# Preliminary Design of Search-coil Magnetometer with ASIC Devise for Lunar Mission

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Space Search Coil (SSCM)

❑ The Space Search Coil Magnetometer (SSCM) is developing for the Korean space exploration missions such as a Lunar lander and an Orbiter.
❑ SSCM consists of MAG unit and Search coil control Electronics (SCE) Unit.
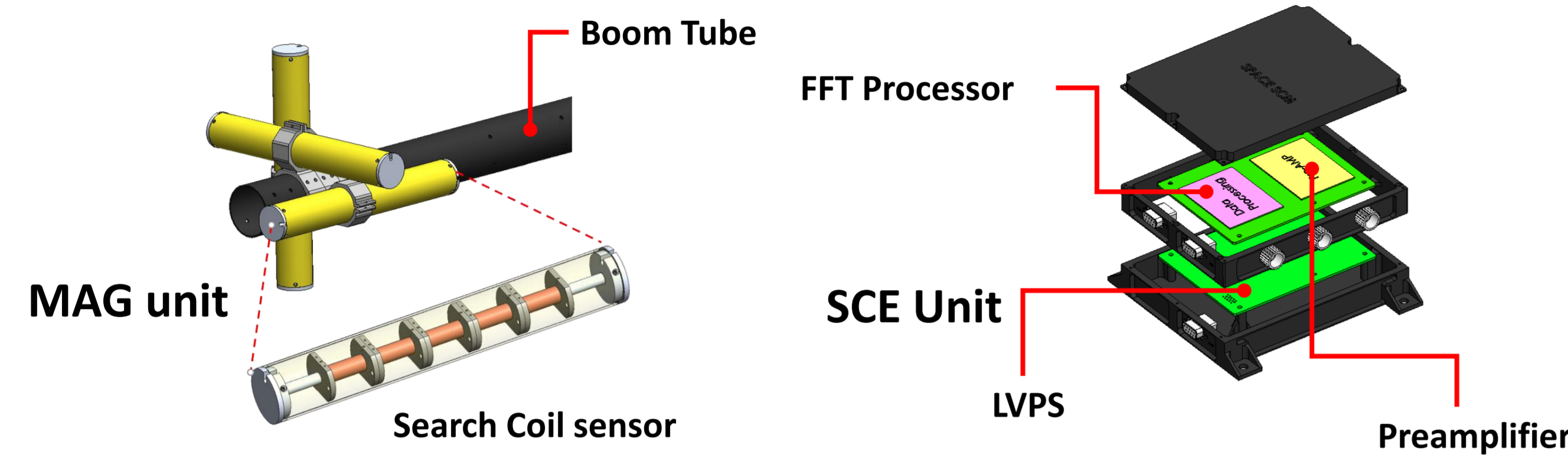
- **MAG Unit**
It consists of the boom tube and the Search Coil Magnetometers (SCM).
The boom tube is the CFRP (Carbon Fiber Reinforced Plastic) which has high strength to weight ratio. The SSCM will be located of end of the boom tube.
The SCM is a three-axis search coil magnetometer. Each axis has a rolling core sheet.

- **SCE Unit**
It consists of the Preamplifier, which amplifies the signal, and a Fast Fourier Transform (FFT) Processor. Both electronic components will be manufactured using Application-Specific Integrated Circuit (ASIC) devices in 2024.
Before manufacturing ASIC chips, the FFT processor verifies the operation using the Field-Programmable Gate Array (FPGA) board.
The Preamplifier is designed to meet the required signal amplification of the SCM sensor, and add resistance to control resonance and cutoff frequency.
The FFT Processor, comprising ASIC chips and FPGA boards, computes the FFT of SCM signal and generates the power spectrogram. ASIC chips handle both FFT computation and power spectrogram generation, while FPGA boards store data in memory and translate data to and from the S/C.

▼ SSCM Requirements and Development Model Specification

List	Req. of Search coil design	Development Model
Axis	3 axis	1 axis
Core length	17 ~ 40 cm	20 cm
N(turn number)	10,000 ~ 51,600	12,000
Frequency range	10 Hz ~ 20 kHz	10 Hz ~ 20 kHz
Sensitivity	10 pT/Hz$^{1/2}$ at 1kHz	10 pT/Hz$^{1/2}$ at 1 kHz
Sampling rate	> 40 kHz (16 bit ADC)	40 kHz (16bit ADC)

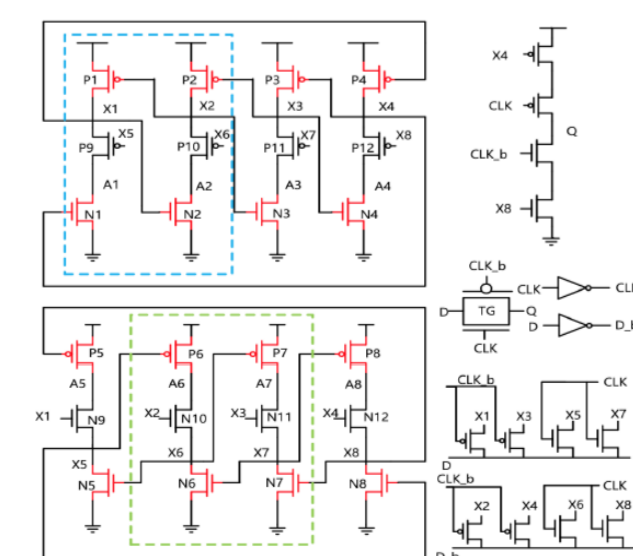## ASIC Devices

Preamplifier ASIC devices
- Planned for customization using TSMC 65-nanometer or Samsung 28-nanometer process technology
- Produced with radiation circuitry to reduce impact by TID (Total Ionizing Dose) and SEE (Single Effect Event)
- DM ASIC(2024), EQM (2025) (TBD)
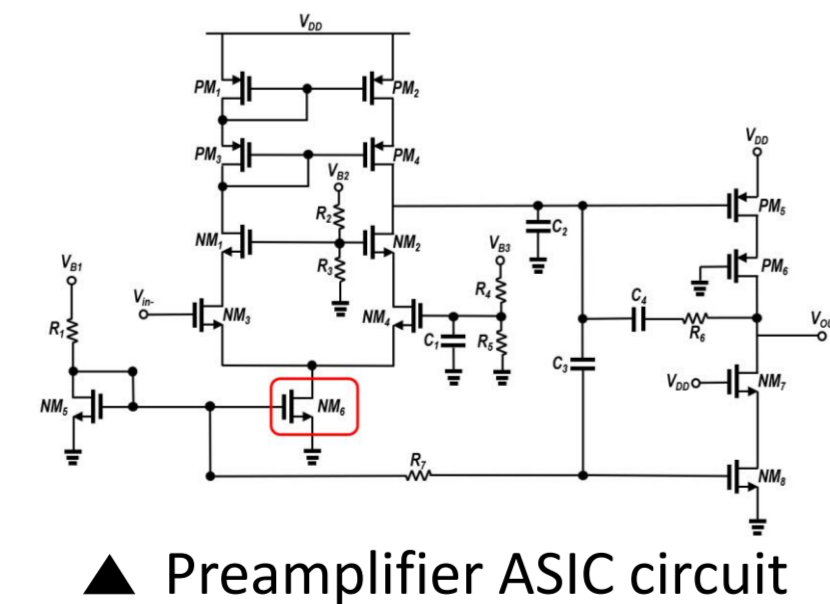
▲ Preamplifier ASIC circuit

FFT Processor ASIC devices
- Scheduled for customization using TSMC 65-nanometer process technology
- Insert Rad-Hard register using We-Quatro and radiation Latch
- DM ASIC(2024), EQM (2025) (TBD)


▲ FFT Processor radiation Latch circuit

As ASIC devises are immutable post-fabrication, the validation of ASIC circuits had been carried out an FPGA boards and analog boards including a circuit simulation at the development model.

SCM Sensor Development Model

Development Model (DM) of the SCM Sensor using various bobbins and cores.

1) Core Types: Rod, Stack sheet, and Rolling sheet
- Two kinds of materials: Fe-Nickel alloy (Rod and Rolling Sheet) and Fe-Cobalt alloy (Stack sheet)
- Three types of core shapes: Rod, Stack sheet, and Rolling sheet (a rolling ferromagnetic sheet on a CFRP rod)
- Size: (D) 6.5 x (L) 200 mm, (W) 5 x (H) 4 x (L) 200 mm
- Mass: Rod 55 g, Stack sheet 20 g, Rolling sheet 9 g
- Induced Voltage: $V_{stack} > V_{rod} > V_{rolling}$
- Stack core structure exhibits a oscillation in a frequency range of more than 20 kHz


Rod   Stack sheet   Rolling sheet
Gain: 41 dB
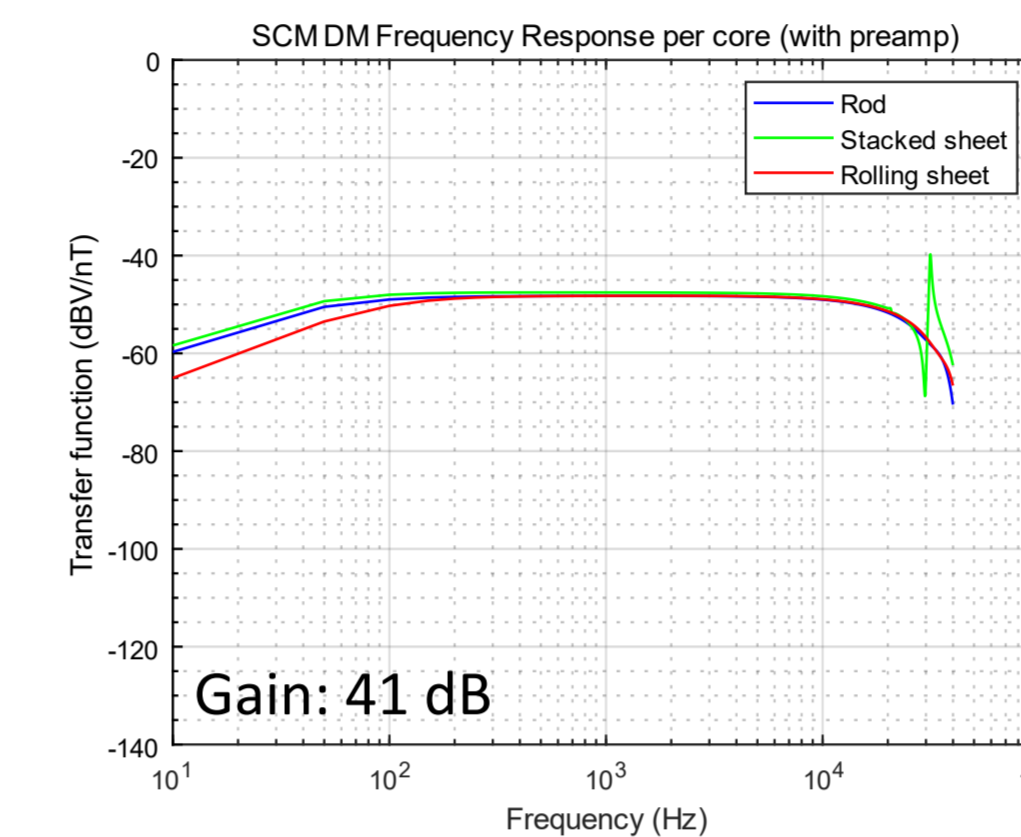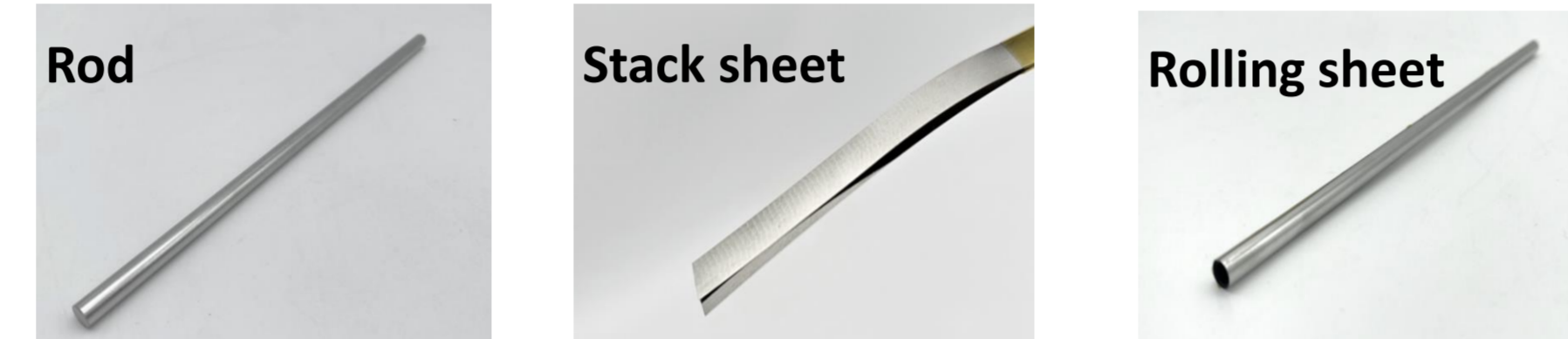
2) Bobbin Types: Narrow Acryl bobbin (NA bobbin), Narrow Delrin bobbin (ND bobbin), and Wide Delrin bobbin (WD bobbin)
- Narrow bobbin (NA bobbin, ND bobbin): wound with 9 mm width and 5.8 mm pitch
- Wide bobbin (WD bobbin): wound with 24 mm width and 2.3 mm pitch
- Total number of windings: 12,000
- Two kinds of Turns per bobbin: 2,000 (NC bobbin, NA bobbin), 2,400 (WD bobbin)
- Induced Voltage: $V_{WD} > V_{ND} > V_{NA}$

NA bobbin   ND bobbin   WD bobbin
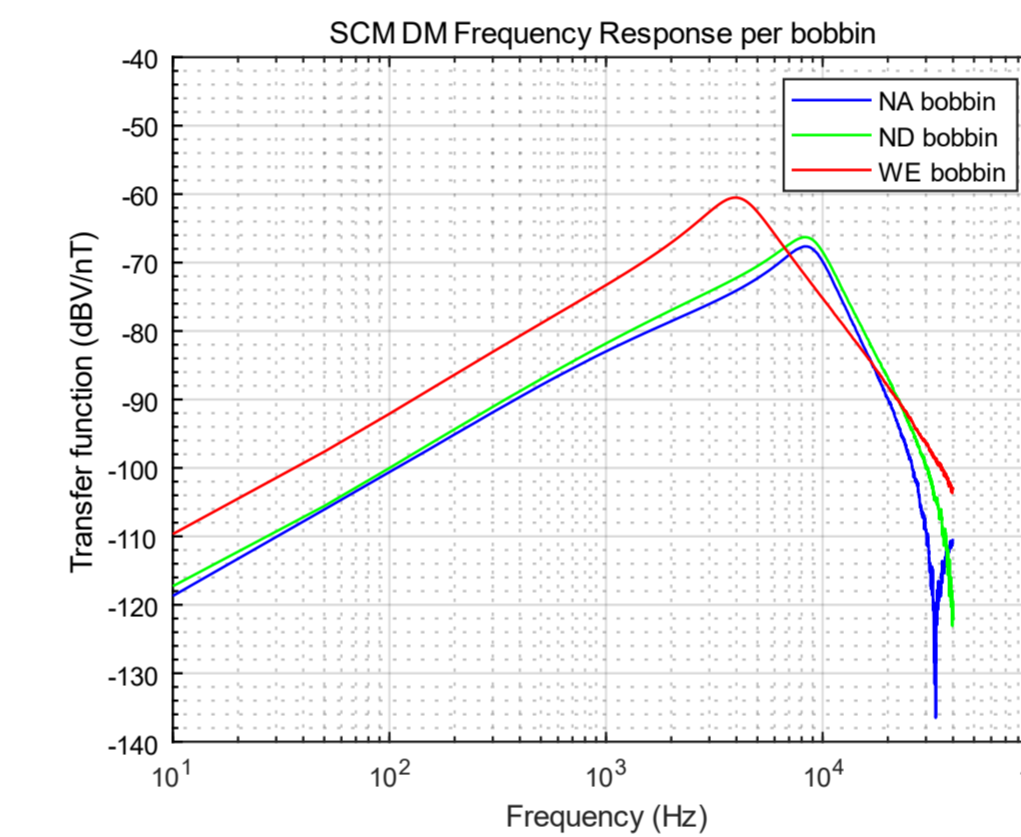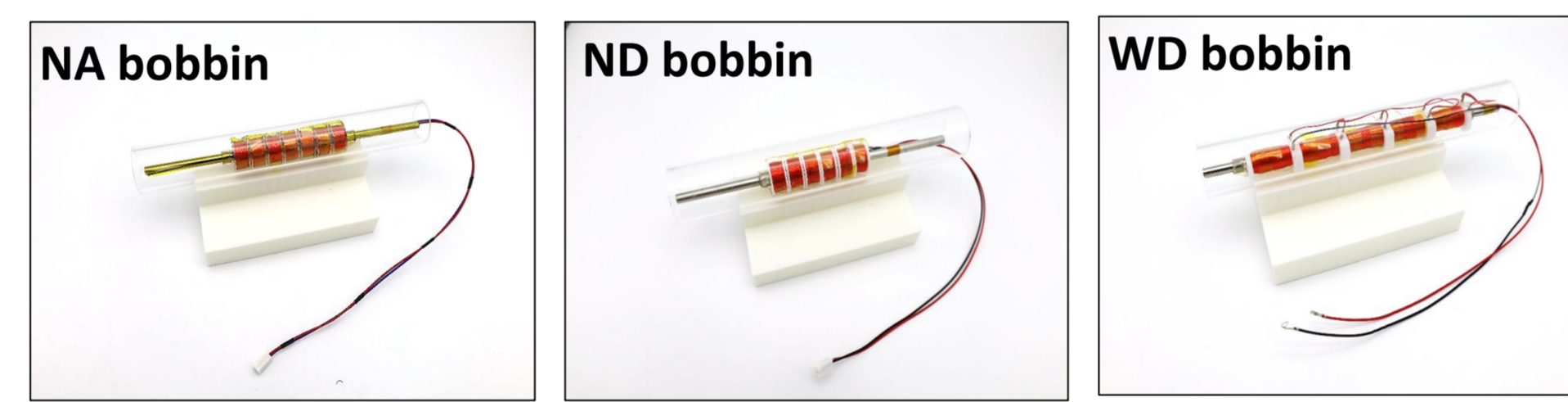
Bobbin simulation
- Electromagnetic simulation (EMS) of *EmWorks*
- Analysis using the measured value of bobbins at 4.5 kHz
- Narrow bobbins severe magnetic distortion inside the bobbin.

Wide bobbin   Narrow bobbin
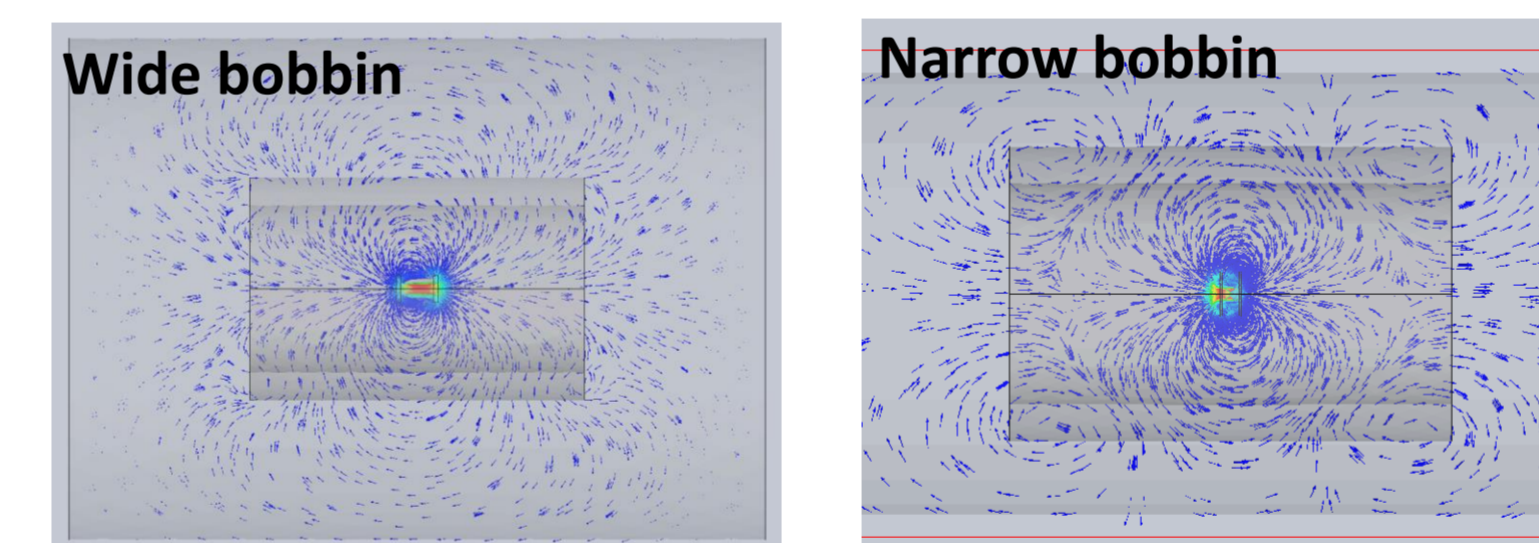
SCE Design Model

Analog Boards
- To verify the functionality of the preamplifier ASIC chip development
- Two-stage amplification structure for 70 dB gain and 20 kHz operation
- Attenuation resistor: Add a parallel resistor on the AMP board instead of a feedback coil (the resistor for Attenuation resonance)
- DM ADC board design using ADS8862 and LABJACK T-7 model
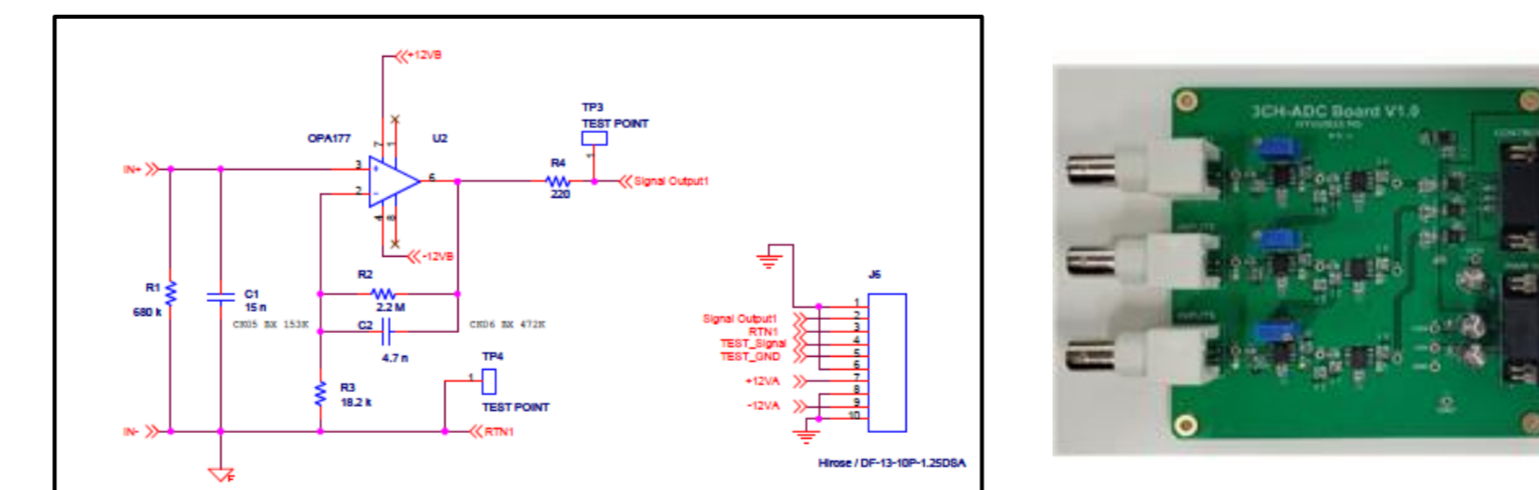
▲ Preamplifier circuit   ▲ ADC board

FPGA Boards
- To verify the ASIC FFT Processor algorithm
- Using DE-10 Nano and DE 2 FPGA boards to adjust timing between FFT processing and data transfer
- ADC to DE-10 nano input signal: ± 2 V
- Serial Peripheral Interface (SPI) communication between DE10-nano and DE-2
- Real-time FFT at DE-2 (16.16 bit Fixed point)
- Radix-r^2 FFT structure
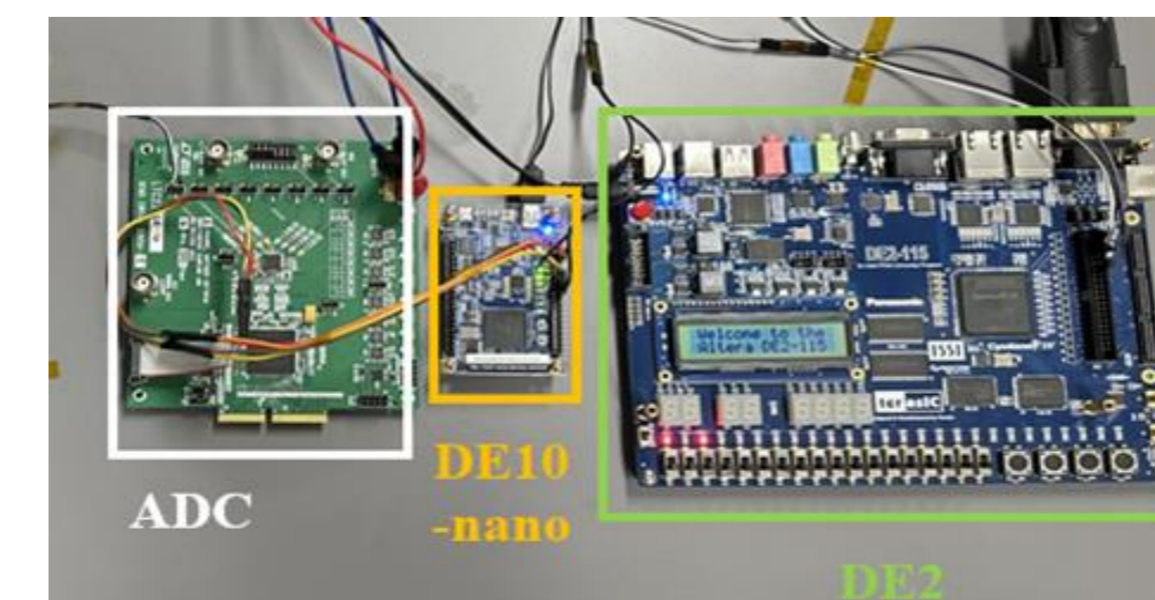
▲ FPGA boards configurated for verification

SCM sensor Design Model Performance test

SCM sensor DM performance test
- Frequency response test to determine sensor measurement range
- Check sensor sensitivity with NEMI (Noise Equivalent Magnetic Induction) test
- Testing inside the 3-layer Zero Gauss chamber
- Applied magnetic field: 113 nT (To detect artificial signals by frequency regardless of ambient noise, 10 Hz, 35 Hz, and 60 Hz (major))
- Pre-amp gain: 70 dB
- Test range: 10 Hz to 20 kHz

SCM sensor DM performance test Results
- Measurement range: 10 Hz to 20 kHz
- NEMI: < 0.01 pT/Hz$^{1/2}$ at 1 kHz
- Acquisition of the spectrogram
- Comparing the spectrograms between the two kinds of SCE DM sets (case I : FFT on board processing(DM),   case 2: FFT on the Personal computer)
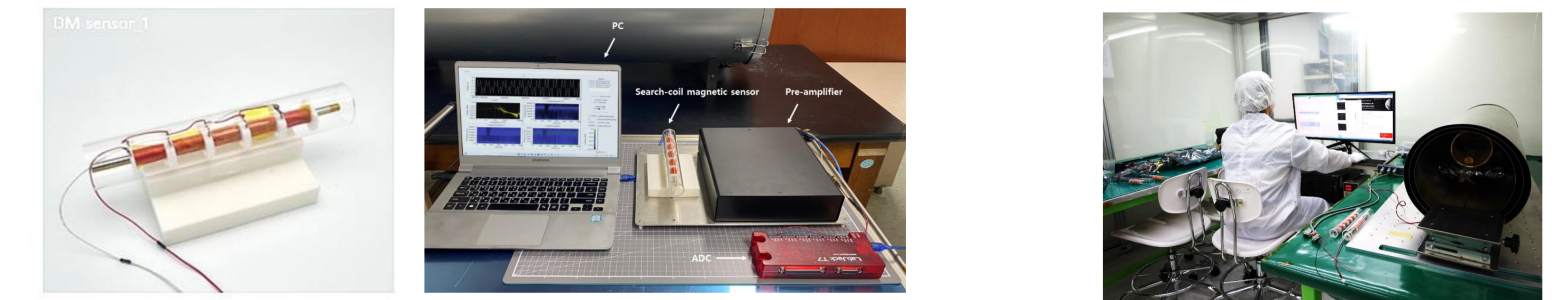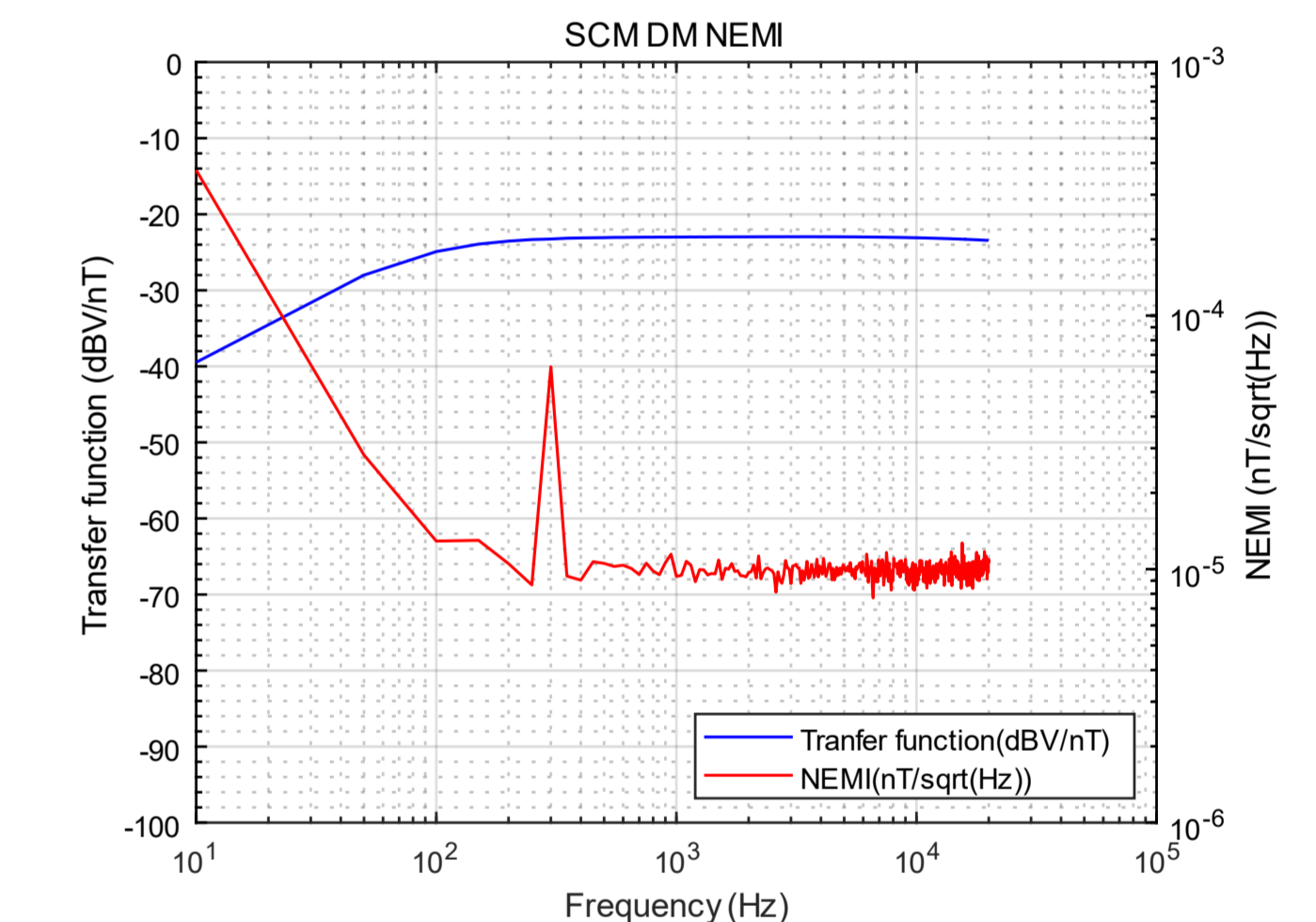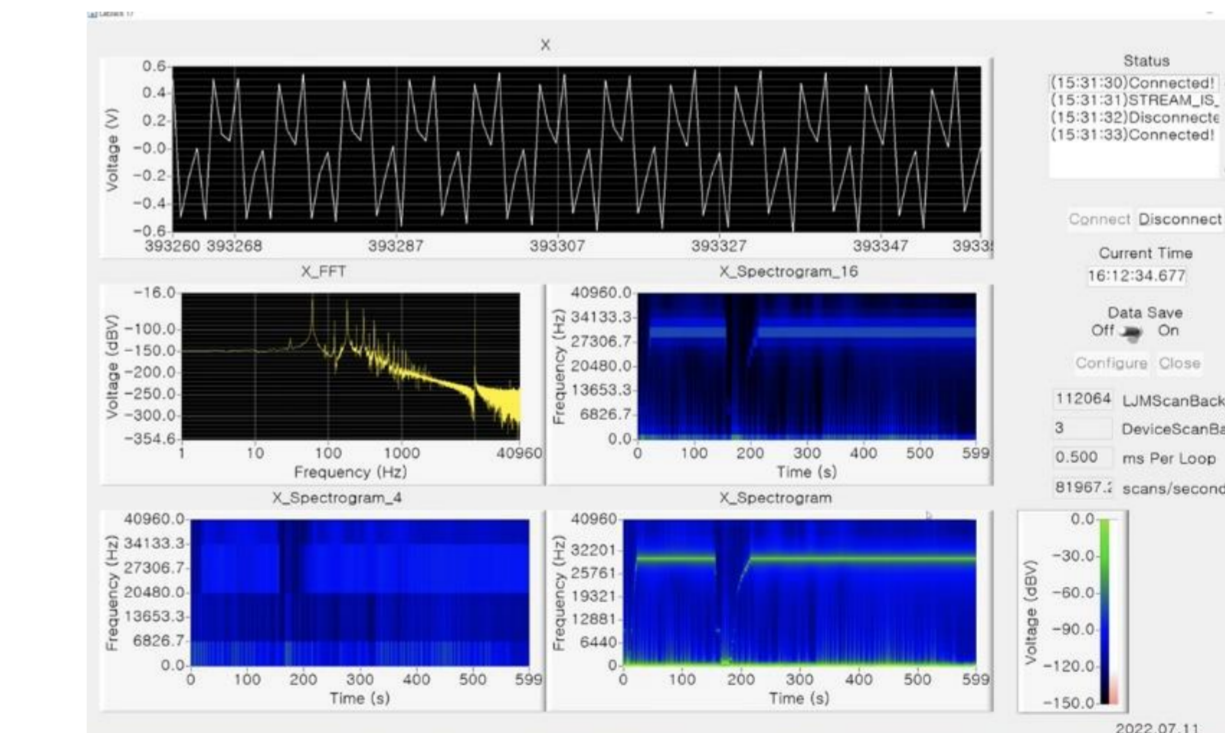

▲ SCM sensor DM test components   ▲ DM sensor performance test environment
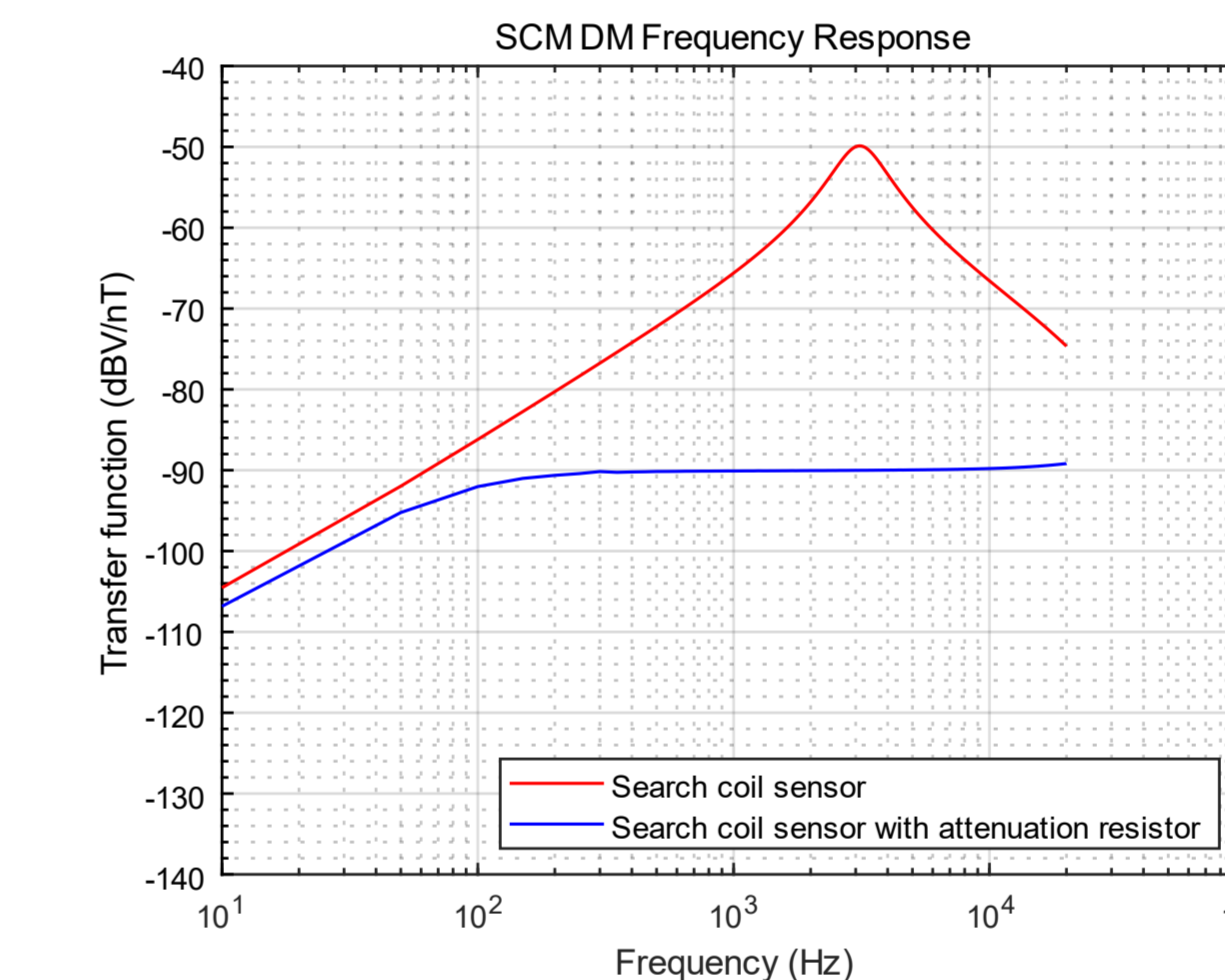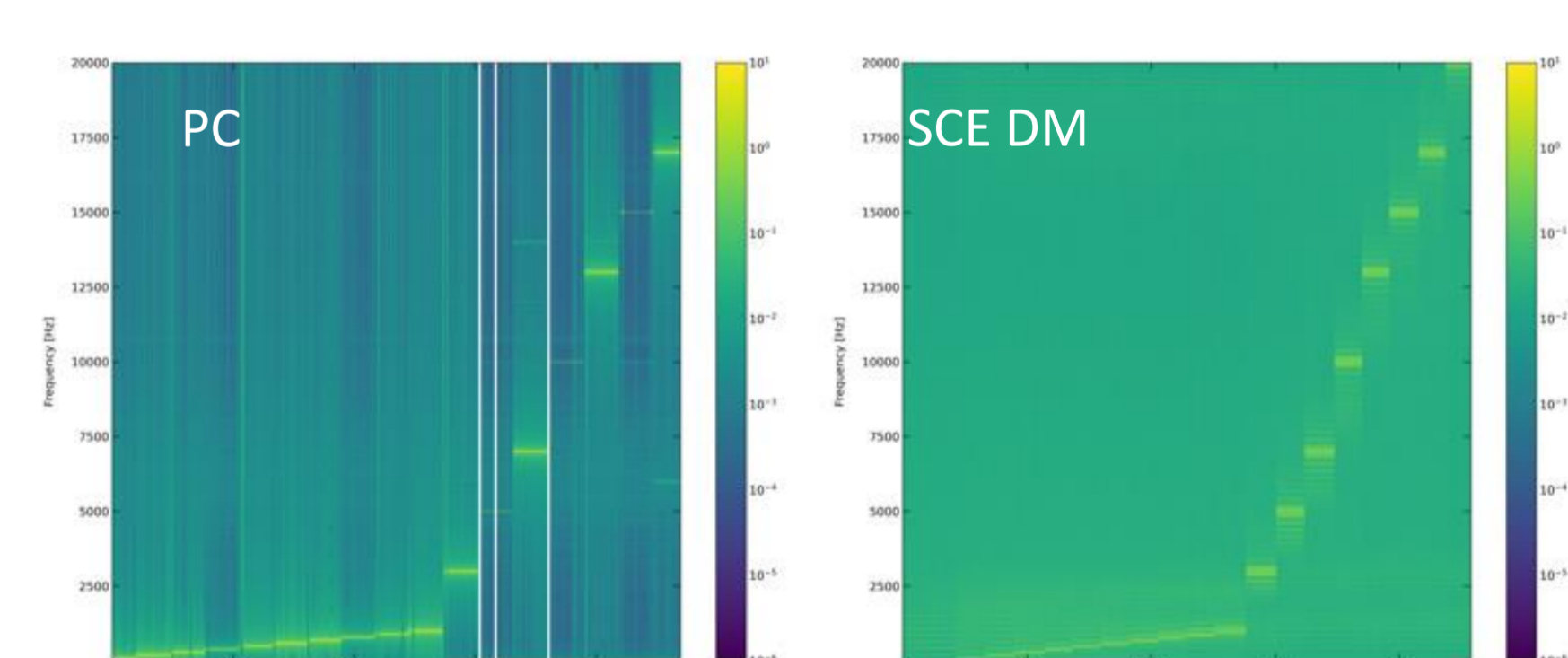

▲ DM sensor Frequency Response test Results (no amplified)   ▲ DM sensor NEMI test Results

▲ SCM DM performance test control GUI   ▲ SCM DM spectrogram

Conclusion & Future work

- **Preliminary design for space search coil magnetometer with ASIC devise**
- **DM had been verified major functions before ASIC device fabrication**
  - SCM sensor DM: (D) 6.5 x (L) 200 mm Rolling sheet core, Wide bobbin, and 12,000 windings
  - SCE DM: 80 dB gain Analog boards for Preamplifier and FPGA boards for FFT Processor
- **Verify SCM DM performance using Zero Gauss Chamber and Solenoid**
  - Frequency range: 10 Hz to 20 kHz
  - NEMI: 10 pT/Hz$^{1/2}$ at 1 kHz

- **Three-axis SCM sensor design in 2024**
- **Planned for ASIC fabrication using TSMC 65-nanometer or Samsung 28-nanometer Processing in 2024**
- **Thermal Vacuum test and TID test in 2024~2025**