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June 19-22 2016 EVS29

Sensorless Vehicle Detection Using Voltage Pulses in Dynamic Wireless Power Transfer System

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Outline

1. Introduction
2. Dynamic Wireless Power Transfer for Electric Vehicles
3. Sensorless Transmitting ON/OFF Switching System
4. Experiment
5. Conclusion



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1. Introduction
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1. Introduction

Advantages of Electric Vehicles

- Environmentally friendly
- Less noise and vibration
- High controllability



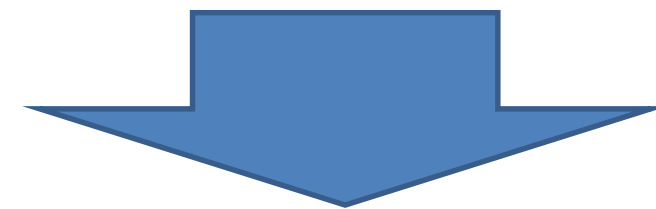
Nissan leaf

[1] Auto blog : <http://jp.autoblog.com/2010/12/04/nissan-launched-ev-leaf/>

1. Introduction

Disadvantages of Electric Vehicles

- Short cruising range (about 150km/1 charge)
- Long charging time (~ 8 hours)
- Troublesome and dangerous charging process
- High price



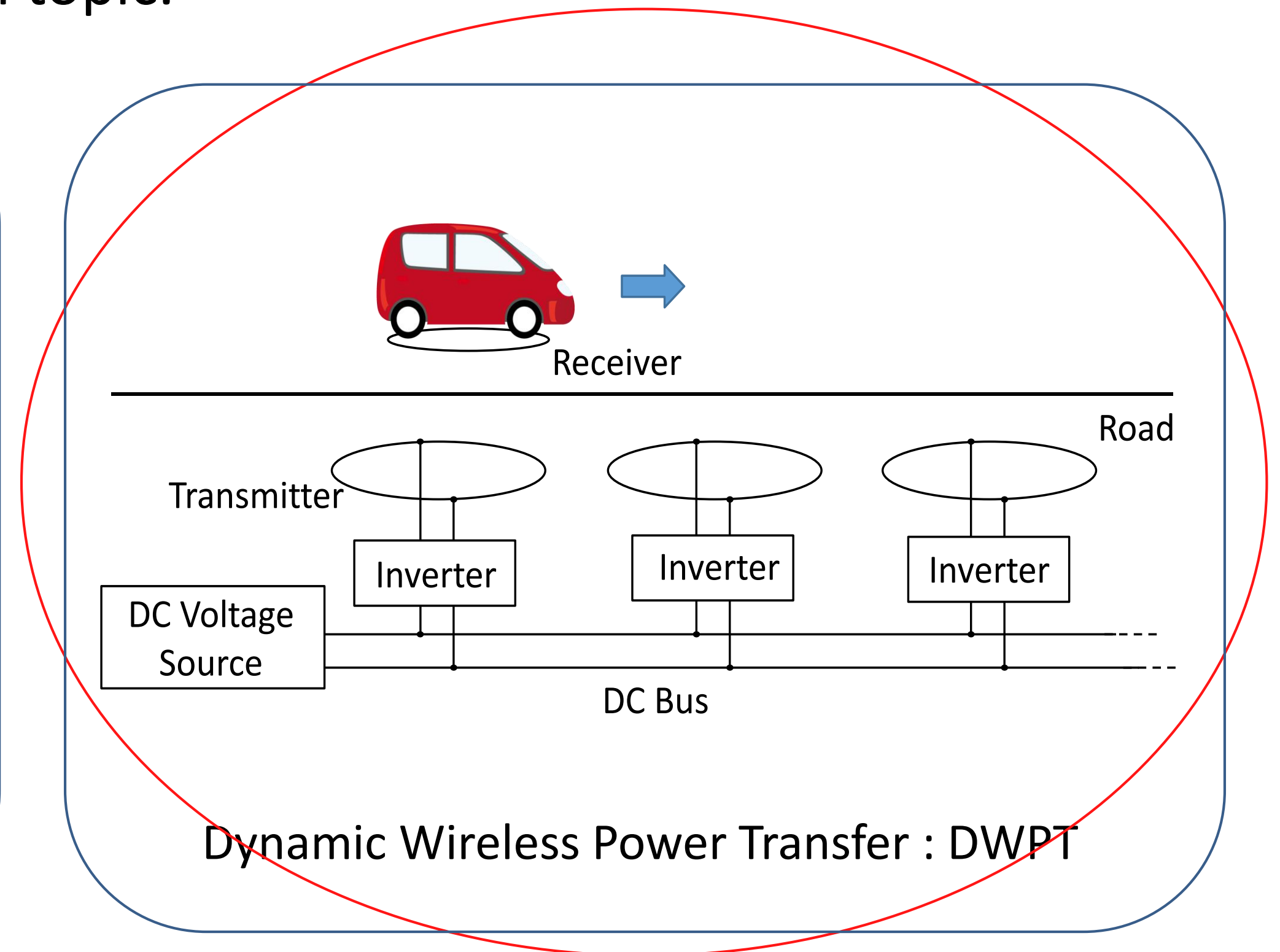
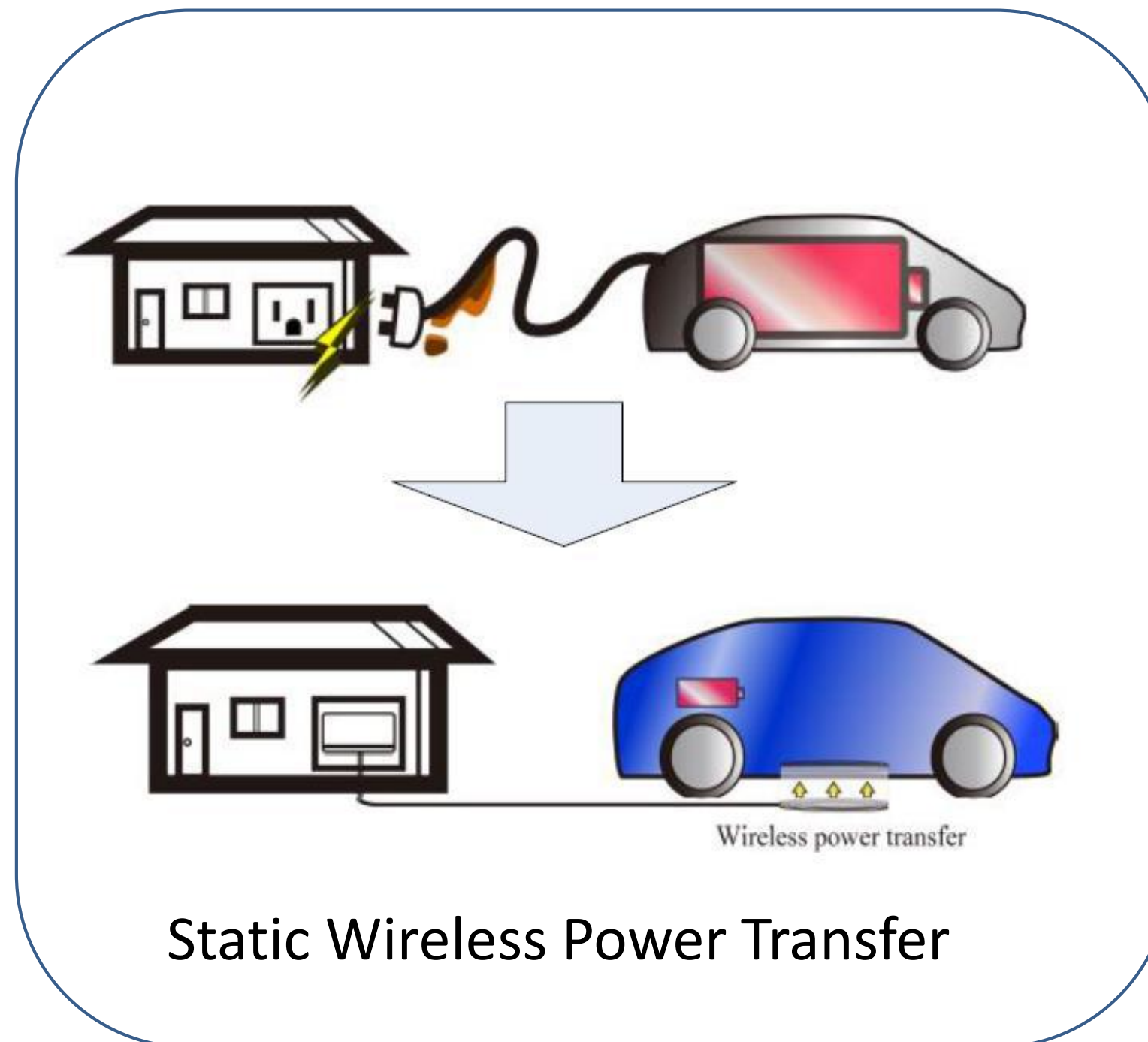
These problems are related to the energy storage system.

1. Introduction

As one of the solutions,

Wireless Power Transfer (WPT) for EVs

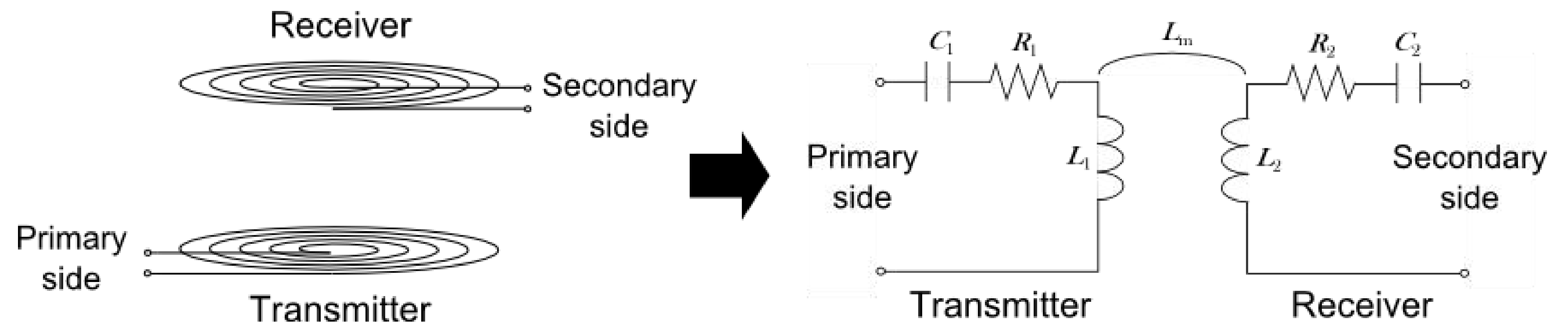
has become a mainstream research topic.



1. Introduction

□ Wireless Power Transfer (Magnetic resonant coupling)

- Use **LC resonance**
- High efficiency
- Long transmitting distance





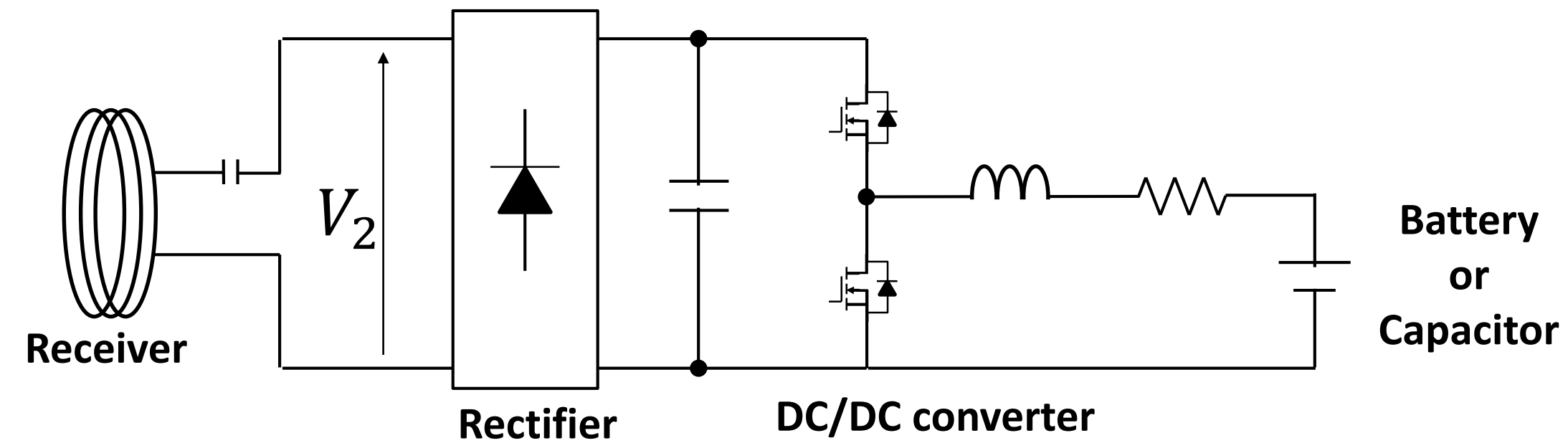
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2. Dynamic Wireless Power Transfer for Electric Vehicles

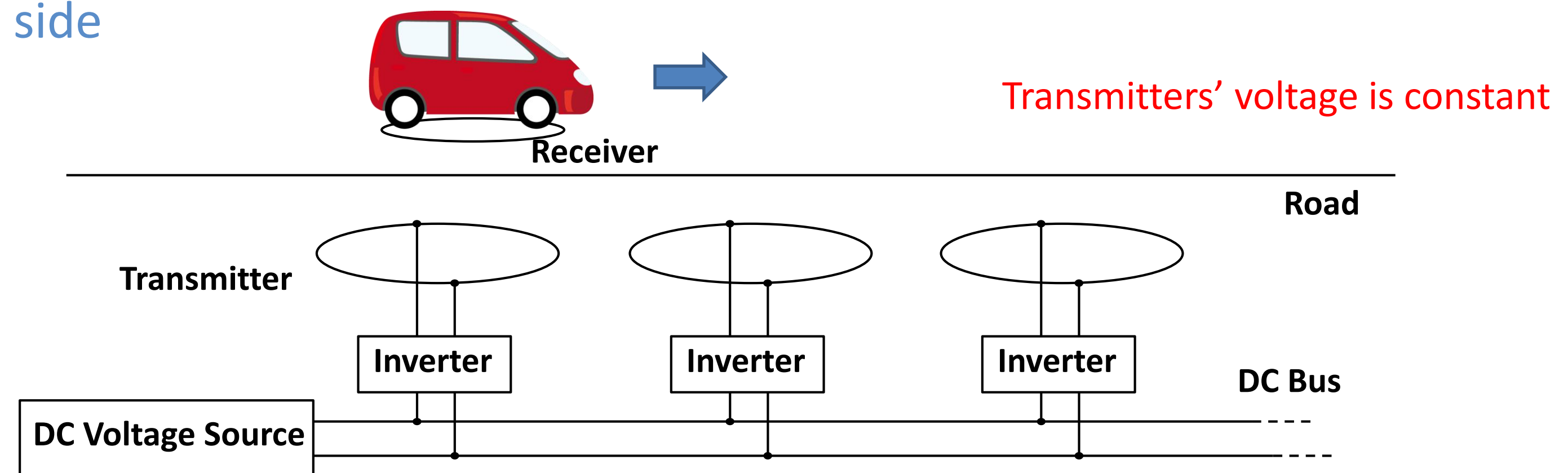
□ Proposed DWPT system

Receiving side



- Controllable secondary voltage V_2 with a DC/DC converter

Transmitting side



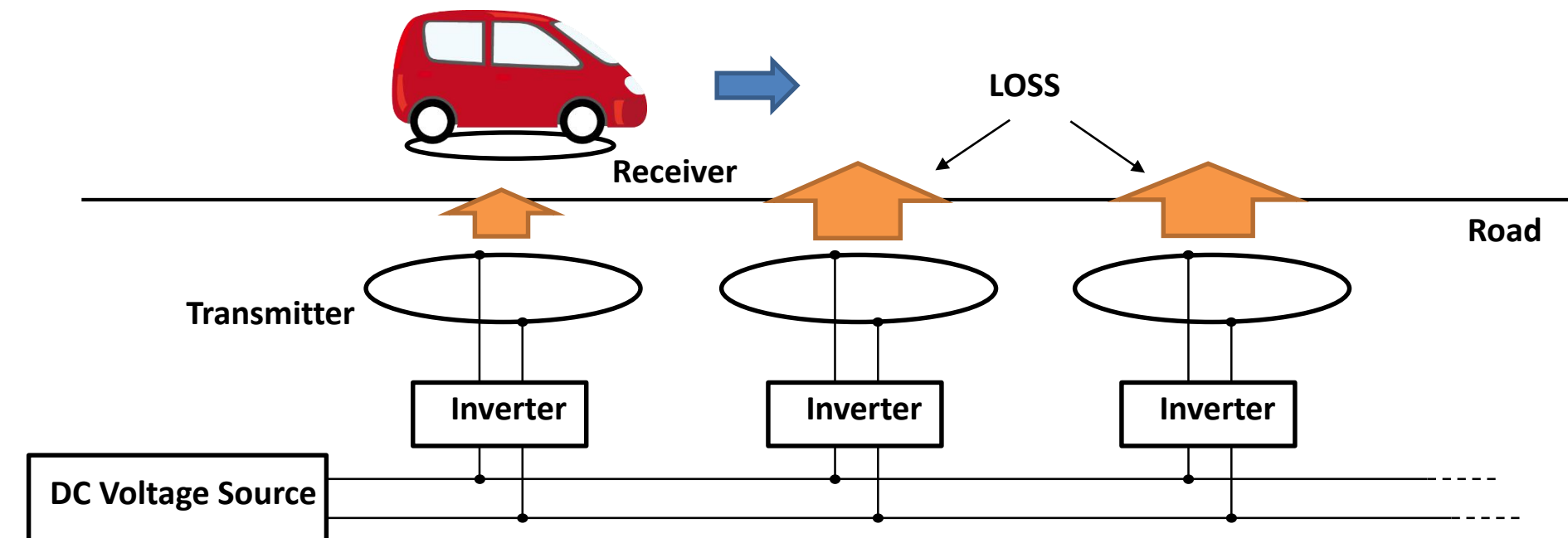
Pros
Cons

Simple (efficient), Easily designed, High power
Necessity of vehicle detection and inverter ON/OFF control

2. Dynamic Wireless Power Transfer for Electric Vehicles

□ Problem of the proposed DWPT system

Huge current loss when no receiving coil is on a transmitter



Conventional

- Constant current control
Not simple
- Vehicle detection with additional sensors
High cost and complexity



Proposed

Automatic transmitting ON/OFF switching system without additional sensor

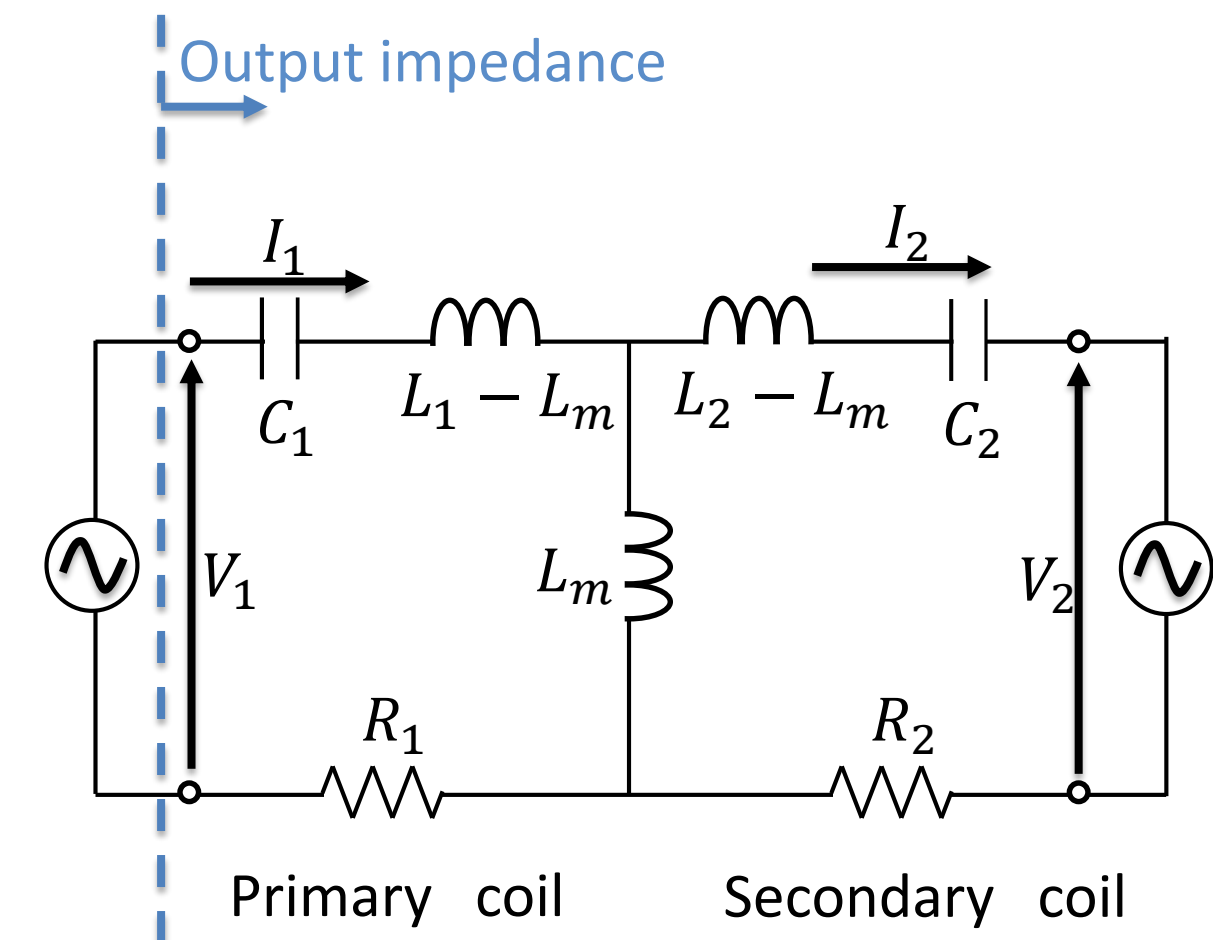
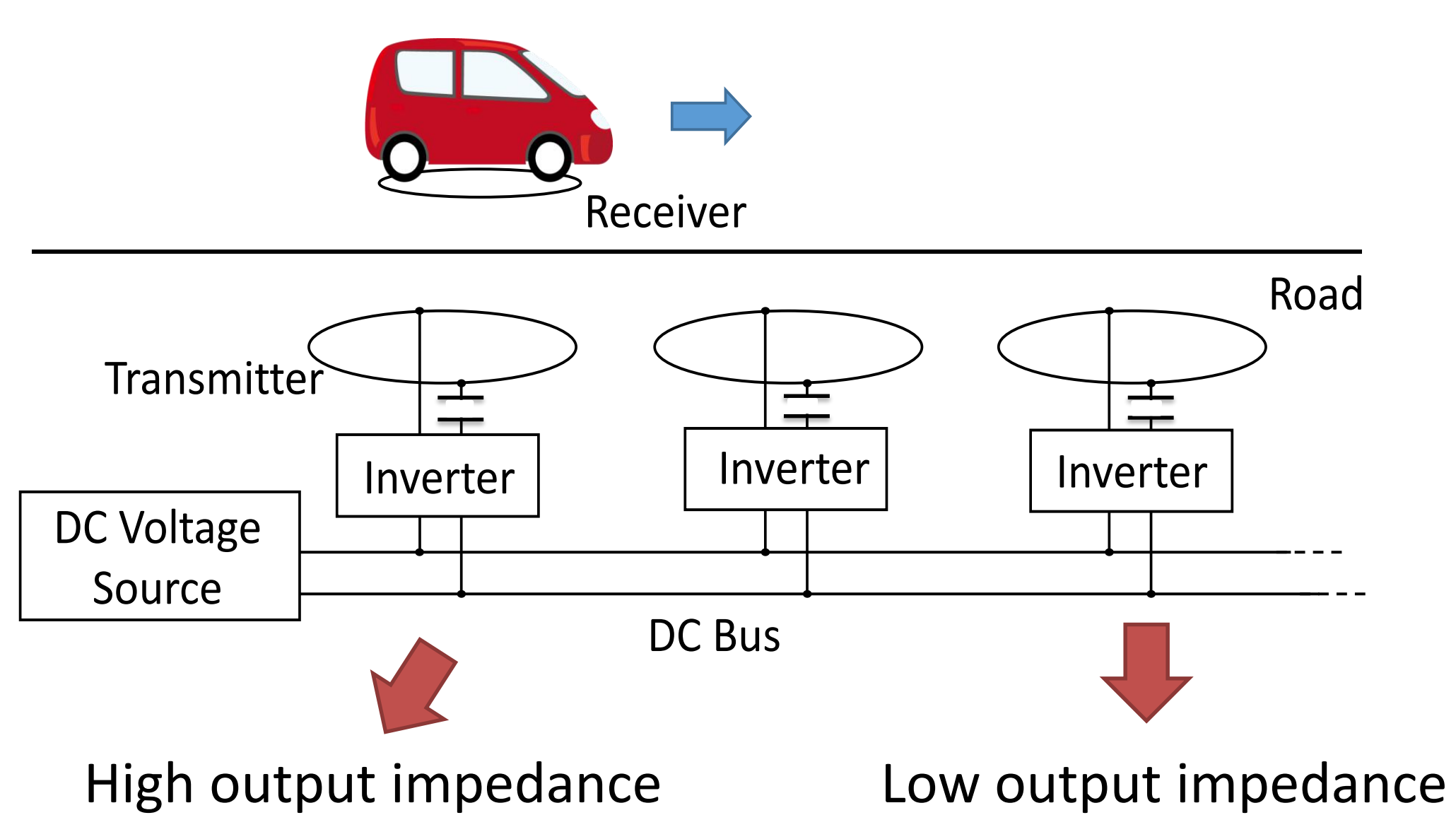


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3. Sensorless Transmitting ON/OFF Switching System

□ Idea of vehicle detection



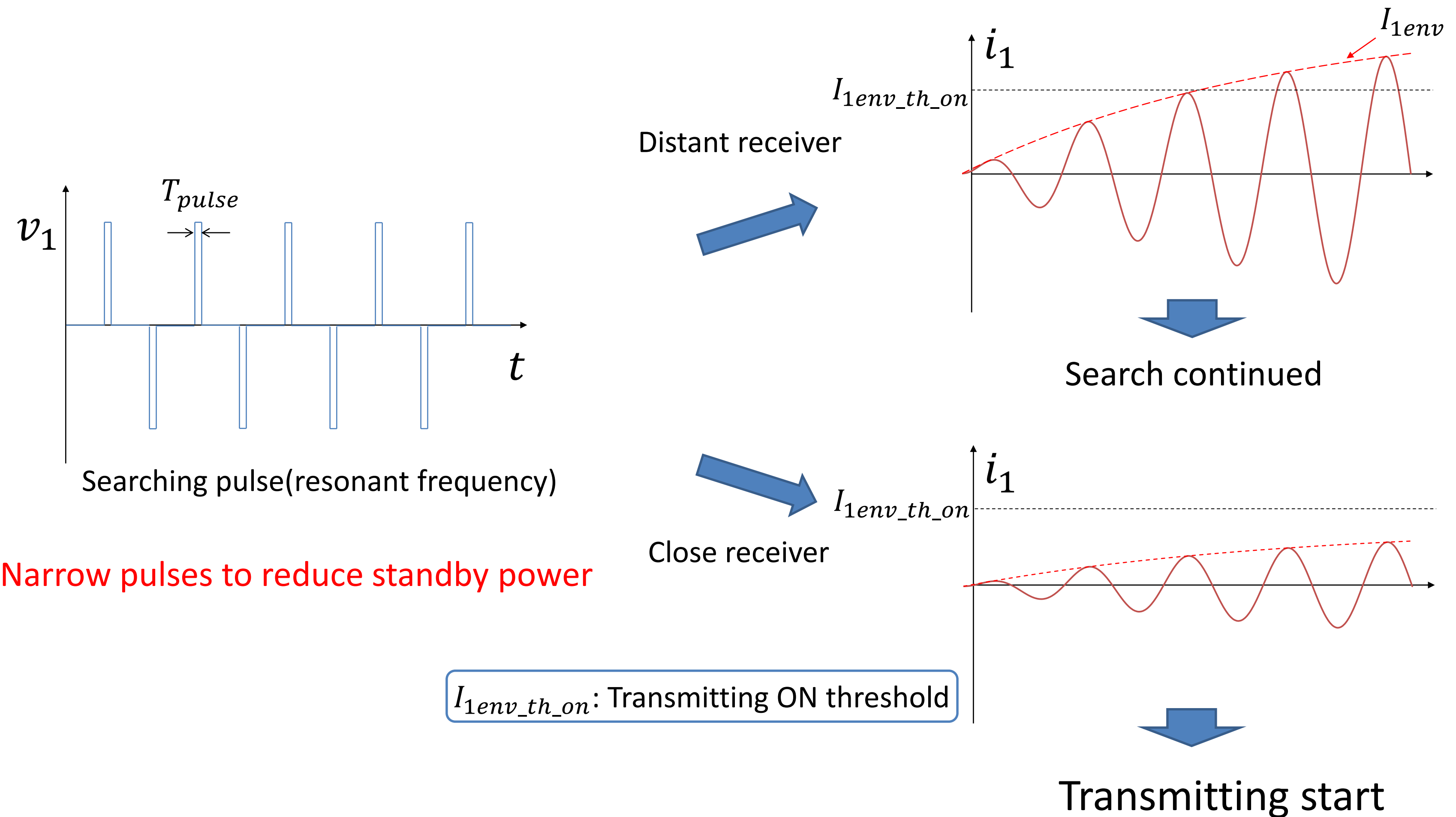
Transmitting current I_1 changes depending on position of a receiver

$$\begin{bmatrix} V_1 \\ jV_2 \end{bmatrix} = \begin{bmatrix} R_1 & -j\omega_0 L_m \\ j\omega_0 L_m & -R_2 \end{bmatrix} \begin{bmatrix} I_1 \\ jI_2 \end{bmatrix} \quad \xrightarrow{\text{resonance}} \quad I_1 = \frac{R_2 V_1 + \omega_0 L_m V_2}{R_1 R_2 + \omega_0^2 L_m^2}$$

3. Sensorless Transmitting ON/OFF Switching System

□ Searching voltage pulses

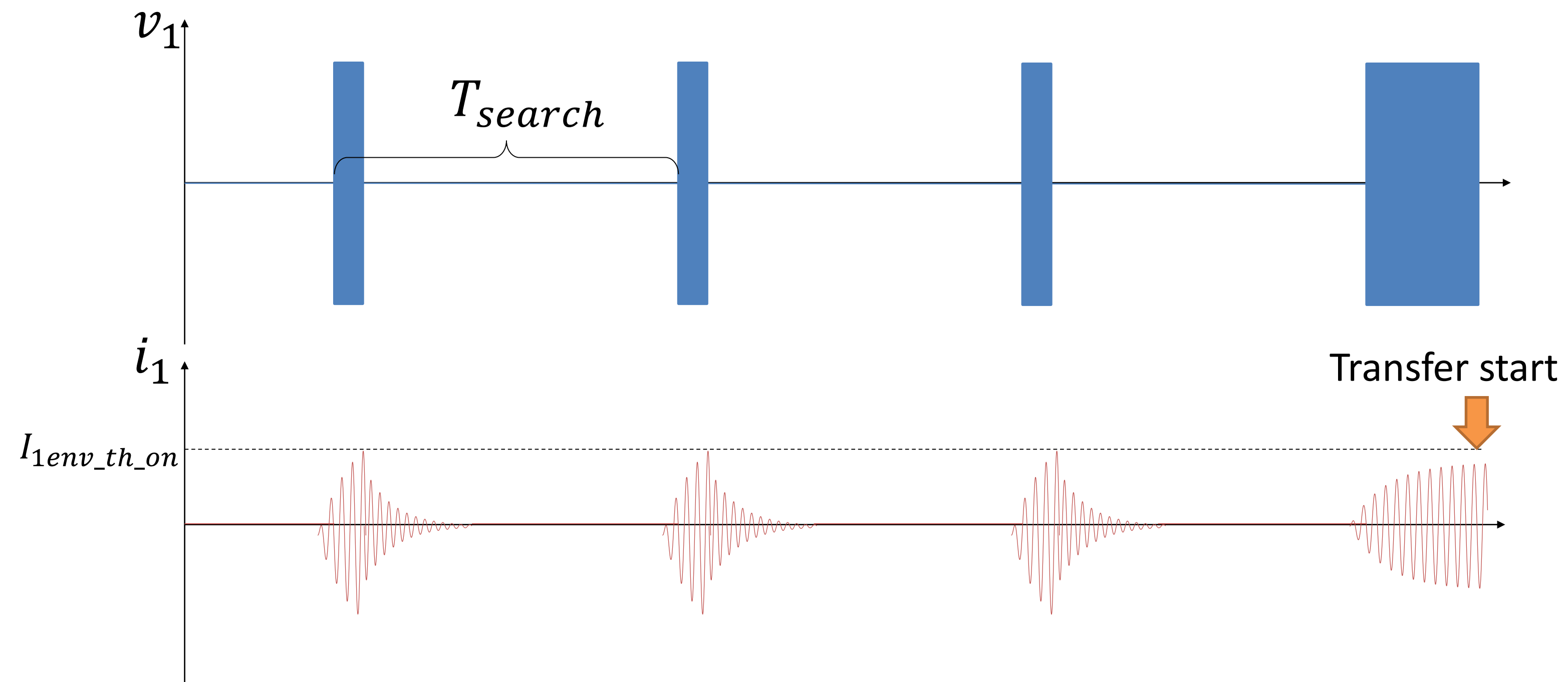
Envelope of the primary current is used to detect the approach of vehicles



3. Sensorless Transmitting ON/OFF Switching System

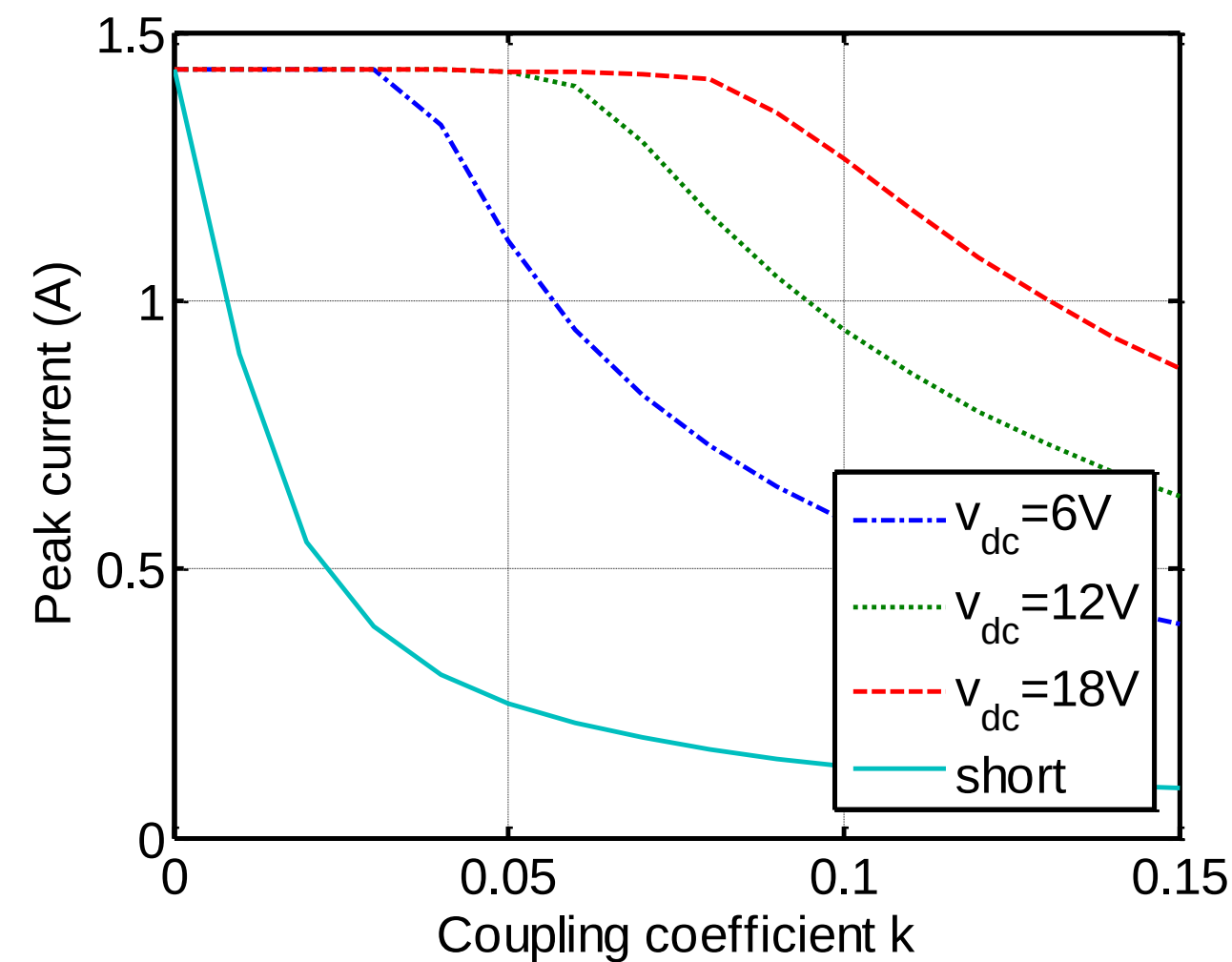
□ Procedure of the proposed searching method

1. Bundles of searching voltages are applied in an interval T_{search}
2. If I_{1env} exceeds $I_{1env_th_on}$, searching is stopped and waits until the next period
3. Power transfer starts if I_{1env} does not exceed $I_{1env_th_on}$ for certain period

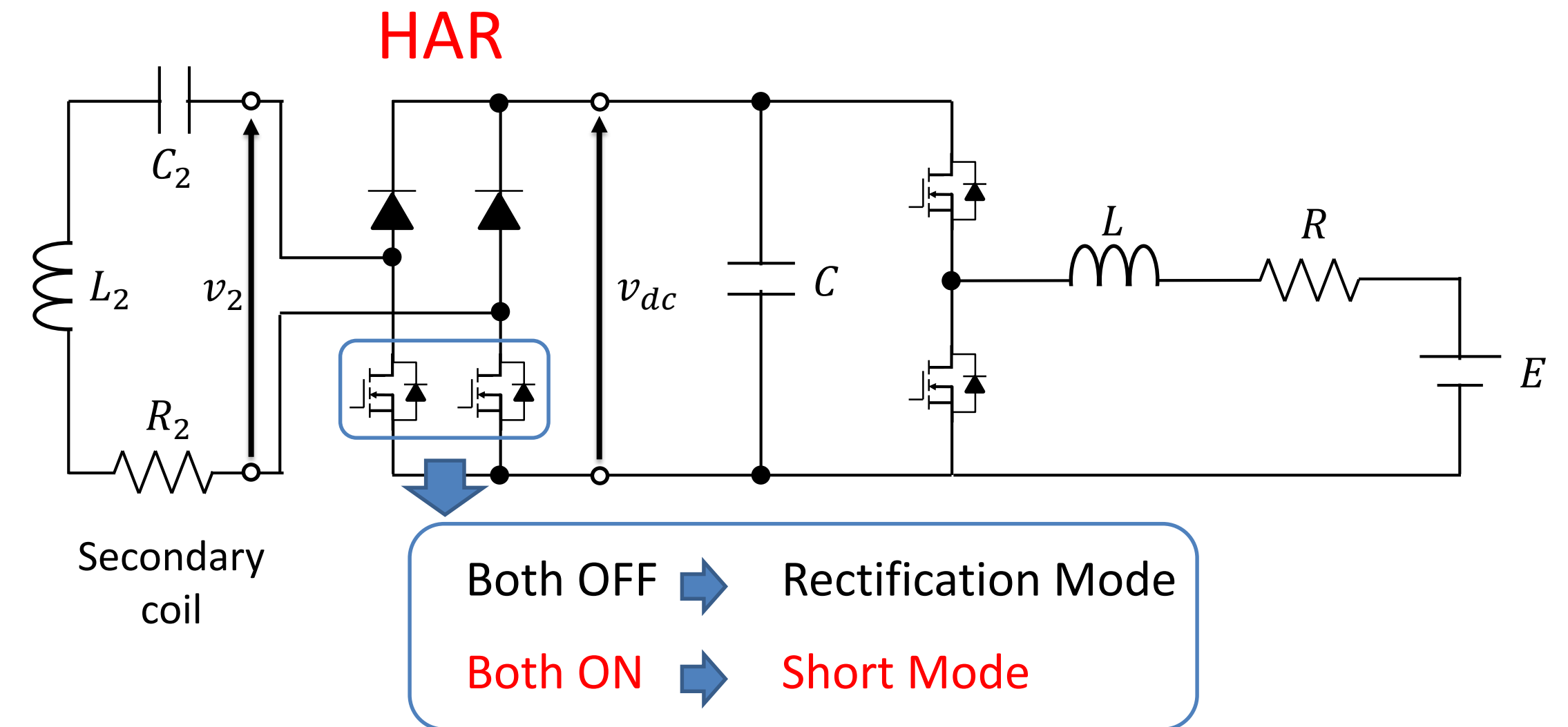


3. Sensorless Transmitting ON/OFF Switching System

□ Standby method of the secondary circuit (Half Active Rectifier)



Coupling coefficient and the peak value of the primary current
(pulse duty : 0.1, primary voltage : 18 V)



$$I_1 = \frac{R_2 V_1 + \omega_0 L_m V_2}{R_1 R_2 + \omega_0^2 L_m^2}$$

I_1 also depends on V_2



The proposed secondary circuit (Half active rectifier : HAR) turns on two MOSFET and short the circuit ($V_2 = 0$) during standby mode (Short mode).

3. Sensorless Transmitting ON/OFF Switching System

□ Stop Method of Power Transfer

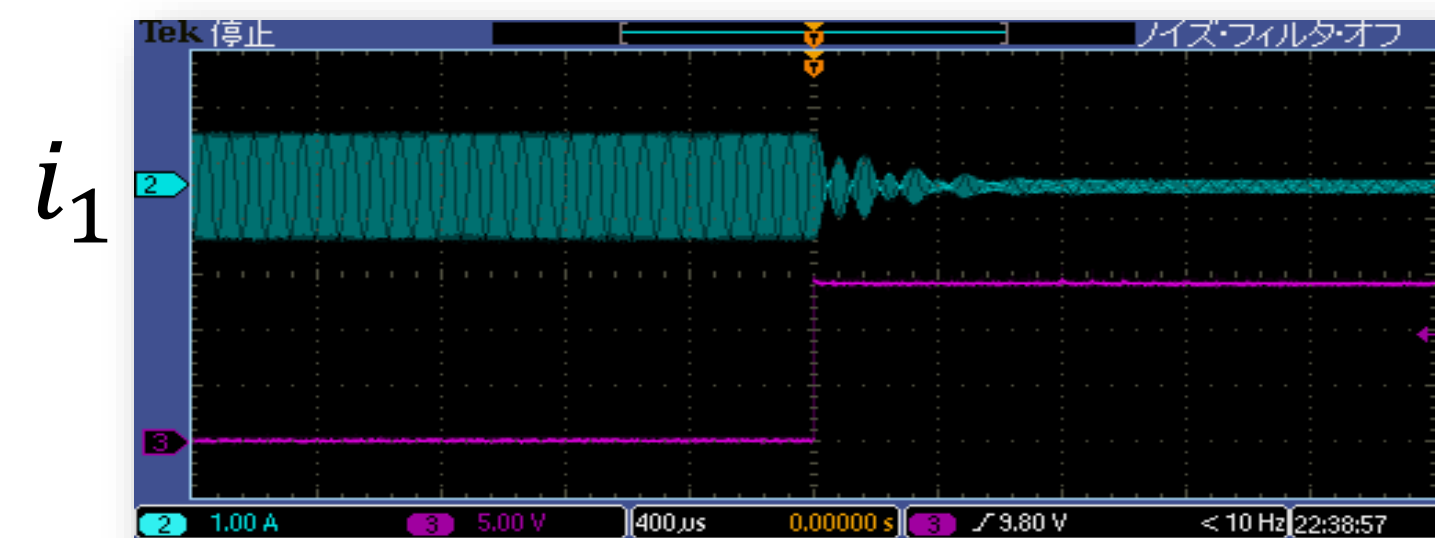
Adaptive transmission is possible if **the receiving side** can stop power transfer

➡ The receiving circuit can tell a stop timing with a switching into short mode

Receiving side

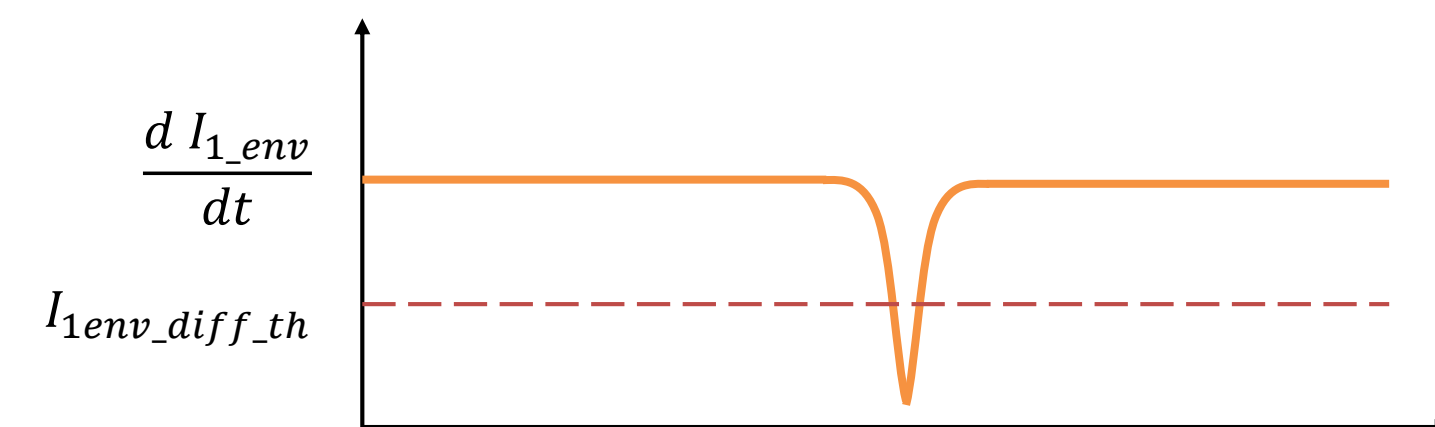
$$\begin{bmatrix} V_1 \\ jV_2 \end{bmatrix} = \begin{bmatrix} R_1 & -j\omega_0 k \sqrt{L_1 L_2} \\ j\omega_0 k \sqrt{L_1 L_2} & -R_2 \end{bmatrix} \begin{bmatrix} I_1 \\ jI_2 \end{bmatrix} \quad \Rightarrow \quad I_{2_off} = \frac{\omega_0 k_{off} \sqrt{L_1 L_2} V_1 - R_1 V_2}{R_1 R_2 + \omega_0^2 k_{off}^2 L_1 L_2} \quad k_{off}: \text{arbitrary}$$

Transmitting side



Transmitting mode

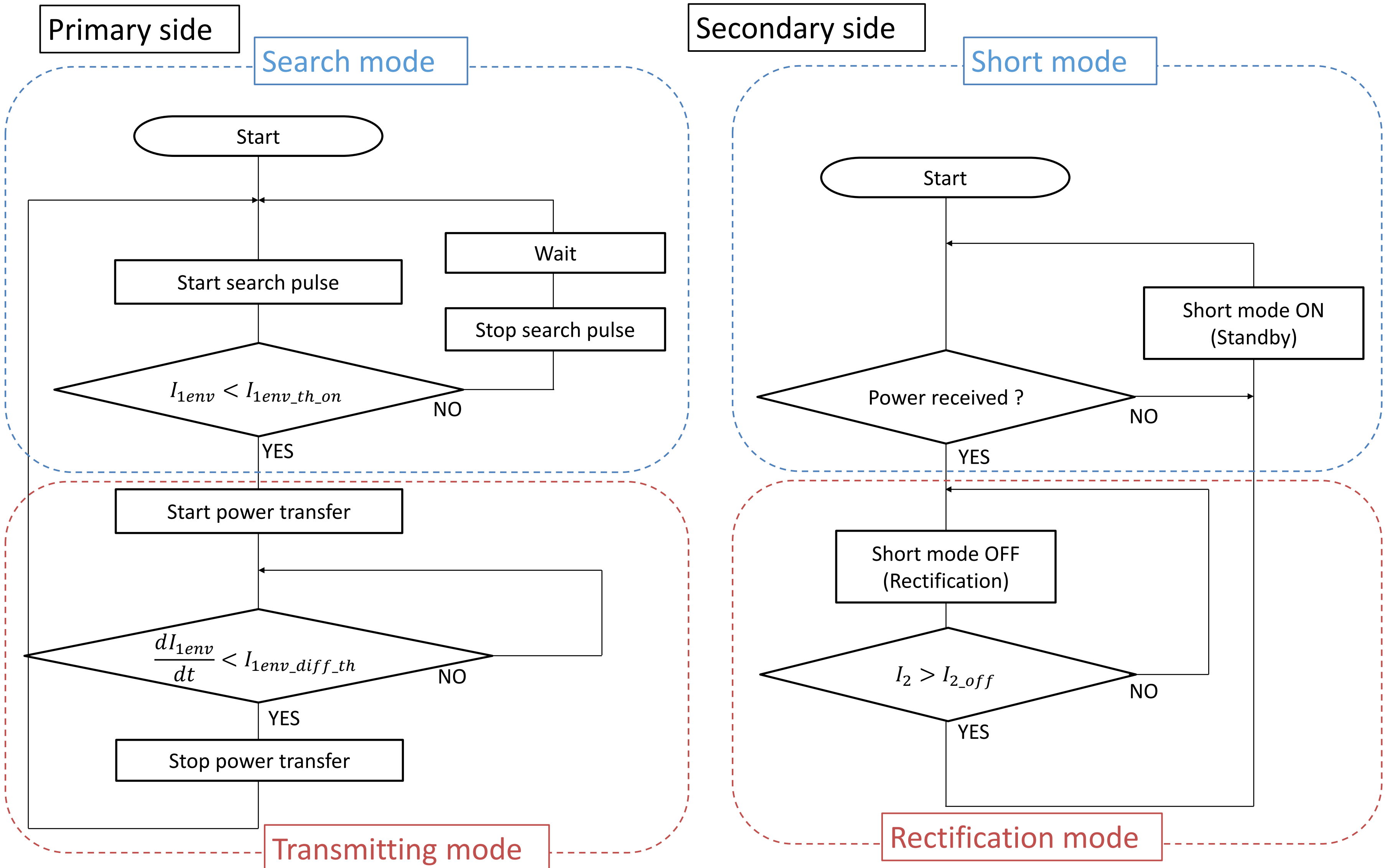
Short mode



$\frac{d I_{1_env}}{dt} < I_{1_env_diff_th} \Rightarrow$ Power transfer stopped

3. Sensorless Transmitting ON/OFF Switching System

□ Flowchart



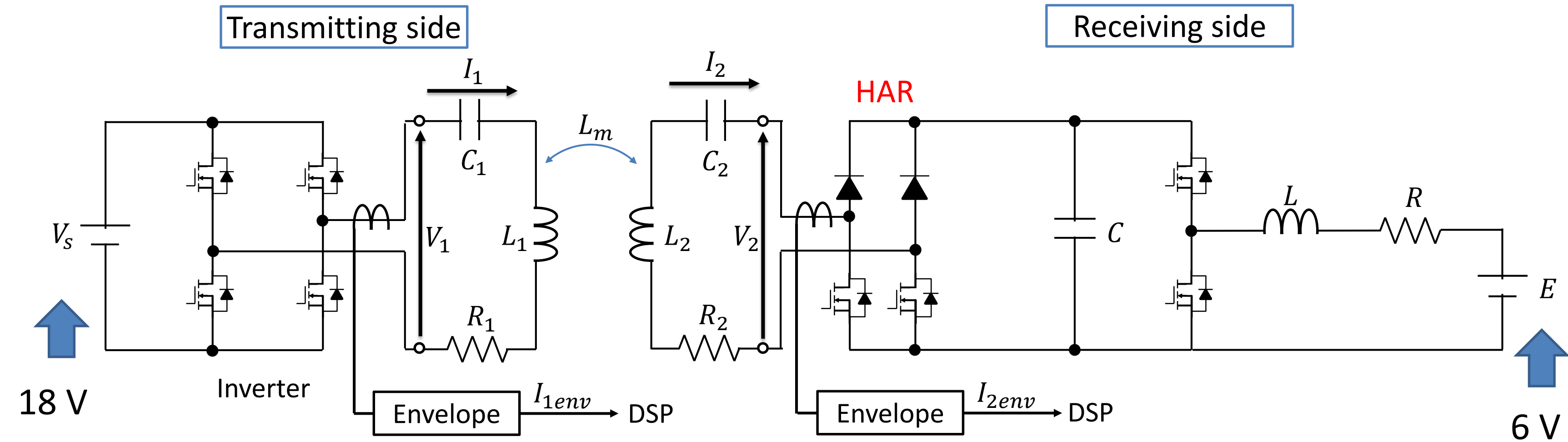


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4. Experiment

□ Experiment



	Primary coil	Secondary coil
L	417.1 μH	208.5 μH
C	6.03 nF	12.15 nF
R	1.83 Ω	1.28 Ω

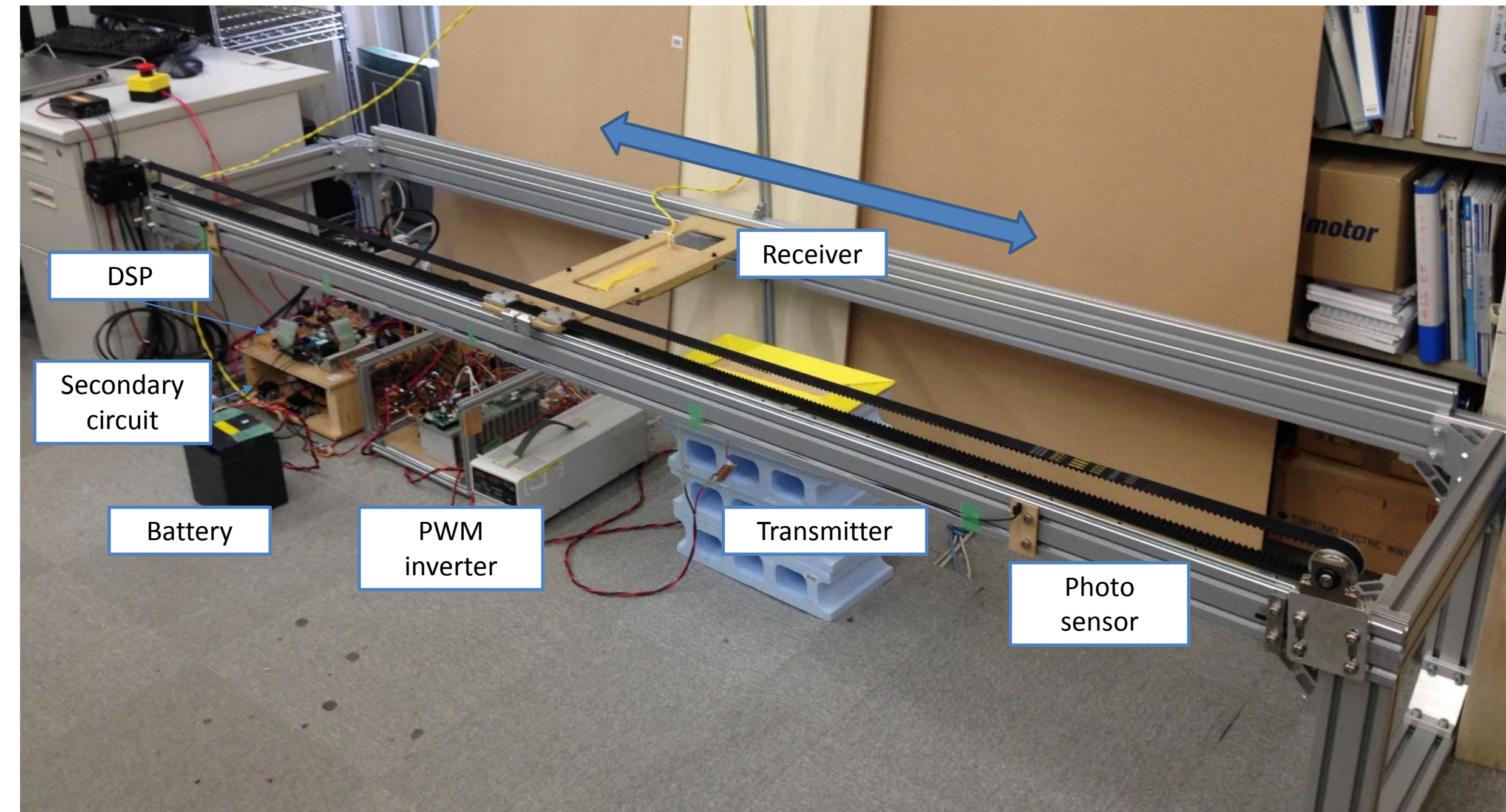
Parameters	Meaning	Value
T_{search}	Searching period	10 ms
T_{pulse}	Pulse width	0.5 μs
$I_{1env_th_on}$	ON threshold current	300 mA
$I_{1env_diff_th}$	OFF threshold differentiated current	-4000 A/s
k_{off}	OFF threshold coupling coefficient	0.06

Operating frequency : 100 kHz
DC/DC converter frequency : 10 kHz

DC voltage source : 18 V
Battery voltage : 6 V

4. Experiment

1/3 scale DWPT simulation setup



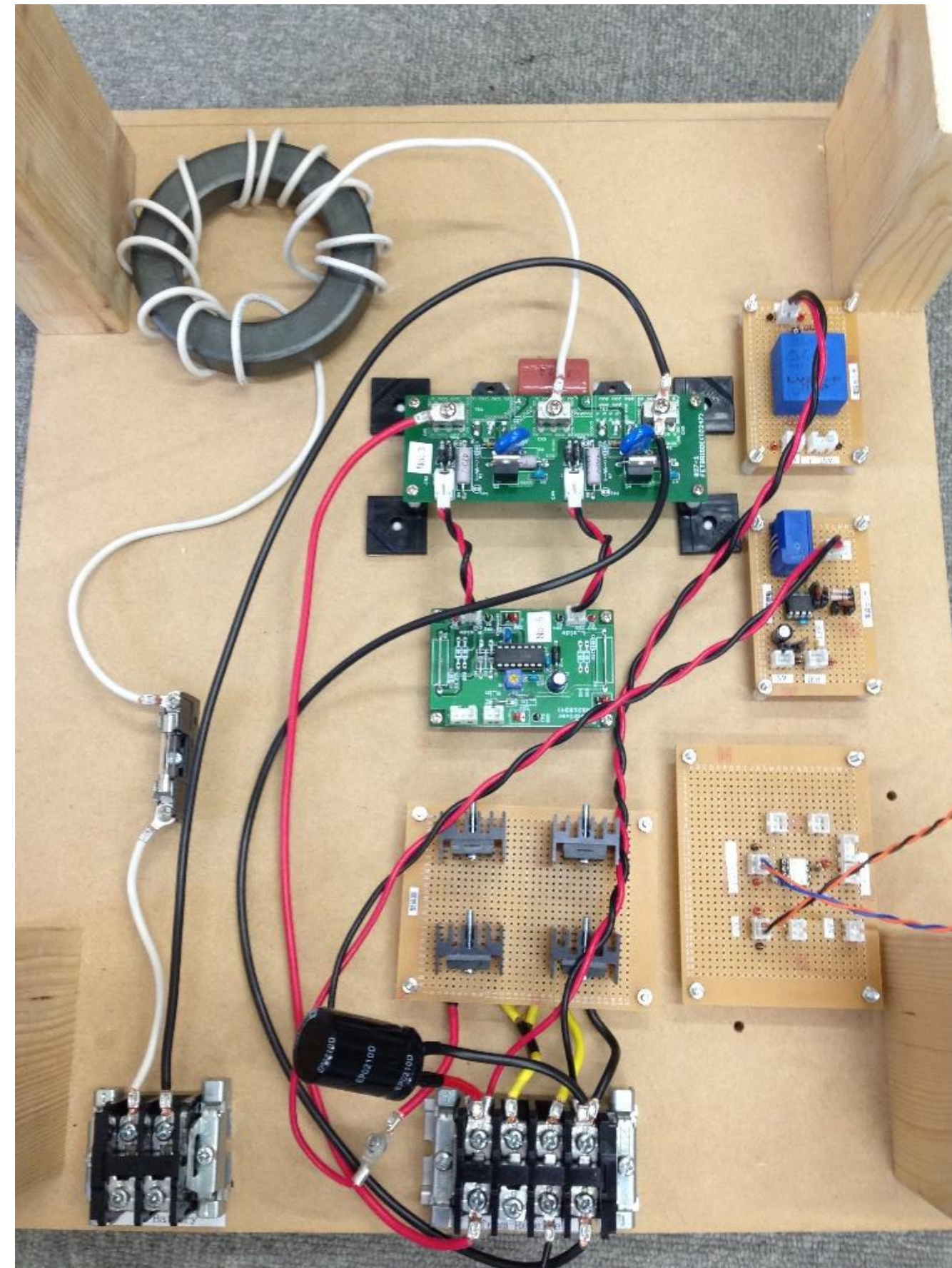
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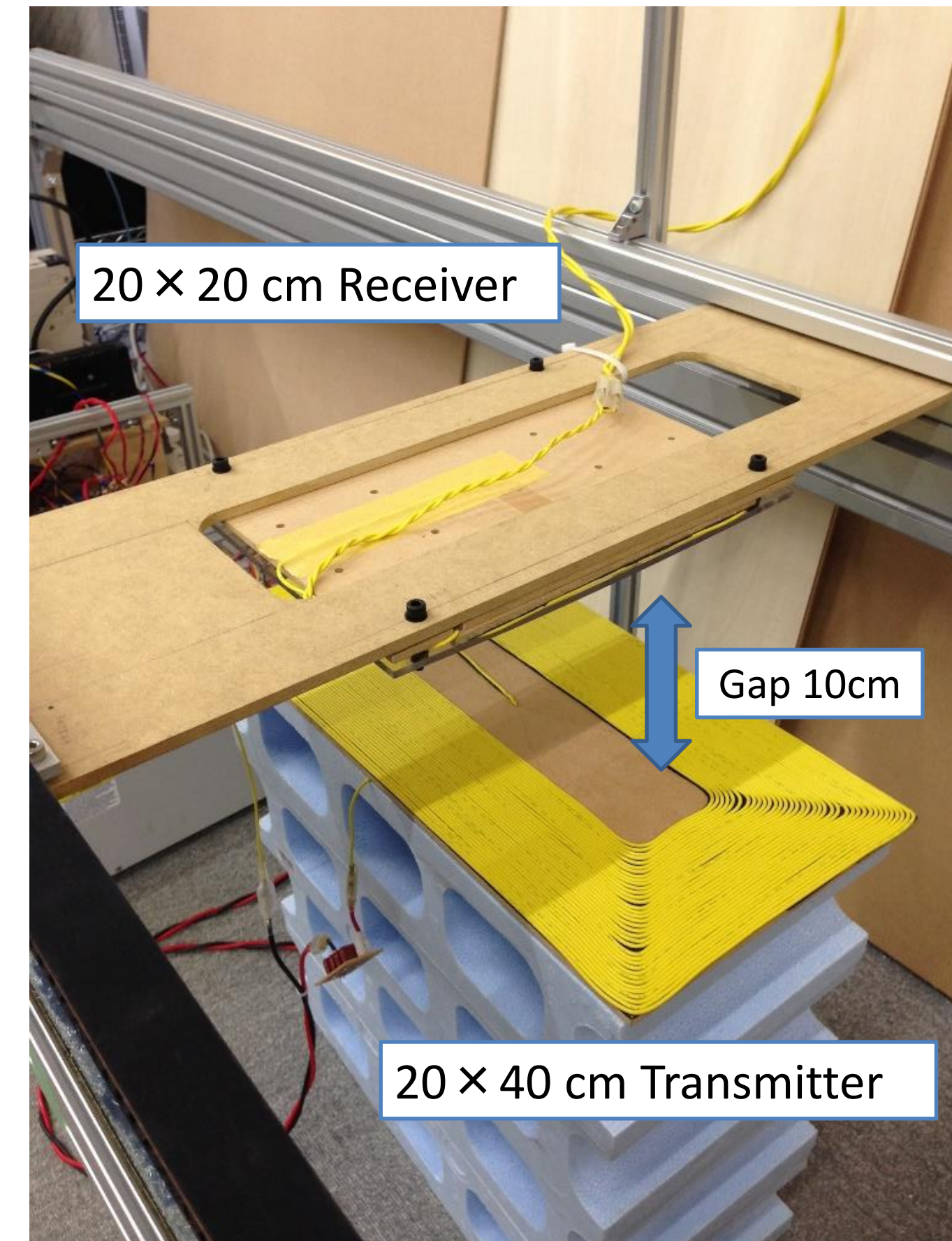
Operating frequency : 100 kHz
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4. Experiment

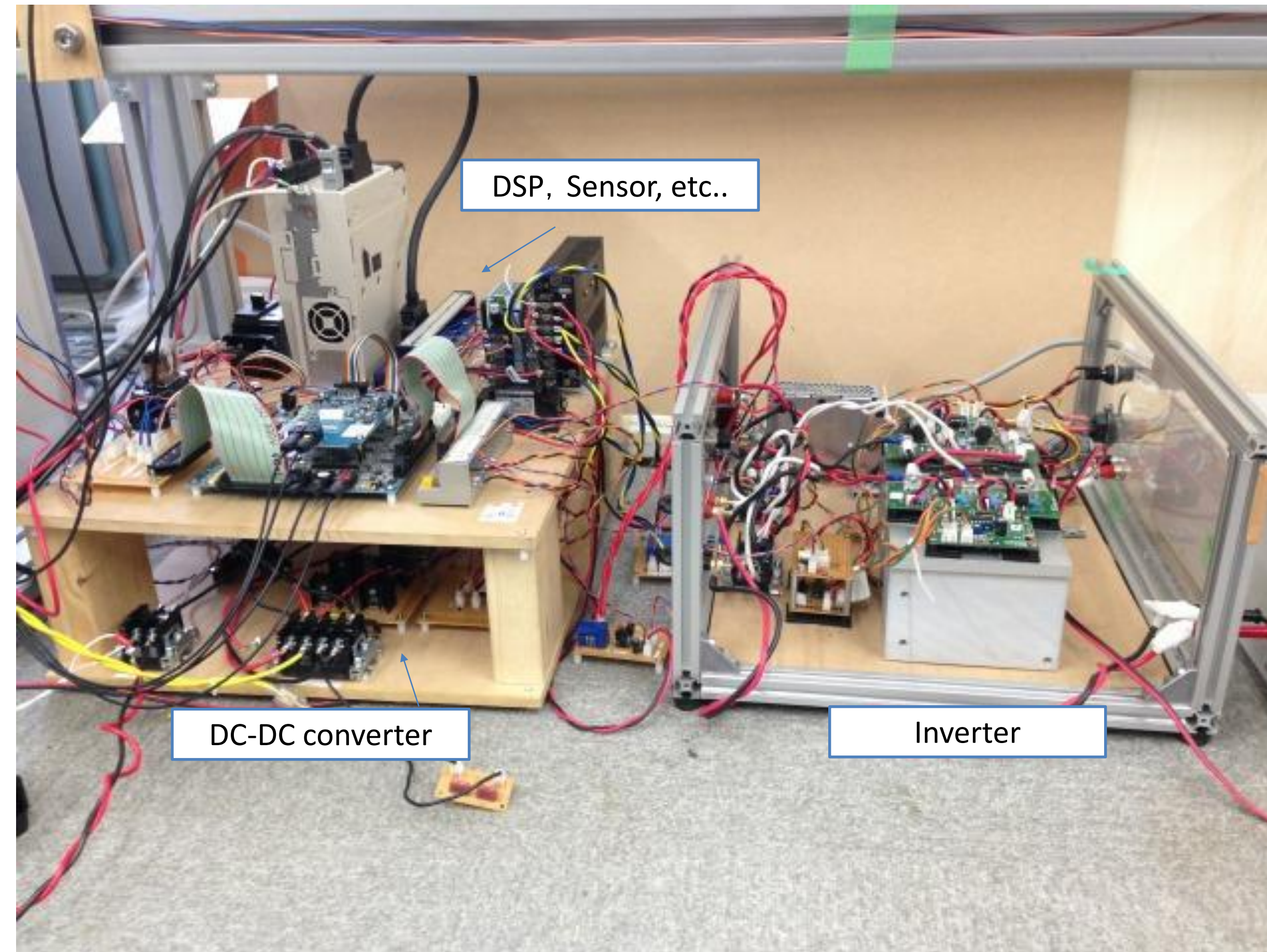


DC/DC converter



Receiver and Transmitter

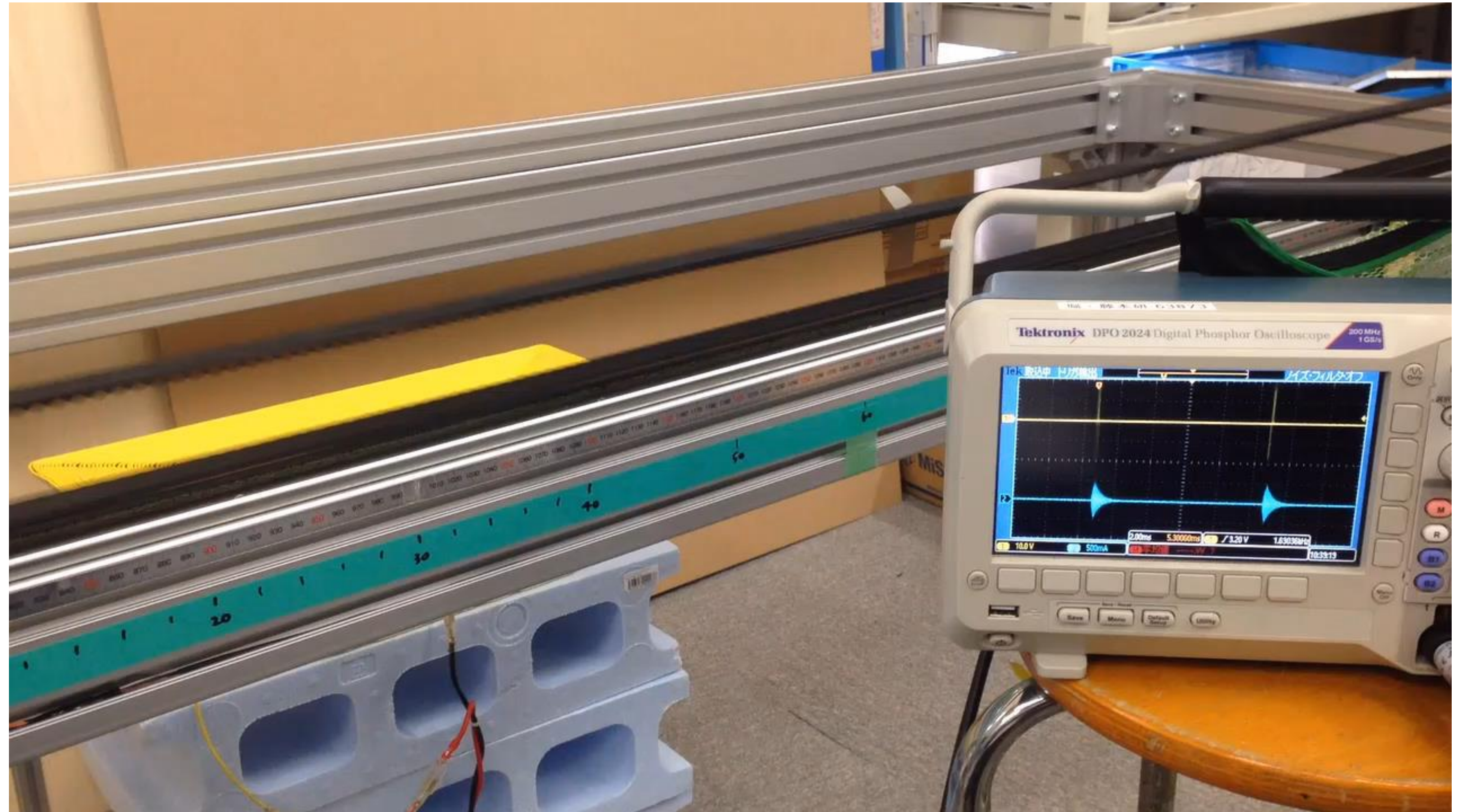
4. Experiment



Primary Inverter, DC/DC converter, Controller

4. Experiment

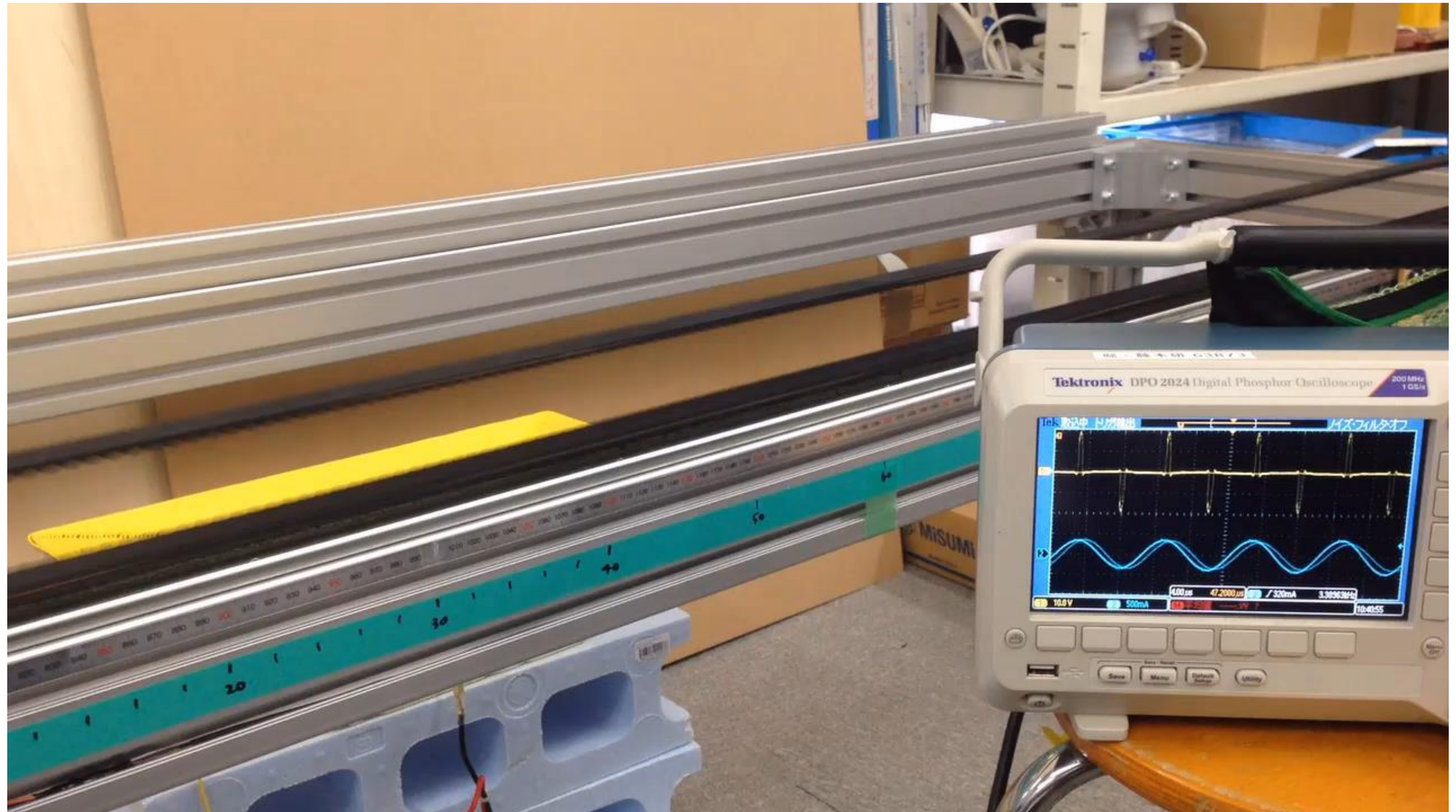
- Experimental movie



— : primary voltage v_1 — : primary current i_1

4. Experiment

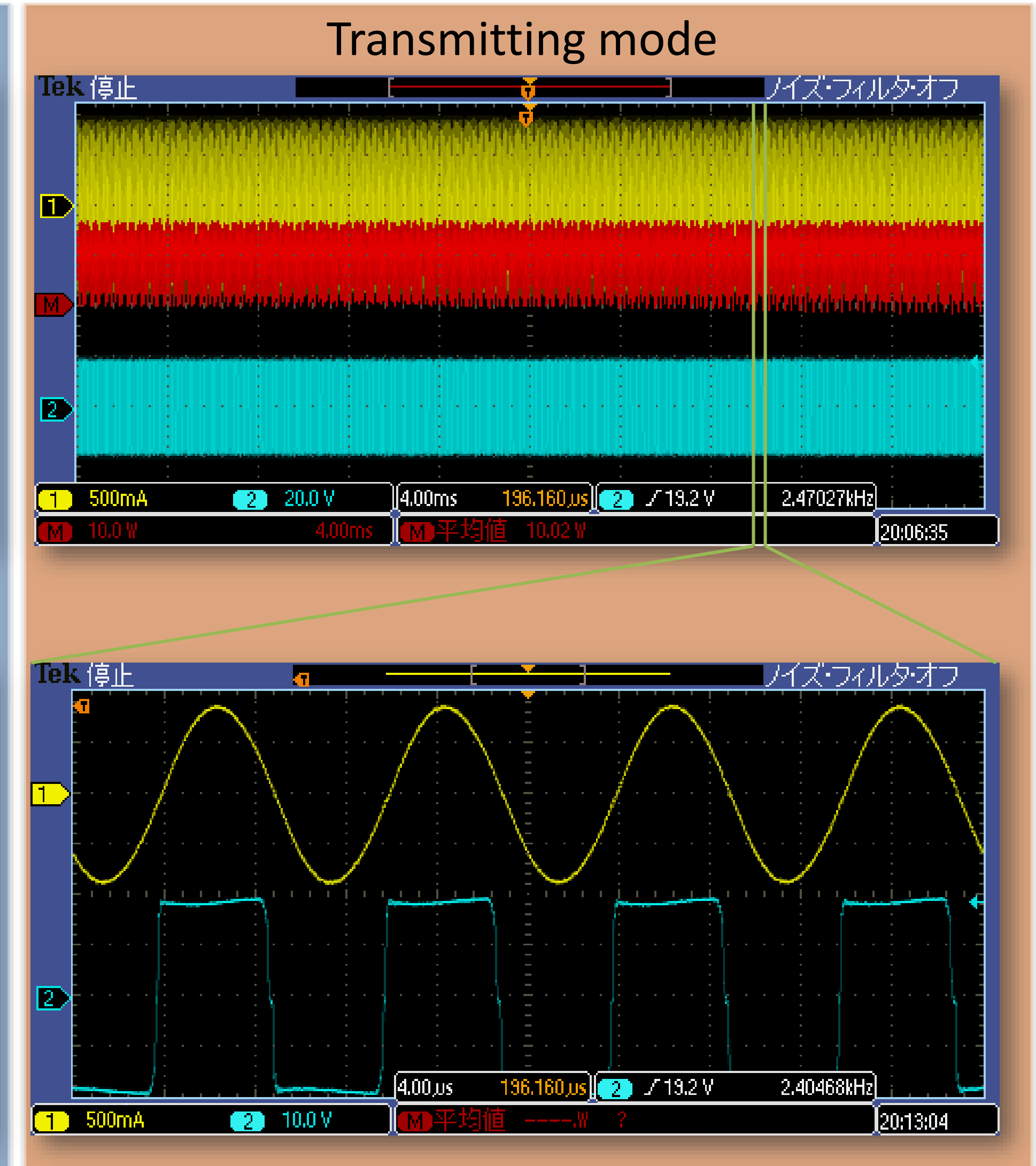
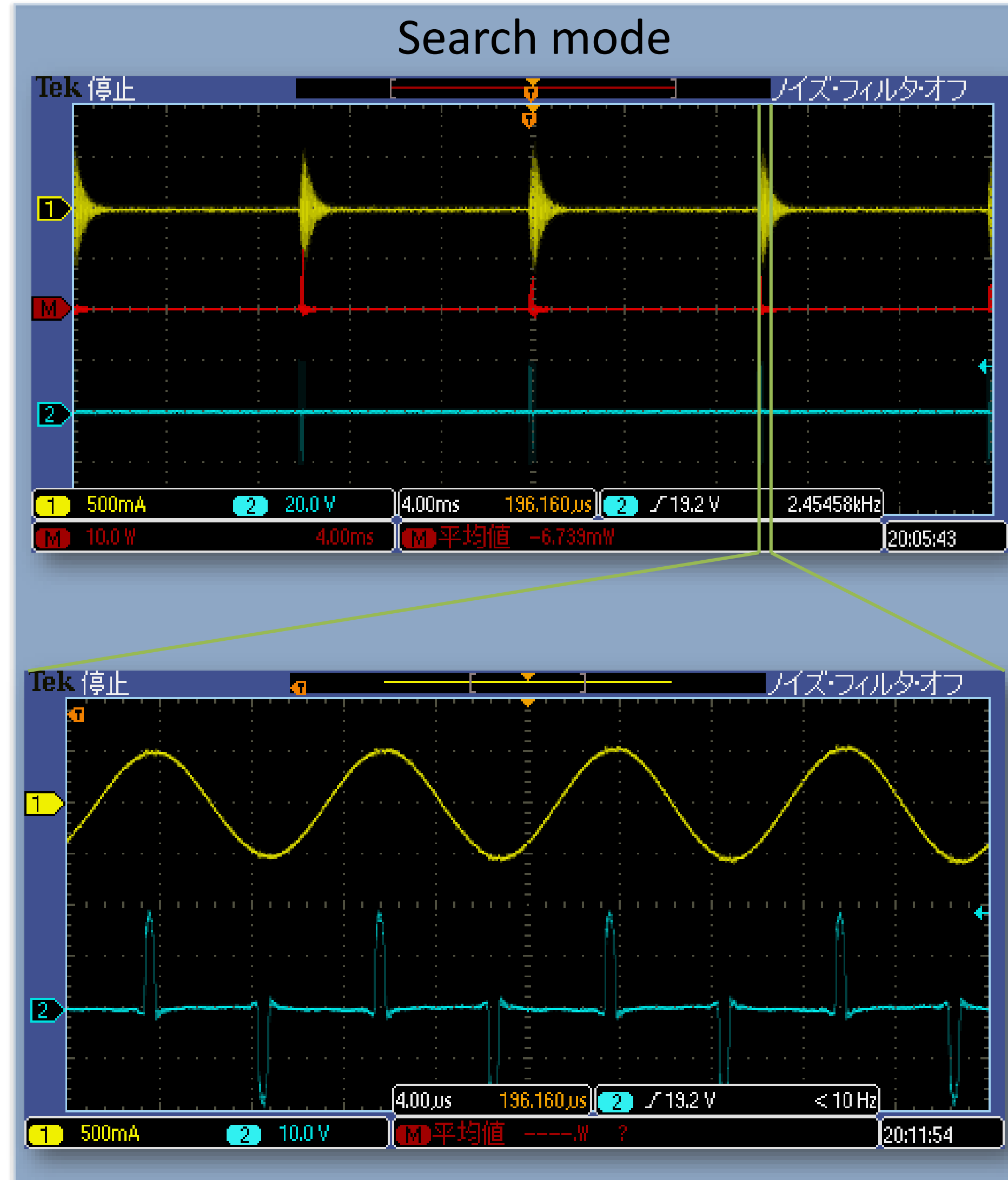
□ Experimental movie



— : primary voltage v_1 — : primary current i_1

4. Experiment

□ Voltage and current wave form

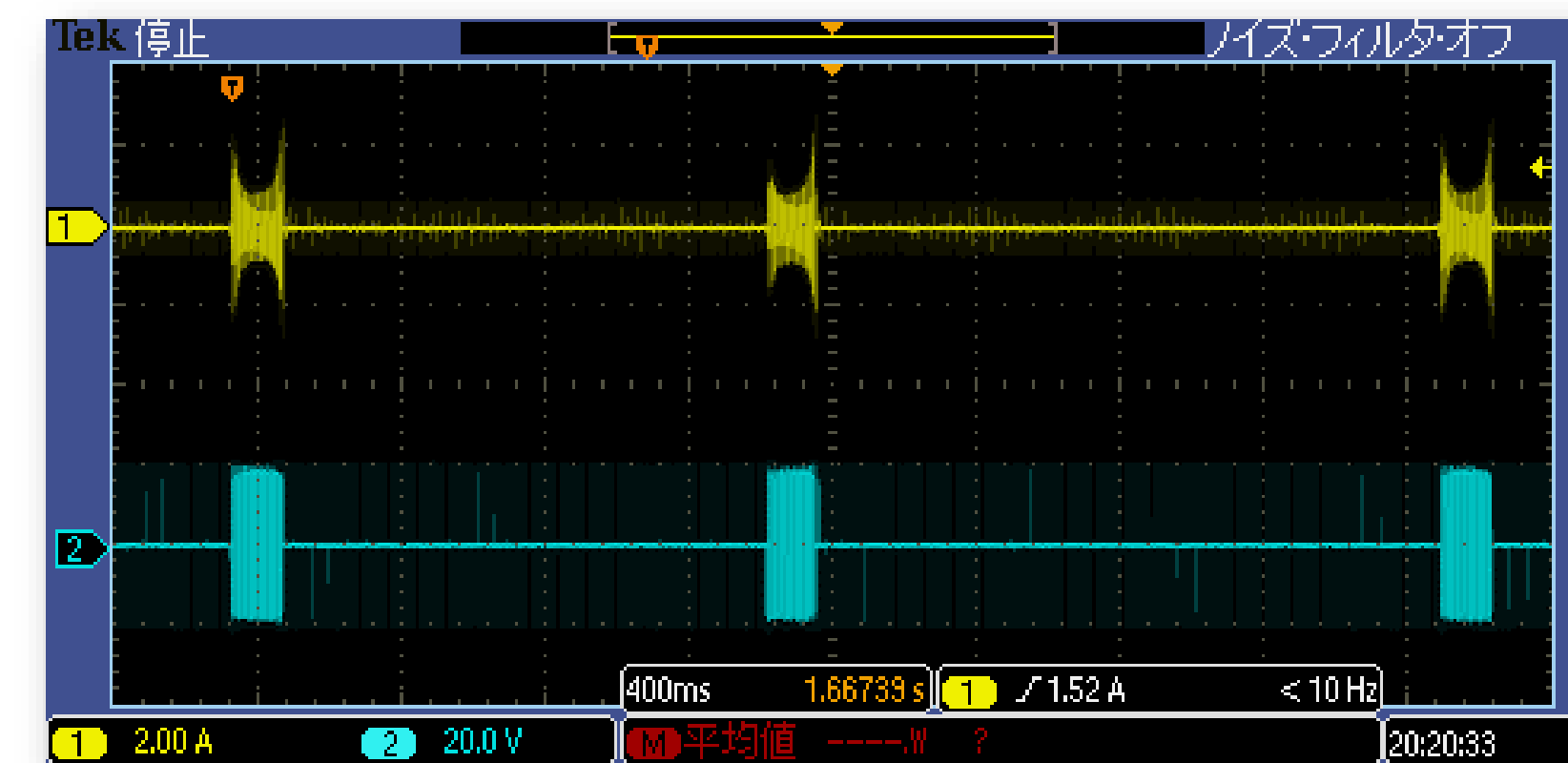
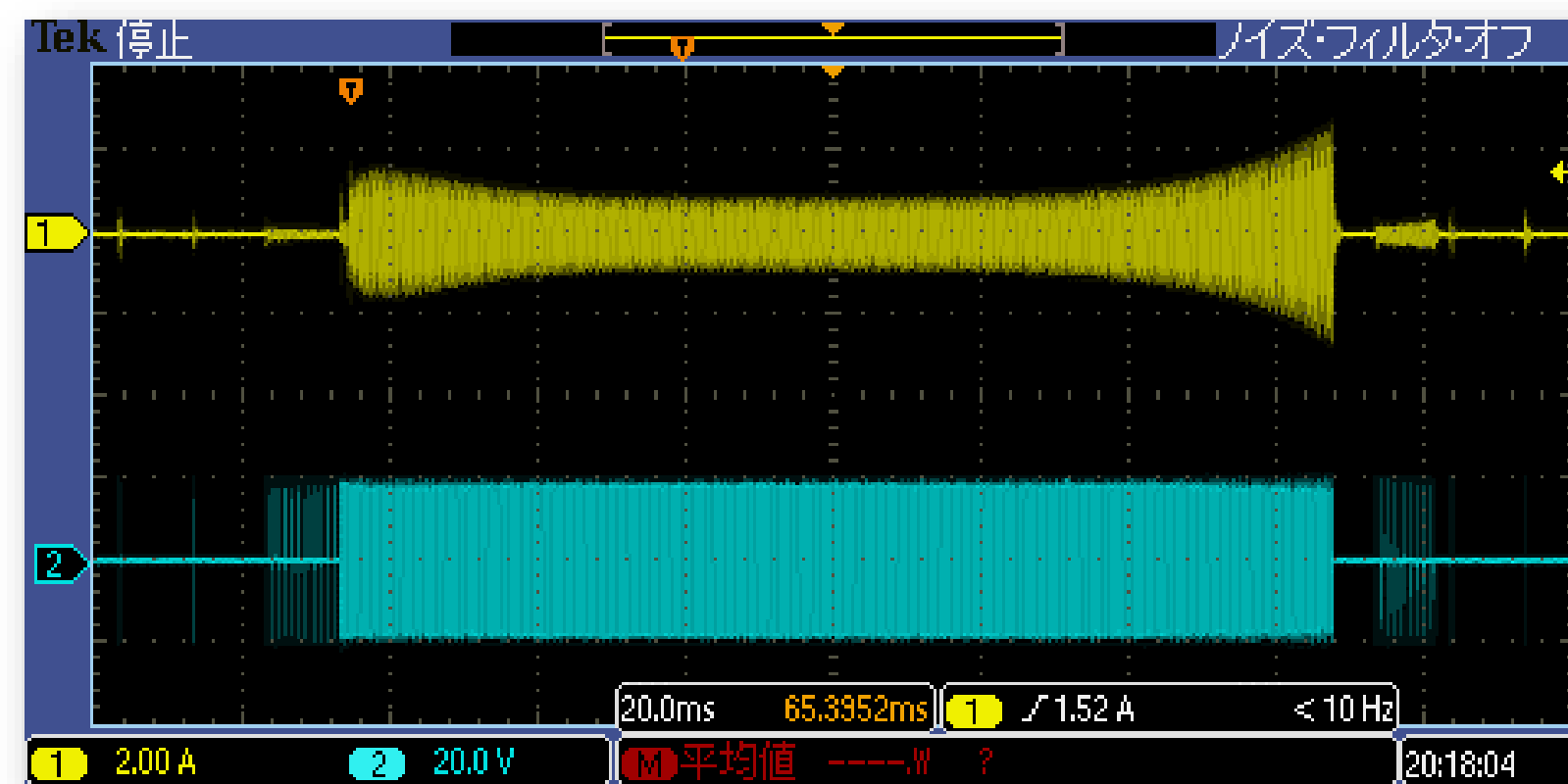
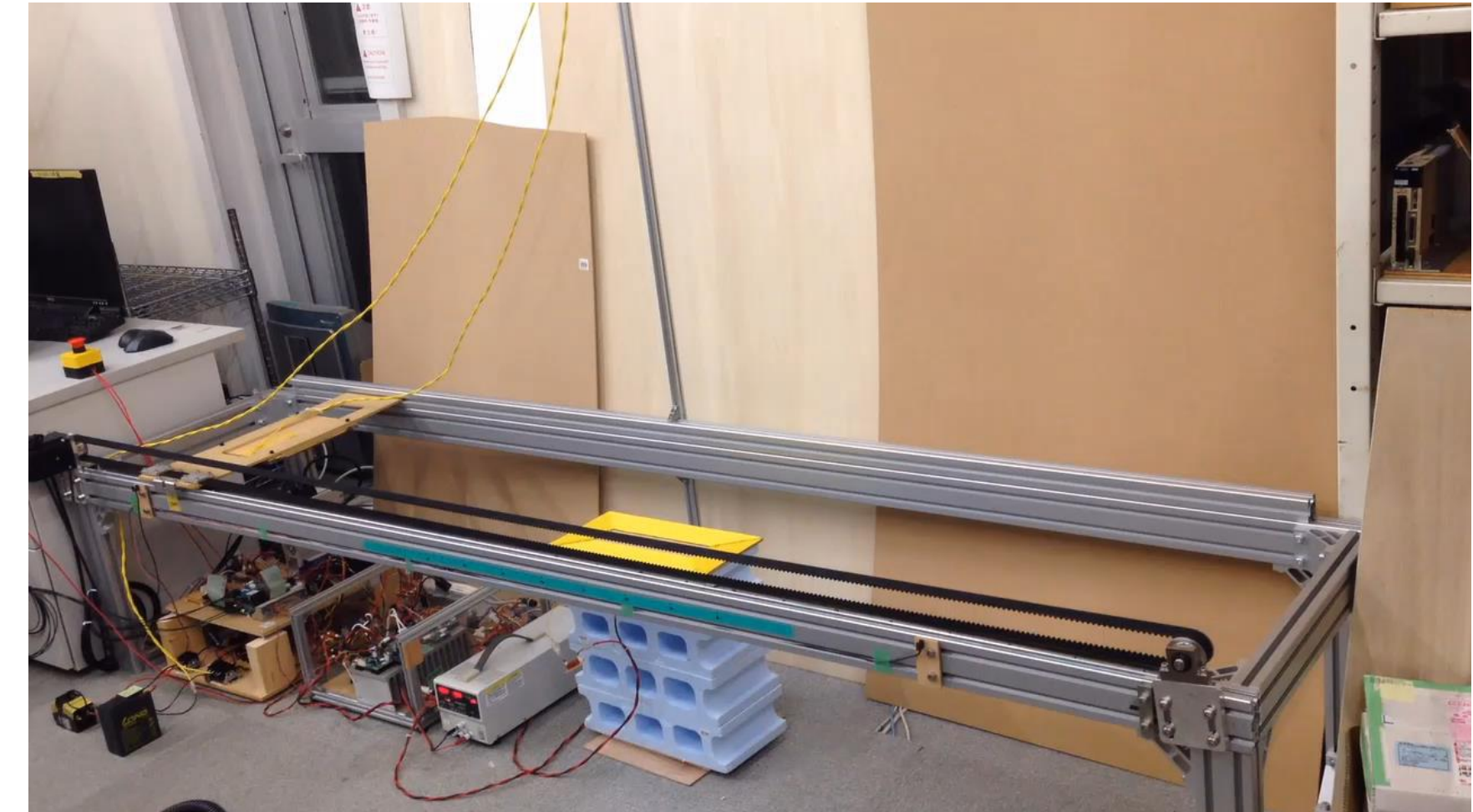


— : primary voltage v_1

— : primary current i_1

4. Experiment

- Experiment at 10 km/h



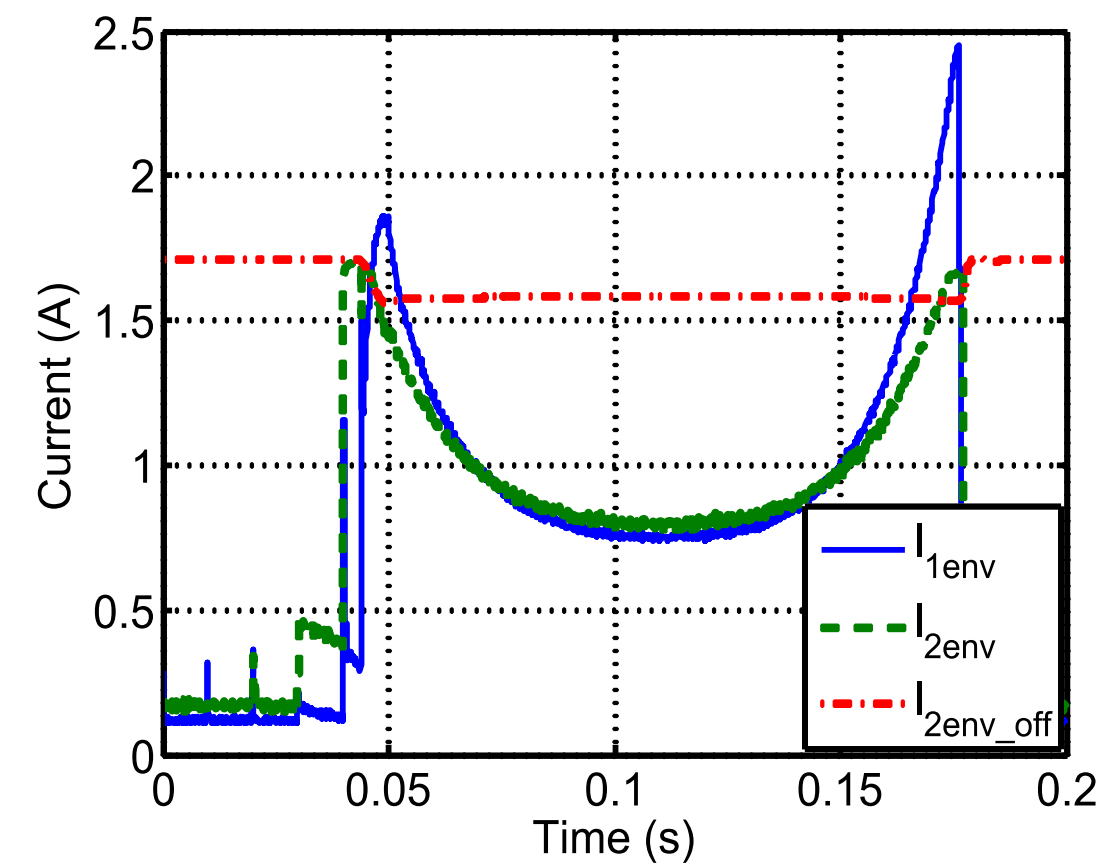
— : primary voltage v_1

— : primary current i_1

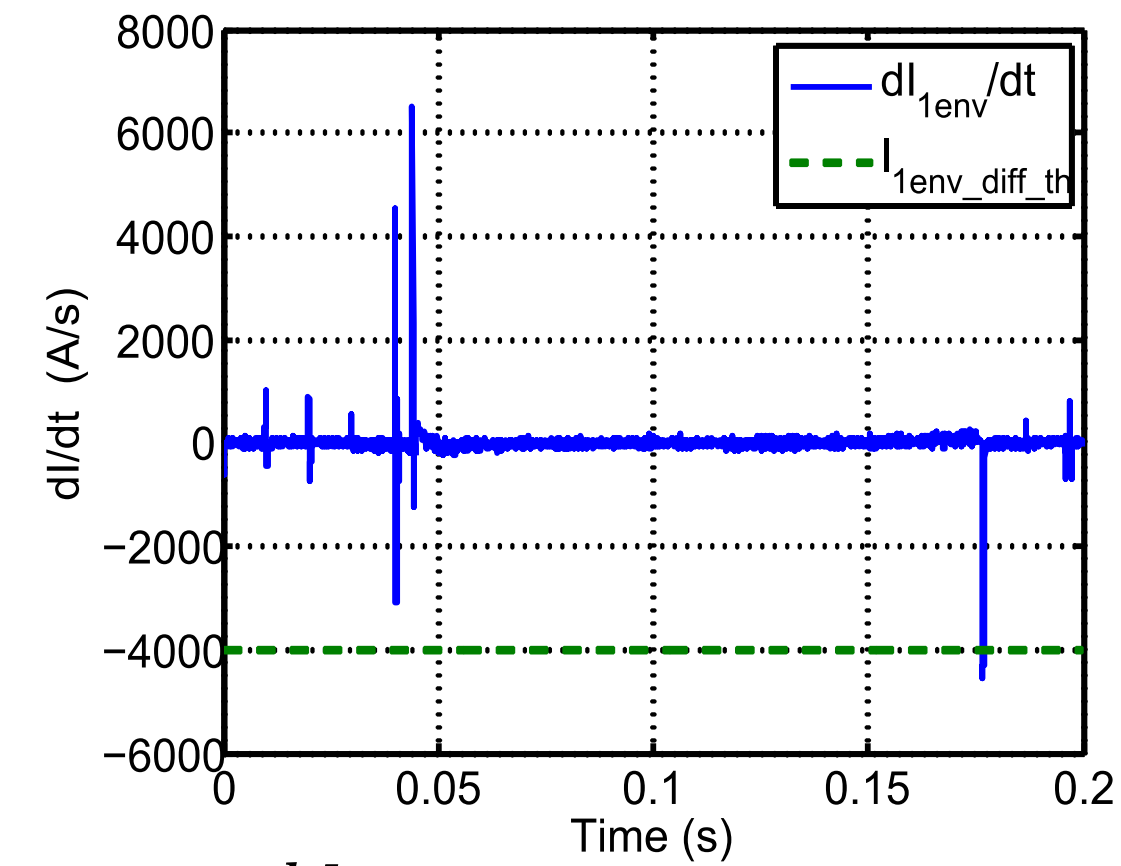
Power transfer automatically switches ON/OFF while 10 km/h driving

4. Experiment

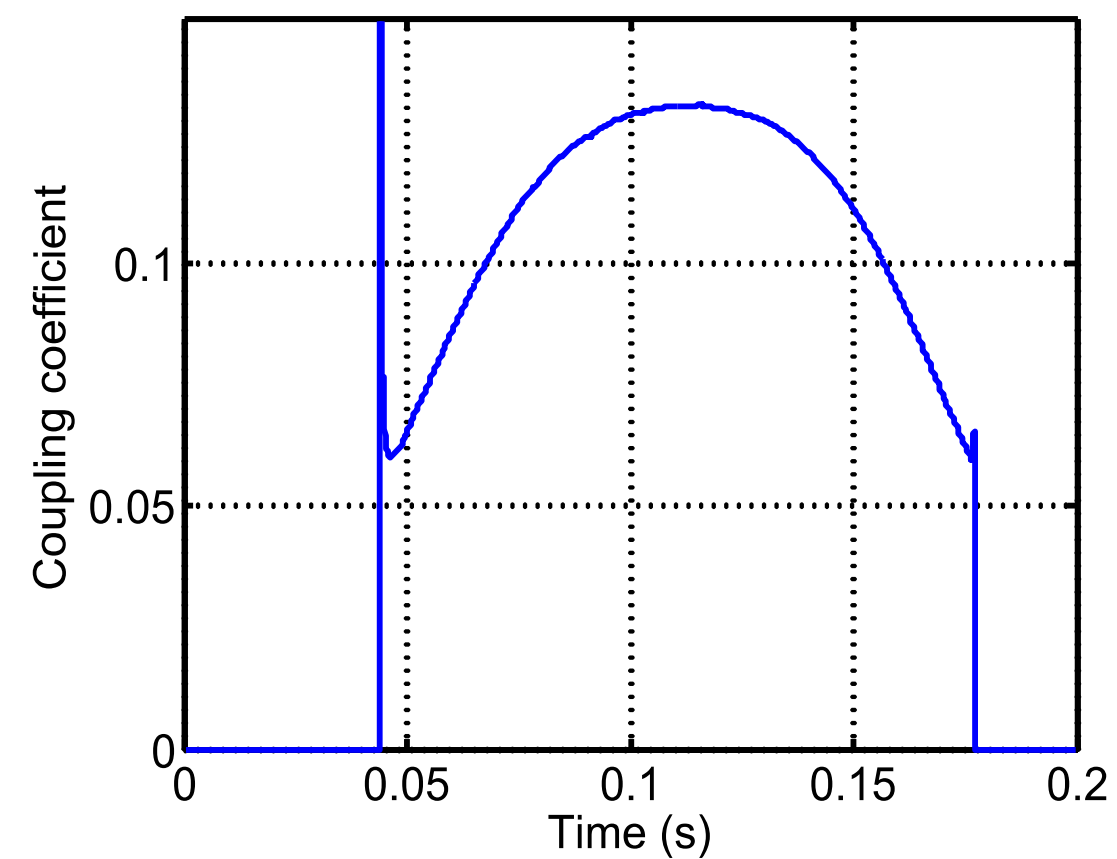
Experiment at 10 km/h



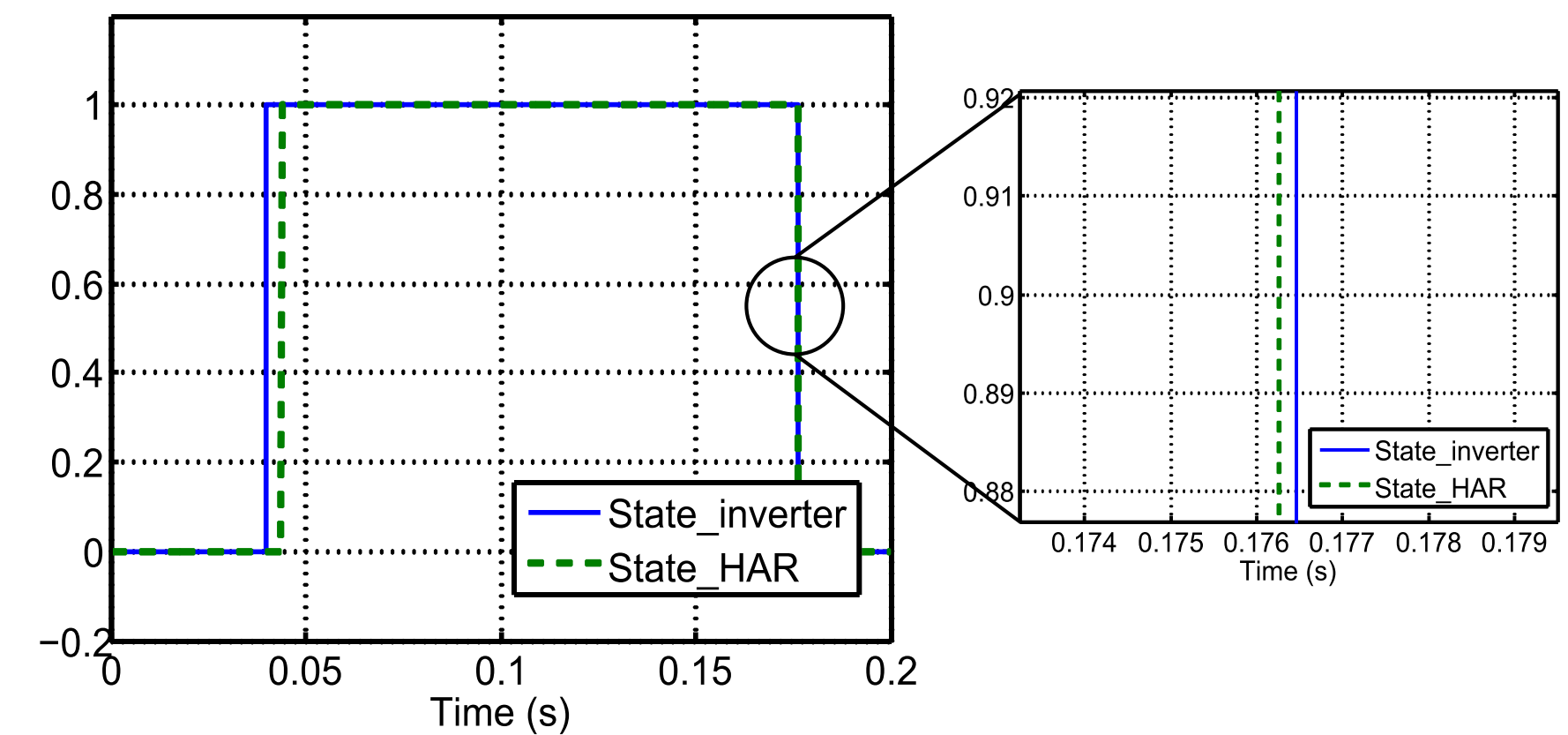
Primary and secondary current



$\frac{d I_{1_env}}{dt}$ (cutoff=100kHz)



Coupling coefficient (estimated)

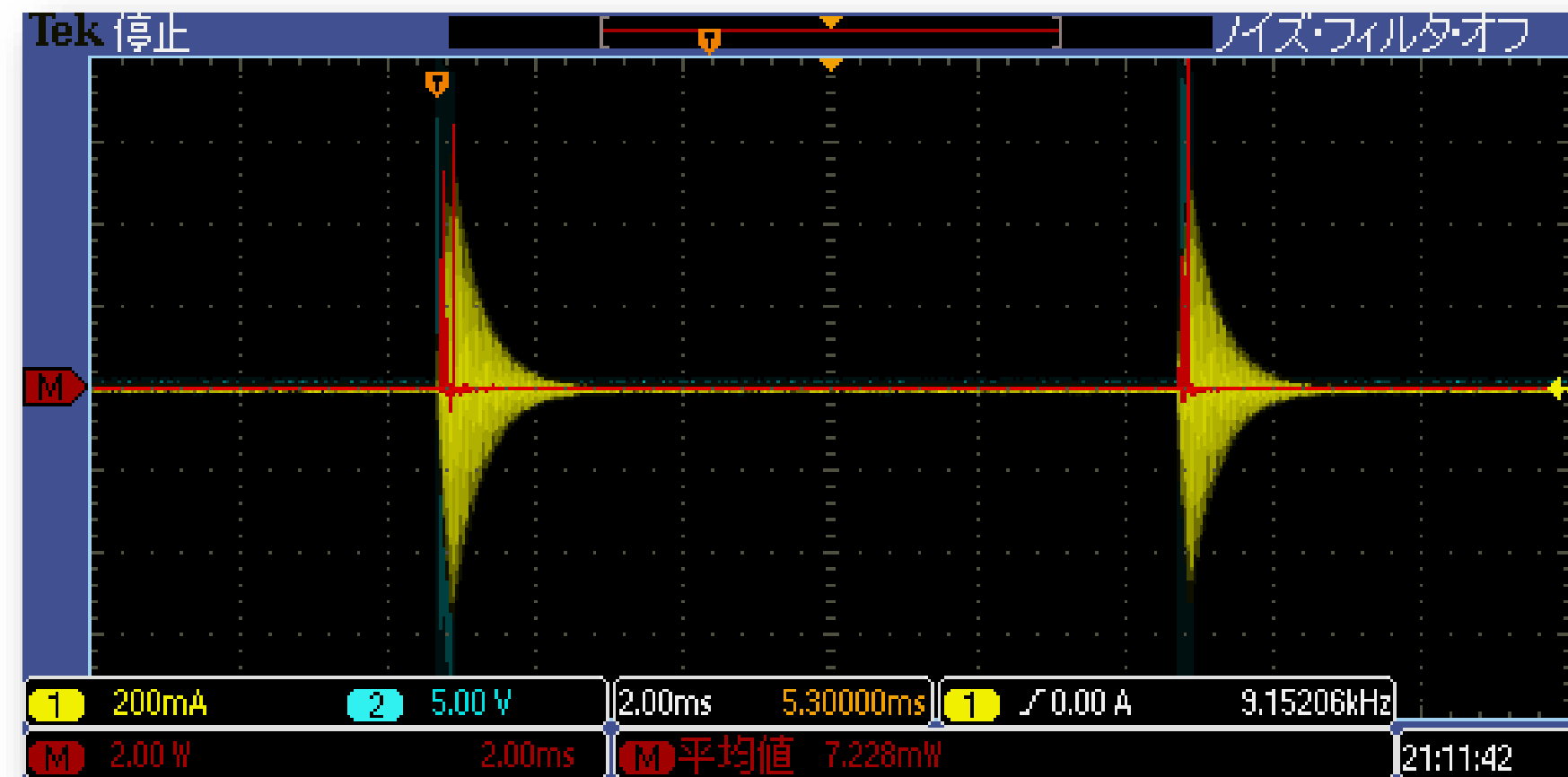


Inverter, HAR flags(1 : ON)

Power was successfully transferred only when the two coils are close enough ($k > 0.06$).

4. Experiment

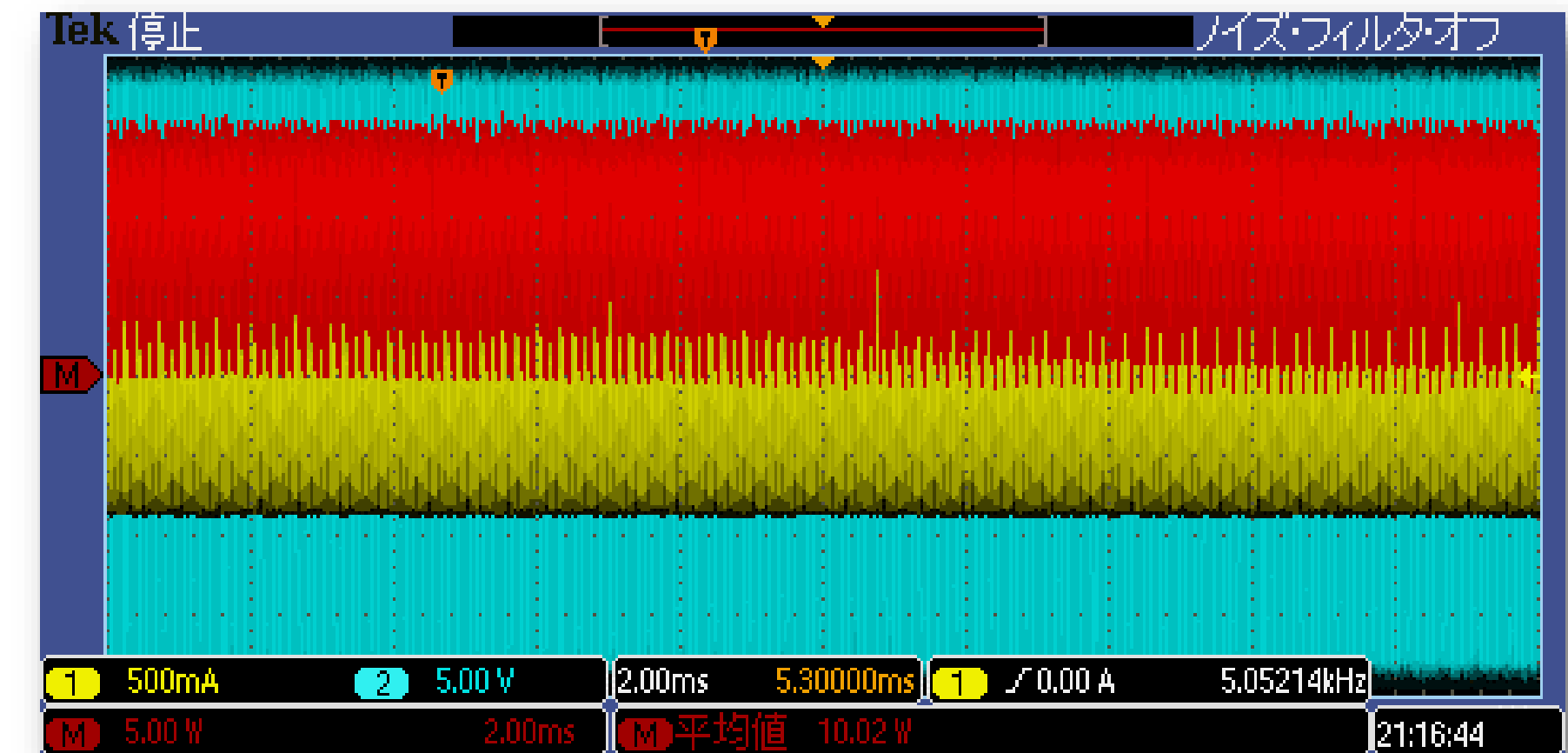
□ standby power



Search mode



Average power 7.228 mW



Transmitting mode



Average power 10.02 W

Average power consumption in search mode is less than 1/1000 of transmitting mode

5. Conclusion

Conclusion

- A vehicle detection system which does not use additional sensors was proposed.
- The effectiveness of the proposed method has been verified with the experimental results

Future Work

- generalized way of threshold determination and the optimization of T_{search} and T_{pulse}



Thank you for listening!