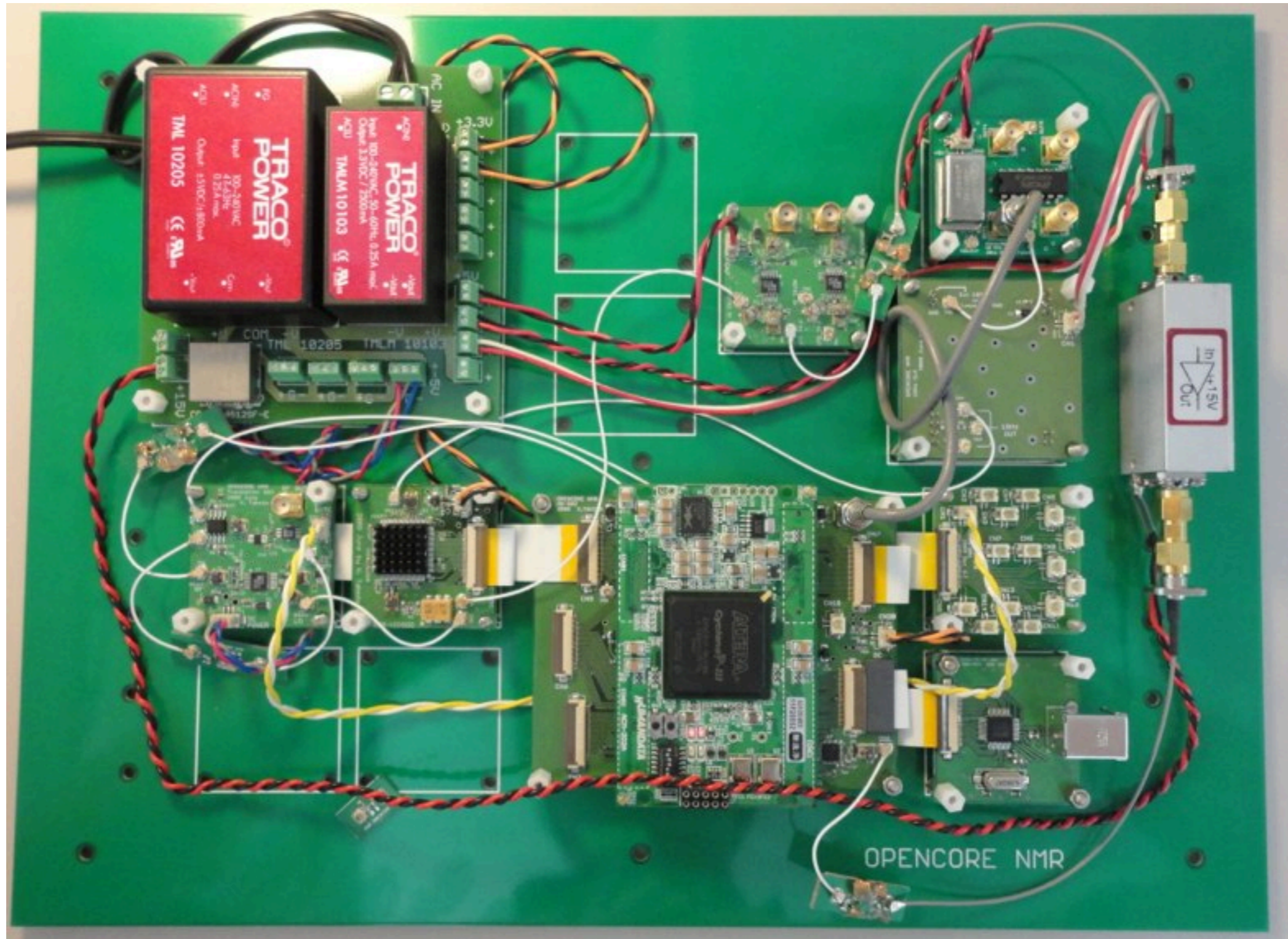# Getting started with
OPENCORE NMR spectrometer

--- Installation and connection ---

# Assembly

USB

virtual Windows on Mac

USB board

- The USB module is bus-powered. That is, DC power is provided by the personal computer via the USB cable. Note that all other boards use a separate power supply module.

- At this moment, the software runs on Windows (I am "trying" to develop a cross-platform software).

- Virtual windows also works. In the right figure, the control software is running on virtual Windows 7, which in turn is running on Mac OS X (10.7 Lion) using VMware Fusion Ver 4.

Top view
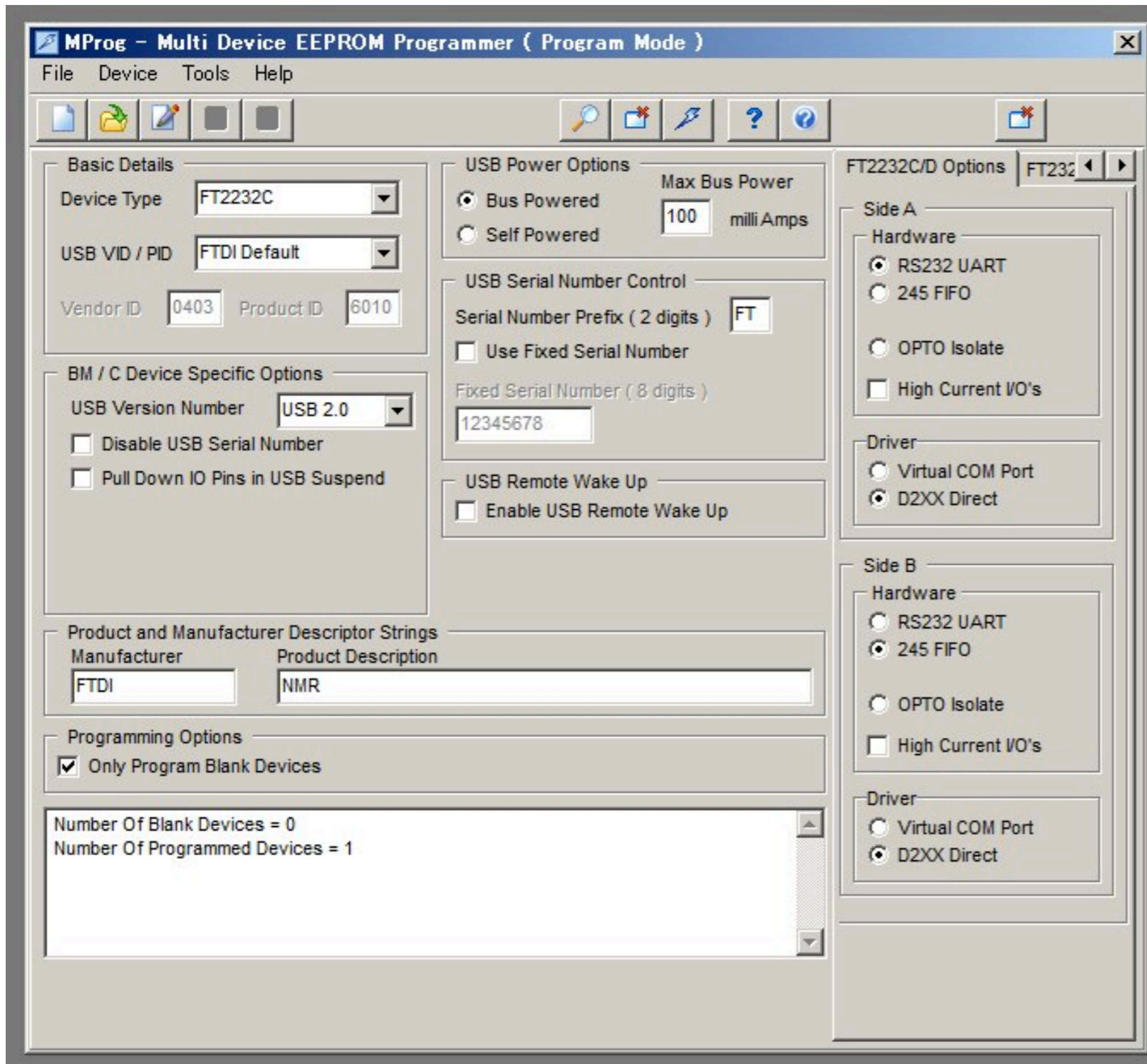

6 MHz crystal

FT2232D
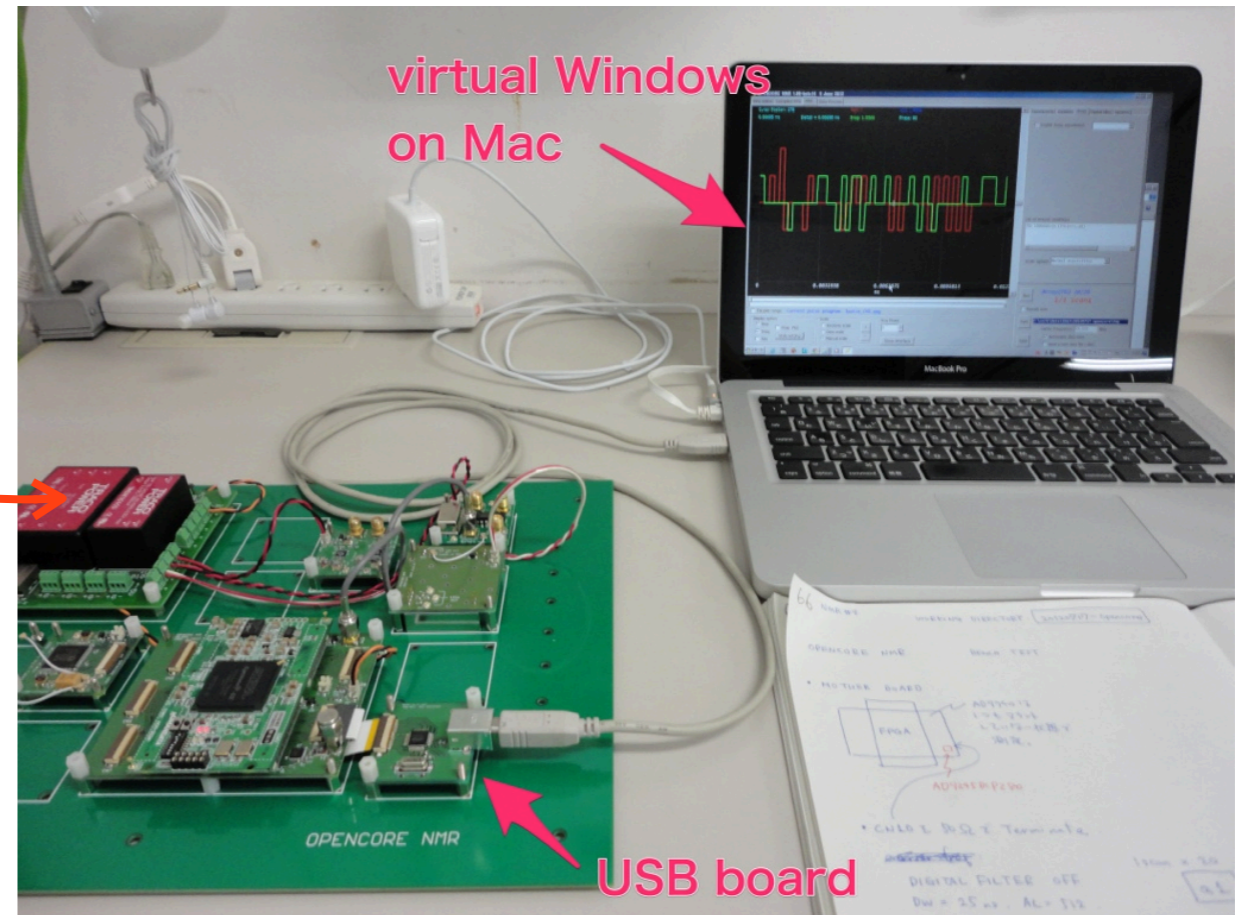
Bottom view
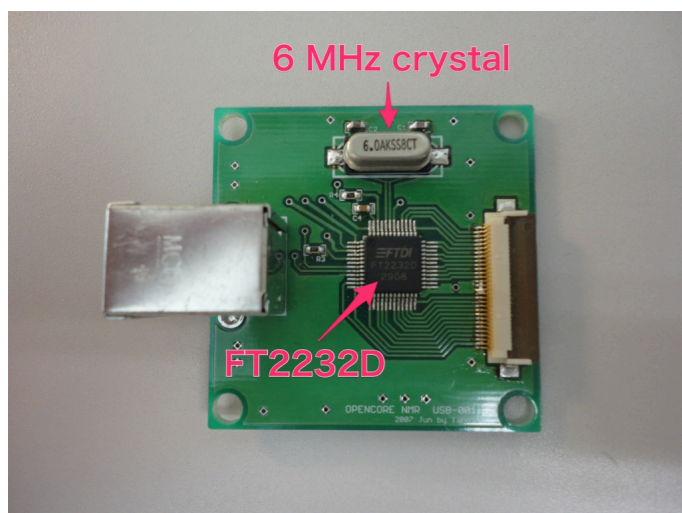
EPROM
AT93C46-10TU-2.7
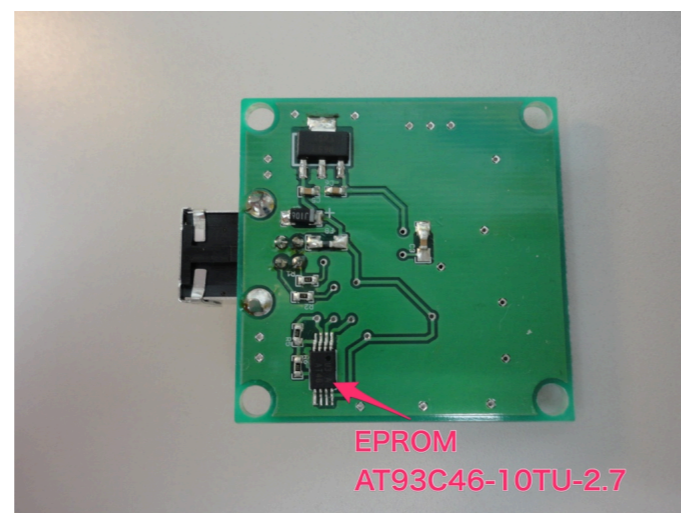
- Before operation, you need to be sure about the following two points:

- First, the EPROM on the bottom side of the USB module board have to be configured properly.

- Also, a D2XX driver software have to be installed in the computer.

MProg – Multi Device EEPROM Programmer (Program Mode)

File   Device   Tools   Help

Basic Details

Device Type: FT2232C

USB VID / PID: FTDI Default

Vendor ID: 0403   Product ID: 6010

BM / C Device Specific Options

USB Version Number: USB 2.0

☐ Disable USB Serial Number

☐ Pull Down IO Pins in USB Suspend

Product and Manufacturer Descriptor Strings

Manufacturer: FTDI

Product Description: NMR

Programming Options

☑ Only Program Blank Devices

Number Of Blank Devices = 0
Number Of Programmed Devices = 1

USB Power Options

◉ Bus Powered
○ Self Powered

Max Bus Power: 100 milli Amps

USB Serial Number Control

Serial Number Prefix (2 digits): FT

☐ Use Fixed Serial Number

Fixed Serial Number (8 digits): 12345678

USB Remote Wake Up

☐ Enable USB Remote Wake Up

FT2232C/D Options   FT232 ◄ ►

Side A

Hardware
◉ RS232 UART
○ 245 FIFO
○ OPTO Isolate
☐ High Current I/O's

Driver
○ Virtual COM Port
◉ D2XX Direct

Side B

Hardware
○ RS232 UART
◉ 245 FIFO
○ OPTO Isolate
☐ High Current I/O's

Driver
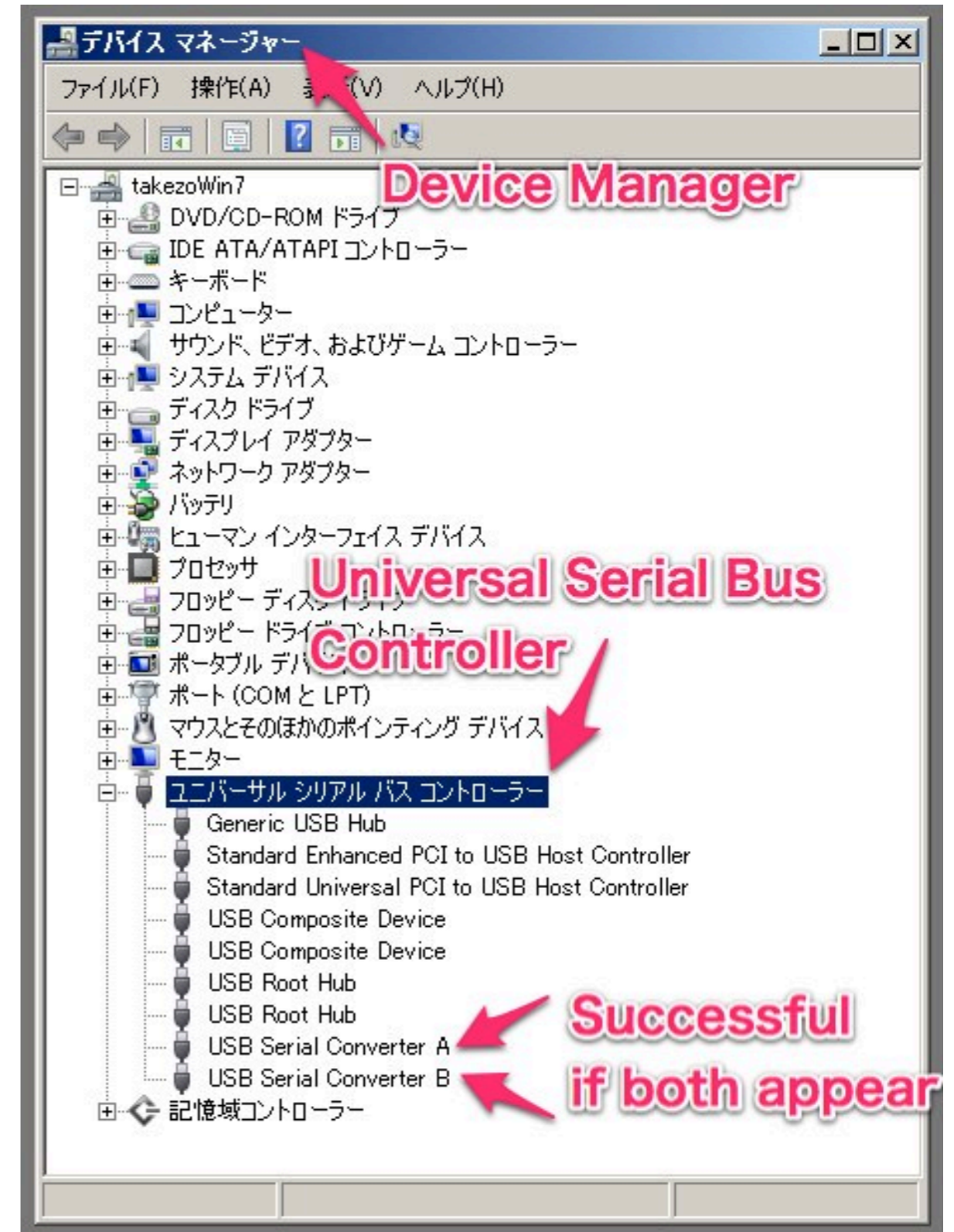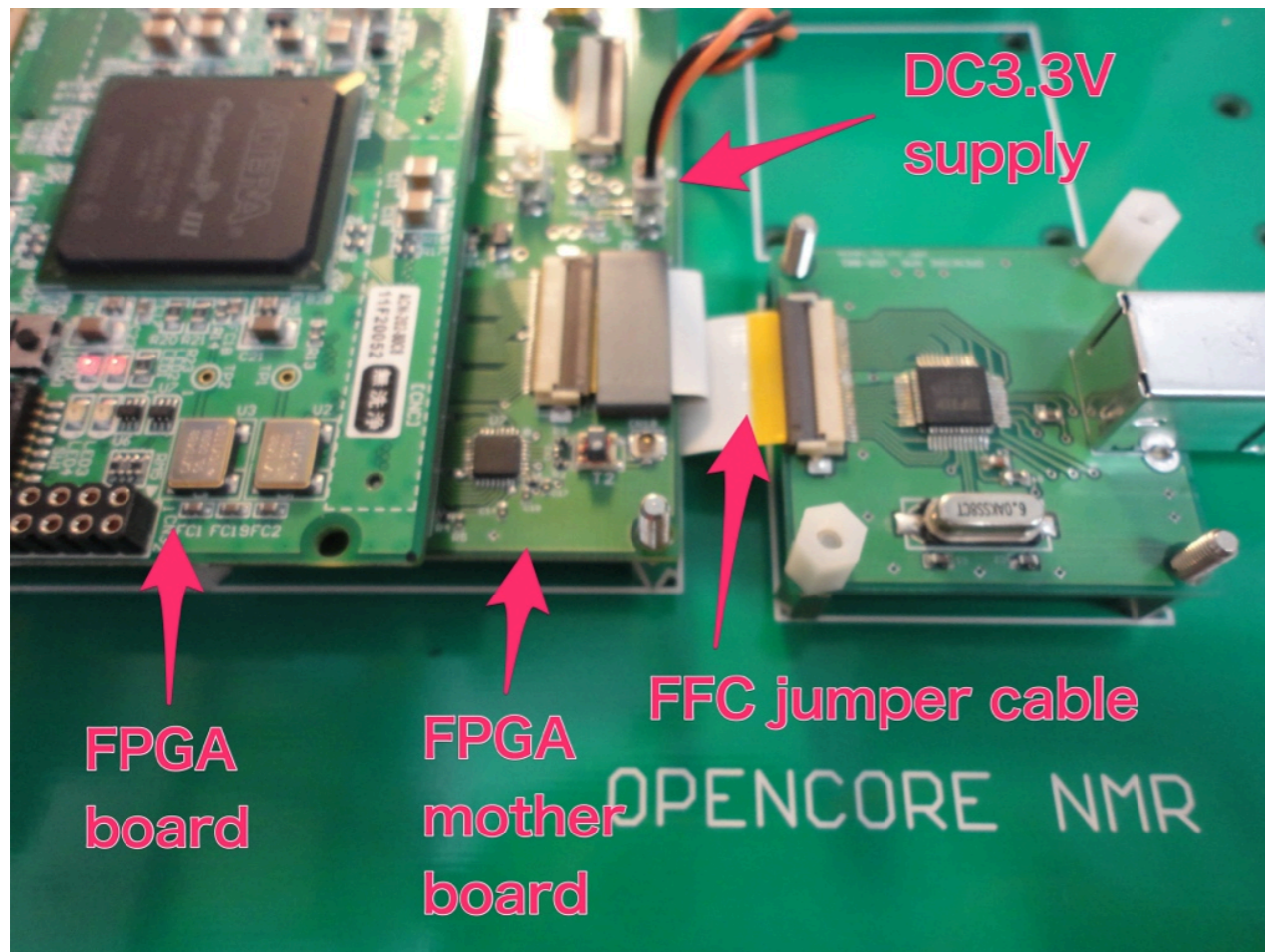○ Virtual COM Port
◉ D2XX Direct

- EPROM configuration is done using MProg, a software freely provided by FTDI.

- Usually I complete this configuration before the module leaves me, so that most people do not have to care about it.

- If, however, one need to configure/re-configure the module, use the parameters shown in the left figure.

- Select "Bus Powered", "RS232 UART" for side A, "245 FIFO" for side B, "D2XX Direct" for both. The Product Description must be "NMR", because the spectrometer software checks if it is the right device by the word "NMR".

- Once the EPROM has been configured successfully, you do not have to do it again (the device remembers the settings).

- The channels A and B are dedicated for data communication with the pulse programmer and the receiver of the spectrometer, respectively. The former uses the RS232 UART protocol, while the latter does 245 FIFO.
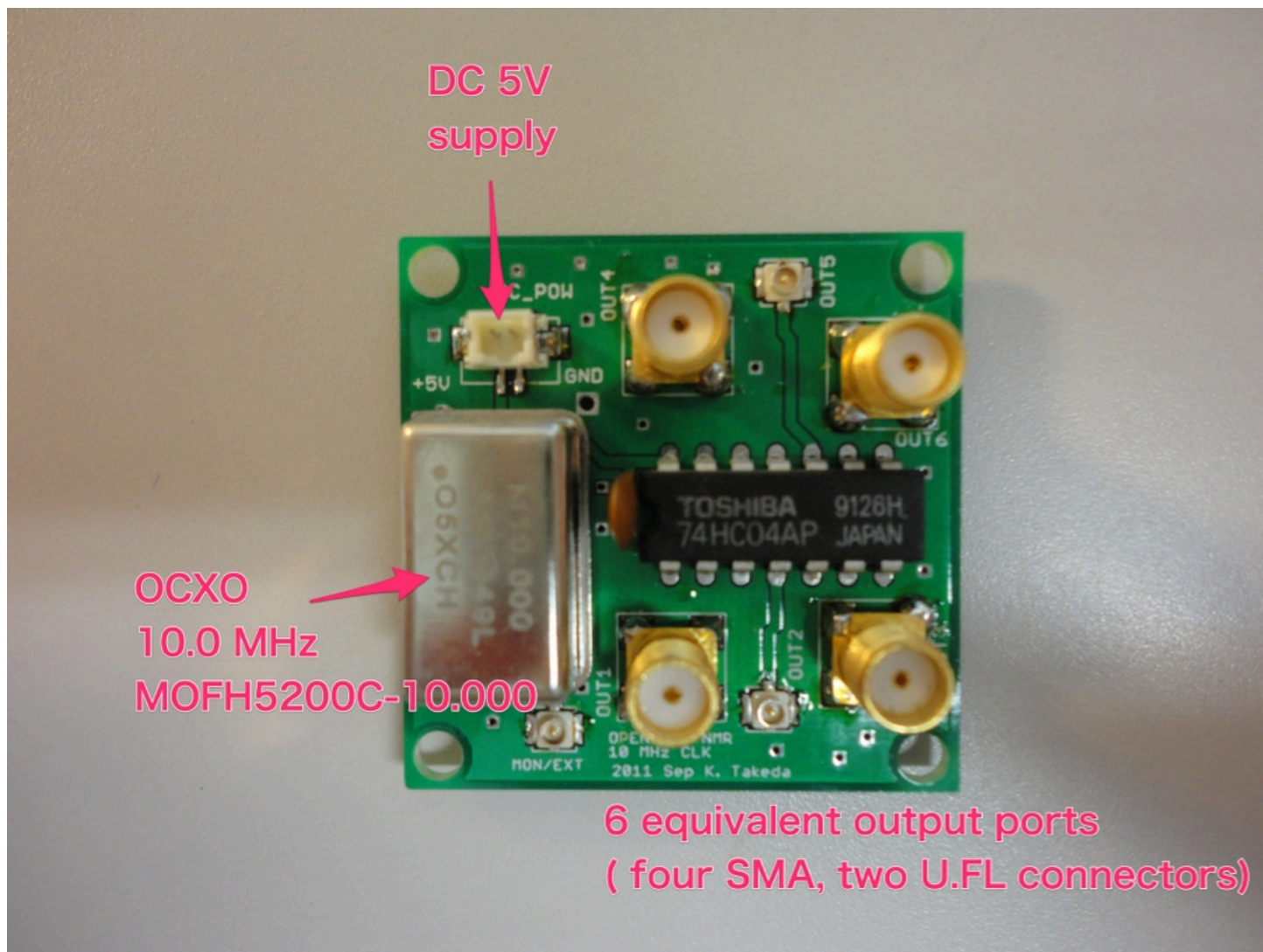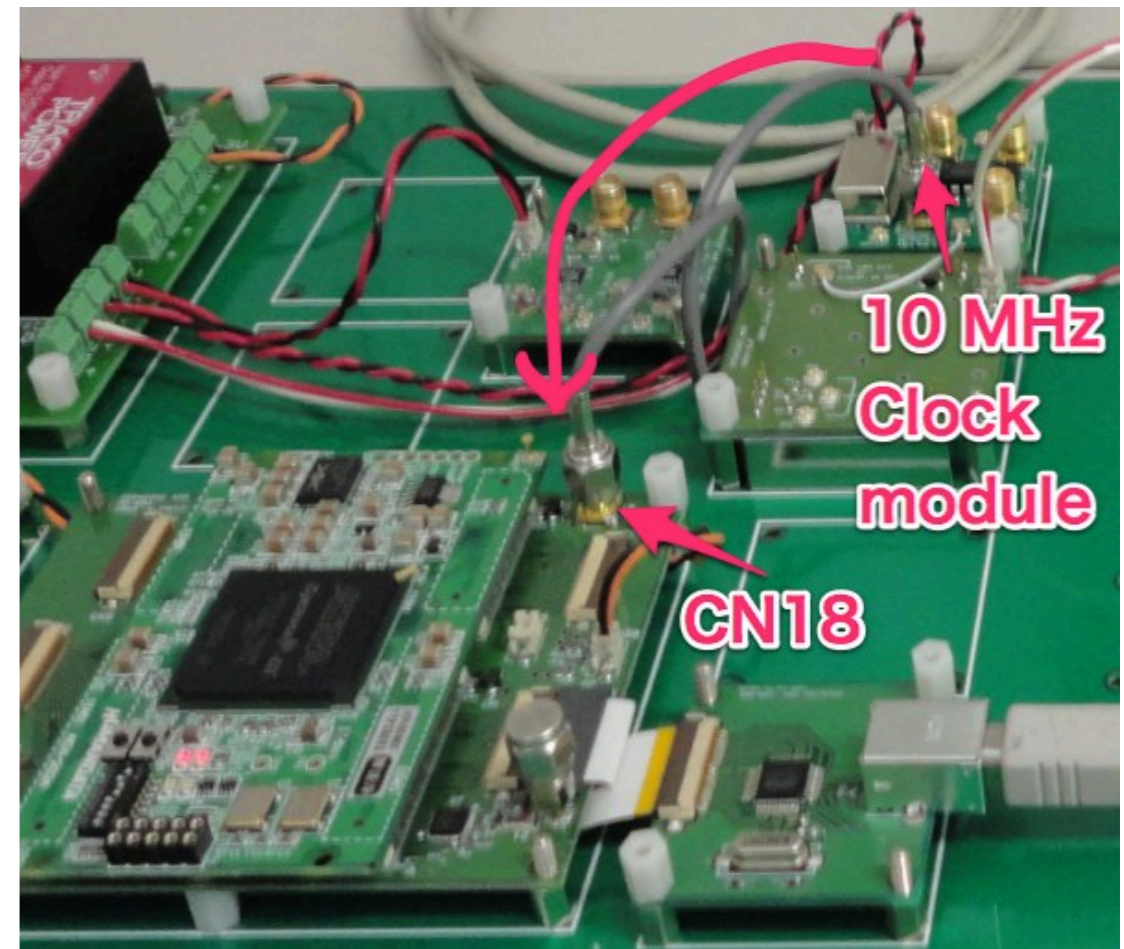
- D2XX driver is available from the FTDI website.

- When the driver has successfully been installed on the Windows OS, the entries "USB Serial Converter A" and "USB Serial Converter B" should appear in the Device manager, which can be accessed from the control panel -> system.

- Using a FFC jumper cable, connect the USB module to the FPGA mother board.

DC3.3V supply

FPGA board

FPGA mother board

FFC jumper cable

OPENCORE NMR

Device Manager

Universal Serial Bus Controller

Successful if both appear

- The OPENCORE NMR spectrometers of recent versions require a 10 MHz clock. Connect the clock signal to the SMA connector (CN18) of the FPGA mother board.

- Otherwise (i.e., if you forgot to feed the 10 MHz clock to the FPGA), the spectrometer would not respond at all.


10 MHz Clock module

CN18

DC 5V supply

OCXO 10.0 MHz MOFH5200C-10.000

6 equivalent output ports (four SMA, two U.FL connectors)

- 10 MHz clock module (left) is composed of a OCXO (200 ppb stability) and a CMOS inverter IC (74HC04).

- The 10 MHz clock signal is also used for driving another 1 GHz clock generator, which is required for the DDS module(s).

- The right figure is a screenshot of the "OPENCORE NMR" software.

- On the "NMR" tab, you see a box serving for a communication terminal, in which you can send/receive characters to/from the pulse programmer of the spectrometer via USB.

- An asterisk (*) which should have appeared now is a command prompt, meaning that the pulse programmer is ready for accepting commands.

- For example, type "v" and press the enter key. "v" is a command to request the version number of the FPGA core module for the spectrometer. You should receive a message from the spectrometer.
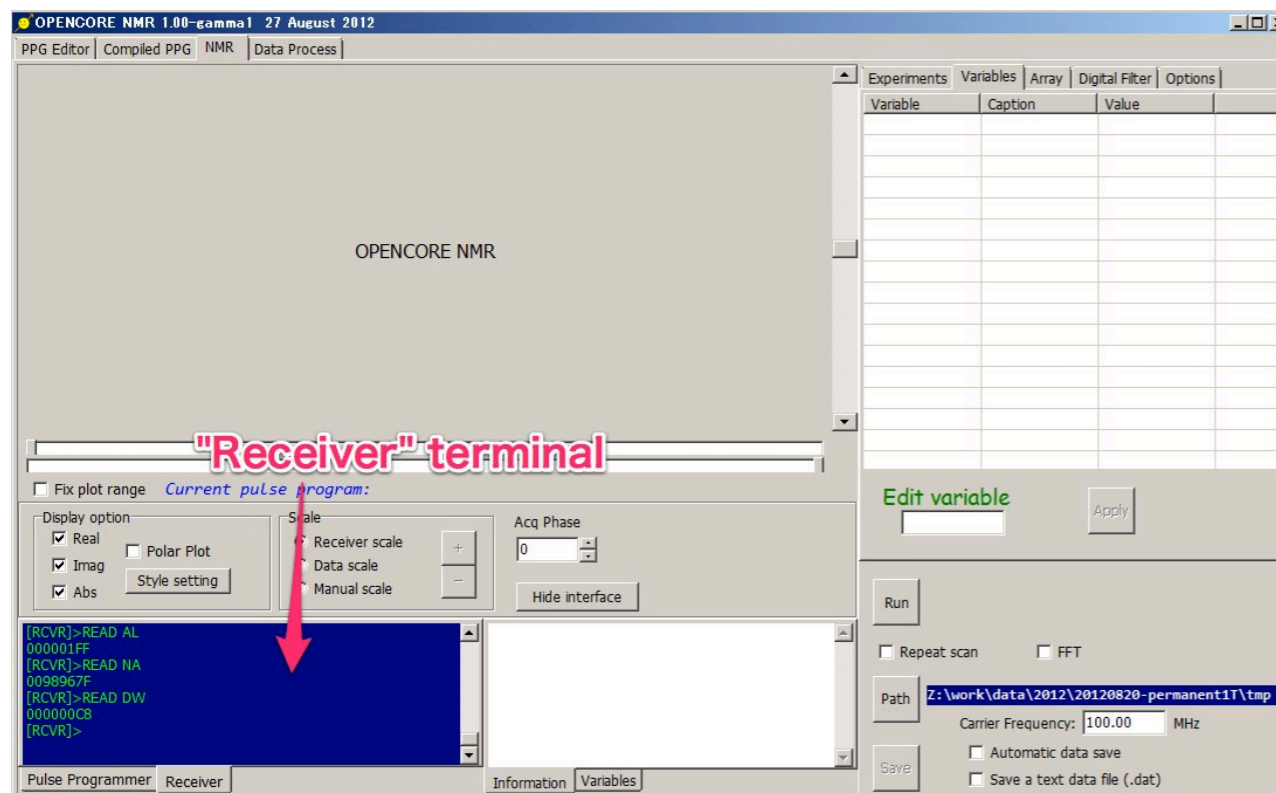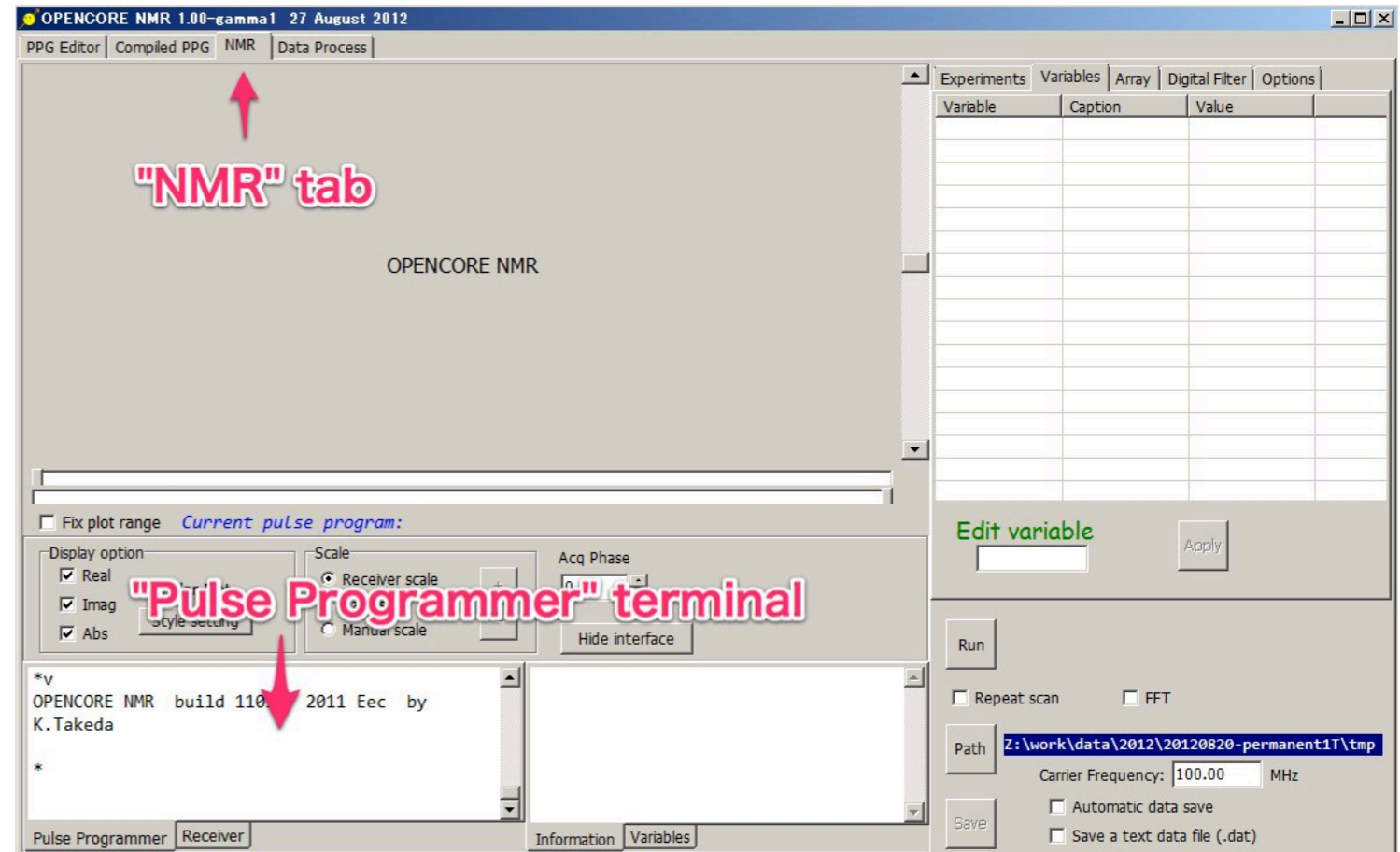
- Another terminal (tab-selectable) is dedicated for communication with the receiver module of the spectrometer.

- Here, the command prompt is "[RCVR]>". For example, type "READ AL" and press the enter key.

- If you have got a 8-digit number, then, the communication is successful.
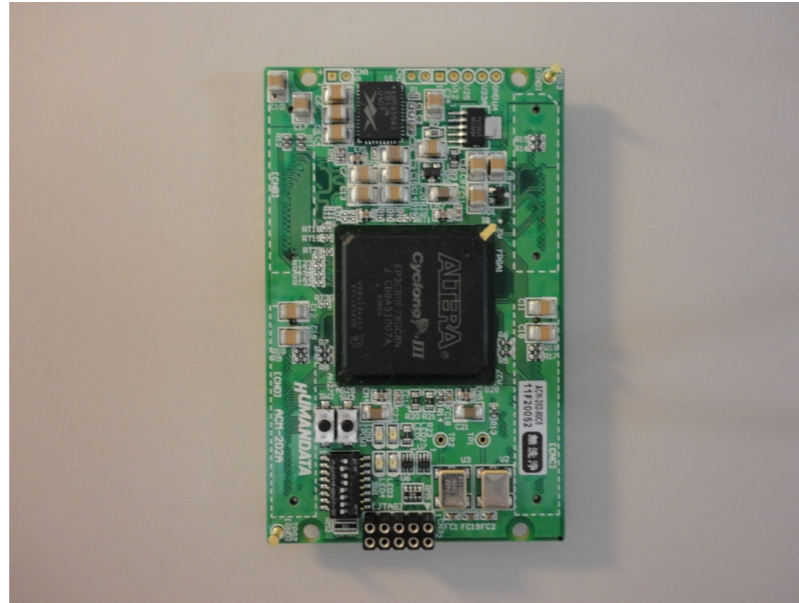
RF channels

- The spectrometer can have up to three rf channels, so that triple-resonance experiments are feasible.

- The spectrometer may not necessarily be fully equipped with the three rf channels, if you are interested in only single-resonance or double-resonance experiments. Shown in the figure is a single-channel spectrometer.

- Each rf channel can generate rf signals at up to ca. 600 MHz without modification.

- Operation at higher frequencies is possible with hardware modification. It is, however, an advanced topic which is outside the scope of this note.
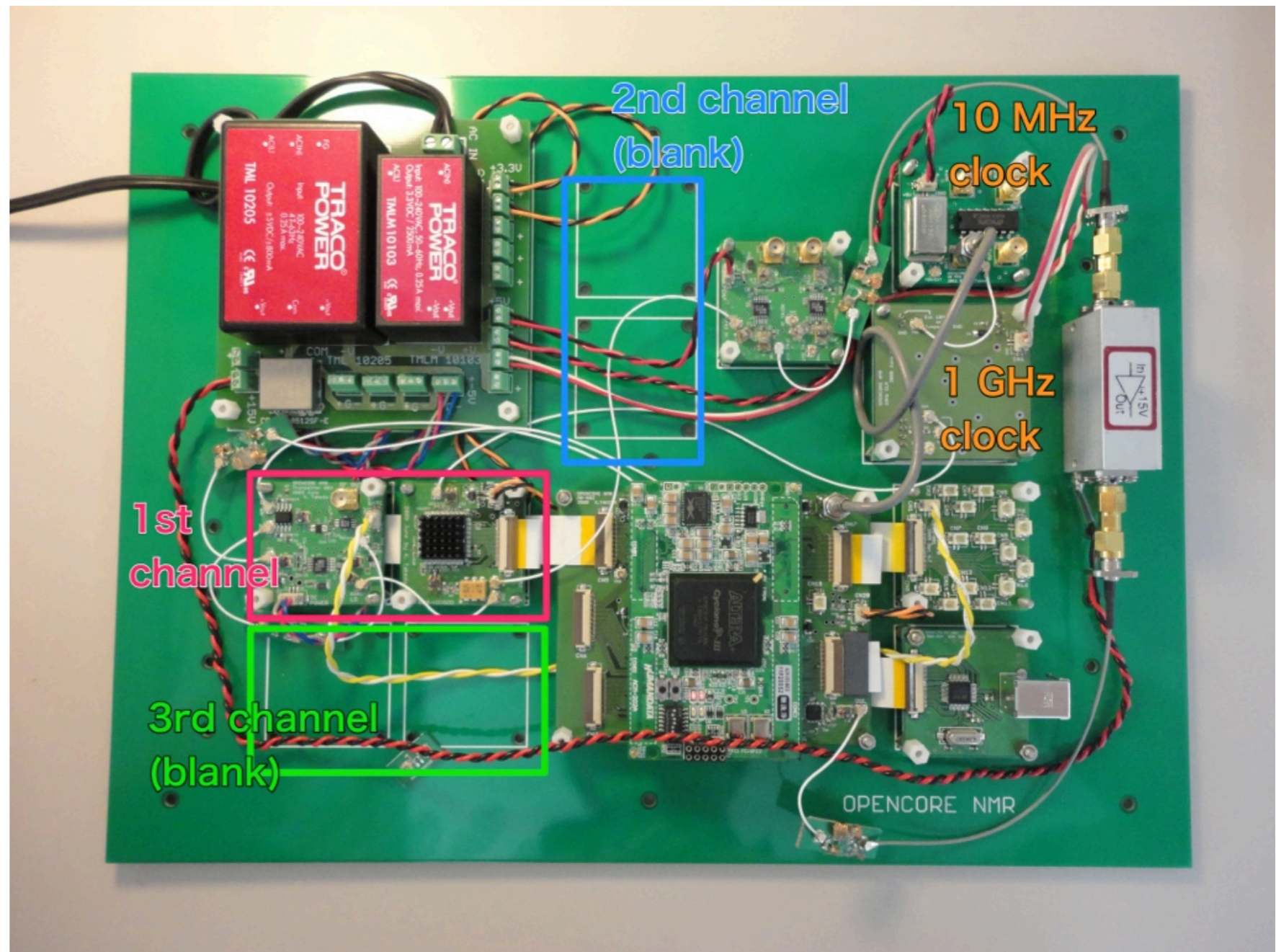
- In addition, there are something important but invisible, because they are located below the FPGA breadboard. See the next page.
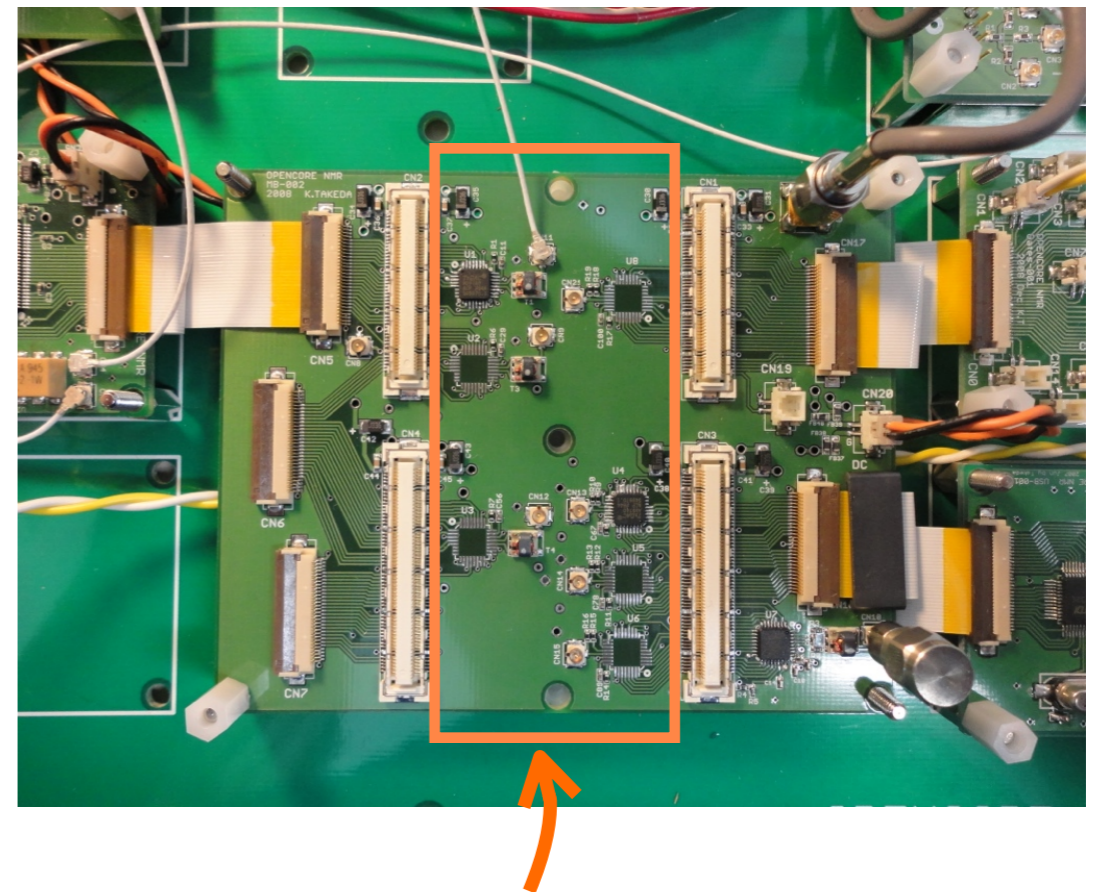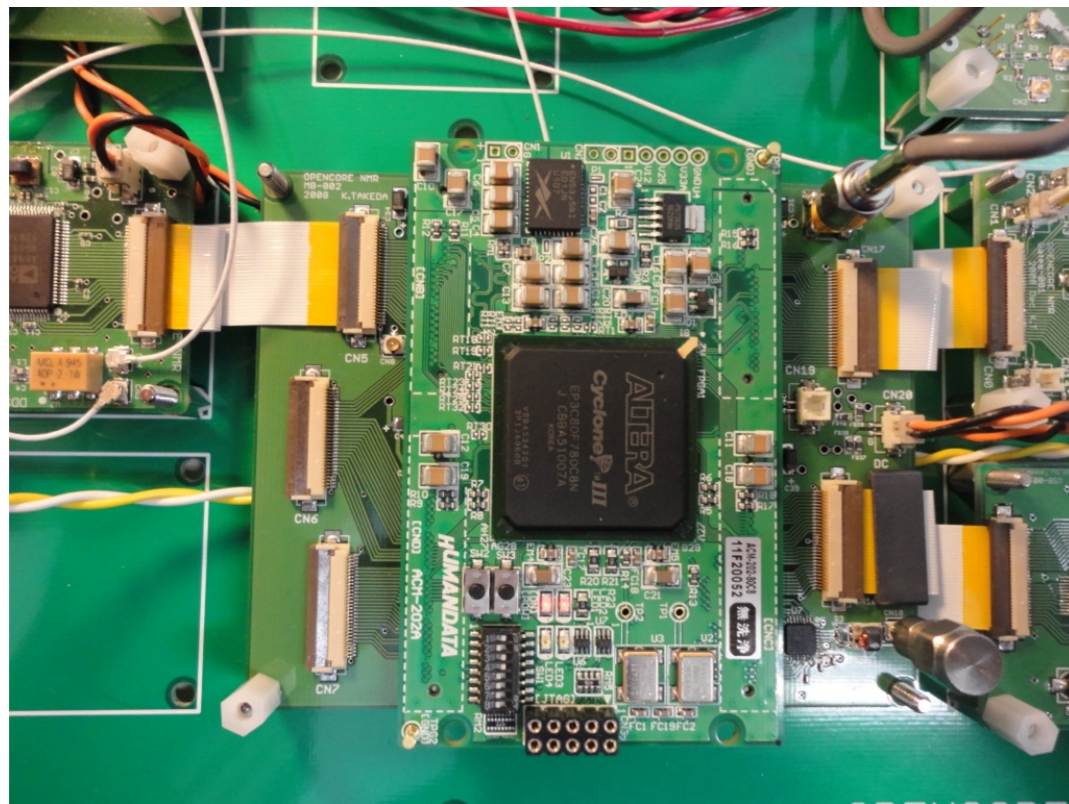
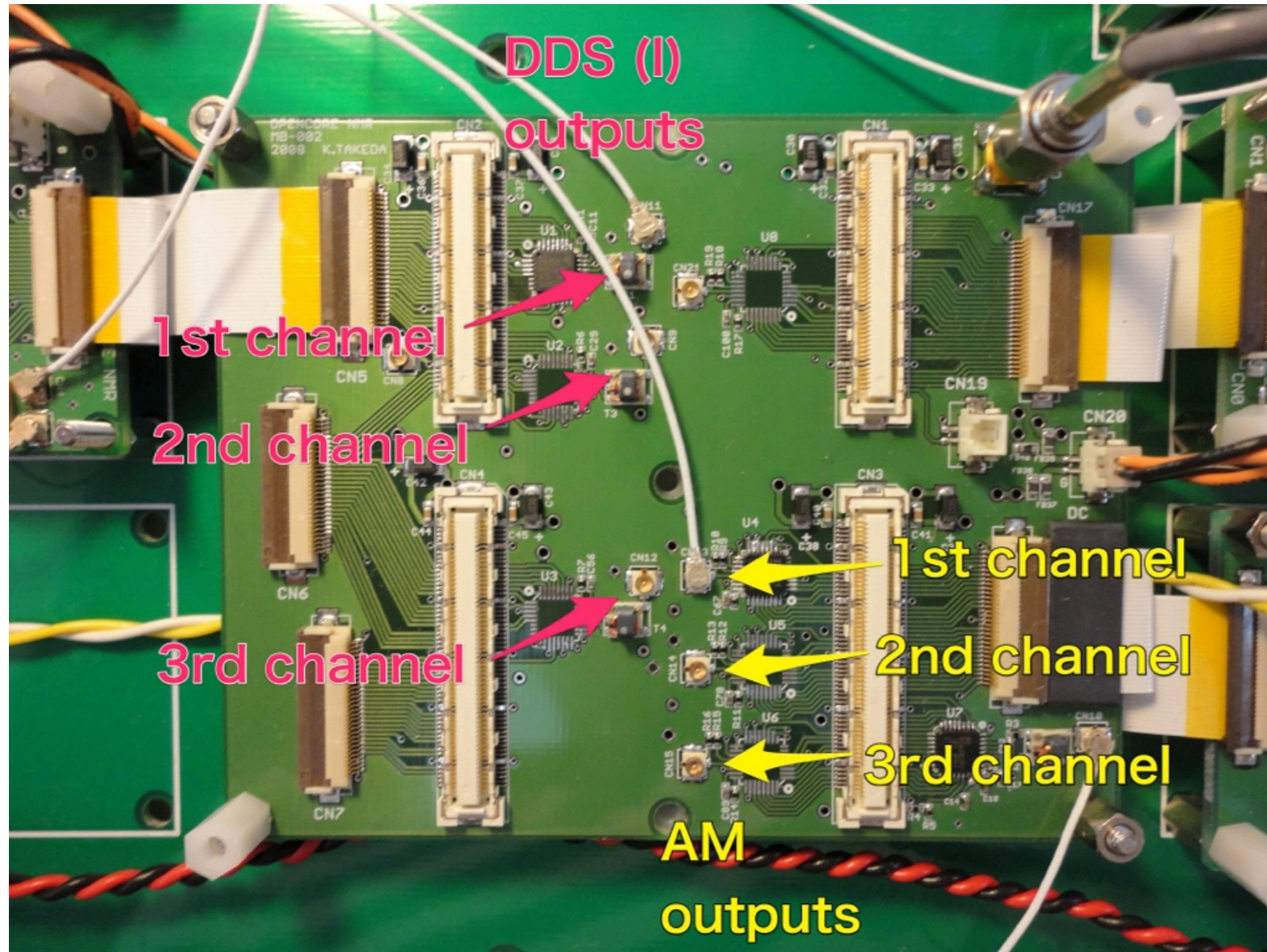Top view   Bottom view
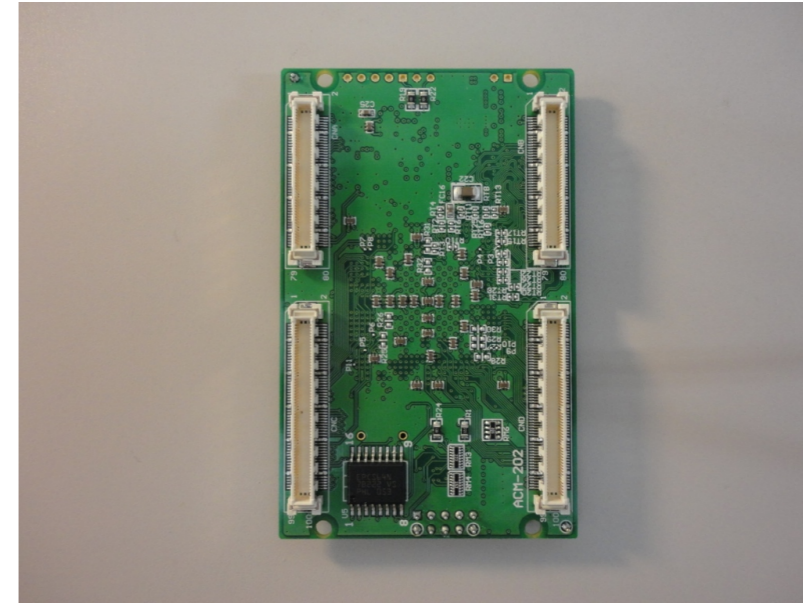
- The FPGA breadboard can be put on/off the FPGA-mother board easily.

- Below the FPGA breadboard located are the DDS and amplitude modulation modules.

- Now, let us take a closer look at them.

DDS

DDS (I) outputs

1st channel
2nd channel
3rd channel

1st channel
2nd channel
3rd channel

AM outputs

- Each rf channel has a pair of direct digital synthesizers (DDS). As a matter of convenience, we call them DDS (I) and DDS (II), respectively.

- DDS (I) is located on the FPGA mother board, as shown in the left figure. DDS (II), seen in the bottom figure, will be described later.

- In addition, there are output ports determining the amplitude of the rf signals.

- They work with the FPGA. That is, the FPGA breadboard needs to be put on the mother board after making appropriate cable connections.

- The amplitude signal is to be connected to CN3 on the transmitter board, as indicated in the right figure.

- Whereas, the DDS (I) signal is passed through a filter before being connected to the transmitter board (next page).


AM signal in

Transmitter DDS (II)
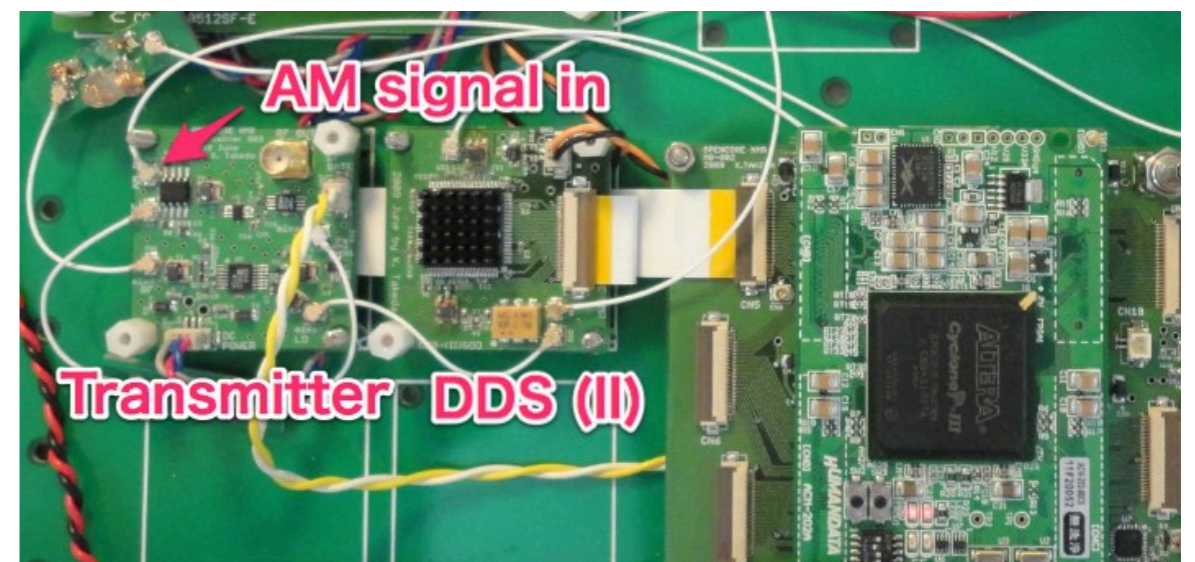
- DDS (I) operates at a clock frequency of 160 MHz, and generates a signal at a fixed fundamental frequency of 20 MHz.

- The phase of the signal can be varied.

- The right above figure shows the spectrum of the DDS (I) output. Here, the harmonics at 180 MHz is of interest.

- Thus, a band-bass filter is employed. It is designed and fabricated to eliminate the unnecessary Fourier components.

- The resultant signal, whose spectrum is shown in the right below figure, is fed to CN1 of the transmitter.
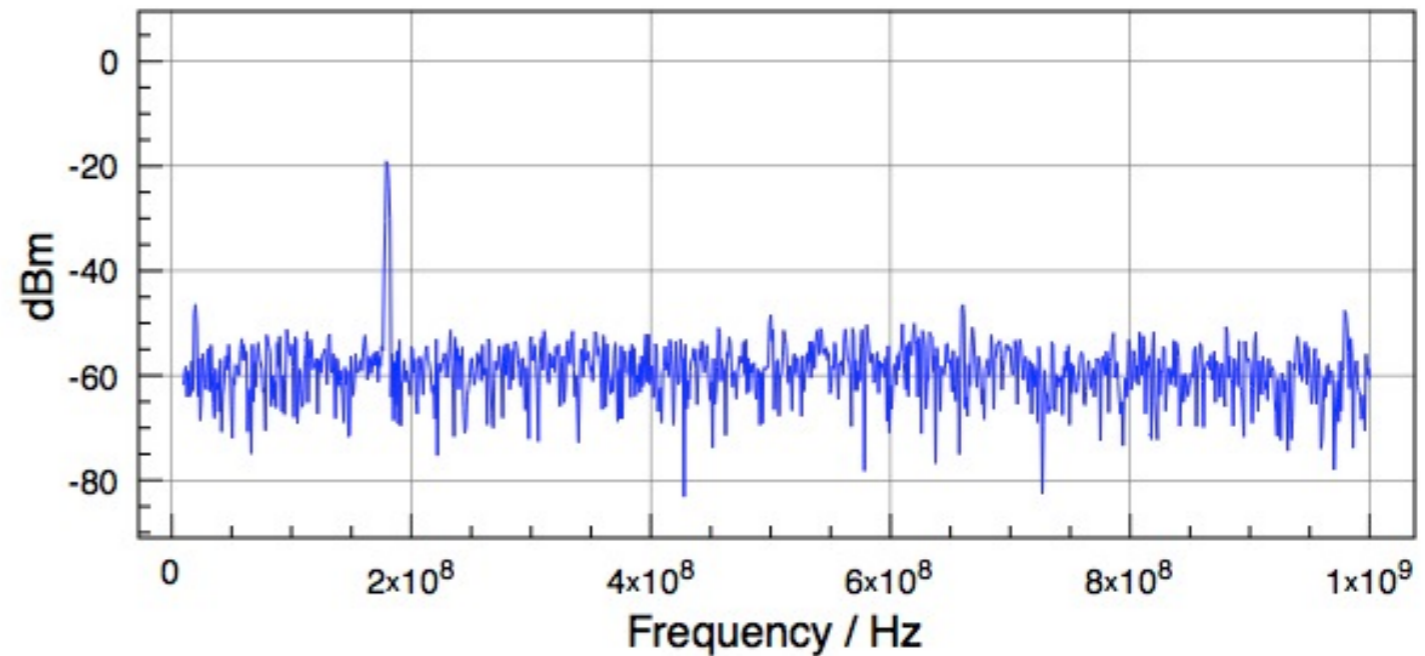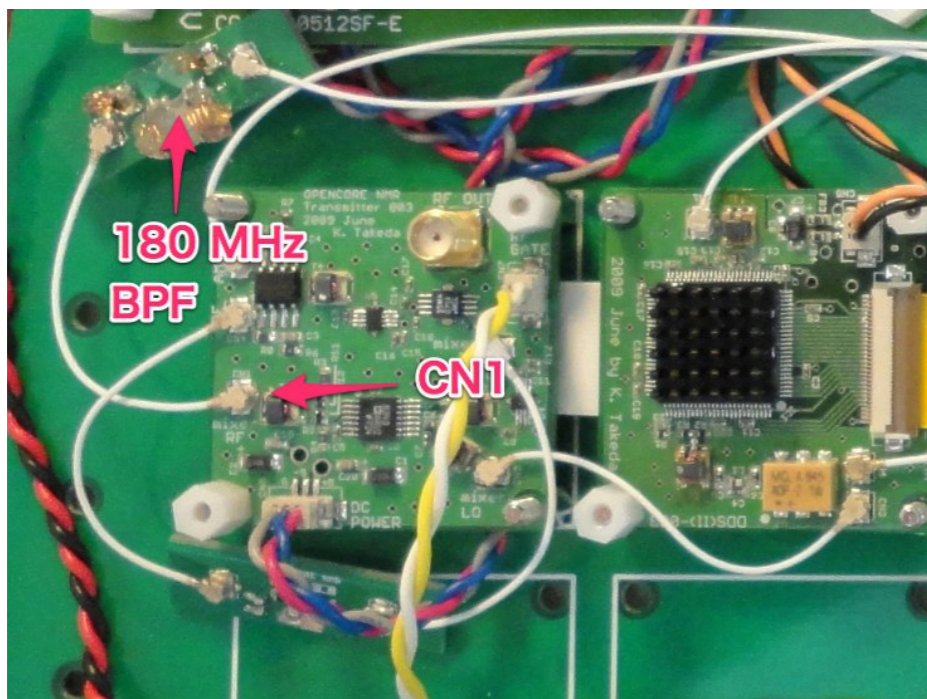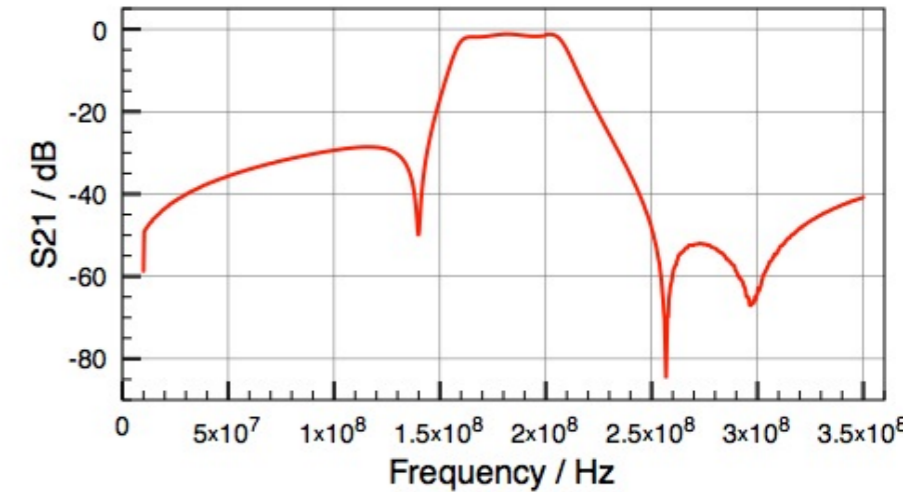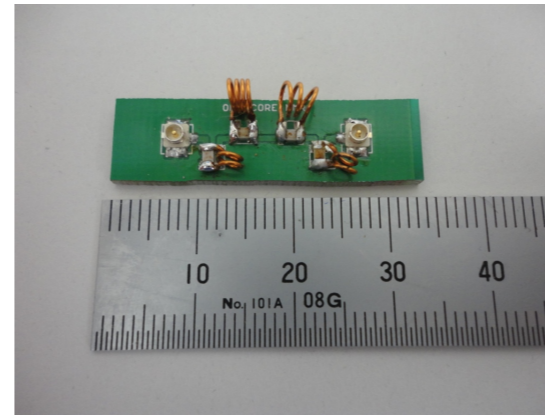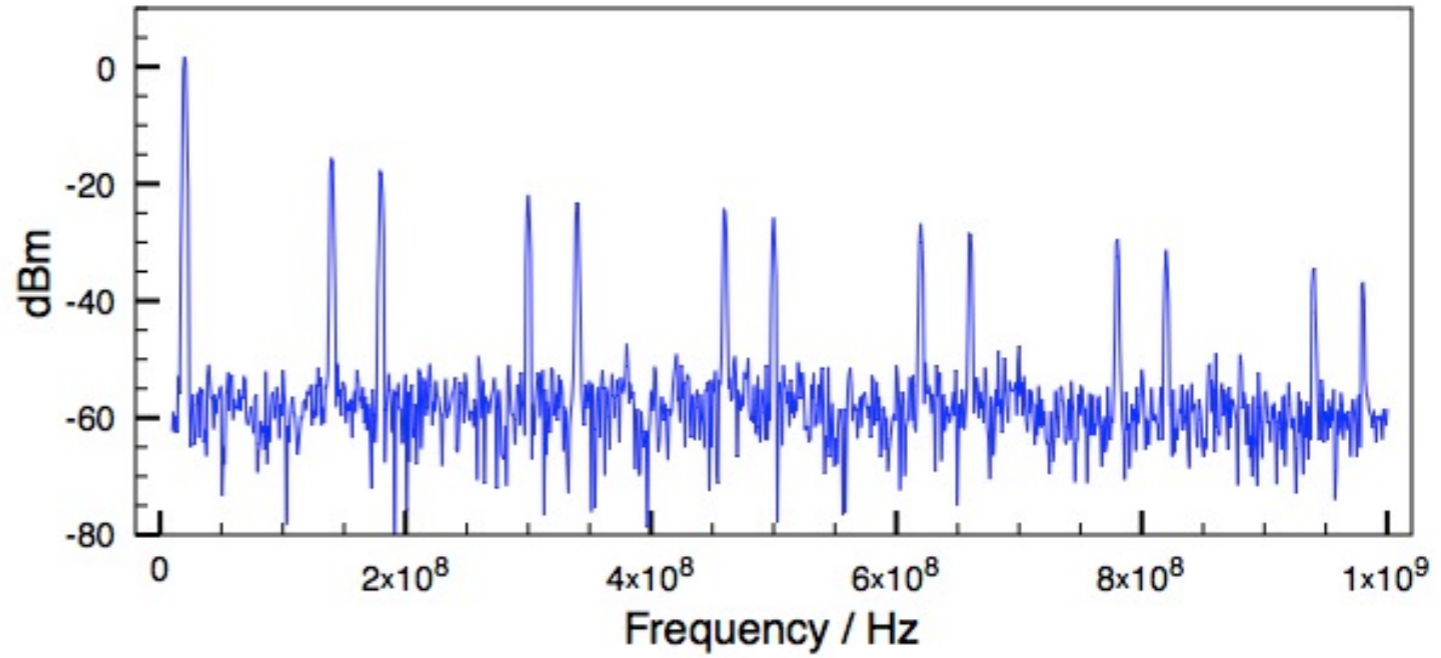
- DDS (II) is dedicated for generating signals at various frequencies.

- It operates with a 1 GHz clock.

- The frequency-tuning word is sent from the pulse programmer built inside the FPGA.

- Frequency modulation is feasible.

- The module has a pair of equivalent outputs. One is connected to CN2 (mixer LO), while the other is used for a receiver reference signal.
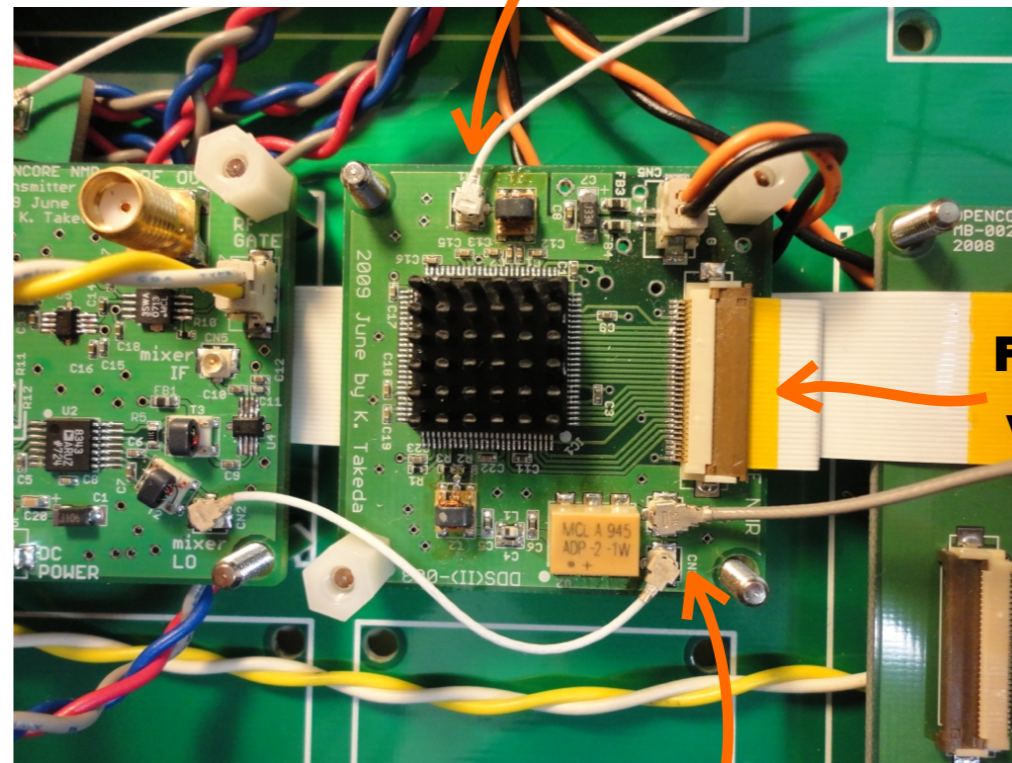
**1 GHz CLK input**

Frequency-tuning word from FPGA

A pair of equivalent outputs
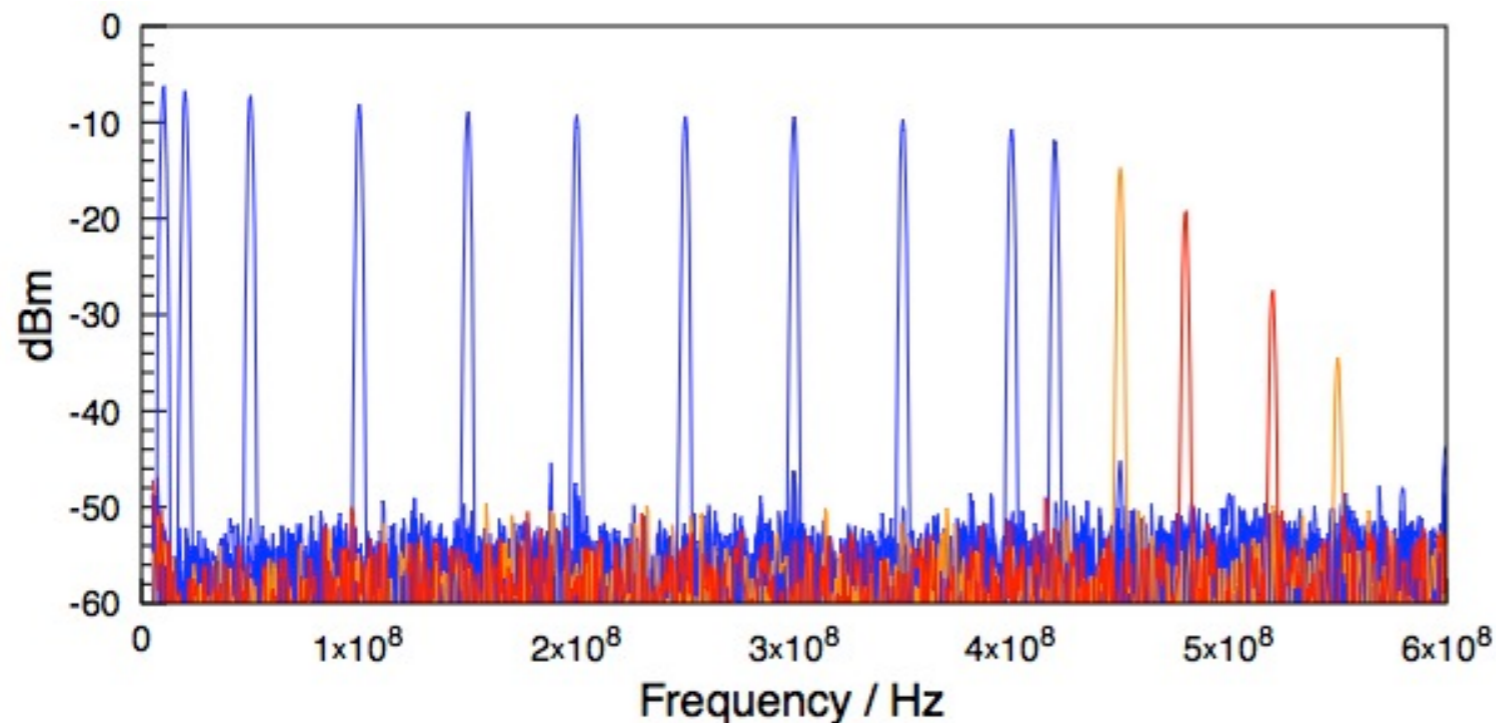
- In principle, the output frequency is bounded by half the clock frequency, i.e., 500 MHz.

- In practice, the reasonable maximum frequency may be ca. 420 MHz, above which the image components appear.

- In the left figure plotted is spectrum of the output signal for various frequencies. At 450 MHz (orange line) and 480 MHz (red line), the magnitude of the image components are considerable.

1 GHz Clock
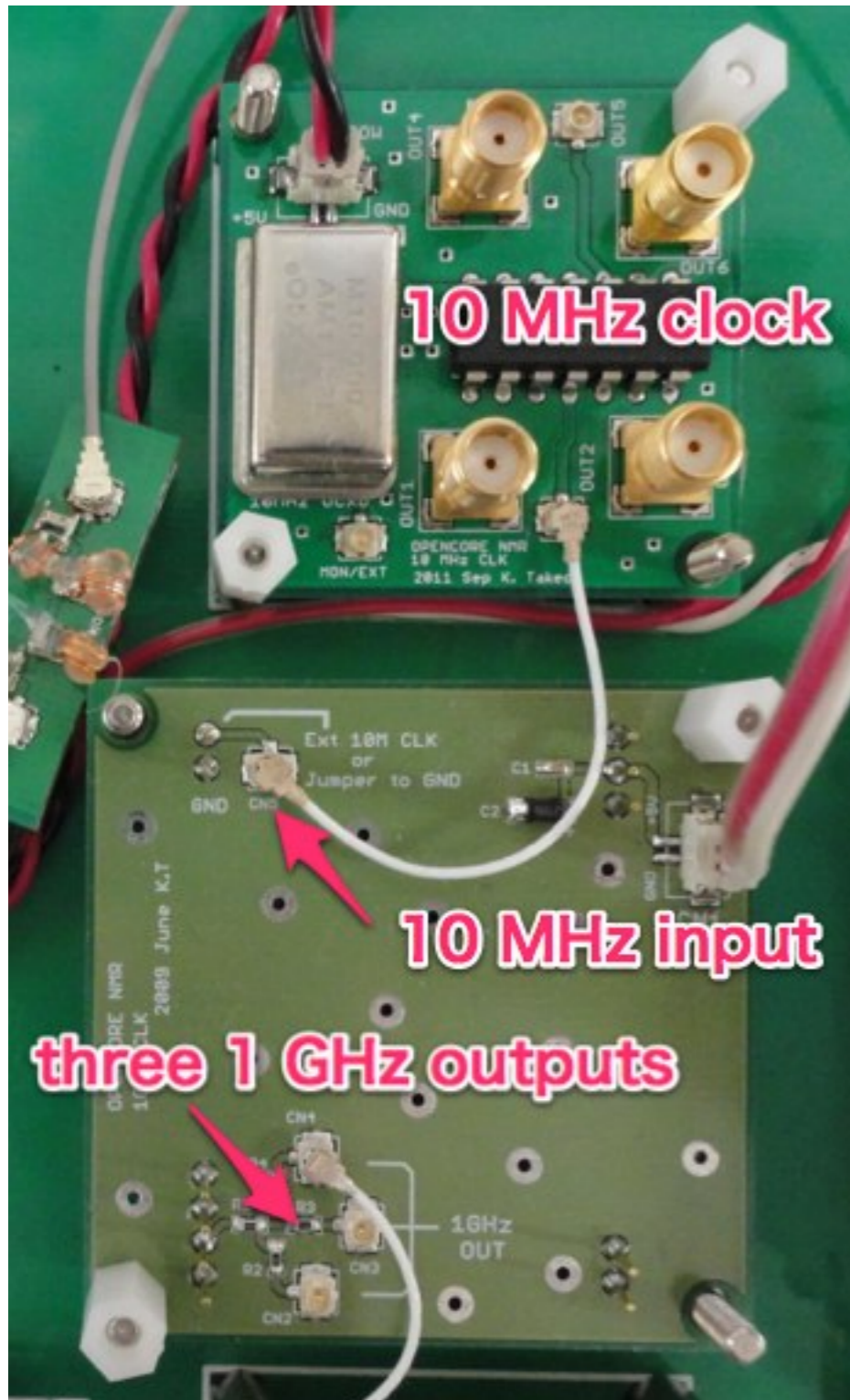
- 1 GHz is used by the DDS (II) module(s).

- The frequency stability is determined by that of the 10 MHz clock.

- Note that some "old" 1 GHz modules do not have an option for accepting the external 10 MHz clock. Their performance is not satisfactory for many NMR applications.

- To tell if your module supports the external 10 MHz input, look for a label written as "ext clock option" somewhere on the module. No label means that no option is equipped.

Bottom view of the 1 GHz clock module

ext clock option

option label

No "ext clock option" label.
No longer recommended for use.
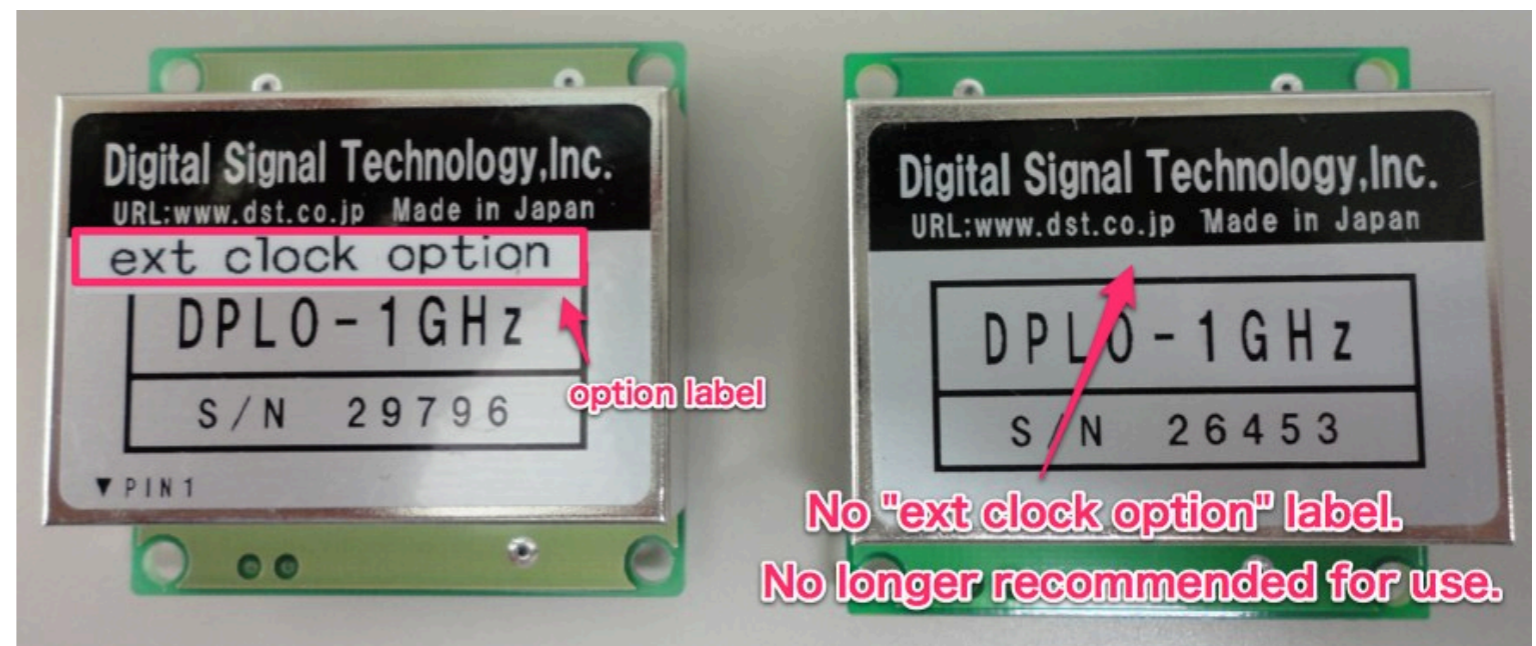
RF transmitter

- Its role is to mix the signals from DDS (I) and DDS (II) into that at a frequency of interest (F).

- The resultant rf phase is determined by that from DDS (I) at 180 MHz.

- The frequency of the signal from DDS (II) is to be set at either F+180 MHz or F−180 MHz.

- At the output of the RF mixer, the main Fourier components of the signal are at F and F+360 MHz (or F−260 MHz). In addition, several image frequencies may appear.

- In order to pick the right component at F, an RF filter is used.

- Then, the signal amplitude is adjusted using a multiplier.

- Finally, the continuous-wave signal is pulse modulated using an rf switch.

- The gate signal for pulse modulation is available on the gate distribution board (next page).
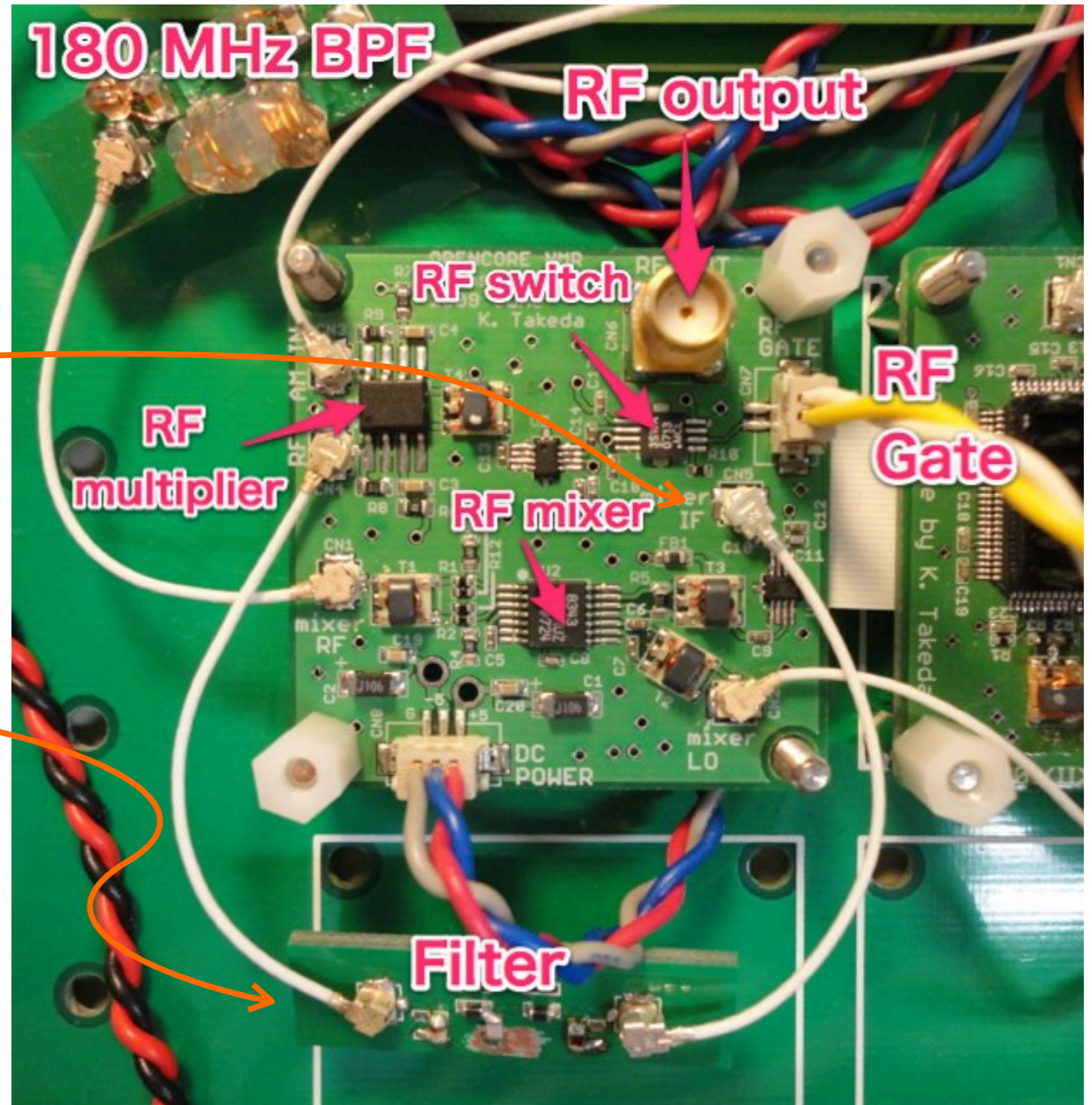
Logic gates
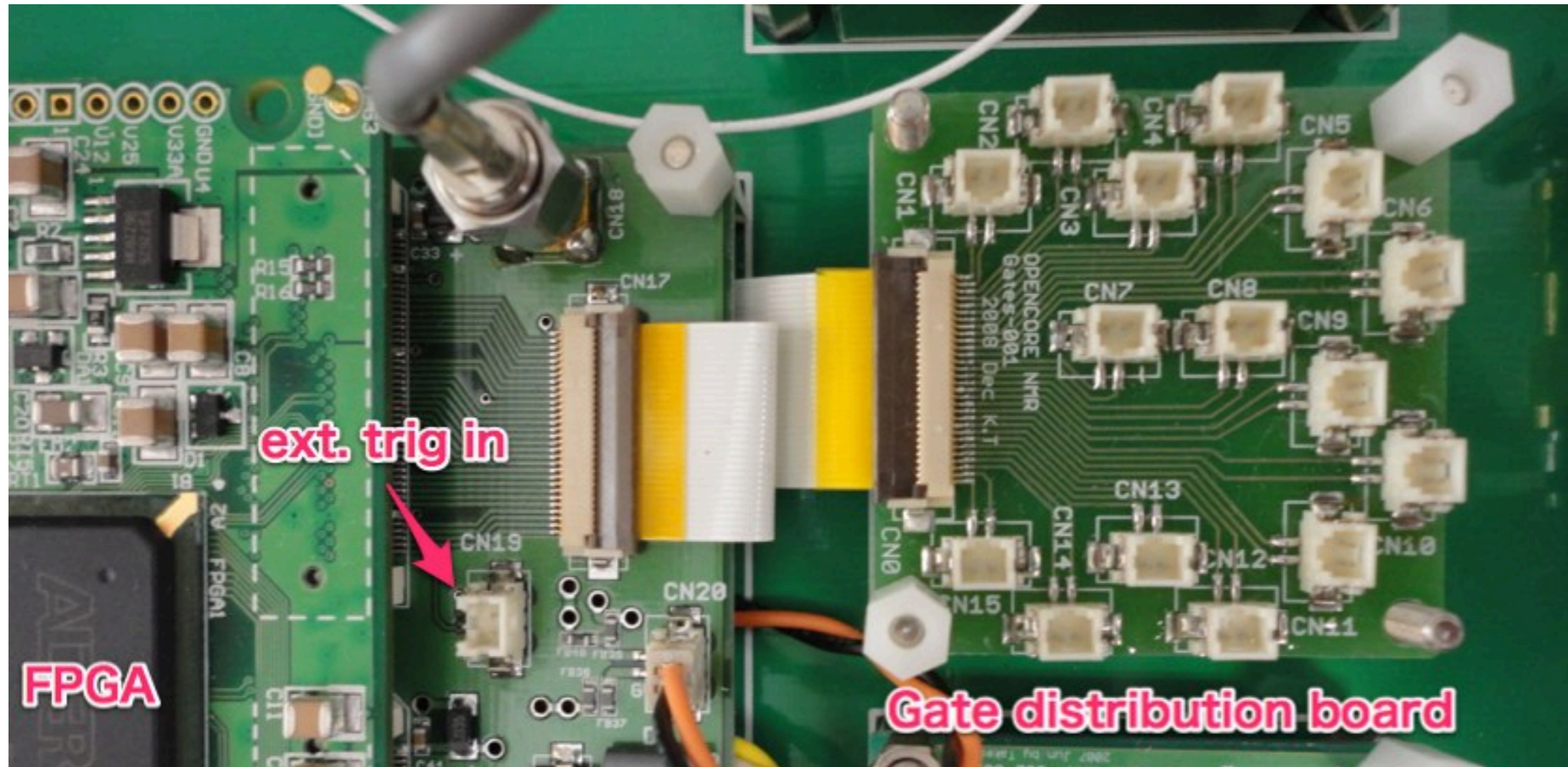
- A number of logic output gates are available on the gate distribution board.

- CN1-CN5, CN6-10, and CN11-15 are used for the 1st, 2nd, and 3rd channels, respectively.

- An external trigger input is also available on the FPGA mother board (CN19), which may be useful for triggering the spectrometer operation.

Pin assignments of the gate distribution board

	RF channel	Gate name	Function
CN1	1	F1_Gate	RF Gate for the transmitter. Positive true.
CN2	1	F1_Unblank	Power amplifier blanking. Positive true.
CN3	1	F1_Unblank	Timing is the same as that of CN2, but the logic is negative true.
CN4	1	RG	Receiver gate, which may be used to switch the gate. This is also used internally (i.e., inside FPGA) to activate the digital filter.
CN5	1	F1TTL1	A general purpose gate. Positive true.
CN6	2	F2_Gate	RF Gate for the transmitter. Positive true.
CN7	2	F2_Unblank	Power amplifier blanking. Positive true.
CN8	2	F2_Unblank	Timing is the same as that of CN7, but the logic is negative true.
CN9	2	F2TTL1	A general purpose gate. Positive true.
CN10	2	F2TTL2	A general purpose gate. Positive true.
CN11	3	F3_Gate	RF Gate for the transmitter. Positive true.
CN12	3	F3_Unblank	Power amplifier blanking. Positive true.
CN13	3	F3_Unblank	Timing is the same as that of CN12, but the logic is negative true.
CN14	3	F3TTL1	A general purpose gate. Positive true.
CN15	3	F3TTL2	A general purpose gate. Positive true.

Receiver

- The right figure shows the receiver module.

- The NMR signal of which channel, out of the three, do you want to observe?

- The observing rf channel is determined by the DDS (II) reference signal of which channel is connected.

- The mixer on the module converts the NMR signal into the signal at the intermediate frequency of 180 MHz, also yielding image signals.

- Thus, 180 MHz band-pass filter(s) are used to extract the Fourier components within the frequencies of interest.

- The signal is then amplified (if necessary), and digitally sampled by an analog-to-digital converter.

Signal input · a reserve · RF in · 180 MHz BPF · LO in · mixer · Reference input · IF out
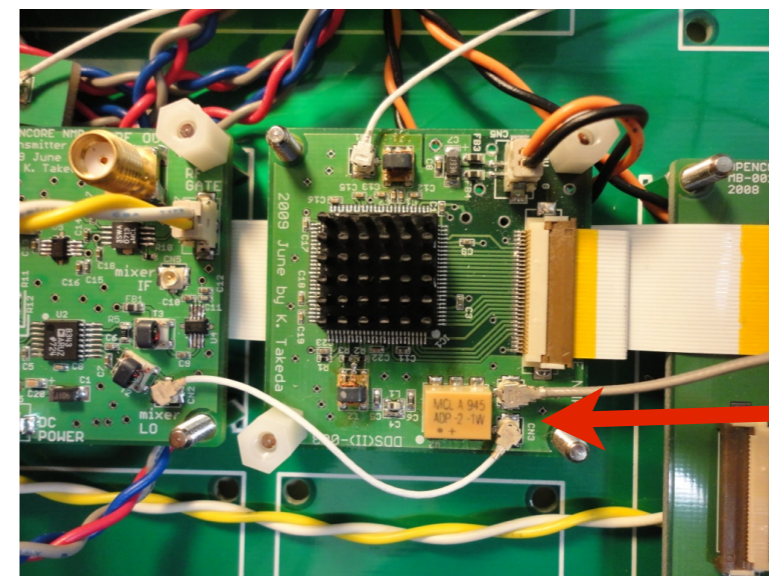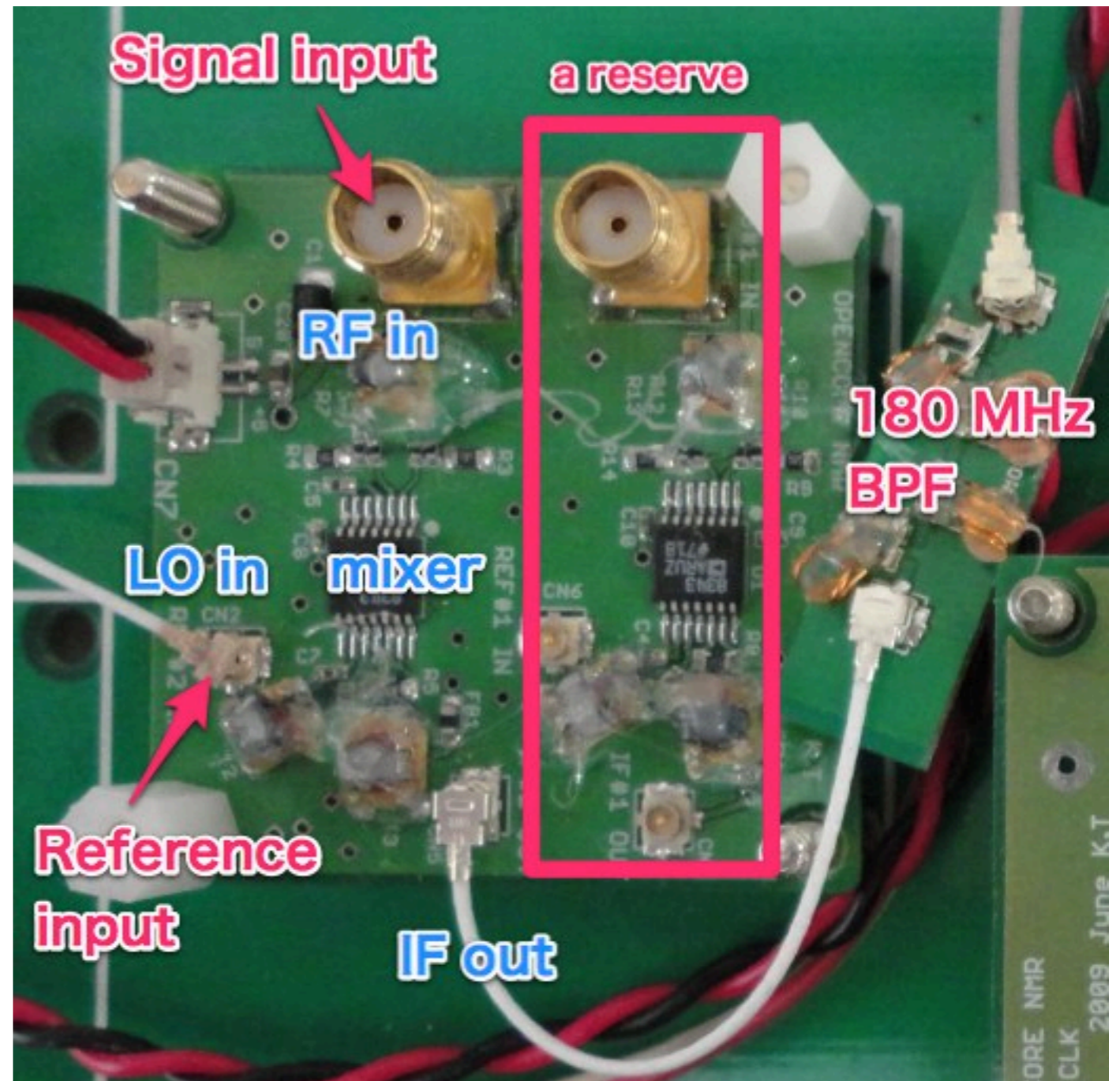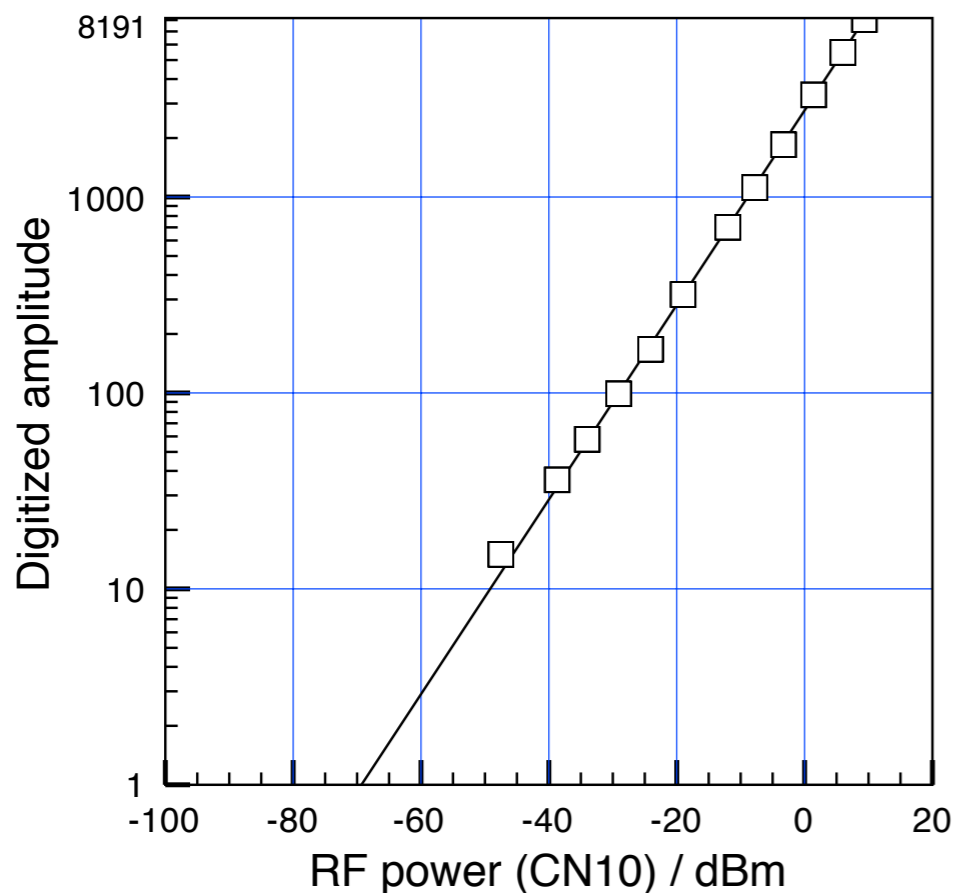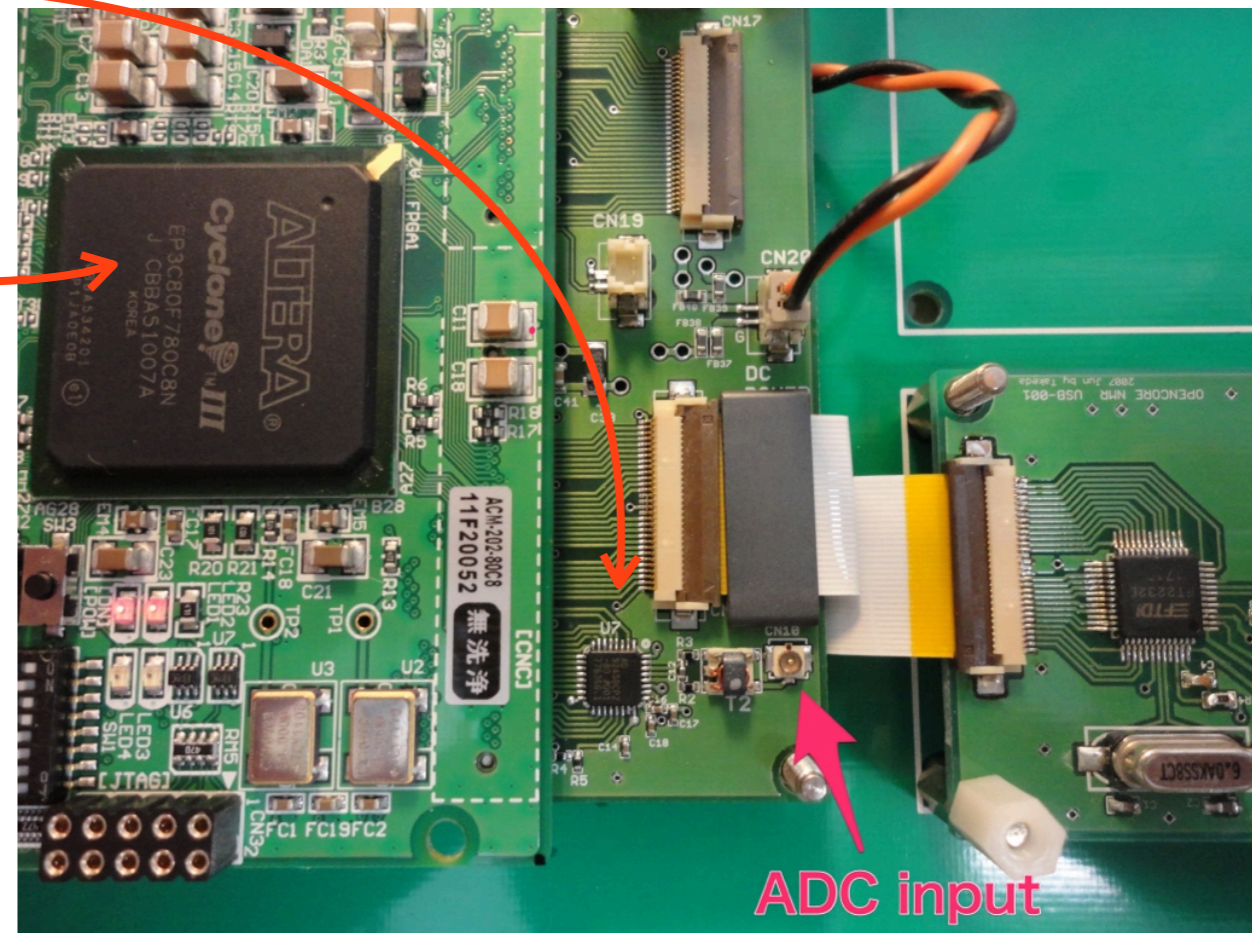

DDS (II) reference signal output

AD converter

- AD9245BCPZ-80 (Analog Devices)

- The sampling rate is 80 MHz. The clock is provided by the FPGA.

- Under-sampling (or super-Nyquist sampling) is feasible. Here, 5th Nyquist zone ranging from 160 to 200 MHz is of interest.

- Thus, measurement of the input-power dependence was carried out at the center frequency of 180 MHz.

ADC input

- The graph shows measured digitized signal amplitudes as a function of the input RF power. The frequency was 180 MHz.

- The ADC overflow occurred with an RF power of ca. 9.5 dBm.

- The underflow level was estimated from data extrapolation to be ca. -70 dBm.

DC power supply
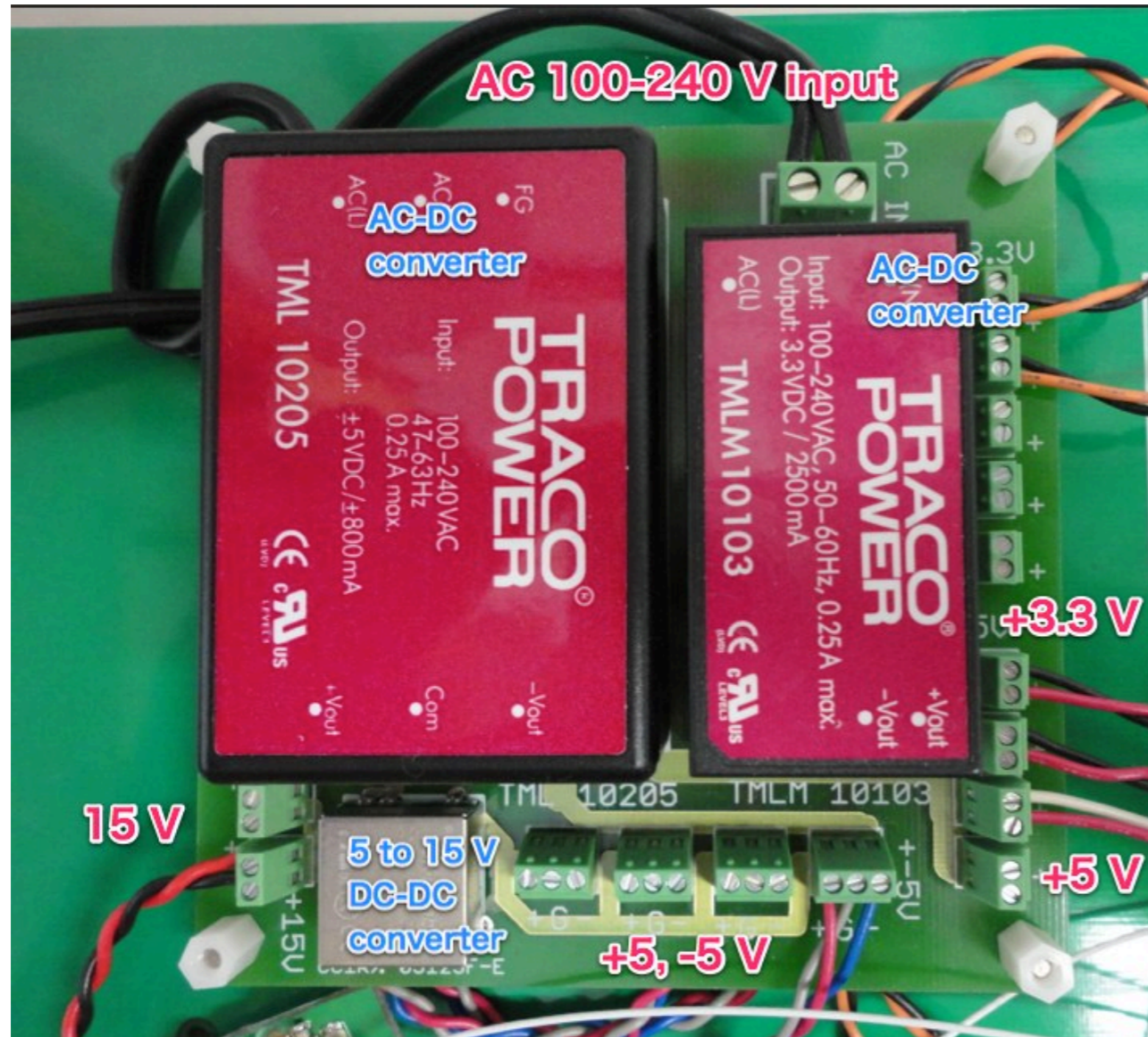
- AC 100-240V is acceptable, so that the spectrometer can be used in most countries.

- All active components except for the USB module are power-supplied by the module shown in the figure.

- Note that the USB module is bus-powered, i.e., supplied from a personal computer via the USB cable.

An important note

- A number of tiny coaxial cables are used.

- They can be used for transmitting signals at up to ca. 6 GHz.

- The connector type is U.FL (HIROSE).

- The small connector is nice, but a bit fragile.

- The cable with a broken connector can be so lossy that can cause problems.

- Please handle them gently.

normal connector

broken connector

no electrical connection between the connector and the cable shield!