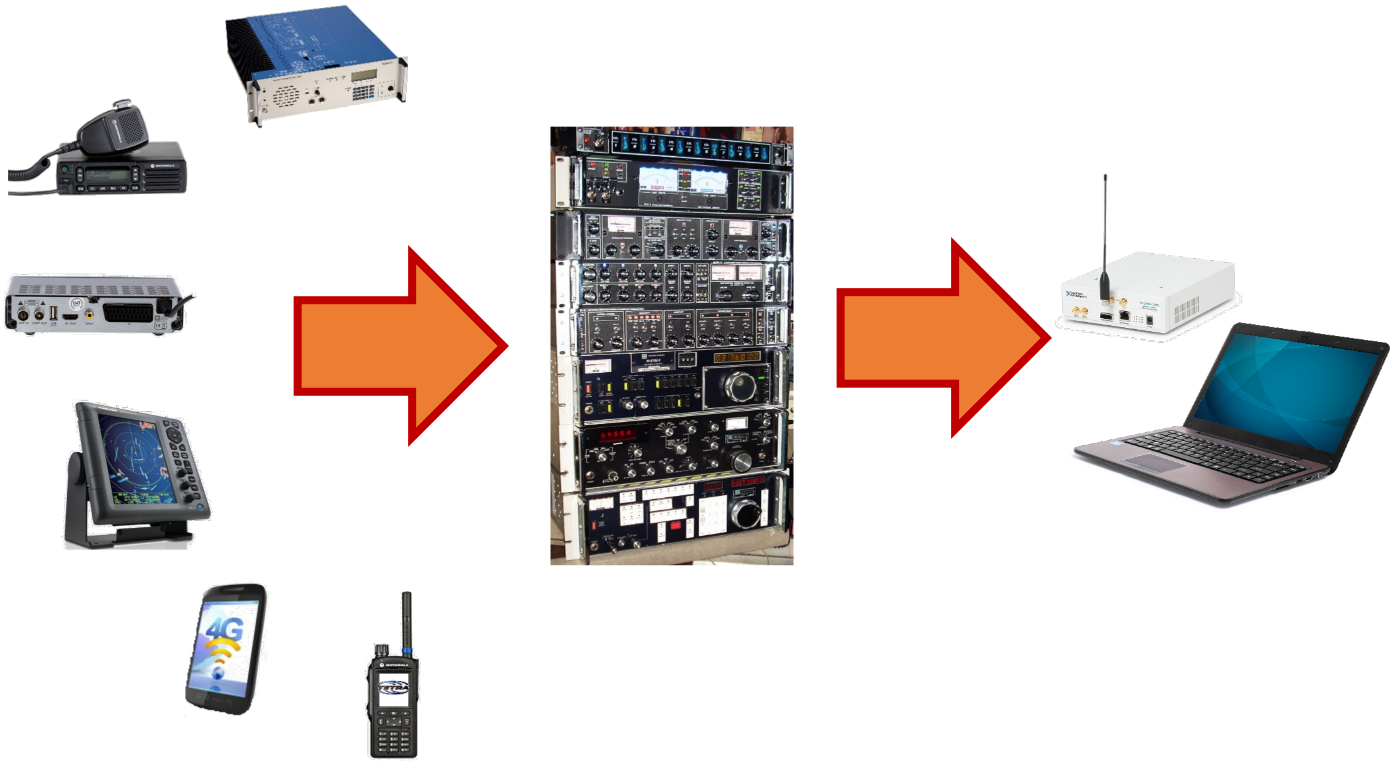
Software defined radio

SDR concept

- Radio components such as modulators, demodulators and tuners are traditionally implemented in analog hardware components.
- The advent of modern computing and analog to digital converters (ADCs) allows most of these HW based components to be implemented in SW instead.



SDR paradigm

VA BENE PER APPLICAZIONI
MOLTO SPECIFICHE

- In a SDR receiver the incoming signal is converted to a digital format and then the signal is processed digitally.
- Most of the HW in a SDR is programmable so that it can be completely configured by software.
  - SDR can be easily reconfigured: it is sufficient to update the SW to keep up with new modulation formats, new algorithms and new applications.
- Common hardware platform can be used across a variety of different products and applications, thereby reducing costs, whilst maintaining or improving the performance.

SDR – Historical milestones

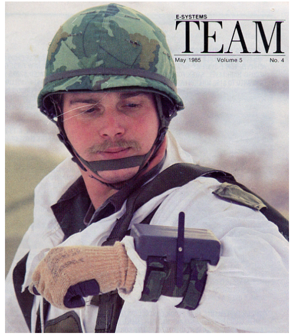
1984 - E-Systems Inc. (Raytheon) coined the term 'software radio'

1992 - J.Mitola publishes the paper: 'Software Radio: Survey, Critical Analysis and Future Directions',

2011 - A finnish hacker discovered that the baseband RTL2832U chip could be forced to operate in test mode to continuously output 8-bit unsigned samples of baseband I/Q data.

1984 1991 1992 2005 2011

SPEAKeasy

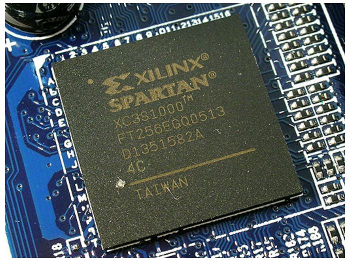


1991 - SPEAKeasy is the first military program that specifically required a radio to have its physical layer components. The objective was a single radio that could support ten different military radio protocols

Ettus Research

2005 - Ettus research produces the first commercial SDR, USRP 1, initially based on the open source software GNU radio.

Programmable HW for SDR



1. Reconfigurable Radio

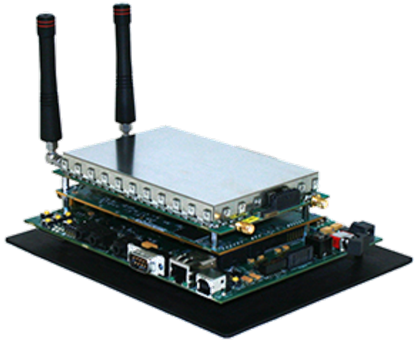
(FPGA-Based)

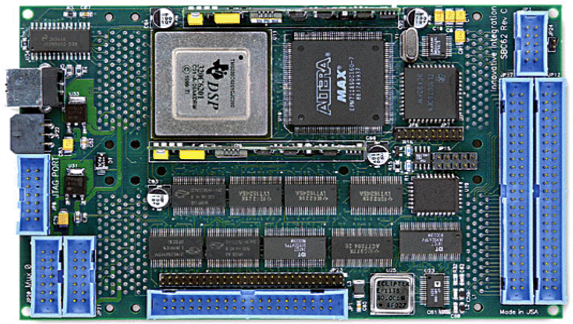
2. Programmable Radio

(DSP-Based or FPGA/DSP Hybrid)

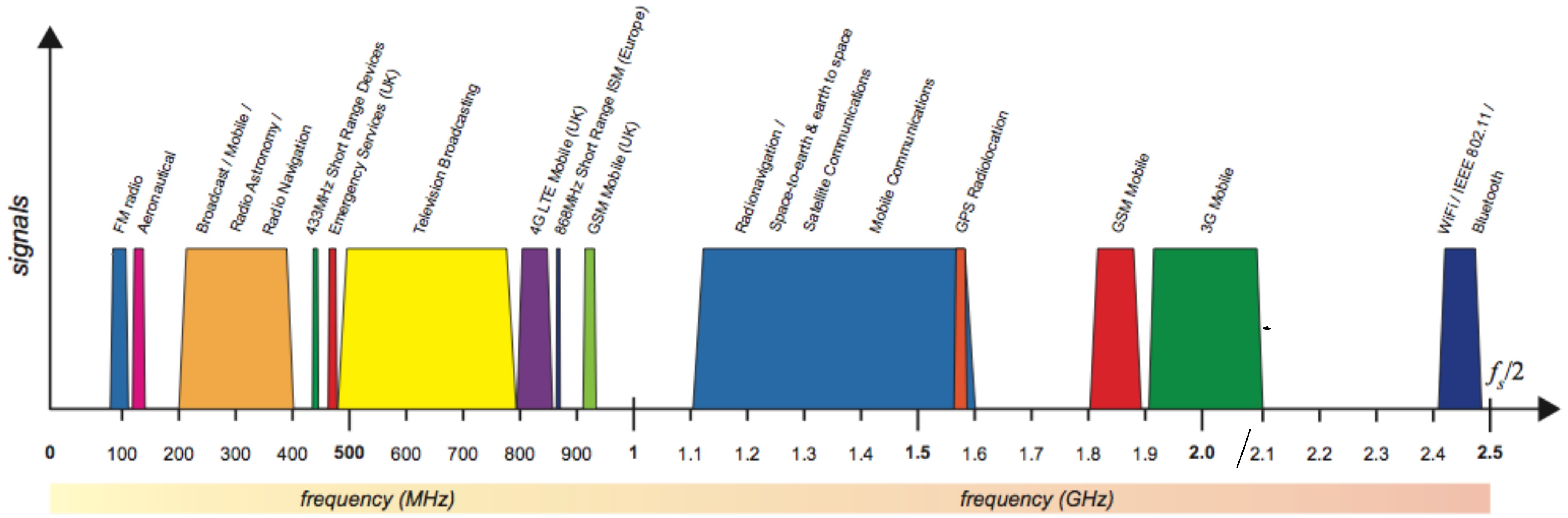
3. Fully Software Radio

(GPP-Based)

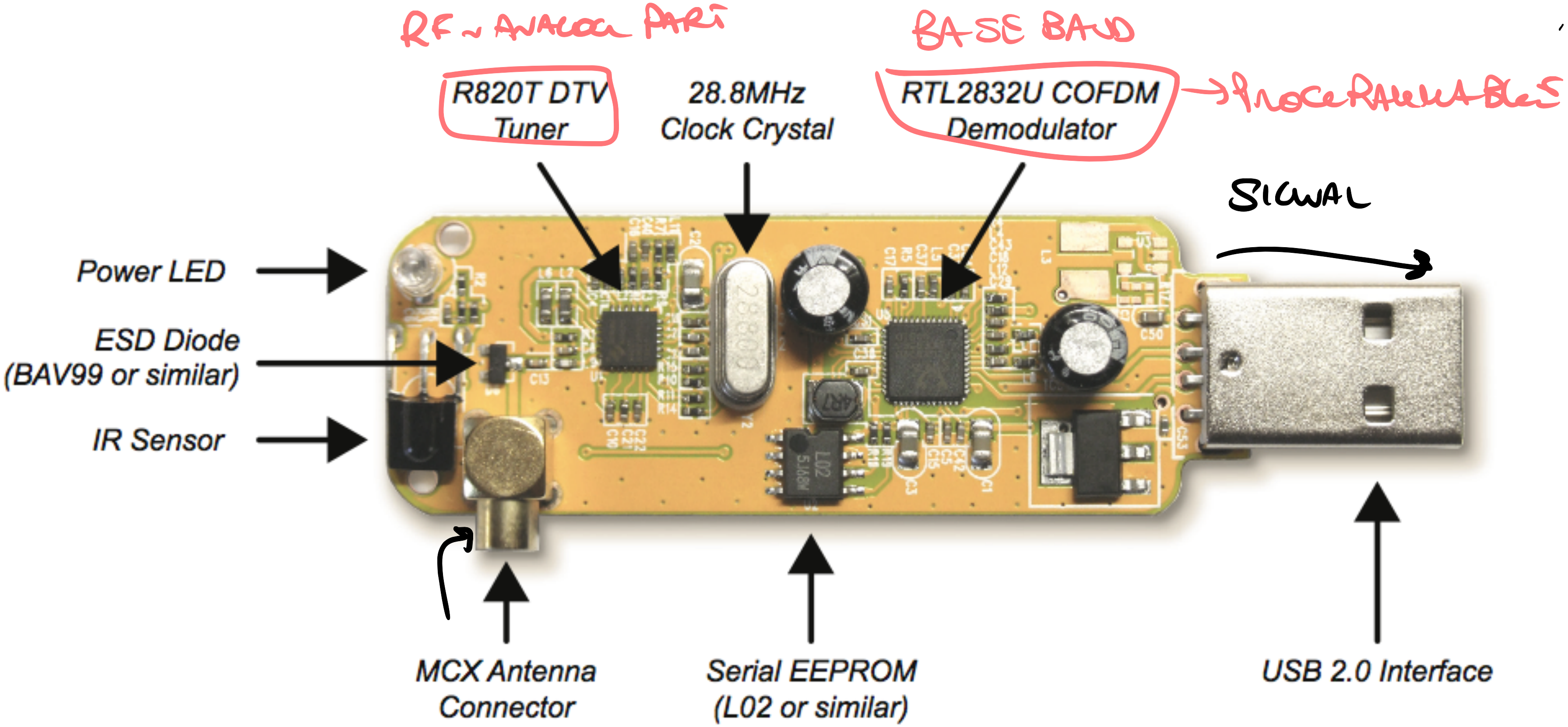




Telecom services in the 0.1-2.5 GHz band

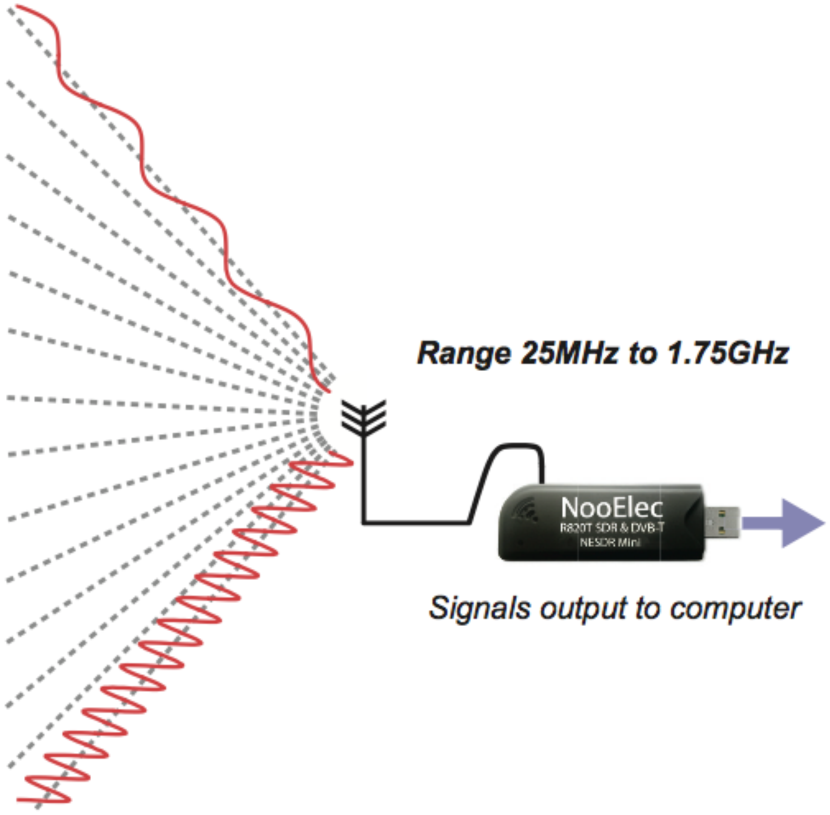


RTL-SDR architecture ~ RECEIVER

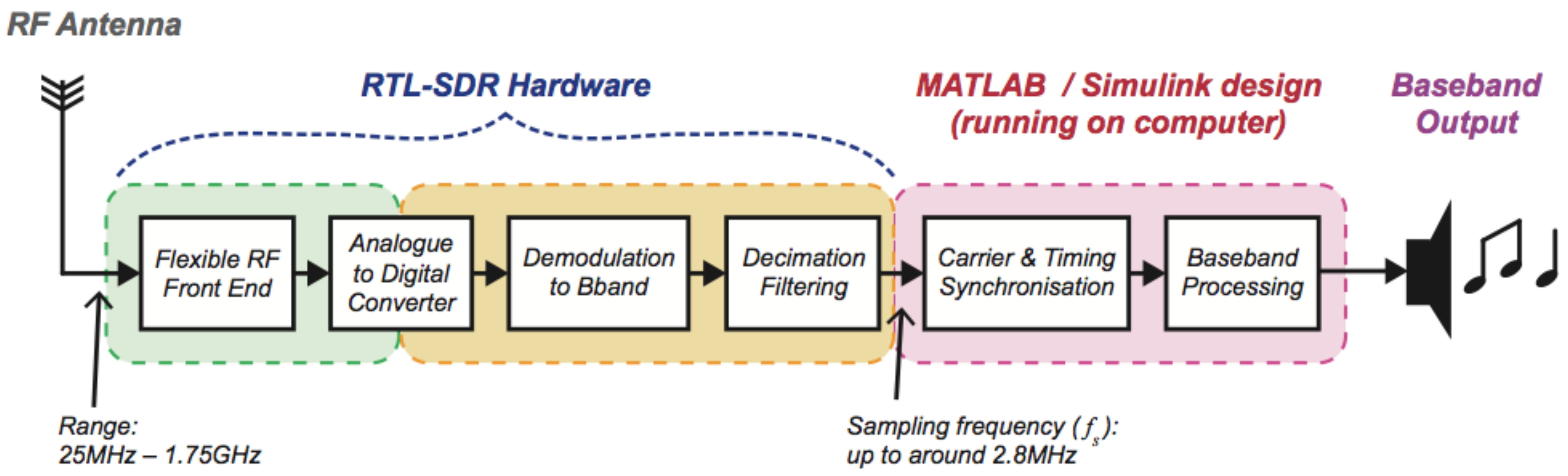


RTL-SDR services

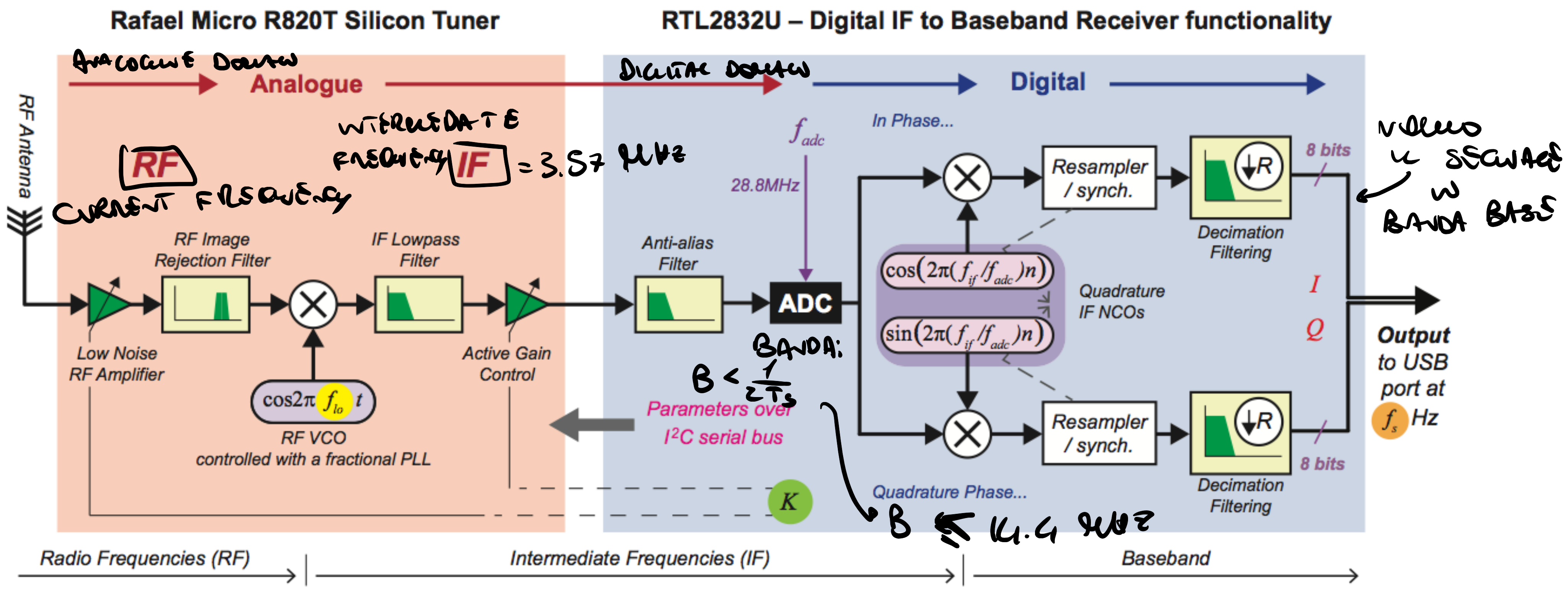
FM Radio	*87.5 – 108 MHz*
Aeronautical	*108 – 117 MHz*
Meteorological	*~ 137 MHz*
Fixed mobile	*140 – 150 MHz*
Special events broadcast	*174 – 217 MHz*
Fixed mobile (space–earth)	*267 – 272 MHz*
Fixed mobile (earth–space)	*213 – 315 MHz*
ISM band (short range)	*~433 MHz*
Emergency services	*450 – 470 MHz*
UHF TV Broadcasting	*470 – 790 MHz*
4G LTE-Advanced	*800 MHz bands*
SRD/ IoT	*863 – 870 MHz*
GSM-R band (UK)	*921 – 925 MHz*
GPS Systems	*1227 MHz / 1575 MHz*



SDR block diagram for an FM receiver



Signal processing flow diagram



LO - Local Oscillator

NCO - Numerically Controlled Oscillator

PLL - Phase Locked Loop

RF - Radio Frequency

VCO - Voltage Controlled Oscillator

f_{lo} *- frequency synthesised by RF VCO*

f_{adc} *- sampling rate of ADC (28.8MHz)*

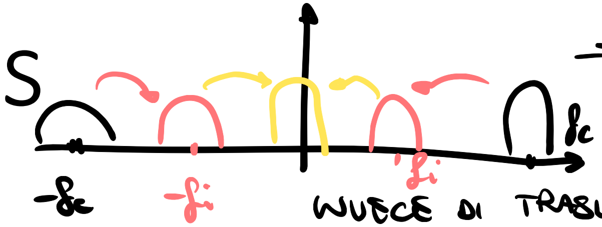
f_{if} *- intermediate frequency*

f_s *- frequency of output IQ samples (up to 2.8MHz)*

K *- gain of RF amplifiers*

n *- discrete sample index*

RTL-SDR receiving steps



→ SE LO FACCIO IN UN COLPO SOLO HOMODYNE RECEIVER

INVECE DI TRASLARE IL SEGNALE VOLENDO FINO A ZERO, LO TRASLO FINO AD UNA FREQUENZA INTERMEDIA

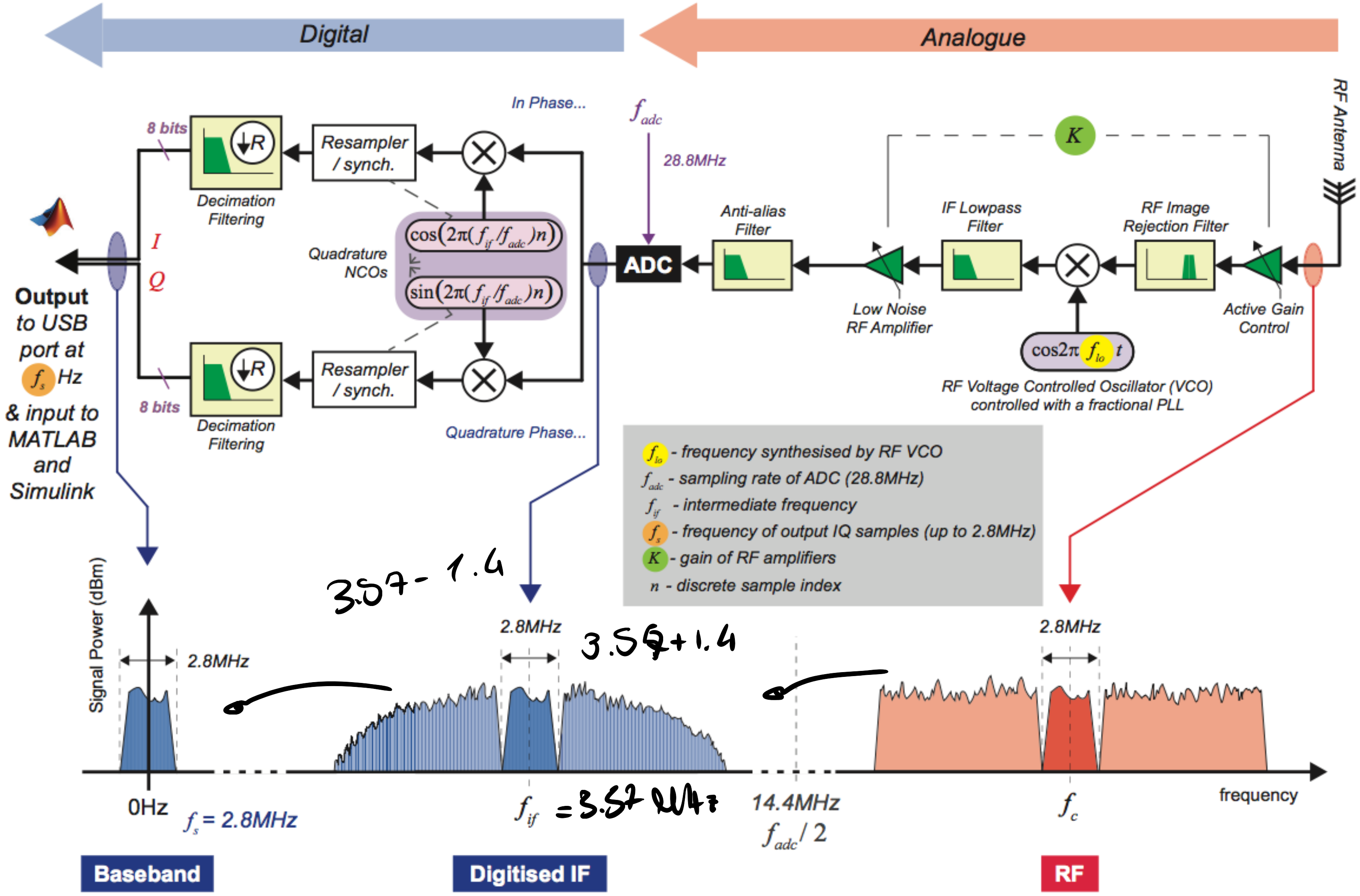
Receiver chain (*superheterodyne receiver*)

1. Incoming signals are mixed down using a super-heterodine receiver to an *intermediate frequency* of **3.57** MHz.
2. The intermediate frequency analog signal is sampled by a 2 channel (baseband I/Q components) **28.8** MS/s 8-bit analog-to-digital converter (ADC).
3. The digitized I/Q data follows parallel paths through a digital downconversion process that mixes, filters, and decimates the input signal to a user-specified rate. The maximum rate is approximately **2.8** MS/s. PERCHE' NON E' 14.4 MS/s?
4. The downconverted samples are passed to the host computer over a standard USB connection.

PER AVERE UNA MIGLIORE PRECISIONE E' SEMPRE MEGLIO OVER SAMPLING!

IL LIMITE E' DATO DALLA FREQUENZA INTERMEDIA! 3.57 MHz

From RF to baseband....



Programming a RTL-SDR with MATLAB

Before starting…….

- Install Support Package for RTL-SDR Radio
  - On the MATLAB Home tab click **Add-Ons > Get Hardware Support Packages**.
  - In Add-On Explorer, browse or search for the **Communications Toolbox™ Support Package for RTL-SDR Radio**.
  - Select the support package and then click Install.
  - During support package installation, you will be prompted to install the drivers needed for the RTL-SDR Radio software.

Hardware Setup

1. Plug the RTL-SDR into your computer
2. Start MATLAB, at the MATLAB command prompt, call the `sdrsetup` function.
3. To get information for all radios connected to your computer, call the `sdrinfo` function.

```
          hwinfo = sdrinfo
hwinfo =
          RadioName: 'Generic RTL2832U OEM’
          RadioAddress: ‘0’
          RadioIsOpen: 0
          TunerName: 'R820T’
          Manufacturer: 'Realtek’
          Product: 'RTL2838UHIDIR’
          GainValues: [29×1 double]
          RTLCrystalFrequency: 28800000
          TunerCrystalFrequency: 28800000
          SamplingMode: 'Quadrature’
          OffsetTuning: 'Disabled'
```

Classes and objects in MATLAB

- Object Oriented Programming (OOP) allows to create classes:
  - Description of the data type structure (fields or properties)
  - The set of operations (methods or functions) defined for this data type
- In MATLAB an object is a variable belonging to a specific class: before defining an object of a class it is necessary to know well the characteristics of the class.
- The operations that can be performed on a class are restricted to the methods defined for that class.
- For almost every class defined by MATLAB there is the `step` command, whose operation changes from class to class and depends on the class itself.

Example (1)

- Command `obj = dsp.SpectrumAnalyzer` creates an object of the class `dsp.SpectrumAnalyzer`.
- To define the value of some fields, the object is treated as if it were a structure.
- In this example we give the value 'Spectrum Analyzer' to the field 'Name' of our object

```
obj = dsp.SpectrumAnalyzer('Name', 'Spectrum
Analyzer')
```

or

```
obj.Name = 'Spectrum Analyzer'
```

Example (2)

- Create an object of the class `dsp.SpectrumAnalyzer`

```
scope =  dsp.SpectrumAnalyzer( ...
    'Name', 'Spectrum Analyzer', ...
    'Title', 'Spectrum', ...
    'SpectrumType', 'Power', ...
    'FrequencySpan', 'Span and center frequency', ...
    'CenterFrequency',0, ...
    'Span',600, ...
    'ShowLegend', true, ...
    'SampleRate', Fs);
```

- The command `step(obj,X)` displays the frequency spectrum of double, single or fixed-point precision input `X`, in the Spectrum Analyzer figure. The columns of `X` are treated as independent channels.

Load RTL-SDR driver

- Construct an RTL-SDR receiver System object:

```
obj_rtlsdr = comm.SDRRTLReceiver
```

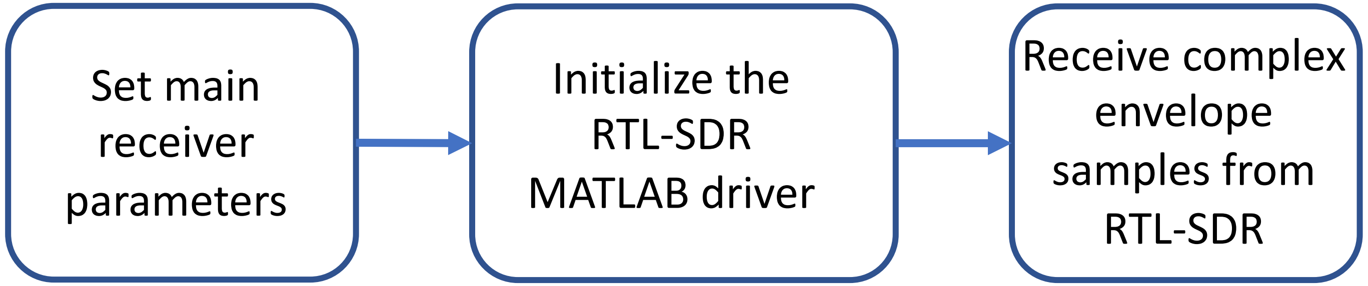
```
obj_rtlsdr =

        comm.SDRRTLReceiver with properties:

        RadioAddress: '0'

        CenterFrequency: 102500000

        EnableTunerAGC: true

        SampleRate: 250000

        OutputDataType: 'int16'

        SamplesPerFrame: 1024

        FrequencyCorrection: 0

        EnableBurstMode: false
```

CenterFrequency: Carrier frequency of the received signal

SampleRate: Bandwidth of the received signal

SamplesPerFrame: Number of samples passed to MATLAB with each call to `step` function

Using RTL-SDR with MATLAB



- Main parameters
  - Carrier frequency

    `CenterFrequency:` = [24-1766]MHz   fc
  - Signal bandwidth

    `SampleRate:` = [225,300]kHz U [900,2800]kHz
  - Buffer data length

    `SamplesPerFrame:` = 10*k

FM receiver

TRASMETTITORE: $\tilde{s}_{FM}(t) = A_c e^{j2\pi k_f \int_{-\infty}^{t} m(\tau)d\tau}$

- <u>Neglecting the effect of noise and channel,</u> the complex envelope of the received signal is

$$\tilde{v}(t) = A_c e^{j2\pi k_f \int_{-\infty}^{t} m(\tau)d\tau}$$

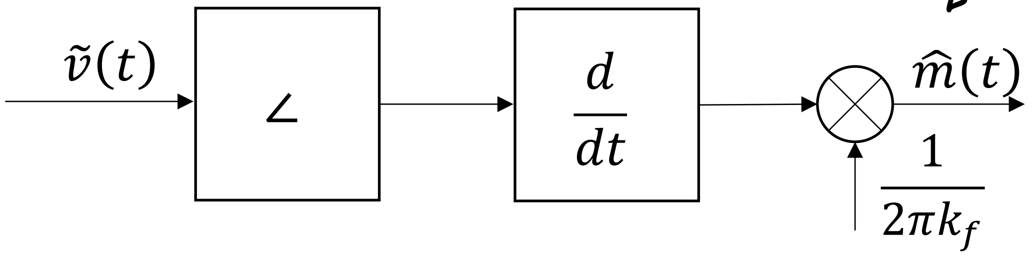
IN CONDIZIONI IDEALI:
$\tilde{s}_{FM}(t) = \tilde{v}(t)$

- The modulating signal can be recovered by differentiating the phase of $\tilde{v}(t)$

$$\boxed{\hat{m}(t) = \frac{1}{2\pi k_f}\frac{d}{dt}\angle\tilde{v}(t)}$$

COME LO IMPLEMENTO NEL DOMINIO DIGITALE?

Conceptual FM baseband receiver



FM receiver – practical implementation

IN OUTPUT HO A CHE FARE CON SAMPLE! NON SEGNALE CONTINUO

- At the SDR output there is the signal complex envelope sampled at frequency $\boxed{f_s = \frac{1}{T_s}}$

COSA VEDO IN OUTPUT: $\tilde{v}(kT_s) = V_I(kT_s) + jV_Q(kT_s)$

$$\tilde{v}(k) = \tilde{v}(t)|_{t=kT_s} = A_c e^{j2\pi k_f \int_{-\infty}^{kT_s} m(\tau)d\tau} \approx A_c e^{j2\pi k_f \sum_{\ell=-\infty}^{k} m(\ell)T_s}$$

$\tilde{v}(kT_s)$

$$\int_{-\infty}^{kT_s} m(\tau)\,d\tau = \sum_{\ell=-\infty}^{k} m(\ell T_s)\,T_s$$

- The product of two consecutive baseband samples yields

$$\tilde{v}(k)\tilde{v}^*(k-1) \approx A_c e^{j2\pi k_f \sum_{\ell=-\infty}^{k} m(\ell)T_s} A_c e^{-j2\pi k_f \sum_{\ell=-\infty}^{k-1} m(\ell)T_s}$$
$$= A_c^2 e^{j2\pi k_f m(k)T_s}$$

- An estimate of $m(k)$, the k-th sample of $m(t)$, is

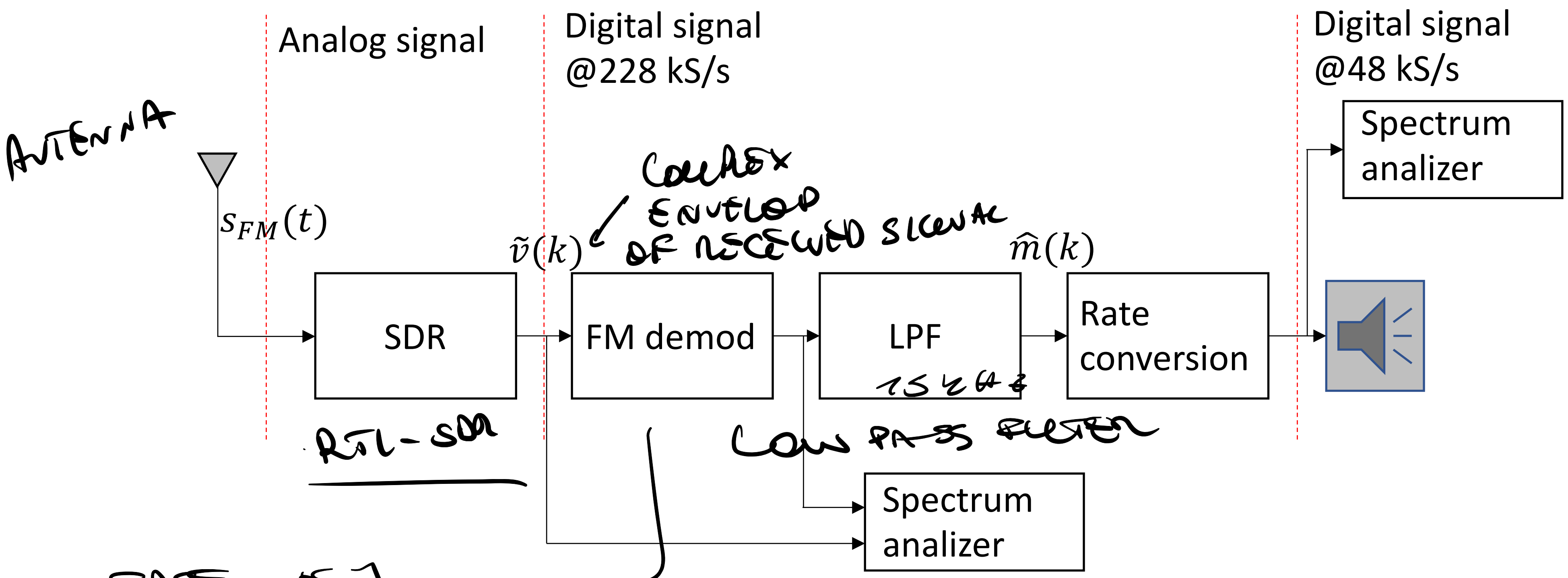
$$\hat{m}(k) = \frac{1}{T_s}\frac{1}{\Delta f}\angle\tilde{v}(k)\tilde{v}^*(k-1)$$

$2\pi k_f m(kT_s)T_s$

$$= \tan^{-1}\frac{\mathrm{Im}\{\tilde{v}(k)\,\tilde{v}^*(k-1)\}}{\mathrm{Re}\{\tilde{v}(k)\,\tilde{v}^*(k-1)\}} =$$

FM receiver – practical implementation

MATLAB



PRENDE LA FASE DI DUE CAMPIONI CONSECUTIVI