3. Radio Receivers (RR) General aspects

3.1 RR: Functions and Specific Performance Parameters

- The main function of a receiver is to successfully demodulate the desired signal in the presence of noise and interferences.

- To be recalled that the power of the received signal depends on the distance between the transmitter and the receiver and on the environment.

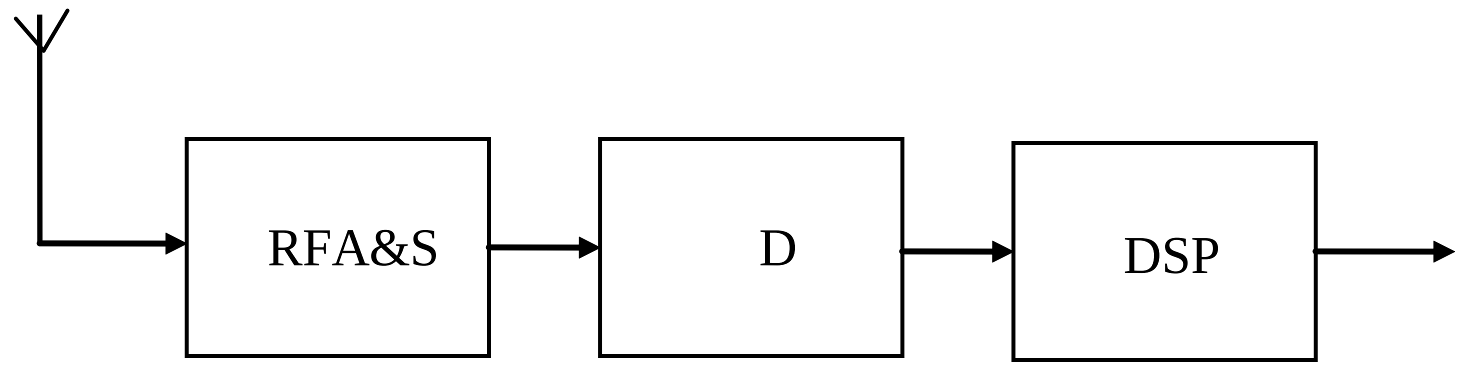
- As such, the RF power at the input of a receiver can vary from a few femtowatts to microwatts.

- In other words, the RR has to possess a very large dynamic range.
- Apart from assuring the dynamic range and the imposed quality, parameters which depend on the noise performances of the RR, a reception system should minimize the cost and the power consumption.
- The compromise between the technical and economical solutions makes from the design of a performant receiver a complex problem.

- Analyzing the role of the receiver, it results that the main signal processing steps that have to be performed are:

  - Selection of the desired EMW,
  - Amplification of the modulated signal,
  - Demodulation,
  - Demodulated signal processing.

- Starting from these processing steps, a very general block diagram of a RR can be imagined.



- This block diagram can be implemented using different architectures in order to fulfil the requirements imposed by both analog and digital communication systems;

- As it is going to be discussed in this chapter, differences can be identified between the two types of communication systems (A and D), both from the architecture and from the used technologies points of view;

- It is also to be noticed that digital communication systems are more and more widely used;

- Regarding the block diagram, it has to be highlighted that the RFA&S block (Selective RF amplifier) has always before its input, a **band pass filter** more or less complex;

- This filter has the role of reducing as much as possible the level of the unwanted signals located outside the band occupied by the desired signal;

- In order to evaluate the level of performance for the functions performed by the RR some specific parameters were defined:
  - Sensitivity (minimum detectable signal – MDS);
  - Selectivity;
  - Noise factor;
  - Dynamic range.

- For analog RR, still used in broadcasting applications, we can analyze:
  - Fidelity;
  - Effectiveness of the AGC system.

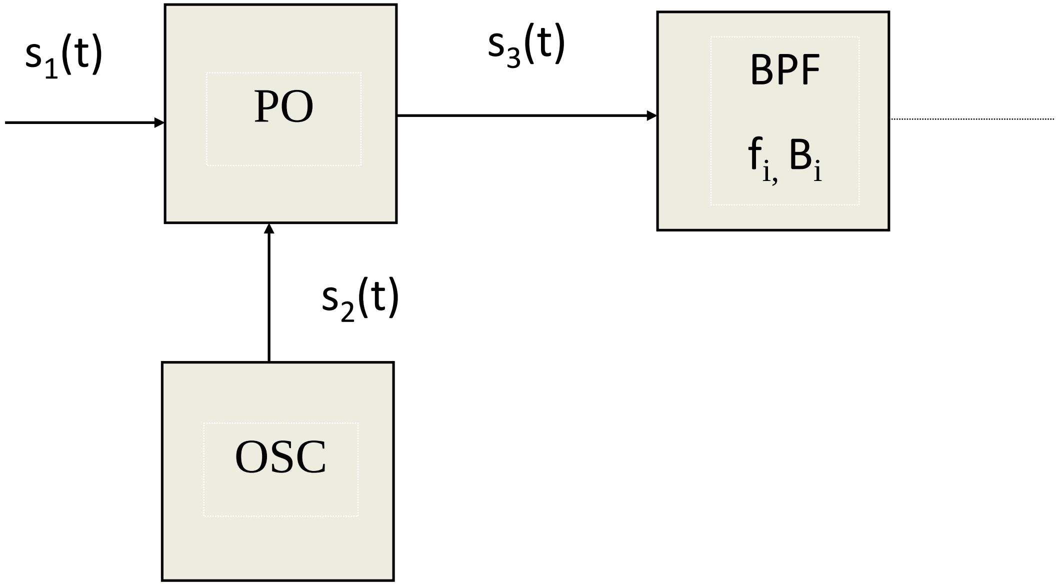
- For digital RR the most important parameter is the bit error rate (BER) which, as known, depends on the SNR.

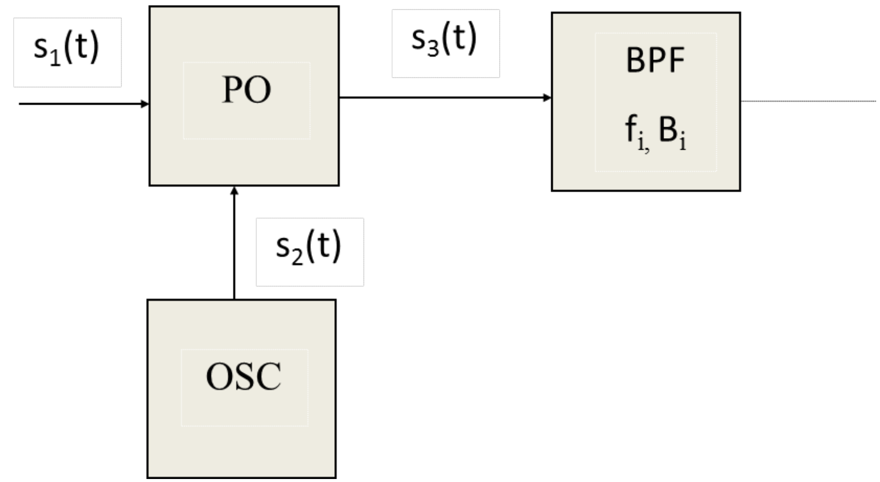
- Before discussing the aforementioned parameters, some aspects regarding signal processing steps specific to RR will be presented, like:

- Frequency change;
- Quadrature demodulation.

3.1.1 Frequency change; aspects specific to RR

- We will start by redrawing the block diagram analyzed in the previous chapter and looking at the signals from the inputs of the PO and their spectra.

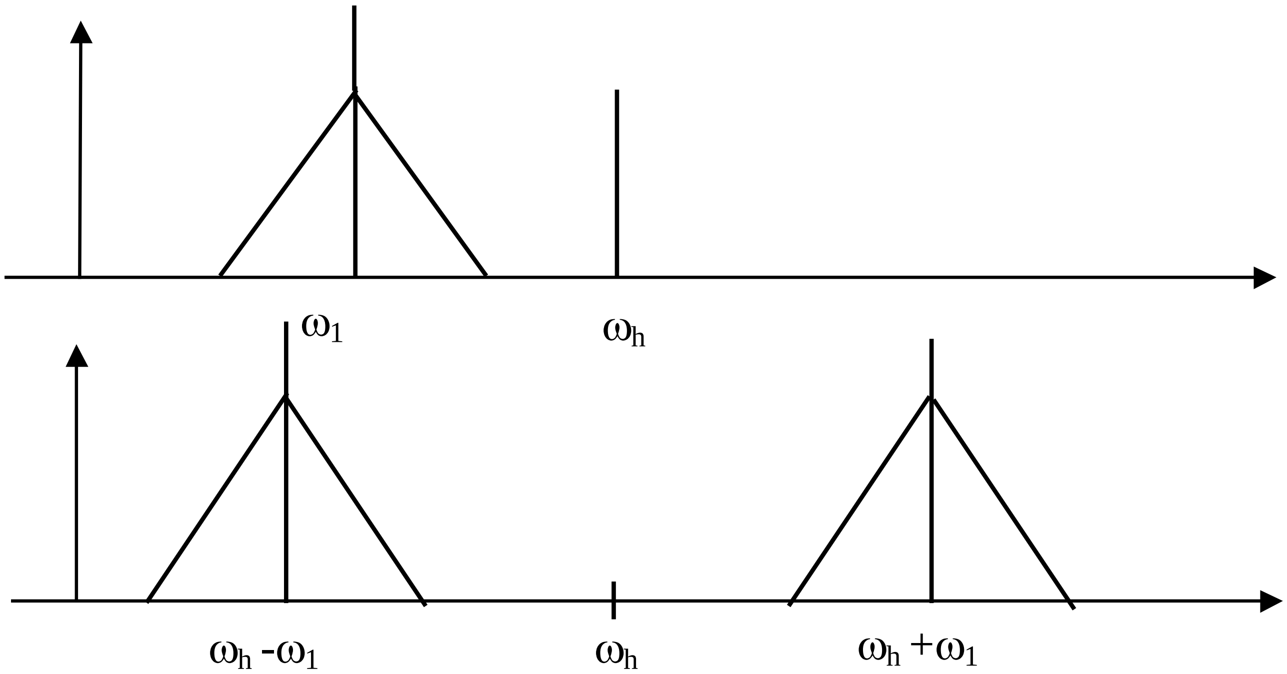




$$s_1(t) = U(t)\cos[\omega_1 t + \varphi_1(t)]$$

$$s_2(t) = U_h \cos\omega_h t : \omega_h > \omega_1$$

$$s_3(t) = \frac{U_h U(t)}{2}\{\cos[(\omega_h + \omega_1)t + \varphi_1] + \cos[(\omega_h - \omega_1)t - \varphi_1]\}$$


ω1
ωh
ωh -ω1
ωh
ωh +ω1

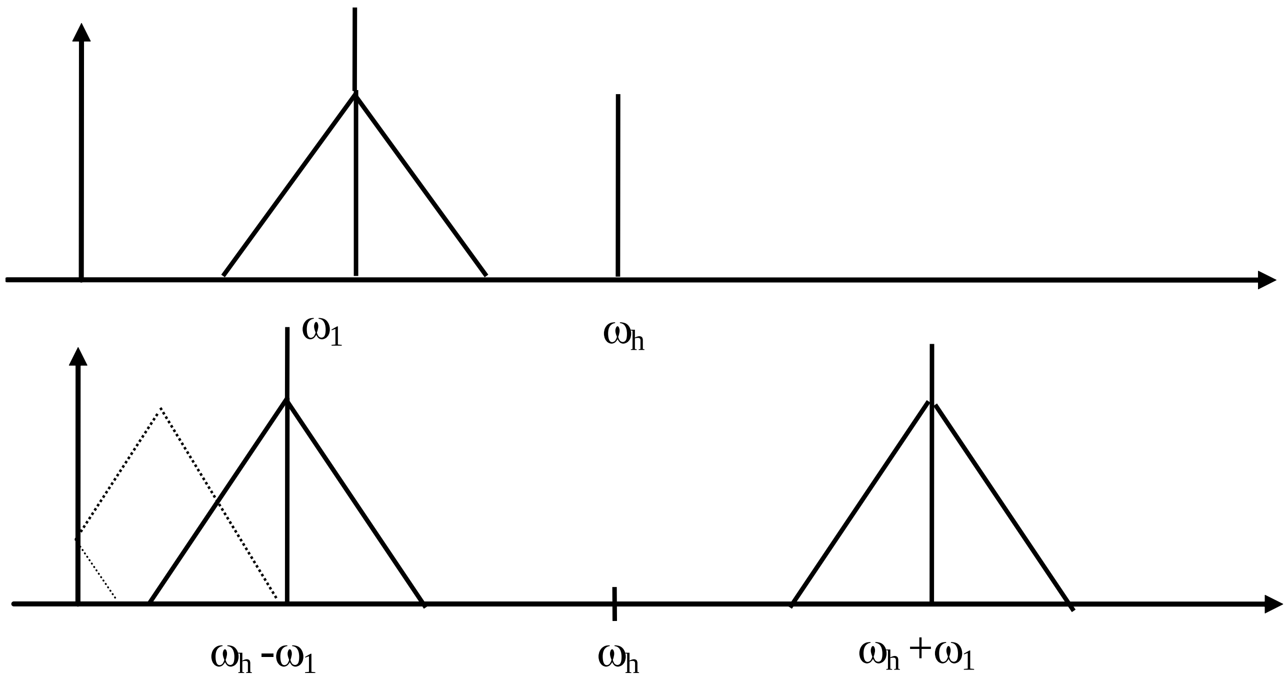
$$s_3(t) = \frac{U_h U(t)}{2}\cos[(\omega_h + \omega_1)t + \varphi_1] +$$

$$+\frac{U_h U(t)}{2}\cos[(\omega_h - \omega_1)t - \varphi_1]$$

- To be reminded that in the expression of signal s_3 both terms correspond to a frequency change, (**by sum or by difference**);
- In case of RR, the difference term is used;

- It was highlighted that in both cases the modulating signal (U(t), φ(t)) is not affected;

- In case of frequency change by difference, if the frequency values are not adequately chosen, changes in the modulating signal might appear.


ω1
ωh
ωh -ω1
ωh
ωh +ω1

- In order to receive a signal with a central frequency f_{s1} the following conditions have to be met:

$$f_{s3} = f_h - f_{s1} = f_i$$
$$B_i \geq B_{os}$$

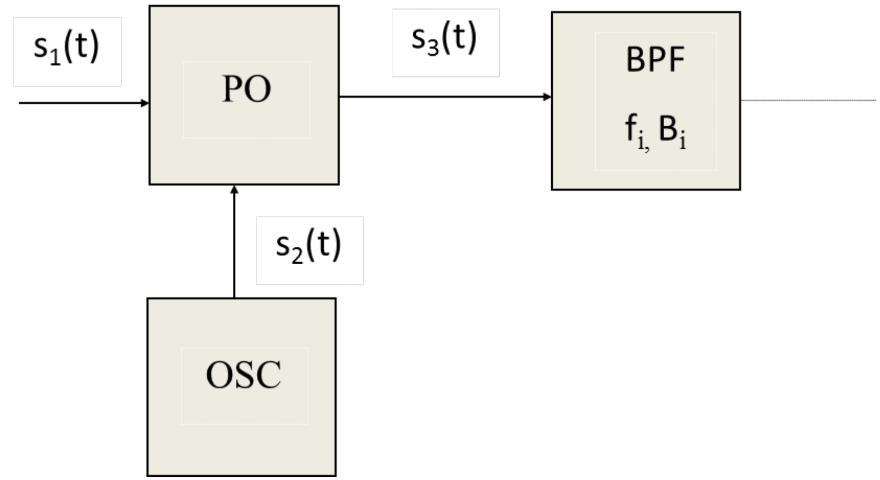
or

$$f_{s3} = f_{s1} - f_h = f_i$$
$$B_i \geq B_{os}$$

- Likewise, it can be noticed that if the central value of the RFA characteristic is specified, f_i, by modifying the f_h frequency one can assure that the signal corresponding to any carrier frequency can be passed through the BPF;

- In this way RR with variable tuning can be implemented;

- By looking at the principle diagram, it can be noticed that the functional block have specific functions;



- A series of notions associated with RR which use frequency change were introduced:
    - ❑ local oscillator (OL),
    - ❑ intermediate frequency (f_i),
    - ❑ intermediate frequency amplifier (AFI),
    - ❑ frequency changer (mixer).

Variants of realizing the frequency change for RR

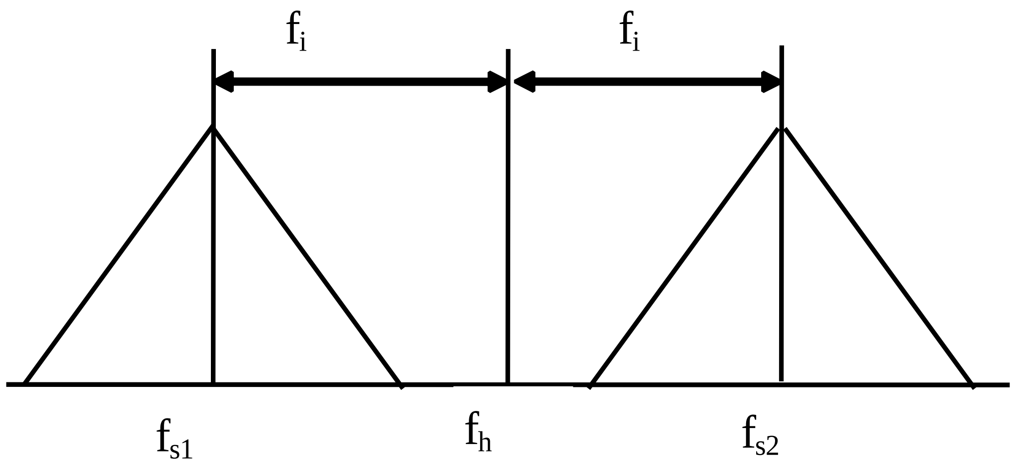
- Depending on the relative value of the carrier frequencies of the two input signals, two different cases result for realizing the frequency change:

  - **Super-heterodyne ($f_h > f_{s1}$);**
  - **Infra-heterodyne ($f_h < f_{s1}$).**

- A limit case exists, the **synchrodyne**: $f_h = f_{s1;}$

- In this paragraph we will highlight a few aspects that influence the design of RR with frequency change;
- We shall emphasize that for broascasting AM RR the superheterodyne solution is the best choice;
- We will end by mentioning a series of criteria for choosing the value of the intermediate frequency and a few typical used values will be given;

- One of the most important aspects is related to the existence of a specific perturbation called **perturbation on the image frequency**;
- This type of perturbation exists for both variants of FC used in RR, even if the mixer is an ideal one.
- In order to define the perturbation on the image frequency we will consider the situation represented through the amplitude spectra from the next slide.

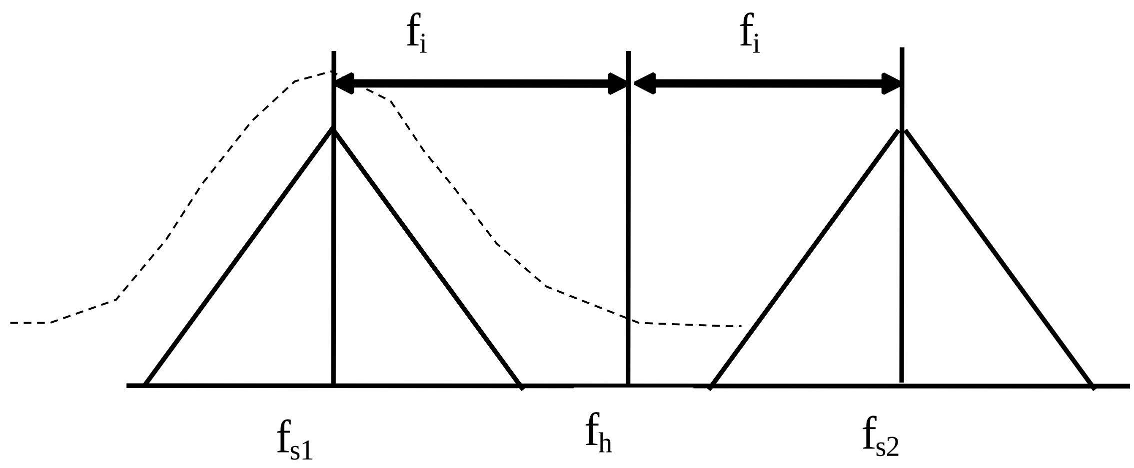


- The two signals can be desired signal or perturbation depending on the FC type that was used;
- For example for a super-heterodyne FC the signal on the f_{s1} frequency is the desired one, and the signal on the f_{s2} frequency is a perturbation signal;
- The mixer will process the two signals in the same way, no matter what type of RR is chosen;

- In conclusion, at the output two different signals centered on the f_i frequency will be obtained;
- It results that over the desired signal a perturbation signal is overlapped; this unwanted signal cannot be removed any longer;
- This signal represents the perturbation on the image frequency; its frequency (the image frequency) is:

$$f_{s2}=f_{im}=f_{s1}+2f_i$$

- The only solution in order to avoid this perturbation is to eliminate it using a BPF placed before the frequency change;



- On the diagram from above a well known fact can be noticed: the attenuation introduced by the BPF is higher when the difference between the frequencies of the two signals (in this case $2f_i$) is bigger;
- Consequently, in order to avoid too harsh requirements for the BPF the value of f_i has to be as high as possible (condition 1).

- The elimination of the perturbation on the image frequency was one of the aspects the imposed the super-heterodyne solution for AM RR;

- The super-heterodyne FC allows choosing a convenient value for the intermediate frequency, in contrast to the other FC solution;

- Another perturbation that can affect the operation of a FC RR is known as the perturbation on the **intermediate frequency.**
- In order to explain the apparition of this kind of perturbation, the case of a real mixer (not an ideal one) will be considered;
- In this case, the mixer is realized by means of some semiconductor devices (Bipolar transistor, FET, differential pair, diodes);

- In this case, at the output appear not only the desired term $s_1 \cdot s_2$ ($f_h \pm f_s$), but also combinations of type $s_1^k \cdot s_2^j$, $k,j=0\ldots\infty$, so components with the frequencies $\pm kf_s \pm jf_h$
- For example components with the frequencies: f_s, f_h, nf_h, $2f_h - f_s$, $f_h - 2f_s$ aso can appear.
- As such, if at the input a signal with the f_i frequency appears, this can be transferred directly to the output, whilst the desired signal is transferred by means of the frequency change;

- The two signals overlap and the desired signal will be disturbed by the unwanted signal with central frequency equal to f_i;
- The unwanted signal has to be eliminated by the filters that precede the FC;
- A fixed frequency filter centered on f_i is often necessary;
- The consequence is that the value of the intermediate frequency has to be chosen outside of the band where desired signals are located, otherwise it wouldn't be possible to receive these signals (condition 2);

- Finally it is useful to mention that a performant intermediate frequency amplifier can be easier implemented if the value of the intermediate frequency is lower;
- This affirmation is valid at least for the technological levels from the periods when these RR evolved and this value was chosen;
- As such, the requirement to choose a relative low value for the intermediate frequency resulted (condition 3);

- Concluding, when the values for the intermediate frequency were chosen, the three conditions that were highlighted in this paragraph had to be considered:

1. Be out of the useful signal frequency bands;
2. Have a low value in order to be able to build a high performance IFA;
3. Have a high value in order to conveniently reject the image frequency interference, f_{im}.

- Concluding we can remark that the super-heterodyne frequency conversion is less restrictive than the infra-heterodyne one from the point of view of the choice of the intermediate frequency value;

- Taking these aspects into account the following values were chosen:

AM-RR f_i=450...470 kHz so f_i=455 kHz

FM-RR f_i=10.7MHz

TV-R f_i=38MHz

- The terminology that imposed itself should be remembered:
  - Frequency changer (mixer);
  - Local oscillator;
  - Intermediate frequency filter/amplifier aso.

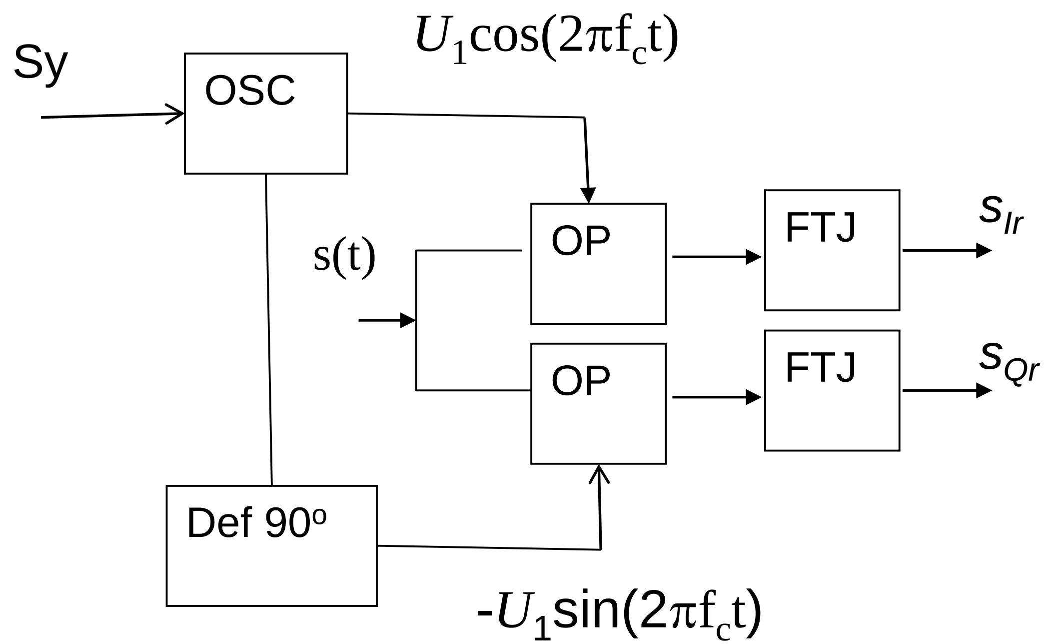
3.1.2 Quadrature demodulators

- The demodulation in case of analog RR is performed by using the solutions specific to the different types of modulated signals: AM, AM-SSB, FM;
- These solutions were analyzed in detail in the CAD course;
- Even for some narrowband communication technologies, demodulators derived from the ones used for analog signals are used;

- For new technologies, starting with GSM, and especially for wideband technologies quadrature demodulators are used;
- In this solution, the received complex signal is processed by means of two product detectors, and afterwards the modulating signals that are carried by the two components are extracted: the in-phase component (I) and the quadrature component (Q);
- Remembering that in the I/Q modulation process a RF signal of the following expression is obtained:

$$s(t) = s_I(t)\cos\omega_c t - s_Q(t)\sin\omega_c t$$

- Consequently, in this case the received signal is processed by using the following block diagram:



- Simple calculation show that at the two outputs variants of the modulating signals: s_I şi s_Q affected by noise and by the transmission through the communication channel are obtained;
- The main problem of this process is the *synchronization of the local carrier with the received one*;
- In some cases, like the one of some phase modulated signals, an adequate processing of the received signal can be used in order to extract the information that will be used for performing the synchronization;

- Some communication technologies use the transmission, for short time intervals, of the unmodulated carrier;
- Other technologies use the transmission of some special data sequences (training sequences) that are known on the receive side;
- In this last situation, the parameters of the local generated RF signals are modified until a correct alternative of the transmitted sequence is recovered;

3.2 Analysis of specific RR parameters

- In this subchapter the following parameters will be defined and discussed:
  - Sensitivity
  - Selectivity
  - Dynamic range
  - Effectiveness of the AGC system.

- In some cases, measurement methods will also be presented;

- When necessary, different approaches will be used for the two types of RR: analog and digital;

3.2.1 RR sensitivity

- In order to notices the differences between the two RR types, the definition and the measurement method will be separately given for analog and digital RR;

3.2.1.1 Sensitivity in case of analog RR

- We are talking about a figure of merit specifying the minimum level of the input signal that can be processed adequately.

- We are talking about a figure of merit specifying the minimum level of the input signal that can be processed adequately.
- A criterion to evaluate if the signal was processed adequately must be defined; there are two approaches:

  a) The output power

  b) The output Signal to Noise Ratio (SNR).

- Depending on the chosen approach one defines:
  - The gain limited sensitivity;
  - The noise limited sensitivity.

a) The gain limited sensitivity, S_a.

- *S_a represents the minimum level of the normal modulated signal at the input of a RR tuned on a measurement frequency, set up with the volume control to maximum gain and the tone controls in the middle position which produces an output signal of standard power.*
- The value for the standard power is often $P_0 = 50 mW$;
- This figure of merit describes the global gain of the RR but do not has in mind the output signal quality;

b) The noise limited sensitivity $\boldsymbol{S_n}$

- *S_n represents the minimum level of the normal modulated signal at the input of a RR tuned on a measurement frequency, set up with the volume control to maximum gain and the tone controls in the middle position which produces an output signal of standard Signal to Noise Ratio (SNR_0).*

- *SNR_0 can be:*

$$AM\text{-}RR - SNR_0 = 20dB$$

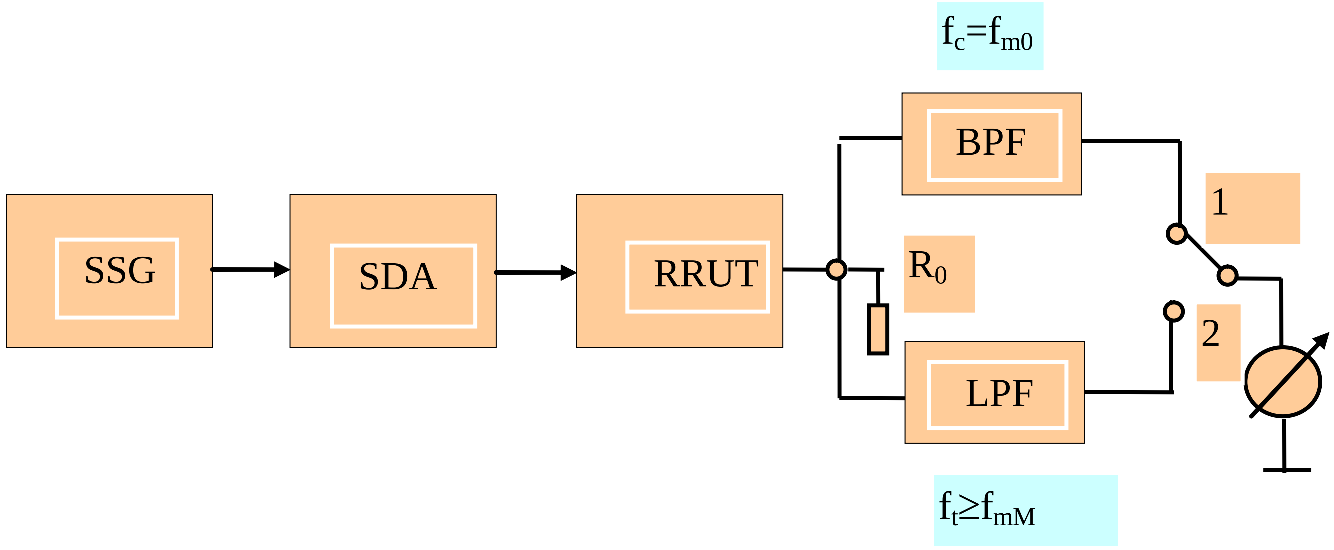
$$FM\text{-}RR - SNR_0 = 26dB.$$

- *We remark that a receiver sensitivity has two values; one has to specify which of them is the one that gives an adequate information about the RR performance .*

- *This is called the usable sensitivity.*

$$S_u = \max\,(S_a, S_n)$$

- To measure the RR sensitivity one can use the next block diagram:



$$SNR=P_S/P_N$$

- We have to note that in a campaign of measuring the sensitivity it is recommended to measure the complementary output signal parameter (output power in the case of S_n and SNR in the case of S_a).

3.2.1.2 Sensitivity in case of digital RR

- In this case, the S_a represents the lowest power of the radio signal from the antenna input, on the work frequency (*o*n-channel, center-frequency), which produces at the input of the detector an usable signal, when there are no other signals that interfere.

- *By usable signal one understands a signal that assures a predefined SNR, denoted SNR_d , at the detector*.

- As such, we assume that from the antenna to the detector, a gain of value G is obtained on the center frequency

- We denote N_d - *the noise power* , *meaning* the result of integrating the thermal noise generated by all the circuits that precede the detector, over the pass-band of the receiver seen at the input of the detector;

- In these conditions, the sensitivity of the RR corresponds to the lowest signal power that complies with the equation:

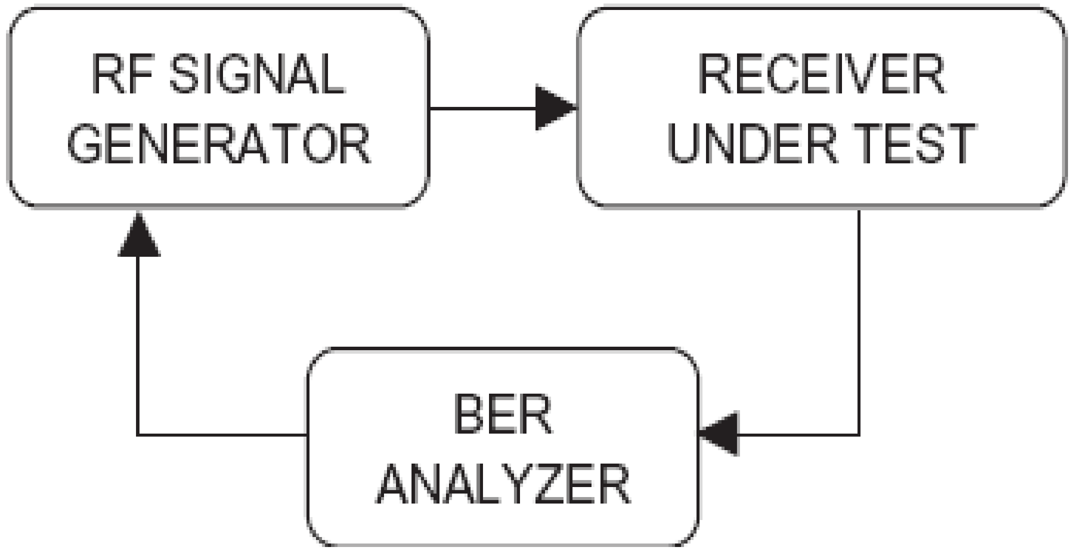
$$(S_a \cdot G)/N_d = RSZ_d$$

- It was noticed that **a 10 dB value** for the SNR represents a ”*magical*” value, which approximately corresponds, to the signal level from which the signal obtained at the output of the detector becomes usable, for most applications.

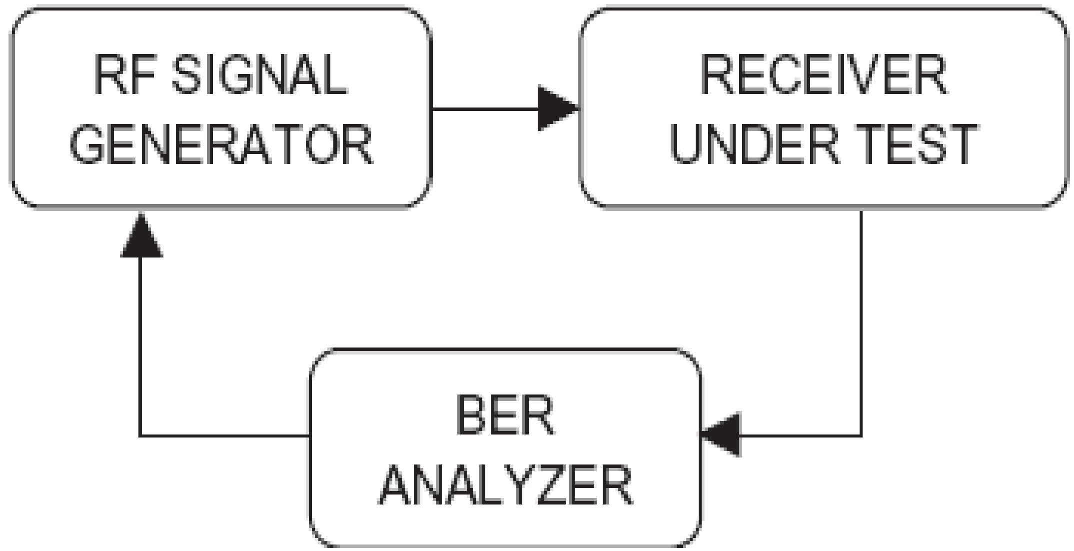
- As such, in the following it will be considered that the sensitivity of a receiver represents the level of the RF signal from the antenna input, on the work frequency, for which RSZ_d =10 dB.

- Obviously, to this signal to noise ratio correspons an input signal to noise ratio RSZ_i.

Sensitivity measurement

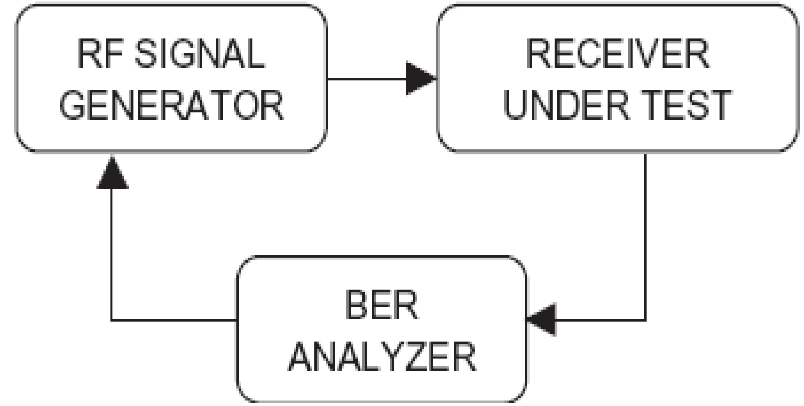


- The main equipment from this measurement platform is the bit error rate (BER) analyzer;



- This device generates a data stream which modulates the RF carrier;

- The same device gets the received data stream and by comparing the transmitted data with the received one computes and shows the bit error rate;



- In order to perform the measurement, the RF generator will be set to deliver a signal with a minimum level and with the frequency value equal with the center frequency of the channel on which the receiver is tuned;
- The generatorul is connected to the antenna input of the RR and the level is increased until the BER reaches the value imposed by the application (for ex. 10^{-2});

- It is also possible to measure the SINAD or the RSZ_d if the input of the detector is accessible, case which is close to the method used in case of analog RR;

- In other circumstances, it might be recommended to measure the packet error rate (PER);

- If the PER has small values, it can be immediately deduced the BER value if we accept the hypothesis that for each packet a single bit is erroneous;

- In order to avoid large errors, it is recommended to use the minimum length of the packet;

3.2.2 RR Selectivity

- Also for this case, the definition and the measurement method will be presented for both types of receivers: analog and digital;
- We will limit this approach to the case of one of the parameters that is associated with the idea of selectivity;

3.2.2.1 Selectivity in case of analog RR

- In this case, this parameter can be defined in two approaches:

    a) Small (weak) input signals

    b) Large input signals.

a) Small (Weak) Input Signals Selectivity

- In this case the superposition principle applies;

- Consequently we can make the sensitivity measurement without applying the useful signal and the interfering one simultaneously .

- One can define:
  - ❑ the adjacent channels selectivity
  - ❑ some signals specific selectivity defined in the case of heterodyne receivers:
    - The intermediate frequency rejection;
    - The image (mirror) frequency rejection.

- The adjacent channels selectivity is given by the attenuation introduced by the selective RF amplifier to a frequency deviation from the central frequency of the receiver equal to the channel spacing, f_a (f_u represents the carrier frequency of the desired channel):

$$f_a=f_u \pm \Delta f; \quad f_p=f_a$$

$$\Delta f=9 kHz\ (MA),$$

$$\Delta f=200\ kHz (MF)$$

- It is defined as the ratio, in dB, between the level of two input signals both of which producing an output signal with the same reference parameter (power or SNR);
- One signal is the useful signal and the other one is an unwanted signal with the carrier frequency corresponding to the adjacent channel

- The measurement set is the same as in the case of the sensitivity measurement; one measures (e.g.) the noise limited sensitivity and then changes the value of the carrier frequency and adjust the input signal level in order to obtain the same output SNR;
- As you can see there are two adjacent channels; usually one obtains two different values for the attenuation:

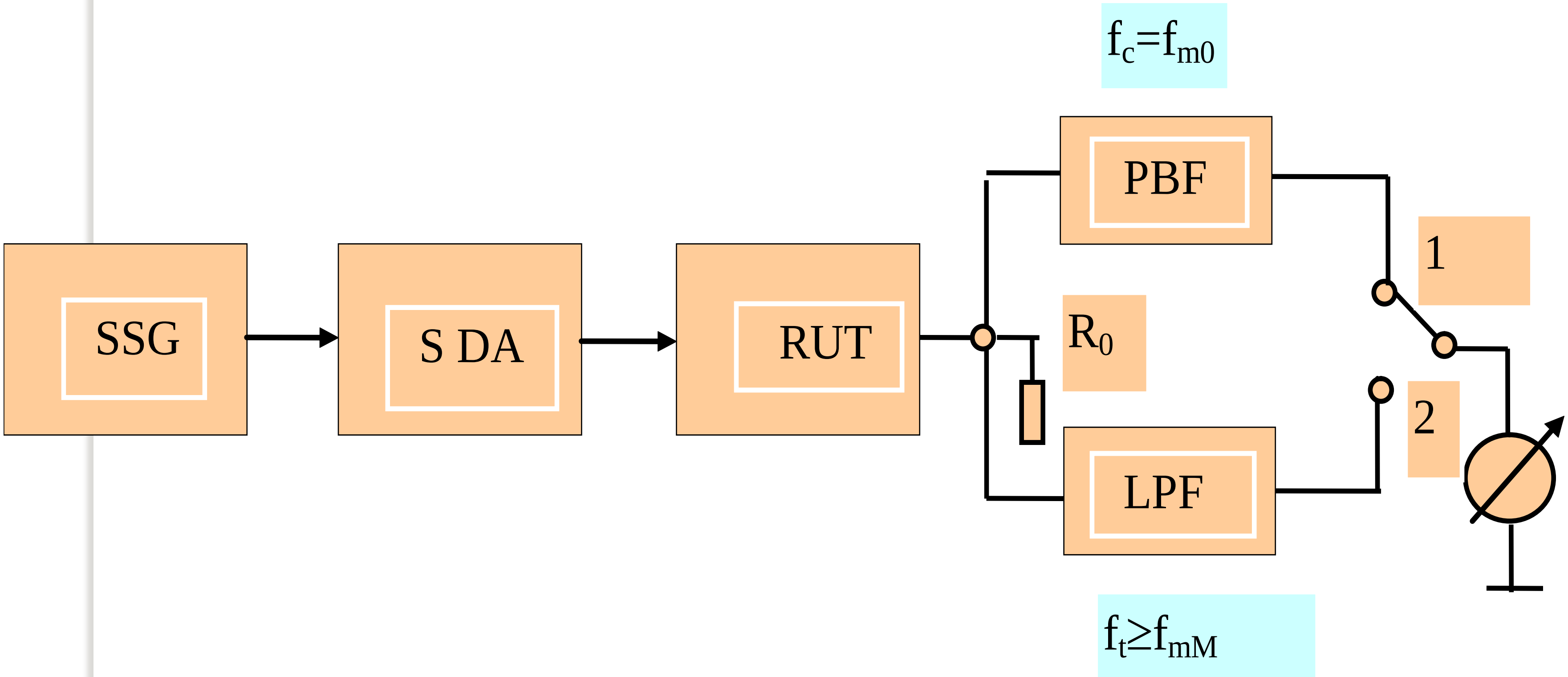
$$a_a = \frac{a_+ + a_-}{2}$$

- *Measurement methods:*

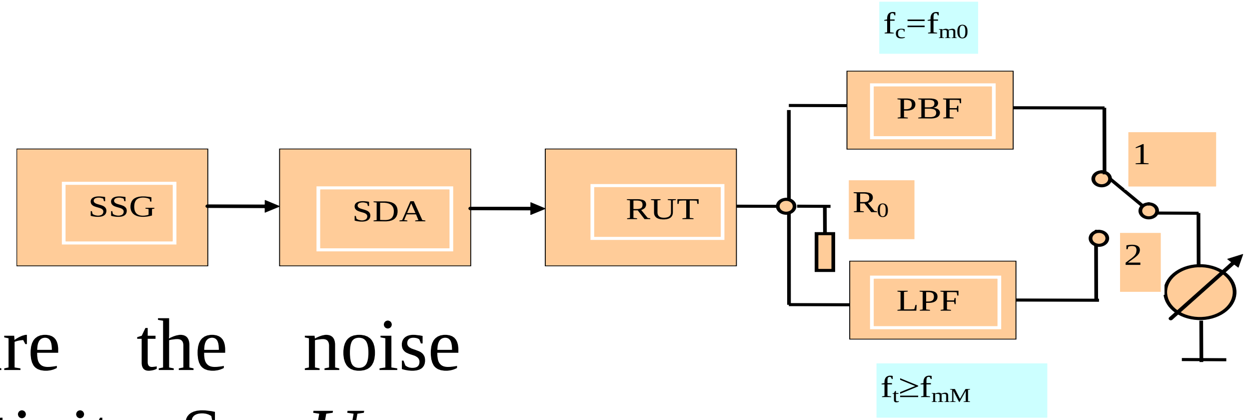
1. The direct measurement method;

2.The method based on the selectivity curve of the RR.

- In both methods we use the measurement set given in the case of sensitivity measurement .



SSG
S DA
RUT
PBF
LPF
R0
1
2
fc=fm0
ft≥fmM



- One measure the noise limited sensitivity, S_z - U_{io}.

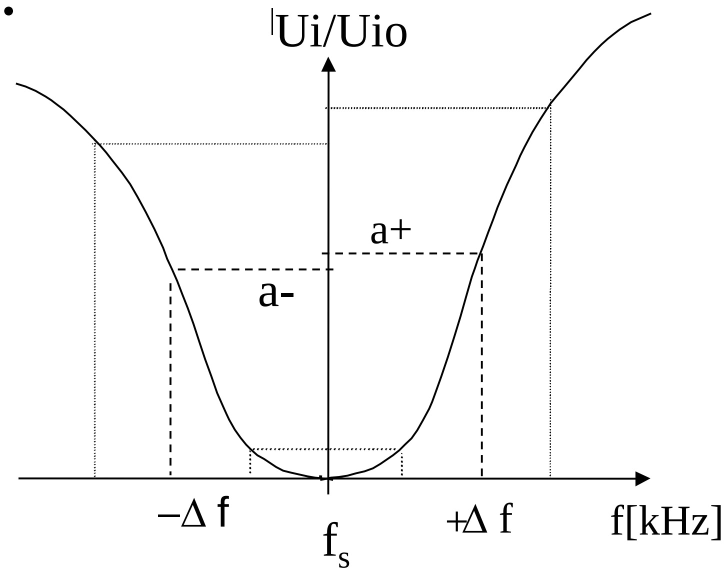
- One modifies the carrier frequency of the signal **produced by the signal generator** with a frequency deviation equal to Δf, and then we enlarge the level of the input signal in order to maintain the output signal power level; the new amplitude of the input signal is U_p, and:

$$a_a = 20\log\frac{U_p}{U_{io}}\,[dB]$$

- One can remark that for an appropriate selectivity measurement we keep the level of the output signal amplitude (U_{out}) (power) constant and we change accordingly the amplitude of the input signal. |

- This way we avoid the undesired influence of the Automatic Gain Control (AGC) loop which opposes to the variation of the output signal falsifying the results.

2. In the case of the second method one plots the selectivity curve by developing the previous action for more values of the frequency both to $f>f_s$ *and* $f<f_s$.



- Using the curve obtained this way we can evaluate both the selectivity parameters and the 3 dB frequency band of the receiver (the *fidelity*).

b) Large Input Signals Selectivity

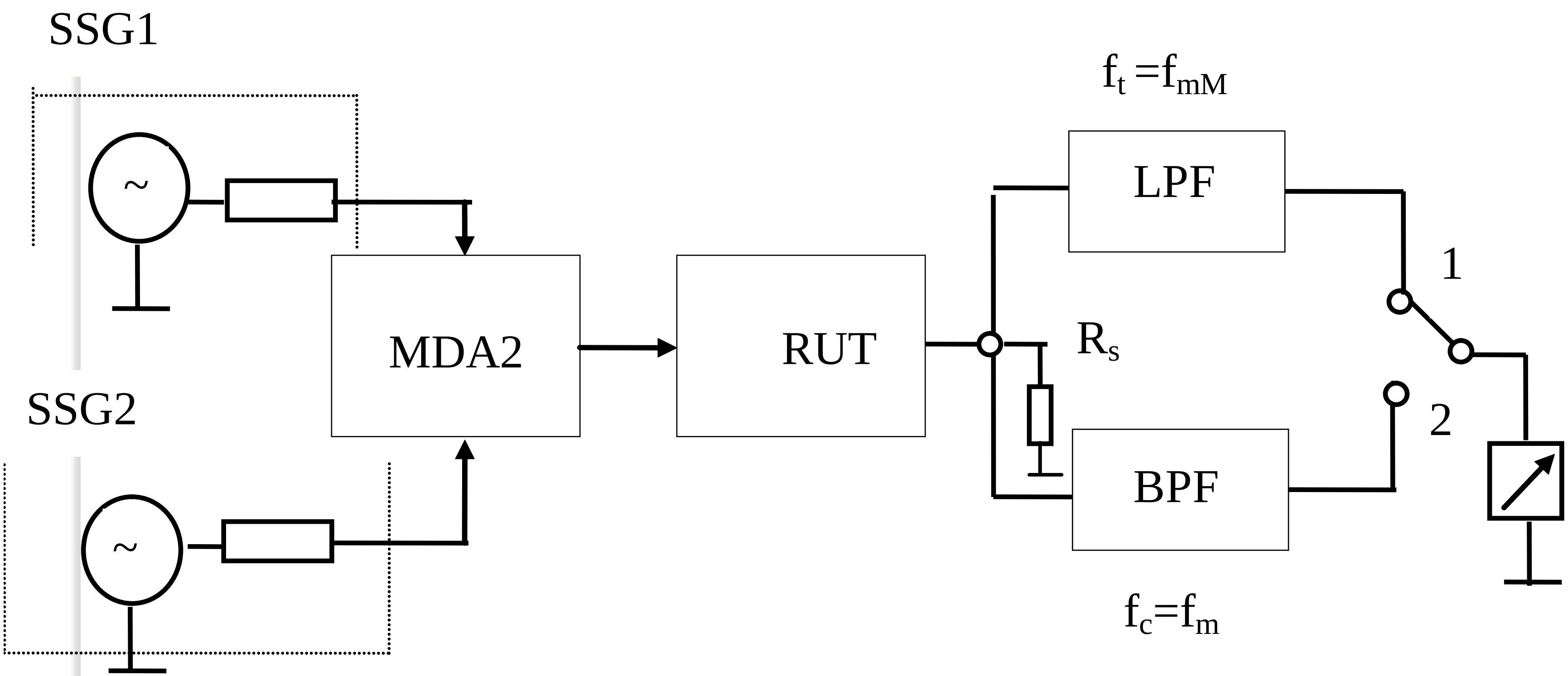
- In this case we have to take account of the effect of the non - linearities .

- The processing of the useful signal is influenced by the level of the interfering ones.

- One can define three more frequently used parameters specifying the high level input signals selectivity:

1. The receiver blocking;
2. The cross-modulation;
3. The intermediate frequency and image (mirror) frequency interfering signals rejection (as in the previous situation this parameter will be analysed later).

- The measurement of these parameters is done by using the a set which allows to apply two input signals simultaneously.



b1. Useful Signal Blocking

- we consider a RR tuned on the useful signal.

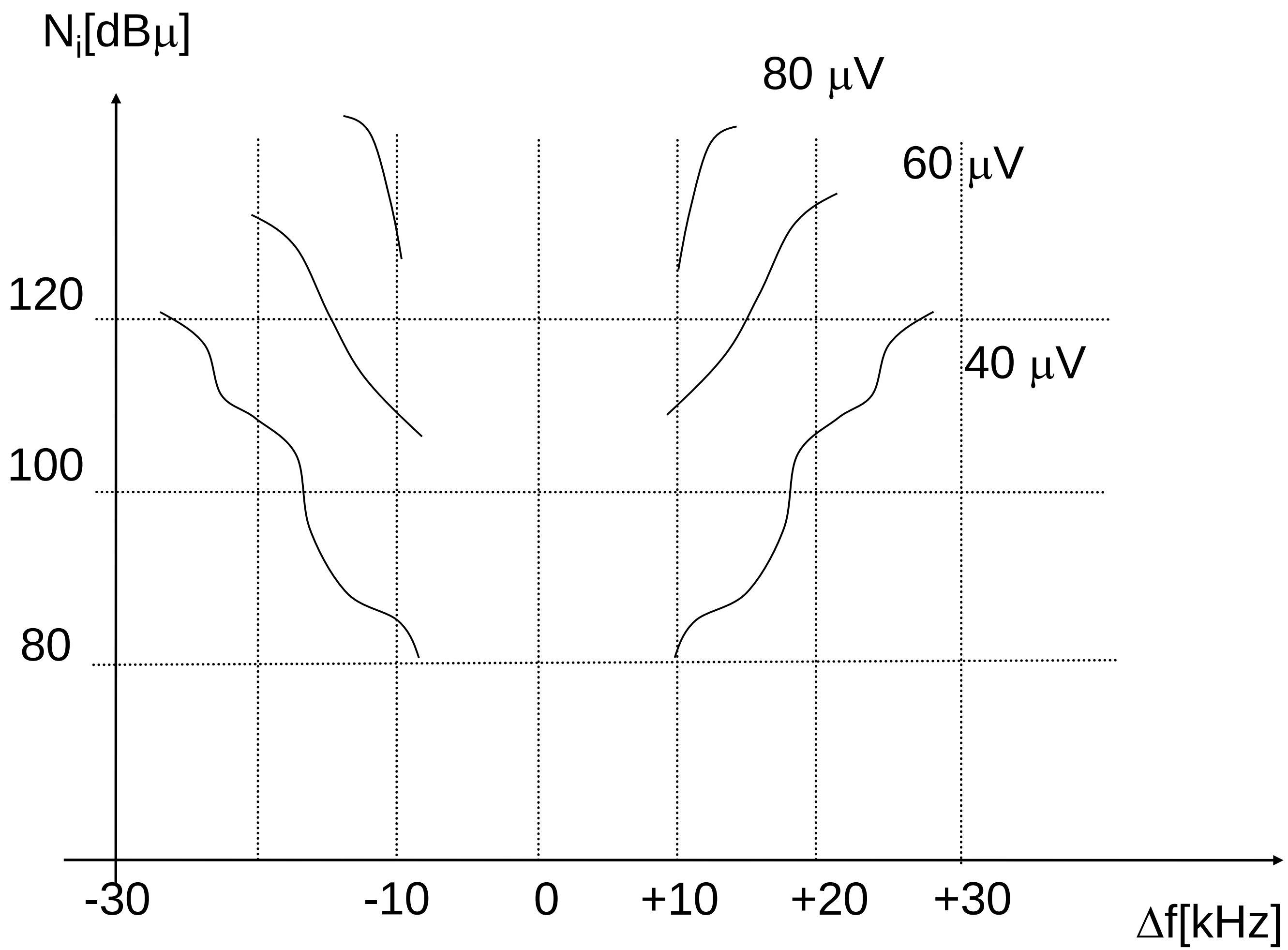
- If one applies simultaneously a varying level interfering signal, when the interfering signal level exceeds a threshold, the level (and other parameters) of the output signal will change according to the level of the interfering signal.

- usually the level of the useful signal decreases as the interfering signal level increases getting beyond (exceeding) a threshold.

- The parameter used to estimate this effect is the **blocking of the useful signal**

- Definition: *The blocking of the useful signal is given by the input level of the un-modulated interfering signal, which reduces the level of the useful output signal power by 3dB; the initial value of the output power can be settled at the standard value.*

- It can be remarked that the value of the blocking level depends on:
  - the level of the useful signal; the effect of the interfering signal decreases as the useful signal level increases;
  - the offset of the interfering carrier frequency related to the useful signal frequency ($\Delta f_p = f_p - f_u$); the effect increases as the offset value (Δf_p) decreases.



N_i[dBμ]
80 μV
60 μV
40 μV
120
100
80
-30
-10
0
+10
+20
+30
Δf[kHz]

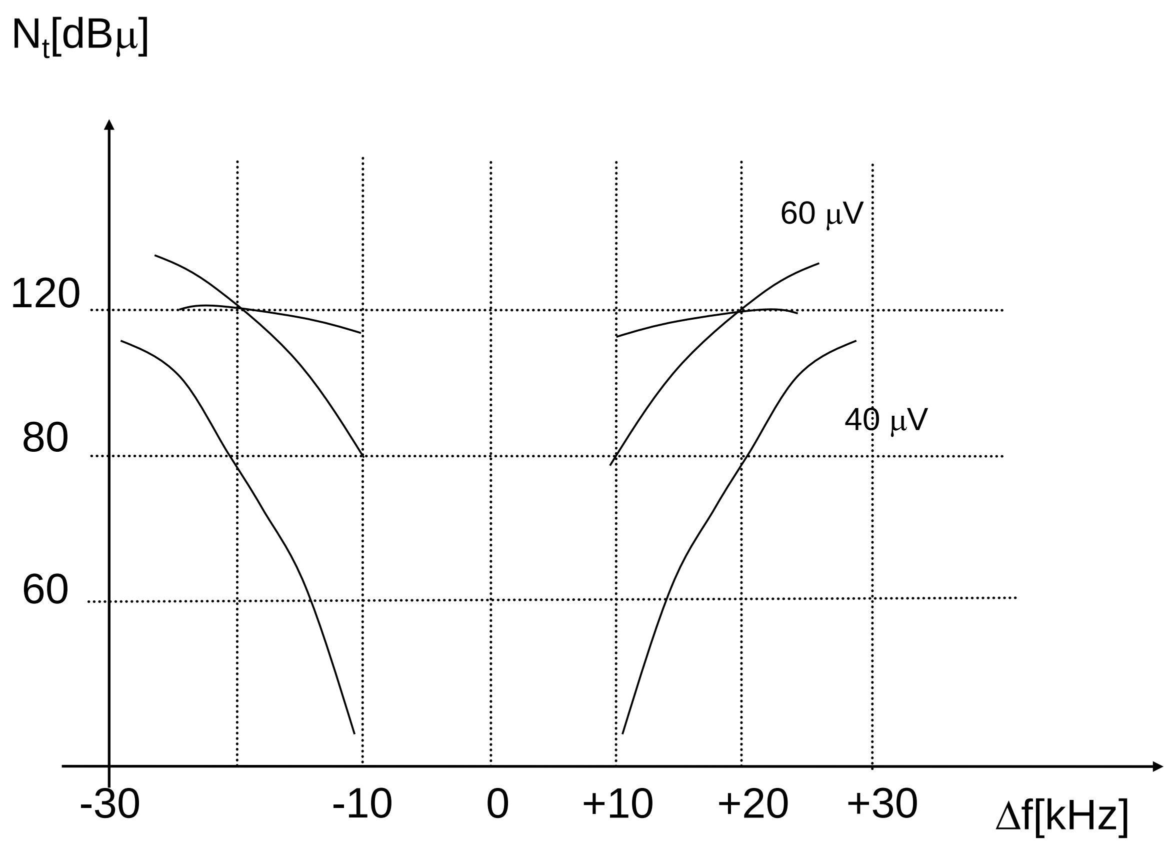
b2. The Cross-modulation

- If an interfering signal is large enough one will remark that although the RR is tuned on the useful signal frequency and we cut the useful modulation signal, there will be output signal depending on the modulation of the interfering signals.

- This effect of this process can be estimated by means of the cross-modulation parameter.

- Definition: *The input level of the normal modulated interfering signal, applied simultaneously with un un-modulated useful signal, which produces an output signal power 20dB below the level of the useful signal power* (The useful signal power was obtained in case of a normal modulated useful signal).

- The measurement campaign is done in the same conditions as in the case of the blocking parameter and we will obtain similar plots .



- Measuring the cross-modulation in the case if the adjacent channel one obtains the parameter called the relative adjacent channel selectivity

b3. Attenuation of parasite signals on the image and intermediate frequency

- In order to define this parameter, it is considered that the two generators produce two unmodulated signals;
- One of the signals has a frequency equal with the center frequency of the desired channel, and the other one is the parasite signal with the frequency $f_s = f_{im/i} + \Delta f$, where Δf=1kHz;

- The first signal is obtained by cutting off the modulation of the desired signal, settled when measuring the noise limited sensitivity;
- In this way, after the FC through the receiver two sine signals will pass, with the f_i and the $f_i+\Delta f$ frequencies;
- After demodulation (which is a non-linear process) a signal having a frequency equal with the difference of the two frequencies (Δf) will be obtained, which will be processed by the last section (LFA);
- It results the definition for the two parameters:

- The ratio, expressed in dB, between *the level of the parasite unmodulated signal on the frequency* $f_s=f_{im/i}+\Delta f$, *where* $\Delta f=1kHz$, which in the presence of the unmodulated desired signal having a level corresponding to the noise limited sensitivity, generates at the output the power corresponding to the noise limited sensitivity and *the level of the desired signal corresponding to the noise limited sensitivity*:

$$a_{i/im} = 20\log\frac{U_{i/im}}{S_z}$$

3.2.2.2 Selectivity in case of digital RR

- In this case there are several parameters used to specify the selectivity, but for now only for two of them the definition and the measurement method will be given:
- Co-channel rejection;
- Selectivity to the neighboring channel;

a. Definition and measurement for the co-channel rejection

- This parameter offers a measure of the capacity of the RR to receive a modulated desired signal, in the presence of a modulated unwanted signal, both being located on the nominal frequency of the RR.

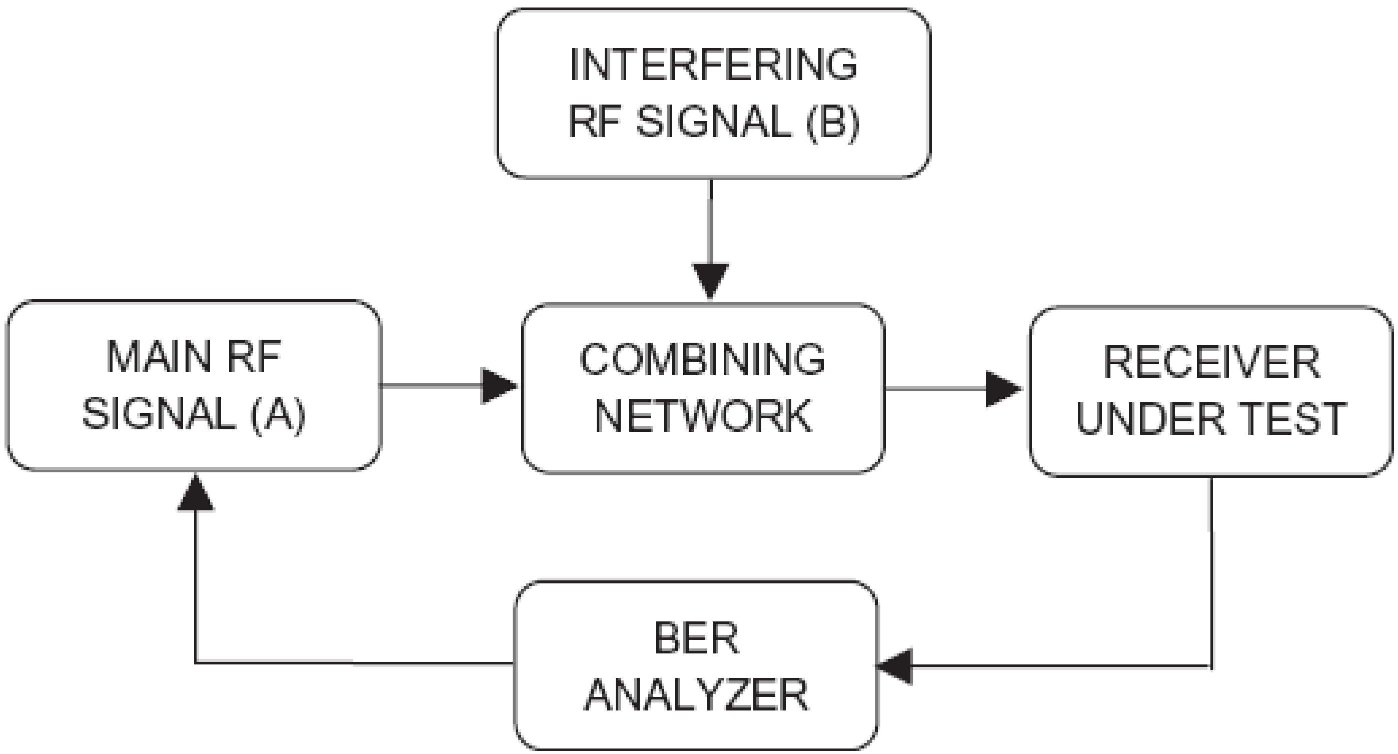
- In order to evaluate the co-channel rejection ratio we denote with S_i the power of a signal which has a power equal with $2S_a$.

- This signal with a power equal with S_i is applied at the input of the receiver;
- By increasing the level of the signal delivered by the generator, obviously the BER will decrease compared to the value obtained when measuring the sensitivity;
- An interfering signal is applied together with the desired signal, having the same frequency as the one of the desired signal;
- We denote with S_{cc} the smallest power of the interfering signal for which the BER returns to the value obtained in the case when only the desired signal with the S_a level was applied.

- The co-channel rejection ratio (CCRR) is given by:

$$CCRR = 10\log\left(S_{cc} / S_a\right)$$

- In order to measure the co-channel rejection ratio the following measurement set will be used:



- It can be noticed that two signals are necessary;
- In the beginning, the interfering generator is turned off and the main generator is adjusted in order to evaluate the sensitivity – the BER value is remembered;
- Keeping in mind that a combining network is used, a slightly higher value for the sensitivity will be obtained;
- The level of the desired signal is afterwards doubled (increased with 3dB), so the BER decreases;

- The interfering signal, modulated with a data stream, is applied at the input of the combiner and its level is increased until the BER value decreases to the value obtained in the first step.

- The CCRR represent the ratio between the level of the interfering signal obtained during this step and the level of the desired signal obtained when measuring the sensitivity.

- To be noticed: the modulating signals will be chosen so that they cannot be mistaken, and the modulation of the interfering signal shouldn’t lead to a wider signal spectrum than the pass-band of the receiver.

b. Definition and measurement for the selectivity to the neighboring channel

- In case of digital RR, the selectivity is defined as: the ability of the receiver to extract in a satisfactory way the desired signal in the presence of some strong interfering neighboring signals and some possible jamming.

- It is to be noticed that, opposite to the definition given in case of analog RR that were mainly used for classic point-to-point, point-to-multipoint or broadcasting communication, here the presence of several high level parasite signals is emphasized;

- Similar to the case of CCRR, we will consider a receiver at whose input a signal with the power $S_i = 2S_a$ is applied;

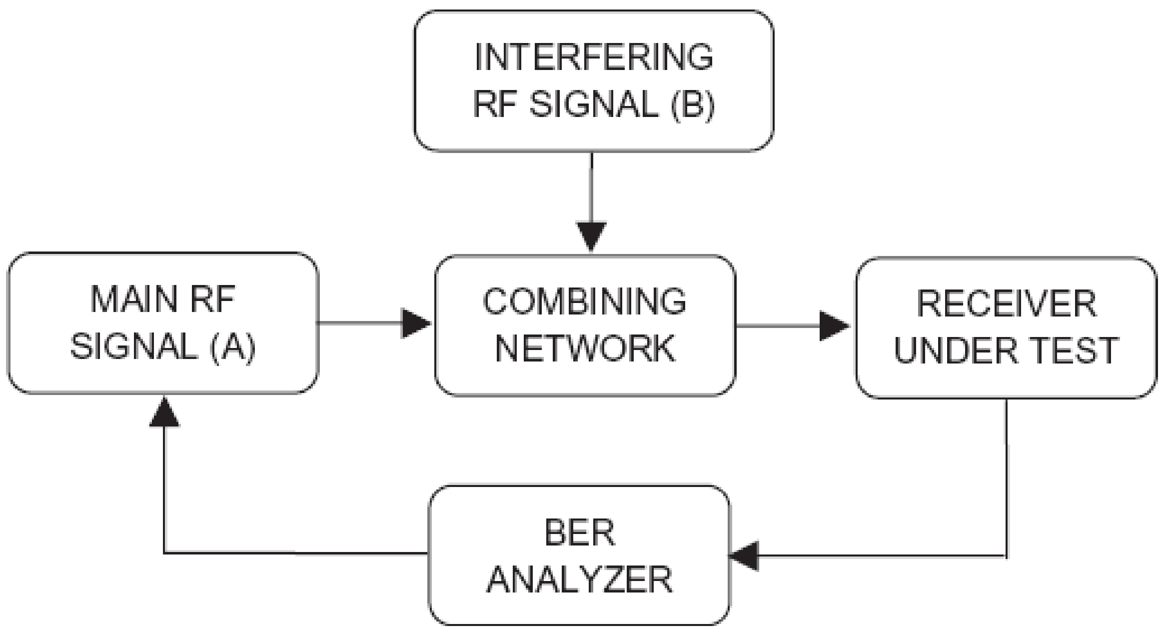
- We denote with f_r the center frequency of the analyzed channel and with Δf the distance to the neighboring channel;

- We will denote with S_{ad} the smallest power level of a signal with frequency $f_{\mathrm{r}} \pm \Delta \mathrm{f}$ which, when applied to the antenna input together with the desired signal having the power $S_i = 2S_a$ causes the performances of the RR to decrease so that they reach the level obtained when the desired signal was applied alone and had the power $S_i = S_a$;

- The RR selectivity, expressed in dB and denoted S_{el} represent the ratio:

$$S_{\mathrm{el}}=10 \log(S_{ad} / S_a) \text{ [dB]}$$

- In order to measure the selectivity to the neighboring channel we will use the same measurement set that was used for measuring the co-channel rejection ratio;
- The measurement procedure is similar; the frequency value for the parasite signal is different;

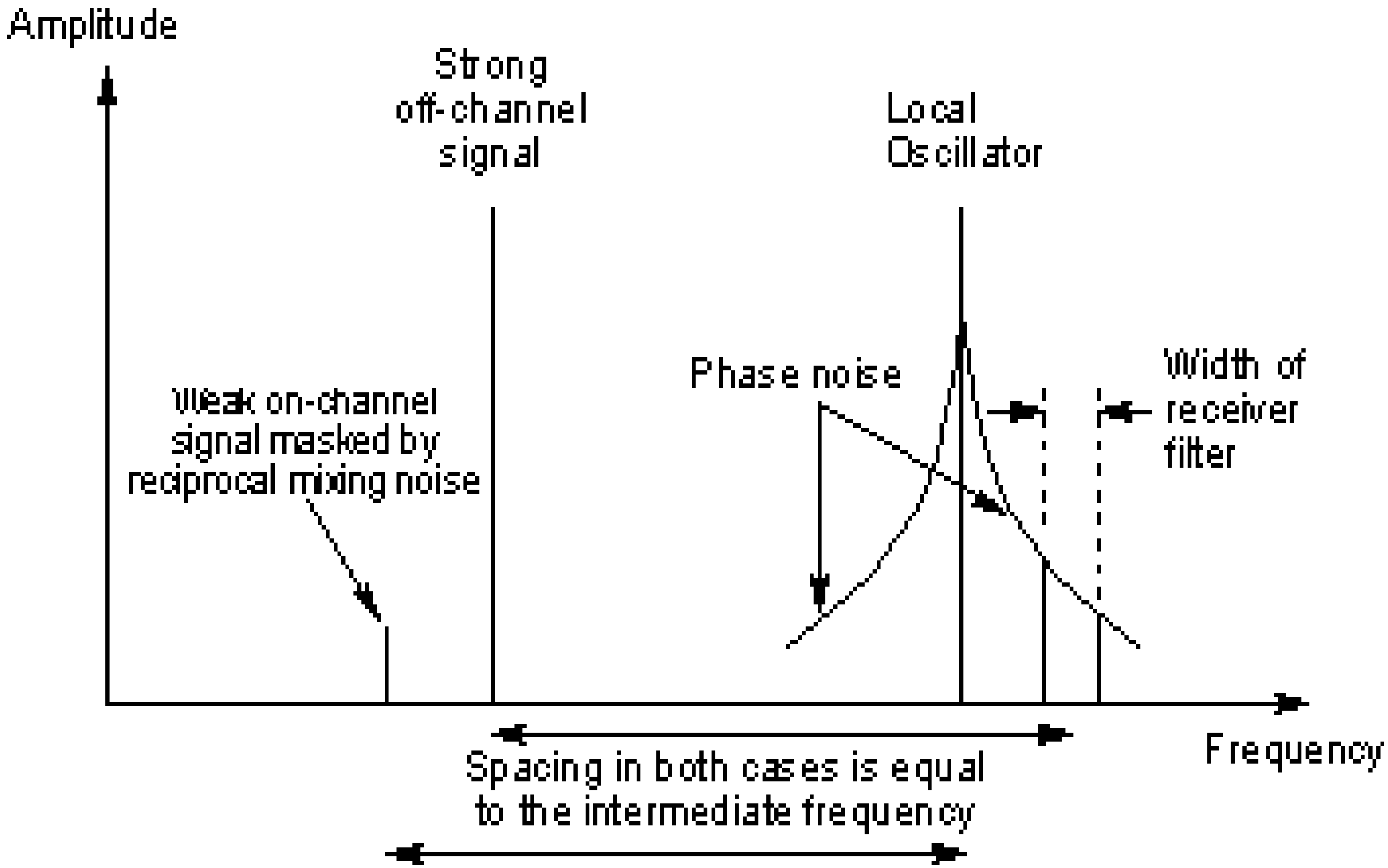


3.2.3 Self mixing

- Another important mechanism that limits the performances of a RR from the dynamic range point of view is the so called self mixing.

- The phase noise of the local oscillator (LO) transfer unwanted interferences in the band occupied by the desired signal.

- This causes a decrease in the output SNR value.



- It can be noticed that together with the desired signal that is transferred on IF, through FC-SH, an unwanted signal is transferred, strong by mixing with the OL noise.

- Therefore, an oscillator has to be designed with a phase noise as small as possible so that in the worst case from the interferences point of view it will produce a noise spectral density below the noise floor of the receiver.

- It can be proven that the maximum value of the spectral density of the noise floor produced by the local oscillator at the frequency deviation Δf is given by:

$$PN(\Delta f)\ [\mathrm{dBc/Hz}] = S_{\min} - P_b(\Delta f) - CCRR - 10\log(B)$$

where by P_b the power of the interfering signal located at a Δf distance from the desired signal, signal which can lead to blocking;

Application: Compare the performances when a single interference signal is present, for two solutions of implementing a GSM receiver: the first uses a autonomous OCT with a noise floor of L = -155 *dBc/Hz*, and the second one uses an on-chip VCO with a noise floor of $L = -130$ *dBc/Hz*. The sensitivity of the RR is of *-95dBm*, the pass-band at IF for a GSM receiver is $B = 140$ kHz and the $CCRR = 8$ *dB*.

It is obtained:

$$P_b = S_{min} - [L + 10\log(B)] - CCCR =$$
$$= -95 - [-155 + 10\log(14 \cdot 10^4)] - 8$$

It results:

$$P_{b1} = 0{,}6\ dBm;\ \ P_{b2} = -24{,}4\ dBm$$

3.2.4 Dynamic range

- As expected, the RF circuits cannot process signals no matter how large;

- When the level of the desired signal becomes very large, performances start to deteriorate;

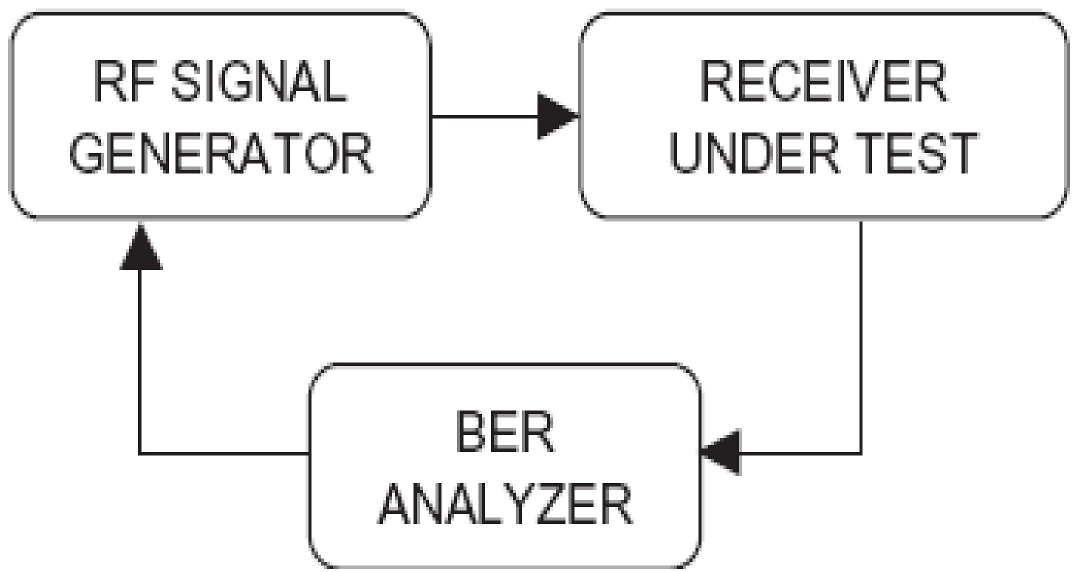
- When reaching a certain level, they can return to the values obtained when measuring the sensitivity.

- We denote with S_{at} the largest level of the desired signal for which, without the presence of interfering signals, the performances are equal with the ones obtained when measuring the sensitivity.

- In these conditions, the dynamic range, denoted with *DR* is:

$$DR = 10 \log(S_{at} / S_a) \text{ [dB]}$$

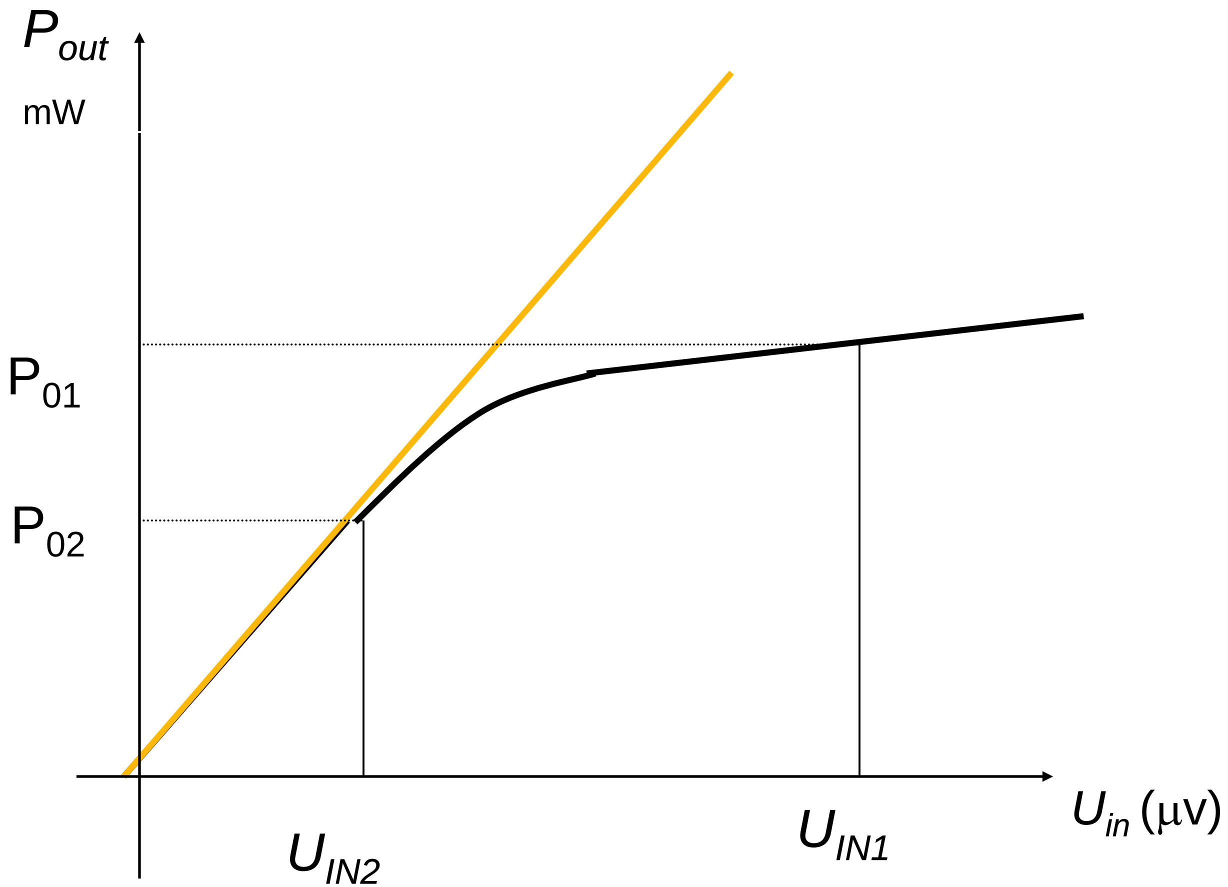
- In order to measure the dynamic range, the measurement set that was used for sensitivity is used in two steps: S_a and afterwards S_{at} are measured;



3.3 The AGC System Characteristics, used in analog RR

- As it will be detailed in a following section, the AGC system aims to maintain constant the RR output power in spite of the fluctuations of the input signal level;
- The decision relative to the AGC action is made by observing the level of the received carrier; such an information can be found in the output signal delivered by many demodulators, especially if we are talking about conventional AM signals; this is a slow variable component.

- The effect of the AGC system can be revealed by measuring the AGC characteristic; this is the plot of RR output power versus the input signal amplitude, $P_{out} = f(U_{in})$.



- in RR documents a concise parameter is used: **the AGC system gain** which represents the input signal level variation for which the output signal level varies with a standard value (10dB).

- This parameter can be measured directly or can be evaluated form the previous characteristic.

- One tunes the RR with a small level input signal; one adjusts the input signal level (U_{in}) to a value (U_{in1}) which corresponds to the nominal output power; by means of the volume control one adjusts the output power to half of the nominal power ($P_{out} = P_N / 2$).
- Finally one reduces the input signal level (U_{in}) until the output power (P_{out}) decreases with 10dB; it results U_{in2} , and:

$$\eta = 20 \log \frac{U_{in1}}{U_{in2}}$$