Information Technologies Labs: Wireless Communication Spectrum & Signal Analyzer

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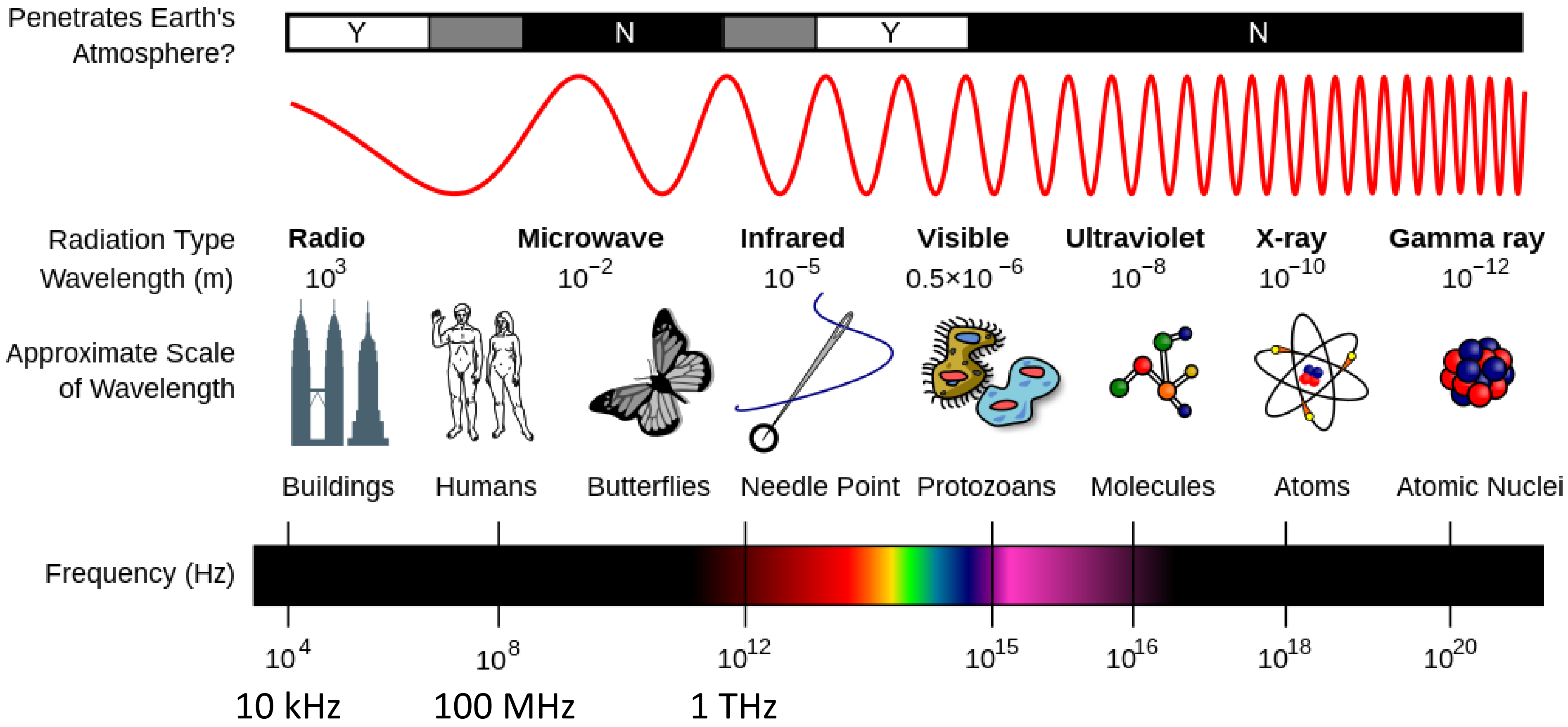
The Electromagnetic Spectrum

Wireless communication: based on “modulation” of electromagnetic waves

The electromagnetic spectrum: range of **frequencies / wavelengths**



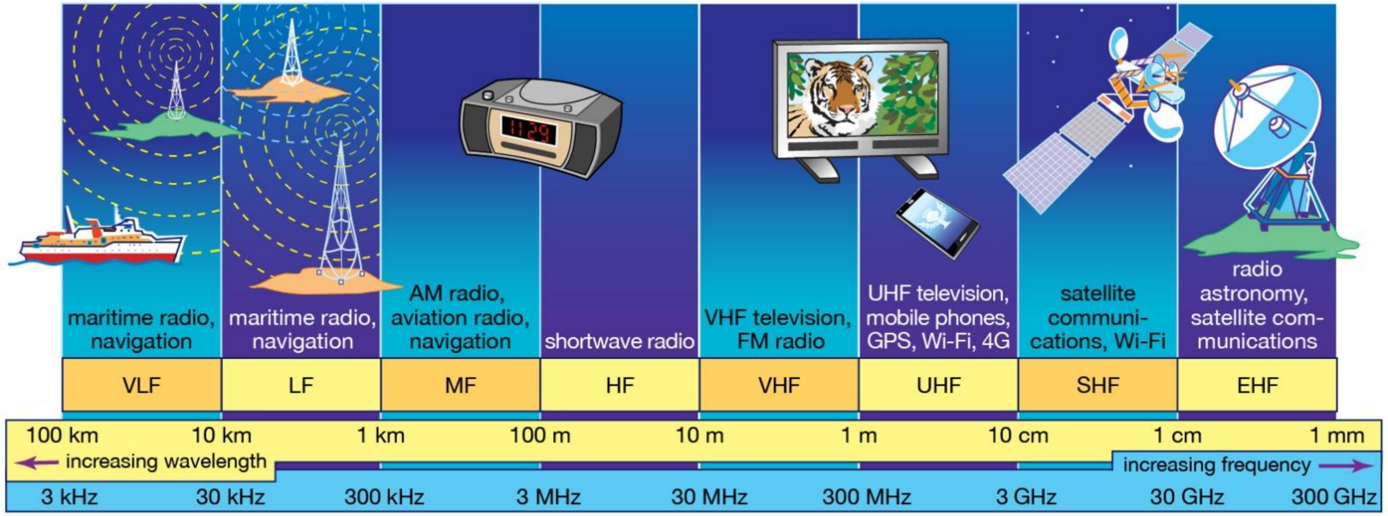
Radio Communications Frequency Range

Radio communications today takes place in the range from few tens of kHz up to about 100 GHz

- Small part of the overall spectrum!
- Trend: ever higher frequencies

Different parts of the radio spectrum are allocated to

- Different applications
- Different communication channels (e.g., service bands)



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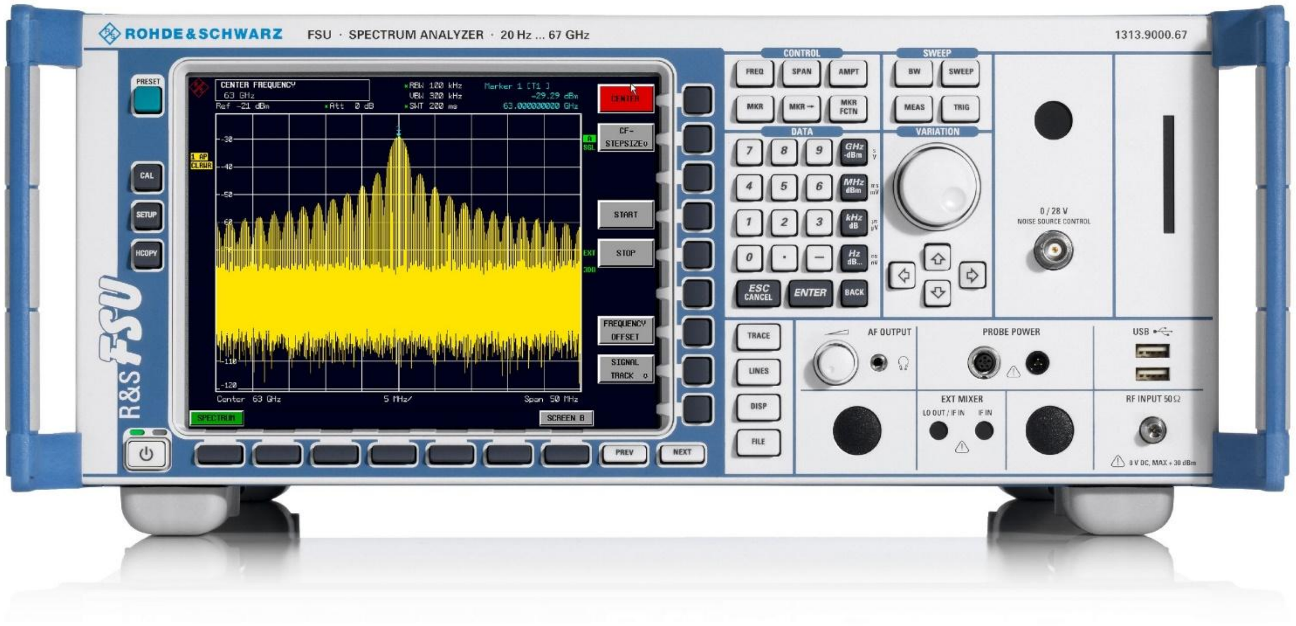
Spectrum Regulations

To avoid collisions between applications/users, countries assign frequency bands

Looking at the Radio Frequency Spectrum

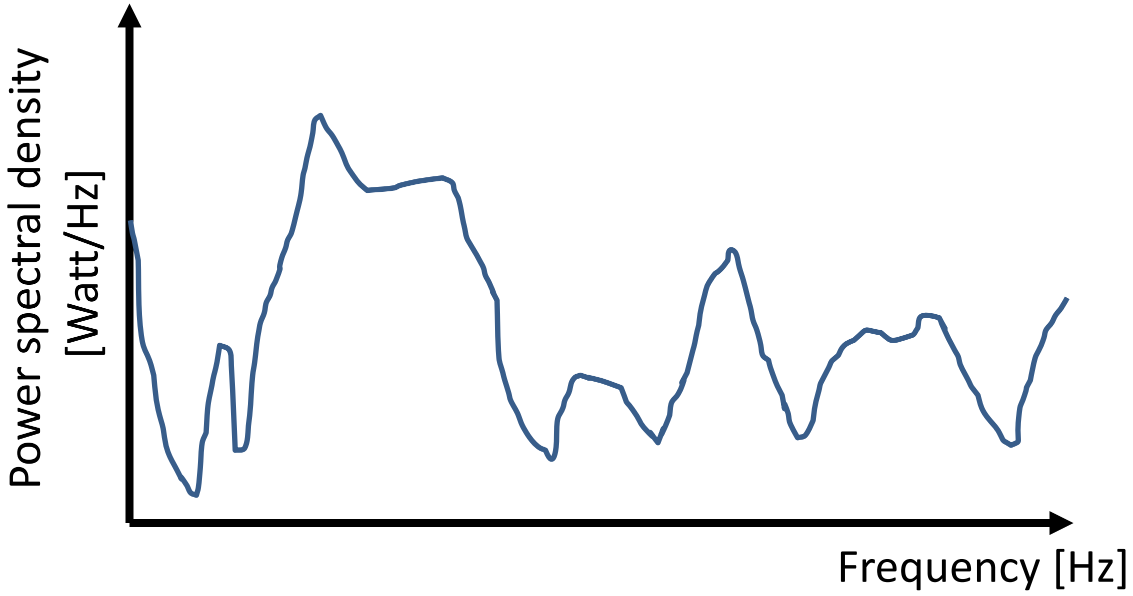
Instrument: **SPECTRUM ANALYZER**



Looking at the Radio Frequency Spectrum

Instrument: SPECTRUM ANALYZER shows

- **Energy in a given fixed bandwidth: power spectral density vs.**
- **Frequency**

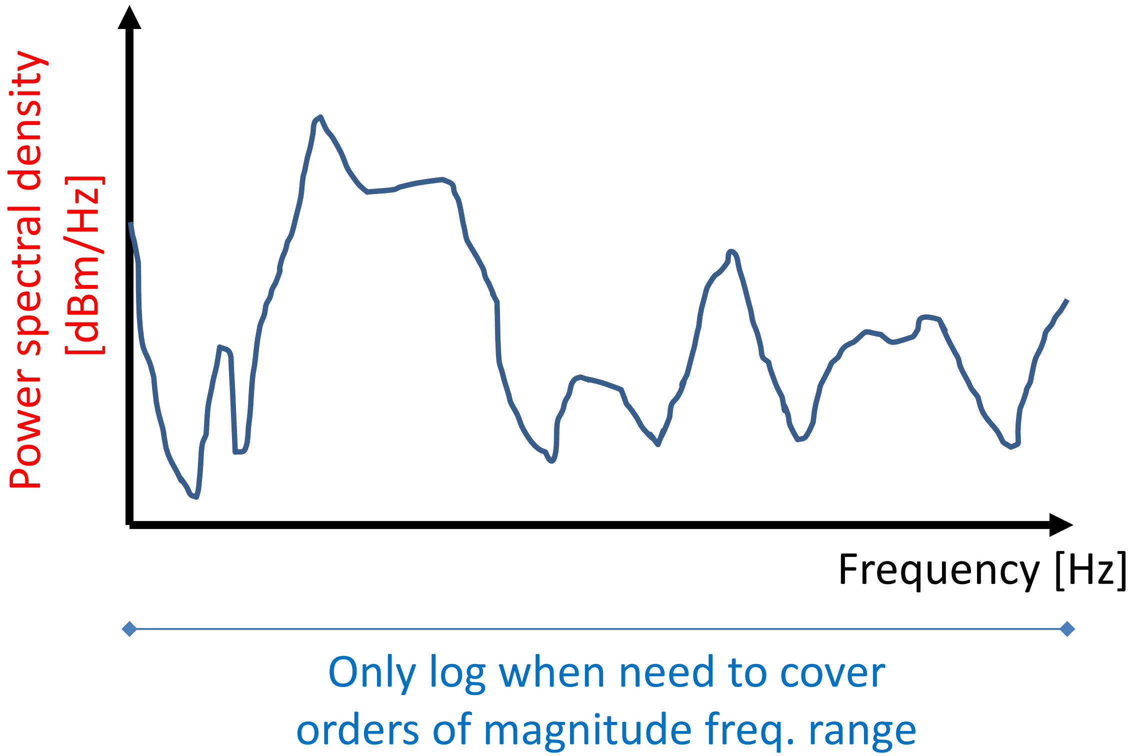


Looking at the Radio Frequency Spectrum

Instrument: SPECTRUM ANALYZER shows

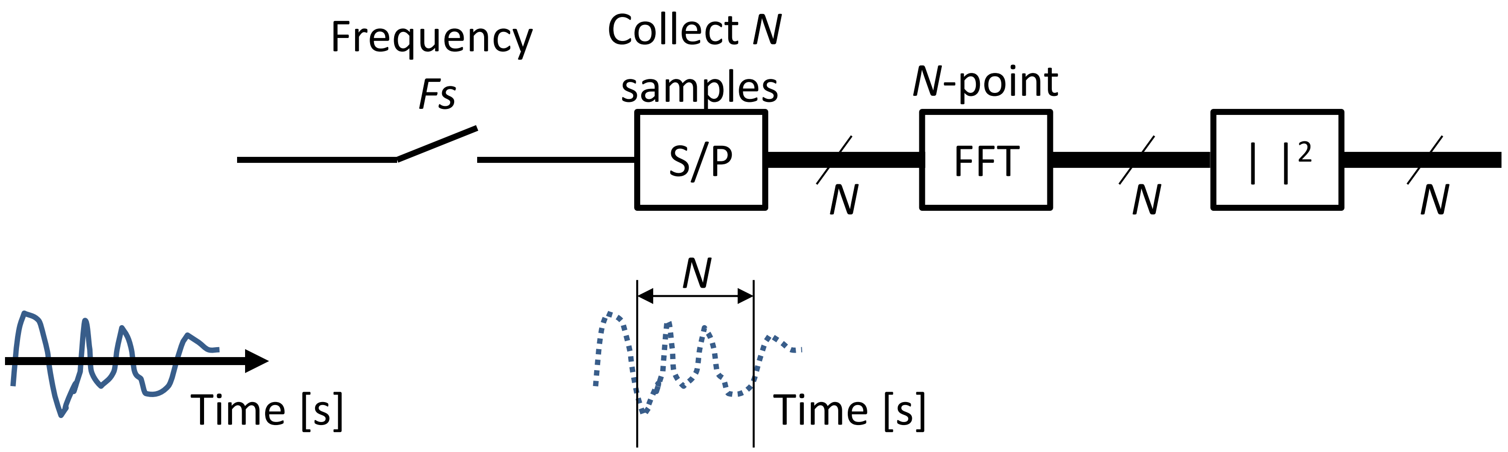
- **Energy in a given fixed bandwidth: power spectral density vs.**
- **Frequency**

Power often on a logarithmic scale to cover a large power range

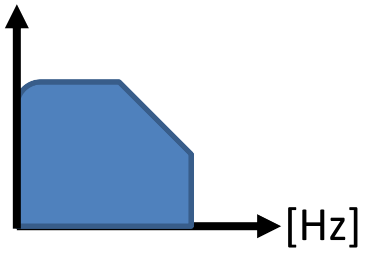


Digital Spectrum Analyzer

- **Samples the analog signal with Fs**
- **Obtains spectrum in the digital domain with N-point FFT**

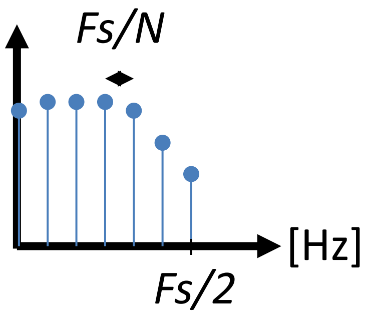


Acquisition time: *T=N/Fs*



Bandwidth (one sided): Fs/2

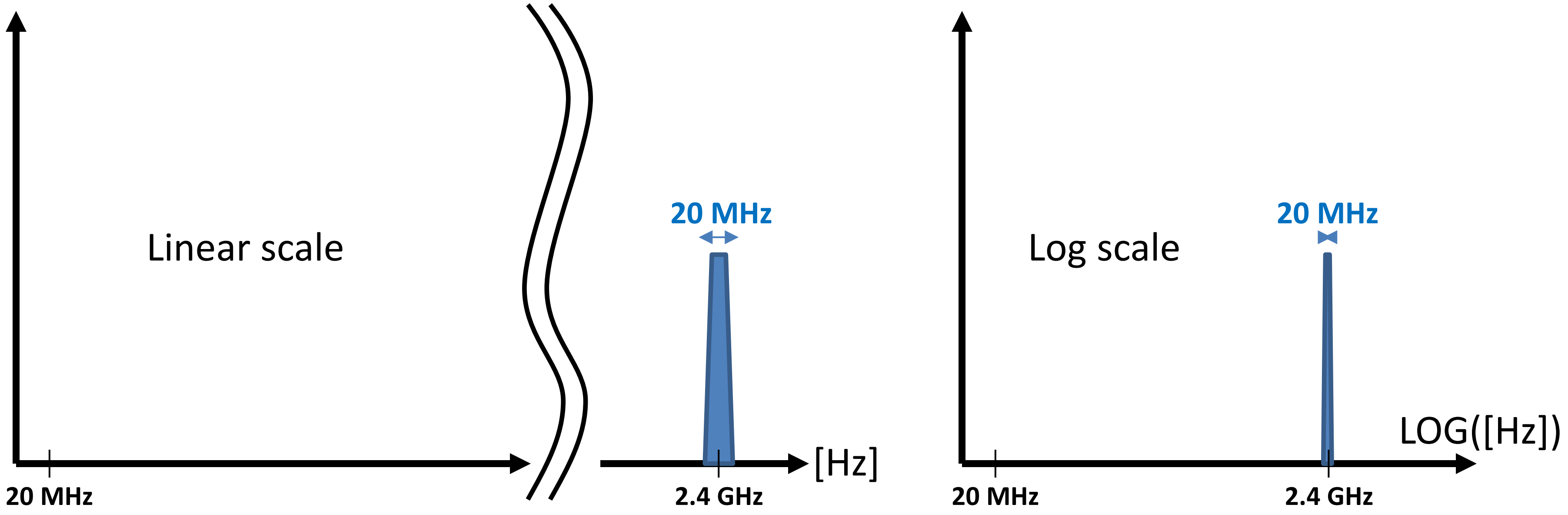
Freq. Resolution: Fs/*N=1/T*



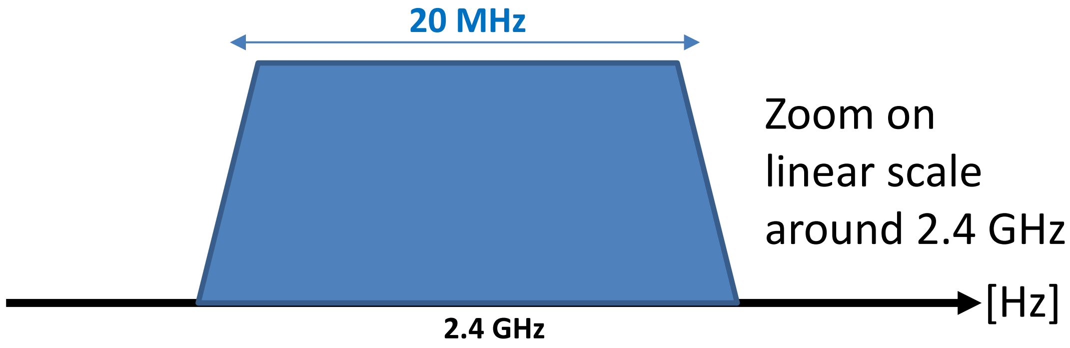
Spectrum Analyzer Basics

Typically we are not interested in the complete spectrum

- Instead, look at a **small bandwidth at a very high frequency**



- **Relevant:**



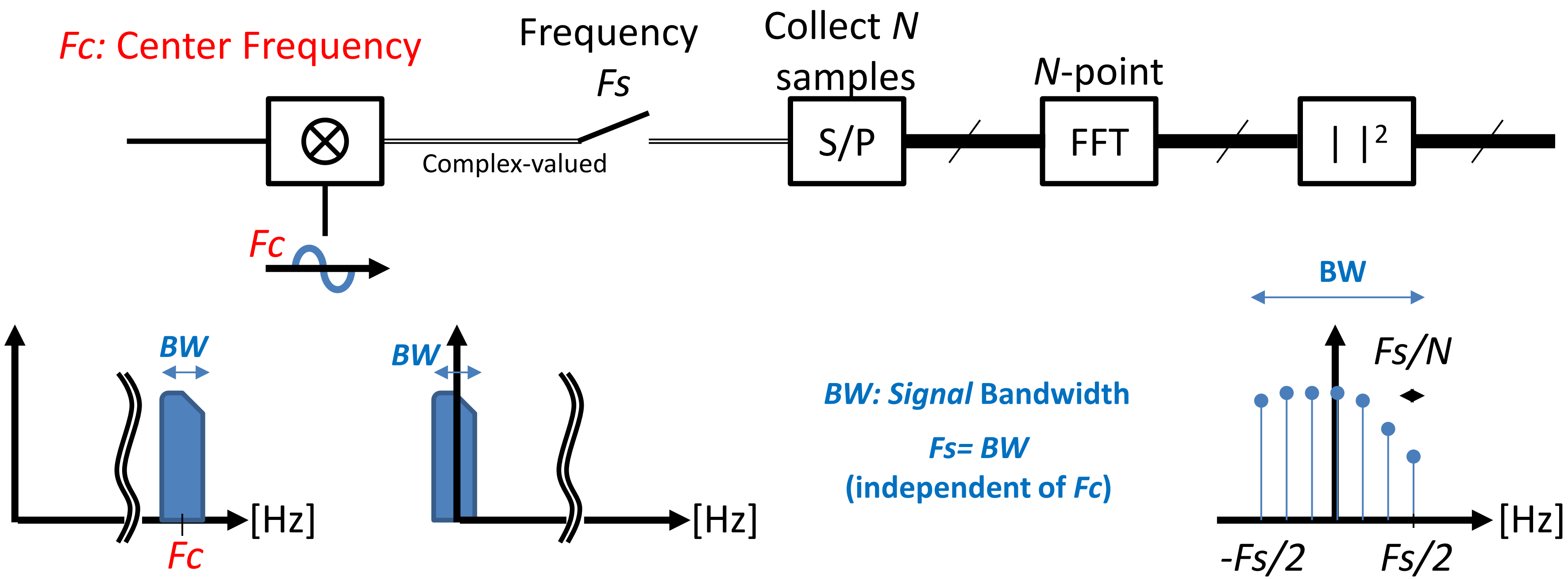
Spectrum Analyzer Basics

Main issue: high resolution at a large bandwidth requires

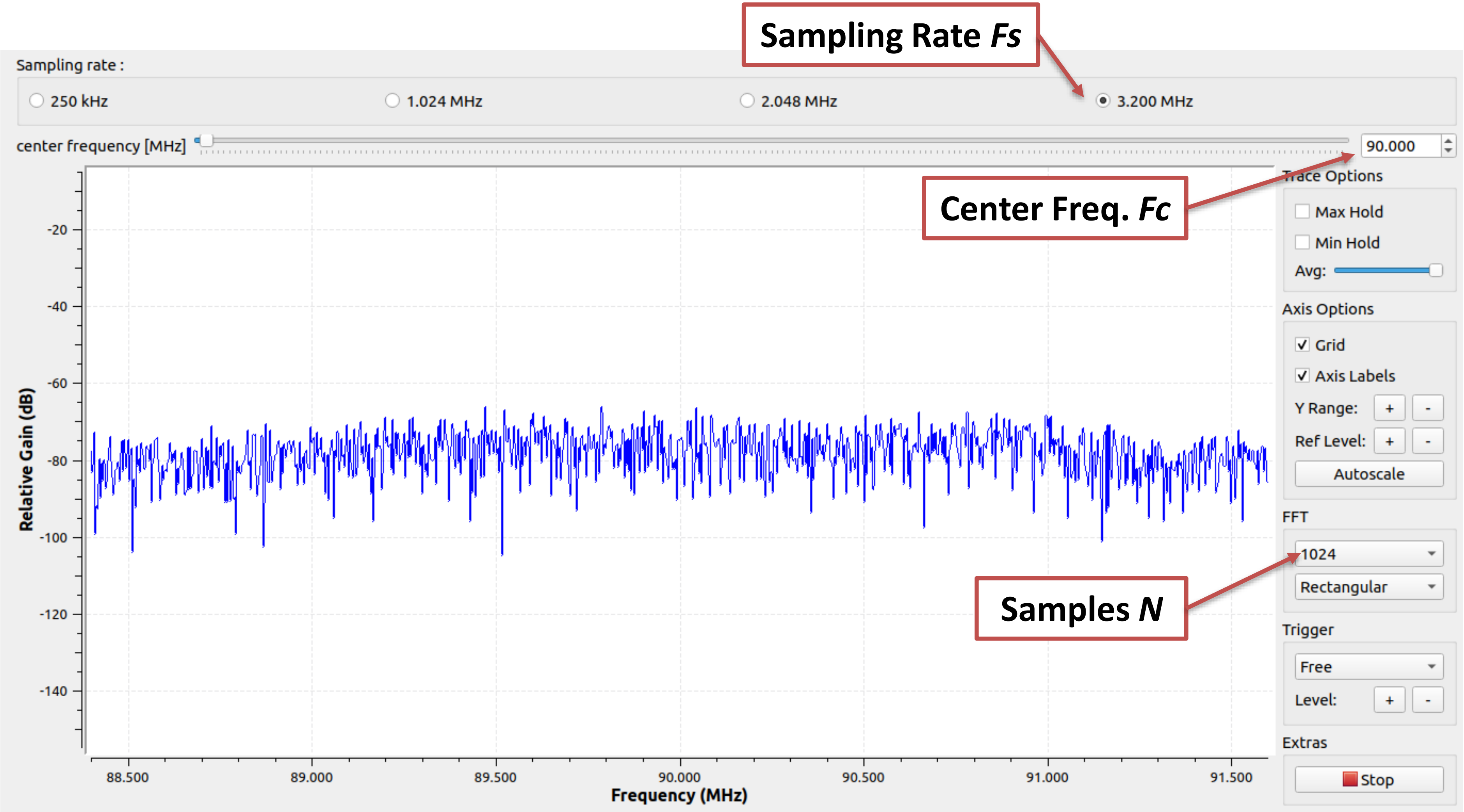
- High sampling frequency (*Fs*) and a long acquisition time (relative to *Fs*)
- Huge number of samples

and is a waste of sampling frequency and memory.

Collecting a small bandwidth at a high frequency with **frequency translation (mixer)**



SDR Spectrum Analyzer

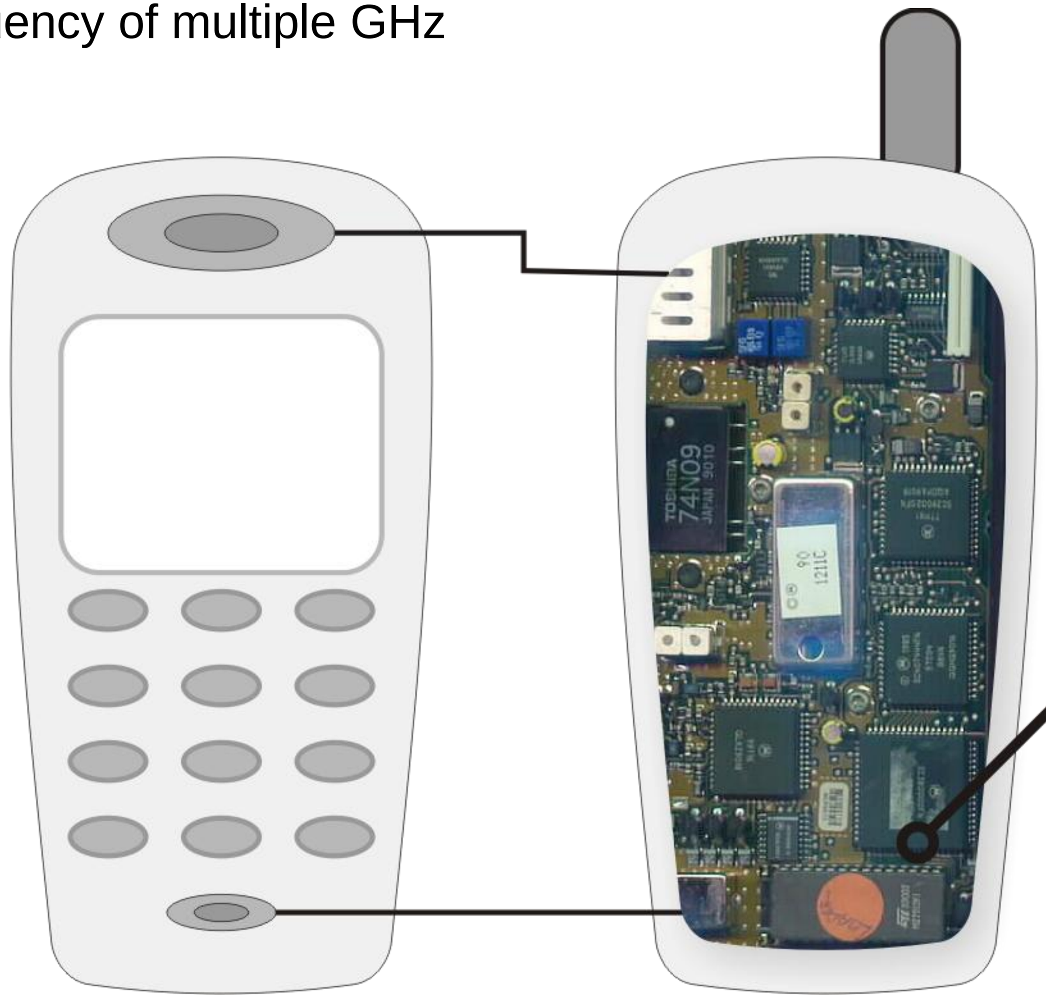


Software-Defined Radio

Analog Radios

Analog signals modulate directly a Radio Frequency Carrier

- Example: voice modulates the RF carrier frequency of multiple GHz



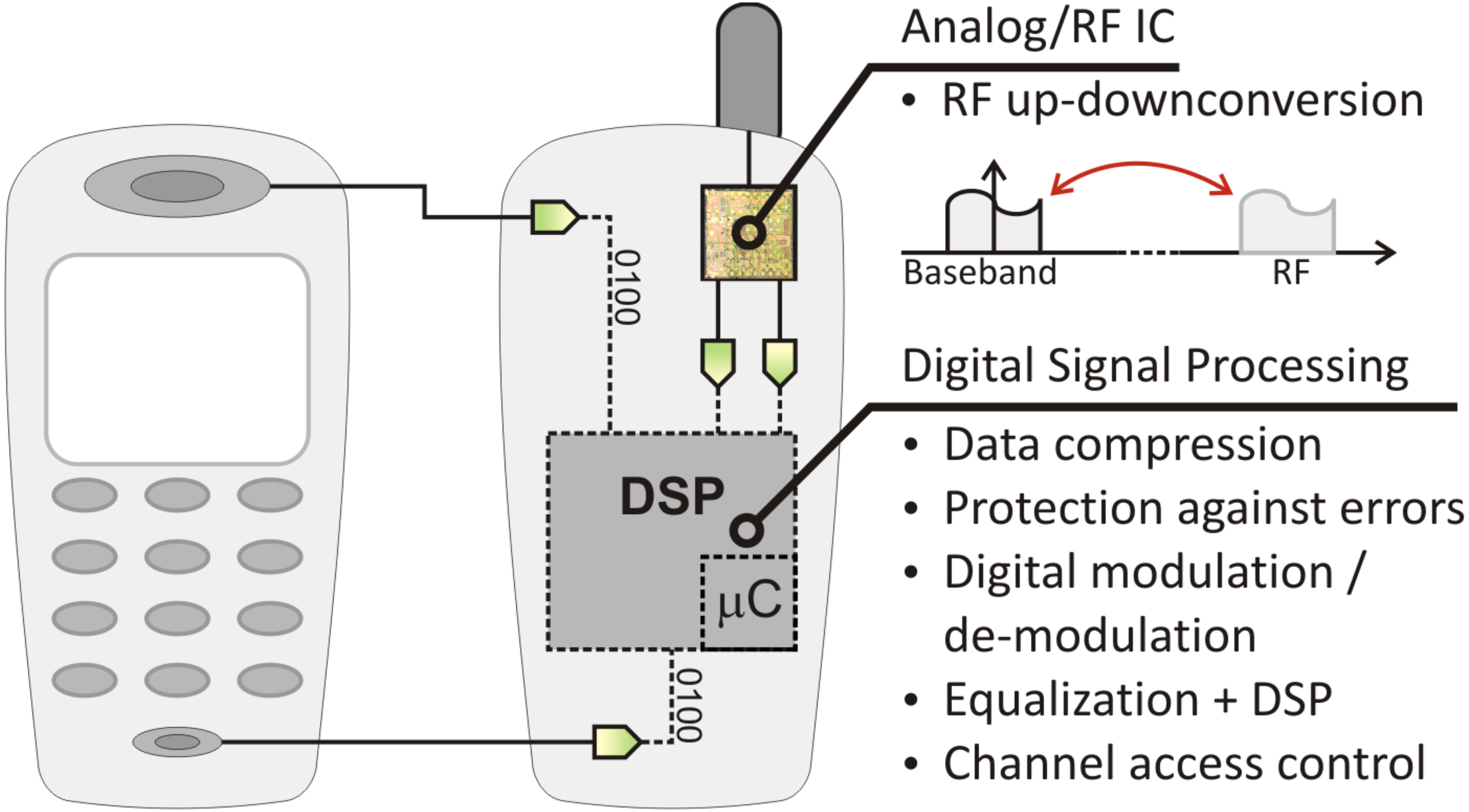
- **Analog data (voice) signal is recovered with analog circuits**

Analog microelectronics

- Analog FM modulation / de-modulation
- Basic filtering only

Digital Radios

Signal generation and recovery almost completely with digital signal processing



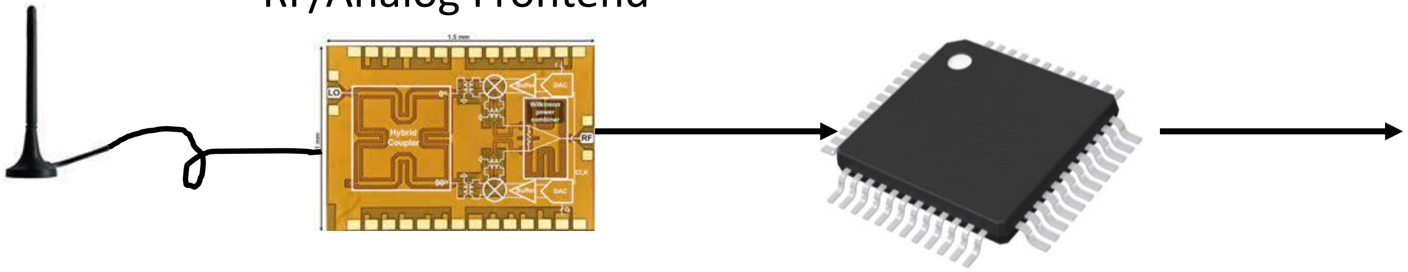
What is a Software Defined Radio (SDR)

From Wikipedia

“Software-defined radio (SDR) is a radio communication system where components that have been traditionally implemented in analog hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system”

RF/Analog Frontend

Fixed (hard-wired) DSP application specific integrated circuit



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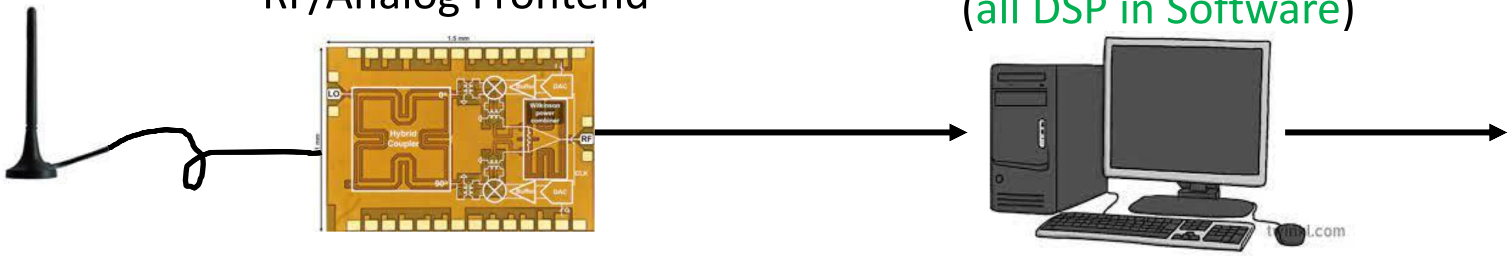
SOFTWARE DEFINED RADIO

RF/Analog Frontend

Any type of programmable computer (all DSP in Software)



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Software Defined Radio needs two main components

An RF/analog Frontend that converts

- Digital baseband signals to analog RF signals
- Analog RF signals to a digital baseband signal

A programmable computer for the DSP of the baseband signal

Common hardware for SDR in 2024

Today, SDR is feasible with cheap off-the shelf hardware

ASALM-PLUTO
(230 USD)

Lime-SDR Mini
(160 USD)

Ettus USRP
(600 – 5000 USD)

Raspberry PI
(< 100USD)

PC

Cloud Radio Access Network

Many RF/analog frontends with different capabilities are commercially available

DSP of many signals can be handled even by low-cost embedded computers or even in the cloud

SDR Hardware for this Lab:

USRP 2920

Transmitter	
Frequency range	50 MHz to 2.2 GHz
Frequency step	<1 kHz
Maximum output power (P_{out})	
50 MHz to 1.2 GHz	50 mW to 100 mW (17 dBm to 20 dBm)
1.2 GHz to 2.2 GHz	30 mW to 70 mW (15 dBm to 18 dBm)
Gain range[1]	0 dB to 31 dB
Gain step	1.0 dB
Frequency accuracy	2.5 ppm
Maximum instantaneous real-time bandwidth[2]	
16-bit sample width	20 MHz
8-bit sample width	40 MHz
Maximum I/Q sample rate[3]	
16-bit sample width	25 MS/s
8-bit sample width	50 MS/s
Digital-to-analog converter (DAC)	2 channels, 400 MS/s, 16 bit
DAC spurious-free dynamic range (sFDR)	80 dB

RTL SDR

Tuner Chip	R828D
ADC Chip	RTL2832U 8-bits
Frequency Range	500 kHz to 1.766 GHz
Bandwidth	2.56 MHz stable (up to 3.2 MHz with drops)
Typical Input Impedance	50 Ohms
Typical Current Draw	250 – 270 mA
HF Implementation	Upconverter with 28.8 MHz LO
Input Connector	1x SMA
USB Connector	USB-A Male
Local Oscillator Stability	1PPM TCXO
Bias Tee	4.5V, 180mA (software switchable)
Enclosure	Aluminum
Heat Dissipation	Thermal Pad to Aluminum Enclosure
Front End RF Design	Triplexor with switchable notch
Transmit Capability	None

GNU Radio

GNU Radio is an **Open-Source** software platform to facilitate the implementation of the signal processing of radio signals using SDR hardware

GNU radio provides:

- A framework to implement data flow graphs of DSP blocks
- Tools to graphically enter the data flow graph
- A variety of pre-built common DSP blocks (FFTs, filters, …)
- A variety of interfaces to common SDR hardware