Kuiper Linux Distribution - simplify hardware prototyping with GNU Radio

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(Software Defined) Radio Systems

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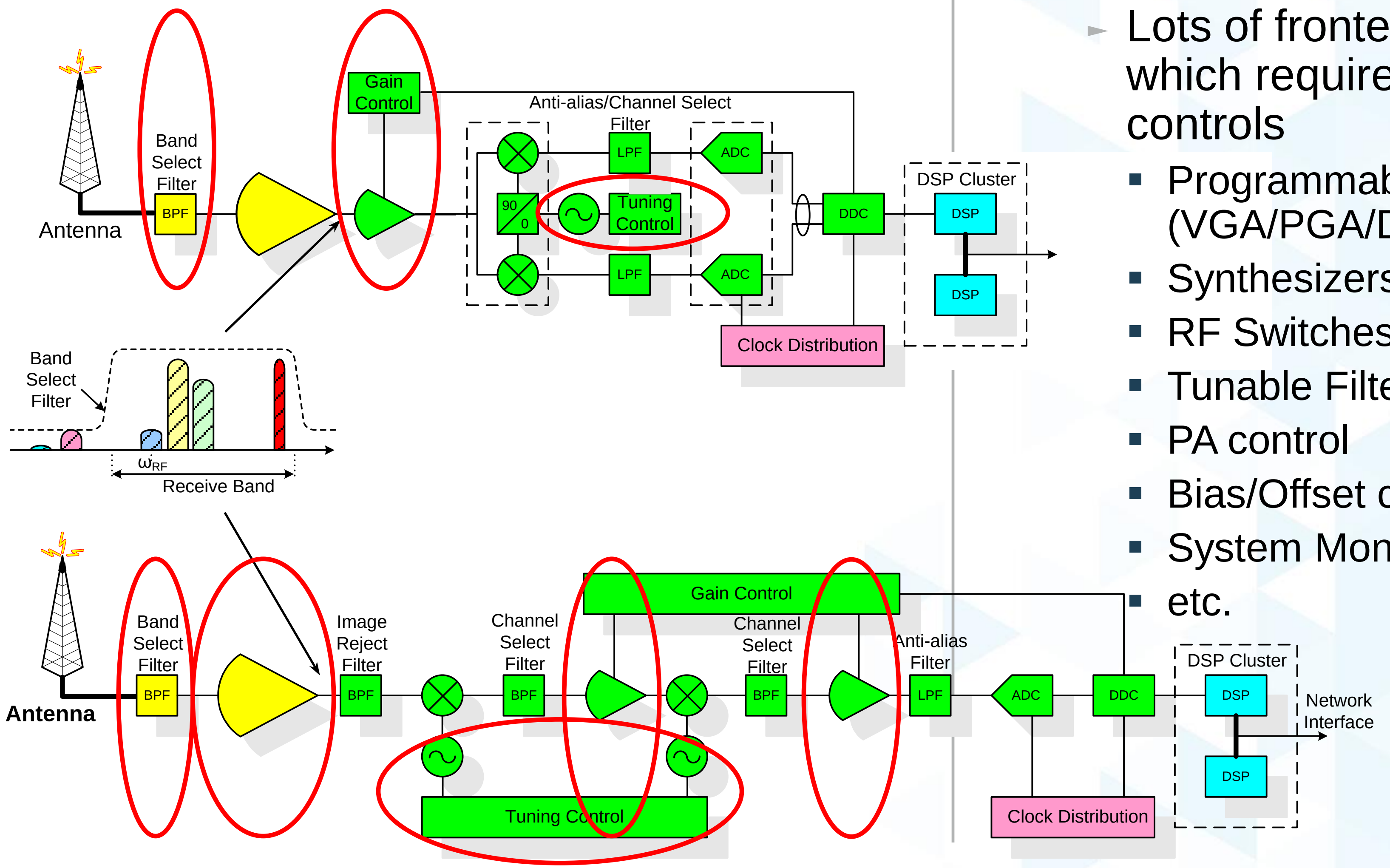

- **Are much more than Digitizers!**
- Lots of frontend **active** RF components which require configuration and runtime controls
  - Programmable Amplifiers and Attenuators (VGA/PGA/DSA)
  - Synthesizers, PLLs, UP/DN Converters
  - RF Switches (TRX, Filters)
  - Tunable Filters, Beamformers
  - PA control
  - Bias/Offset control
  - System Monitoring (V, I, T)
  - etc.

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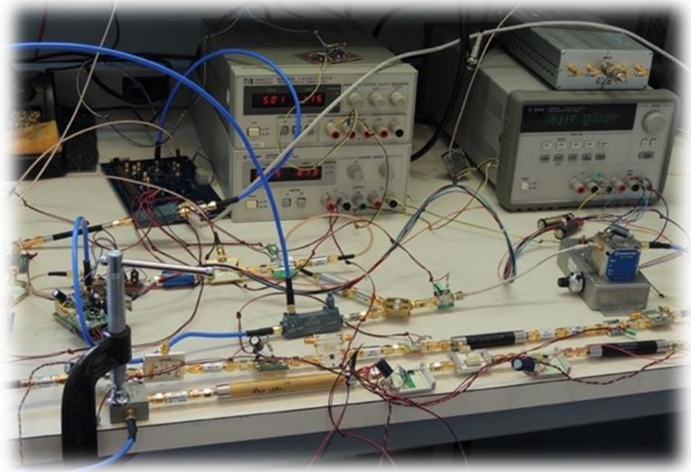
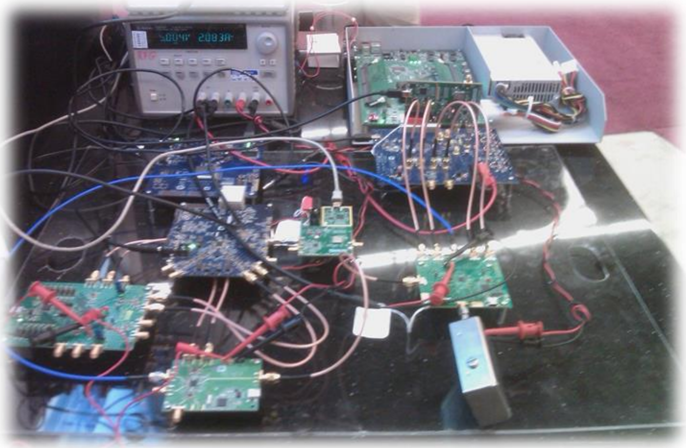
Typical prototyping challenges



Typical Lab Bench



- Observation
  - Lots of interconnected evaluation/protype circuit boards
  - Lots of different supply voltages needed
  - No homogeneous way to control this mess
- Implication
  - Loss of RF performance
  - Mechanically difficult to test this in the field
  - Control nightmare
    - Every active component has its own Windows EVAL software
    - Sometimes missing software and drivers
    - No way to remote control
    - No easy way to integrate command and control into a GRC flowgraph
- Possible Solutions
  - Custom PCB design & System controller + Firmware
    - High cost and risk, typically comes 2nd after prototyping phase
  - Modular RF and Microwave building blocks
  - **Commercially of the shelve control hardware and FOSS software**
  - Industry standard soft- and hardware components
  - Single and powerful Embedded Controller which can control all components at a very high level

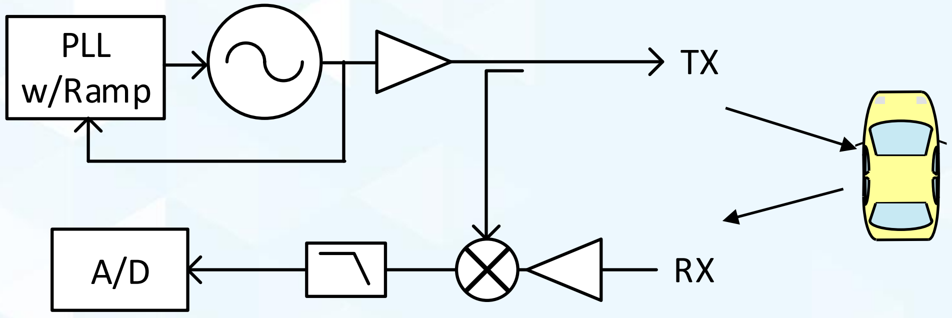
Prototyping a FMCW Radar

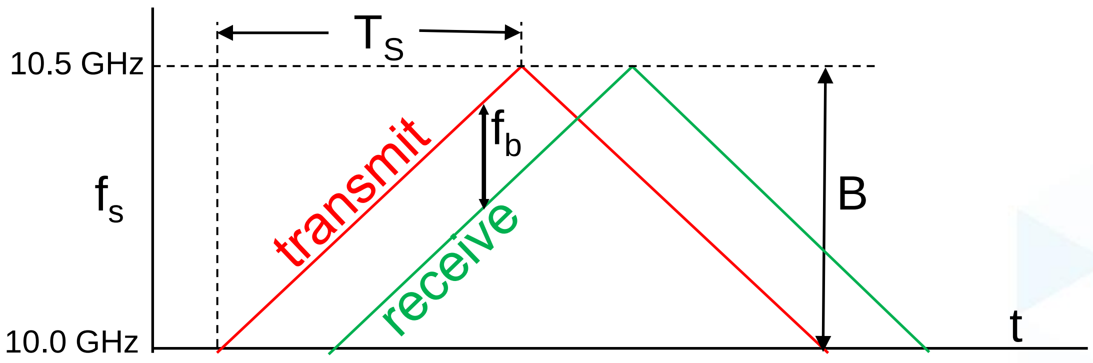
(in less than a day)

FMCW Radar

- **FMCW:** Frequency Modulated Continuous Wave
- Different than Pulsed Radars
- **Beat frequency** proportional to time delay -> FFT for range estimation

Basic Architecture

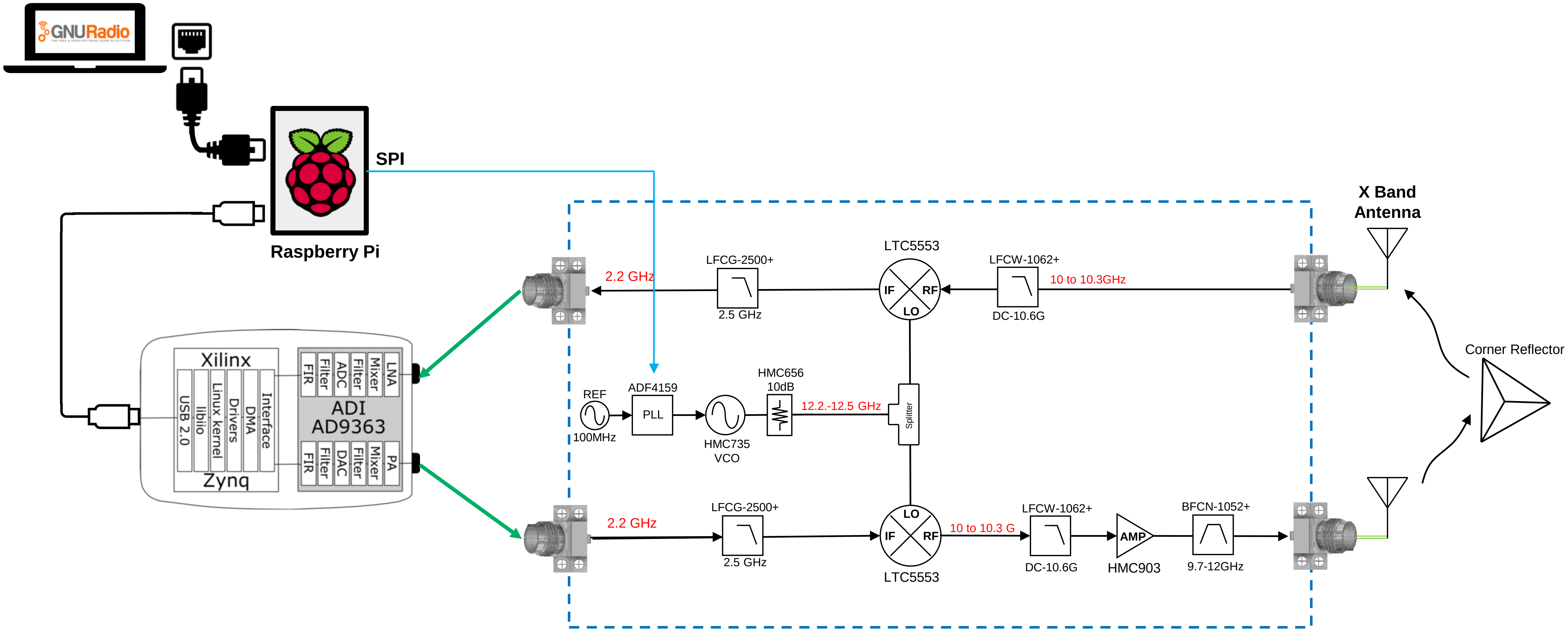




$$R = \frac{cT_s}{2B}(f_b)$$

R = distance to target
c = speed of light (3E8 m/s)
T_s = transmit frequency ramp rate
B = bandwidth of the frequency ramp
f_b = transmit to receive frequency difference

Build your own 10 GHz FMCW radar



Build your own 10 GHz FMCW radar

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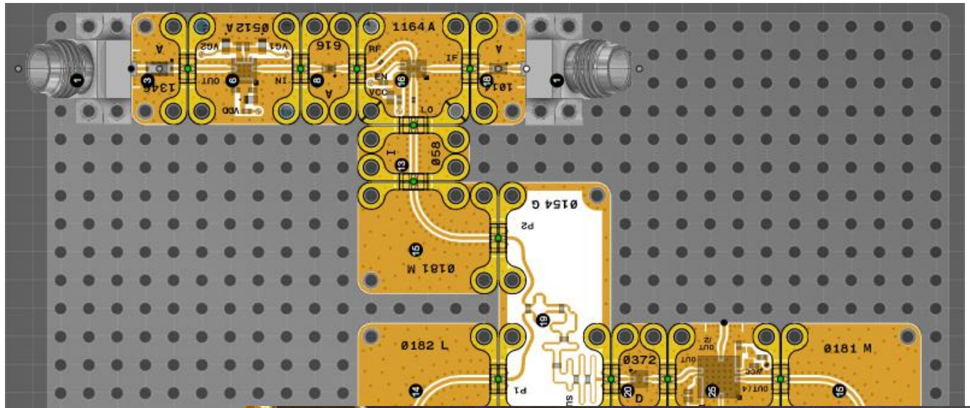

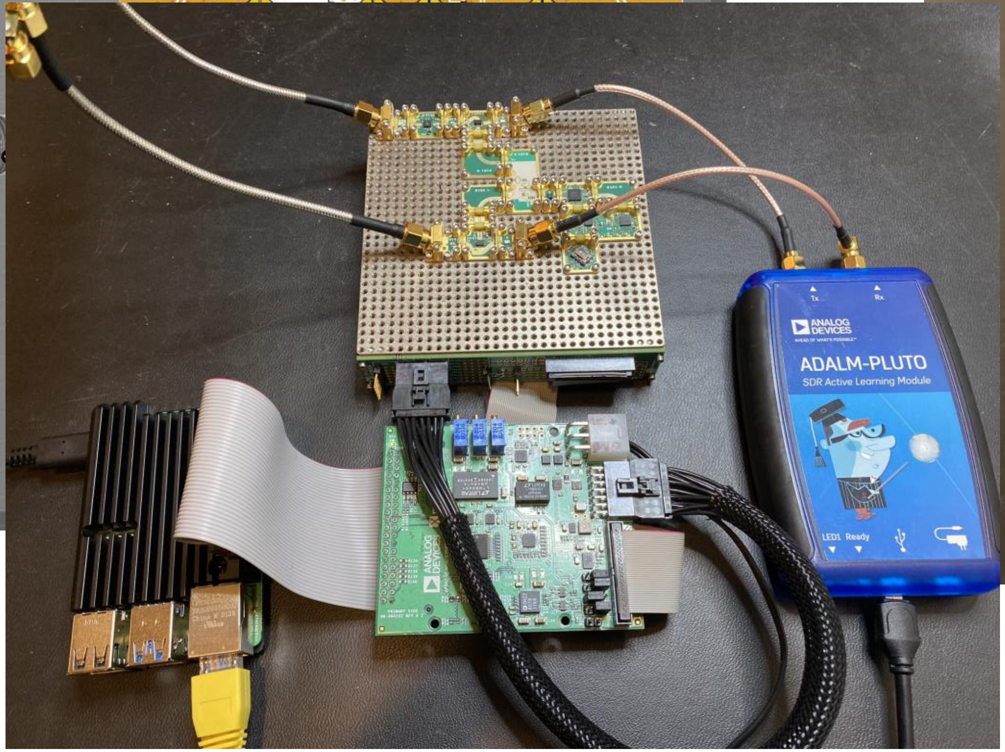

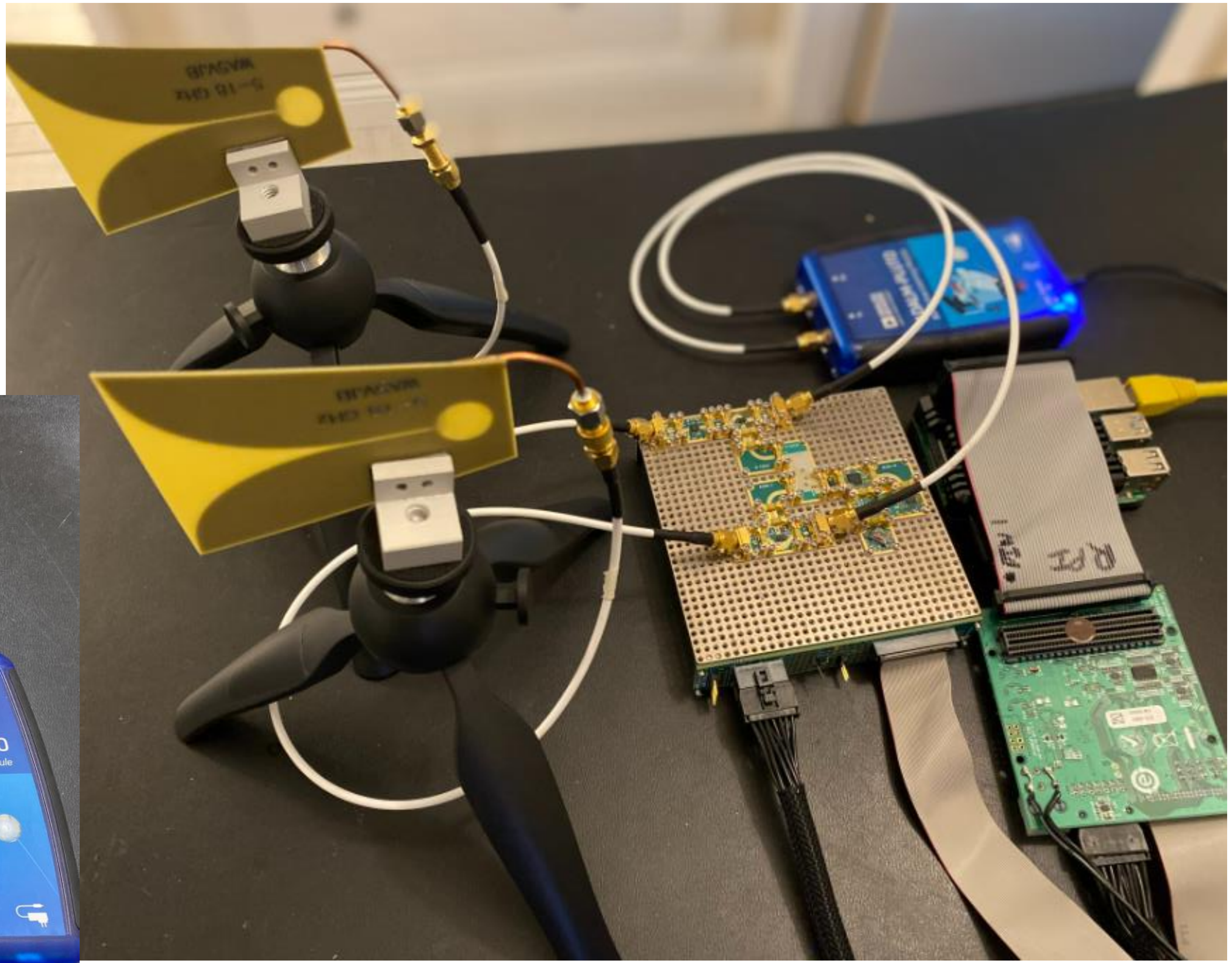

microwave
A Quantic Company

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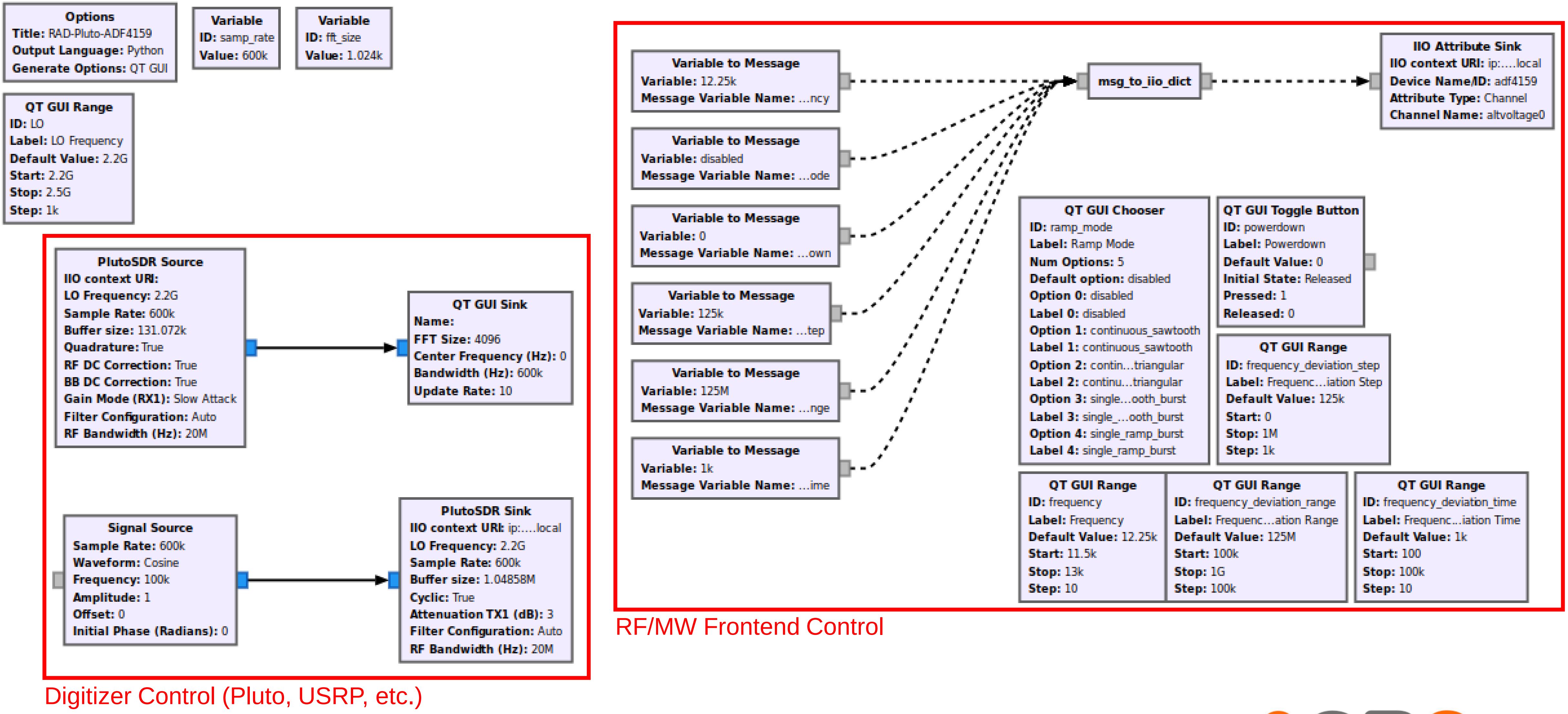
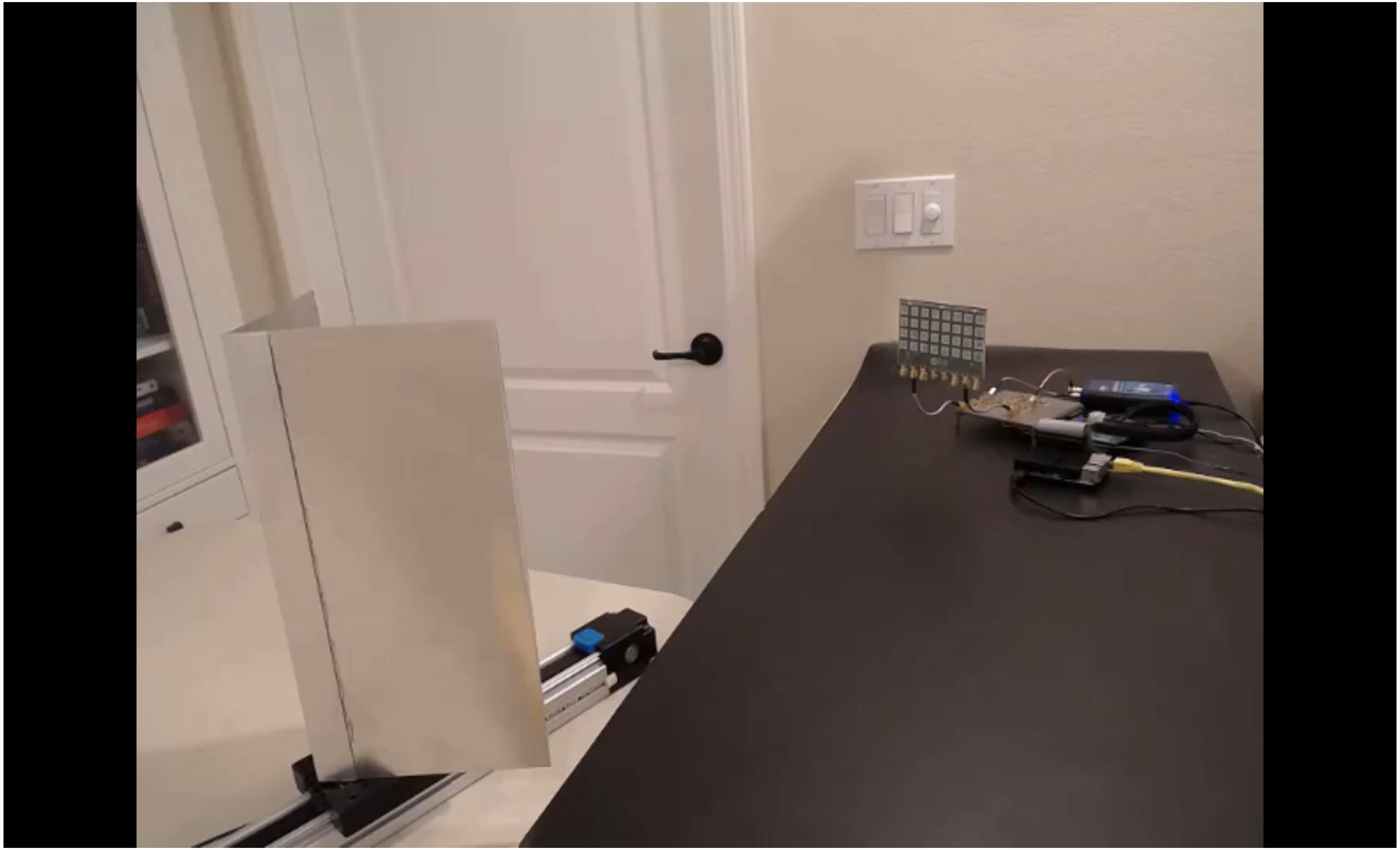
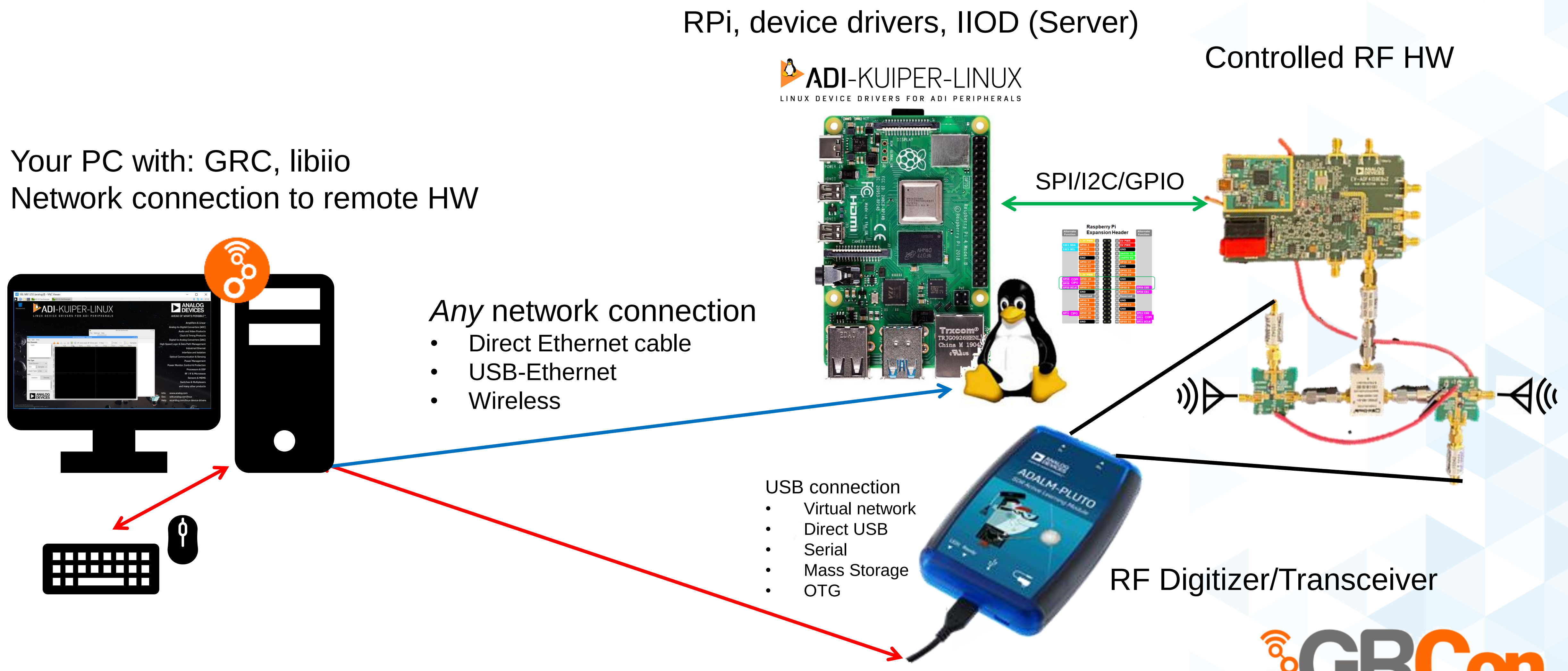
Hello World FMCW!



Demo Time

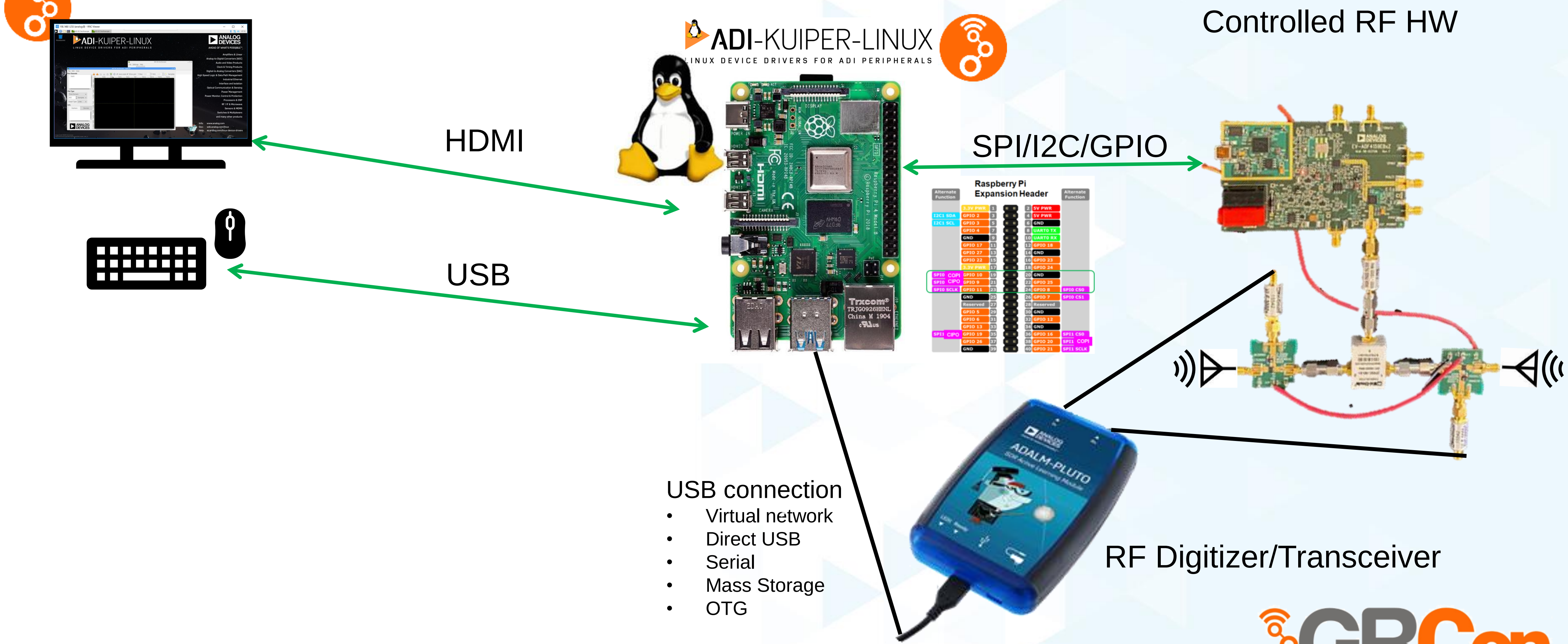


Example #1: RPi as control Bridge



Example #2: Arm-Based Computing Platforms

Your SBC Raspberry Pi running
Graphical Desktop Environment and GRC



USB connection

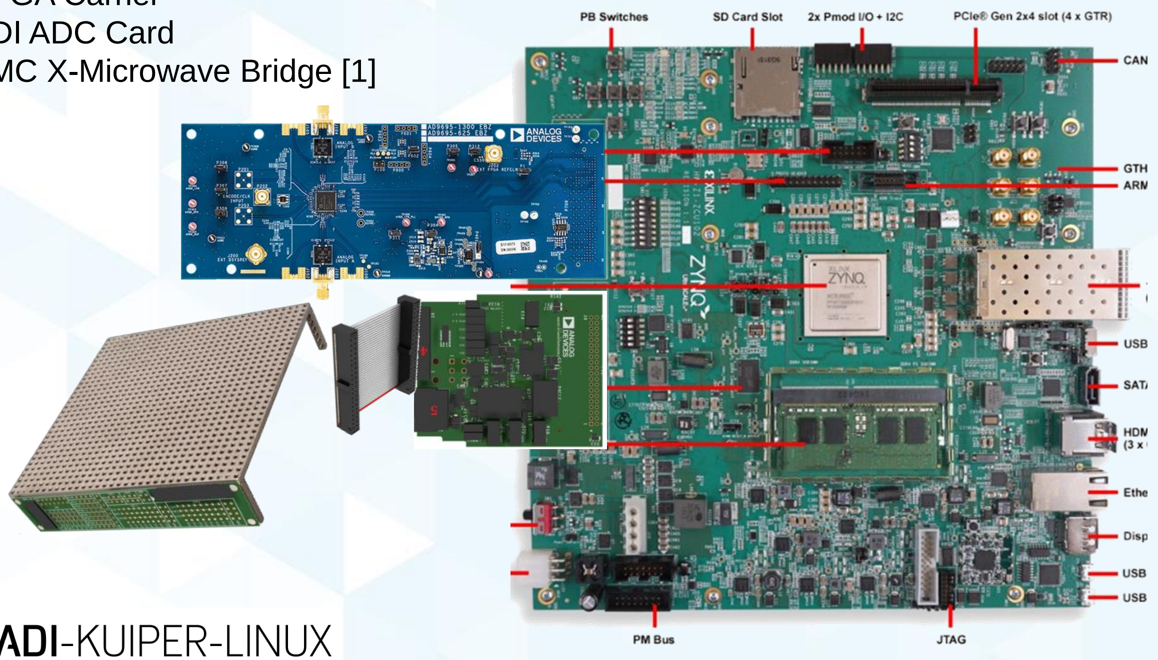
- Virtual network
- Direct USB
- Serial
- Mass Storage
- OTG

Example #3: All digital back to the same SoC/FPGA

- All digital back to the same SoC
  - TRX data
  - TRX control
  - Clock control
  - Microwave/RF Control

- Enables:
  - Single / Cohesive environment to interface with digitizers and RF/Microwave
  - System level verification
  - Easier Power Supplies
  - Synchronization between digitizer and MW
  - Sync between data and control
  - Easier device driver verification and development
  - Control MW from GnuRadio, MATLAB or Python
  - Simplifies path to production (all SW together, all HW together)

- FPGA Carrier
- ADI ADC Card
- FMC X-Microwave Bridge [1]



ADI-KUIPER-LINUX
LINUX DEVICE DRIVERS FOR ADI PERIPHERALS

- ADI RF SOM
- ADI Carrier
- FMC X-Microwave Bridge [1]

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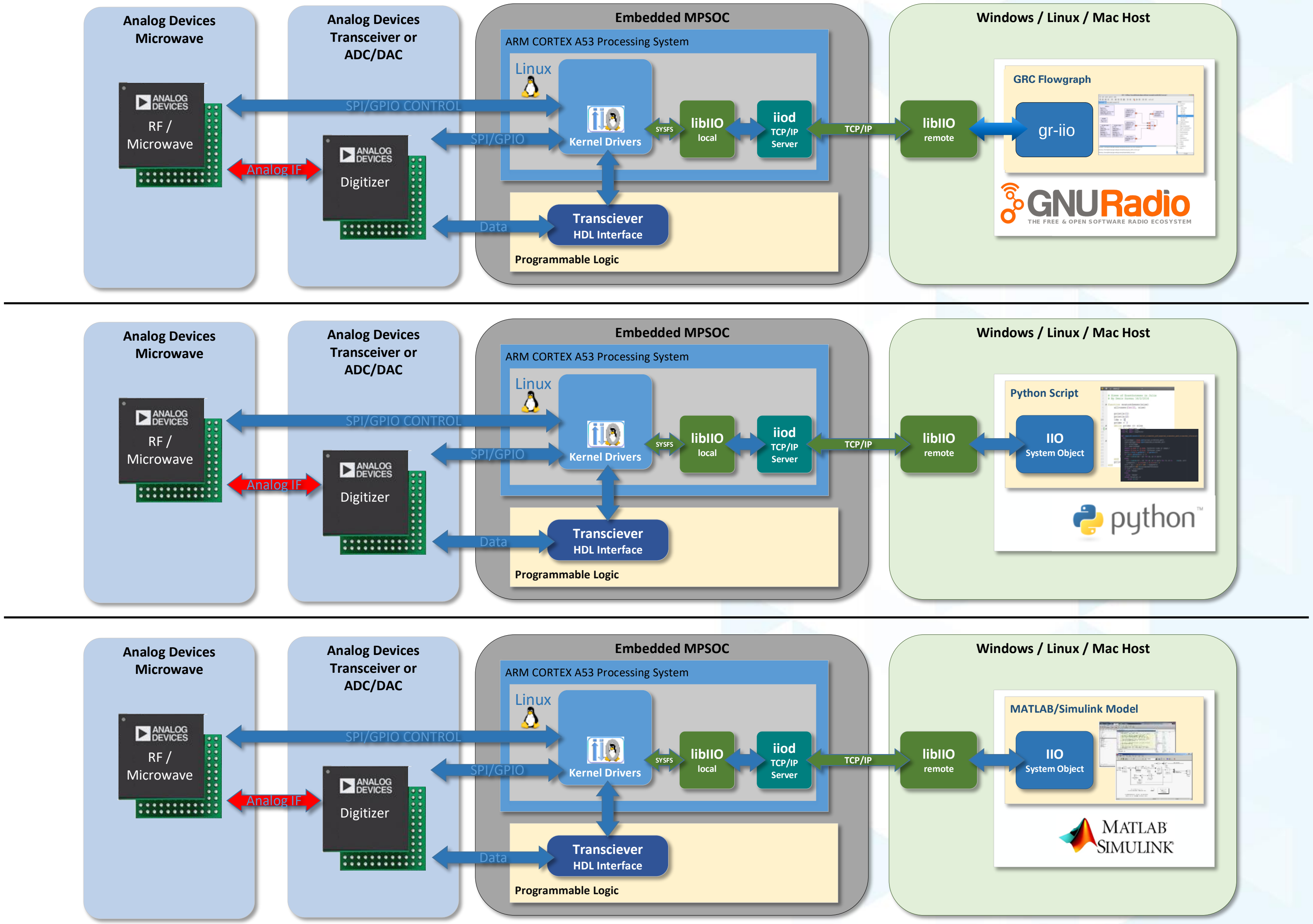
Single cohesive software solution



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ADI-KUIPER-LINUX

LINUX DEVICE DRIVERS FOR ADI PERIPHERALS

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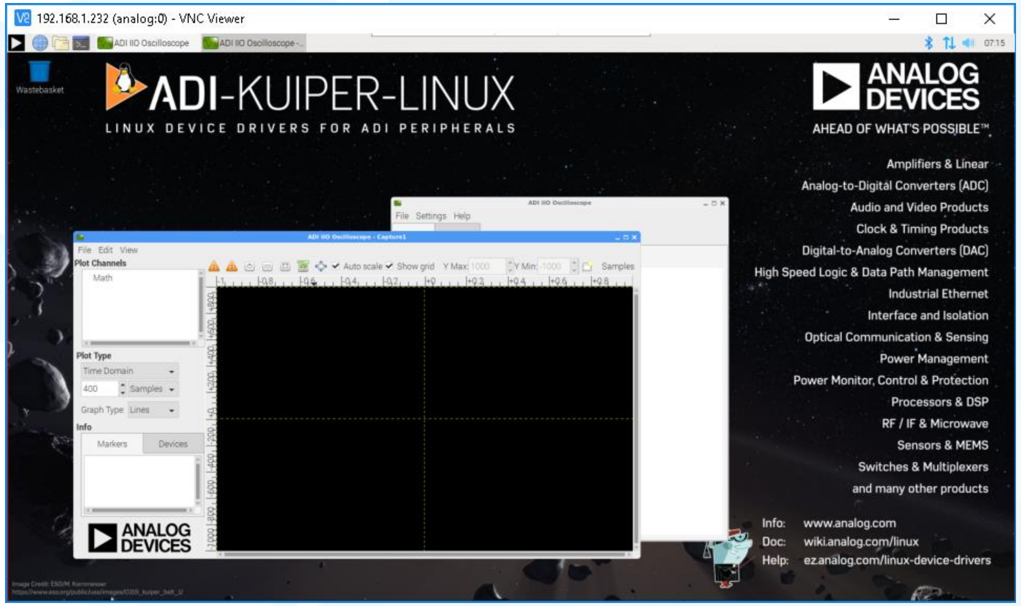
- A distribution based on Raspbian but NOT only for Raspberry Pi [2].
  - It incorporates **Linux device drivers for ADI products [6]** and is created with **ease of use** in mind.
  - Supports multiple ADI Circuit Note and Eval boards with FMC, RPi HEAD, Arduino and PMOD connectors.
- **Minimize the barriers** to integrating hardware devices into a Linux-based system.
- ADI Kuiper Linux solves this problem, and includes a host of additional applications, software libraries, and utilities.



Kuiper Imager Utility [4]

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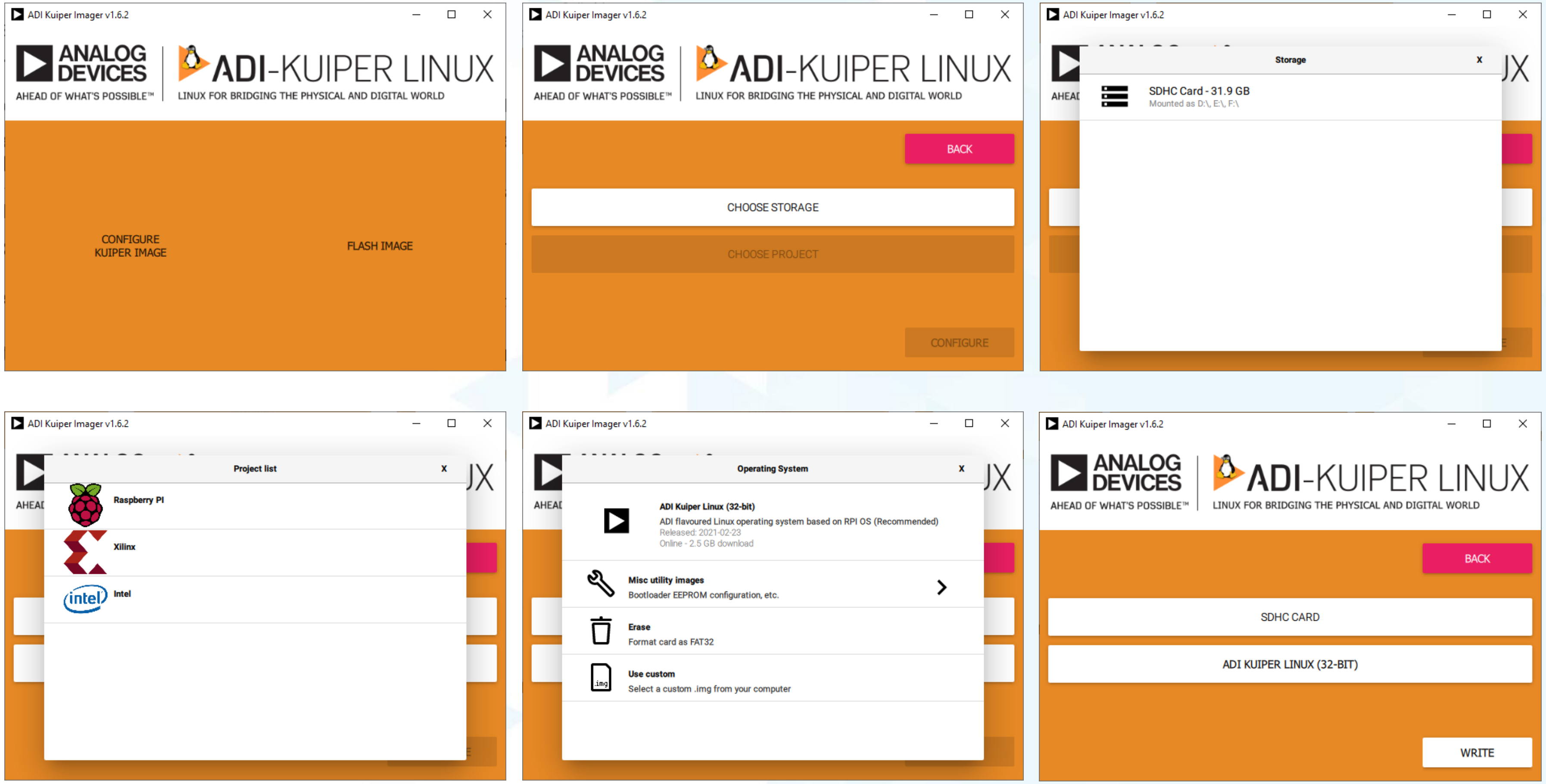
- Windows/Linux/Mac
- Downloads Image file from the internet
- Writes image to removable media storage device
- Eases customization for a specific Base Platform + Add-On or Attach
- Released in the coming weeks



<u>Alternative</u>: **$wget https://swdownloads.analog.com/cse/kuiper/image_2022-08-04-ADI-Kuiper-full.zip**

$unzip image_2022-08-04-ADI-Kuiper-full.zip

$sudo dd if=2022-08-04-ADI-Kuiper-full.img of=/dev/sdX bs=4M

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Customizing?

- While Raspbian targets Raspberry Pi platform boards, ADI Kuiper Linux supports several other platforms in addition
  - Arduino form factor ARM based FPGA platforms such as
    - Intel/TerASIC DE10-Nano
    - Xilinx/Digilent Cora Z7
  - Most popular FMC FPGA carriers from Xilinx/AMD and Intel with ARM/ARM64 support
    - Zynq7000 (Zed board, ZC706, ZC702)
    - MPSoC (ZCU102)
    - SoC FPGA (A10Soc, A5Soc)
- Configure the Kuiper SD card to be used with a specific Hardware
  - Base Platform + Add-On or Attach
  - Move boot files from folders to the root of the FAT partition so that they can be picked up by the first stage bootloader (Intel or Xilinx/AMD FPGAs)
    - FPGA Bitstreams
    - Linux kernel blobs
    - Devicetree blobs
  - Instruct early-stage bootloader to load a certain overlay (Rpi: Edit config.txt)

Devicetree (overlay)

- Tree data structure with nodes that describe the physical devices in a system.
- Describes device information in a system that cannot be dynamically detected.
- Organized in nodes and properties
- Overlays enables addition of extra nodes to the live device tree of an embedded Linux system.
- **dts, dtsi**: devicetree source
  - Human-readable
  - Textual
  - Used when editing devicetree files
- **dtb, dtbo**: devicetree blob
  - Machine-readable
  - Binary
  - Flattened
  - The Device tree compiler (dtc) generates dtb, dtbo

$dtc -I dts -O dtb rpi-adf4159-overlay.dts > rpi-adf4159.dtbo

Example file: rpi-adf4159-overlay.dts [3][5]

```
/dts-v1/;
/plugin/;

&spi0 {
        #address-cells = <1>;
        #size-cells = <0>;
        status = "okay";

    adf4159:adf4159@0 {

        compatible = "adi,adf4159";

        reg = <0x0>;

        spi-max-frequency = <12500000>;

        /* Clocks */
        clocks = <&clkin>;
        clock-names = "clkin";
        clock-output-names = "rf_out";
        #clock-cells = <0>;
        adi,power-up-frequency-hz = /bits/ 64 <6000000000>;
        /* --- snip ---- */
    };

};
```

Parent Node – SPI BUS #0

New device node

Driver to bind

SPI Chip Select 0

Properties

Devicetree

- The Analog Devices kernel tree contains a number of such Device Tree Overlays in the *arch/arm/boot/dts/overlays* folder.
- Each of those overlays, stored in .dts file gets compiled into a .dtbo files using dtc.
- On the SD card those .dtbo files reside in *BOOT\overlays* or from within the rootfs at */boot/overlays*
- Those .dtbo can be loaded and applied to the main Device Tree by adding the following statement to the Rpi config.txt file:

- **Load at boot:**
  - config.txt file is read by the early-stage boot firmware
- dtoverlay=overlay-name,overlay-arguments

  EXAMPLE:

  dtoverlay=**rpi-adf4159**

- **Load from command line:**
- dtoverlay <overlay> [<param>=<val>...]

  EXAMPLE:

  root@analog:~# **dtoverlay rpi-adf4159**

  root@analog:~# dtoverlay -l

  Overlays (in load order):

  0: rpi-adf4159

  root@analog:~# systemctl restart iiod

What is IIO?

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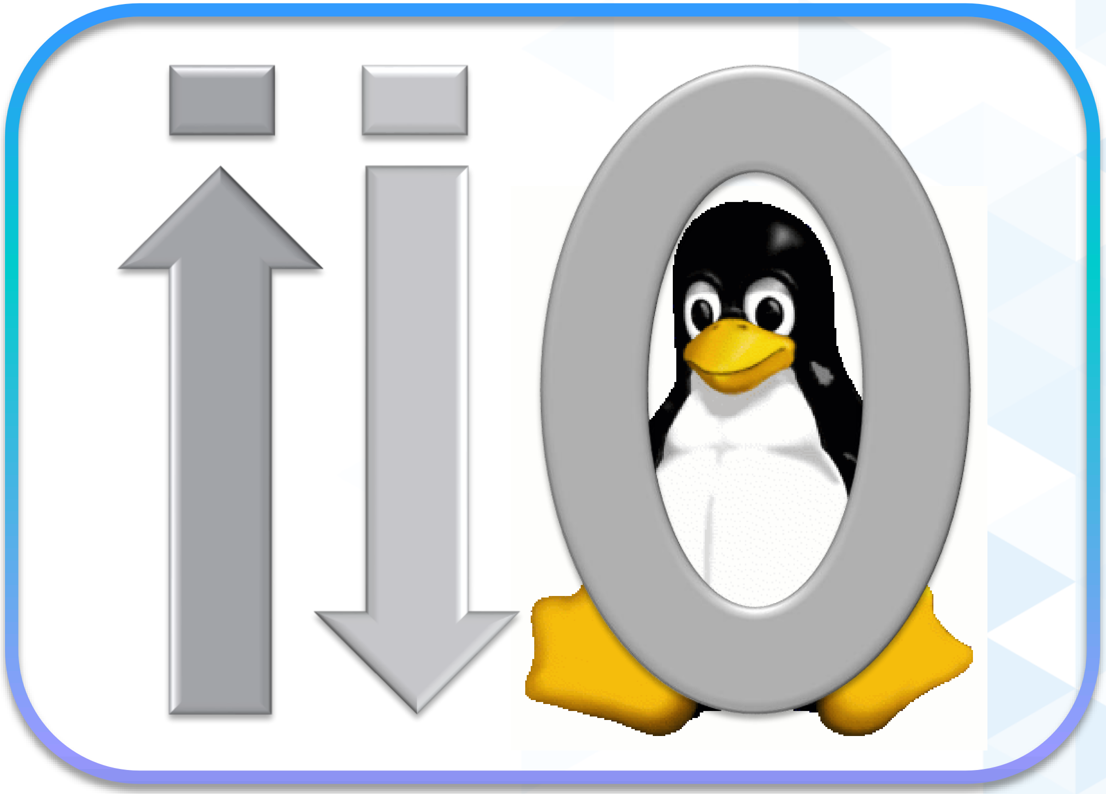
- Linux kernel **I**ndustrial **I**nput / **O**utput framework
  - Not really just for Industrial IO
  - All non-HID IO
  - ADC, DAC, TRX, light, accelerometer, gyro, magnetometer, humidity, temperature, pressure, rotation, angular momentum, chemical, health, proximity, counters, amplifiers, synthesizers, RF Up/Down converters, tunable filters, etc.
- In the upstream Linux kernel for more than 10 years.
- Mailing list:
  - linux-iio@vger.kernel.org



https://www.kernel.org/doc/html/latest/driver-api/iio/index.html

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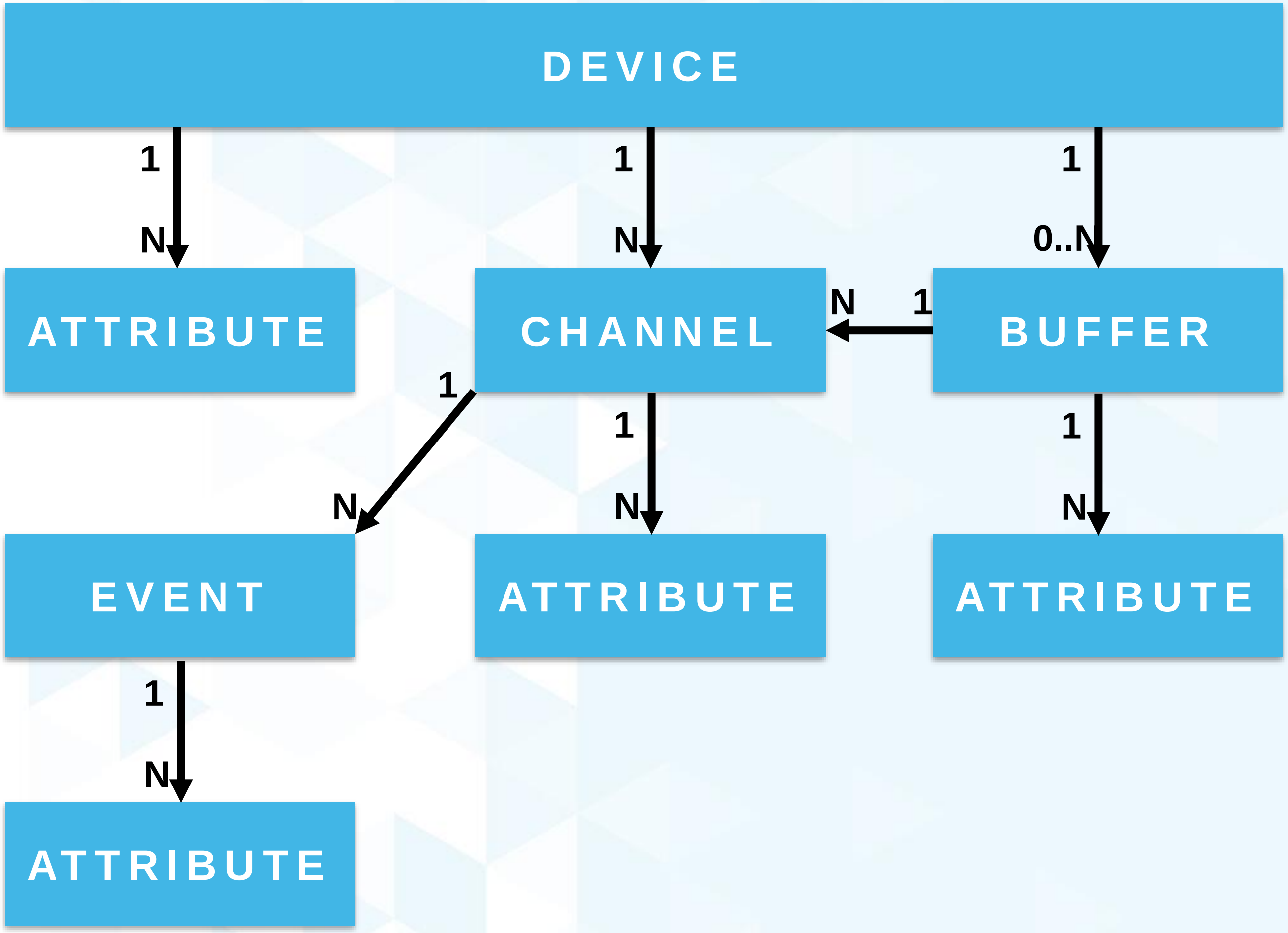
IIO – Devices

- Main structure
- Typically corresponds to a single physical hardware device
- Represented as directories in sysfs

/sys/
bus/
iio/
iio:device0/
iio:device1/
iio:deviceX/



IIO – Attributes

- Describe hardware capabilities
- Allow to configure hardware features
  - SAMPLING_FREQUENCY
  - POWERDOWN
  - PLL_LOCKED
  - SYNC_DIVIDERS
  - etc.
- Represented as files in sysfs

```
# ls /sys/bus/iio/devices/
iio:device0  iio:device1  iio:device2  iio:device3  iio:device4
# cat  /sys/bus/iio/devices/*/name
adm1177
ad9361-phy
xadc
cf-ad9361-dds-core-lpc
cf-ad9361-lpc
#
```

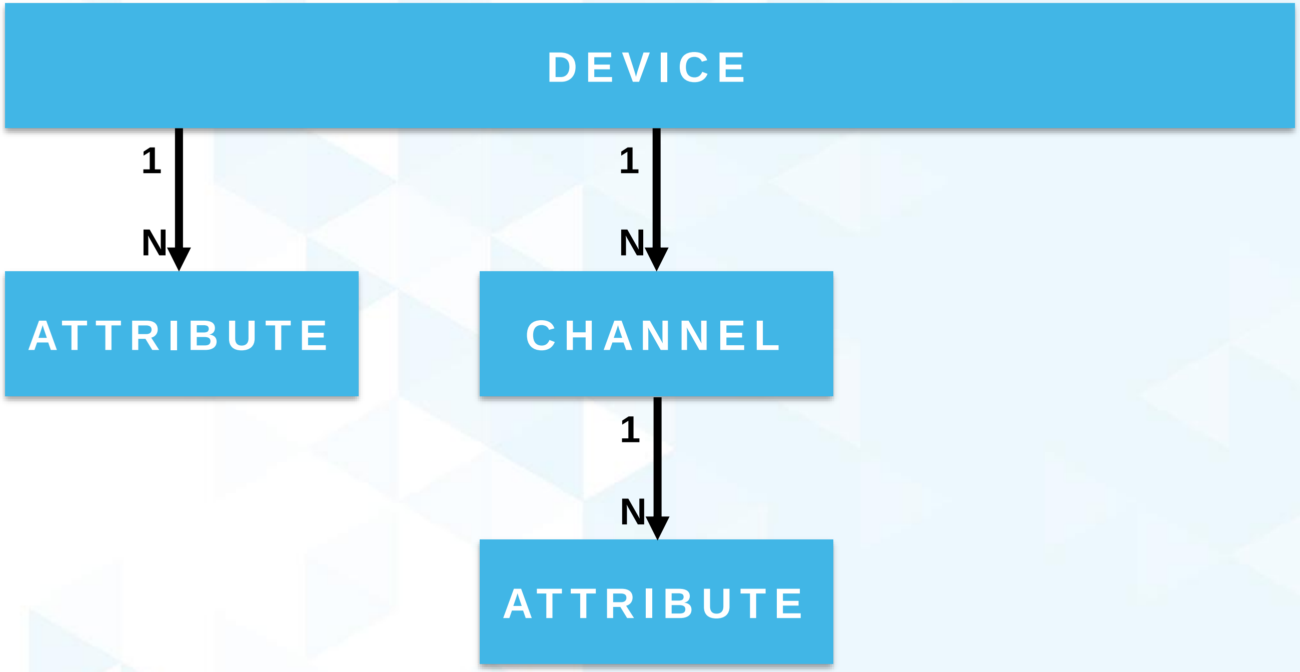
IIO – Channels

- Representation of a data channel
- Has direction, type, index and modifier
  - Direction
    - IN
    - OUT
  - Type
    - IIO_VOLTAGE
    - IIO_TEMP, etc.
  - Index
    - 0..N
  - Modifier
    - IIO_MOD_I, IIO_MOD_Q

Example:

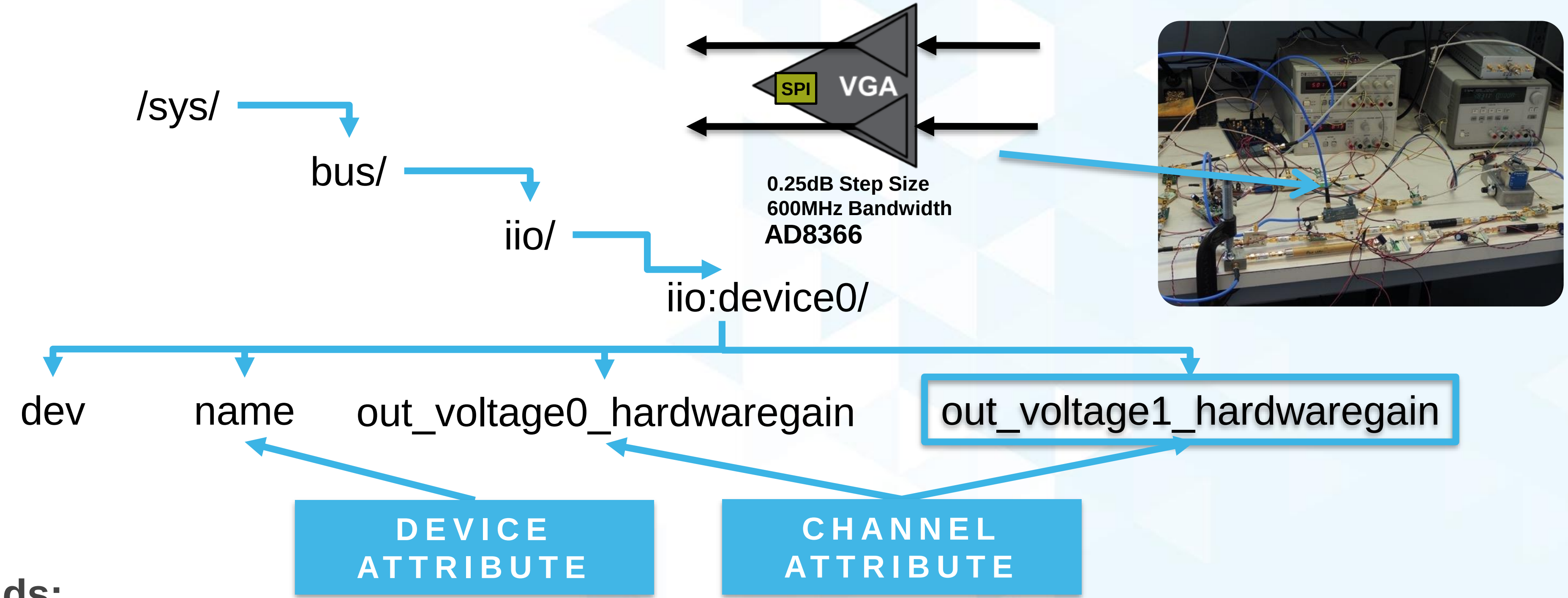
out_altvoltage0_frequency

- Channel Attributes provide additional information
  - RAW
  - SCALE
  - OFFSET
  - FREQUENCY
  - PHASE
  - HARDWAREGAIN
  - etc.



- Example: Read voltage from ADC Channel X in mV
  - *VoltageX_mV = (in_voltageX_raw + in_voltageX_offset) * in_voltageX_scale*

VGA/PGA Gain or DSA Attenuation Control



Shell Commands:

```
/sys/bus/iio/iio:device0 # cat name
ad8366
/sys/bus/iio/iio:device0 # echo 6 > out_voltage1_hardwaregain
/sys/bus/iio/iio:device0 # cat out_voltage1_hardwaregain
5.765000 dB
```

ADF4159 Direct Modulation/Fast Waveform Generating, 13 GHz, Fractional-N Frequency Synthesize

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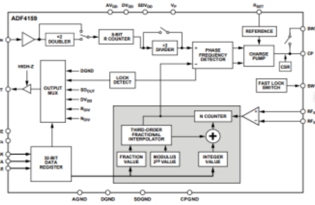
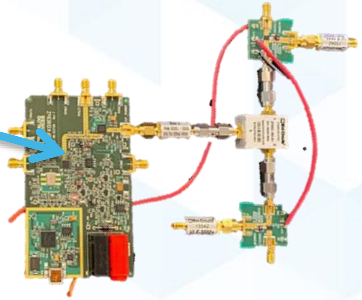
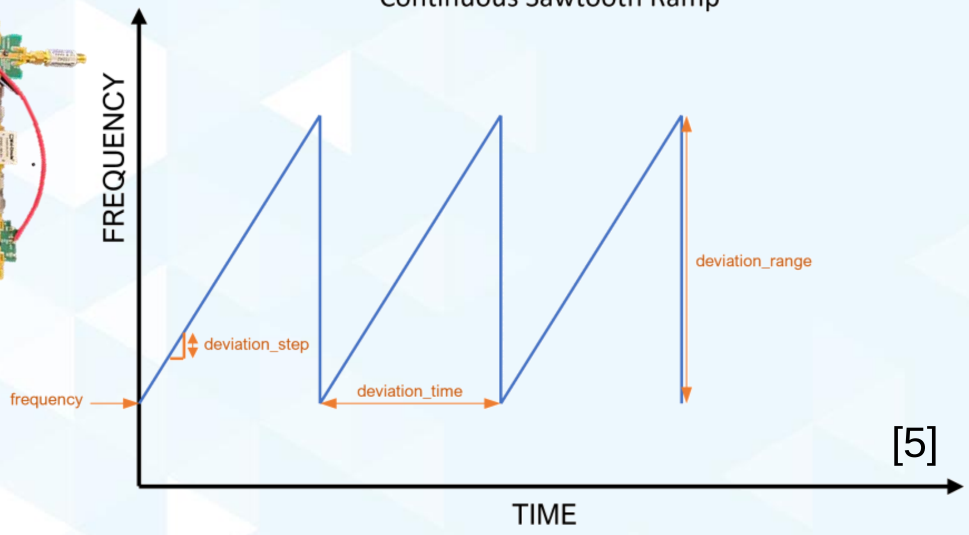
/sys/
bus/
iio/
iio:device0/

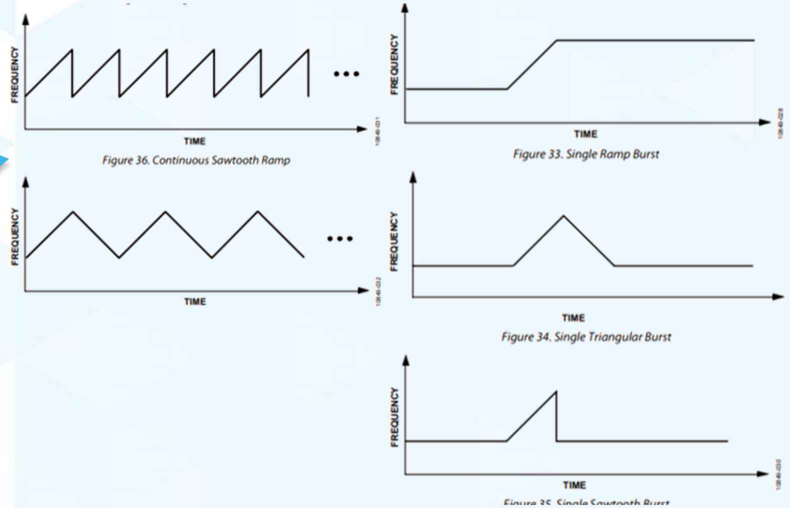
- dev
- name
- out_altvoltage0_**frequency**
- out_altvoltage0_**frequency_deviation_range**
- out_altvoltage0_**frequency_deviation_step**
- out_altvoltage0_**frequency_deviation_time**
- out_altvoltage0_**powerdown**
- out_altvoltage0_**ramp_mode**
- out_altvoltage_**ramp_mode_available**







[5]



Shell Commands:

```
root@analog:~# iio_attr -c adf4159 altvoltage0
dev 'adf4159', channel 'altvoltage0' (output), attr 'frequency', value '6000000000'
dev 'adf4159', channel 'altvoltage0' (output), attr 'frequency_deviation_range', value '0'
dev 'adf4159', channel 'altvoltage0' (output), attr 'frequency_deviation_step', value '5960'
dev 'adf4159', channel 'altvoltage0' (output), attr 'frequency_deviation_time', value '0'
dev 'adf4159', channel 'altvoltage0' (output), attr 'powerdown', value '0'
dev 'adf4159', channel 'altvoltage0' (output), attr 'ramp_mode', value 'disabled'
dev 'adf4159', channel 'altvoltage0' (output), attr 'ramp_mode_available', value 'disabled continuous_sawtooth
continuous_triangular single_sawtooth_burst single_ramp_burst'
```

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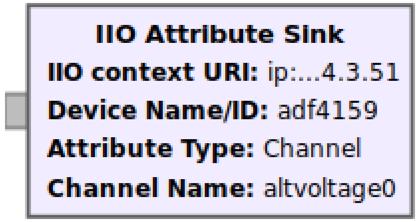
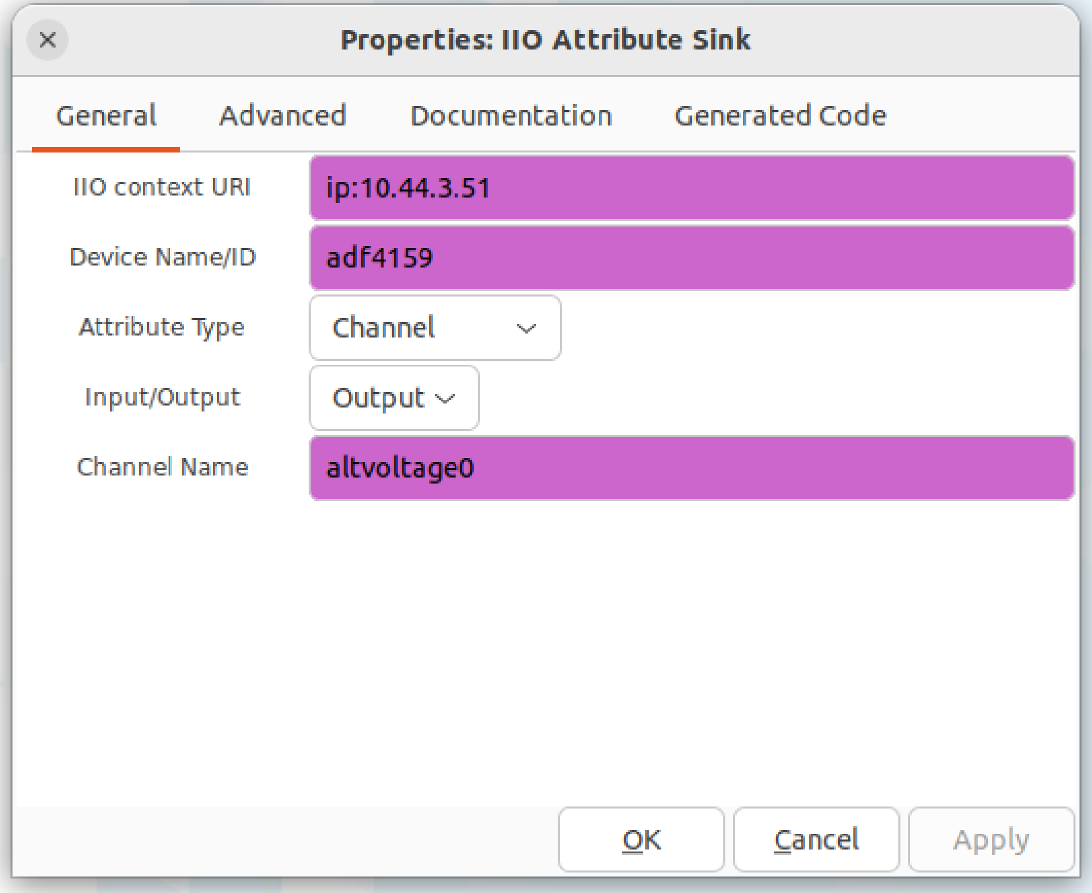
iio_attr_sink

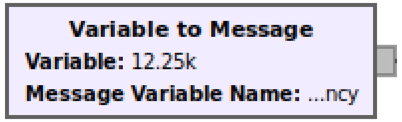


- Generic writer for attributes of IIO devices.

- This block allow for updating of any IIO attribute that is writable. This includes channel, device, device buffer, device debug, and direct register attributes. All messages must be a **pmt dictionary** where the key is the attribute to update and the value is the value to be written. Messages can be an array of dictionaries or a single dictionary.

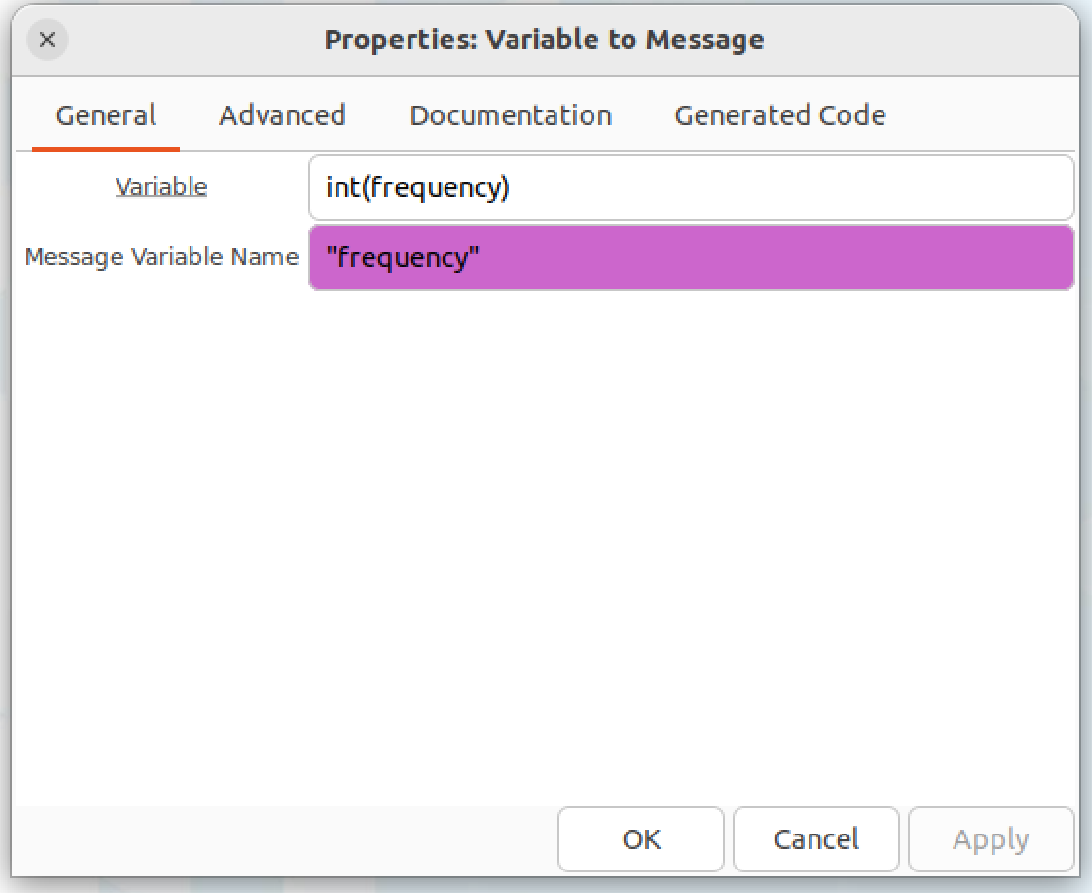


blocks_var_to_msg (since 3.10)

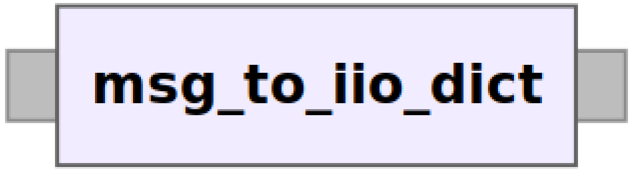


- This block will monitor a variable, and when it changes, generate a message.

- This block has a callback that will emit a **message pair** with the updated variable value when called. This is useful for monitoring a GRC variable and emitting a message when it is changed.



msg_to_iio_dict (custom Python block)



- Gr::basic_block

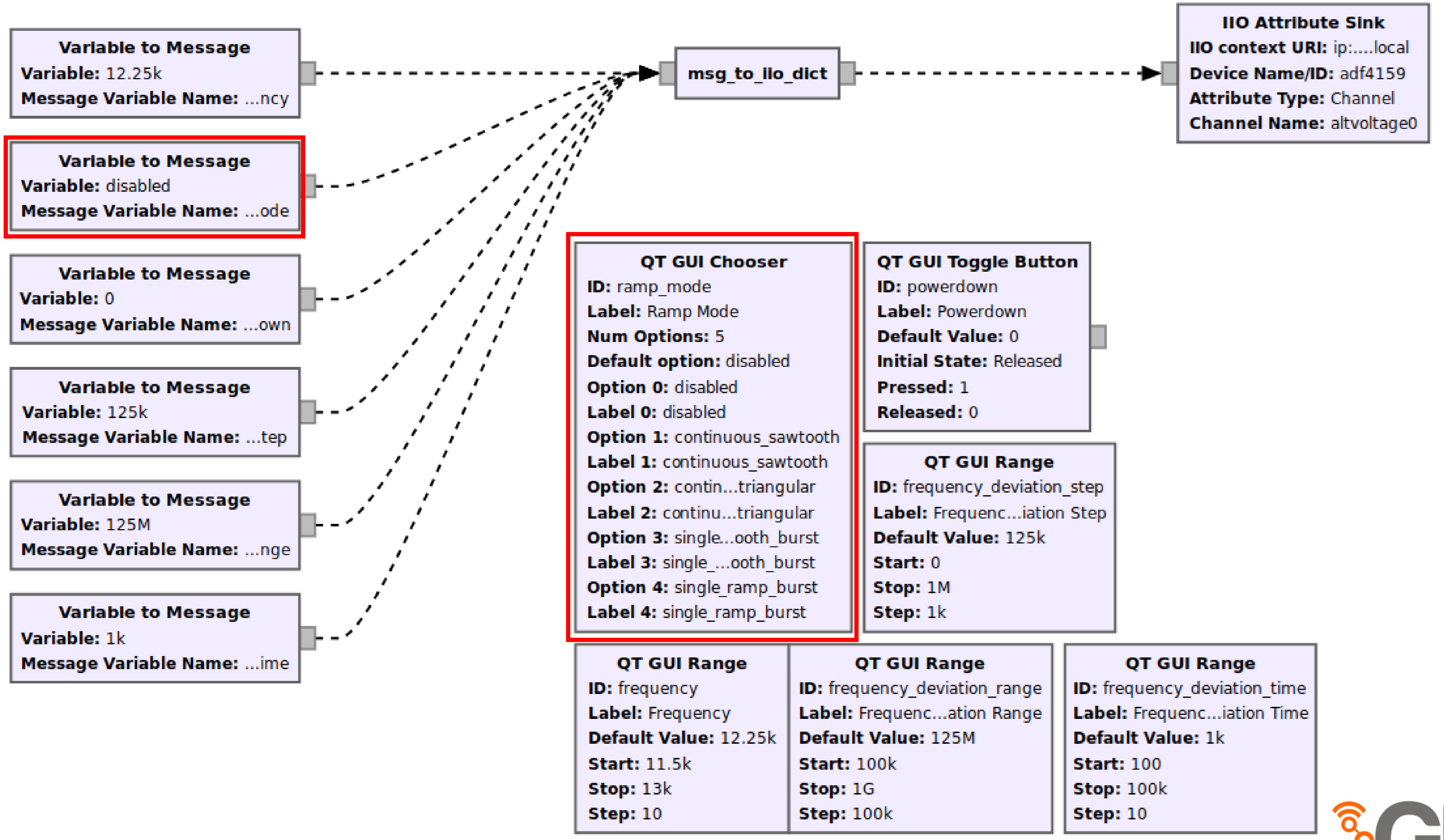
- This block will convert a PMT message pair, into a PMT dictionary.
- Useful to interface the blocks_var_to_msg with the iio_attr_sink block.

```
from gnuradio import gr
import pmt

class msg_block(gr.basic_block):
    def __init__(self):
        gr.basic_block.__init__(
            self,
            name="msg_to_iio_block",
            in_sig=None,
            out_sig=None)

        self.message_port_register_out(pmt.intern('msg_out'))
        self.message_port_register_in(pmt.intern('msg_in'))
        self.set_msg_handler(pmt.intern('msg_in'), self.handle_msg)

    def handle_msg(self, msg):
        nkey0 = pmt.intern(str(pmt.car(msg)))
        nval0 = pmt.intern(str(pmt.cdr(msg)))
        msg_dic = pmt.make_dict()
        msg_dic = pmt.dict_add(msg_dic, nkey0, nval0)
        self.message_port_pub(pmt.intern('msg_out'), msg_dic)
```


Variable to Message
Variable: 12.25k
Message Variable Name: ...ncy
Variable to Message
Variable: disabled
Message Variable Name: ...ode
Variable to Message
Variable: 0
Message Variable Name: ...own
Variable to Message
Variable: 125k
Message Variable Name: ...tep
Variable to Message
Variable: 125M
Message Variable Name: ...nge
Variable to Message
Variable: 1k
Message Variable Name: ...ime
msg_to_iio_dict
IIO Attribute Sink
IIO context URI: ip:....local
Device Name/ID: adf4159
Attribute Type: Channel
Channel Name: altvoltage0
QT GUI Chooser
ID: ramp_mode
Label: Ramp Mode
Num Options: 5
Default option: disabled
Option 0: disabled
Label 0: disabled
Option 1: continuous_sawtooth
Label 1: continuous_sawtooth
Option 2: contin...triangular
Label 2: continu...triangular
Option 3: single...ooth_burst
Label 3: single_...ooth_burst
Option 4: single_ramp_burst
Label 4: single_ramp_burst
QT GUI Toggle Button
ID: powerdown
Label: Powerdown
Default Value: 0
Initial State: Released
Pressed: 1
Released: 0
QT GUI Range
ID: frequency_deviation_step
Label: Frequenc...iation Step
Default Value: 125k
Start: 0
Stop: 1M
Step: 1k
QT GUI Range
ID: frequency
Label: Frequency
Default Value: 12.25k
Start: 11.5k
Stop: 13k
Step: 10
QT GUI Range
ID: frequency_deviation_range
Label: Frequenc...ation Range
Default Value: 125M
Start: 100k
Stop: 1G
Step: 100k
QT GUI Range
ID: frequency_deviation_time
Label: Frequenc...iation Time
Default Value: 1k
Start: 100
Stop: 100k
Step: 10

Conclusions

- You don‘t need to be a Linux expert to enable and use ready made IIO drivers
- Gr-iio much more than controlling a transceiver/digitizer
- Gr-iio iio_attr blocks should also accept PMT message pairs

- More interest in gr-iio and next generation libiio?
  - Latest libiio v0.24 also supports HWMON devices
  - Attend: Libiio 1.0 design and how it will affect GNU Radio, Paul Cercueil, 9/28/22
    - Multibuffer, Async Protocol, DMABUF compatible interface, Timestamp API (WIP)

References

[1] https://www.analog.com/ad-fmcxmwbr1-ebz

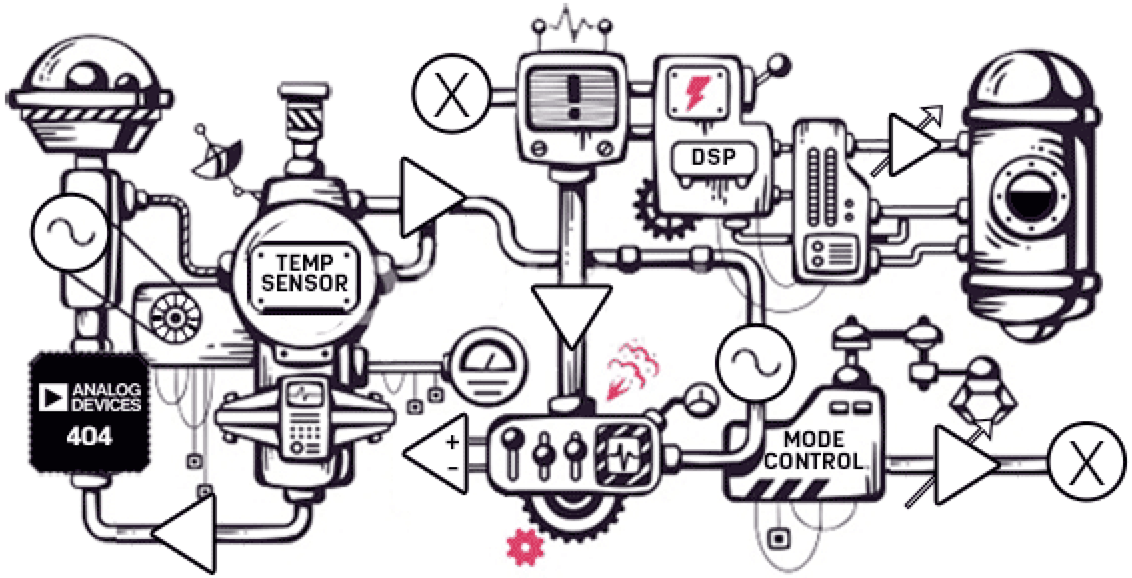
[2] https://wiki.analog.com/resources/tools-software/linux-software/kuiper-linux

[3] https://github.com/analogdevicesinc/linux/blob/rpi-5.10.y/arch/arm/boot/dts/overlays/rpi-adf4159-overlay.dts

[4] https://github.com/analogdevicesinc/adi-kuiper-imager

[5] https://wiki.analog.com/resources/tools-software/linux-drivers/iio-pll/adf4159

[6] https://wiki.analog.com/resources/tools-software/linux-drivers-all



Ahhh, technology. We can't find that page.

Thanks

Q & A