Superheterodyne receiver

Heterodyning: translation of the signal from higher Radio Frequency (RF) to lower Intermediate Frequency (IF)

*The reason: to facilitate filtering and demodulation

*Three important frequencies of the superheterodyne RX:

RF - Radio Frequency. The central frequency of the RF signal
IF - Intermediate frequency. The frequency at which the signal is processed
LO - Local Oscillator. Frequency of the local oscillator used for down conversion

Satellite RX use heterodyning. The RX may be single conversion or double conversion. Single conversion - single IF. Double conversion - two IF frequencies

Single conversion SH receiver.

**Diagram:**

- LNA
- BSF
- Band selection
- RF Section
- IF Amplifier
- Channel selection
- IF Section
- Dewd
- IF - Message signal
- Baseband

BSF - Band selection filter, IFF - IF filter
Two possibilities for $\phi_L$:

$\phi_L = \phi_R + \phi_I$ - high side injection

$\phi_L = \phi_R - \phi_I$ - low side injection

Hahmowahal properties:

RF signal: $S_{RF1} = A_H \cos(2\pi f_{RF} + \phi_{RF})$

LO signal: $S_{LO1} = A_L \cos(2\pi f_{LO} + \phi_L)$

Let $\phi_L = \phi_R - \phi_I$

After mixing stage:

$X_{LO1} = S_{RF1} \cdot S_{LO1} = A_H \cos(2\pi f_{RF} + \phi_{RF}) \cdot A_L \cos(2\pi f_{LO} + \phi_L)$

$X_{LO1} = \frac{1}{2} A_H A_L \cos(2\pi (f_{RF} + f_{LO}) - \phi_{RF} + \phi_{LO}) + \frac{1}{2} A_H A_L \cos(2\pi (f_{RF} - f_{LO}) + \phi_{LO} + \phi_{RF})$

Bandpass filter at the IF eliminates the double frequency component, and therefore,

$Y_{IF1} \sim k \cdot A_H \cdot \cos\left[2\pi (f_{RF} - f_{LO}) + \phi_{RF} + \phi_{LO} + \phi_{LO}\right]$

$= k \cdot A_H \cdot \cos\left[2\pi f_{IF} + \phi_{LO} + \phi_{RF}\right]$ - Signal is shifted to IF.

In digital receivers, the signal at IF is amplified and then sampled. The demodulation and signal processing tasks are performed in DSP/FPGA software/hw.
Double conversion SIF receiver.

* Double conversion uses the same principle as single conversion.
* Double conversion is common for higher frequency bands Ka, or even Ku.
* First and second IF stages may be physically separated, with the first stage located as close to the antenna as possible.

**Downlink Link Budget**

Link budget is a tabular way of evaluating the link (sometimes referred to as the power budget).

Downlink

- Satellite to the ground dish/chim
  - Usually limiting link in satellite communications

There are several ways of doing link budget.

In this case, we adopt a "receiver power based" link budget.
4 Schemes of the link budget

1. Transmitter section
   - PA power
   - PA backoff
   - cabling, filtering
   - antenna gain

\[ \Rightarrow \text{EiRP on the TX side} \]

PA - power. Satellite transponders use Traveling Wave Tube Amplifiers (TWTAs). PA power is the maximum power that can be put out by the TWTA.

PA backoff

\[ \text{PAPR - Peak to average power ratio} \]

\[ \text{peak of the signal} \]

\[ \text{average power of the signal} \]
The average power of the amplifier needs to be smaller than peak.
The power needs to be "backed off" for PAPR to make sure that the amplifier operates in the linear region of its transfer curve.
The backoff depends on the characteristics of the signal waveform.
Workforms with small PAPR are preferred.
If TWTA operates in a nonlinear region:
+ Spectra regrowth
+ Distortion of the amplified signal

The link needs to be dimensioned for the use at the edge of the coverage region of the antenna — in broadcast links.
Therefore:

\[ E_{RP} = P_t [\text{dBW}] + G_{tx} [\text{dB}] - B_0 [\text{dB}] - L_{ant} [\text{dB}] - L_e [\text{dB}] \]

- \( P_t [\text{dBW}] \): average TX power at the output of the amplifier.
- \( G_{tx} [\text{dB}] \): gain of the satellite antenna.
- \( B_0 [\text{dB}] \): backoff in dB.
- \( L_{ant} [\text{dB}] \): loss of antenna gain at the edge of the coverage.
- \( L_e [\text{dB}] \): losses of cabling at the TX side.

2) RX Section

* RX Sensitivity
* \( T_s \): System noise temperature
* Cabling losses
* Figure of merit \( G/T \)
* RX Antenna gain

Required S/N ratio for digital systems:

\[ (S/N)_{\text{ req}} = 10 \log (10^{B R}) + 10 \log (10^B) + 10^H \text{ [dB]} \]

- \( B \): bit rate, \( B \): bandwidth
- \( H \): Implementation factor margin

**RX Sensitivity** - minimum signal level required for operation of the RX

\[ RX_{\text{Sensitivity}} = 10 \log \left[ 10 \log (T_s + T_{in}) \cdot B \right] + (S/N)_{\text{req}} [\text{dB}] \]

- \( T_s \): System noise temperature.
- \( T_{in} \): Temperature of the noise entering the receiver.
- \((S/N)_{\text{req}}\): Required signal to noise ratio (function of the used waveform and error control coding).
$T_{in} = T_a \cdot G_c + T_p \left( \frac{1}{G_c} - 1 \right)$

$T_a$ - temperature of the noise coming from the antenna.
$G_c$ - gain of the connecting cable
$T_p$ - physical temperature of the cable

Rx Sensitivity is defined at the input of the RX

Example. Consider a receiver with equivalent $T_s = 150k$. The receiver is connected to the antenna with a waveguide having a loss of 0.5 dB and physical temperature of 270k. Used waveguide assures bandwidth of 20 MHz and S/N ratio of 9.5 dB. Calculate the RX sensitivity. If the temperature of the sky is 75k.

$T_{in} = T_a \cdot G_c + T_p \left( \frac{1}{G_c} - 1 \right)$

$G_c = \frac{10^{-0.5/10}}{10} = 0.89$

$T_{in} = 75k \times 0.89 + 270k \left( \frac{1}{0.89} - 1 \right) = 109.26k$

$\text{Rx Sensitivity} = 10 \log \left[ \frac{k (T_{in} + T_s) B}{(S/N)_{rez}} \right]$

$= 10 \log \left[ \frac{1.38 \times 10^{-23} \cdot (10926k + 150k) \cdot 27 \times 10^6 \text{ Hz}}{10^{-0.5/10}} \right] + 9.5 \text{ dB}$

$= -120.65 \text{ dBW} \quad (-90.65 \text{ dBm})$

$\text{RSL}_A$ The RX sensitivity is defined at the input of the receiver. Sometimes the sensitivity is wanted to the point before the antenna.

$\text{RSL}_A = \text{Rx Sensitivity} + G_c - G_{RX}$

In satellite communication $\text{RSL}_A$ is less commonly used - changes due to the noise.
temperature of the sky...

3) Propagation section

Propagation losses consist of

* Free space losses
* Atmospheric losses (clear sky)
* Losses due to unfavourable atmospheric conditions

4) Reliability & Margin calculations

* This is a separate calculation
* Used to determine the margins that guarantee a certain level of system reliability
* This will be addressed in following chapters

Sections 1-4 are usually put together in a tabular Excel format
* Analyze spreadsheet provided in the class.
  - Focus on Sections 1-4.