Wireless Link Project 2020
Course Organization

Teaching Team:

Vessen Vassilev	Examiner, MEL (C621)
~~**Parastoo Taghikhani**~~	Instructor/HW (B632)
~~**Ahmed Hassona**~~	Instructor/HW, MEL (C621)
Husileng Bao	Instructor/SW, MEL
Zonglong He	Instructor/SW, Photonic (B442)

- Max 24 Students divided in 4 groups
- All documents related to the course will be located at the course website in Canvas.
- All documents, designs, reports, etc. will be submitted in Canvas.

Teams

1 Walkie Talkies

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4 Antennas AB

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Course Organization

- **Duration:** The course starts on November 1th 2021 and after 7 weeks, it ends on December 16th with a final presentation given by the groups. Before that, on December 13th the functionality of the links will be verified through a transmission of a message between 2 points in the MC2 building.

- **Attendance:** we run the course in its “normal” mode. You will be working mostly in the student lab, however you are allowed to work at other premises too. Students are required to keep a time log of the hours spent on the project and the task they have been working on and also indicate which part of the reporting they contribute to. The time log is also a part of the individual grading and should be available at the group-documents folder at Canvas.

- **Presentations:** Each team will present their work in two presentations during the course. The first presentation is the “midterm review” where each team present their progress to the teachers. The second presentation is the “final presentation”, where each group will present both to the teachers and the other groups. To encourage overall understanding of all the parts of a communication link we require students who have focused on the software (DSP) part to present the hardware design/performance and vice versa.

Important dates and Deadlines

Time	Event	Place
Monday 1 Nov, 13:15-17:00	Introduction	**A820**
Thursday 4 Nov, 9:00-12:30	Lectures	**A820**
Wednesday 10 Nov.	Groups present their Link Budget	
Wednesday 17 Nov.	Preliminary PCB designs ready for DRC check	
Thursday 25 November, 9:00-12:30	Mid term presentations	**A820**
Friday 19 Nov.	Final PCB designs are submitted for fabrication	
By Thursday 25 Nov.	SW groups demonstrate data transmission over cable	**B 518**
Monday 13 Dec	Link demonstration	**MC2 corridor**
Thursday 16 Dec, 9:00-12:30	Final Presentations	**A820**
15 Jan 2021	Report submission	

A “happy” student demonstrates his “16 QAM link”.

Your Task:

HW

SW

Demonstrate a simplex (one way) wireless data transmission

- To convert the data to complex numbers
- To generate a baseband or IF signal in to the URSP Transmitter module
- To build Transmitter hardware that can up-convert the baseband or the modulated IF to RF at either 2.4 or 5.8 GHz.
- To build a Receiver hardware that can down-convert the modulated RF to IF or baseband.

- To be able to compensate frequency offsets between the Rx/Tx LO sources.
- Down sample and time synchronization
- To detect the start of the message
- To compensate for phase offset
- To display the received message

We require:

Distance: about 100 m, (Message can be text, picture, voice, …)
RF frequency 2.4 or 5.8 GHz.

Minimum order of modulation QPSK (higher order is considered as a advantageous)

We recommend using Matlab to construct the software part of the link.
We do not allow the use of toolbox components for impairment corrections.

Rest is entirely up to you:

Wireless Link Project Schedule

Only 7 weeks available to complete the course.

7.5p correspond to 200 h of work.
(Work load 5-6 h/day).

	Måndag	Tisdag	Onsdag	Torsdag	Fredag
8-10	A	D	D	C	D
10-12	A	D	A	C	D
Lunch					
13-15	C	B	A	B	B
15-17	C	B	A	B	C

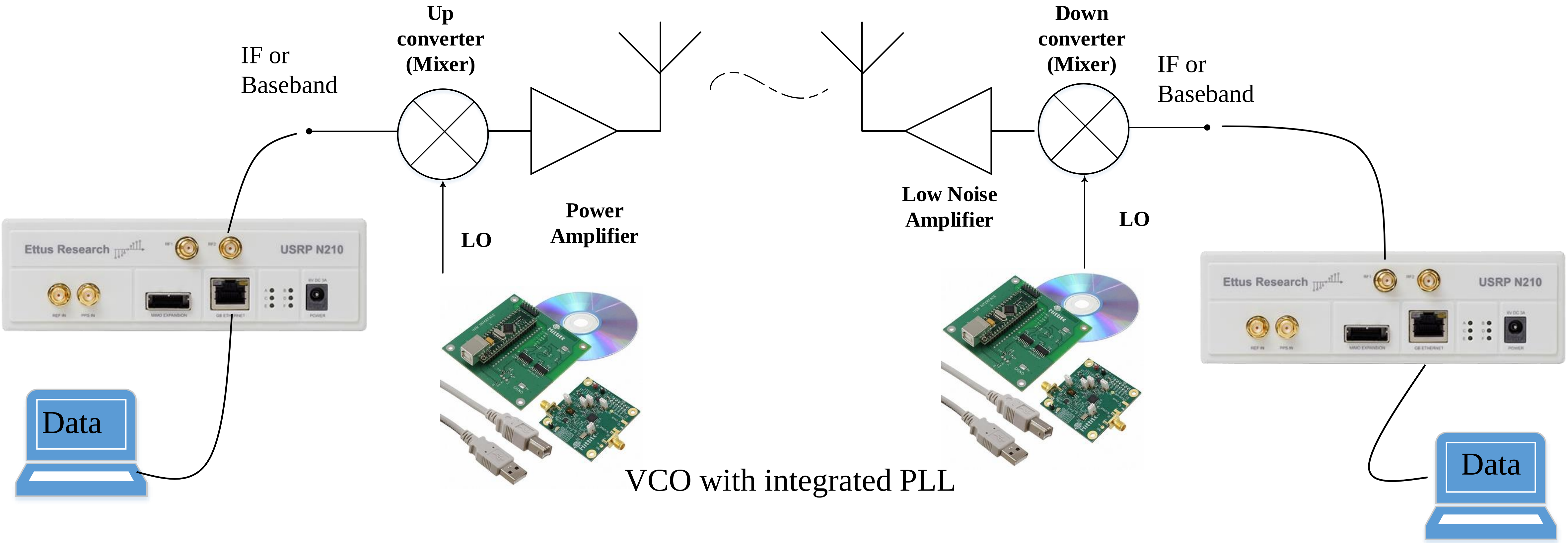
In these time slots supervision is guaranteed

The time reserved for the course is every Monday 13:00-17:00 and Thursday 8:00-11:45. However, these hours are not sufficient to accomplish the course and therefore students will be able to access and work in the lab which will be available to them between 08:00-17:00 **during weekdays**.

Additional rooms available

To avoid crowded student lab you can use other rooms in the building such as “Kristallen” (A819) and “Gaten” (A402). These rooms can be booked upon request.

Simplex wireless radio link – Hardware



Project workflow

- Link budget – choice of hardware configuration: single ended (DSB) or IQ up-converter, Transmitter output power, Receiver noise, Antennas, RF frequency (2.4 or 5.8 GHz).
- Matlab programming – set up and communicate with the USRPs.

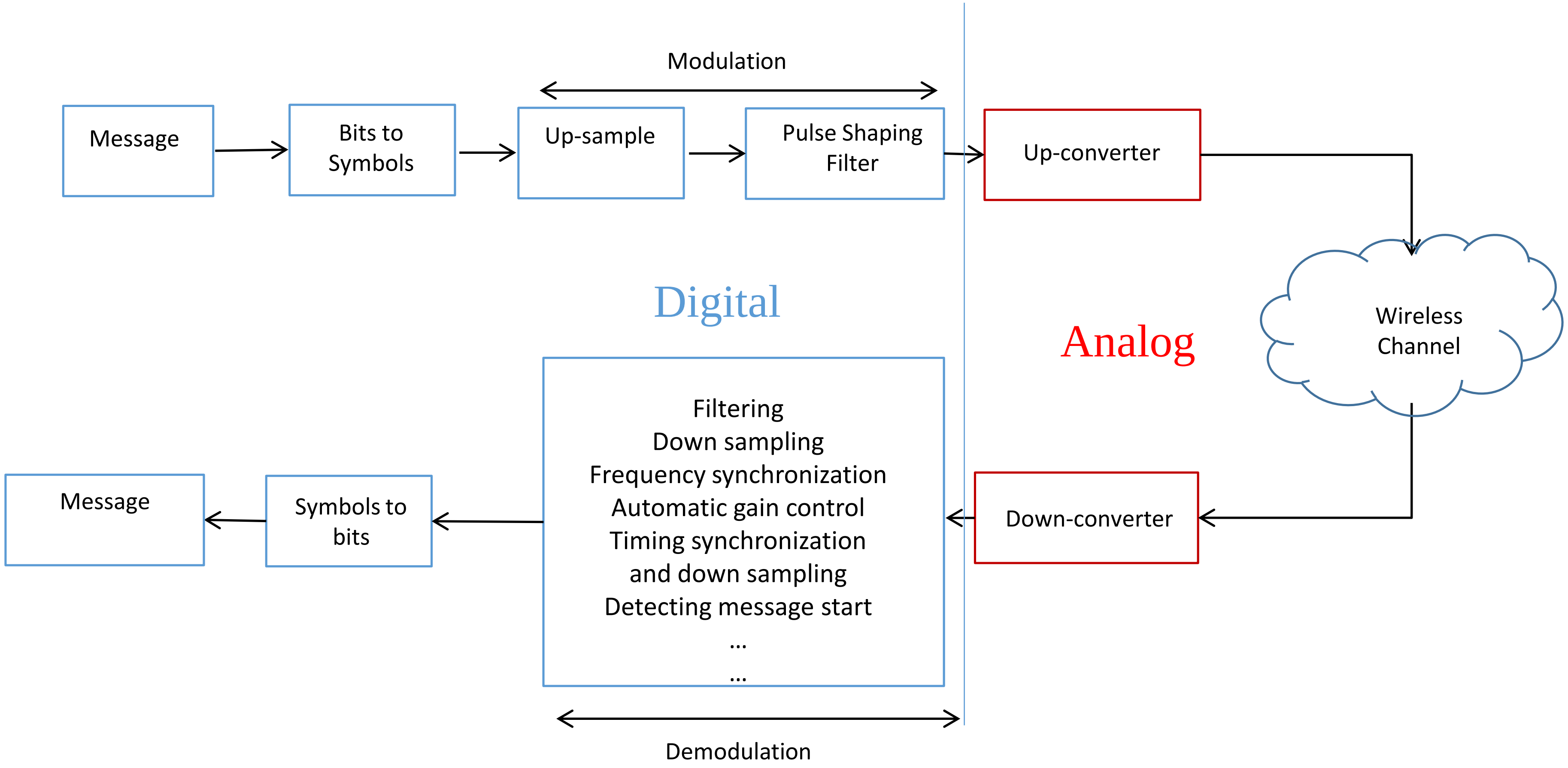
  - ✓ In the transmitter the data is arranged into an I+jQ vector. Data is divided into frames where each frame consists of bits for frame synchronization (for detecting start of the message), and the message itself. Data is then up sampled filtered and sent to the USRP for transmission.

  - ✓ The receiving software should be able to detect the beginning of a frame, to perform the necessary frequency, phase and timing synchronization and to extract the message bits.

- Microwave hardware design – frequency up/down conversion. Parameters such as: transmitter output power, RF return loss, receiver noise, power consumption, cost will be used to evaluate the HW.

Divide the work within the group according to your interests and competence. Help each other!

A wireless radio link

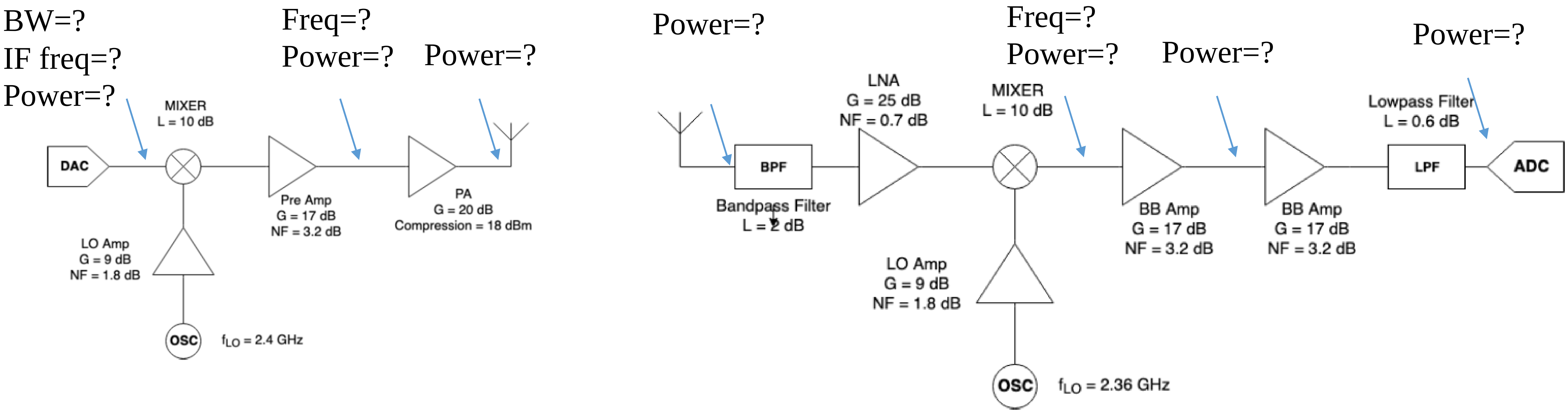


- As a part of the course, you are expected to implement functionality required in order to transmit data in a digital modulation format **QPSK** or **16 QAM**.

- Particular attention will be paid to the demodulation block. This block entails the critical compensation routines that will help you combat many of the undesirable effects that you will see in a real-world communication system. These effects primarily arise from the effects of imperfect hardware.

Link budget

1-2 pages. Should contain the block diagram of the Tx/Rx Modules with notation of power levels and frequencies at each node. The purpose of the link budget is to ensure that given the choice of components you will be able to communicate over a distance of 100m.



Start with the symbol rate and modulation order you targeting. Verify how much power the Tx USRP can provide, how much power the Rx USRP needs.
For the link budget you need to define the structure of the Tx/Rx. Indicate frequency and power level at each node in your circuits!

Link Budget 1 – the SNR

Eb/No energy per bit /noise power spectral density

A minimum ***Eb/No*** is required to achieve a specific BER for a specific modulation

The required ***Eb/No*** is converted to a min ***SNR*** at the receiver.

$$SNR_{In} = \frac{P_r}{P_n} = \frac{Eb}{No} \frac{Bit\ Rate}{Channel\ BW}$$

The received power

Power density at a distance from an isotropic source $$S = \frac{Pt}{4 \cdot \pi \cdot d^2} \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right]$$

Link Budget 2 – the received power

Power density at a distance from a transmitting Antenna with gain Gt

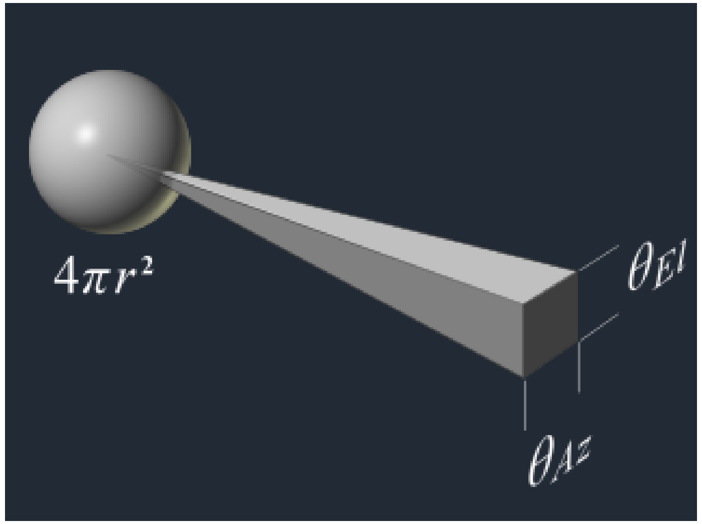
$$S = \frac{Pt \cdot Gt}{4 \cdot \pi \cdot d^2} \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right]$$

Received power by the receiver Antenna

$$\mathrm{Pr} = \frac{Pt \cdot Gt}{4 \cdot \pi \cdot d^2} Ar \ \ [\mathrm{W}]$$

Antennas are specified in terms of gain (dBi),
we need a relation between Antenna-area and antenna-gain.

Link Budget 3 – the received power



Gain of antenna

$$G = \frac{4\pi}{\theta \cdot \varphi}$$

Antenna beam width
In 1 dimension

$$\theta_{3dB} = \frac{\lambda}{L}$$

$$G = \frac{4 \cdot \pi \cdot L^2}{\lambda^2} = \frac{4 \cdot \pi \cdot A}{\lambda^2} \Rightarrow A = \frac{G \cdot \lambda^2}{4 \cdot \pi}$$

$$\mathrm{Pr} = \frac{Pt \cdot Gt}{4 \cdot \pi \cdot d^2} Ar = \frac{Pt \cdot Gt \cdot Gr \cdot \lambda^2}{(4 \cdot \pi \cdot d)^2}$$

Free Space Loss
FSL

Assume 3dBi antenna
gains for your budgets

Link Budget 4 – the Noise

Available Noise power
Of a matched source $P_n = k \cdot T \cdot B$ $\quad k = 1{,}38 \cdot 10^{-23}\,[\mathrm{J/K}]$ or $[\mathrm{Ws/K}]$ Boltzmann constant

$$P_n = -174 dBm/Hz + 10\log_{10}(B) \quad [dBm]$$

Noise Power of a noiseless receiver terminated with matched load at 300 K

Noise power at the
Receiver in terms of ***NF***

$$P_n = -174 dBm/Hz + 10\log_{10}(B) + \mathrm{NF} \quad [dBm]$$

Noise power at the
Receiver in terms of
equivalent noise temperature

$$P_n = k \cdot (300 + T_{rec}) \cdot B \quad [W]$$

The receiver equivalent
noise temperature
referenced to its input.

$$\boxed{SNR = \frac{P_r}{k \cdot (300 + T_{rec}) \cdot B}}$$

Example of Optimistic link budget for Channel Bandwidth 1 MHz.

<u>Noise</u>

$$P_n = -174 dBm/Hz + 10\log_{10}(B) + \mathrm{NF}_{\mathrm{rec}} \left[dBm\right]$$

for channel BW $= 1$ MHz and NF rec $= 10$ dB

$$P_n = -104 dBm$$

<u>Signal Power</u>

free space loss for isotropic antennas, FSL $= \left(\dfrac{4\cdot\pi\cdot d\cdot f}{c}\right)^2$

for $f = 2.4GHz$ and distance of 100m FSL $= 80dB$

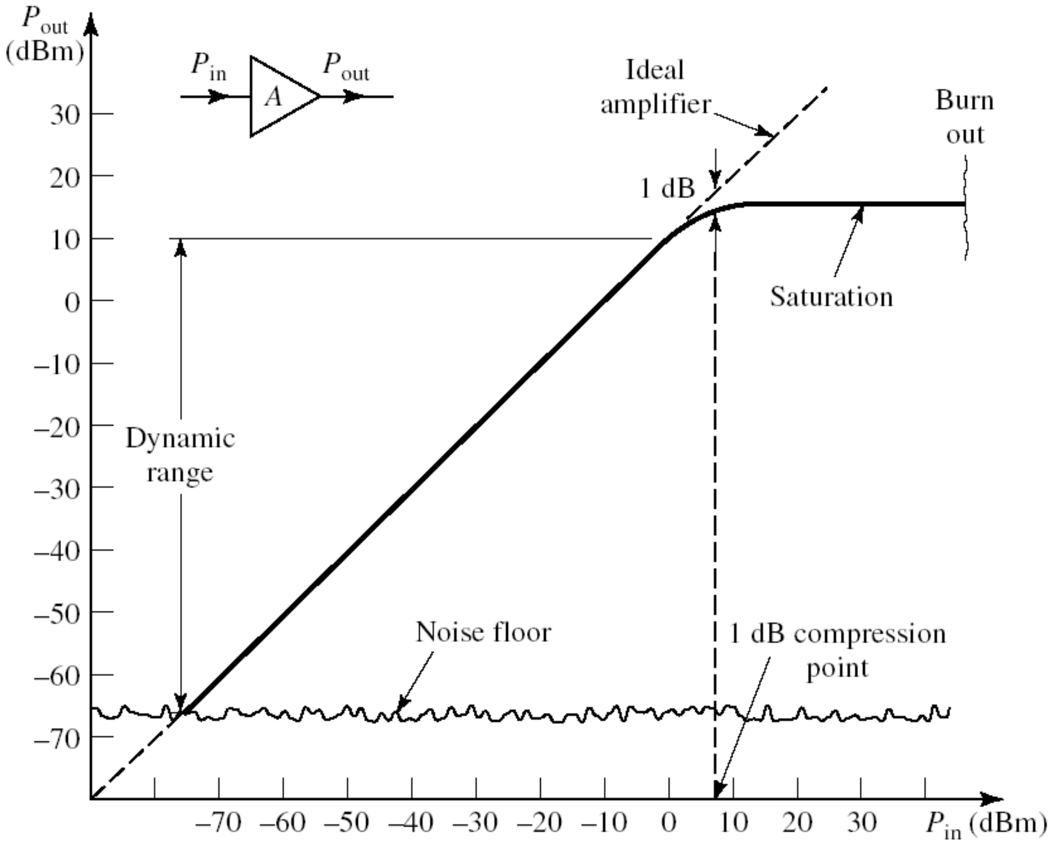
with 2 antennas of 6 dB gain the path loss is $68dB$

Output P1dB $= 13dBm \Rightarrow$ Power applied at the receiver $= 13 - 68 = -52dBm$

SNR $=$ -52 - (-104) $= 52dB$

However : .....

Effects of HW imperfections - Gain Compression (Saturation)



<u>1-dB gain compression point)</u> is the output power at which the gain is reduced by 1 dB over the small-signal linear power gain.

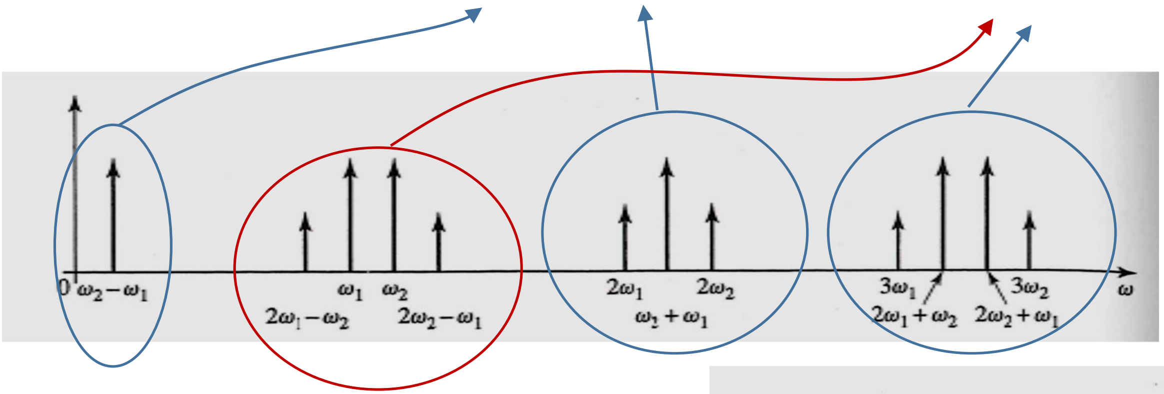
- For a single tone amplifier nonlinear (saturated) operation of an amplifier is acceptable.
- For modulated signals a saturated amplifier will give rise to intermodulation products

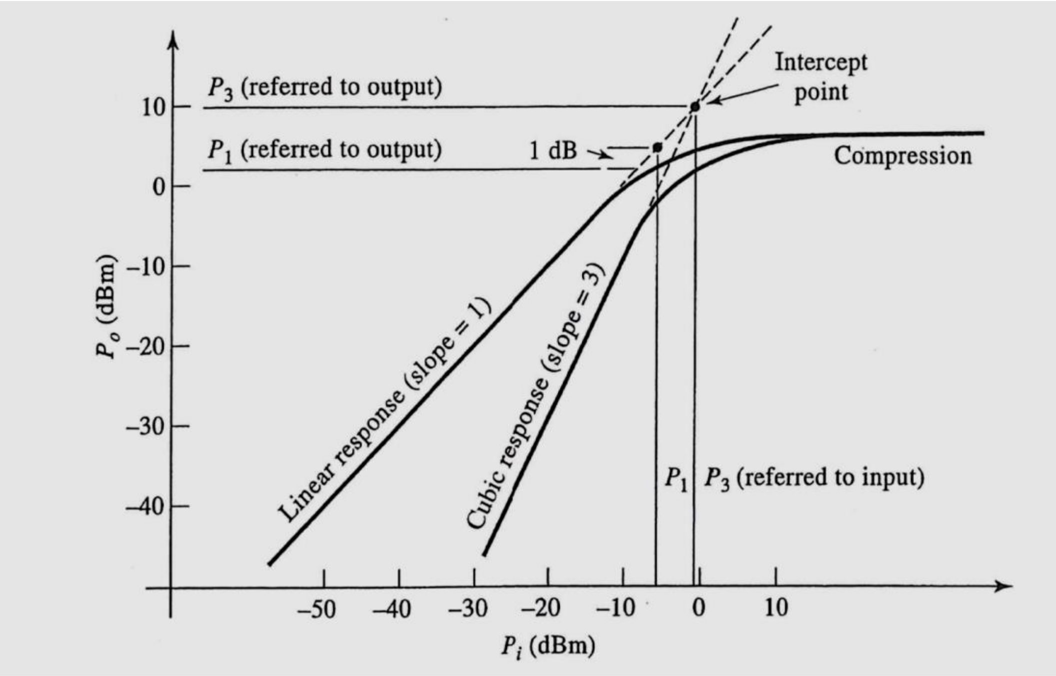
Effects of HW imperfections - Intermodulation distortion

$$V_0 = a_0 + a_1 V_i + a_2 V_i^{\,2} + a_3 V_i^{\,3} + ...$$

$$\text{for } \mathrm{V_i} = V_0\left(\cos\omega_1 t + \cos\omega_2 t\right)$$

$$V_0 = a_0 + a_1 V_0\left(\cos\omega_1 t + \cos\omega_2 t\right) + a_2 V_0^{\,2}\left(\cos\omega_1 t + \cos\omega_2 t\right)^2 + a_3 V_0^{\,3}\left(\cos\omega_1 t + \cos\omega_2 t\right)^3 + ...$$

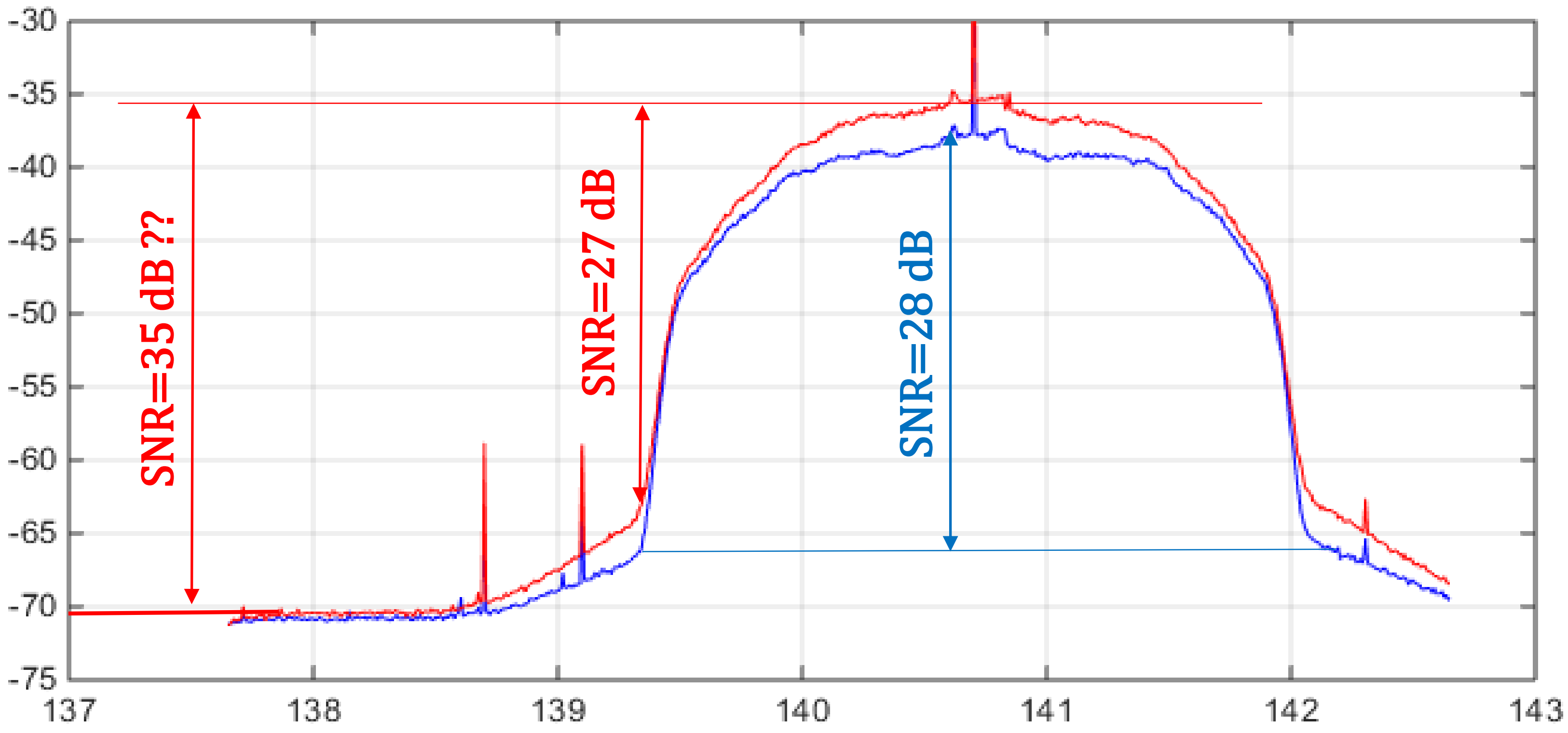




You need to back off from Output P1dB point!

The higher is the order of the modulation the higher is the requirement for linearity in the Transmitter.

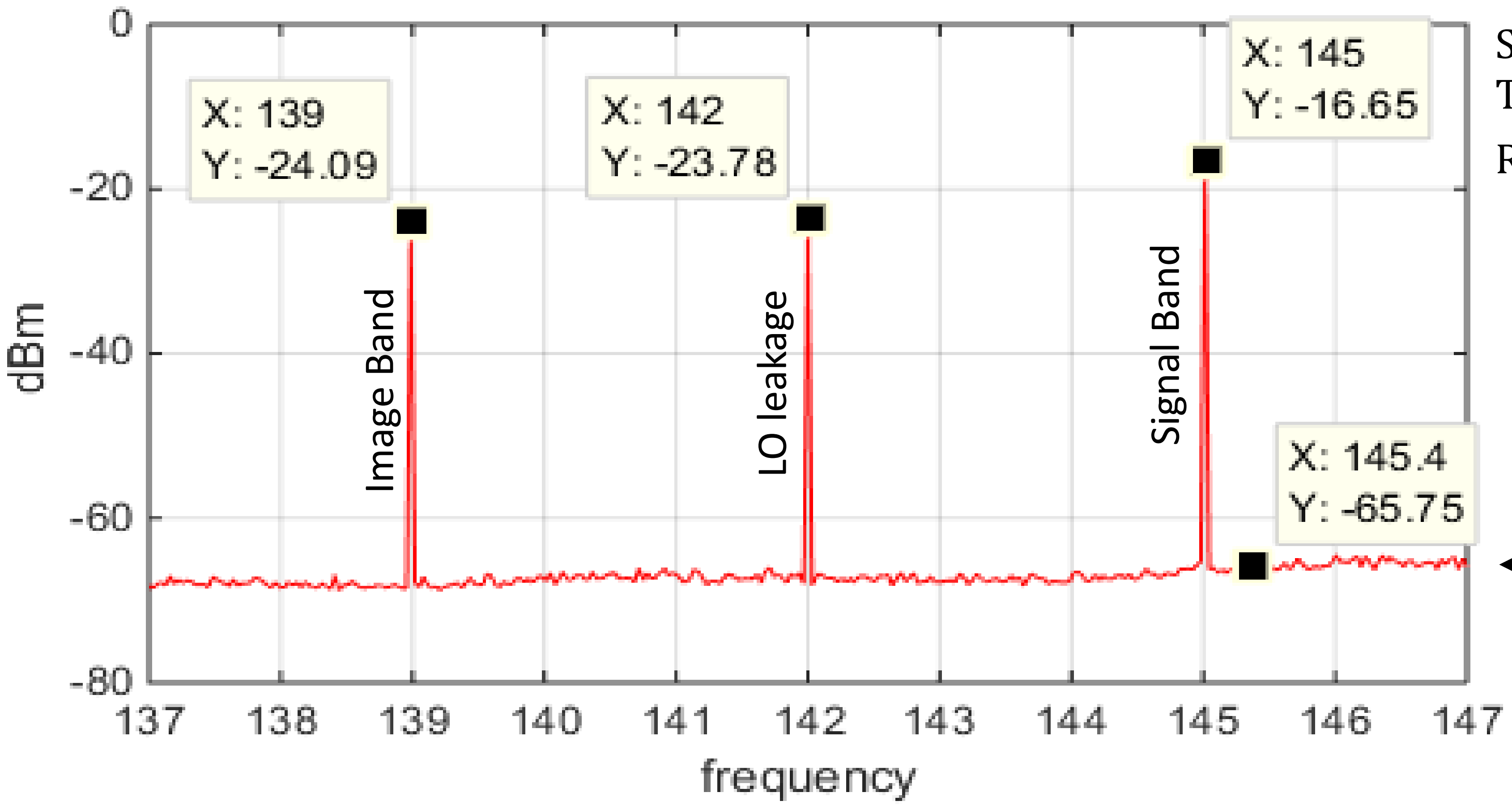
Effects of HW imperfections – example 1 nonlinearities in Tx



Spectrum at the output of an IQ Transmitter for a modulated signal for 2 different input powers

More transmitted power does not mean higher SNR because…

Effects of HW imperfections – example 2



Spectrum at the output of an IQ Transmitter for CW input

RBW of the spectrum analyzer = 1MHz

T=19 MK for RBW 1MHz
We need 48 dB path loss before Tx Noise=Rx Noise

SNR=49 dB at the transmitter !! This SNR does not account the receiver noise
There is no way you can get SNR=52dB at the receiver.

In our SNR calculations we assumed a background noise temperature =300K, however in this example for path loss < 48 dB, the noise background will be dominated by the transmitter noise floor.

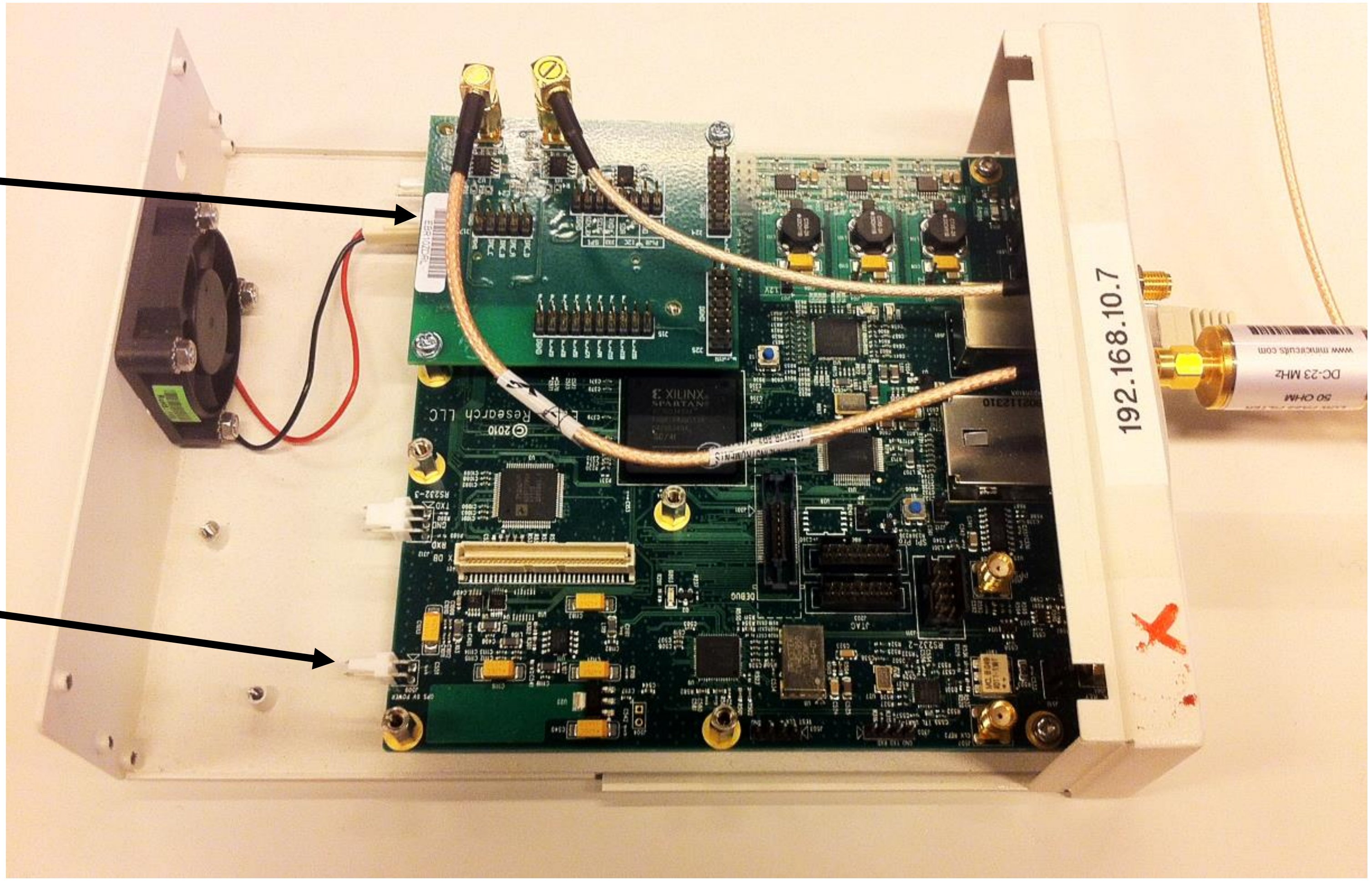
USRP hardware N210

100 MS/s dual ADC, 400 MS/s dual DAC and Gigabit Ethernet connectivity to stream data to and from host processors.

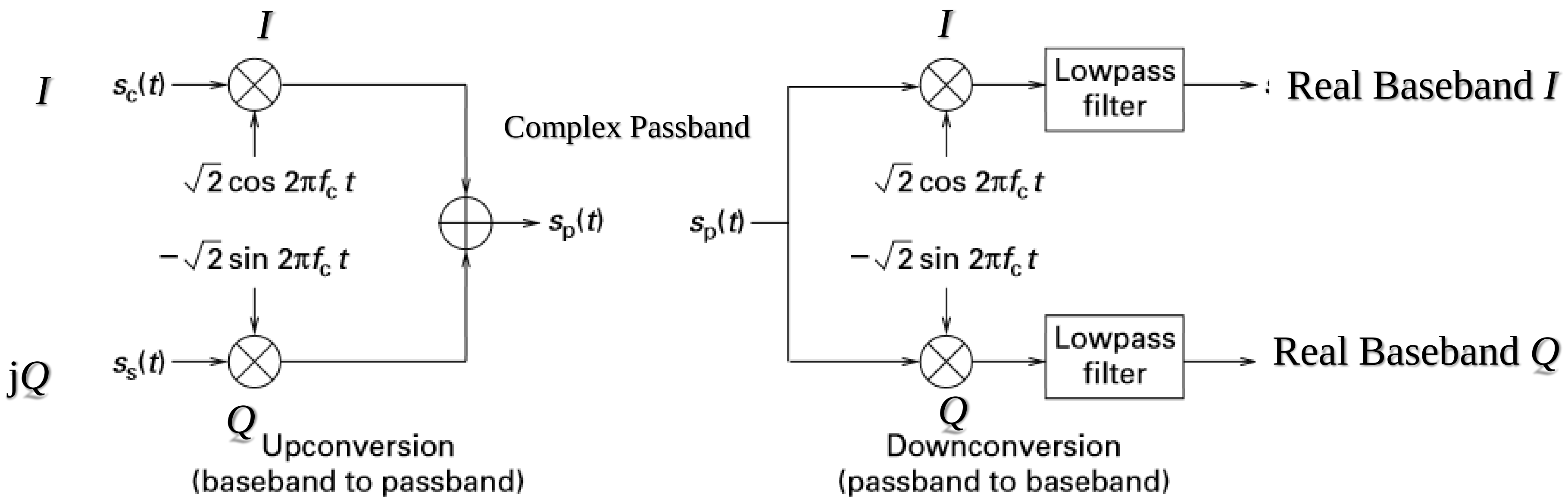
Transmitter or receiver analogue extension board. Specified from DC to 50 MHz.
OBS the board is active from DC to >100 MHz, which is > fs/2.

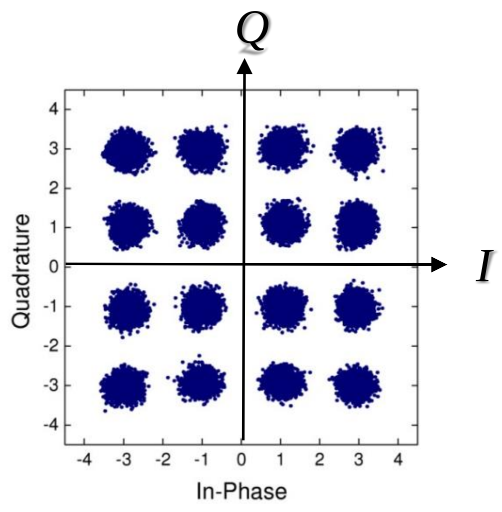
Input Signals within 50-100+ MHz will overlap with the 0-50 MHz signal. LPF might be required.

Digital motherboard, contains FPGA, AD/DA converters ...



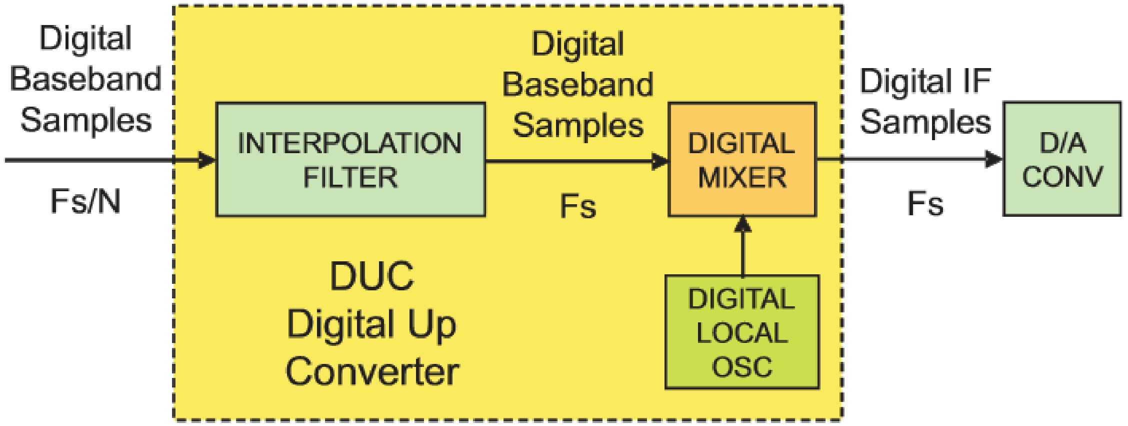
Signal constellations and IQ Mixing



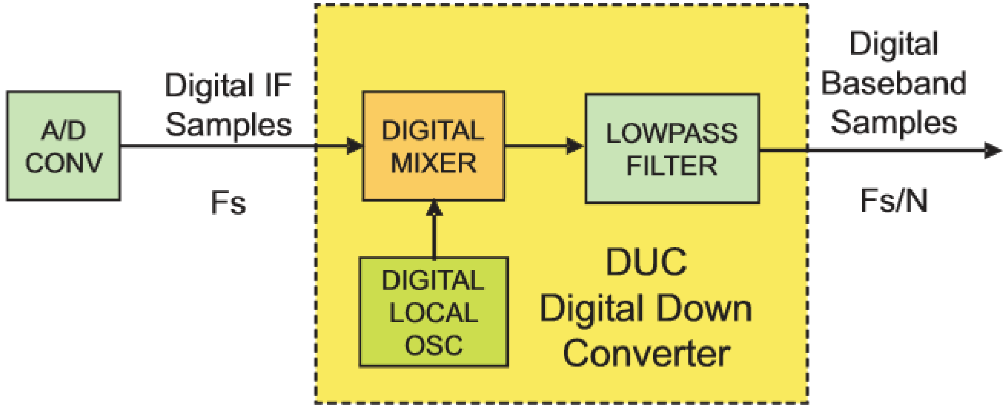


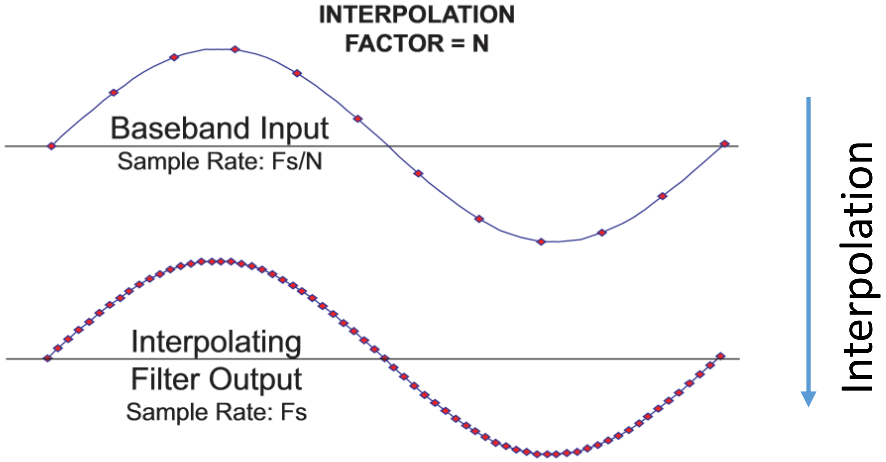
Software Radio

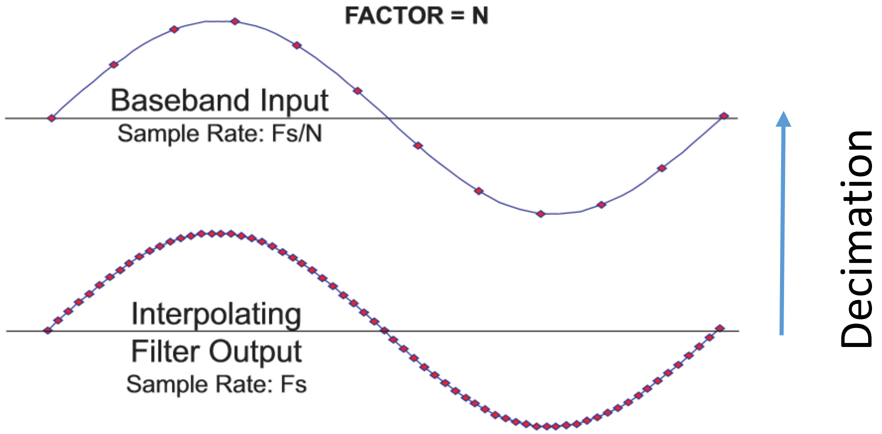
Digital Up-conversion



Digital Down-conversion



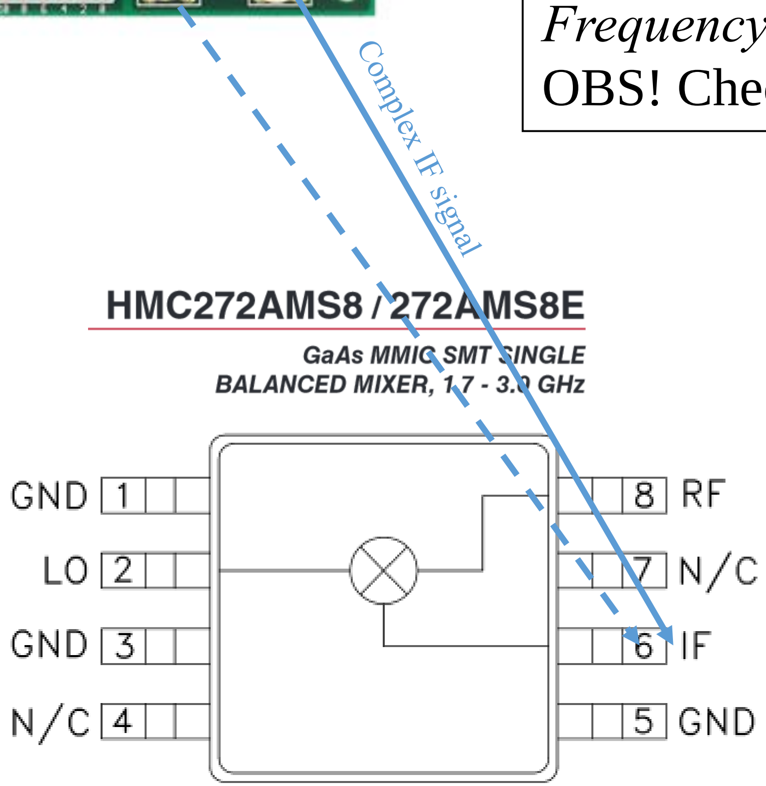


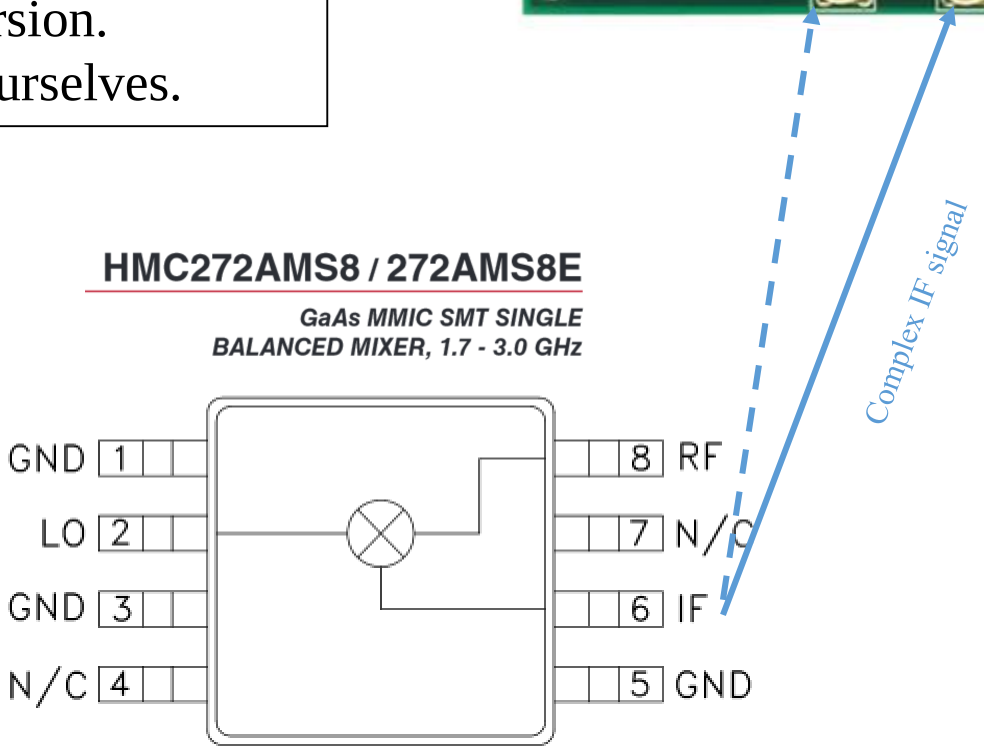


http://www.pentek.com/

Up-conversion alternatives – IQ mixing in the USRP

IQ mixing can be performed in the USRP by setting a carrier frequency up to 50 MHz. The modulated carrier is available at both outputs and can be used as an "*Intermediate Frequency*" (IF) for up-conversion.
OBS! Check this statement yourselves.





Up-conversion alternatives – external IQ mixer

Tr

Rec

Carrier frequency=0 directs the *I* and *Q* baseband signals at the outputs of the board.

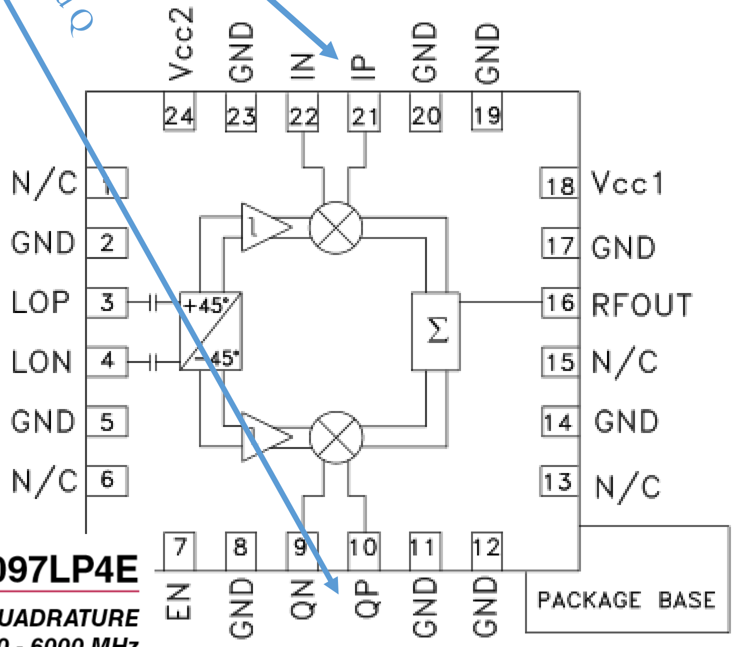
UN balanced

Base Band I

Base Band Q

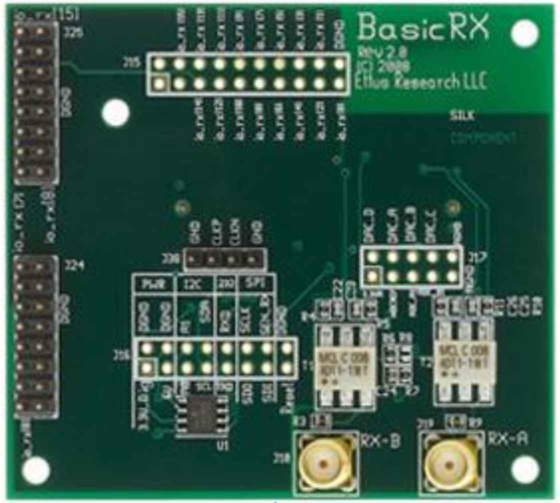
Transformer is required

Balanced



HMC1097LP4E

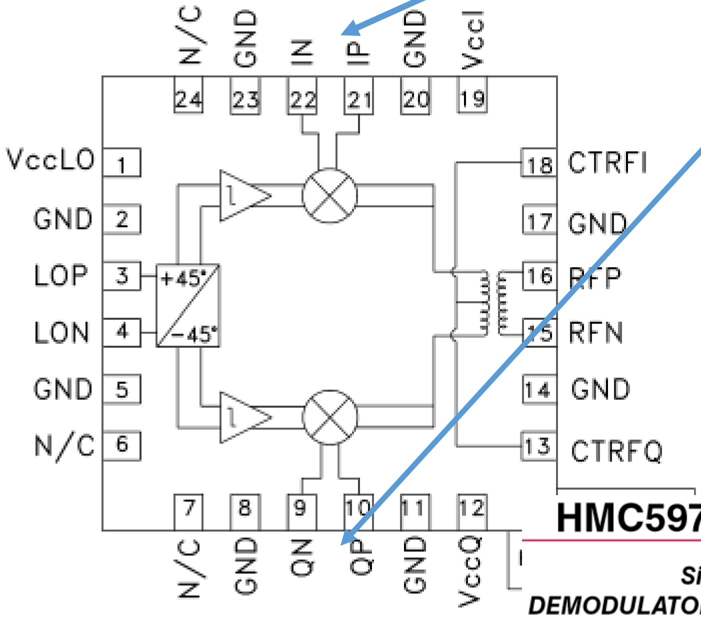
WIDEBAND DIRECT QUADRATURE MODULATOR, 100 - 6000 MHz



UN balanced

Balanced

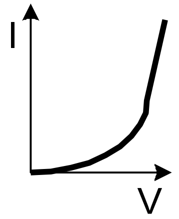
Transformer is required



HMC597LP4 / 597LP4E

SiGe WIDEBAND DIRECT DEMODULATOR RFIC, 100 - 4000 MHz

Microwave Mixers – the Double Sideband Property (DSB)



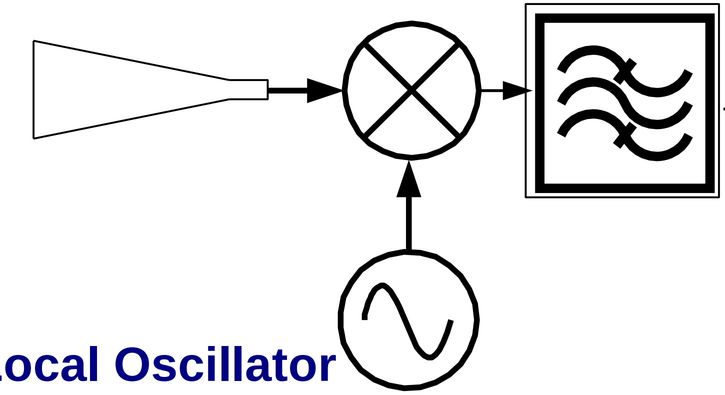
$$I(t) = a_0 + a_1 V(t) + a_2 V^2(t) + a_3 V^3(t) + ...$$

$$\left[\sin(\omega_s t) + \sin(\omega_{LO} t)\right]^2$$

$$\left[\sin(\omega_s t) + \sin(\omega_{LO} t)\right]^3$$

Radio Signal

$V_s \sin(\omega_s t)$



Local Oscillator

$V_{LO} \sin(\omega_{LO} t)$

$$\cos(2\omega_{LO} t)$$

$$\cos(\omega_{LO} t + \omega_s t)$$

RF when used as a up up-converter

$$\cos(\omega_{LO} t - \omega_s t)....$$

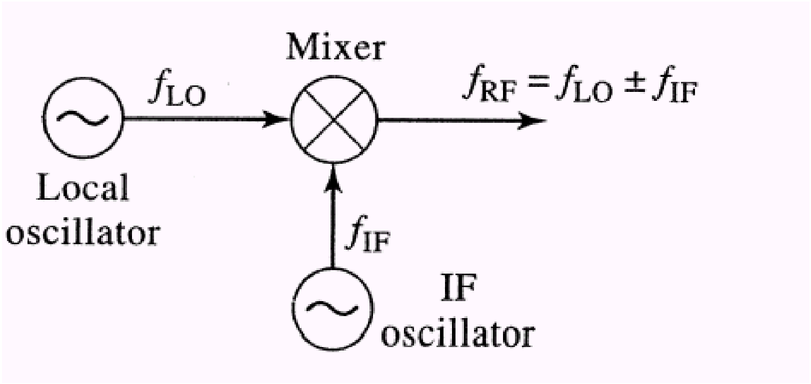
Intermediate Frequency IF
When used as a down-converter

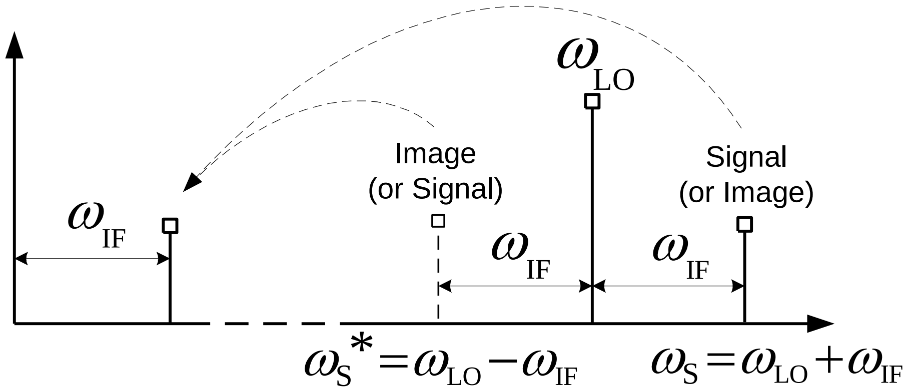
$$\cos(3\omega_{LO} t)$$

$$\cos(2\omega_{LO} t + \omega_s t)$$

$$\cos(2\omega_{LO} t - \omega_s t)...$$

Microwave Mixers – the Double Sideband Property (DSB)



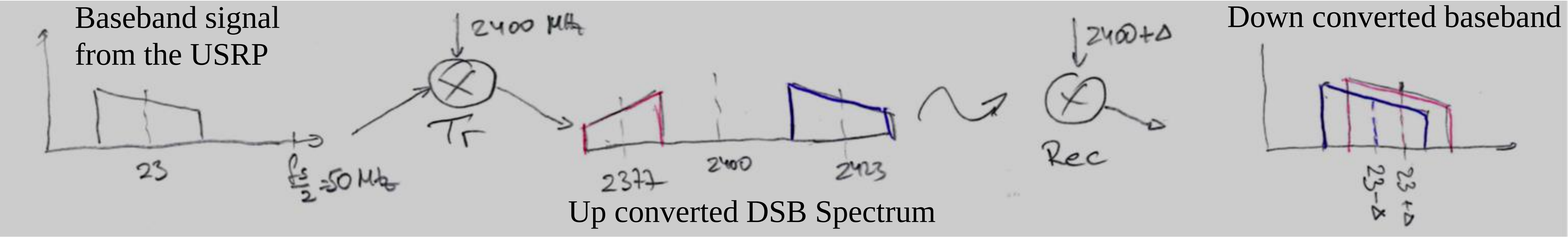


Mixers can be used as either up-converters (as in transmitters) or down-converters (in receivers).

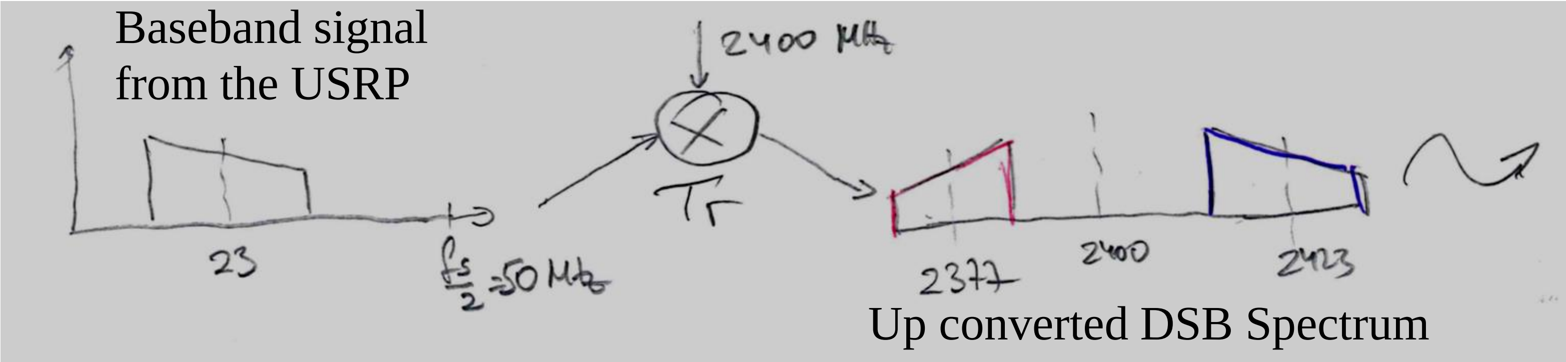
- For a specific LO frequency two RF sidebands will be **down-converted to IF**.
- Two RF sidebands will be generated under **up-conversion of the IF**.

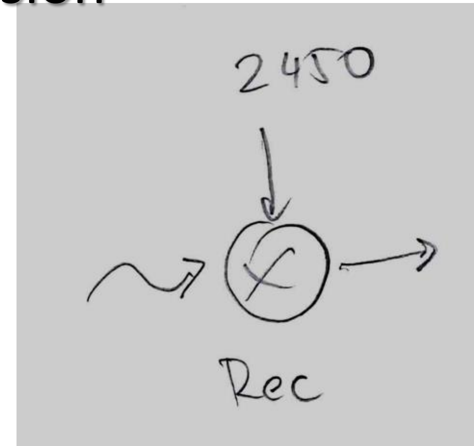
Using DSB mixers, some potential pitfalls

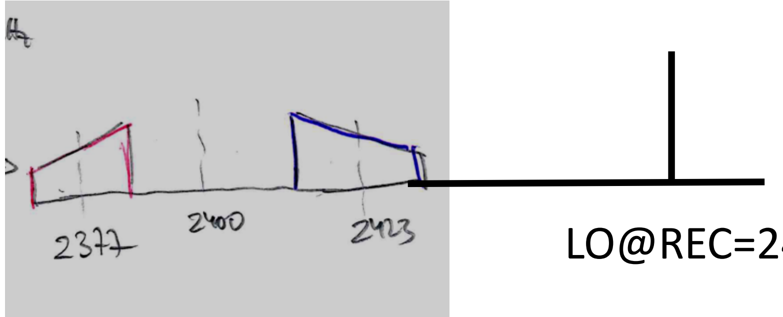
Sideband misalignment due to frequency offset in the Tr/Rec LO



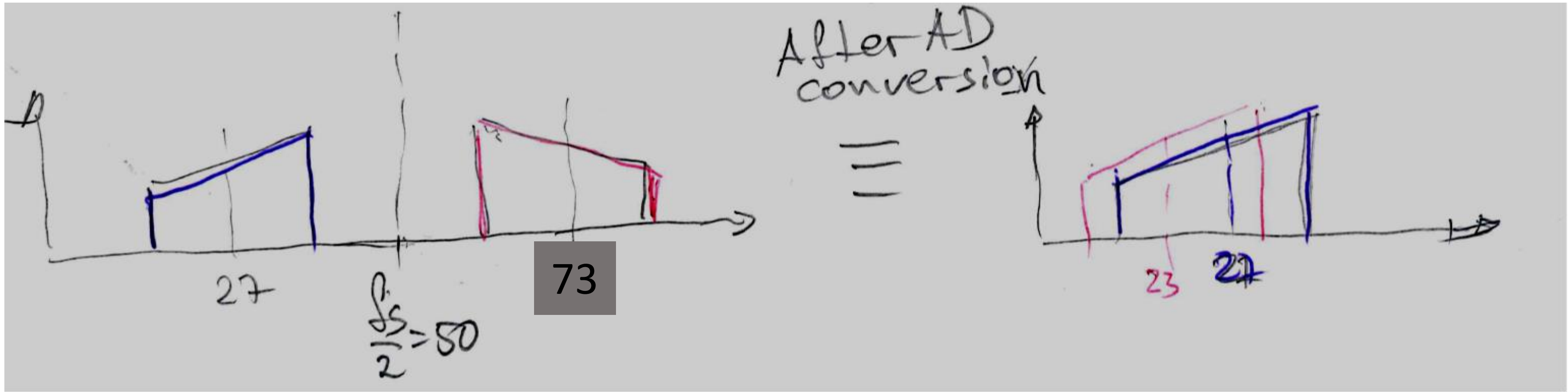
Sideband misalignment due to Aliasing in the AD conversion

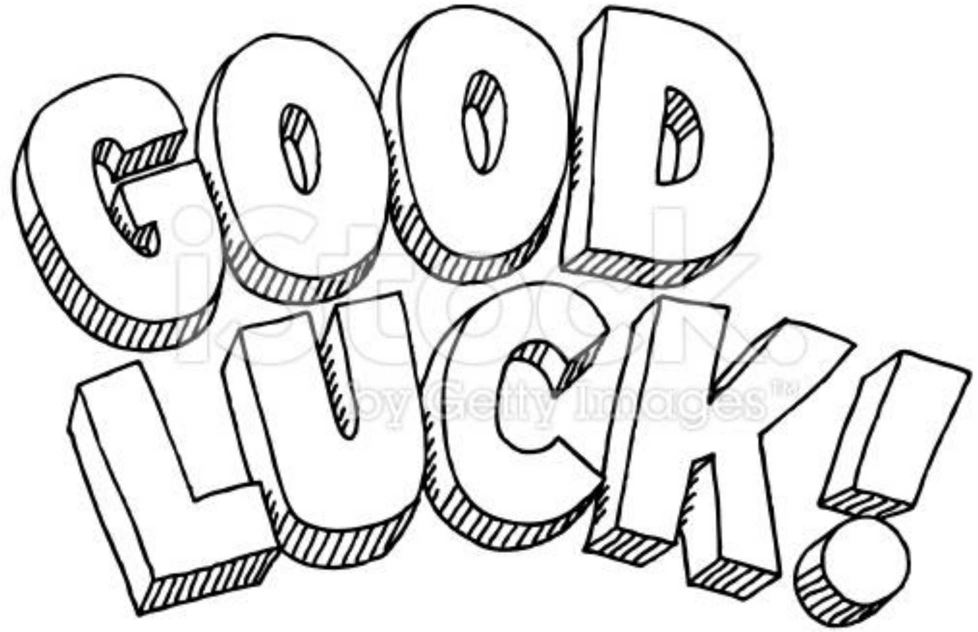






LO@REC=2450





The harder you work…

The more luck you'll get

Course evaluation

Course representatives for MCC125 Wireless link project

MPWPS	zifoo_2000@live.com	Hozaifa Abdelgadir
MPEES	rakshithamadhusudhan1999@gmail.com	Rakshitha Byadarahalli Madhusudhan
MPWPS	vikmatt@student.chalmers.se	Viktor Mattsson
MPCOM	AISHWARYASree19@gmail.com	Aishwarya Sreedhar

Grades

Even though students are graded individually each individual grade is based on the group rating. The grading system is based on maximum 100 points divided as following:

Group grade		***70%***
	Link functionality	
	Report and Presentations	
	Link Performance	
Individual grade		***+/-30%***
	TA feedback	
	Report/Presentation (on individual level)	
	Log book	
	Self Evaluation	

Self-evaluation:

- ✓ Collaboration
- ✓ Commitment
- ✓ Technical understanding
- ✓ Availability

	Not Passed	Three	Four	Five
Marks	<40	40-60	60-80	80- >100

- ➢ You are required to divide the work so that each student is responsible for a certain part of the project and it's reporting.
- ➢ Students are expected to be aware of others work and help each other when necessary.
- ➢ Keep a time log of the hours spent on the project and the task they have been working on and also indicate which part of the reporting they contribute to.