The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

EVS 27 (19 Nov. '13)

Study on Maximize Efficiency by Secondary Side Control Using DC-DC Converter in Wireless Power Transfer via Magnetic Resonant Coupling

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1. Background of Wireless Power Transfer
2. Relation between efficiency and secondary impedance
3. Changing impedance using DC-DC converter
4. Experiment: improving efficiency using DC-DC converter
5. Conclusion

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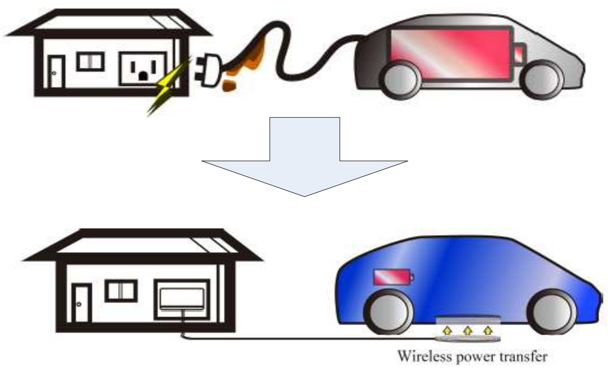
Why wireless power transfer?

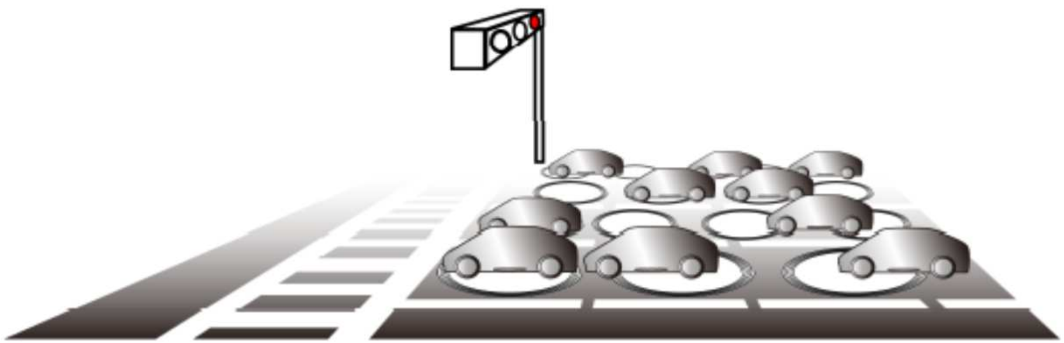
What is Wireless Power Transfer (WPT)?

- the technology of sending electric power to load without any cable.

If WPT applied to Electric Vehicles (EV) ...

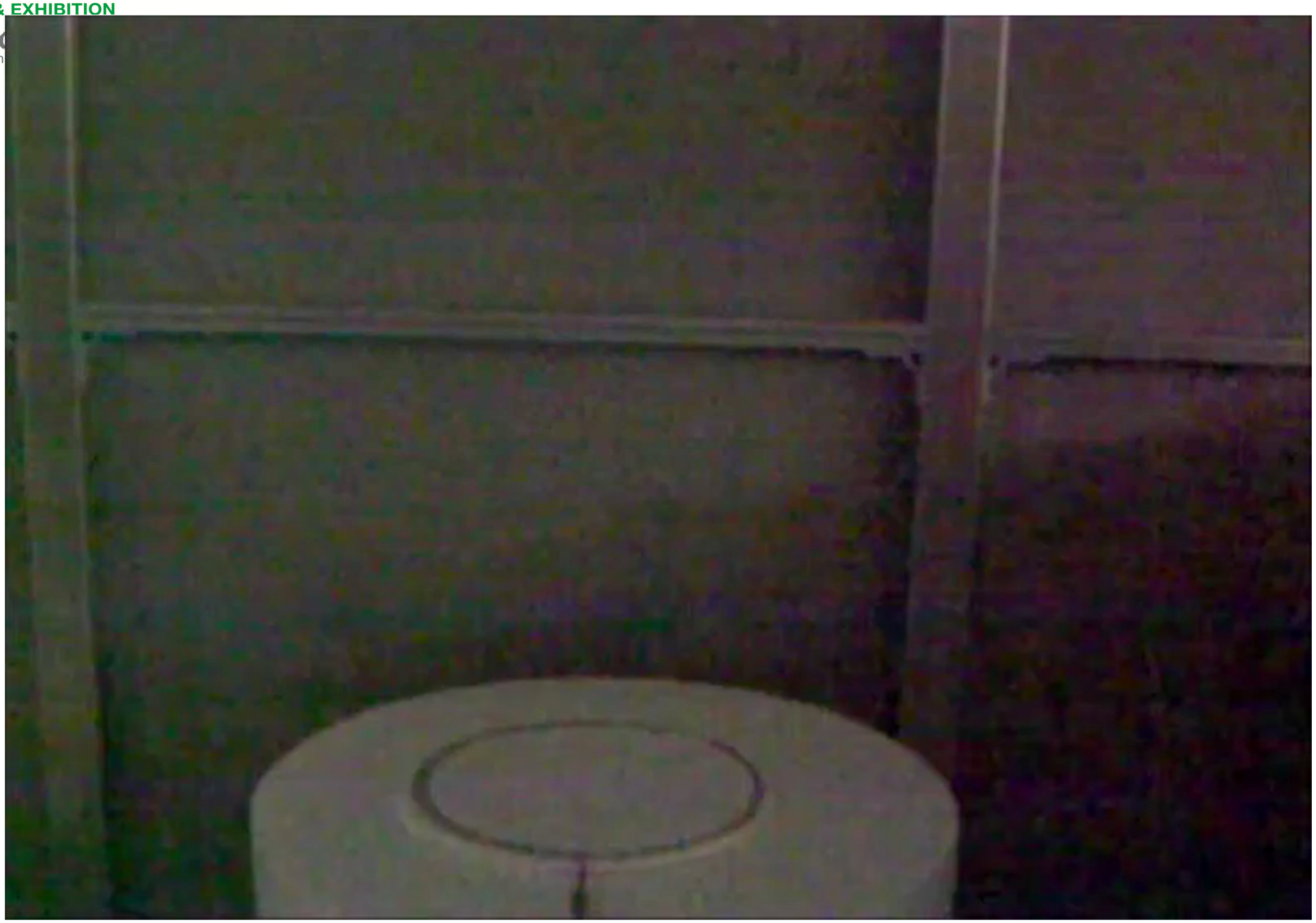
- Convenience & Safety – contactless
- Battery become smaller –be charged anywhere





WPT technology is useful for EV

Magnetic resonant coupling (Movie)

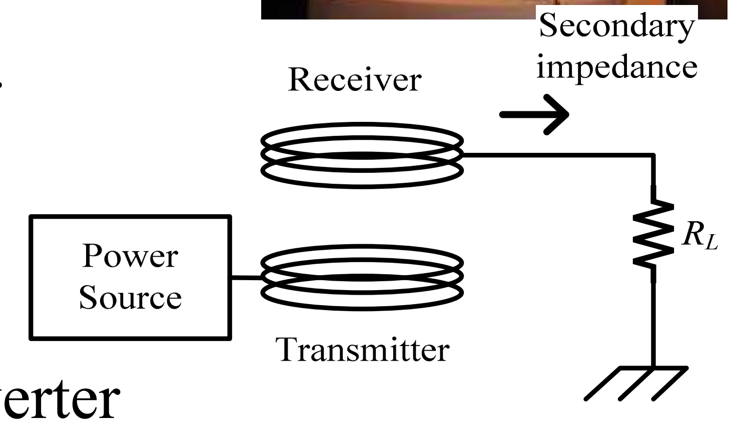


Overview of research

How to improve efficiency?

1.Increase performance of transmitter and receiver

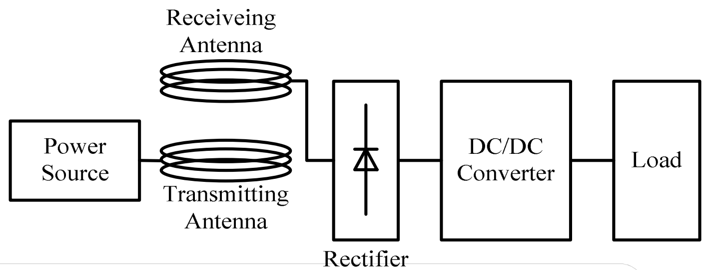
2.Tune secondary impedance to optimum value



Overview of this research

Study on maximized efficiency using DC-DC converter

1. Relation between efficiency and secondary impedance
2. Principle of changing impedance using DC-DC converter and control method
3. Experiment of WPT with DC-DC converter



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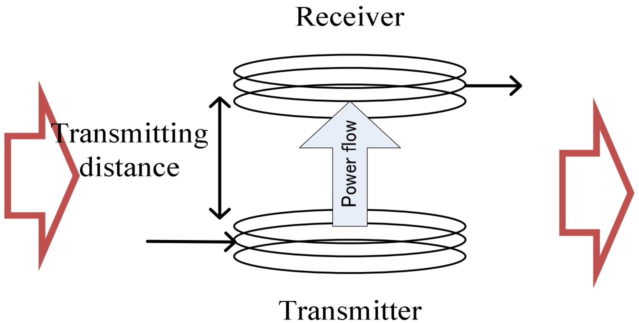
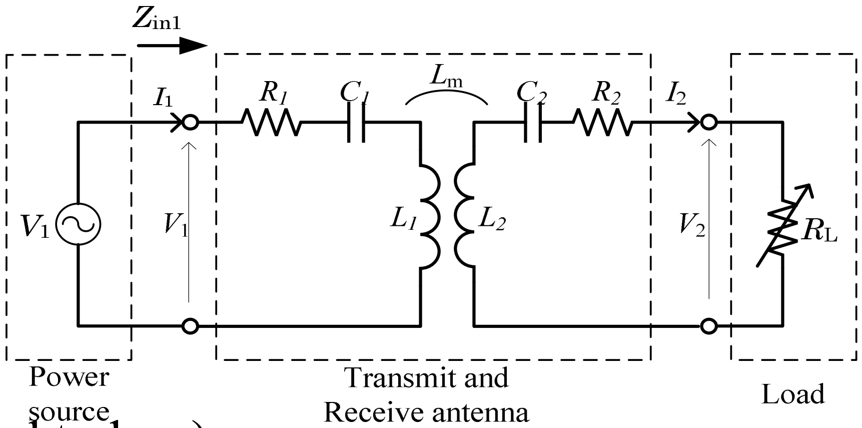
Equivalent circuit and transmitting efficiency

Equivalent circuit





- R_1, R_2: Transmitter and receiver resistance (related to loss)
- L_1, L_2: Coil inductance
- C_1, C_2: Capacitance
- L_m : Mutual inductance (related the transmitting distance)
- Z_{in2}: Secondary input impedance (same as R_L in this case)

Change according condition

Efficiency equation (A_P)

▪Derived from the equivalent circuit

$$A_P = \frac{(\omega_0 L_m)^2 Z_{in2}}{(Z_{in2} + R_2)\left\{R_1 Z_{in2} + R_1 R_2 + (\omega_0 L_m)^2\right\}}$$

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Analyze characteristics of efficiency: Analysis setup

Analysis objective

•Clarify efficiency characteristics when load value and transmitting distance changes

Analysis condition

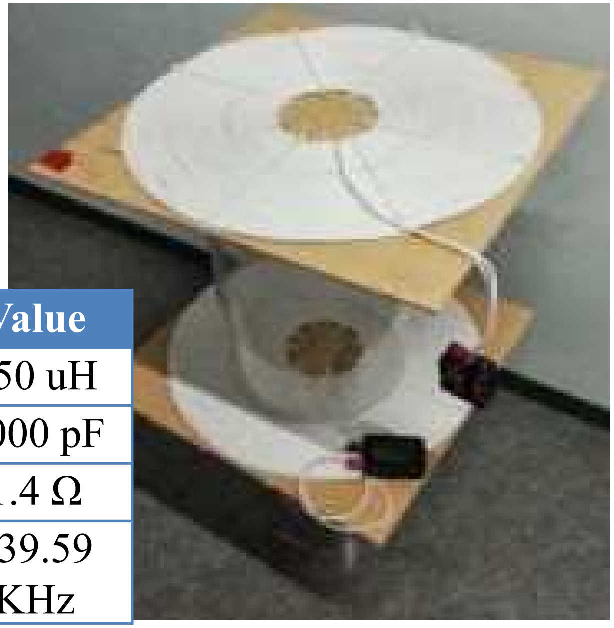
•Using Equation of efficiency (A_P)

•Parameter :Actual coil used for experiment

•Transmitter and receiver are the same

($L_1 = L_2$, $C_1 = C_2$, $R_1 = R_2$)

$$A_P = \frac{(\omega_0 L_m)^2 Z_{in2}}{(Z_{in2} + R_2)\{R_1 Z_{in2} + R_1 R_2 + (\omega_0 L_m)^2\}}$$



Description	Value
Outer diameter [mm]	450
Inner diameter [mm]	115
Number of turn [turn]	50
Pitch [mm]	3.4
Wire cross-section area [mm2]	2.0

Transfer distance [cm]	L_m [uH]
20	86.3
30	41.4
40	22.2

parameters	Value
L_1 , L_2	650 uH
C_1, C_2	2000 pF
R_1, R_2	1.4 Ω
Resonant Frequency	139.59 KHz

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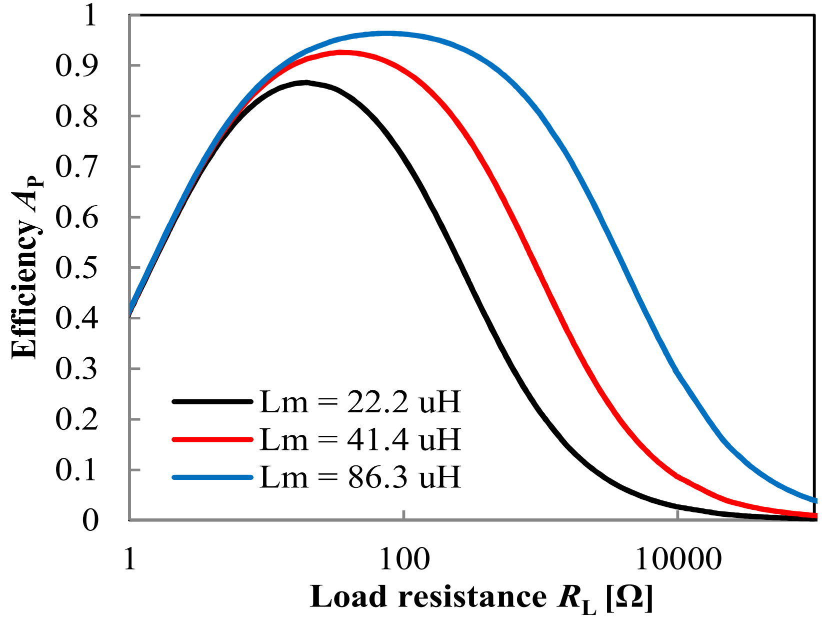
Optimum secondary impedance

Analysis result: changing load resistance

Efficiency (A_P) peaks at certain load value (R_L)

- Important to set optimum secondary impedance



Optimum secondary impedance ($Z_{in2APmax}$)

$$Z_{in2AP\max} = \sqrt{R_2\left(\frac{(\omega_0 L_m)^2}{R_1} + R_2\right)}$$

Transfer distance [cm]	L_m [uH]	Optimum impedance $Z_{in2APmax}$ [Ω]
20	86.3	75.7
30	41.4	36.3
40	22.2	27.8

1. Background of Wireless Power Transfer

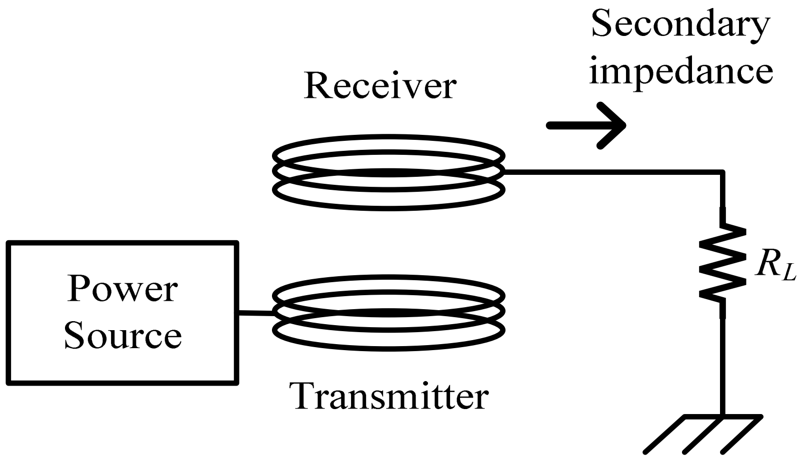
2. Relation efficiency and secondary impedance

3. **Change impedance by DC-DC converter**

4. Experiment: improve efficiency by DC-DC converter

5. Conclusion

Method of changing impedance



How to chance secondary impedance?

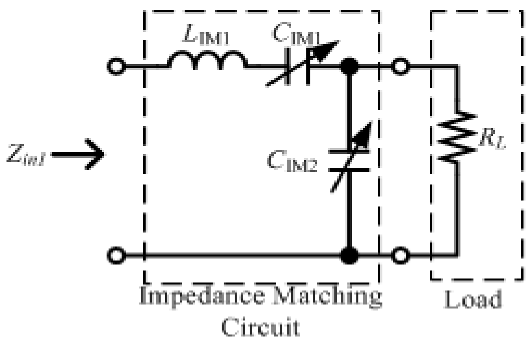
Load resistance depend on load condition

- Cannot be changed by WPT system
    - ➢ Method of change impedance is needed

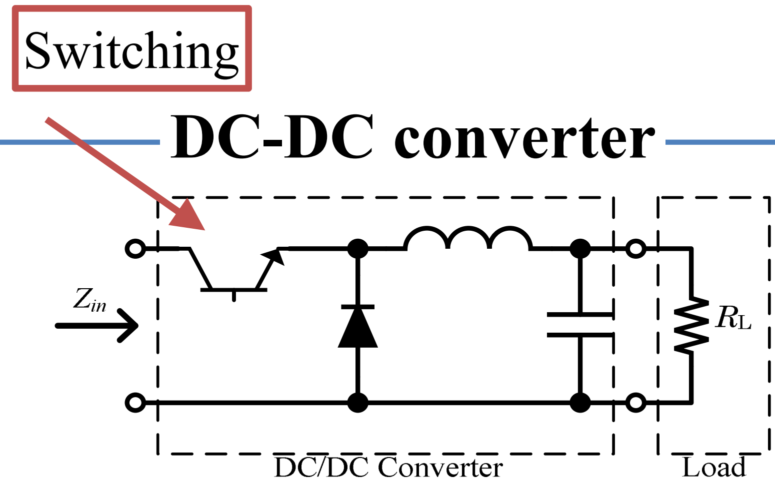
How to change impedance ?

1. **Impedance matching circuit (LC circuit)**
    - Popular in radio technology.
    - Slow response because of mechanical elements (relay, variable capacitance)
2. **DC-DC converter**
    - Fast response : No mechanical elements
    - Suitable for EV : Power electronics

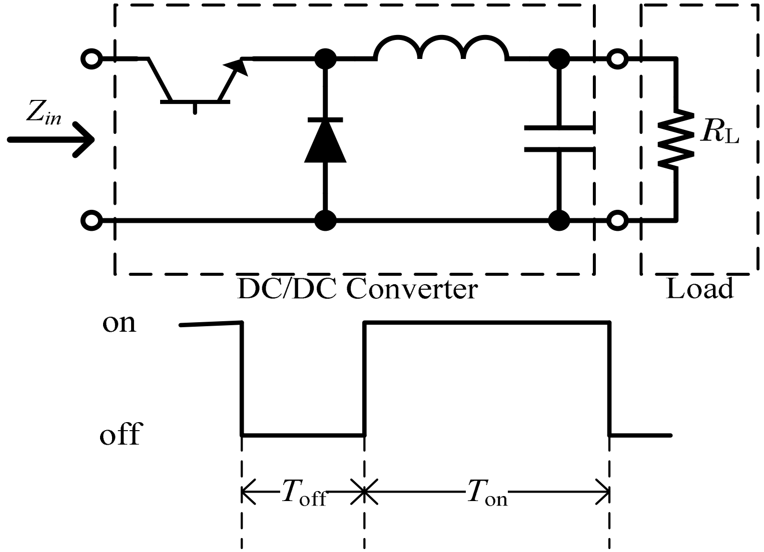
Impedance matching circuit



DC-DC converter



Changing impedance using DC-DC converter



changing impedance by DC-DC converter

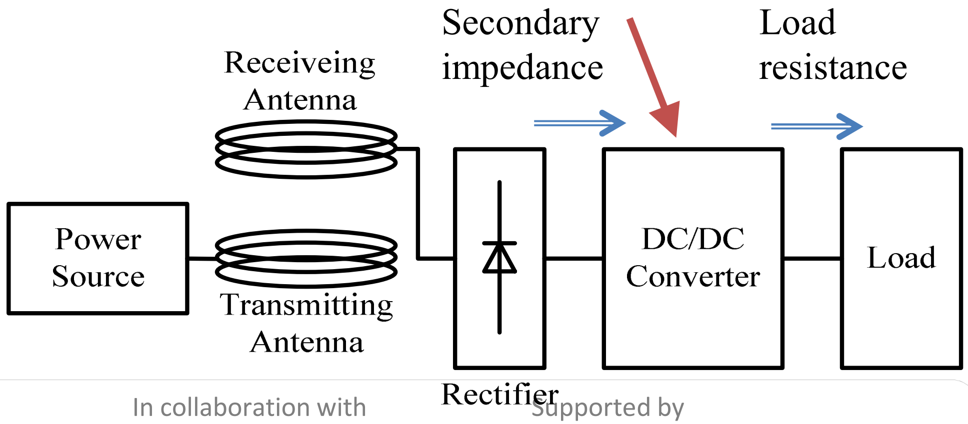
- Changing impedance by switching
- Conversion equation

$$Z_{in2} = \frac{R_L}{D^2} \qquad R_L \le Z_{in2} \le \infty$$

- D: Duty cycle

$$D = \frac{T_{on}}{T_{on} + T_{off}} \qquad (0 \le D \le 1)$$

Convert to optimum impedance



Application of WPT

- Insert in secondary side
  - ➢ Changing secondary impedance to optimum

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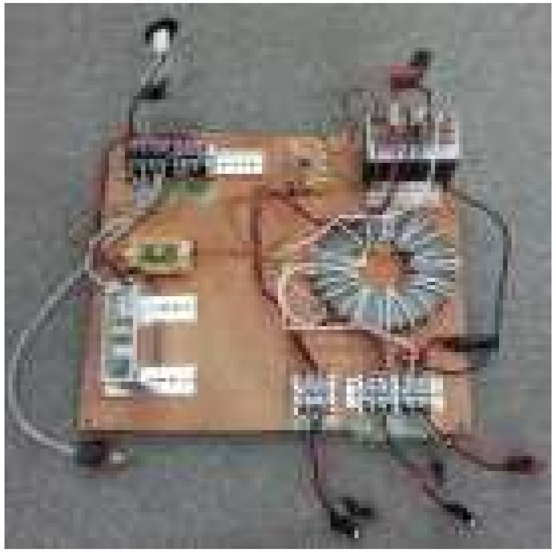
Experiment: setup

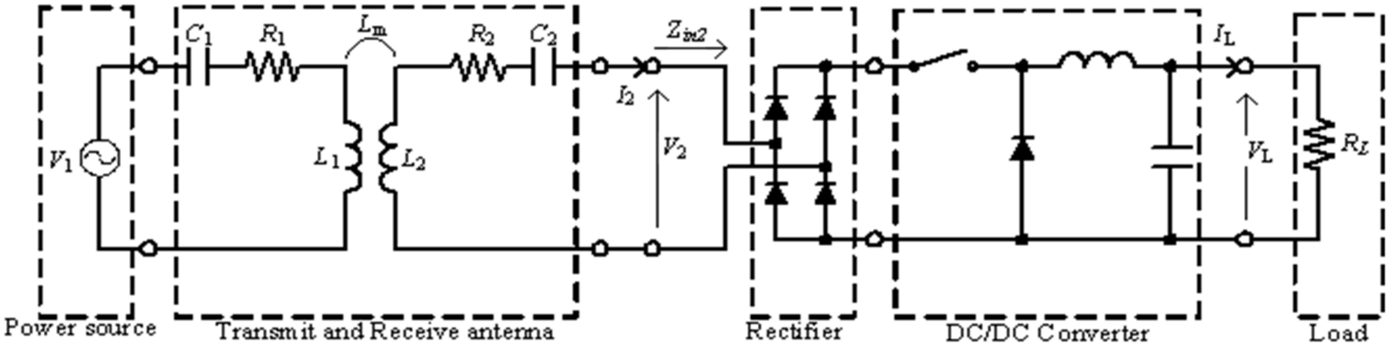
Experiment method & condition

- Compare with and w/o DC-DC converter
- Transmitting distance: 20cm and 40cm

Experiment equipment

- Transmitter and Receiver: same one used for analysis
- DC-DC converter: use IGBT, 20KHz switching





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Experiment: results

Transfer distance [cm]	Optimum impedance $Z_{in2APmax}$ [Ω]
20	75.7
40	27.8

$$R_L \leq Z_{in2} \leq \infty$$

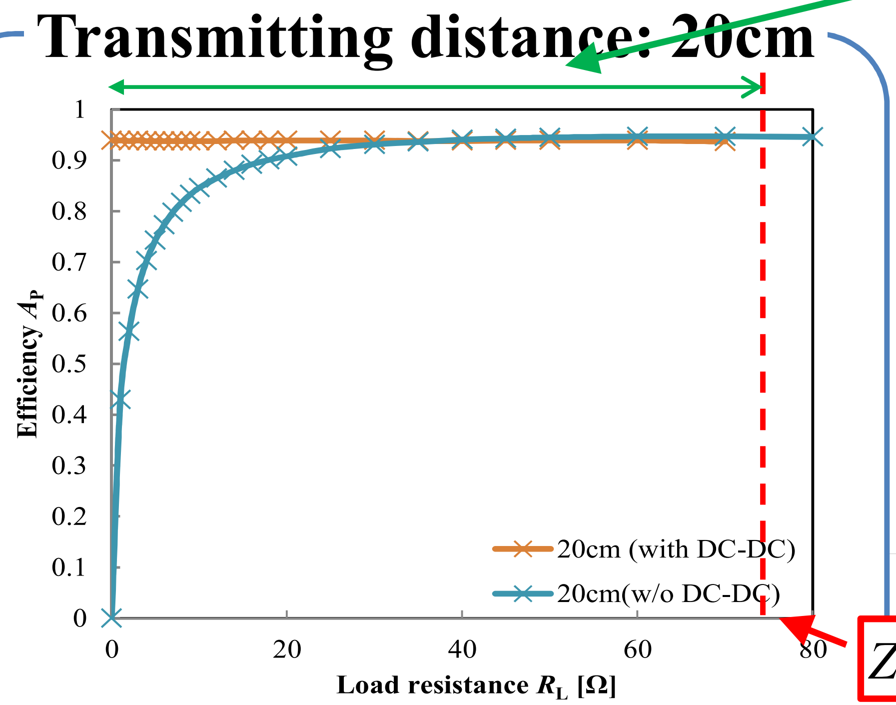
Result: Transmitting distance: 20cm

efficiency has improved in case $R_L < Z_{in2APmax}$

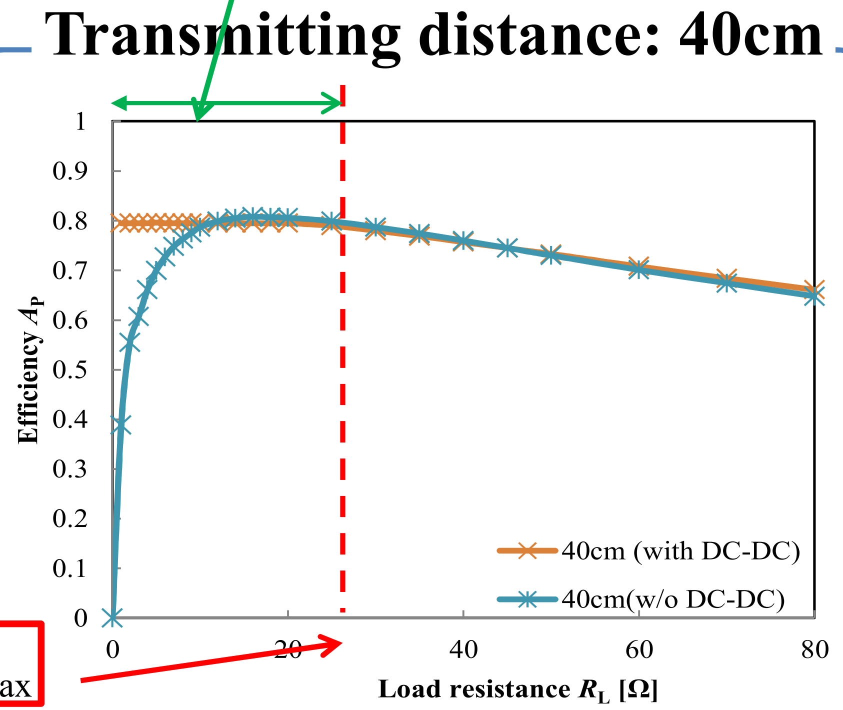
Result: Transmitting distance: 40cm

efficiency peak is not matched from analysis result but efficiency has improved in low R_L

Improved efficiency



$Z_{in2APmax}$



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Conclusion

Method for transmission efficiency improvement using DC-DC converter is proposed

1.Relation between efficiency and secondary impedance is explained

2.Principle of changing impedance using DC-DC converter is explained

3.Experiment is performed. And confirm transmission efficiency is improved by DC-DC converter.

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Thank you for your attention

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Control method of DC-DC converter

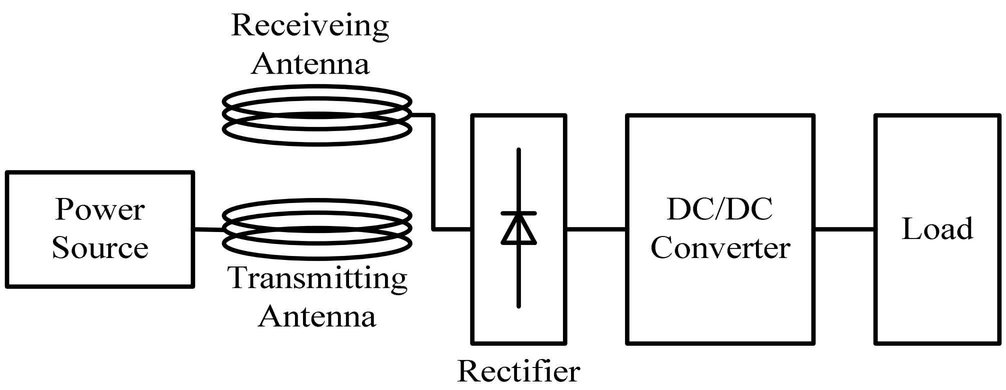
$$R_{L\_AP\max} = \sqrt{R_2\left(\frac{(L_m\omega_0)^2}{R_1} + R_2\right)}$$

Obtaining Lm value

How to obtain Lm value?

=> Fix primary voltage (V_1) to a constant value, estimate from secondary voltage (V2)

Communication between primary and secondary is not needed



$$\hat{L}_m = \frac{\frac{V_1}{V_2}Z_{in2} + \sqrt{\left(\frac{V_1}{V_2}Z_{in2}\right)^2 - 4R_1(Z_{in2}+R_2)}}{2\omega_0}$$

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Analyze characteristics of efficiency: Analysis result

Analysis result: transmitting distance has change

Efficiency (A_P) is high when mutual inductance (L_m) is large

- ➢ Efficiency is high when transmitting distance is near