Software Defined Radio

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ESAC

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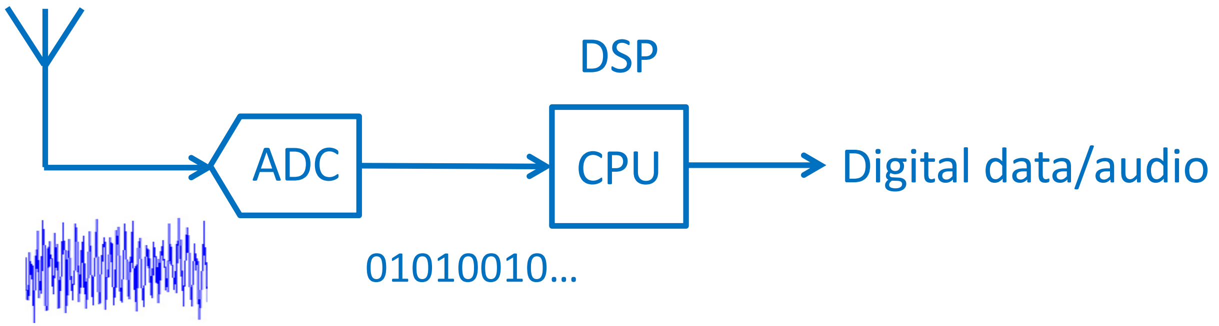
Imagine …

- Imagine we digitized the voltage from an antenna
- Then we could implement a radio receiver in software using DSP



Imagine …

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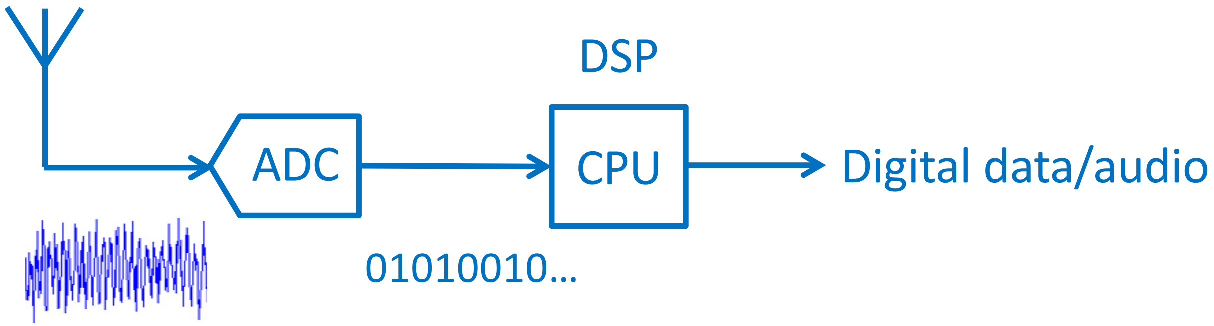
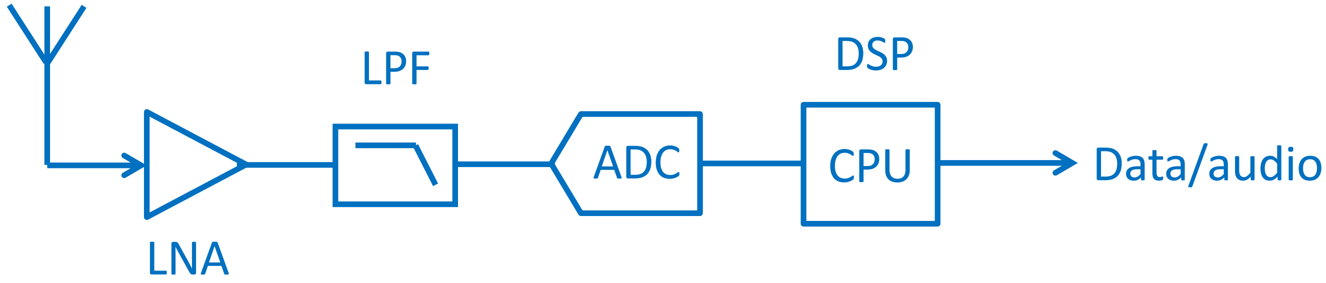


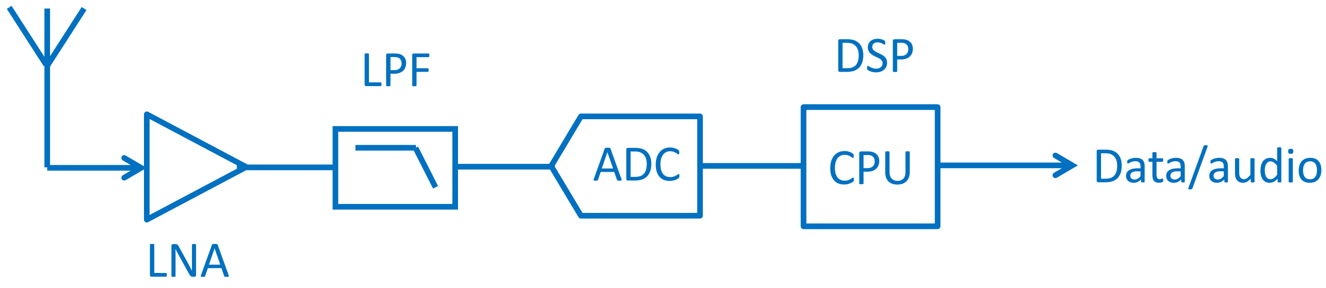
- This actually works!
- In fact, it works very well – Better mixers, filters etc
- It’s very flexible – Everything is ‘soft’
- Of course, there are a few more details in practice ...

A Few More Details

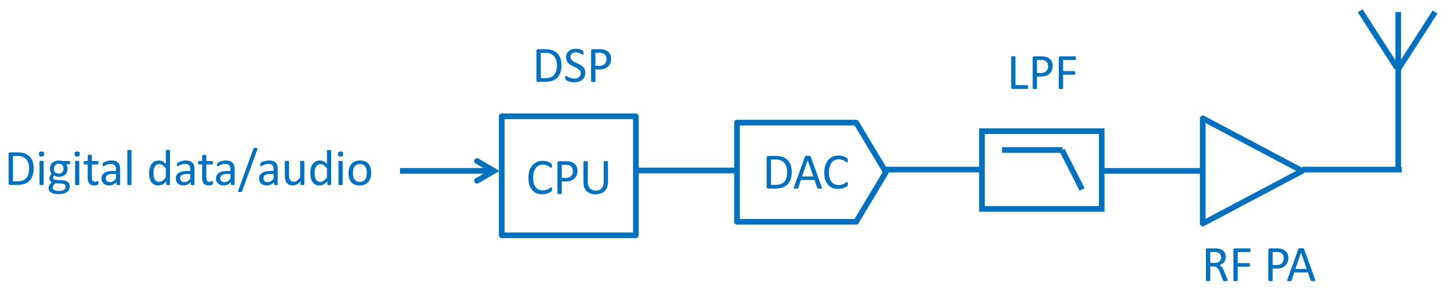


Basic direct sampling SDR receiver

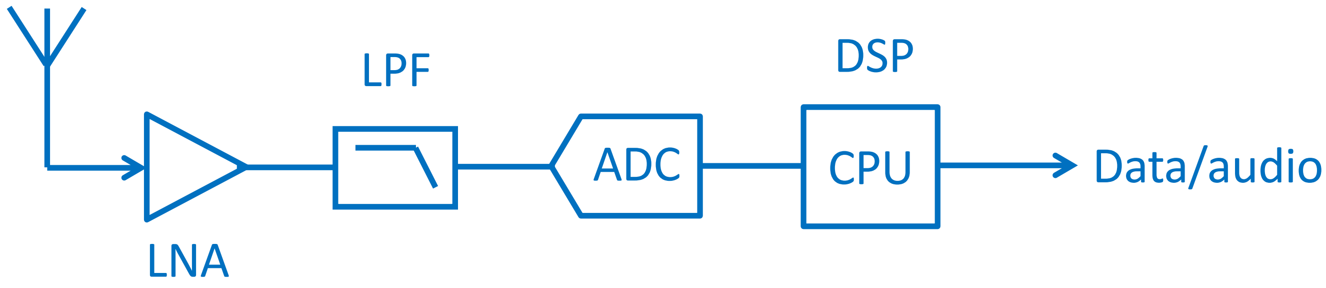
A Few More Details



We can do the same in reverse for a transmitter:

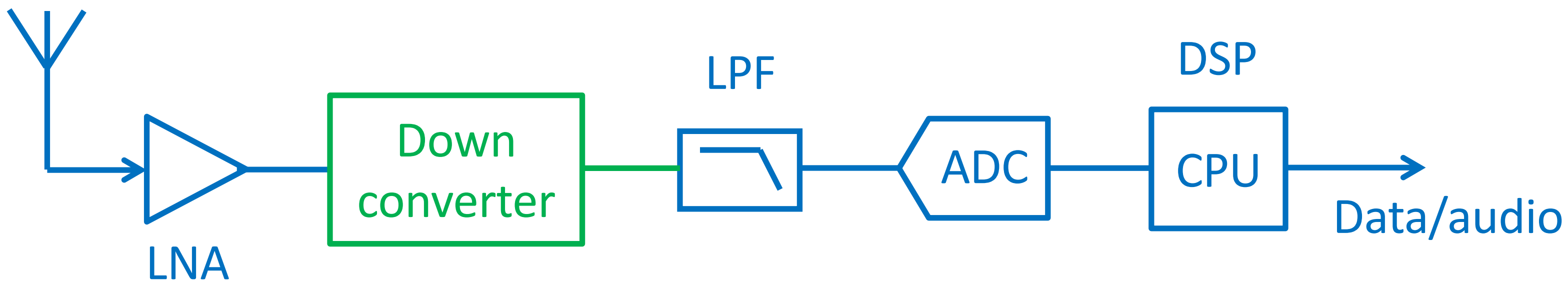


Down Conversion

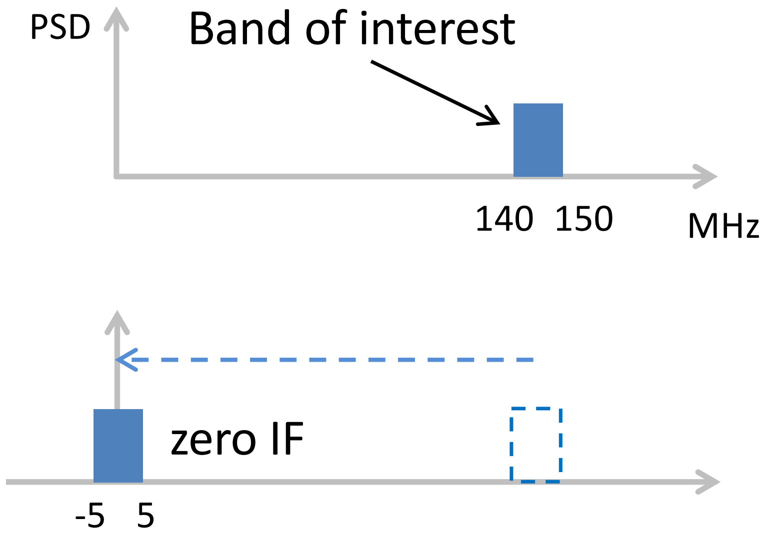


The maximum frequency we can receive is half the sampling rate

So shift the RF frequencies down to a range the ADC/CPU can handle:



Down Conversion

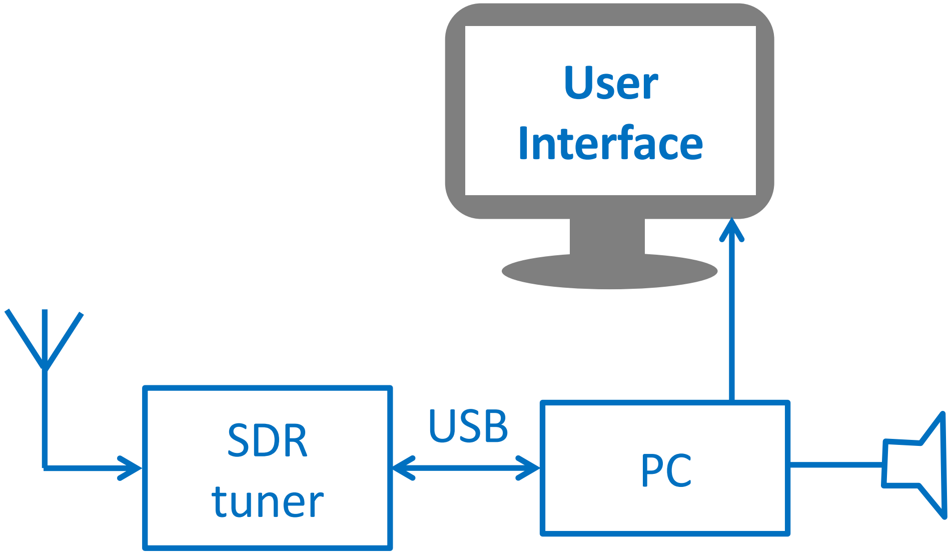


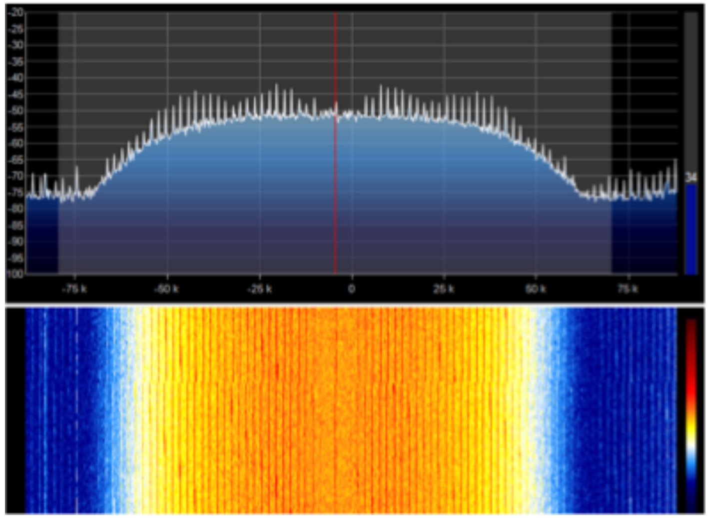
Direct sampling
Sample at > 300 MHz

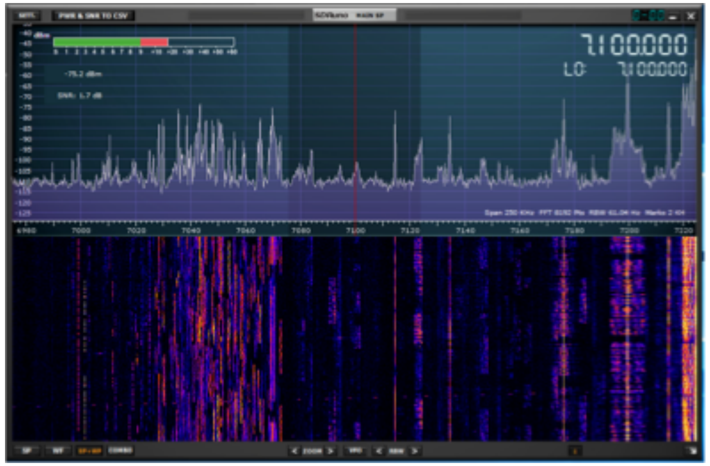
Shift down to 0 ± 5 MHz
Sample at > 10 MHz

The minimum sampling rate then depends on bandwidth not RF frequency

SDR as a Computer Peripheral







Example software:

- SDR#, SDR Uno, HDSDR, GNU Radio, ...

Demo: FM broadcast band with SDRplay

Examples of Low-Cost SDRs

RTL-SDR

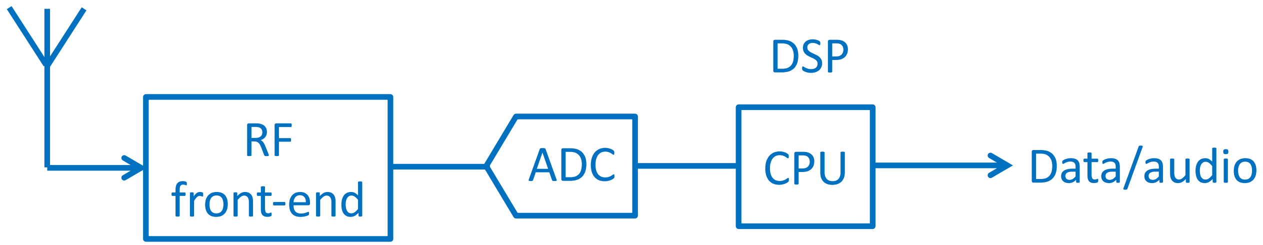
25 MHz to 1.75 GHz
Sample rate 2.4MS/s
ADC 8-bits
R820T2 + RTL2832U chipset
USB interface

SDRplay RSP1A

1 kHz to 2 GHz
Sample rate 10MS/s
ADC 14-bits to 6 MS/s, 8-bit to 10 MS/s
Switchable filters
USB interface

What is Software Defined Radio?

- Flexible radio system using DSP in software
- Generalises to programmable software/firmware/FPGA/DSPs
- Ideally flexible RF front-end: wide frequency range & bandwidth
- Radio: audio, video, data, navigation, radar etc
- Used with a PC or as part of an embedded system



Advantages of SDR

- Very flexible / reconfigurable
- One radio can support many kinds of signals
- Wide frequency range and bandwidth
- High performance: Better mixers, filters, etc
- Upgradeable / maintainable by software/firmware update
- Longer equipment lifetime
- Same hardware platform for multiple products/applications

Applications of SDR

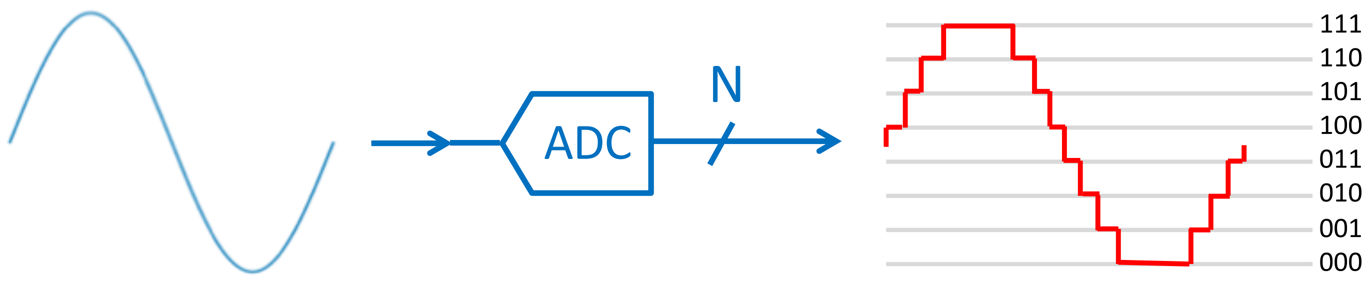
- Military - A major user from early on
- Space
  - NASA Electra radio on ExoMars, MRO & MAVEN[1]
  - ESA ARTES SDR project with Lime Microsystems[2]
  - NASA SCaN Testbed on ISS[3]
- Mobile phones and base stations
- Broadcast TV and radio
- WiFi routers
- Amateur radio
- …

1 https://en.wikipedia.org/wiki/Electra_(radio)

2 http://www.limemicro.com/press-releases/european-space-agency-selects-limesdr-app-enabled-satcoms/

3 https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_scantestbed.html

Quantisation Noise



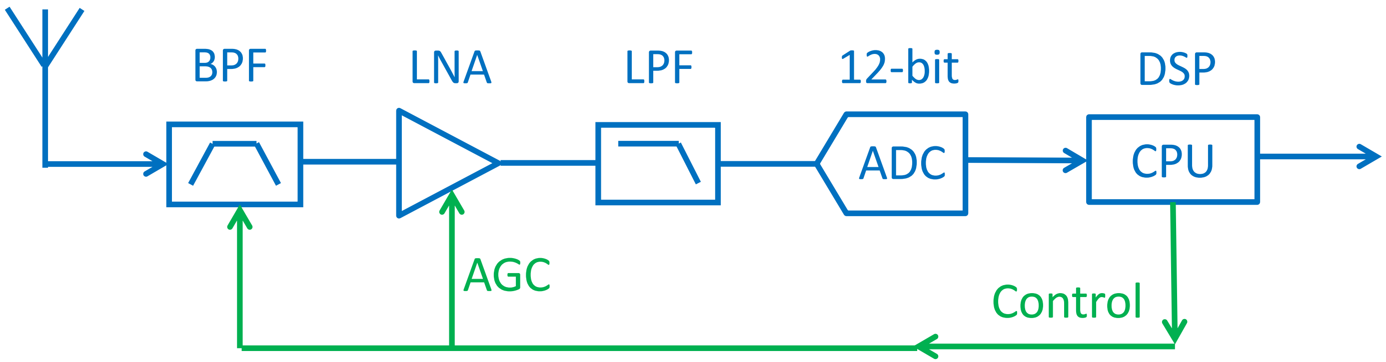
SQNR ≈ 6 N dB (for N bits)

- 12-bit ADC gives SQNR of 72 dB
- 14-bit ADC gives SQNR of 84 dB

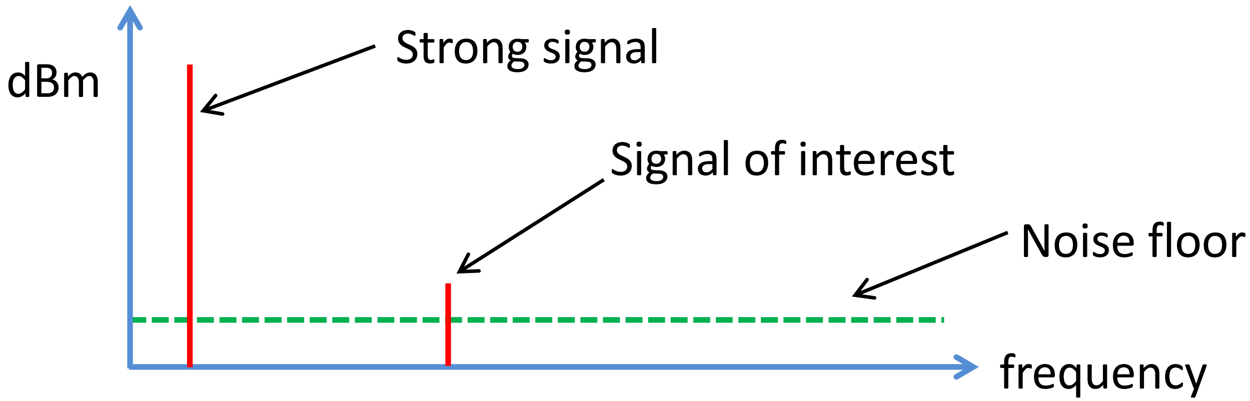
Improving SQNR

- Oversampling and decimation
- Dithering

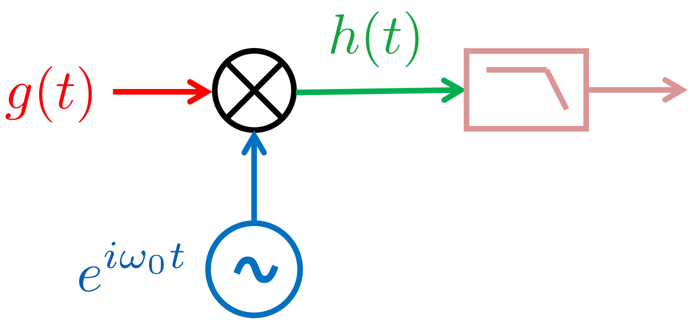
Dynamic Range



- Strongest signals must not saturate ADC
- Weak signals may be > 100 dB smaller
- Wideband AGC to keep ADC in good range
- Filters to remove unwanted strong signals

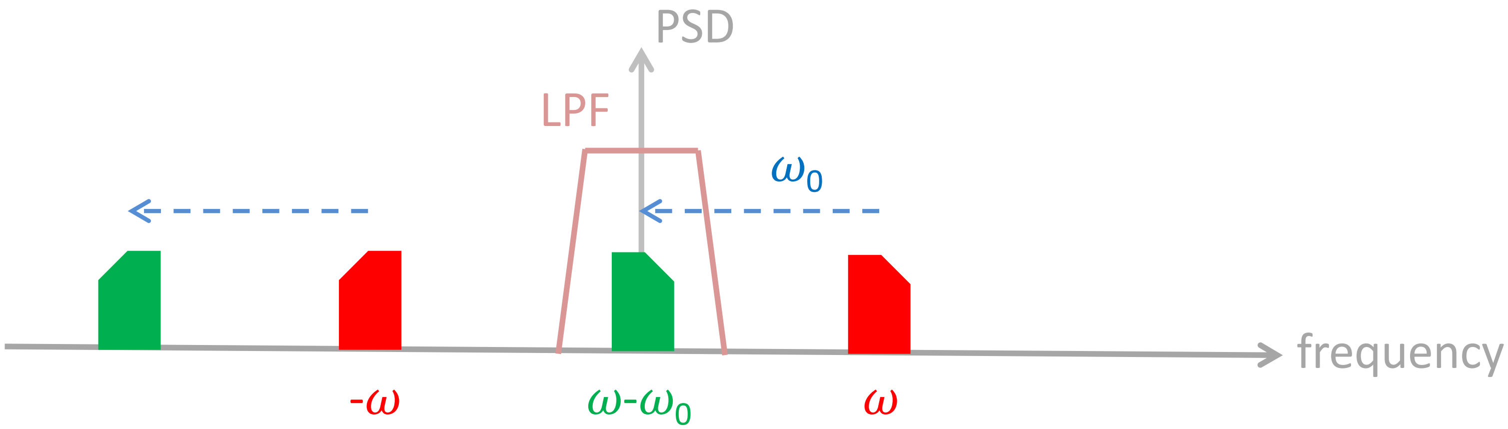


Complex Down Conversion



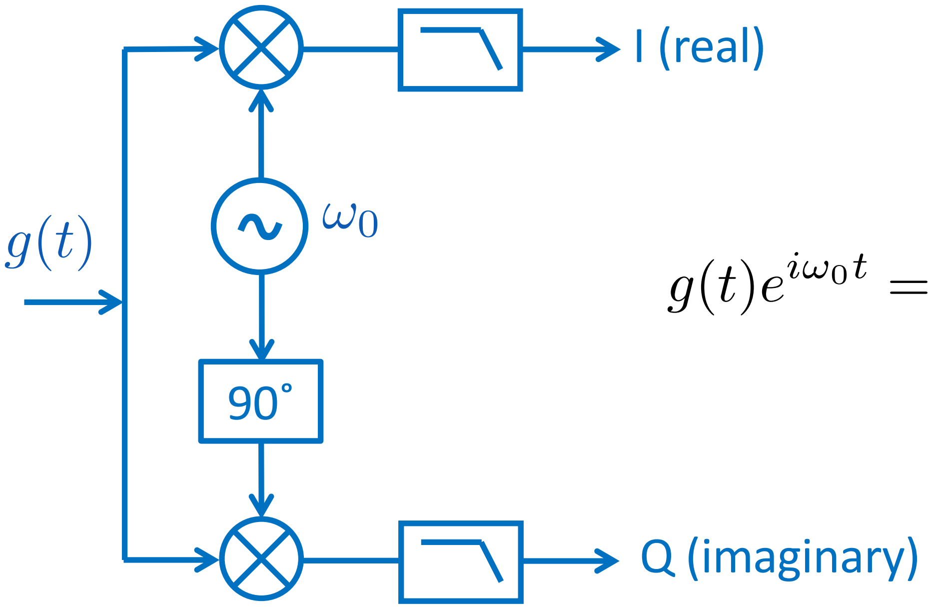
Fourier shifting theorem:

$$g(t)e^{i\omega_0 t} \Leftrightarrow G(\omega - \omega_0)$$



- Avoids image response of a traditional balanced mixer
- Filtering out image is difficult for a wide-band receiver

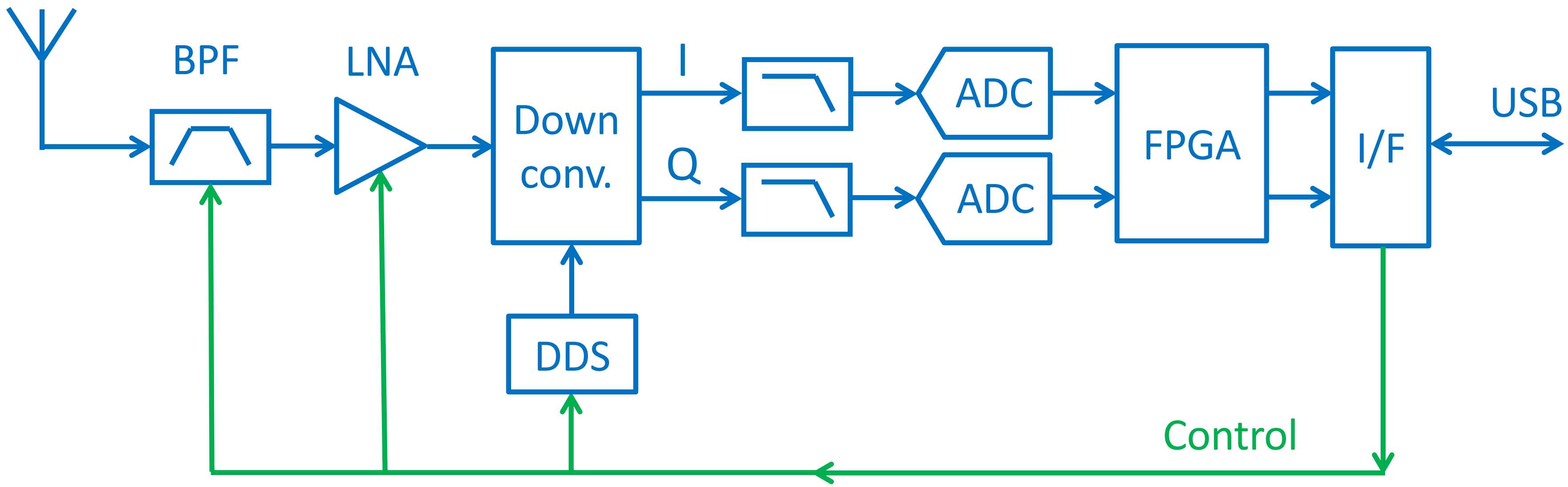
Quadrature Mixer



$$g(t)e^{i\omega_0 t} = g(t)\cos(\omega_0 t) + i\,g(t)\sin(\omega_0 t)$$

- This mixer must be analogue because it is before the ADC

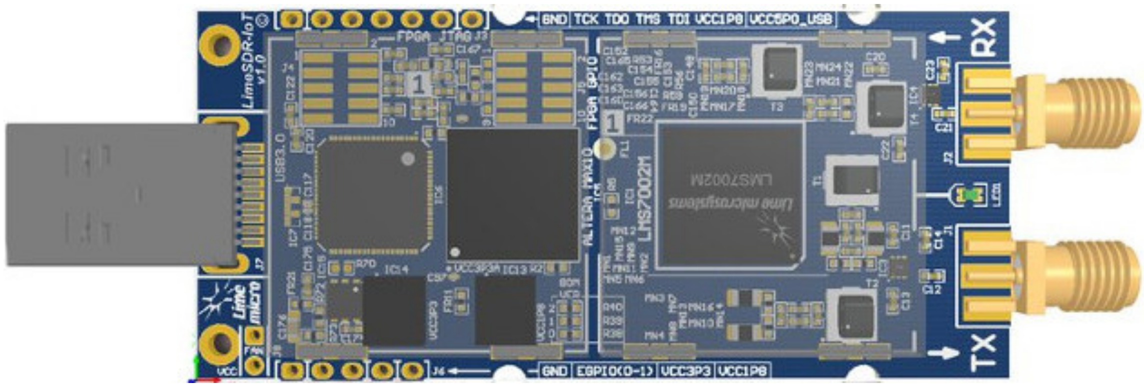
A Common SDR Receiver Architecture



- Analogue quadrature down conversion to shift band of interest
- FPGA: DDC, decimation, etc
- IQ interface to CPU over USB or LAN

Example: Lime Mini SDR

Lime Microsystems have a project with ESA as part of ARTES



LMS7002M RF Transceiver IC

Intel (Altera) Max 10 FPGA

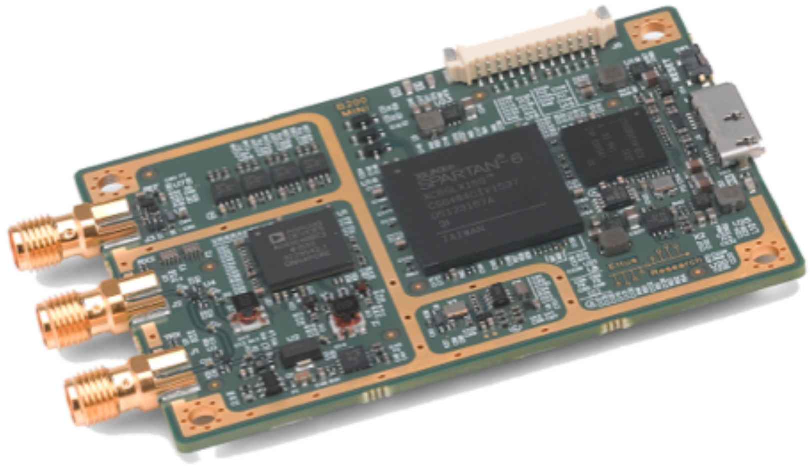
10 MHz to 3.5 GHz

Bandwidth 30.72 MHz

Sampling: 30.72 MS/s 12-bit

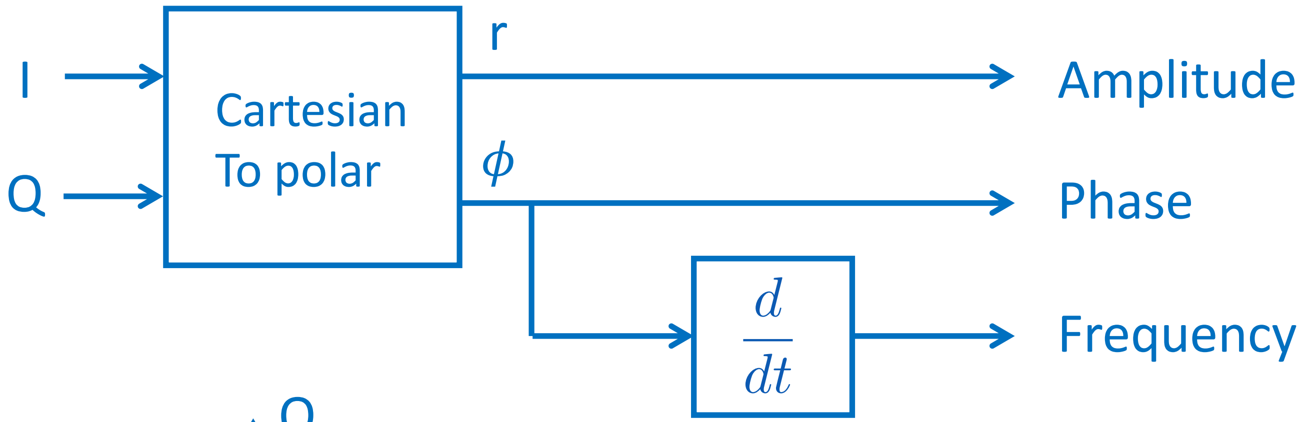
USB 3.0 interface

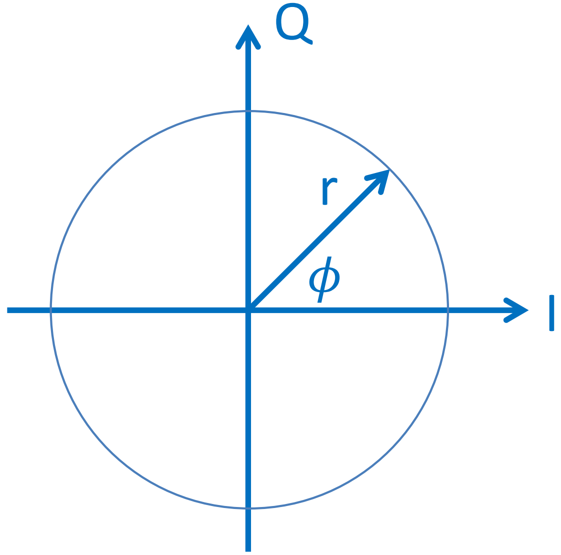
Example: Ettus Research USRP B200mini-i



AD9364 RF Transceiver IC
Xilinx Spartan 6 FPGA
70 MHz to 6 GHz
Bandwidth 56 MHz
12-bit ADC + 10-bit DAC
USB 3.0 interface

AM/FM Demodulation of IQ Signals





$$r = \sqrt{I^2 + Q^2}$$

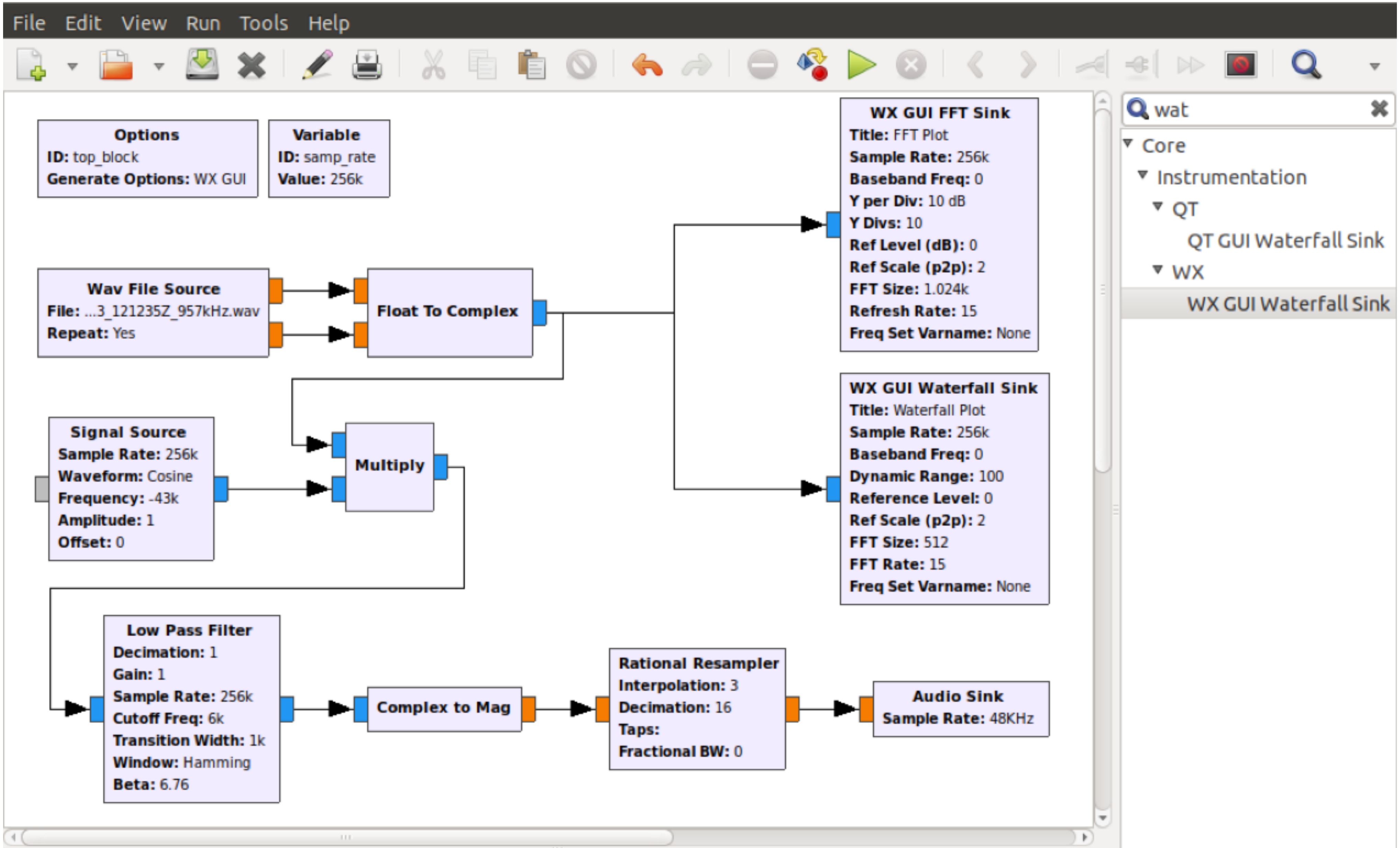
$$\phi = \mathrm{atan2}(Q, I)$$

$$f = \frac{d\phi}{dt}$$

First use DDC to shift frequency of station to zero and low-pass filter

Demo: AM demodulation with GNU Radio

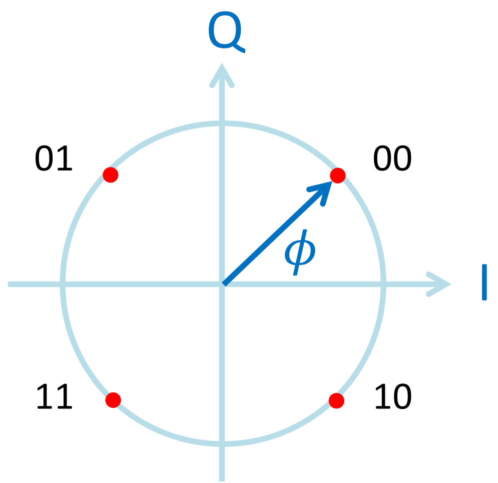
GNU Radio – AM Demodulation



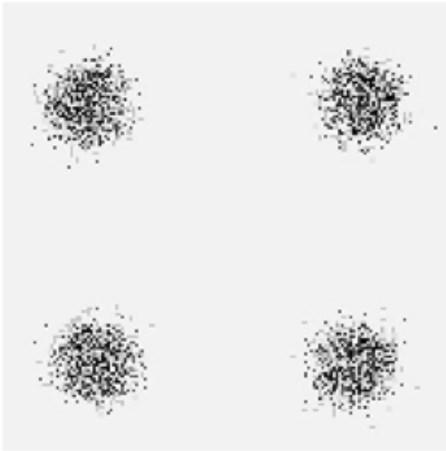
Digital Modulation

- More efficient use of spectrum
- Combined with data compression & error correction
- ASK, FSK, PSK, QPSK, QAM, OFDM, …

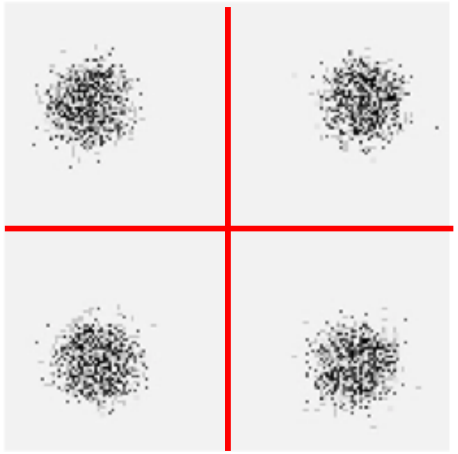
Quadrature Phase Shift Keying (QPSK)



Constellation diagram



Meteor M2 data



Threshold to decode

- First recover carrier and shift to zero frequency
- Then threshold I and Q

Demo: Meteor M2 with SDR#

(Data from www.sigidwiki.com)

Conclusions

- SDR uses DSP in software/firmware/FPGA to build flexible radios
- SDR may be embedded or use a PC
- Already in widespread use; you may already use one!
- Likely to become even more common as better SDR chips become available
- You can buy an RTL-SDR for €25 – A fun way to learn about DSP