Recent Approaches to Develop High Frequency Power Converters

Location

Fireworks

Much snow

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Prof. Jun-ichi Itoh
Dr. Koji Orikawa (Presenter)

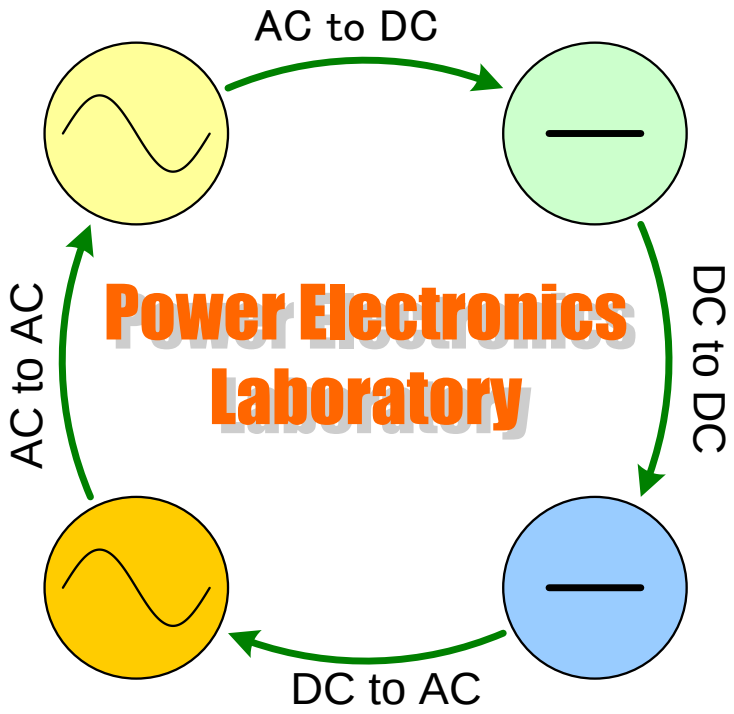
☆Objectives

- Efficiency improvement & size reduction of all kinds of power sources.

"Save the earth"

☆Research Subjects

Four directions of energy conversion



- *Circuit topologies and control technique*
- *Optimization of the circuit design*
- *Development of directional technology on applications*

Members

Associate Professor: **Jun-ichi Itoh**

PD: 1, Ph. D: 9, M : 12, B: 5

=> Total: 28 persons

Field of our research

Theme

Grid connected inverter
Power decoupling

Three Ph. D students

-PV inverter, Micro inverter
-Matrix converter for wind turbines
-Multi-level converter
-PFC("Active buffer")
etc.

Motor

Three Ph. D students

- Motor drive(IM, PMSM)
- Motor design(PM)
- Parameter identification method
- Flywheel energy storage system
etc.

High switching frequency converter

Three Ph. D students

Today's contents

- PCB implementation techniques
- Applications of SiC and GaN
- DC-DC converter
- Gate drive circuit
- Wireless power transfer
- Pulse density modulation
etc.

☆**Key technology** High switching frequency

- **Fundamental technologies**
  - DC bus bar analysis in printed circuit boards (PCBs)
  - High speed & Low power consumption gate drivers
- **Applications**

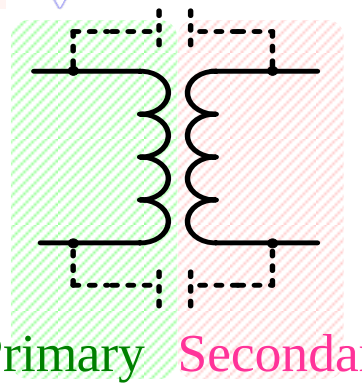
Today's contents

  - Wireless power transfer for gate drive supplies of a medium-voltage inverter
  - High power density PWM Inverter with wide band-gap devices
  - Frequency multiplying circuit for MHz output frequency
  - Wireless charger for electric assisted bicycle using EDLCs
  - Wireless power transfer with a Rail system
  - Several-Hundred-kHz Single-phase to Commercial Frequency Three-phase Matrix Converter

- Conventional : Special isolated transformers are used

  Problems

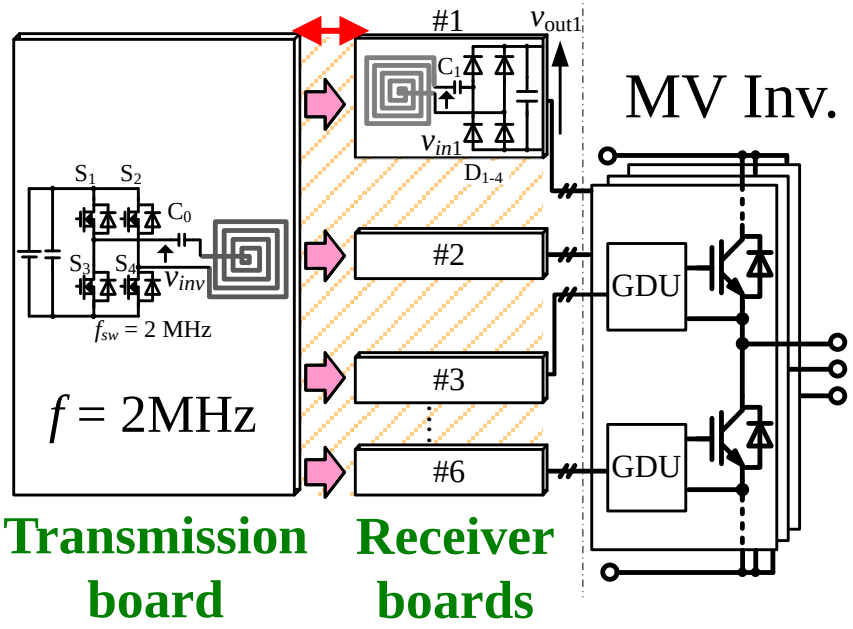
  - High cost and bulky due to custom designs
  - Reduction of parasitic capacitances is difficult



- Proposed method

Multiple wireless power transfer with transmission coils on PCBs for multiple gate driver supplies

Only PCBs are used without solid magnetic cores

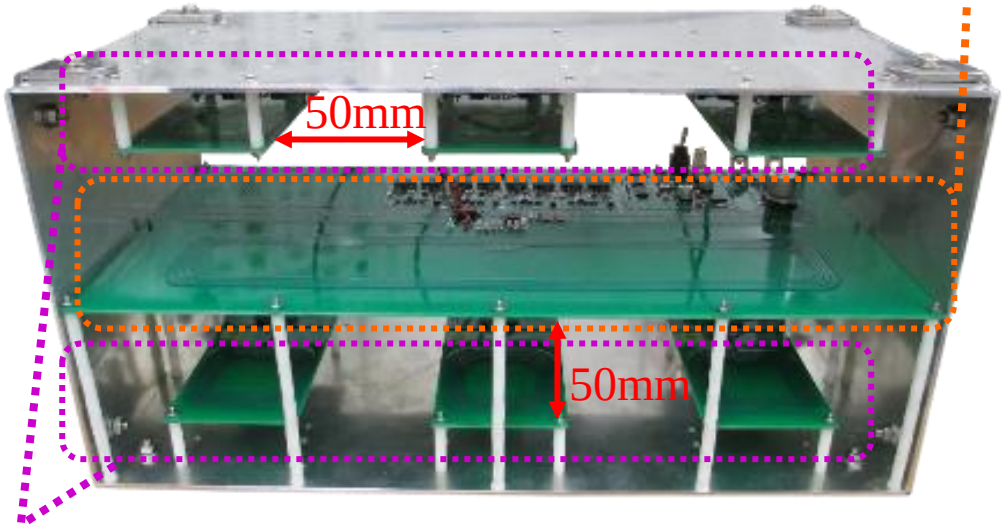


Cost reduction & Downsizing of the isolation system

System configuration of wireless multiple power transfer

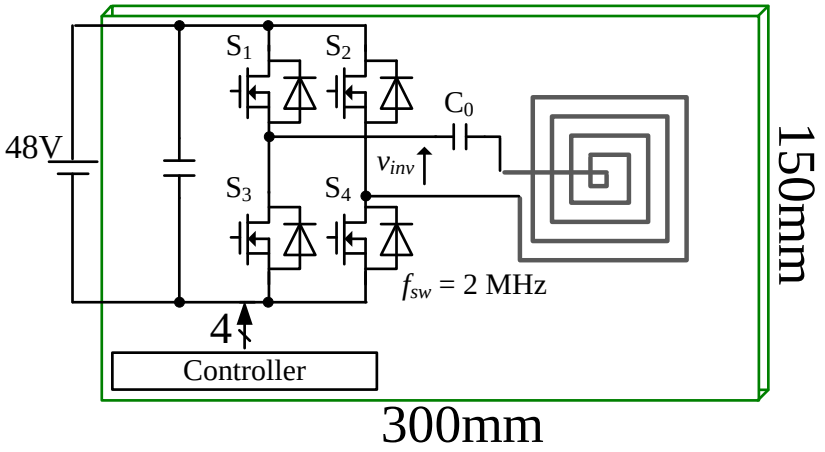
Substrate spacing : 50 mm

- Clearance and creepage distance are secured



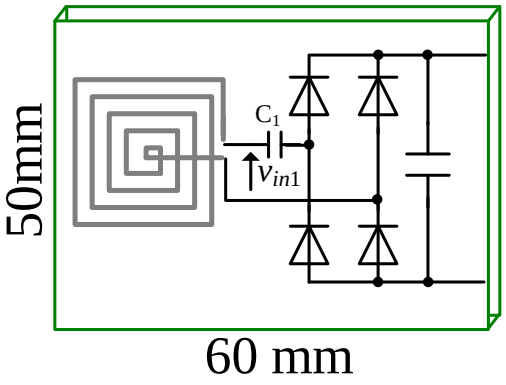
Transmission board #0

- High frequency INV (2MHz)
- Series resonance capacitor C_0
- Transmission coil

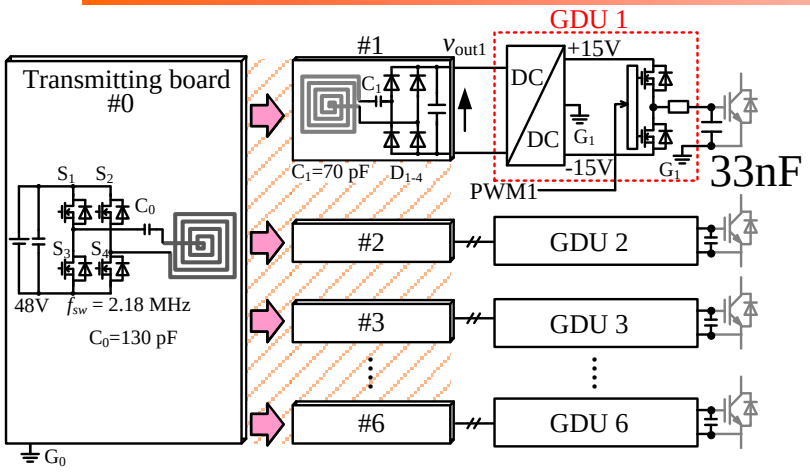


Receiver boards #1~#6

- Diode bridge rectifier
- Series resonance capacitor C_1
- Receiver coil



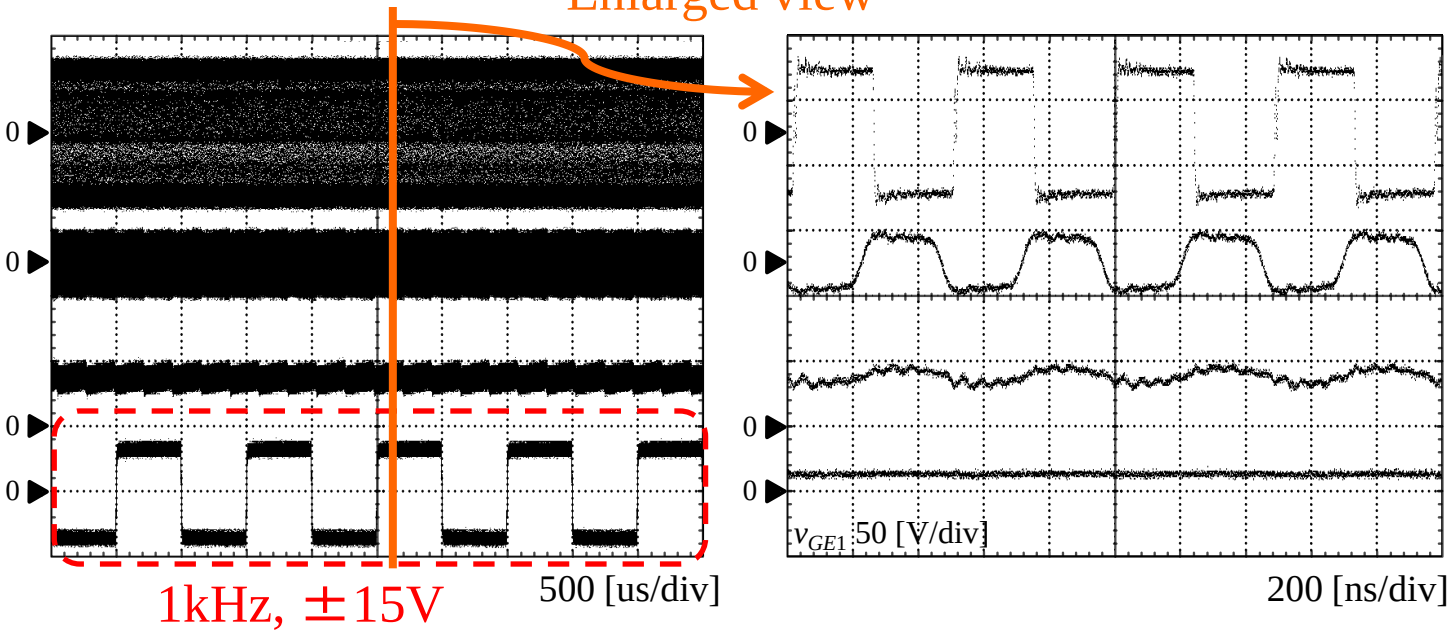
Experimental results (Operation with gate drivers)



- Gate drivers are connected
- Capacitors are connected assuming IGBTs

Operation waveforms

Enlarged view



Inverter output voltage (Transmitting board)
v_{inv} 50 [V/div]

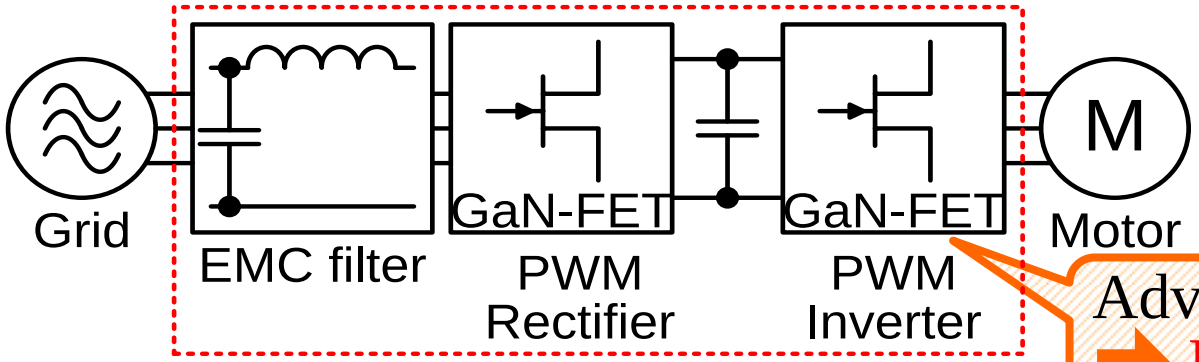
Input voltage (Receiving board #1)
v_{in1} 25 [V/div]

Output voltage (Receiving board #1)
v_{out1} 10 [V/div]

Gate-emitter voltage (Receiving board #1)
v_{GE1} 20 [V/div]

A switching operation on all of receiver boards is confirmed

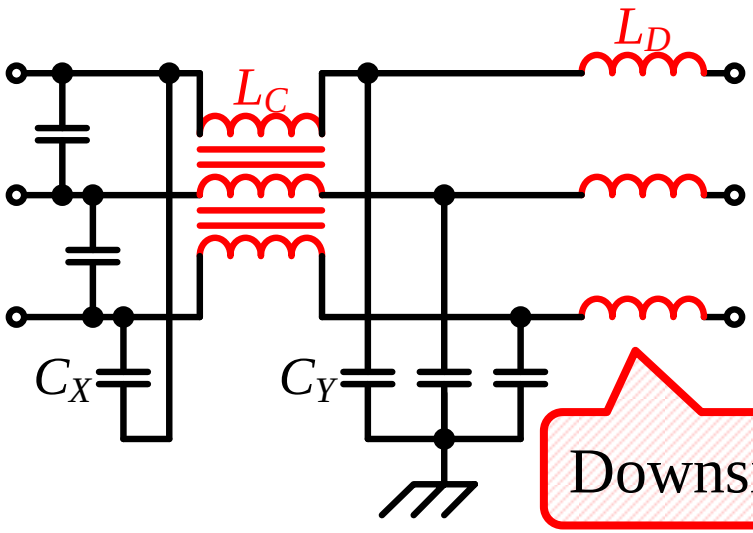
GaN-FET Inverter & EMC filter



GaN-FET Inverter

Motor drive system using GaN-FET

Advantage of GaN-FET
➡ Fast switching



Downsizing

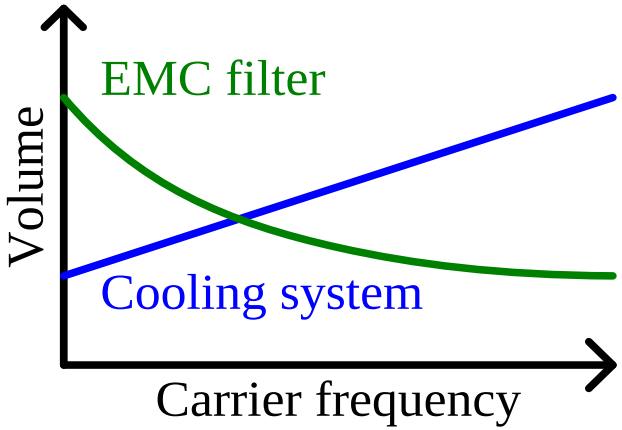
Single stage EMC filter

GaN-FET inverter

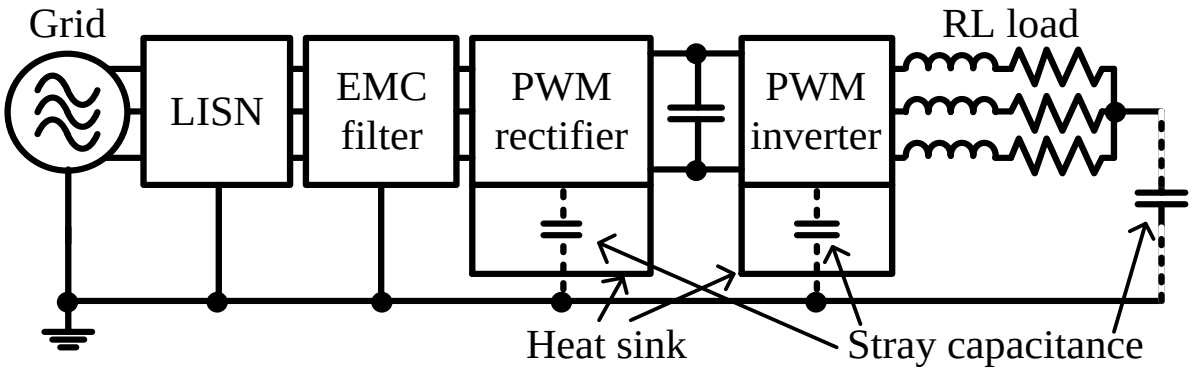
- Use a PWM rectifier
  ➡ Sinusoidal input current
- High frequency switching
  ➡ Reduce the ripple current

Miniaturize the EMC filter by using high frequency carrier

Relationship between volume and carrier frequency



Volume of the system



Conduction noise measurement system

➡ Estimate the conduction noise

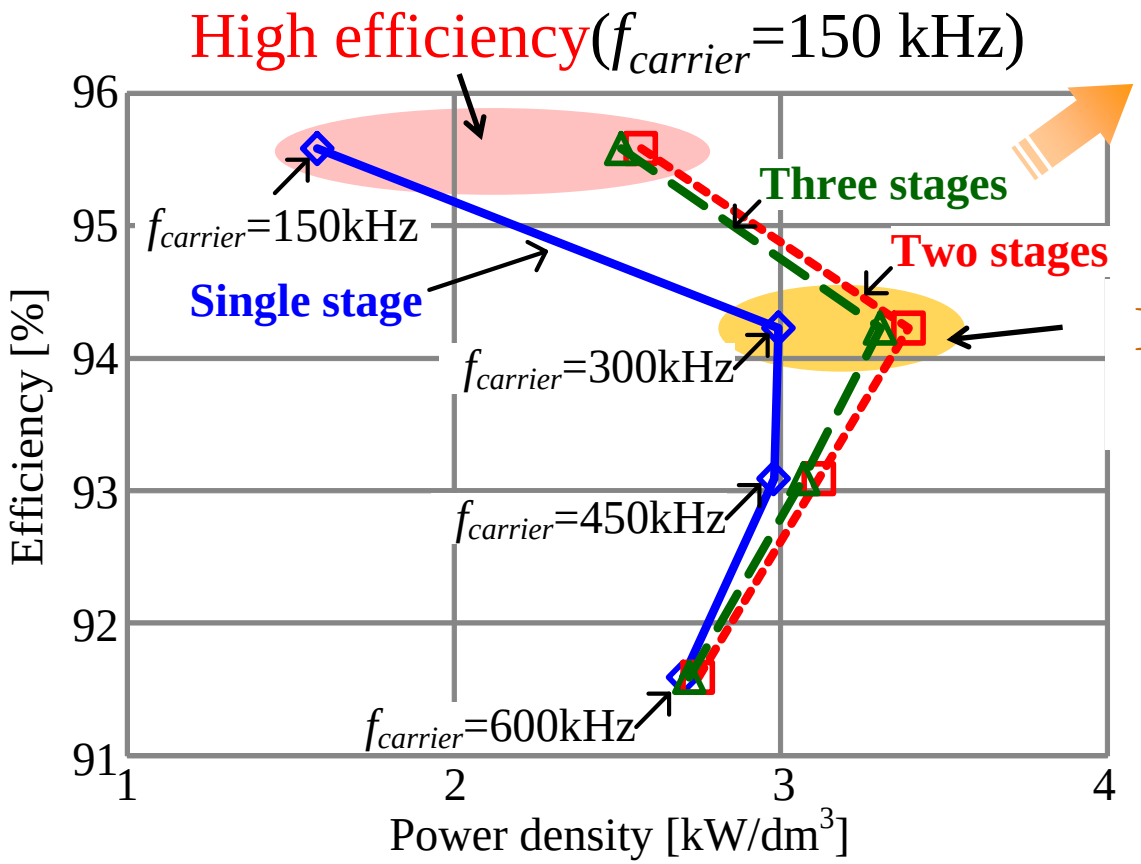
GaN-FET inverter system with high frequency carrier

- High frequency noise ➡ Smaller EMC filter
- Large switching loss ➡ Larger cooling system

Each volume is calculated based on the simulation results

Relationship between the carrier frequency and the total volume of GaN-FET inverter system is evaluated

Relationship between efficiency and power density



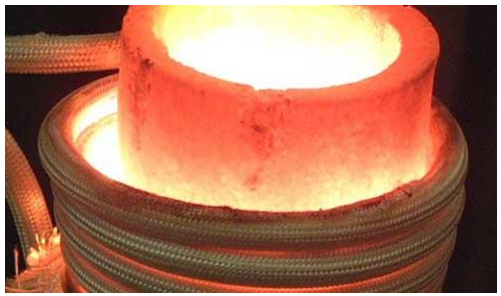
High efficiency
High power density

High power density
($f_{carrier}$=300 kHz)

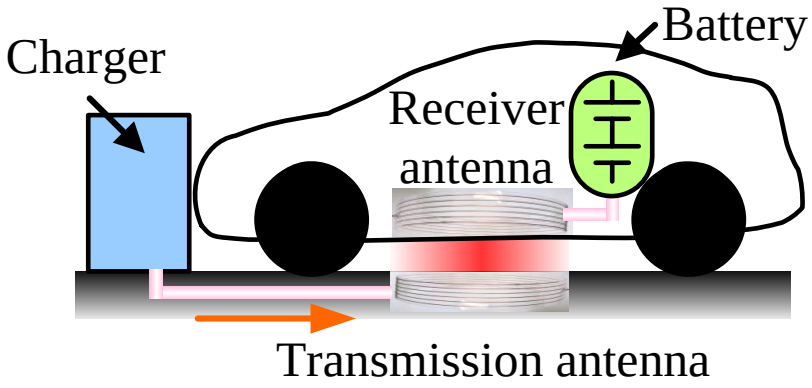
- High efficiency :$f_{carrier}$=150 kHz
  High power density :$f_{carrier}$=300 kHz
- EMC filter should be constructed by two stage filter in order to achieve high power density and high efficiency

Applications

Generation of plasma

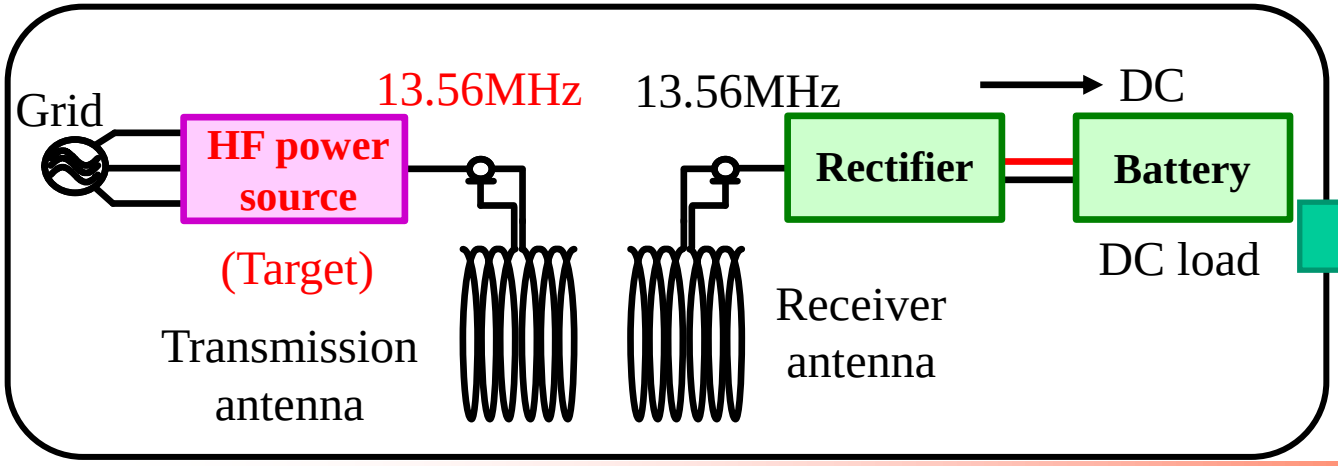


Induction heating



Wireless power transfer

Wireless power transfer



Requirements for HF power source

- >High frequency
- >High efficiency
- >Downsizing

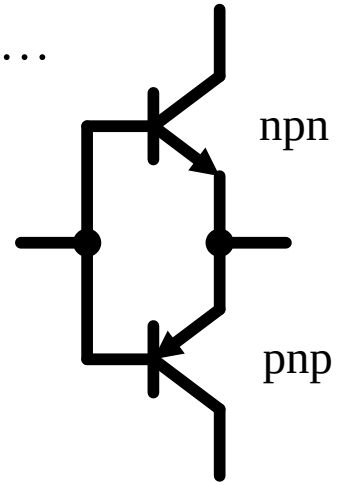
Conventional method of high-frequency power converter

Linear amplifier method

Ex) Class A, AB, C, etc…

- Vacuum tube, Power Transistor

>Electromagnetic interference (EMI): Low
>Efficiency : Low
>Cooling system : Large size



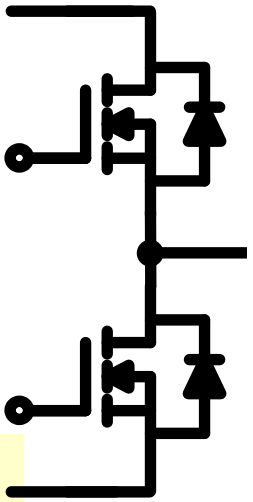
Switching amplification method

- Power MOSFET

>Efficiency : High
>Cooling system : Downsizing

- Employing wide band gap semiconductors
: Silicon carbide(SiC), Gallium nitride(GaN)

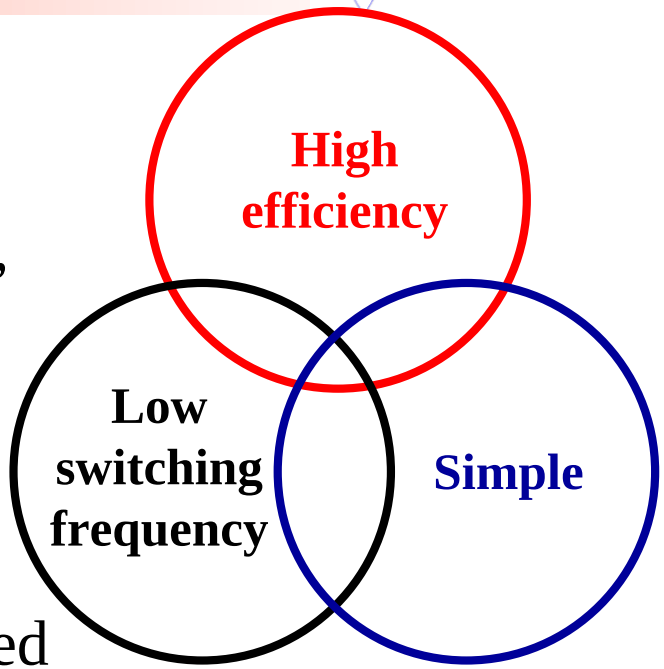
>Fast switching, low power loss
>Implementation of gate drive unit (GDU) : Complicated
>Control gate-source voltage : Difficult

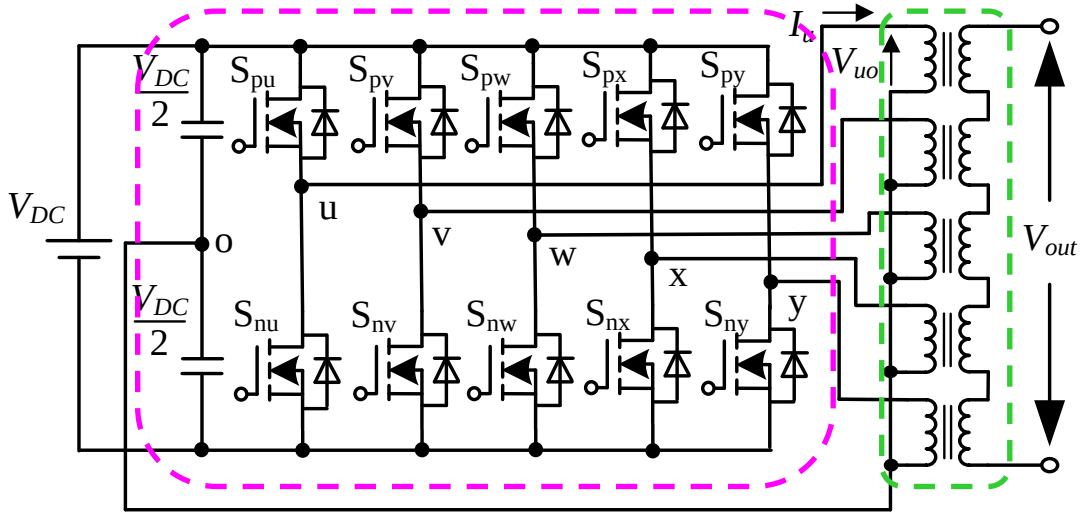


Concept of the proposed circuit and purpose of this study

Concept

- Simple method
  - Without wide band gap semiconductors, only conventional Si devices are used
    >Conventional GDU can be used
- High output frequency over switching frequency
  - Frequency multiplying method is adopted

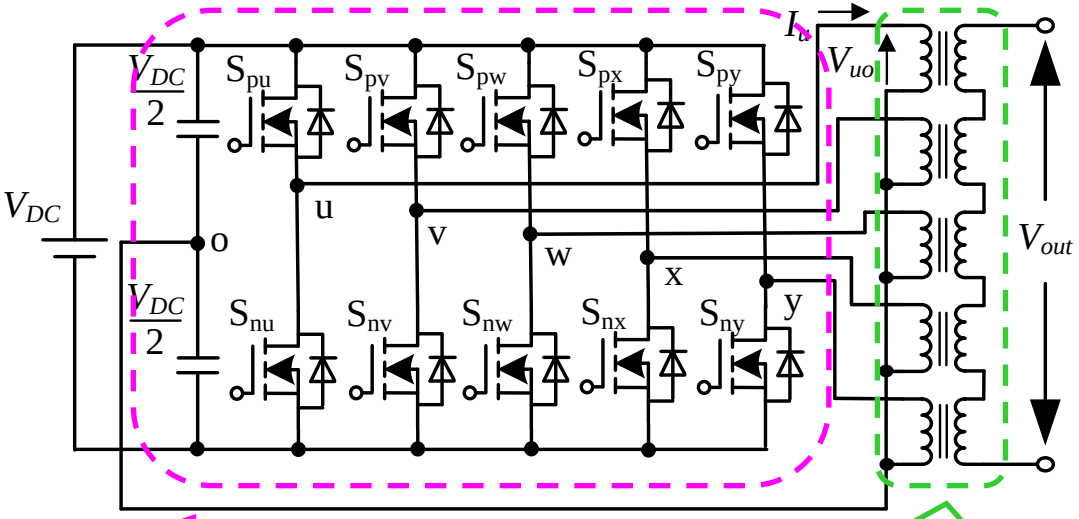


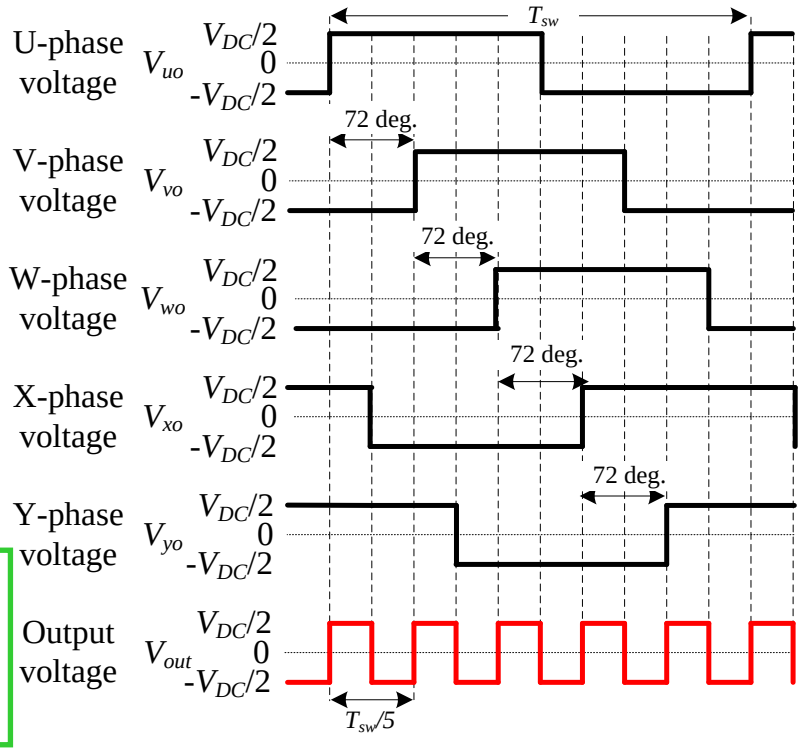


Proposed circuit –Frequency multiplying method -

1. Multiphase inverter with square wave drive using shifted gate signal

2. Multicore transformer is adopted
➡ Sum of the inverter output voltage can achieve high output frequency



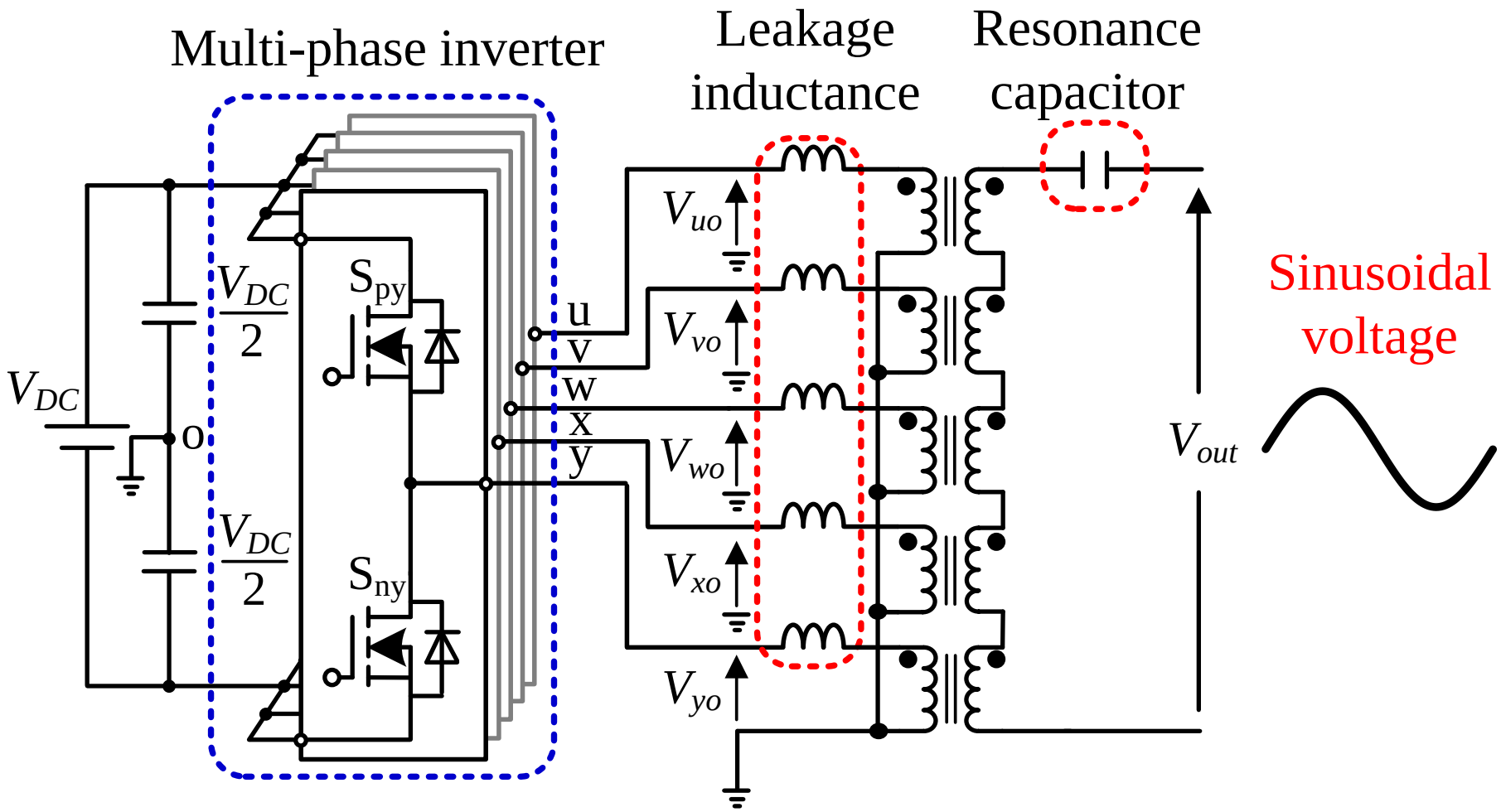


1. Multi-phase inverter
Square wave drive

2. Multi-core transformer
Primary : Parallel connection
Secondary: Series connection

$f_{out} = N * f_{sw}$ Ex.) f_{out} = 2.5 MHz, N = 5 ➡ f_{out} = 500 kHz

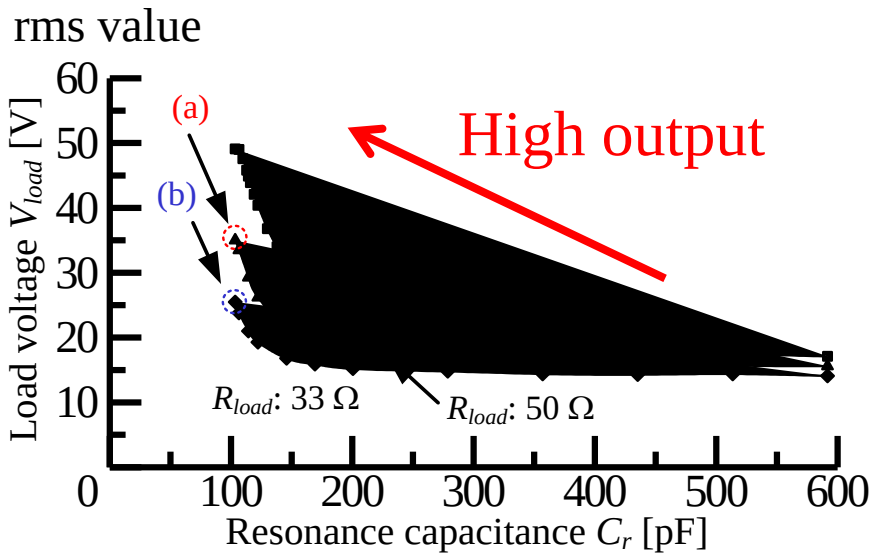
Applying series resonance using resonance capacitance

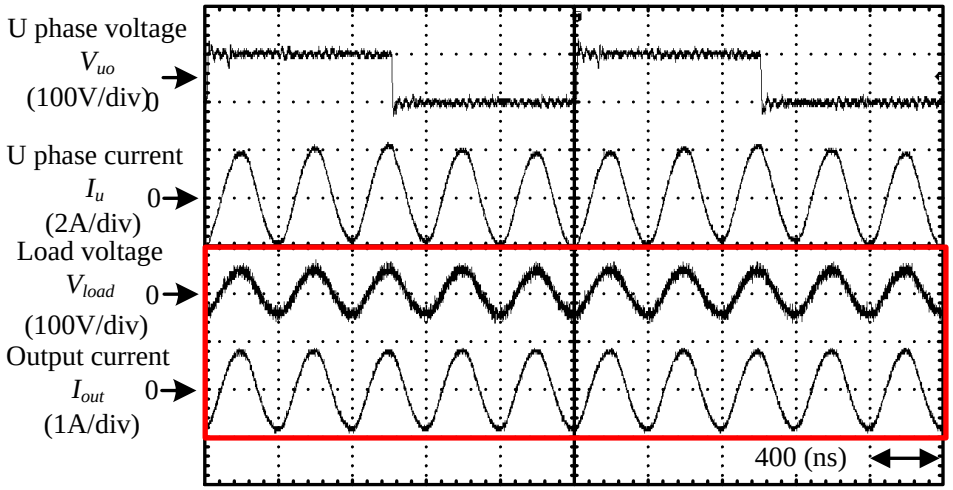


- A resonance capacitance is connected to the secondary side of multi-core transformer

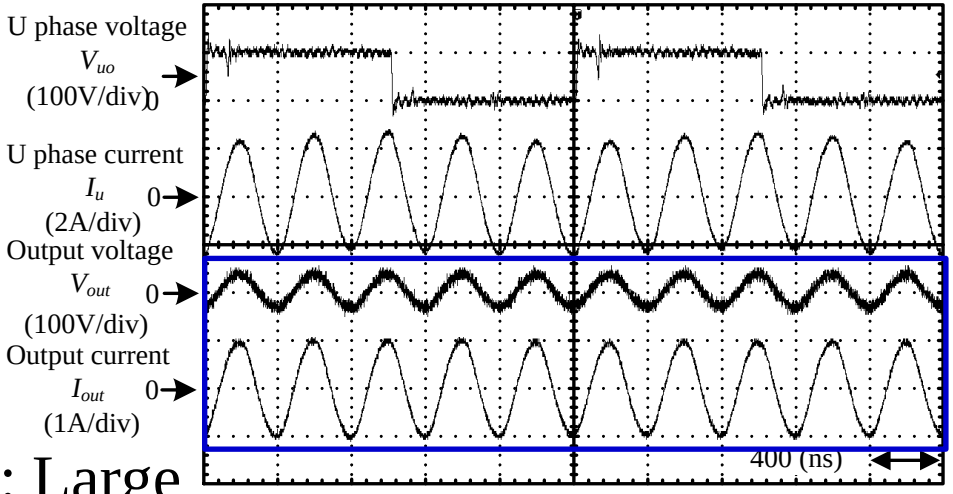
➡ Leakage inductance is effectively used for sinusoidal output voltage

Experimental results (Series resonance, f_{out}=2.5MHz)





(a) R_{load}: 50Ω (C_r:100pF)



(b) R_{load}: 33Ω (C_r:100pF)

- Load voltage and current
  - ➡ Almost sinusoidal waveform
- Output voltage is changed by resonance capacitance value
- Load resistance: Small
  - ➡ Quality factor for resonance: Large
    - > Output voltage: Decreased

Conclusion

- **Power loss calculation**
  (Semiconductors, passive components)
- **Printed circuit board design**

High frequency switching

- **Clarification of design methods**
- **Volume estimation**
  (Passive components, heat sinks)

Combination

Applications

- Wireless power transfer for gate drive supplies of a medium-voltage inverter
- High power density PWM inverter with wide band-gap devices
- Frequency multiplying circuit for MHz output frequency

etc.