Lecture 6: Mixer (*Frequency Converter*)

Prof. Mohammed Hawa
Electrical Engineering Department
The University of Jordan

Meaning of Mixer

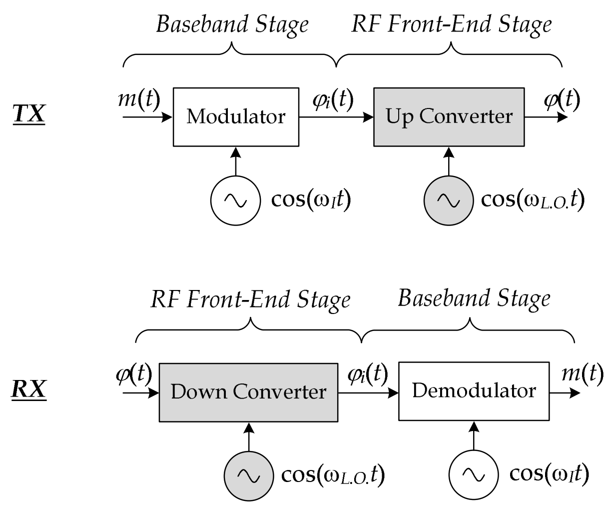
- Frequency converter is commonly called a **mixer**, but do not confuse it with a multiplication device.
- Frequency converter is **not** a demodulator.
- Frequency converter is **not** a modulator.
- **Up converter** takes you from *low* input frequency to *high* output frequency.
- **Down converter** takes you from *high* input frequency to *low* output frequency.

Heterodyne: Multiple Frequencies

- Typical **transmitters** do not modulate immediately from baseband to carrier frequency ω_c. Rather, they modulate to an *intermediate frequency* ω_I, then an up-converter shifts the frequency to the higher frequency ω_c.
- Also, real-life **receivers** do not demodulate immediately from carrier frequency ω_c to baseband. Rather, they use a down-converter to shift the modulated signal to an *intermediate frequency* ω_I, then demodulate to baseband.
- This has advantages, especially in FDM systems and digital systems (see later).

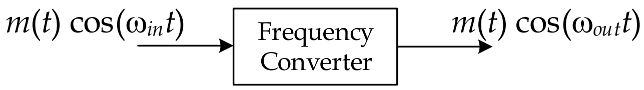
 Electrical Engineering Department, The University of Jordan 3

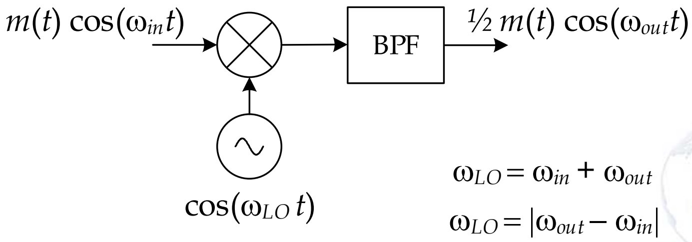
Frequency Conversion



 Electrical Engineering Department, The University of Jordan 4

Frequency Converter Hardware





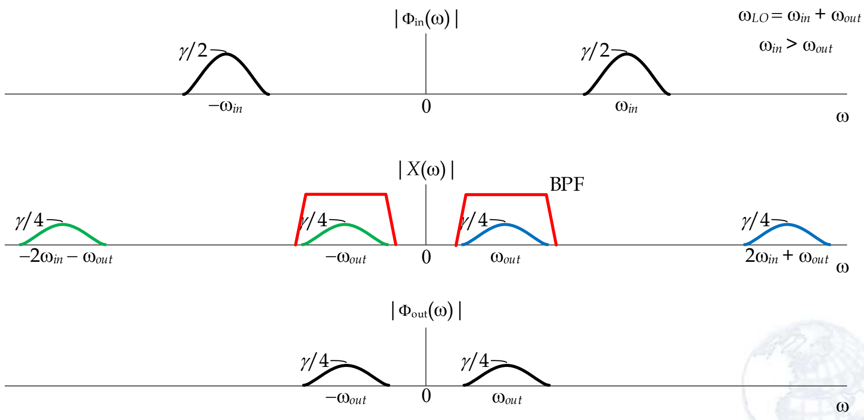
$\omega_{LO} = \omega_{in} + \omega_{out}$

$\omega_{LO} = |\omega_{out} - \omega_{in}|$

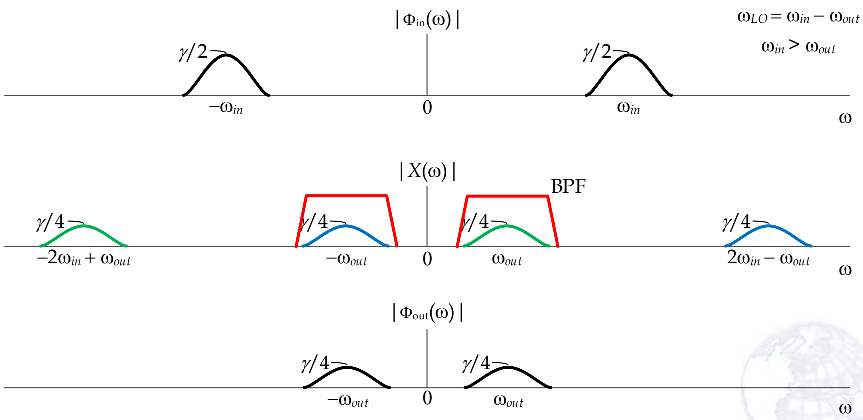
Examples

Input frequency f_{in}	Output frequency f_{out}	Device Type	L.O. frequency
300 MHz	100 MHz	Down converter (*sum*)	400 MHz
300 MHz	100 MHz	Down converter (*difference*)	200 MHz
100 MHz	300 MHz	Up converter (*sum*)	400 MHz
100 MHz	300 MHz	Up converter (*difference*)	200 MHz

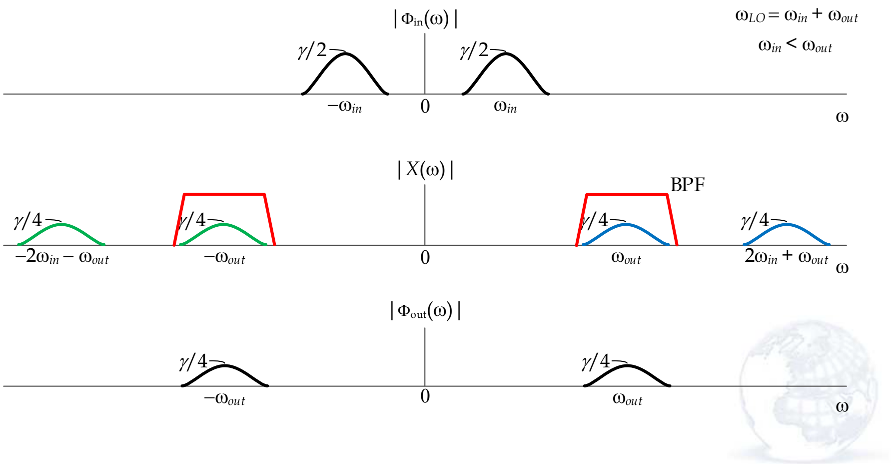
Frequency Converter
(Down Converter, Sum)



Frequency Converter
(Down Converter, Difference)

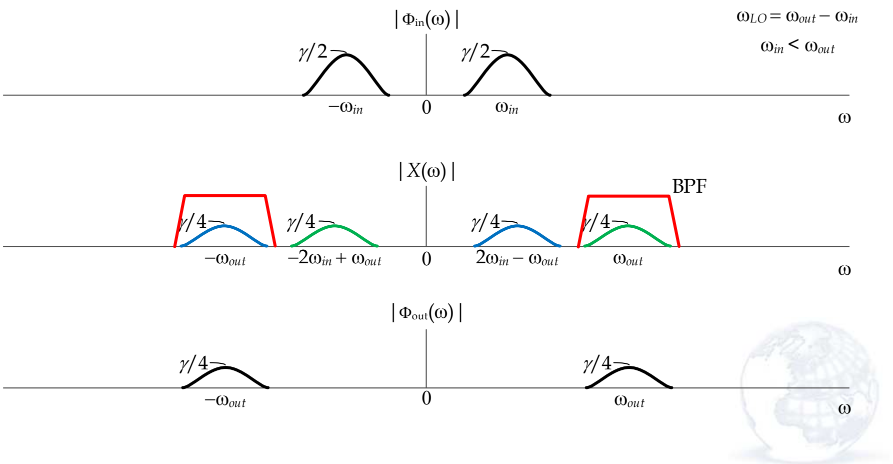


Frequency Converter
(Up Converter, Sum)



 Electrical Engineering Department, The University of Jordan 9

Frequency Converter
(Up Converter, Difference)



 Electrical Engineering Department, The University of Jordan 10

Homework 1

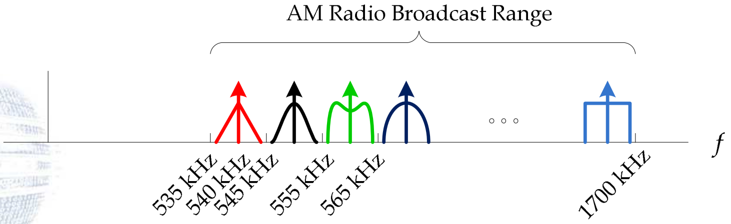
- Repeat the four cases above for SSB-SC (USB) input modulated signal:
  - Up converter, Sum
  - Up converter, Difference
  - Down converter, Sum
  - Down converter, Difference
- Find k in the output signal:
  $y(t) = k\ \varphi_{SSB-SC}(t)$
- Provide specifications for the BPF to be used.

Multiplexing: FDM

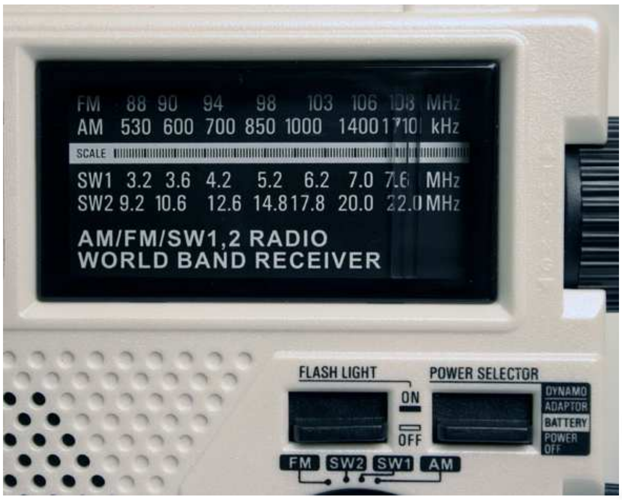
- Frequency Division Multiplexing (**FDM**) is a process that allows the transmission of several signals over the same channel at the same time.
- This is achieved by modulating the different signals on different carriers with different **carrier frequencies**.
- The receiver isolates one signal from the rest using a **tuneable BPF**.

AM Radio Broadcasting

- Each station is an AM modulation of human voice.
- FDM is used to multiplex signals on the air waves.
- **US:** Each station occupies a bandwidth of 10 kHz.
- **Europe:** Each station occupies a bandwidth of 9 kHz.



HW: Look at Your Radio Dial

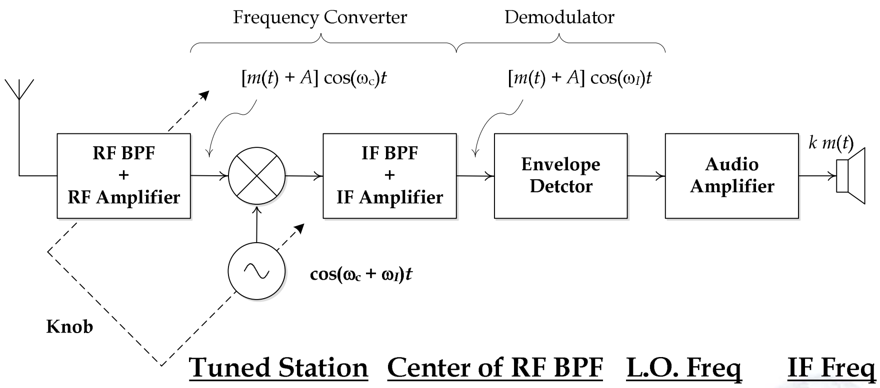


The Superheterodyne Receiver

- Receivers in FDM system require a BPF.
- It is extremely difficult (*expensive*) to design highly selective (*narrowband*) filters at **high** center frequencies.
- This is specially true if the filter is **tuneable**.
- Solution: Use a two-stage filtering process, one of which at lower frequency.

 Electrical Engineering Department, The University of Jordan

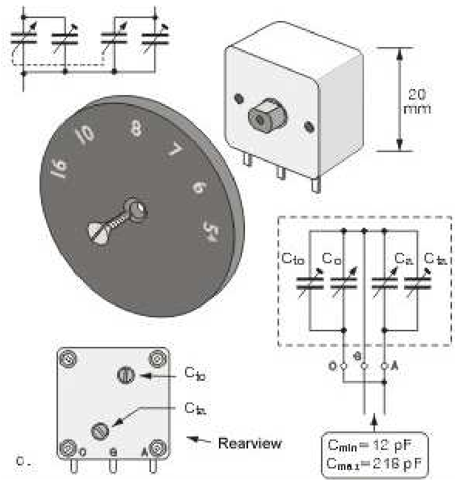
AM Superheterodyne Receiver



Tuned Station	Center of RF BPF	L.O. Freq	IF Freq
1000 kHz	**1000 kHz**	**1455 kHz**	**455 kHz**
1020 kHz	1020 kHz	1475 kHz	455 kHz
1500 kHz	1500 kHz	1955 kHz	455 kHz

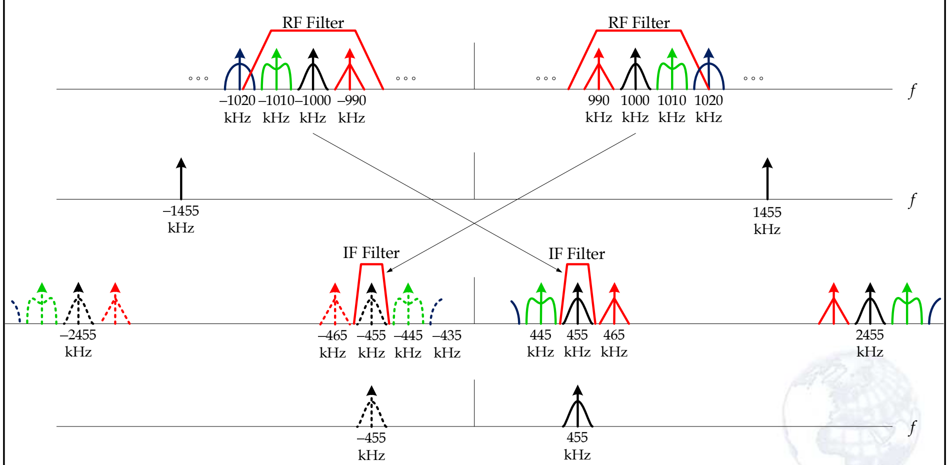
 Electrical Engineering Department, The University of Jordan

Ganged Capacitor



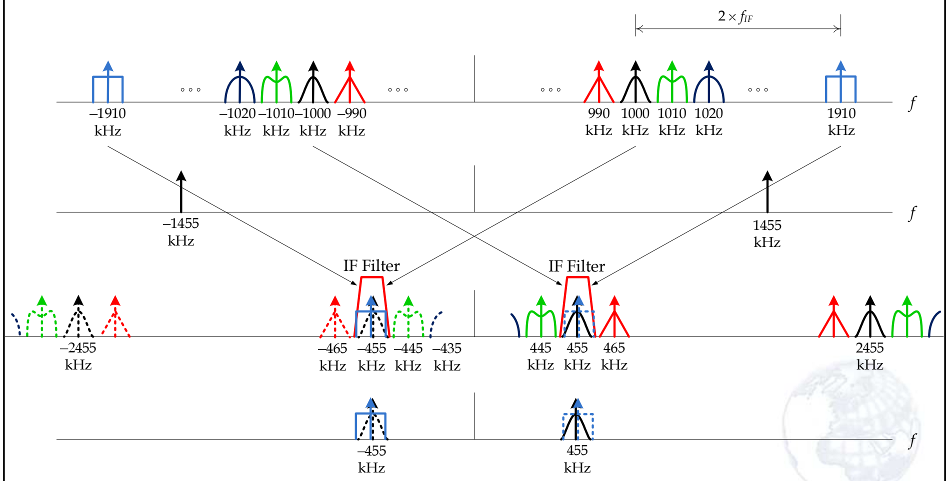
 Electrical Engineering Department, The University of Jordan 17

Image Station Problem



 Electrical Engineering Department, The University of Jordan 18

Image Station (*Part* 2)



 Electrical Engineering Department, The University of Jordan

Superheterodyne *Why*'s

- *Why* the RF Filter?
  - Eliminates the *image station*.
  - Reduces the amount (power) of noise that enters the receiver.
- *Why* the IF Stage (heterodyning)?
  - With its high-selectivity and lower price, the IF filter isolates the desired radio station from all others sent using FDM.
  - Since the IF frequency does not change with the tuned station, it is easier to design the E.D.

 Electrical Engineering Department, The University of Jordan

Superheterodyne *Why*'s

- *Why* the sum, not difference?
- The sum (as opposed to the difference) in the receiver results in a smaller tuning range ratio, which requires a smaller tuning capacitor for the local oscillator.
- Hence, this solution is cheaper.

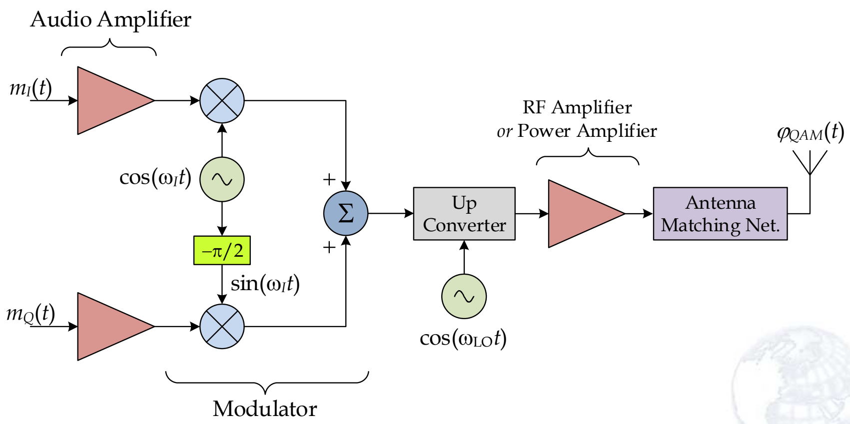
Homework

- Now design a superheterodyne receiver, but this time using the difference for L.O.:
  - If you want to listen to the station at 1000 kHz what settings should you choose for the RF BPF, the oscillator, and the IF BPF?
  - Repeat the same problem if you want to listen to the 1020 kHz and 1500 kHz stations.
  - What is the frequency of the image station if you are listening to the station at 1000 kHz?

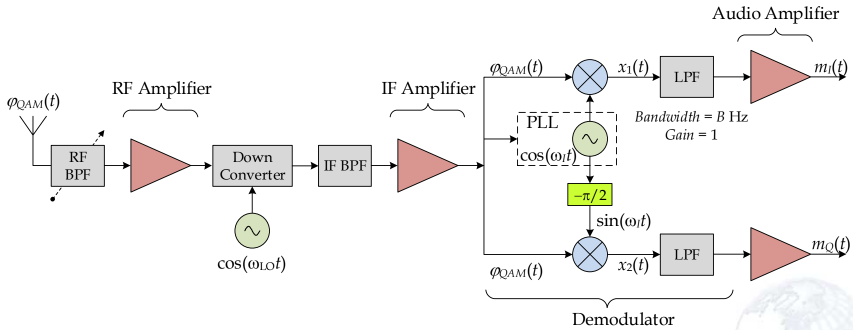
Superheterodyne *Everywhere!*

- The superheterodyne receiver is much more popular nowadays compared to the homodyne receiver.
- It is used in many communication systems including: FM Radio, Analog and Digital TV broadcasting, Cellular phones, WiMAX, Satellite and Microwave systems, GPS, etc.

Full Transmitter

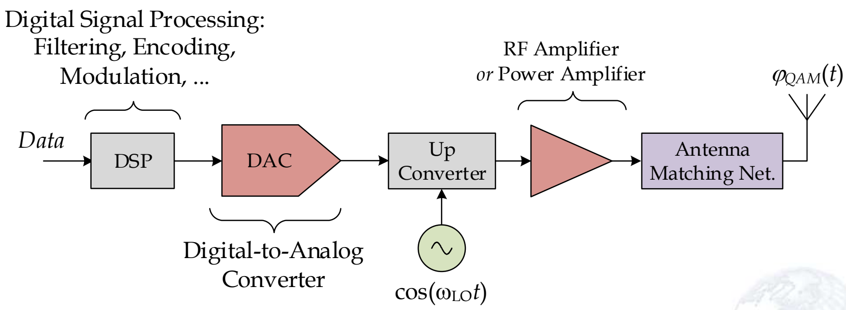


Full Receiver



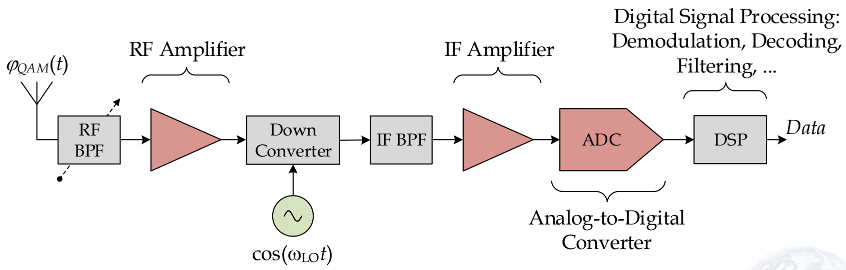
 Electrical Engineering Department, The University of Jordan 25

Full Transmitter with DAC



 Electrical Engineering Department, The University of Jordan 26

Full Receiver with ADC



Homework

Solution: *Not in the Exam*

Supply		Block		Local oscillator frequency	Intermediate freq. range
Voltage	Tone	Polarization	Frequency band		
13 V	0 kHz	Vertical	10.70–11.70 GHz, low	9.75 GHz	950–1,950 MHz
18 V	0 kHz	Horizontal	10.70–11.70 GHz, low	9.75 GHz	950–1,950 MHz
13 V	22 kHz	Vertical	11.70–12.75 GHz, high	10.60 GHz	1,100–2,150 MHz
18 V	22 kHz	Horizontal	11.70–12.75 GHz, high	10.60 GHz	1,100–2,150 MHz

Mixer Performance Parameters

- The frequency converter design can apply tradeoffs for different performance parameters:
- Conversion loss (*opposite* of gain).
- Noise figure.
- Image rejection ratio.
- Harmonic content: Mixing is sometimes achieved using nonlinear devices and/or processes, thus generating extra undesired harmonics (tones), not just the ones of interest.

Conversion Loss

- Measures loss of power in device. Ratio of average power of input signal to that of output signal after mixing. Typically expressed in dB.

$$L_c = 10\log_{10}\left(\frac{P_{in}}{P_{out}}\right) = -10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

- Similar to attenuation, but positive:

$$Attenuation = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

- A mixer with conversion loss of 3 dB loses half the power from the input signal as it moves to the output.

Noise Factor

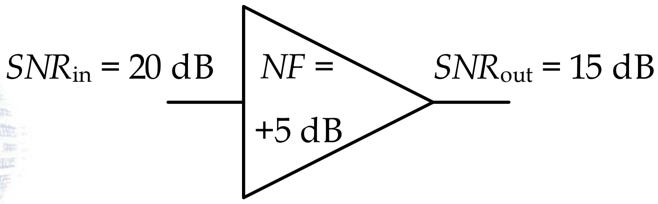
- Measures *degradation* of the quality (SNR) caused by components in the device.
- Noise factor is the ratio of SNR at the input to SNR at the output (typically using input noise generated by a resistor at standard temperature, 290 K = 16.85°C).

$$Noise\ Factor \triangleq \frac{SNR_{in}\ \text{(unitless)}}{SNR_{out}\ \text{(unitless)}}$$

Noise Figure, NF

- Noise Figure (NF) is Noise Factor but expressed in dB:

$$NF \triangleq SNR_{in}(dB) - SNR_{out}(dB)$$



 Electrical Engineering Department, The University of Jordan 33

Image Rejection Ratio, IRR

- Measures the ability of the mixer to reject the image signal. This is typically decided by the design of the input RF BPF.
- If the applied image and intended signal powers are the same, and the power of the output signal (at IF) is P_{out}, while the power of the image signal from the mixer at the output is $P_{out,image}$, then

$$\mathrm{IRR} = 10\log_{10}\left(\frac{P_{out}}{P_{out,image}}\right)$$

 Electrical Engineering Department, The University of Jordan 34

Example

- A mixer has LO frequency of 10 GHz. The mixer converts an RF signal at 10.1 GHz to IF at 100 MHz, and has a conversion loss of 3 dB and IRR of 20 dB.
- Two signals are presented to the mixer, one at 10.1 GHz with power of 100 nW and the other at 9.9 GHz with power of 1 μW.
- Find power of (intended) output signal at IF.
- Find signal-to-interference ratio at IF (ignoring noise).

 Electrical Engineering Department, The University of Jordan 35

Solution [1]

$$L_c = 3 \text{ dB} = 2 \text{ unitless}$$

- Output power of (intended) signal

$$P_{out} = \frac{P_{in}}{L_c\ \text{(unitless)}} = \frac{100 \text{ nW}}{2} = 50 \text{ nW}$$

- *Or*

$$P_{out}(\text{dBm}) = P_{in}(\text{dBm}) - L_c(\text{dB})$$

$$P_{out}(\text{dBm}) = -40 \text{ dBm} - 3 \text{ dB} = -43 \text{ dBm}$$

 Electrical Engineering Department, The University of Jordan 36

Gain, Power	Gain in dB
1 (no gain)	0 dB
2 (twice the power)	≈ +3 dB
10 (ten times the power)	+10 dB
100	+20 dB
1000	+30 dB
10000	+40 dB

Attenuation, Power	Attenuation in dB
0.5 (half the power)	≈ -3 dB
0.25 (quarter the power)	≈ -6 dB
0.1 (tenth the power)	-10 dB
0.01 (one hundredth)	-20 dB
0.001 (one in a thousand)	-30 dB
0.0001 (one in 10 thousand)	-40 dB

Solution [2]

IRR = 20 dB = 100 unitless

- If powers of intended signal and image are the same, then image (interference) power is:

$$P_{out,image} = \frac{P_{out}}{\text{IRR (unitless)}}$$

- To account for difference in power levels

$$P_{out,image} = \frac{P_{out}}{\text{IRR (unitless)}} \times \frac{P_{in,RF,image}}{P_{in,RF,signal}}$$

$$P_{out,image} = \frac{50\text{ nW}}{100} \times \frac{1\ \mu\text{W}}{100\text{ nW}} = 5\text{ nW}$$

Solution [3]

- Can also use dB (subtraction and addition):
  $P_{out,image}(\text{dBm})$
  $= (-43\ \text{dBm}) - 20\ \text{dB} + \big(-30\ \text{dBm} - (-40\ \text{dBm})\big)$
  $= -53\ \text{dBm}$

- Hence,
  $$\text{SIR (unitless)} = \frac{P_{out}\ \text{(unitless)}}{P_{out,image}\text{(unitless)}} = \frac{50\ \text{nW}}{5\ \text{nW}} = 10$$
- Same as,
  $$\text{SIR (dB)} = -43\ \text{dBm} - (-53\ \text{dBm}) = 10\ \text{dB}$$

