High Repetition Rate Pulse Generator for Induction Synchrotron

~Modulator R&D at KEK ~

Graduate University for advanced studies
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- ***Concepts and Key Device for Induction Synchrotron***
- ***Power Modulator Design***
  - ***Circuit and its trigger sequence to generate bipolar pulse***
  - ***Design parameters and the characteristics of MOS-FET***
- ***Result from the test operation and the modification of power modulator***
- ***CW operation with Resistor Load***
  - ***Output voltage***
  - ***Stability in temperature evolution at MOS-FETs***
  - ***2.2kV burst mode operation***
- ***Summary***

Concept of Induction Synchrotron

Principle

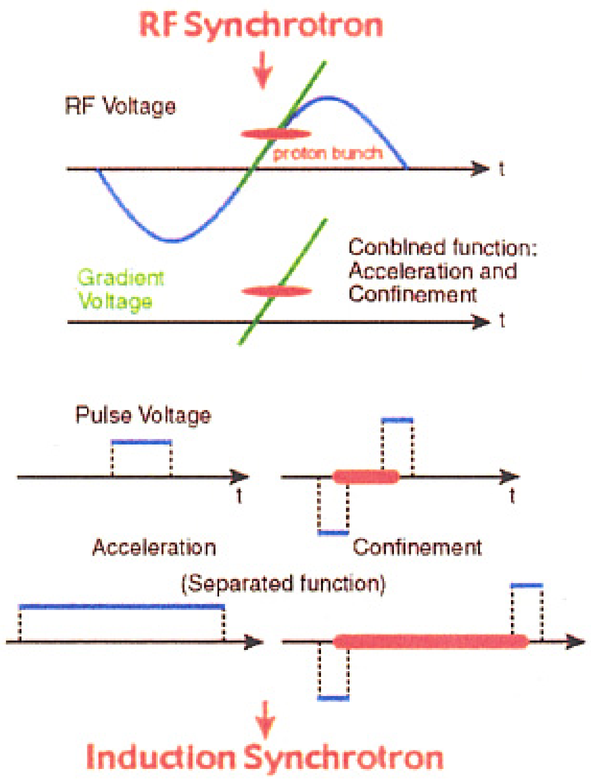
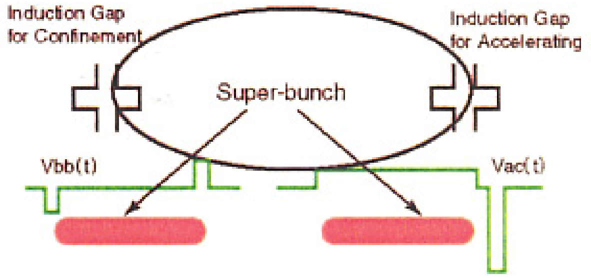
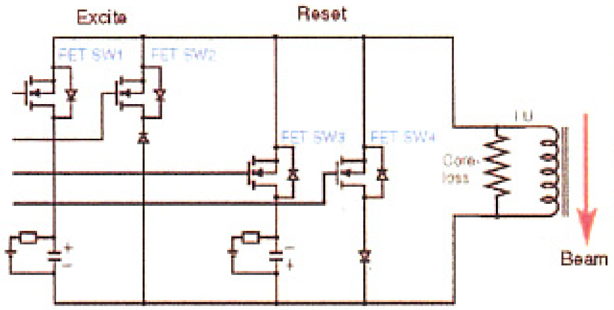


Image of Ring

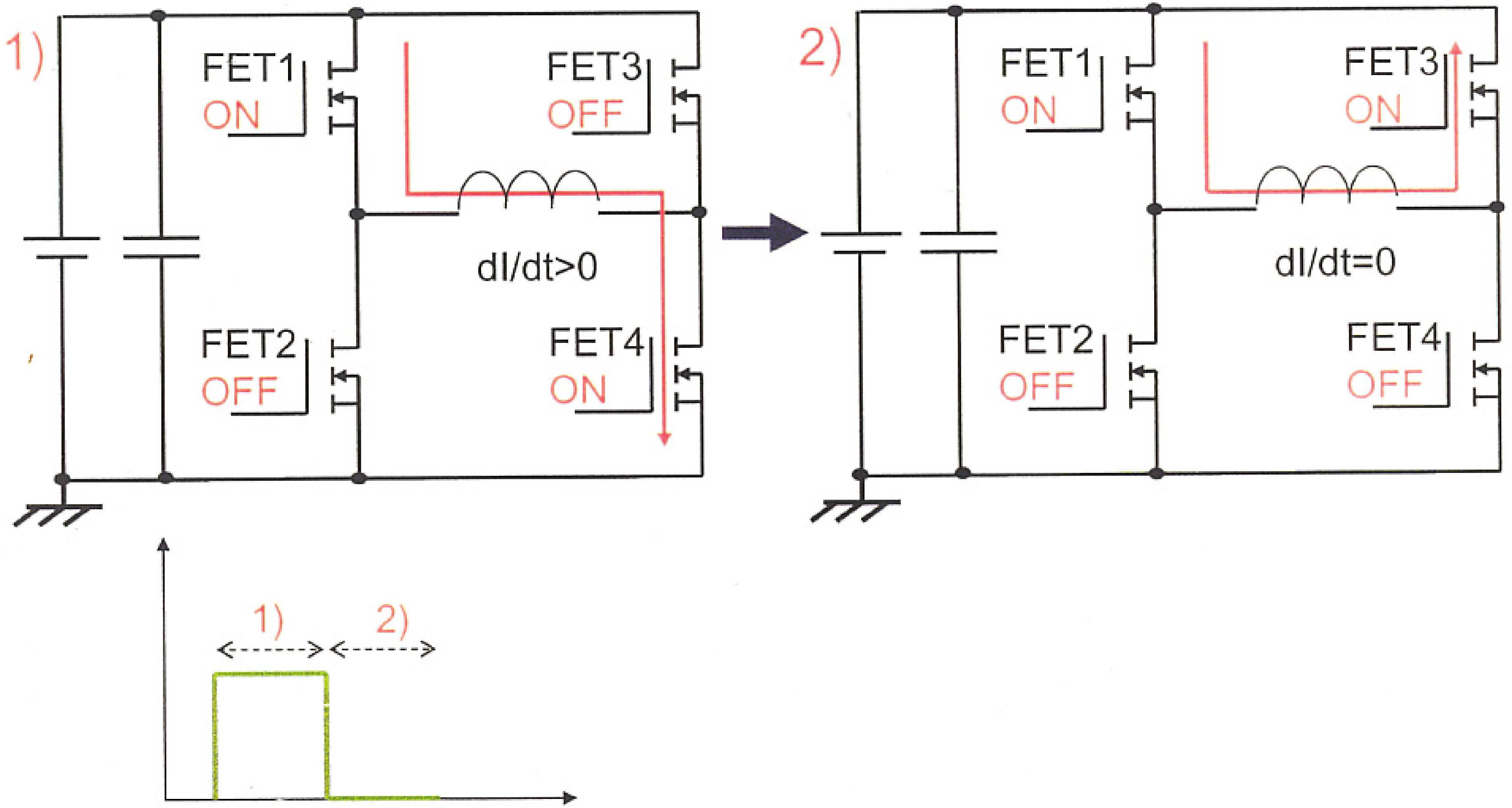


Modulator Circuit



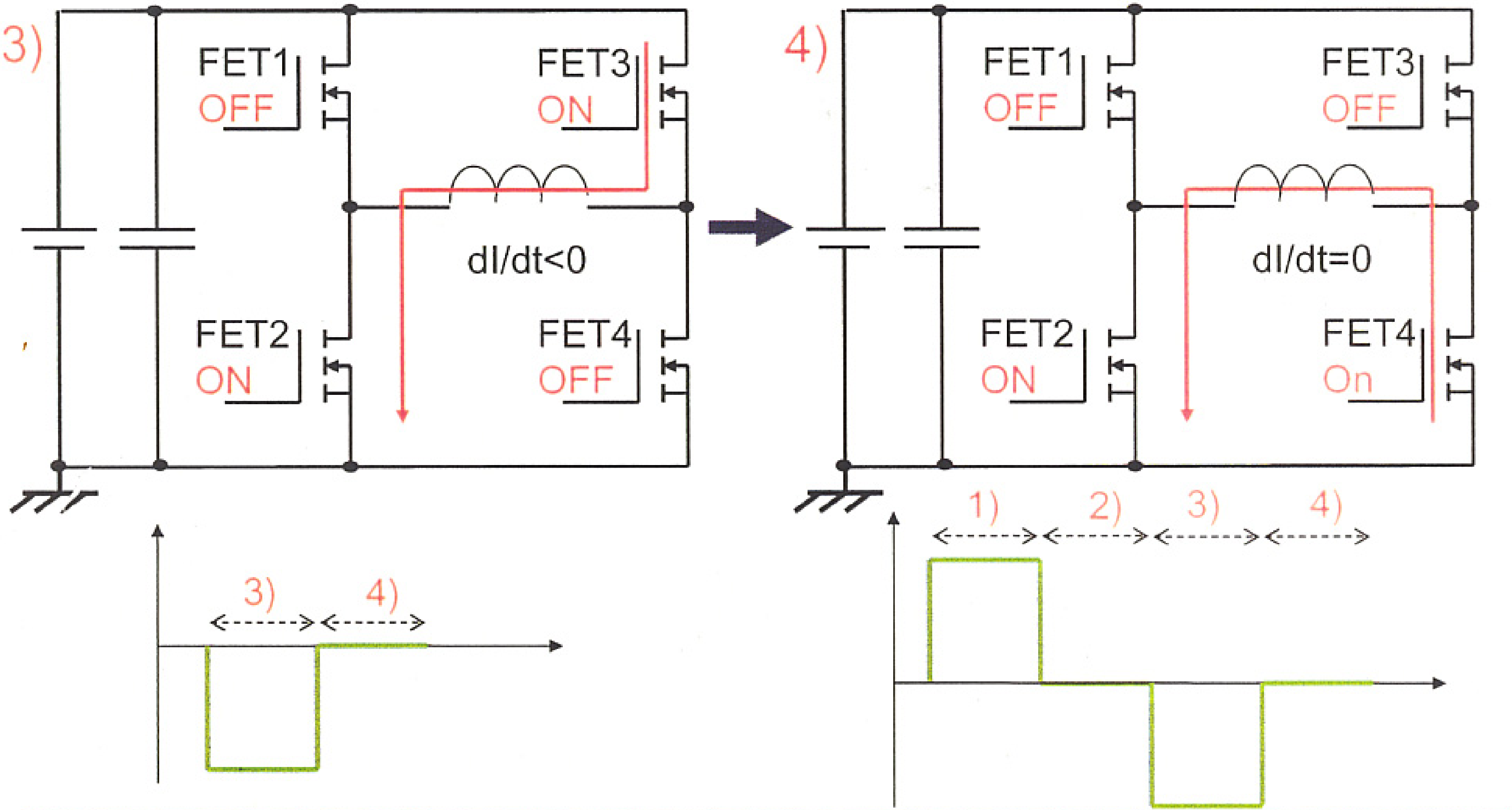
Power Modulator Design

Full bridge circuit and its trigger sequence to generate bipolar pulse



Power Modulator Design

Full bridge circuit and its trigger sequence to generate bipolar pulse



Power Modulator Design

Design parameters and the characteristics of MOS-FET

Designed values and characteristics of Power Modulator

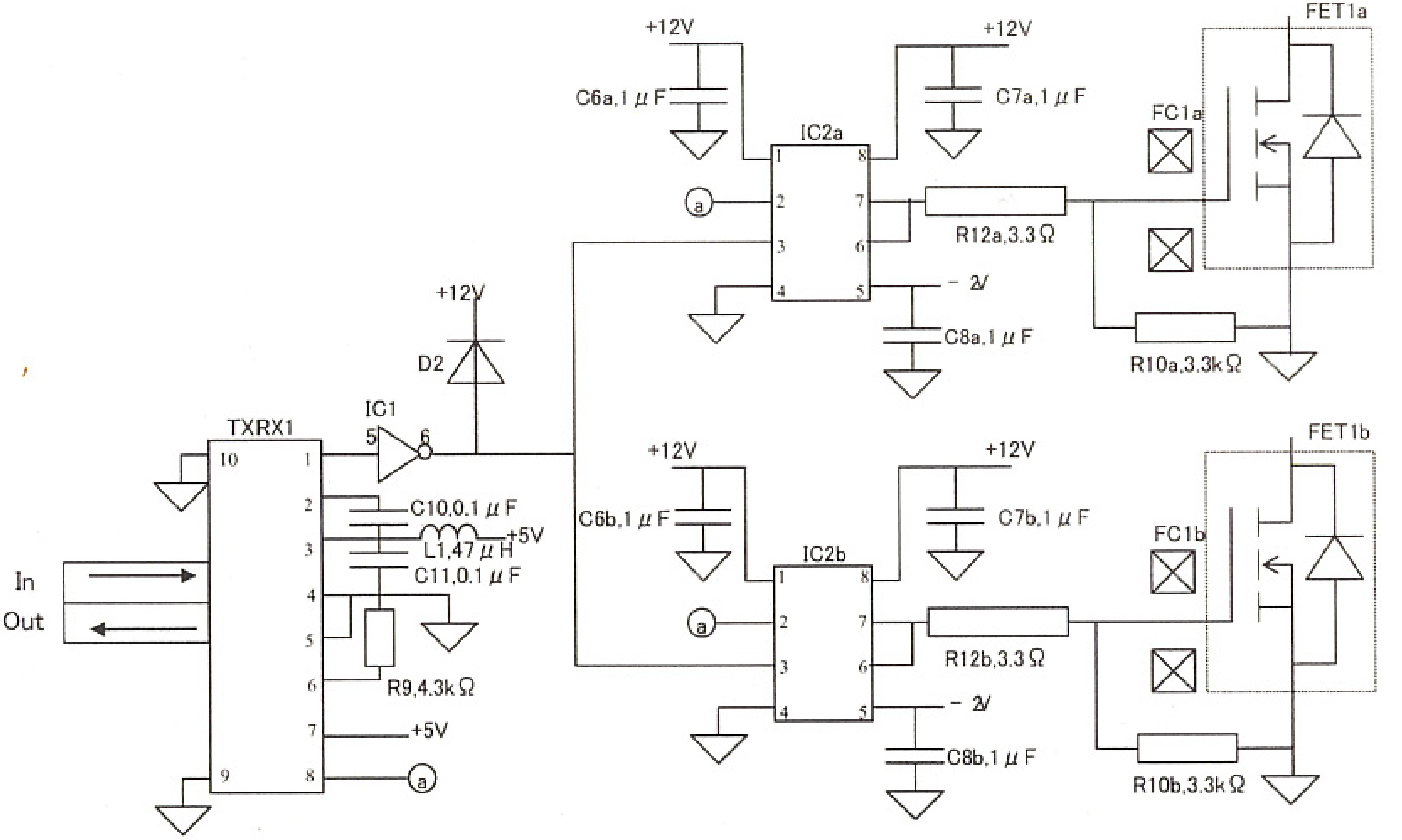
DC Power Supply	11.25 [kW]
Output Voltage	2.5 [kV]
Peak Output Current	8 [A]
Duty of Pulse	50 [%]
Power Loss at MOS-FET	16 [W]
Cooling of MOS-FET	Forced Air
# of MOS-FETs in Series	5
# of MOS-FETs in Parallel	1 or 2

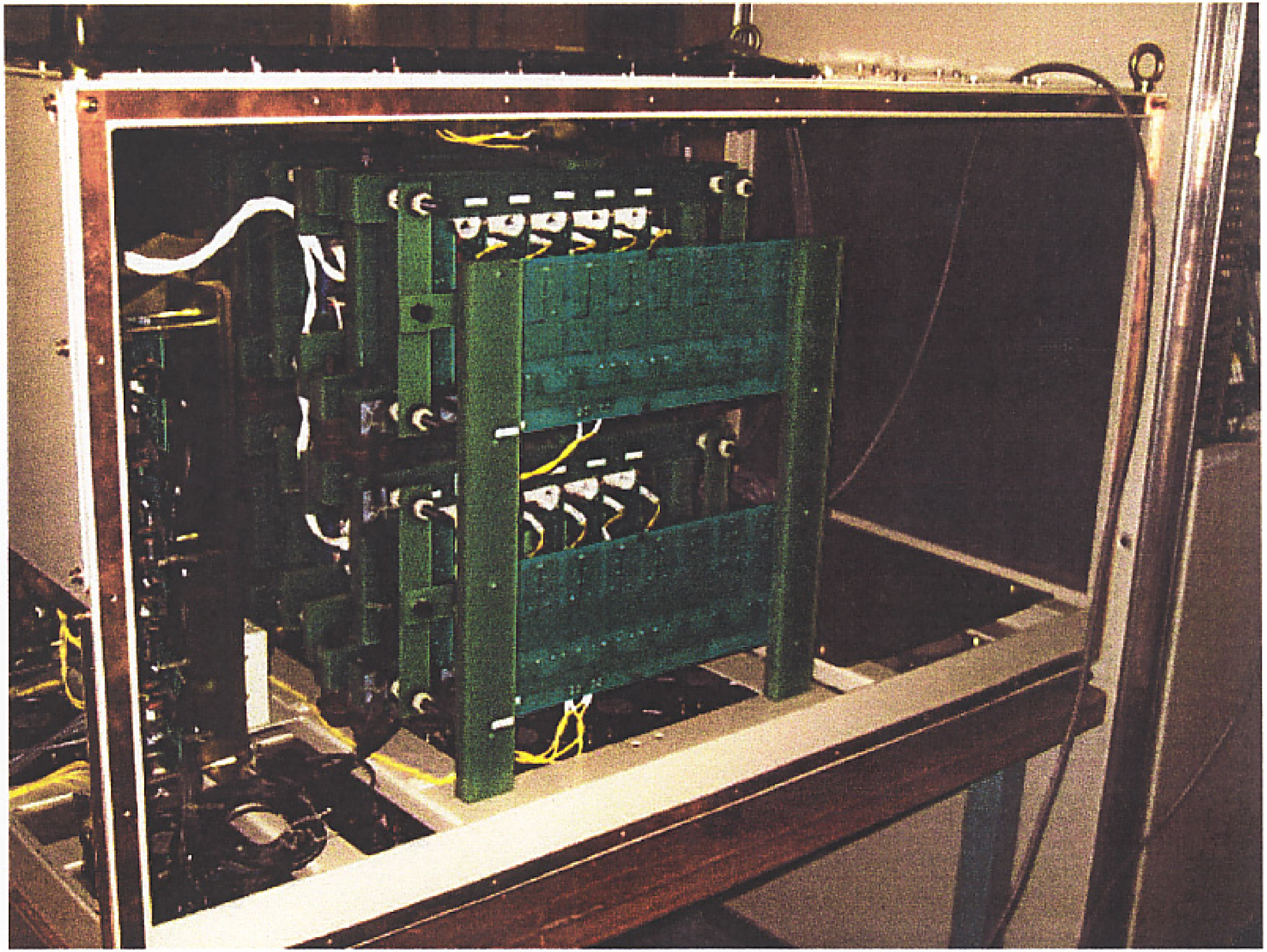
Characteristics of MOS-FET

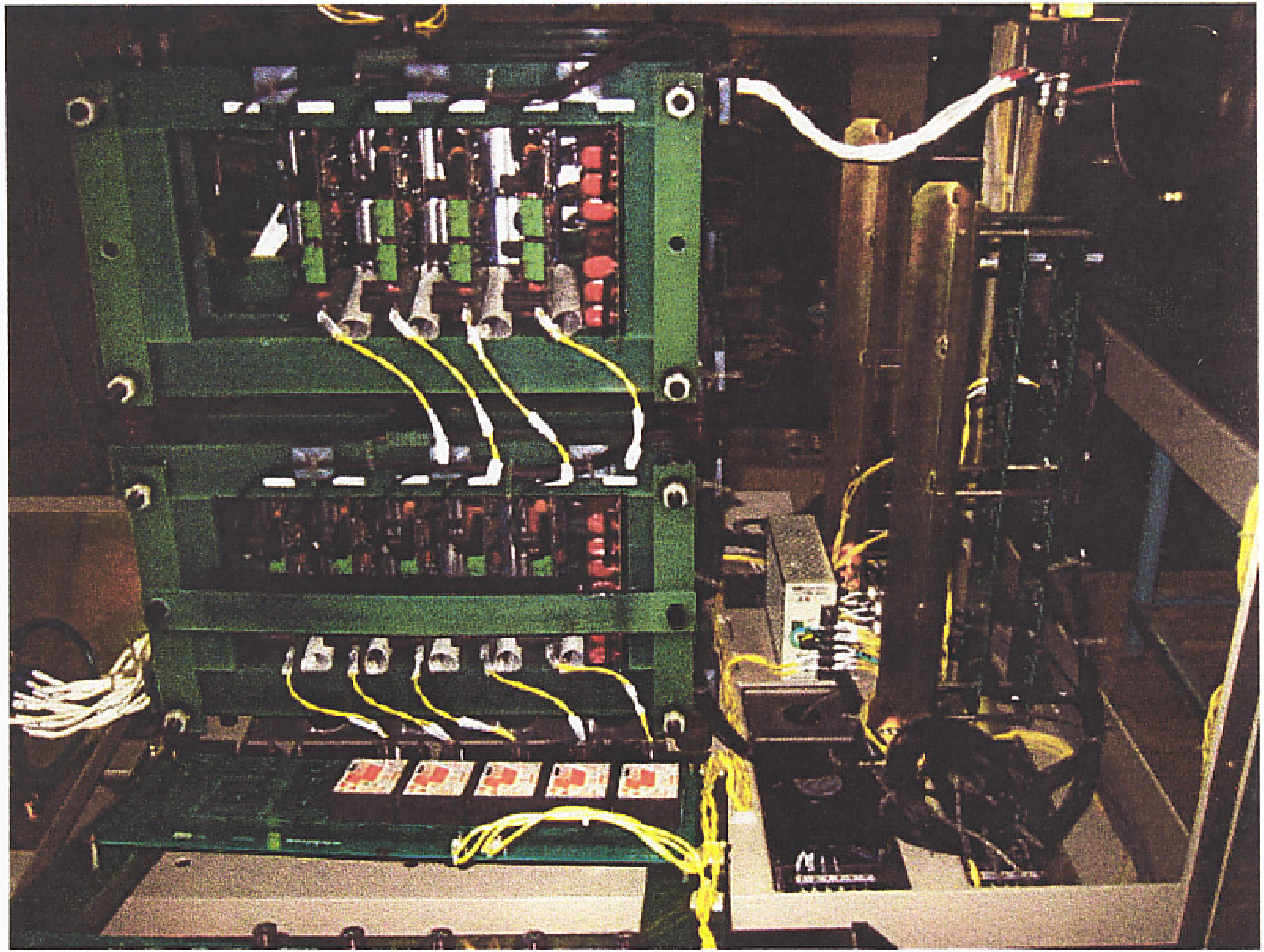
Vds	900 [V]
Id(DC)	9 [A]
Id(Pulse)	27 [A]
On resistance	1.5 [ohms]
Maximum power loss	150 [W}

Power Modulator Design

Drive circuit for MOS-FET of Enhancement type with N channel







500kHz,200V operation with 450ohms of Resistor Load

Horizontal;500nsec/div, vertical;100V/div

Our estimation to this waveform ringing structure is that there exists resonant frequency coupled by the capacitance of MOS-FETs during in its OFF-State and the inductance of the circuit

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There's no way of controlling the capacitance once after deciding the # of MOS-FETs and its applied voltage

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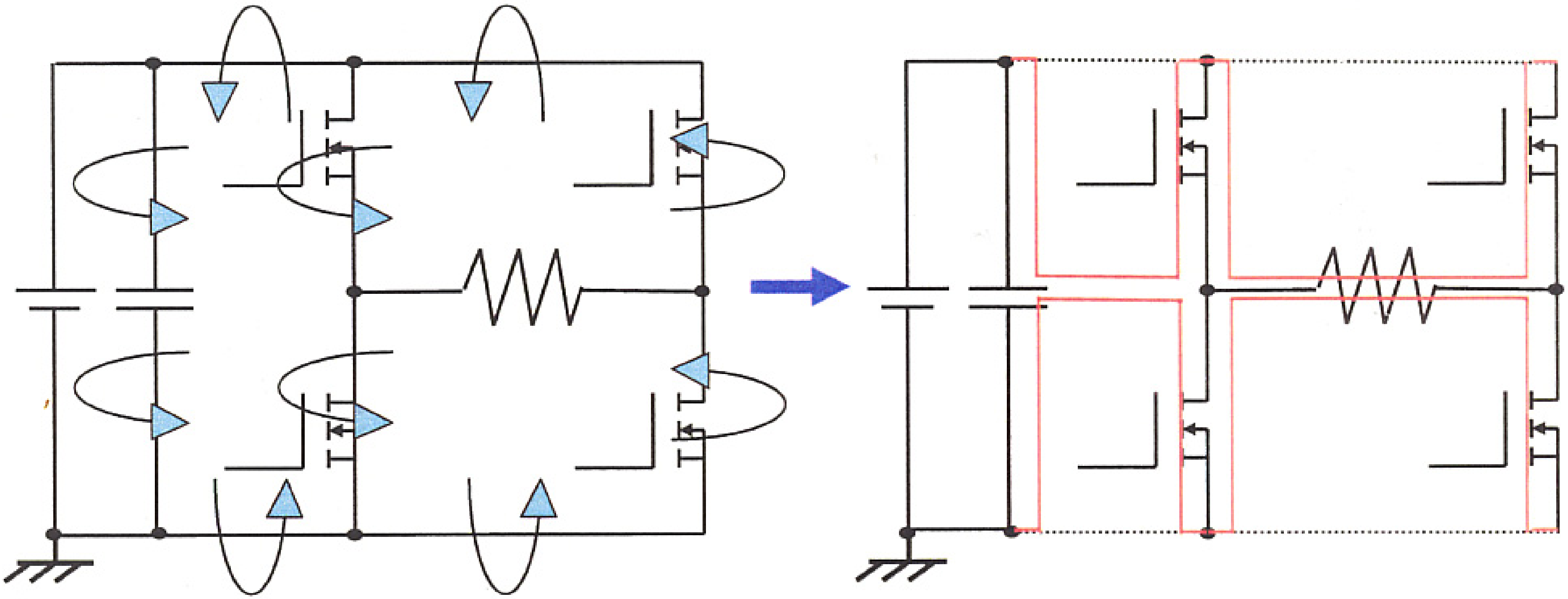
Inductance of the circuit should be minimized

Modification of Wiring

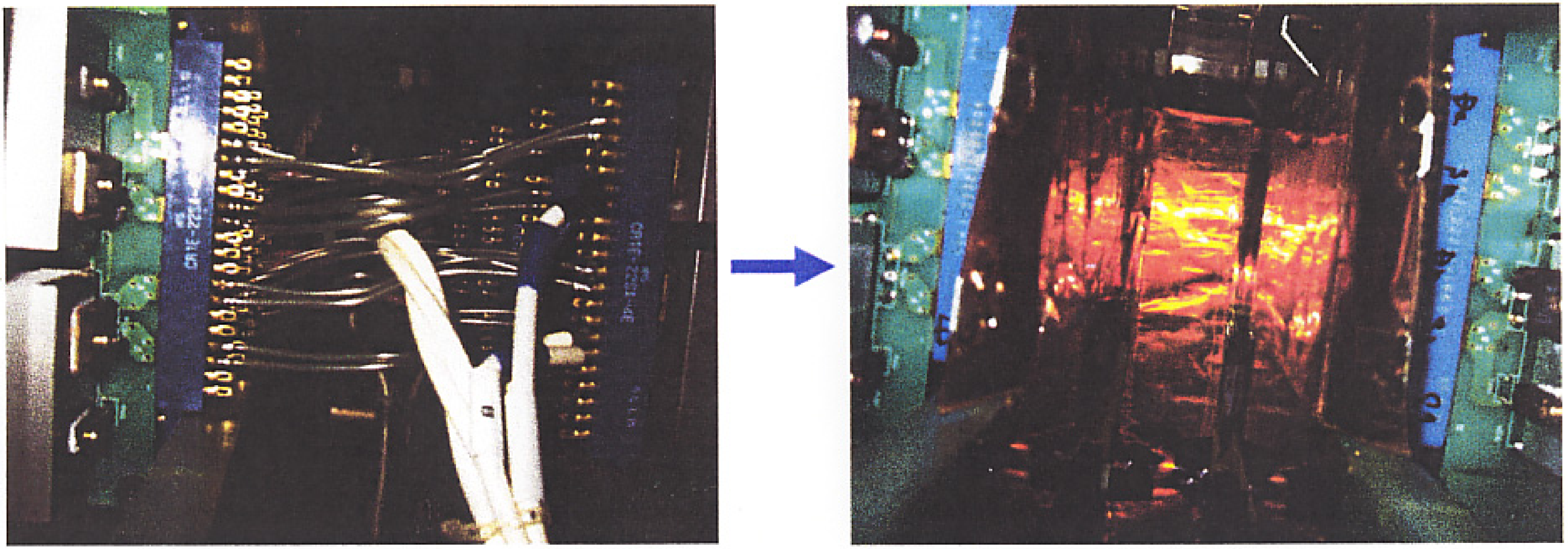


Reducing the induced magnetic flux density by operation causes the reduction of parasite Inductance of the circuit

⇒Resonant frequency goes up

Parasite Inductance of the circuit has been minimized by minimizing the area closed by the Induction current

Modification of Wiring

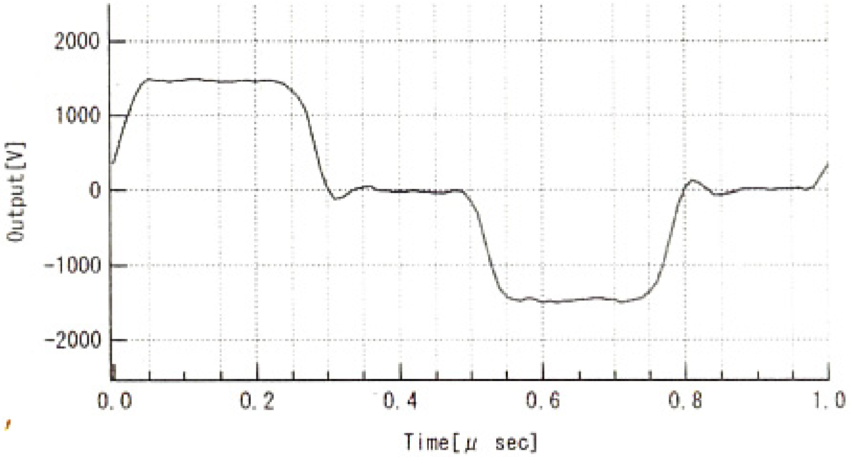


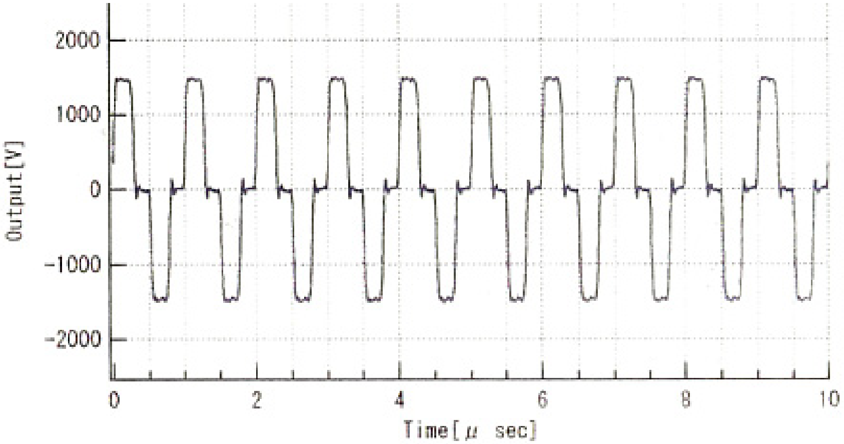
Before the modification

After the modification

CW operation with 450ohms of Resistor Load

-1.5kV Output Voltage-

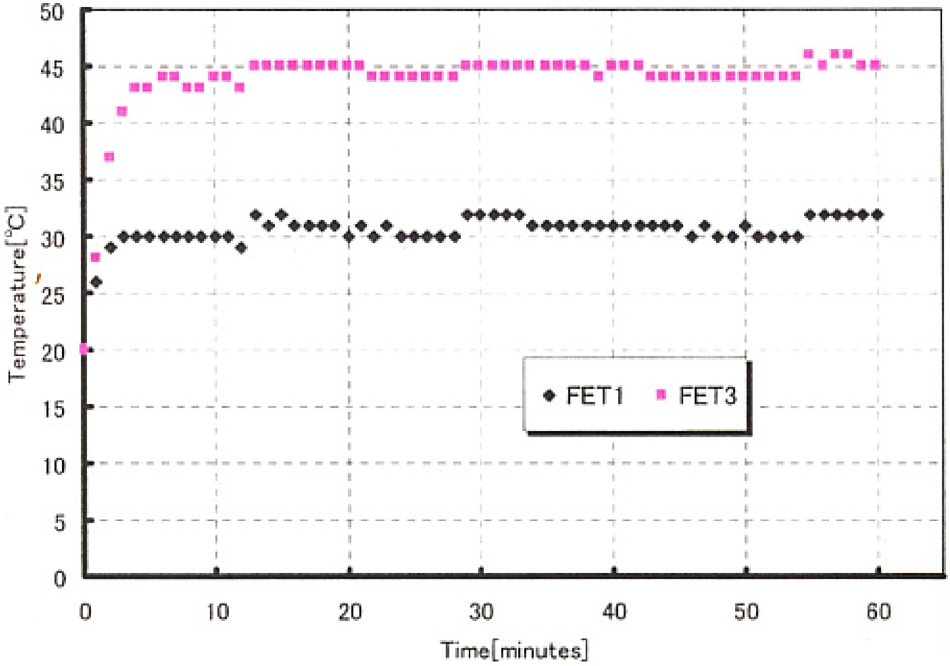




Operation Mode	Quasi-CW (for 1sec with output, for 2sec without)
Operation Time	60 [minutes]
Repetition Rate	1 [MHz]
Pulse width	250 [n sec]
Output Voltage	1.5 [kV]
10% to 90% Rise time	45 [n sec]
90% to 10% Fall time	40 [n sec]

CW operation with 450ohms of Resistor Load

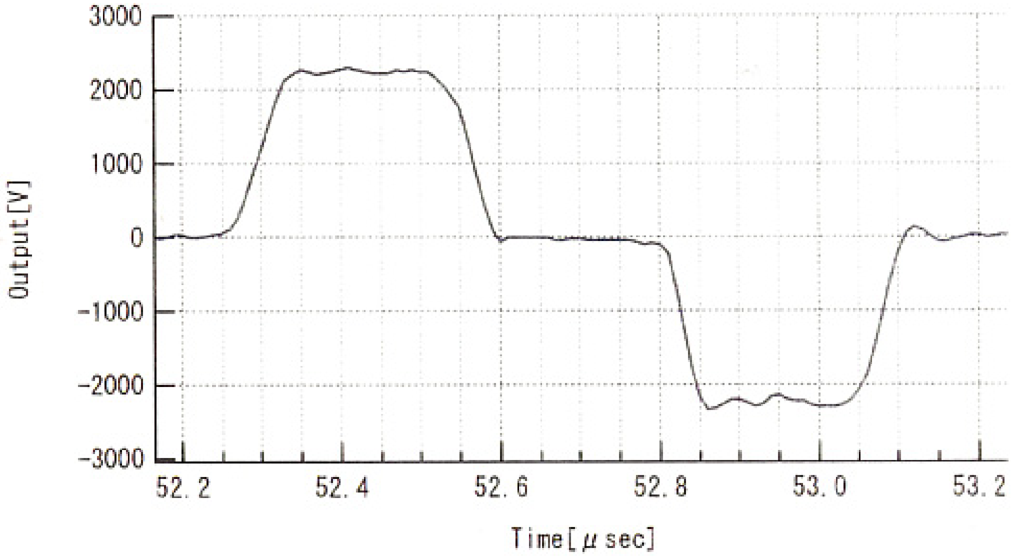
-Stability in temperature evolution at MOS-FETs-



Room Temperature	20[°C]
On Resistance of MOS-FET	1.5 [ohms]
Current	3.3 [A]
Duty-pulse	50 [%]
Duty-operation	33 [%]
Duty-total	17 [%]
Estimated power loss at MOS-FET	3.7 [W]
Thermal resistance from MOS-FET to Heat-sink	0.833 [°C/W]
Estimated temperature of Heat-sink	22 [°C]

Burst-Mode operation with 450ohms of Resistor Load

-2.2kV Output Voltage (snap shot from 100 pulses)-



Summary

- Induction Power modulator was successfully operated in Quasi-CW mode with 1MHz of repetition rate generating 1.5kV, 250nsec of bipolar pulses
- Temperature at Heat-Sink of MOS-FETs was measured and confirmed to be in acceptable value
- Burst-Mode operation with 2.2kV of output voltage was achieved for 100 pulses

Future Study

- 2.5kV Quasi-CW operation
- Power feed to the Induction cavity and the Impedance matching with it
- Demonstration of manipulation of pulse width and height
- Feedback system for Induction power modulator for the stable beam acceleration
- Beam acceleration at 12GeV Proton Synchrotron at KEK