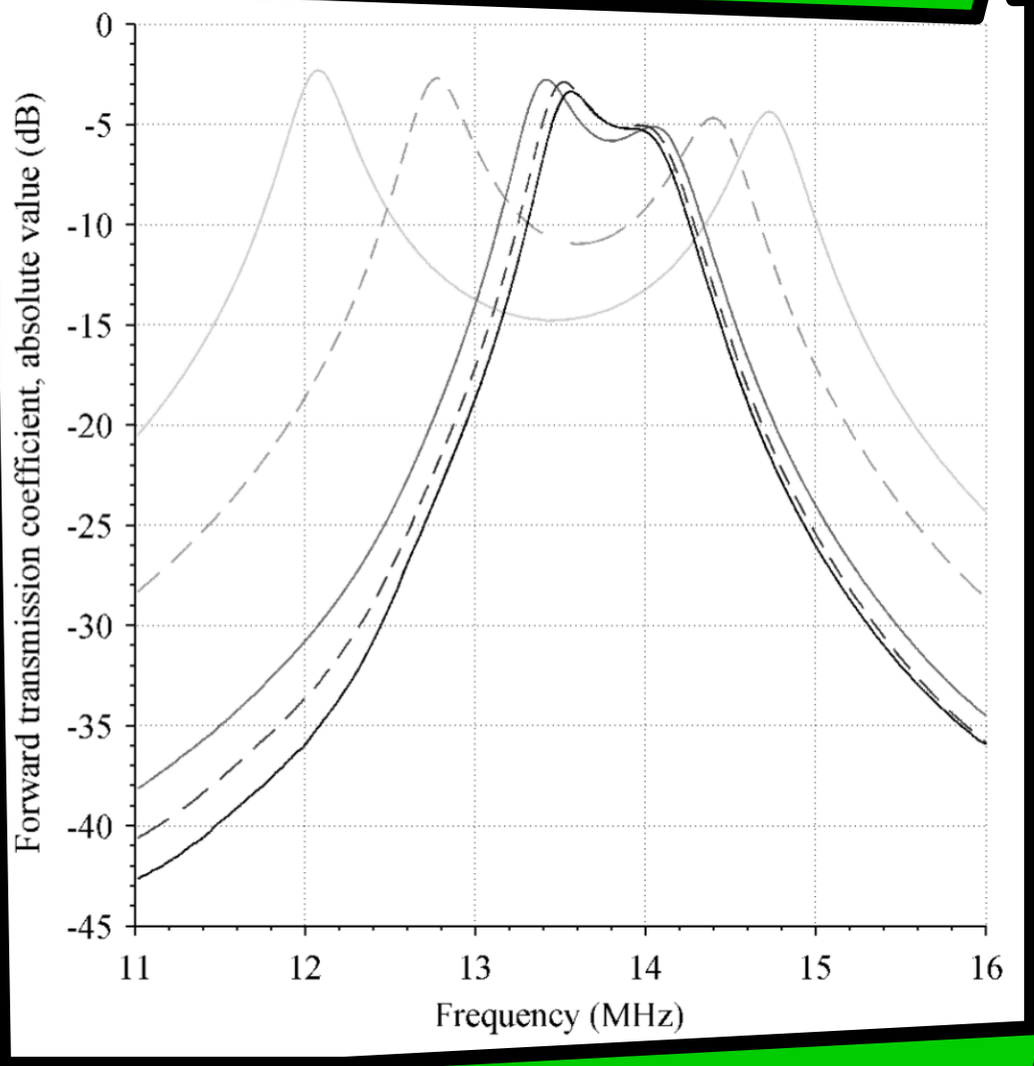
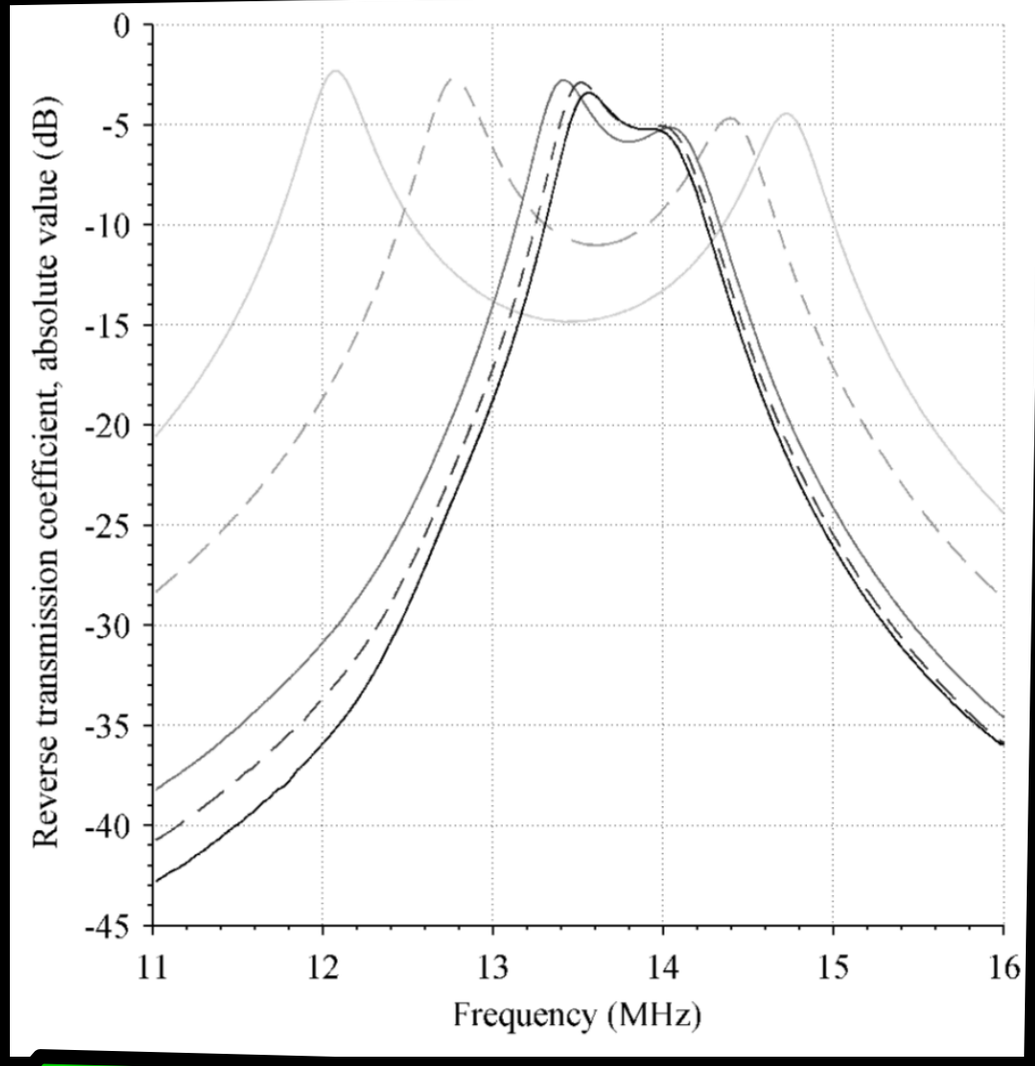






distance (cm)	10	20	60	90	500





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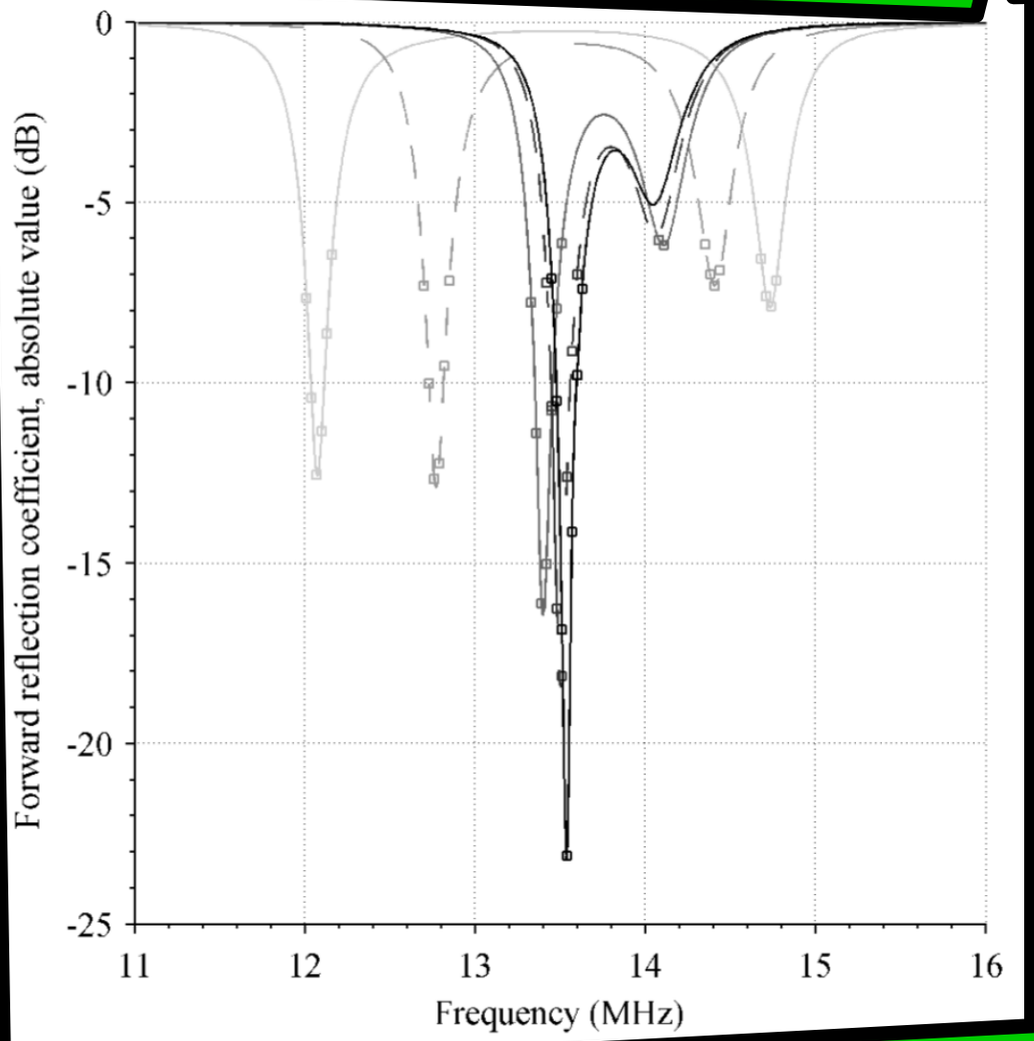
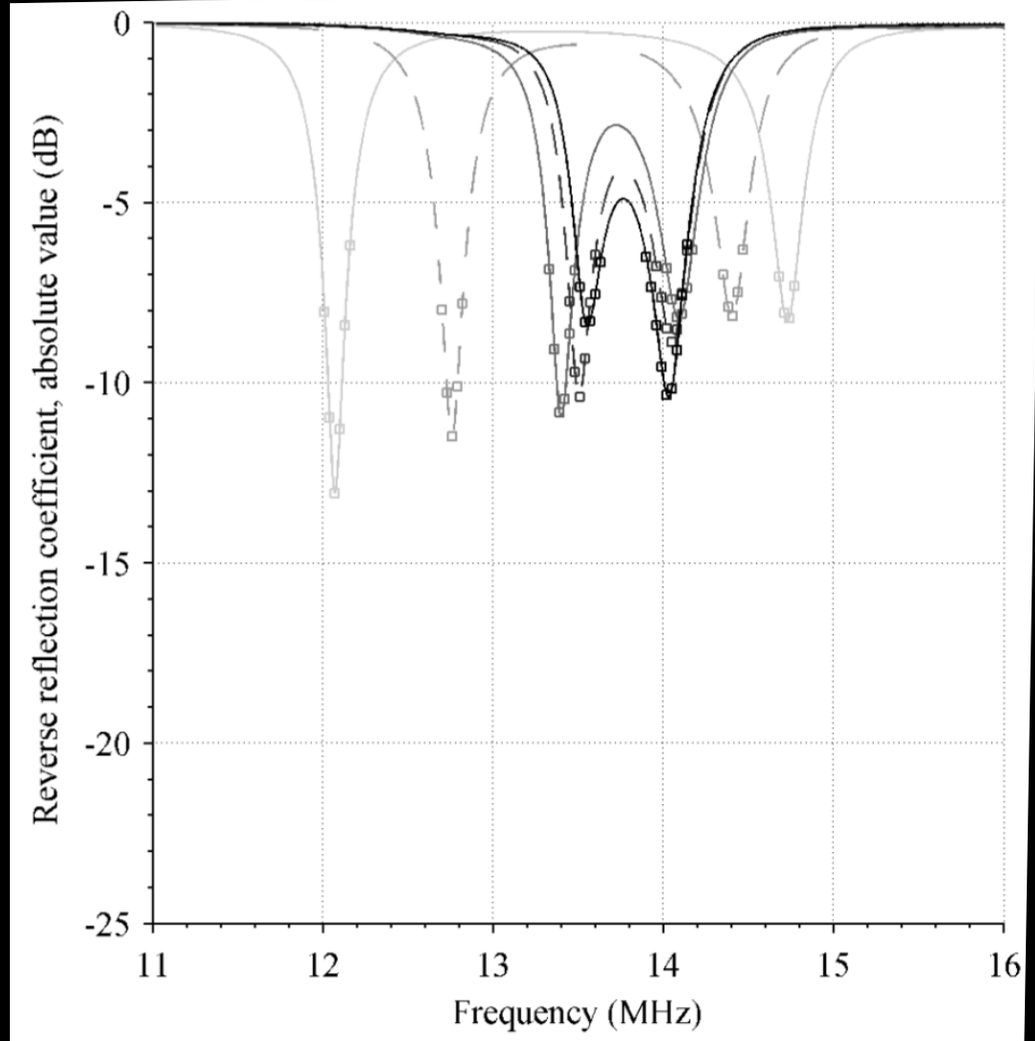
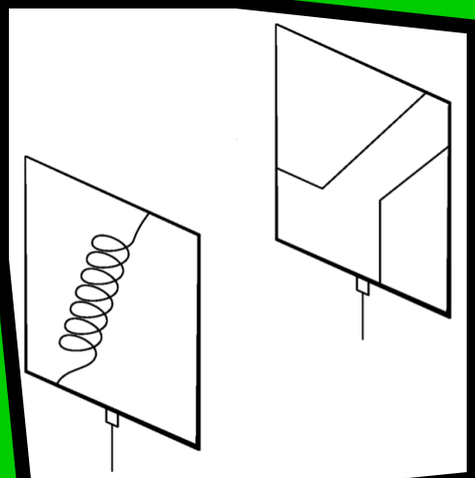
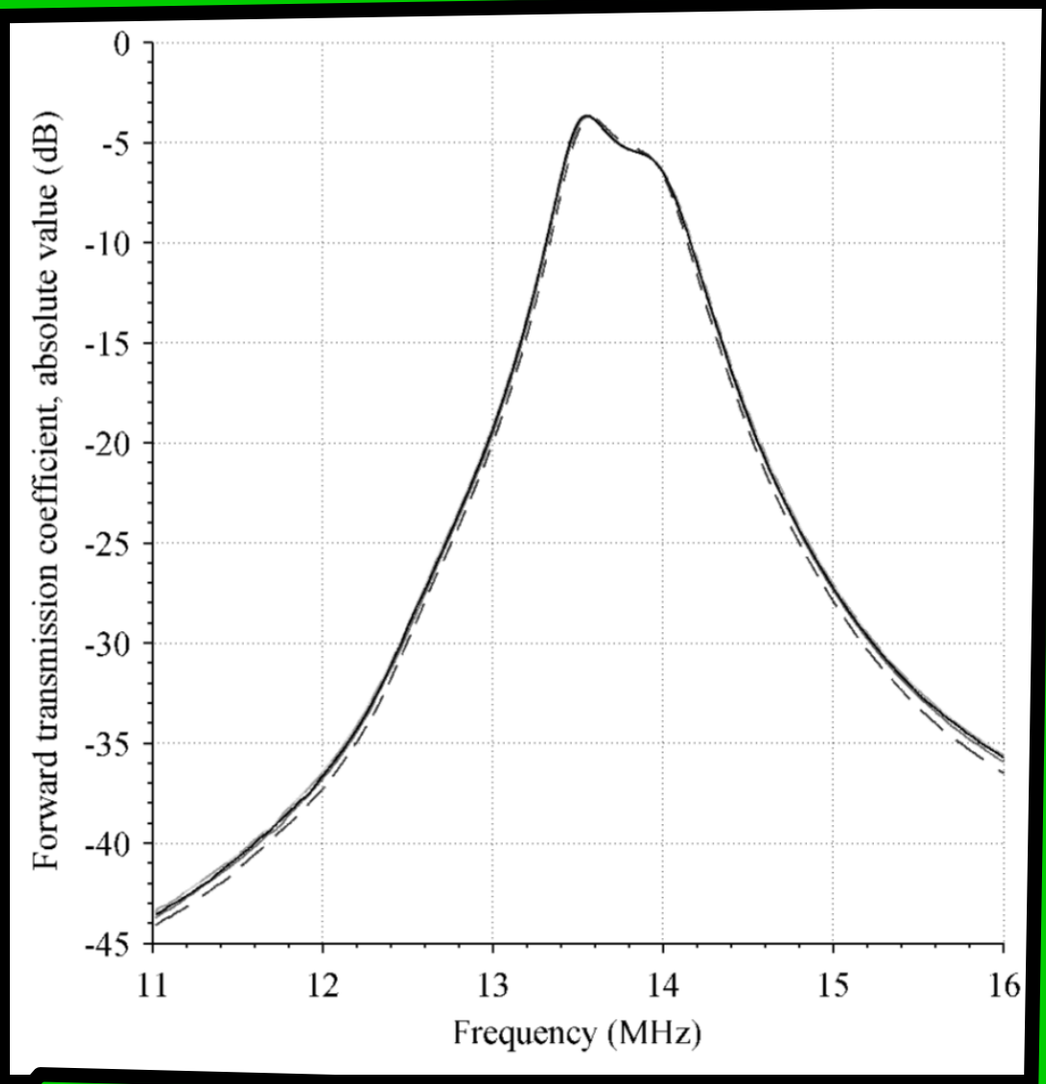


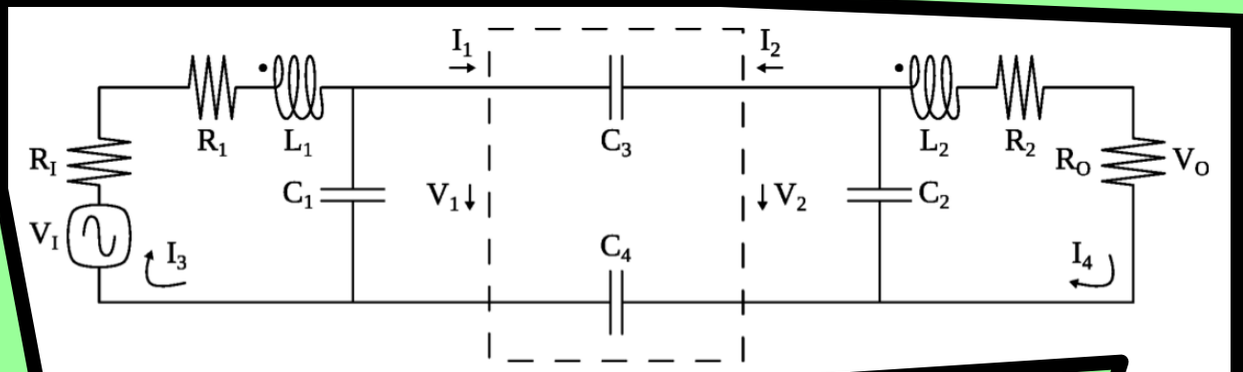


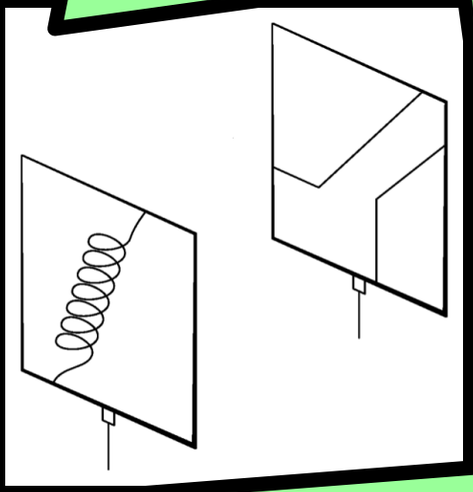
angle (°)	0	40	90	180	270



distance (cm)	500





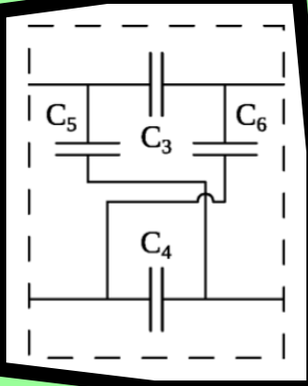


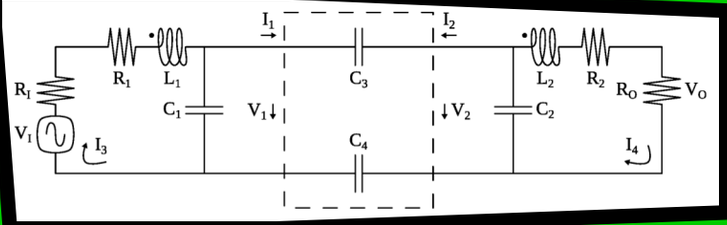
$$Y_{11} = jw \frac{C_3C_4 + C_3C_6 + C_4C_5 + C_5C_6}{C_3 + C_4 + C_5 + C_6}$$

$$Y_{12} = jw \frac{C_5C_6 - C_3C_4}{C_3 + C_4 + C_5 + C_6}$$

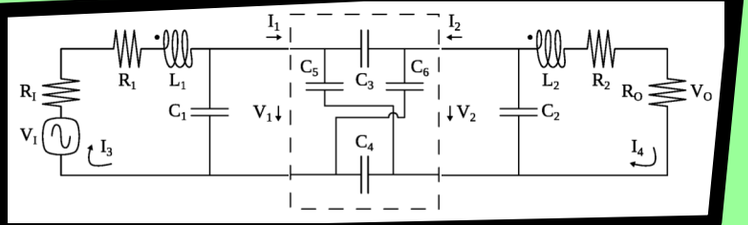
$$Y_{21} = Y_{12}$$

$$Y_{22} = jw \frac{C_3C_4 + C_3C_5 + C_4C_6 + C_5C_6}{C_3 + C_4 + C_5 + C_6}$$





$C_5 = C_6 = 0.7 C_3$



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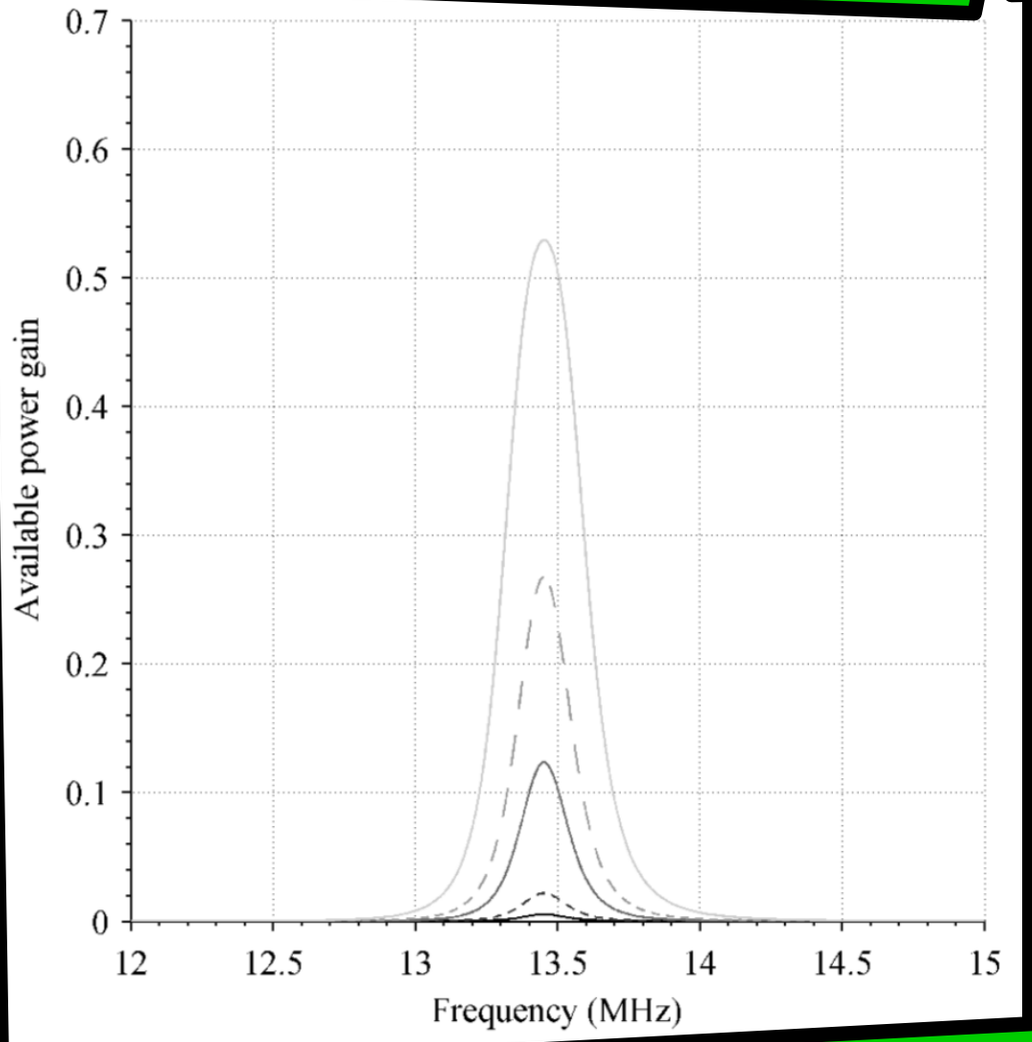
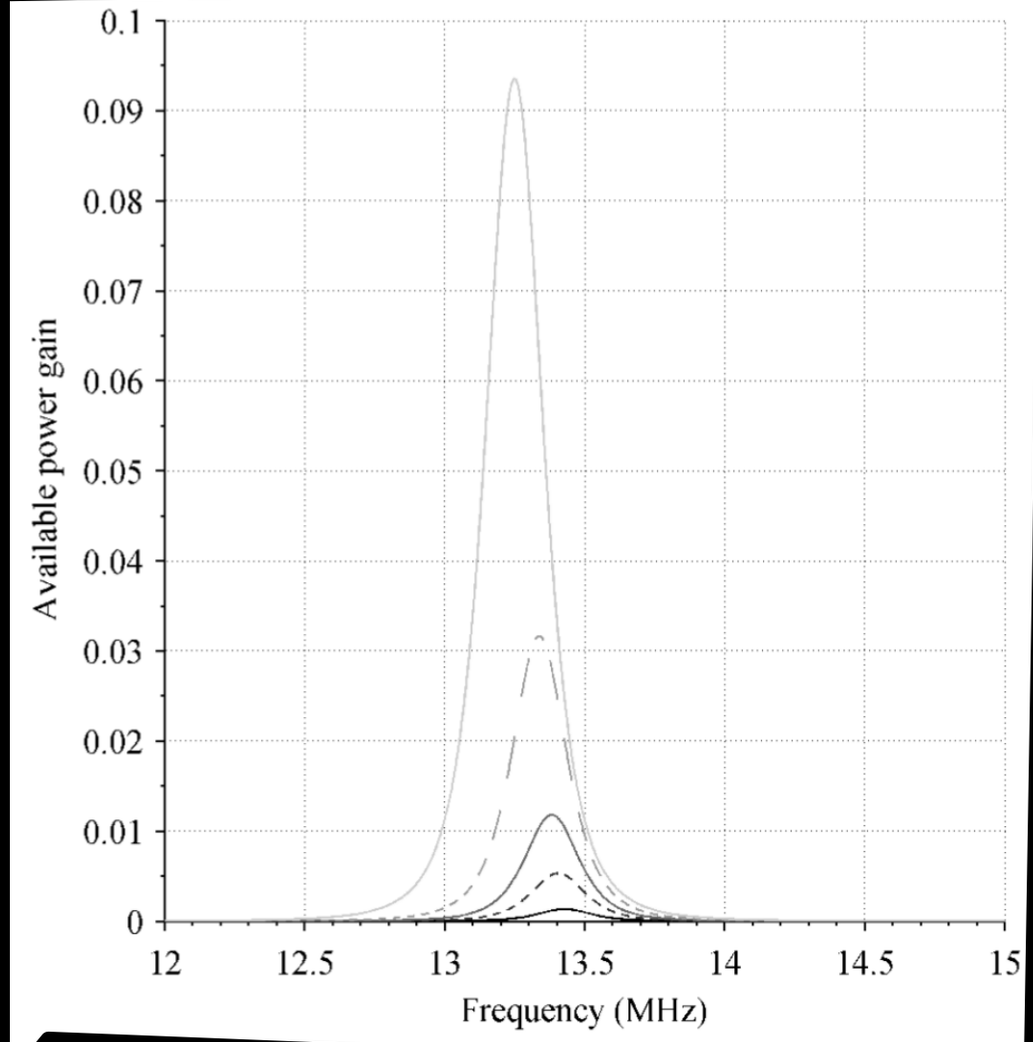
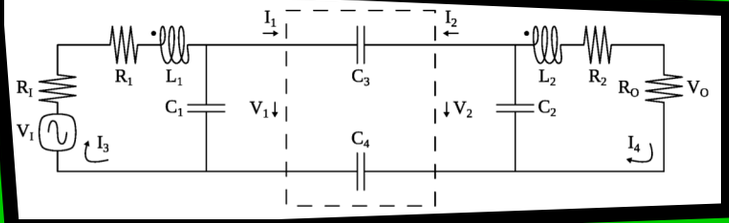
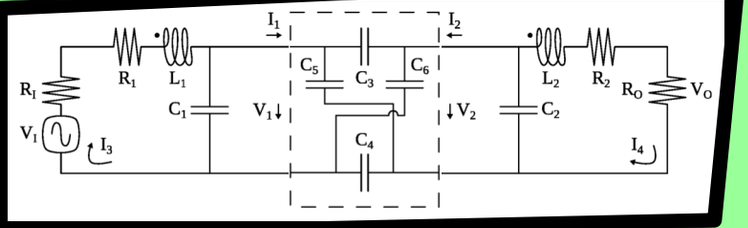


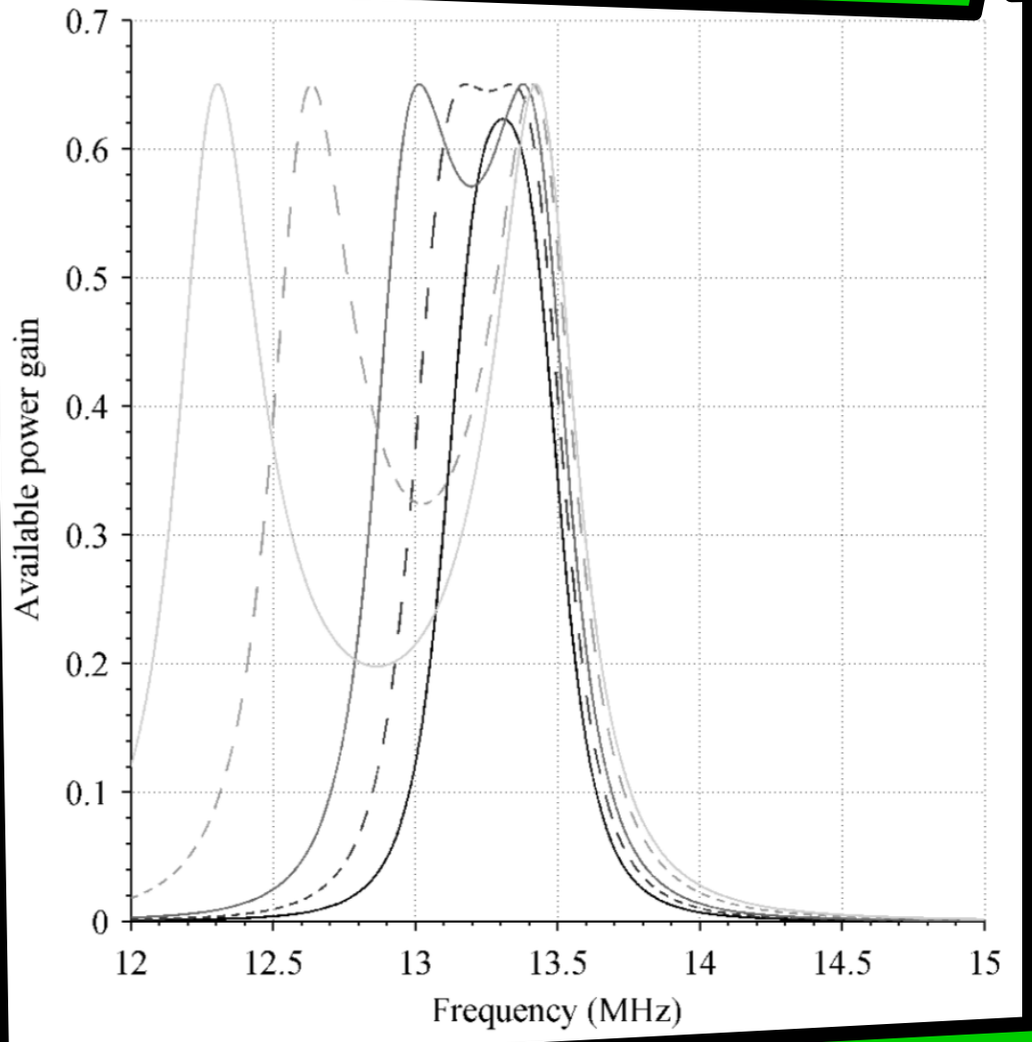


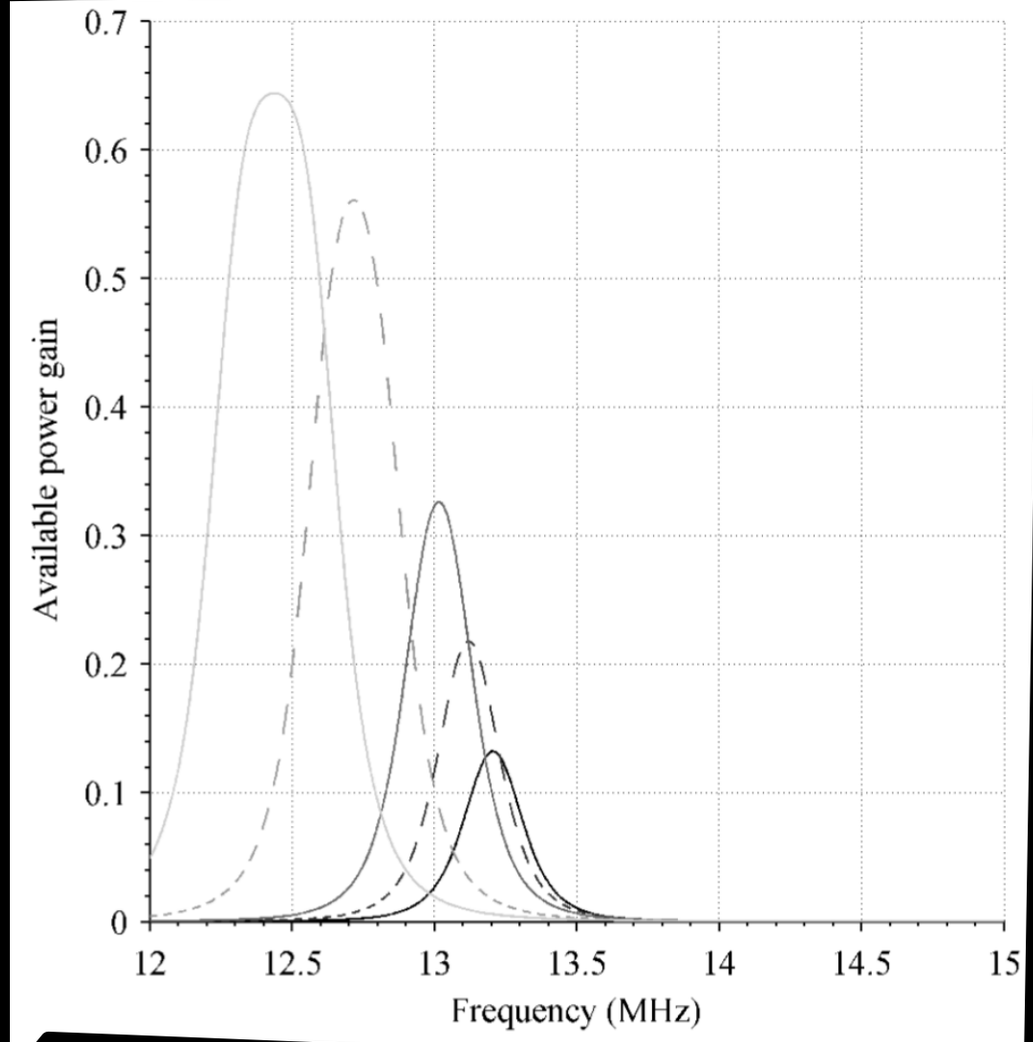


$C_5 = C_6 = 0.7\,C_3$



C_3 (pF)	0.22	0.3	0.4	0.7	1



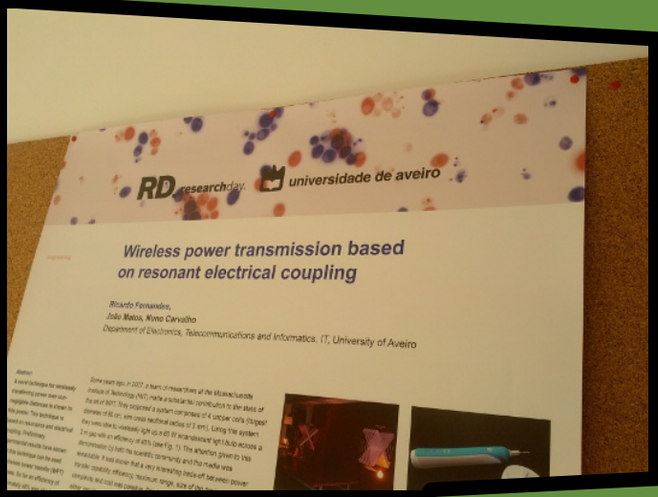


Conclusions:

Systems based on resonant magnetic coupling are currently very popular in the literature, systems based on resonant electrical coupling are not;
The duality between resonant magnetic coupling and resonant electrical coupling is quite noticeable;
It was not yet possible to obtain a complete match between experimental results and theory, but some key aspects were confirmed.

Feedback from the scientific community:

Best paper award at the IEEE Wireless Power Transfer Conference (WPTC) 2014, Jeju, South Korea, May 8-9, 2014;
Best poster award (engineering category) at the Research Day poster session promoted by the University of Aveiro.



Patent pending.

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Thank you for your attention