4. Radio Receivers – RR architectures

4.1 Introduction

- In the last decades, the continuous tendency to migrate towards solutions that use digital signal processing and transmission can be noticed;
- Furthermore, a tendency towards producing telecommunication equipment with a very small size and a very low cost is also remarked;
- To put it in other words: it was targeted the fulfilment of the performance level imposed by different applications together with a decrease in the consumed power, size and production cost;
- One of the methods: an increase in the integration level (components integration, functional blocks integration).

- The increase in the integration level for the circuits located between the antenna and the output of the RR is not as simple as the replacement of the integrated external components with on-chip components.
- As such, a first step would be the optimization of the constituent sub-systems.
- This is the reason for a general change in the design concept.
- New radio architectures were proposed and studied in order to imply as few as possible external discrete components (outside of the integrated circuit).

- In this context, it was reached the conclusion that a division of the RR equipment into three sections is useful:
  - The final part of the transmitter or the initial part of the receiver (front-end), which will still imply analog signal processing,
  - An intermediate frequency (IF) section (when it exists) which gradually switches to digital signal processing;
  - The final section (back end) which uses digital signal processing.

- The digital section which doesn’t necessarily include only the final section might be implemented in an integrated form (one or several ICs).
- It can be based on ultra-fast DSP and it extends more and more towards the frontal section, taking over more and more of the equipment functionalities and providing stable and reproducibility;
- Moreover, more complex functions can be provided and more spectral efficient modulation techniques can be chosen;
- Multi-standard, reconfigurable and/or adaptive equipment can be implemented in such a way.

- Obviously, in these conditions, in the design and implementation steps very few standard off-the-shelf components (COTS) will be used;
- As they are general purpose components, they cannot be properly used for the above mentioned objective;
- However, if such components are used, they are intended in order to avoid negative effects in a subsequent design stage;
- Except for the catalog data sheets that can be incomplete or inadequate for such applications, a careful selection of the selected components is necessary;

- Furthermore, it is necessary, at least for series production, the design and implementation of *dedicated circuits integrated (ASIC - Application-Specific Integrated Circuit)*;

- In the same time, the evolution of the technology called Software Definited Radio (SDR) can be remarked;

- An intermediary solution called Radio Equipment controlled through software also exists;

- If the final section and even the intermediate frequency section can be prospectively implemented on a single chip (SoC), the frontal section is in such a degree dependent on the application, that it will still to be ad-hoc designed for the near future.

- In the following sub-chapters, a review of some solutions used regarding the receiver architecture will be made, for both analog and digital transmissions.

- Some requirements at system level will also be discussed, as they may impose the choice of a certain architecture for the radio receiver.

4.2 RR Architectures used in analog broadcasting transmissions

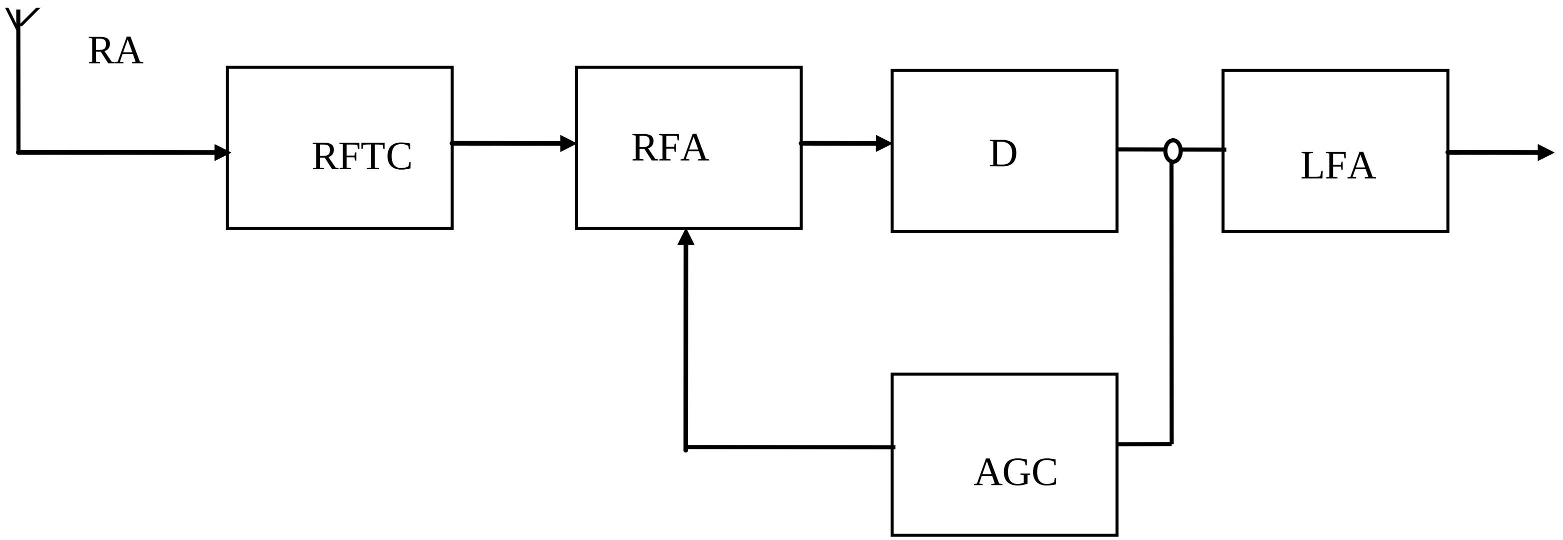
- Although less and less new technologies use such RR, they are still widely spread considering their use in radio broadcasting;
- It was noticed that although digital radio broadcasting technologies exist (DAB) there haven't been enough efforts made in order to replace the analog transmission with the digital one;
- At least not as much efforts as in TV broadcasting (DVB);

- The explanation can be found in the economical advantages, considering the releasing of several frequency bands, that are clearly superior following the transition to digital TV broadcasting;
- Another argument in favor of describing the architectures for analog RR is the better accessibility to theoretical aspects in case of this category of RR;

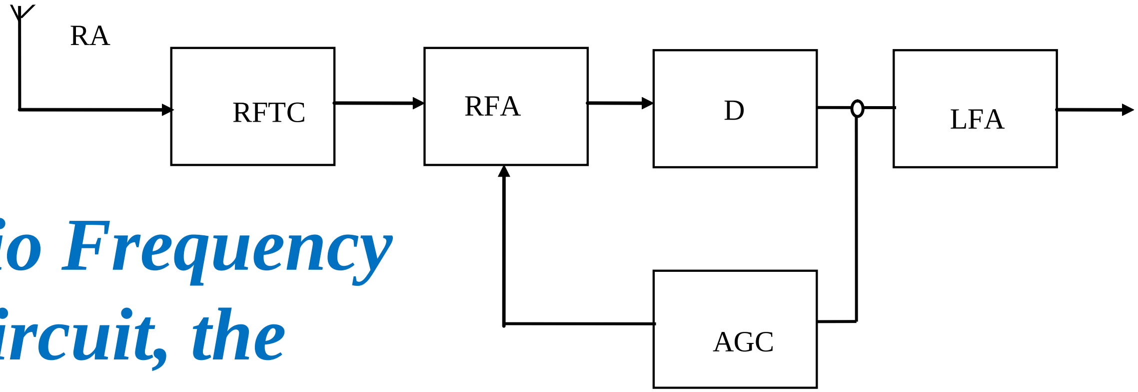
- As such, in this subchapter we will briefly analyze:
- Direct Amplifying Receivers (simple, regenerative or super-regenerative)
- RR with one or several frequency changes;

4.2.1 Directly Amplifying Receiver – Tuned Radio Frequency Reicever (TRF)

- The block diagram:



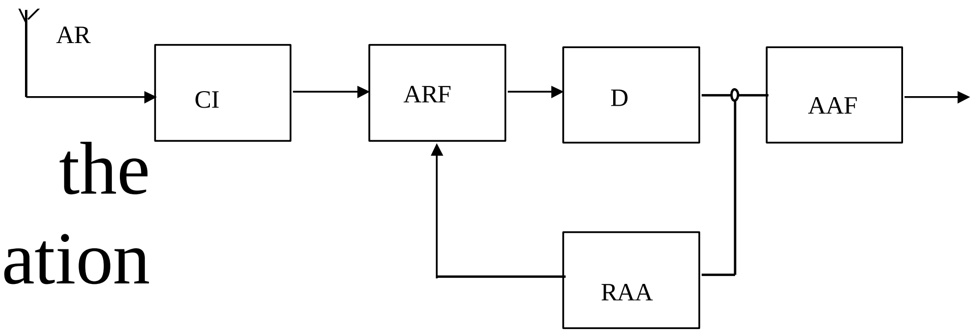
4.2.1.1 The role of the building blocks:



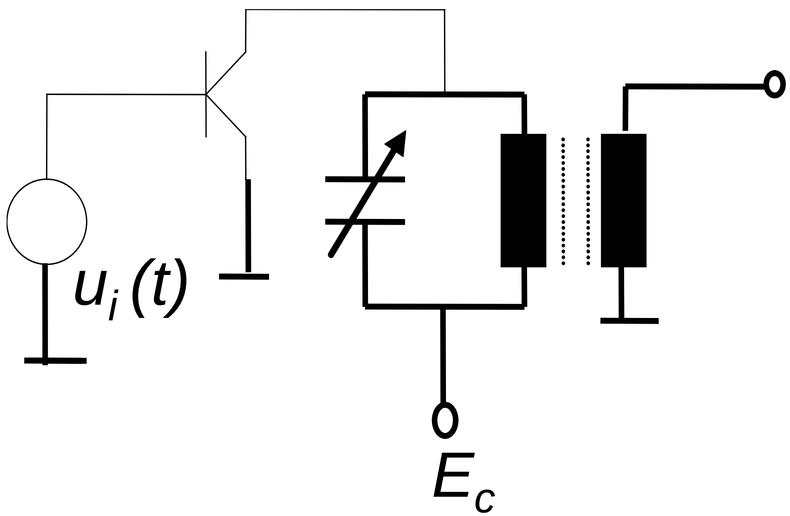
RFTC – the Radio Frequency Tuned Circuit, the RR Input Filter

- *connecting the antenna to the first active stage of the RR;*
- *it must have low losses – an LC tuned circuit ;*
- *has a contribution to the selectivity function ;*
- *it makes a preliminary selection before the signal enters the active stage;*

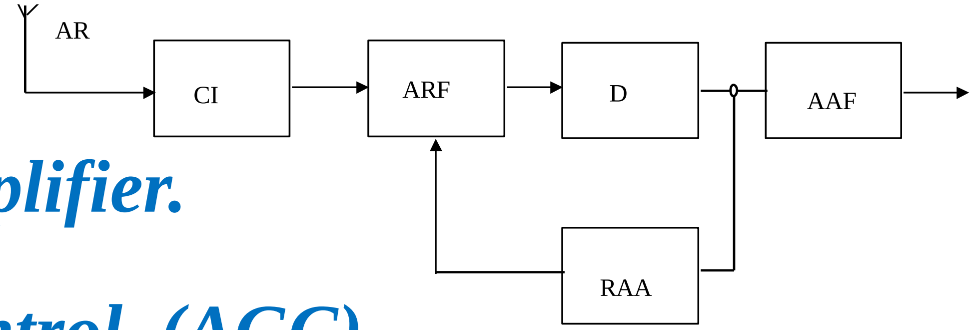
▪ *RFA – the Radio Frequency Amplifier*



- It has the performs the selection and amplification functions.
- the signal level is low so that if we want a high sensitivity receiver - the RFA must be a low noise one.
- it consists of more amplifying stages; an LC tuned circuit acts as a load for every active device;



- ***Demodulator***



- ***Low Frequency Amplifier.***
- ***Automatic Gain Control (AGC)***

❑ the input signal level is changing;

❑ any user would like to have the output signal level maintained as constant as possible;

❑ control of the RF amplifier gain – from the received signal one derives a voltage dependent on the input signal level;

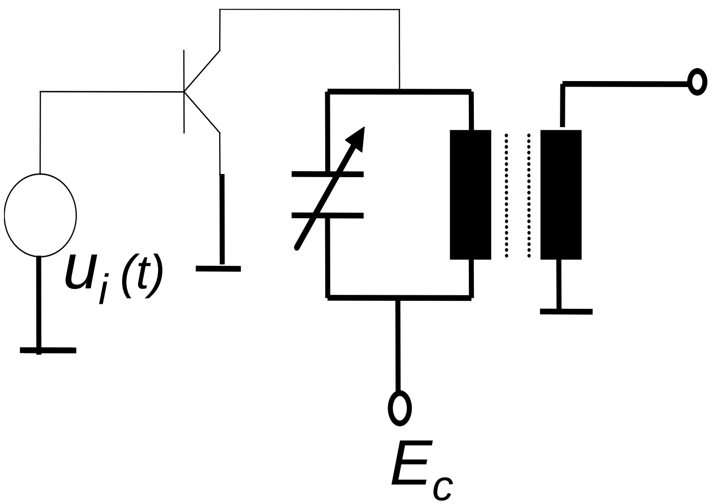
❑ This voltage is used to control the amplifier gain;

- If we have in mind AM broadcast RR, the demodulated signal contains such a component: the DC component corresponding to the carrier;
- In this case the component can be extracted by filtering;
- In the case of high performance receivers the AGC processor can include a DC amplifier in order to improve the performance of the AGC loop.
- In the case of other types of radio receivers according to the modulated signal one must use an AGC detector;

4.2.1.2 The performance analysis:

1. *sensitivity* – is relatively low, and in the case of variable tuning receivers, it changes when the received signal frequency changes;

- Usually the RR tuning is done by means of variable capacitors;

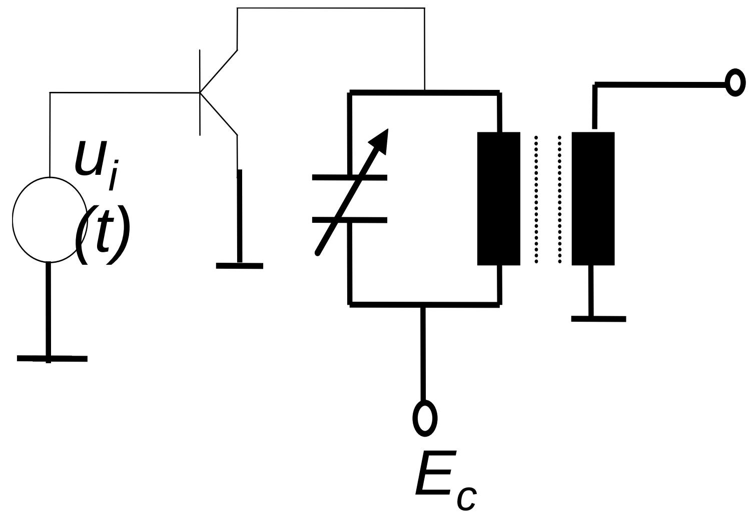


- if the amplifier consists in multiple stages the variable capacitor must include multiple sections; it is expensive and difficult to build; usually variable capacitors have 2-3 sections.

$$A_r \approx g_m Z_{dr} \qquad Z_{dr} = Q\omega_r L$$

$$Q \approx ct.$$

$$A_r \approx k \cdot f_r$$



- It can be remarked that the gain depends on the frequency ; of course the sensitivity varies the same way.

2. *Selectivity* – it can be pointed out that either the selectivity is low and frequency dependent.

- Indeed, we have:

$$B = \frac{f_r}{Q}$$

$$a = 10\log[1 + (\frac{2\Delta f\, Q}{f_r})^2]$$

$$a_n = 10n\,\log[1 + x^2]$$

$$x = Q(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}) = \beta\, Q \cong \frac{2\Delta\omega}{\omega_r} Q \cong \frac{2\Delta f}{f_r} Q$$

- if the number of the RF stages is small the selectivity is low;

- *In the ca*se of variable tuning RR the number of RF stages is limited due to the limited number of capacitor sections;

- Changing the operating frequency (even in the case of RR tuned on a single frequency):

$$B = \frac{f_r}{Q} \quad Q<100$$

- It can be shown that for high operating frequency the adjacent channels can be no more rejected;

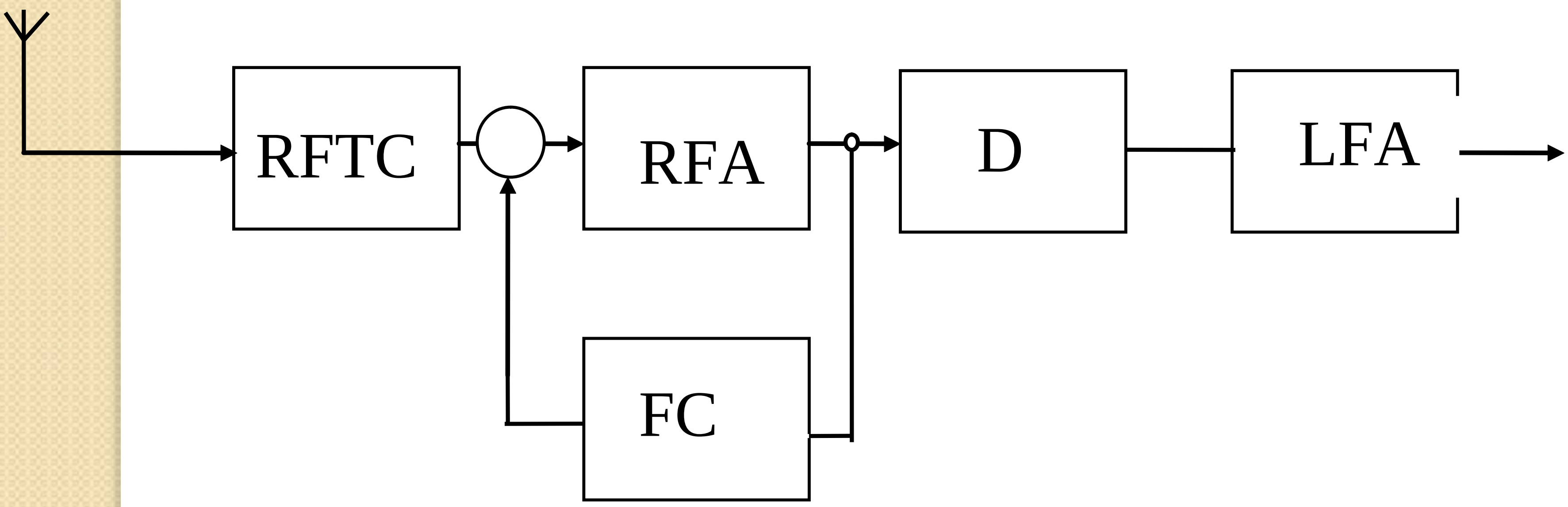
  Ex. f_r=10MHz; Q=100

  B=10000/100=100kHz

  So that the pass band includes more than ten channels.

- We can conclude that the directly amplifying receivers can have acceptable performance if they operate on a single not very high frequency (max. 2MHz).

4.2.2 Regenerative R.R.



- **Working principle:**
- Let consider a feedback amplifier having the open loop gain A_0 and the bandwidth B_0; the feedback is realized by means of an all-pass circuit with the gain β, the closed loop parameters are:

$$A_r = \frac{A_0}{1 \pm \beta A_0} \qquad B_r = B_0(1 \pm \beta A_0)$$

$$A_r = \frac{A_0}{1 \pm \beta A_0} \qquad B_r = B_0(1 \pm \beta A_0)$$

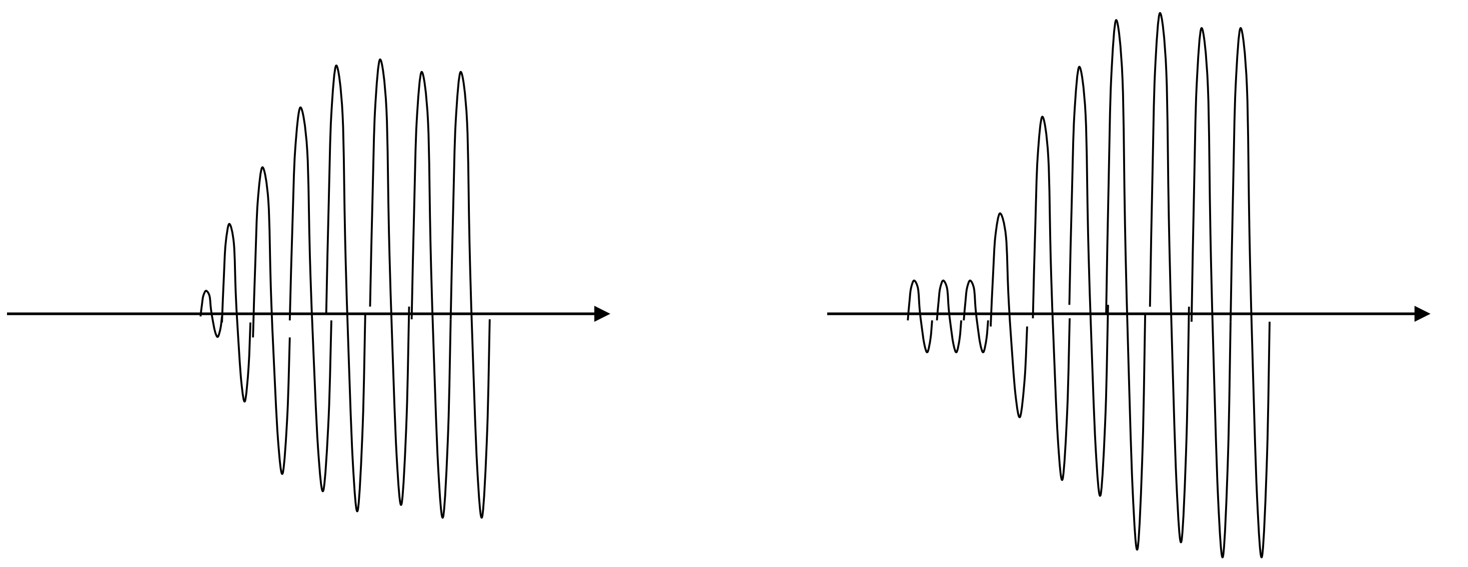
- In the case of a positive feedback (the sign in the denominator expression is -) **βA_0** trends **to 1**, **$A_r \to \infty$ $B_r \to 0$**, so that the effect is favourable: both the sensitivity and the selectivity become higher.

- **The main drawback** – the amplifier can reach the oscillation regime due to the drift of various parameters -> **instability**.

4.2.3 The super-regenerative radio receivers (AM-RR)

- **The operating principle**:
- A positive feedback amplifier experiences a stable working regime only if it is used as oscillator .
- But, in this situation the output signal does not depend in any way of the input signal.
- One has to find out a solution to get beyond this difficulty and transfer the useful information from input to output.

- It was observed that the input signal has an impact on the output signal only during the setting-in of the oscillations:



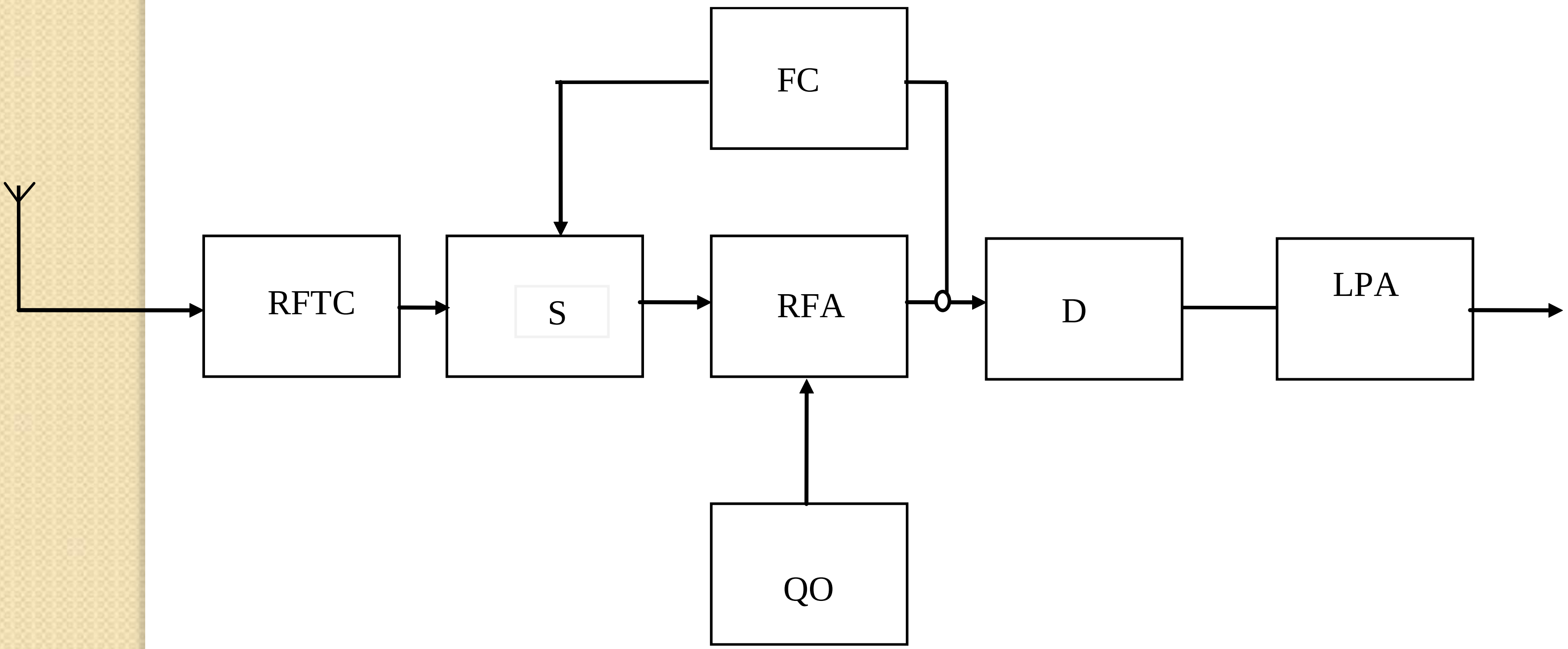
- The setting-in of oscillations period is dependent on the initial conditions.

- These conditions are determined by the parameters of the input signal if such a signal exists (carrier frequency equal to f_0).

- The setting-in period is shorter if the amplitude of the input signal is larger .

- Consequently, in order to transfer samples of the input signal (modulation degree) one interrupts the RF oscillation and forces the oscillator to repeat the setting-in of oscillations.

- This action is done by means of a supplementary building block: the quenching oscillator (QO); QO stops the oscillations regime and let it start again;

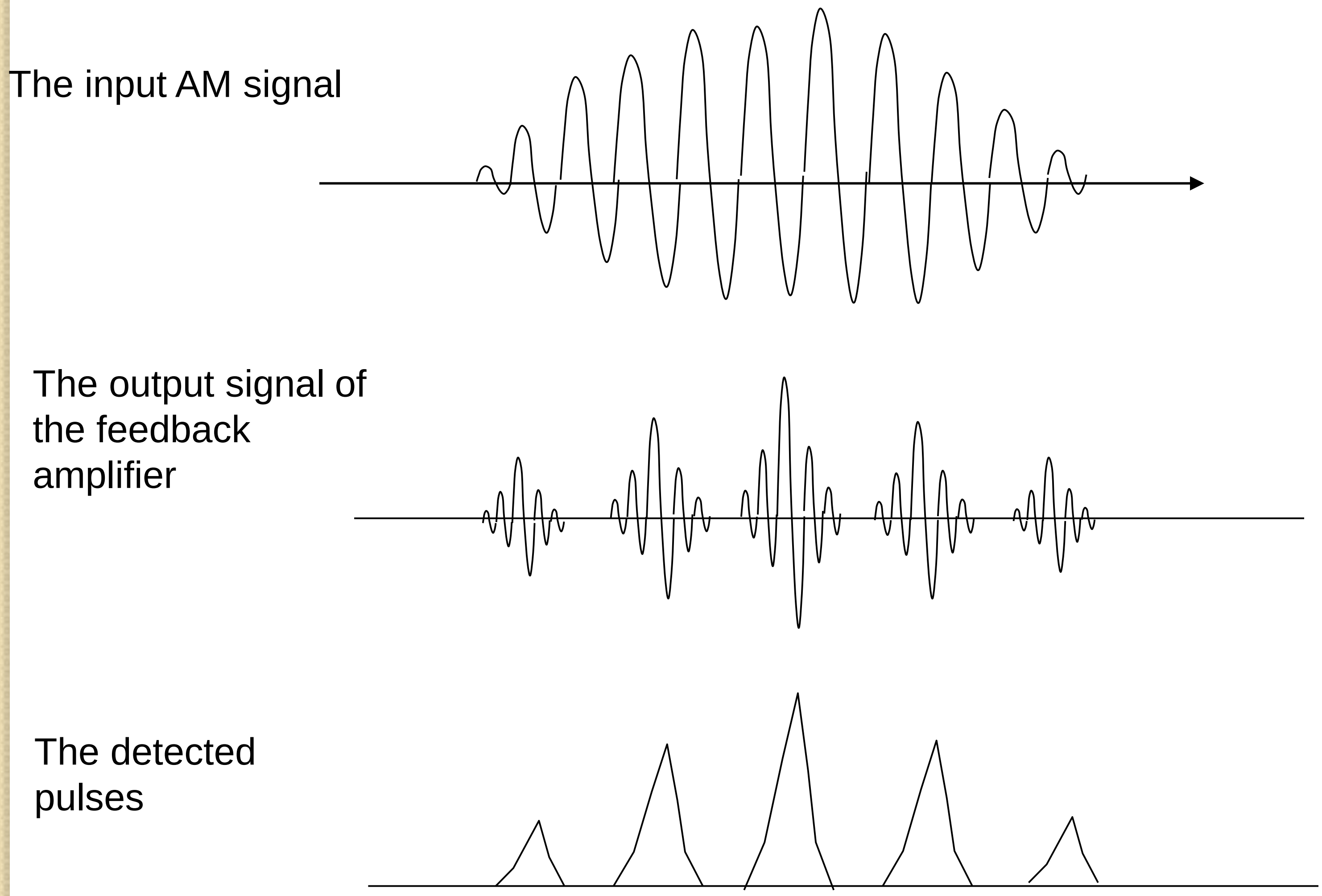

FC
RFTC
S
RFA
D
LPA
QO

- One can identify three working regimes for the super-regenerative RR:
  - ❑ linear (this approach will be presented)
  - ❑ logarithmic,
  - ❑ self-quenched.

- The main criterion for this classification is the ratio between the setting-in duration and the quenching period (first two approaches).

- The SR-RR working in linear regime uses such a ratio between the two time intervals that the setting-in phase never comes to an end;

- That is the oscillator never reaches the steady state phase;


The input AM signal
The output signal of the feedback amplifier
The detected pulses

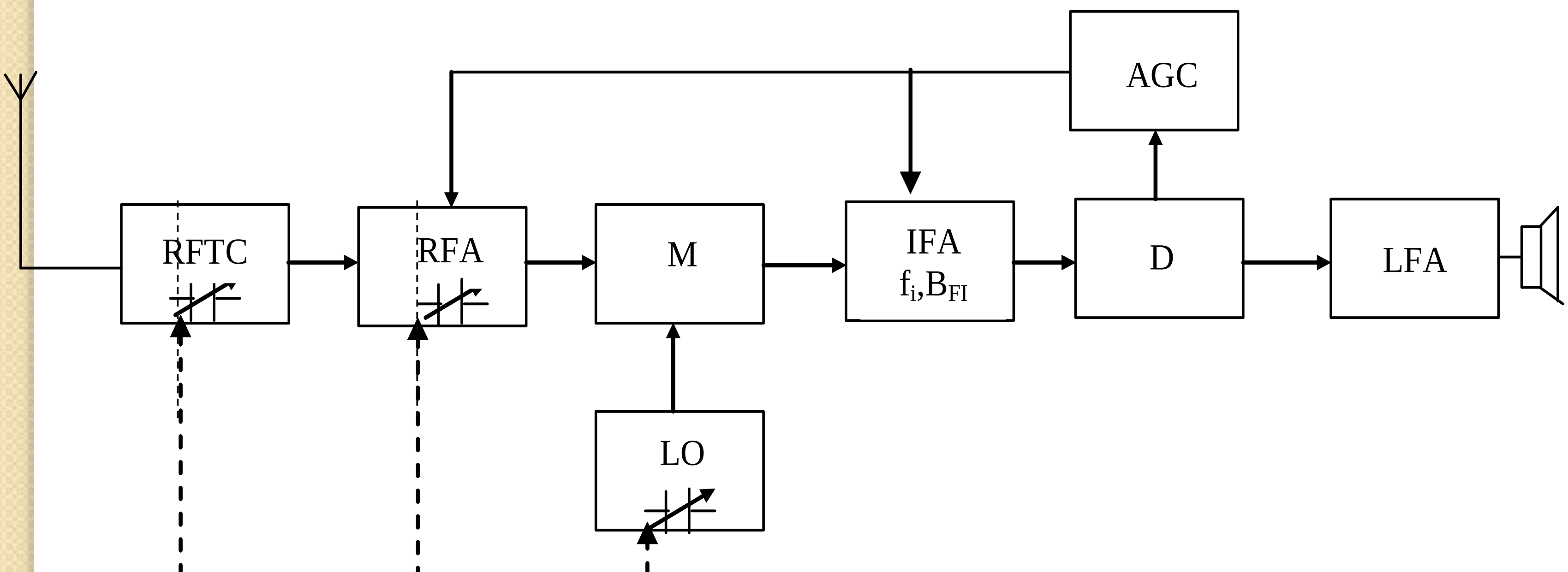
- It can be demonstrated that the spectra of a PAM signal includes a LF component which is the modulating signal;

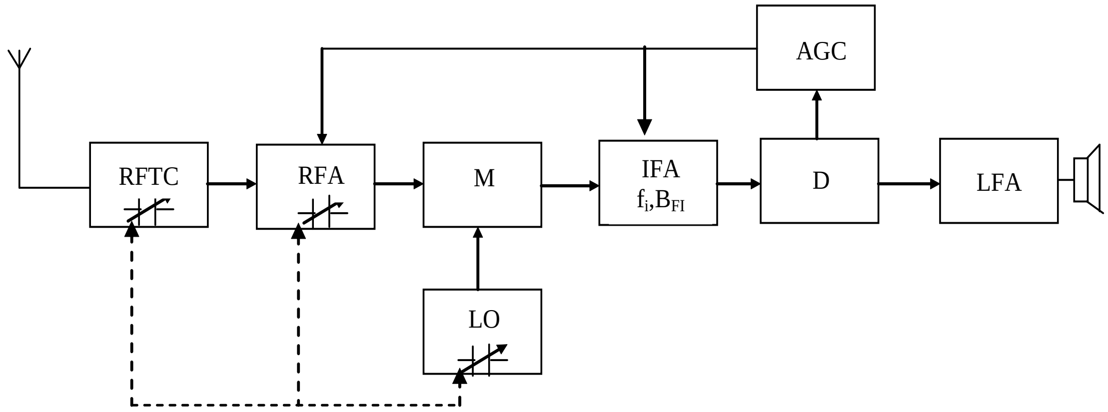
- So that the useful signal can be recovered simply by means of a LPF;

- SR/RR applications: commercial applications such as garage-door openers, radar detectors, microwatt RF data links, and very low cost walkie-talkies;

4.2.4 Single Frequency Conversion Receivers; Super-heterodyne RR

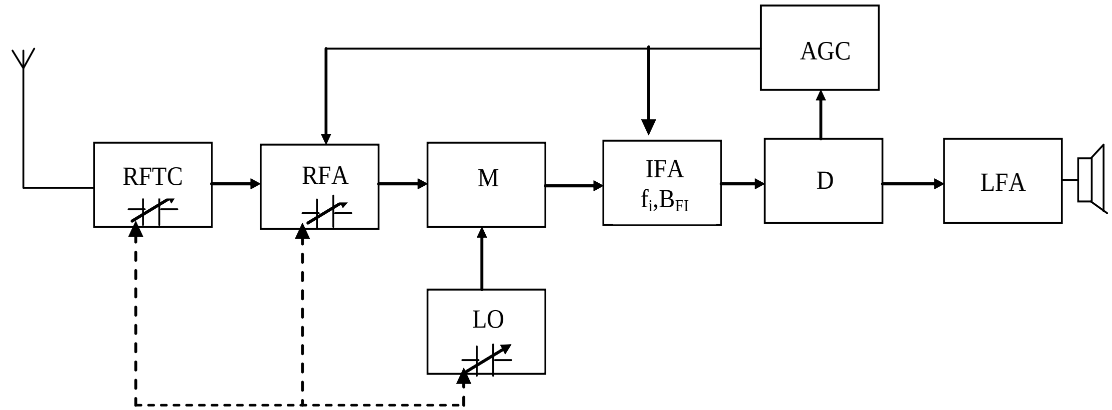
- The super-heterodyne architectures – 1917 – Armstrong.
- Allowed a significant increase in the performances of the RR;





➢ In what follows we shall analyze:

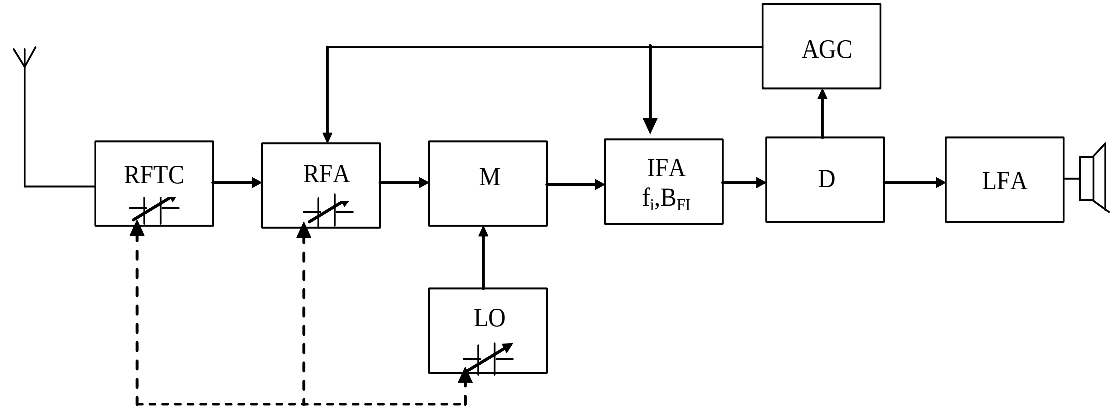
- the main functions of the building blocks;
- the main solutions used to realize the building blocks;
- the impact of the building blocks performance over the overall performance of the receiver.



- ***Automatic Gain Control*** – has the same function and operating principle as in the case of the TFR-RR;

- In contrast with this one, in this case, AGC may achieve a higher gain having in mind that it can control a larger number of amplifying stages (2-3) IFA, (1-2) RFA.

4.2.4.1 The Intermediate Frequency Amplifier (IFA)

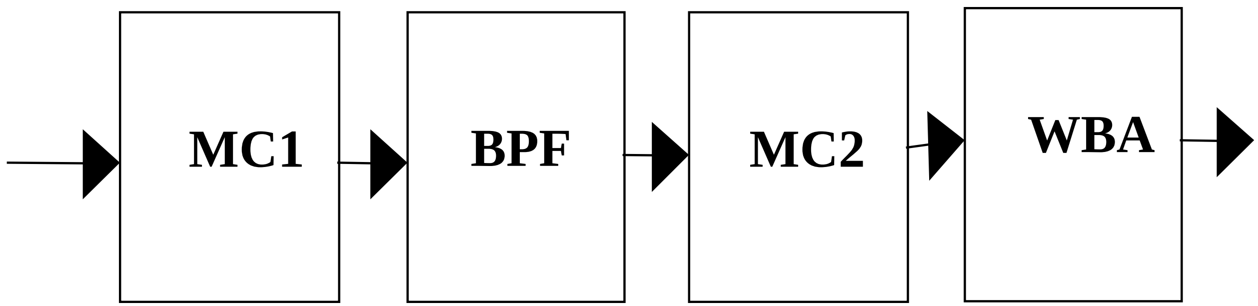


- This block has a crucial role for the overall performance of the receiver:
  - it realizes the adjacent channel selectivity;
  - it has a major contribution to the global receiver gain;

- Consequently it must be carefully designed and implemented.
- The building solutions are strongly dependent on the technological level.

➢ Implementation choices:

- Currently used RR use concentrated selectivity IF amplifiers:



- As it can be remarked the amplifying function is separated from the selectivity one;

- A wide band amplifier adequately designed is used;

- It is associated with a band pass filter (BPF) realized by means of an appropriate technology, accompanied by two Matching Circuits (MC1/2);

- Usually, especially in the case of broadcast radio receivers, piezo-ceramic filters are used (455 kHz , 10,7 MHz).

- Other radio receivers uses piezoelectric crystal filters or mecano-electric, magneto-strictive filters, etc

- A concentrated selectivity amplifier used for a while was based on multiple tuned RLC resonant circuits (n=4...5...6) but it did not became very wide spread having in mind the complexity of the tuning process.

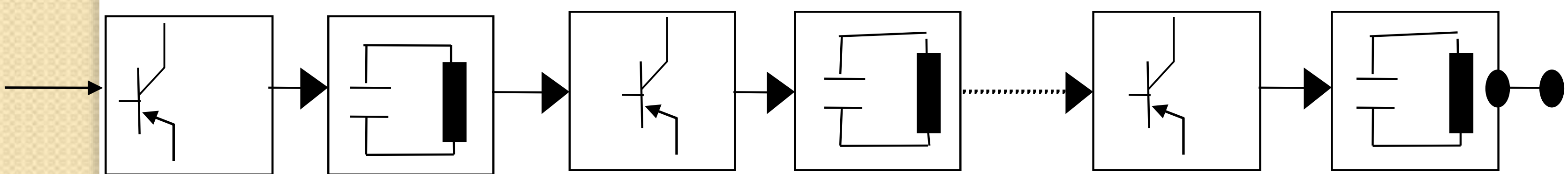
- The IFA performance can be specificated by means of :

  - 3 dB bandwidth and the attenuation of the adjacent channels;
  - Shape factor

$$K_s = \frac{B_{20dB}}{B_{3dB}}$$

- During the evolution of RR other variants existed, like:

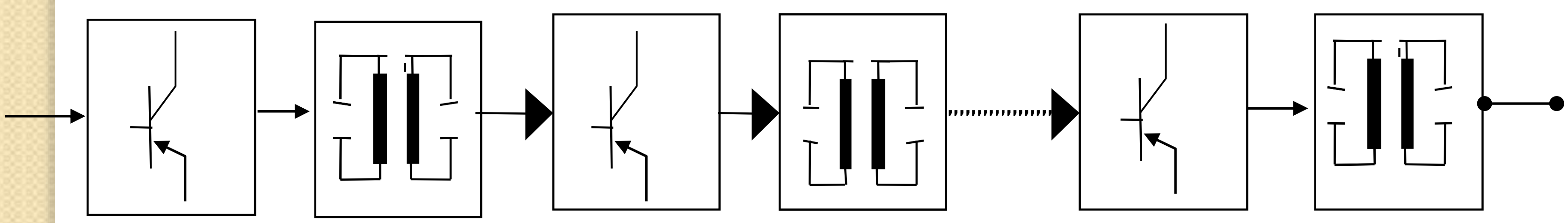
a) *A few amplifying stages with resonant circuits acting as loads of the active devices*:



- This solution could ensure a good performance if the circuits are tuned on adequately chosen frequencies around the intermediate frequency but the complexity of the adjustment and the cost are relatively large.

- From the point of view of the cost a more convenient solution can be obtained by using synchronously tuned on the intermediate frequency circuits but the technical performance is poorer.
- The second approach has been used with acceptable performance in AM-RR (2-3 stages).
- The FM-RR performance using this approach was not satisfactory because the phase characteristic of the IF amplifier is not enough linear.
- Some stability issues have to be solved at the same time.

b) *A few number double tuned RLC circuits separated by amplifying stages:*

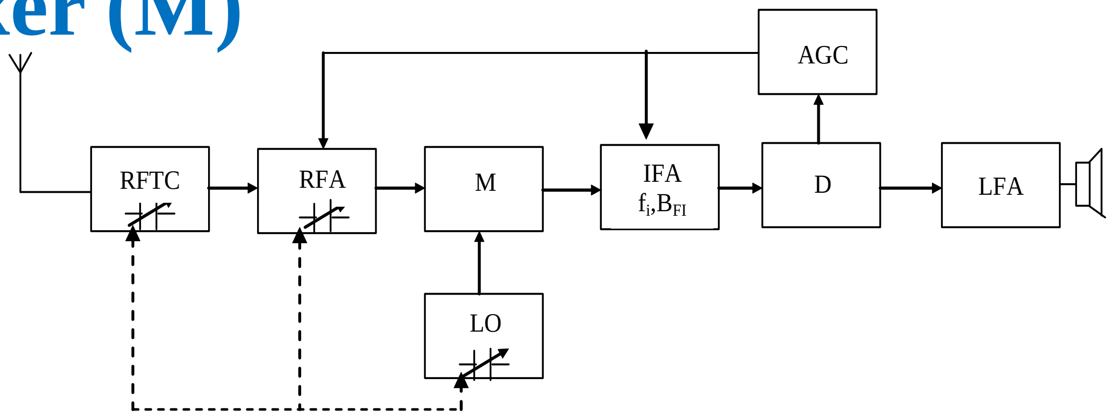


- This solution ensured a higher selectivity performance comparing to the previous one.
- Higher operating stability (a better separation between the active devices);

- Both AM-RR (2-3 stages) and FM-RR (3-4 stages) have used this solution;
- The phase characteristic depends on the coupling coefficient (g=kQ) too so that it could be optimised;
- This option have been used extensively at the technological level which allowed the use of miniature coils with a ferrite core.

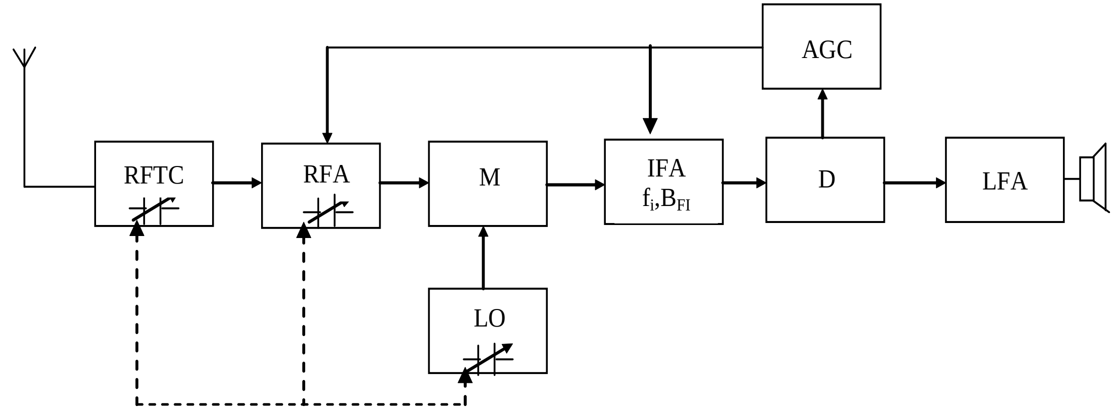
c) Hybrid solutions; many times the last stage used single tuned RLC circuit while the others used double tuned RLC circuits.

4.2.4.2 The mixer (M)

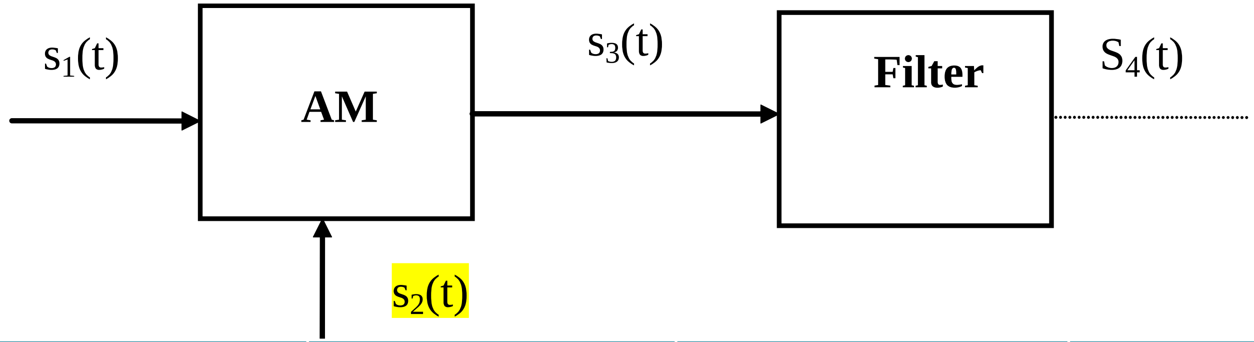


➢ The mixer has to process the received signal (central frequency f_s) and the locally generated signal (a sine wave signal with frequency f_h) and to deliver an output signal with the central frequency f_i.

- ❑ it is obvious that it is mainly a non-linear building block;
- ❑ it must be carefully designed in order to avoid the distortion of the modulating signal;



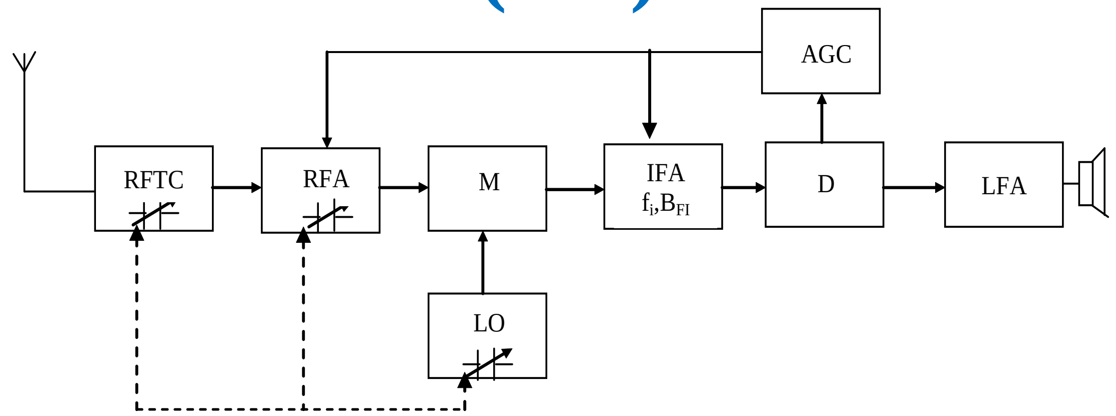
- the mixer can be build on the basis of any schematic diagram conceived for AM signal modulation by changing few parameters;



	s_1	s_2	Filter
AM Modulator	g(t)	$U_0\cos(\omega_0 t)$	BPF f_0
AM demodulator	Modulated signal, ω_0	$U_0\cos(\omega_0 t)$	LPF
Mixer	Modulated signal, ω_0	$U_h\cos(\omega_h t)$	BPF f_i

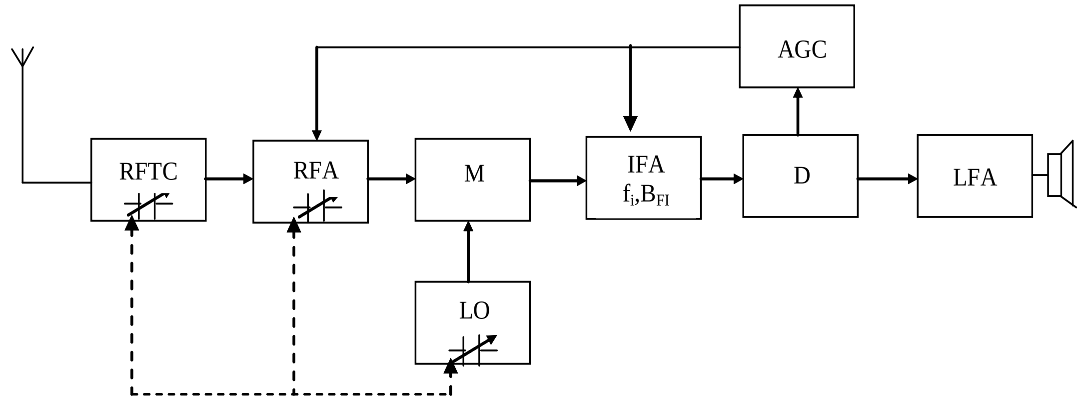
- the type, the level and other parameters of the locally generated signal depends on the chosen building solution;

4.2.4.3 The Local Oscillator (LO)



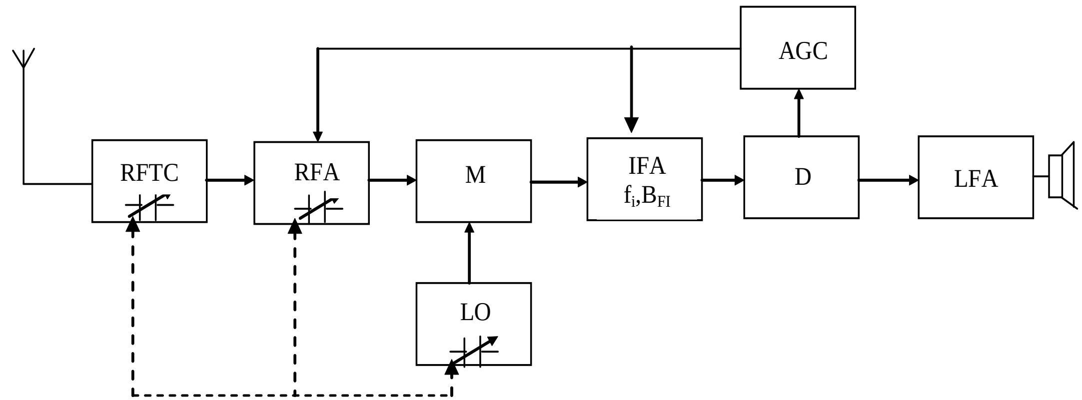
- The LO have to generate the local signal as required by the chosen schematic diagram for the mixer;
- The signal could be a sine wave or a rectangular wave one;
- If a sine wave is required than it must have a small level of harmonics;
- In the case of variable tuning receiver LO have to deliver a variable frequency oscillation with a level as constant as possible along the desired frequency band;

4.2.4.4 The Radio Frequency Amplifier (RFA)



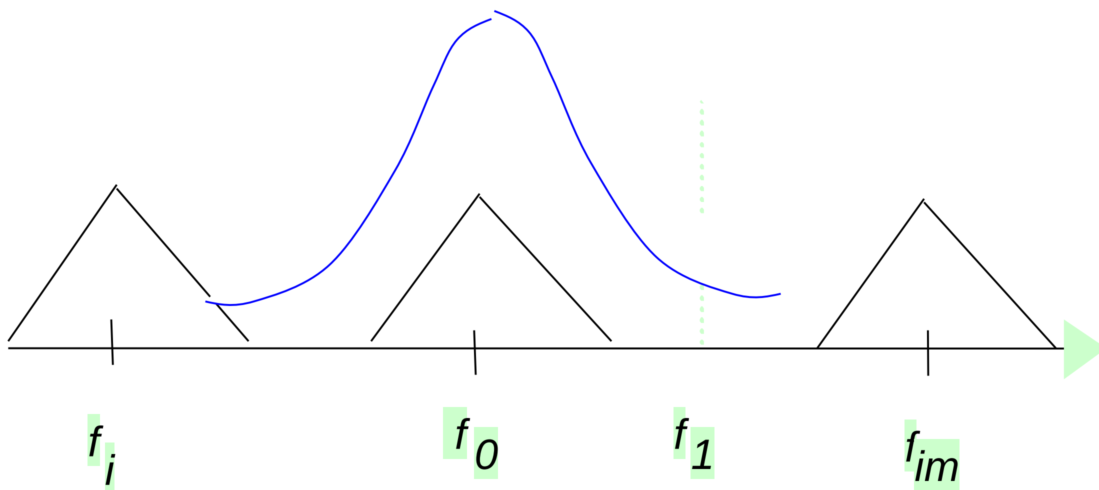
- RFA amplifies the received signal in its original frequency range.

- One of the RFA contribution consists in augmenting the overall gain, and consequently, in enhancing the gain limited sensitivity;



- Usually it is required to design the RFA to ensure low noise figure;
- Anyway, the noise limited sensitivity is higher than the one expounded by a receiver with no RFA (the noise parameters of a RFA are always better than the ones of a mixer);
- This is possible and, hence, the receiver can expound a high noise limited sensitivity;

- Having in mind that we have to attenuate as much as possible the signals around the intermediate frequency, f_i, and around the image frequency, f_{im}, and that the RFA is a block placed in front of the mixer it must fulfil a selective function targeting these signals;



- Consequently a RFA will improve the receiver selectivity but it has not a significant contribution to the rejection of the adjacent channels;

- In the case of a variable tuning receiver the RFA has to be tuned on the central frequency of the useful signal (CV, LV).

- Considering this requirement one has to use a simple building solution: one or two amplifying stages with single or double tuned circuits acting as load of the active devices.

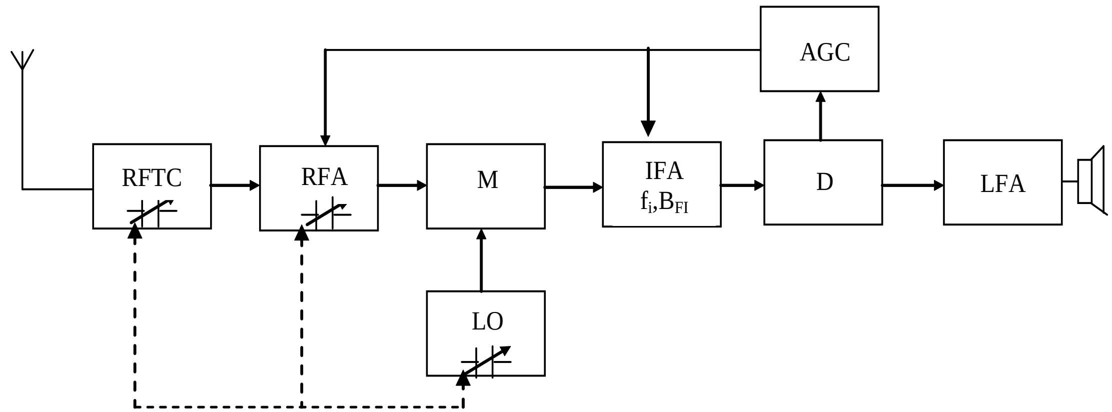
- We can remark that in order to receive the desired signal we have to tune the RFA on the central frequency of the signal and, simultaneously to adjust the LO to deliver a sine wave signal with an adequate frequency.
- It is hard to consider that a user would accept a receiver involving the two adjustment actions sequentially realized.
- The adjustment must be done simultaneously by means of a single tuning knob controlling both building blocks: RFA and LO;

- This leaded to the definition of another concept specific to RR with variable tuning: **the alignment of RR;**
- In order to solve the **alignment problem** a series of theoretical and experimental studies were necessary;
- The alignment implies a laborious and expensive operation during the manufacturing process;
- For details regarding the alignment the paragraph from the annex is recommended.

- Having in mind that the number of the variable devices (coils or capacitors) would increase the dimensions and the cost of the receiver some commercial receiver do not include a RFA or the RFA consists in a single stage.
- Nowadays when the variable devices are varicap diodes (variable capacitance diode – VCD) this argument is no more relevant;

- Usually the gain of a RF amplifying stage is (10...30) dB;
- Its value must be large enough in order to reduce, as much as possible, the noise contribution of a second stage or the one of the mixer;
- Another contribution of the RFA: it ensures a good isolation between the tandem M/LO and the antenna;
- This way it reduces the leakage of the locally generated oscillation and the influence of the antenna on the LO frequency stability.

4.2.4.5 The Radio Frequency Tuned Circuit (RFTC)



- This circuit has to optimize the signal transfer from the antenna to the first active device of the receiver;
- The optimizing means to ensure a transfer with minimum losses, with little modification of the useful signal and with significant attenuation of the un-wanted signals;
- Hence this circuit usually is a serial or parallel LC tuned circuit, having the resonance frequency equal to the central frequency of the useful signal;

- In the case of a variable tuning receiver the RFTC will be tuned on the central frequency of the useful signal by means of a variable capacitor or variable inductance coil.
- From the point of view of the selectivity function the RFTC, as the RFA, is a block situated in front of the mixer, and addresses the undesired signals which stands far from the useful signal in the frequency domain:
  - Intermediate frequency channel;
  - Image frequency channel.

- It has no significant contribution (in many cases either it can not have) from the point of view of the rejection of the adjacent channel (as the RFA);

- As one can remark the two building blocks: RFA and RFTC have similar functions from the point of view of the selectivity;

- In the case of cheap receivers with no RFA all the specific selectivity is realized by the RFTC;

- Concluding, we point out again that the RFA and the RFTC have similar functions:
  - they are tuned on the central frequency of the useful signal, f_s;
  - they contribute to the attenuation of the undesired signals situated in the vicinity of f_i *and* f_{im};
  - they have no significant contribution from the point of view of the rejection of the adjacent channels;
- That's why they can be treated together and can be referred to as *RF circuits*.

4.2.4.6 Conclusion, the performance level

- For the commercial broadcasting RR the single conversion radio receivers can ensure a quite high level of performance.
- High enough sensitivity (usually nowadays receivers have the gain limited sensitivity higher than the noise limited one: $S_z > S_a$):
  - ❑ USW - (10-20) μV
  - ❑ MW - 50-200μV
  - ❑ SW - 50-200μV
  - ❑ LW - 100-300μV

- *The adjacent channel selectivity* higher than 30 dB and it is not dependent of the frequency range;

- Usually more than 35dB can be obtained in case of the intermediate frequency selectivity (rejection ratio).

- If there is no RFA and the RFTC is not able to ensure the desired performance a notch filter (an additional series or parallel RLC circuit tuned on f_i) can be added.

- The image frequency channel selectivity (image frequency rejection ratio):

- It depends on the input signal frequency as the TFR receiver sensitivity depends on the same parameter;
- In the case of LW, MW and USW frequency ranges, as $\Delta f_{im}/f_s$ is relatively large, the attenuation is acceptable (>30dB)
- For the SW frequency range the attenuation is low (10...16dB).

- *When better performances were necessary (better sensitivity, selectivity for all types of perturbations better than 50dB, the elimination of the necessity of the alignment procedure) RR with two or more frequency changes were used.*

- For the interested ones, on the next slide a table with the performances of some older RR is given;

- It can be noticed that, for the respective technological level:

  - According to the level of the performance four classes have been defined for transistor based RR.
  - The highest performance corresponds to the class 1.
  - The table contains the performances for class I and class II transistor radio receivers.

Performance parameters	Frequency band	Class I	Class II
$S_{zp}(\mu v)$	LW MW USW	100 50 5	150 100 10
$a_{ac}(dB)$	AM FM	36 36	30 26
$a_{im}(dB)$	LW MW USW	36 12 35	30 10 30
$a_{i}(dB)$	LW MW USW	35 30 30	30 25 40
$\eta_{AGC}(dB)$	AM	50	40

Annex 4.2.5 Single knob receiver tuning and RFA/IFA tuned circuits alignment

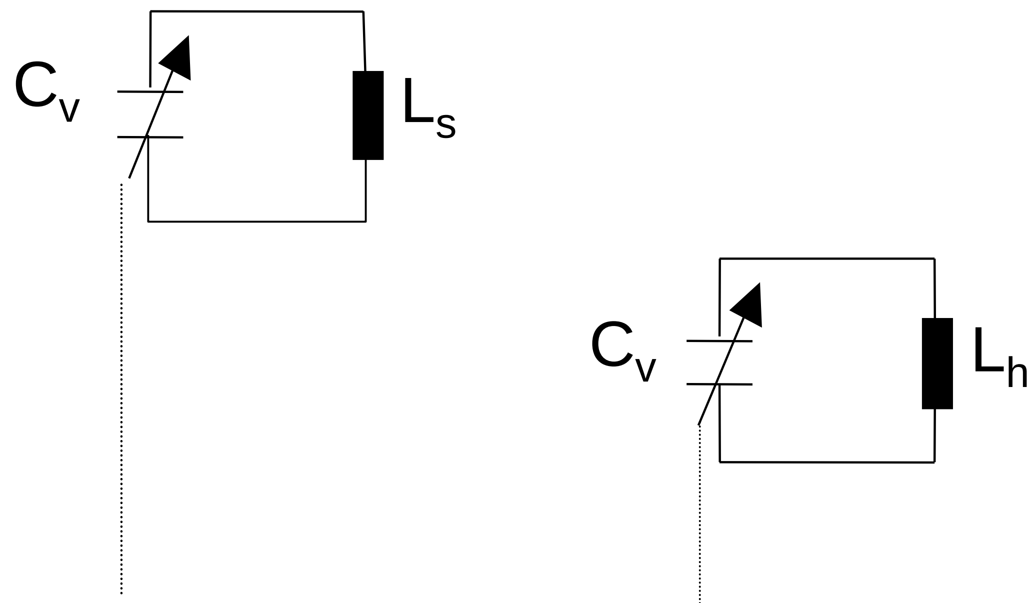
- According to the observations mentioned in the section where the frequency change principle for the case of super-heterodyne RR was discussed, in order to adequately process the useful signal the next two conditions must be fulfilled simultaneously

$$\begin{aligned} f_{rs} &= f_s \\ f_h - f_s &= f_i \end{aligned} \qquad (1)$$

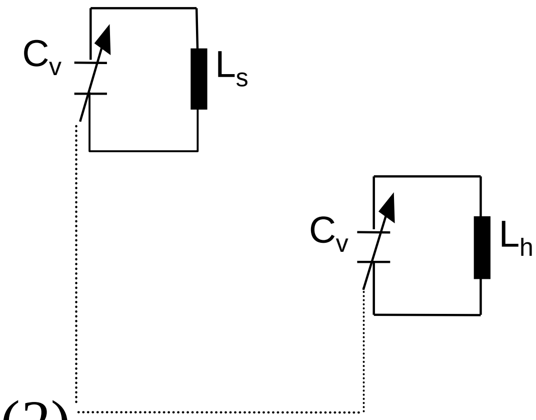
- So that one must adjust the parameters of two building blocks (RFA and LO);
- A variable multi-sections capacitor (gang variable capacitor) or coil is used;
- The sections are adjusted by means of a single knob (they are mechanically ganged).
- From practical reasons the sections are identical (the values of the capacitance or inductance change according to the same law);

- A short analysis will show that, in this case, if one takes no other action, the conditions (1) can be fulfilled for a single frequency from the desired frequency range;

- Indeed let’s consider the next schematic diagram:



- (C_v , L_s) represents one of the tuned circuits from the RF block and (C_v , L_h) represents the tuned circuit controlling the LO frequency;

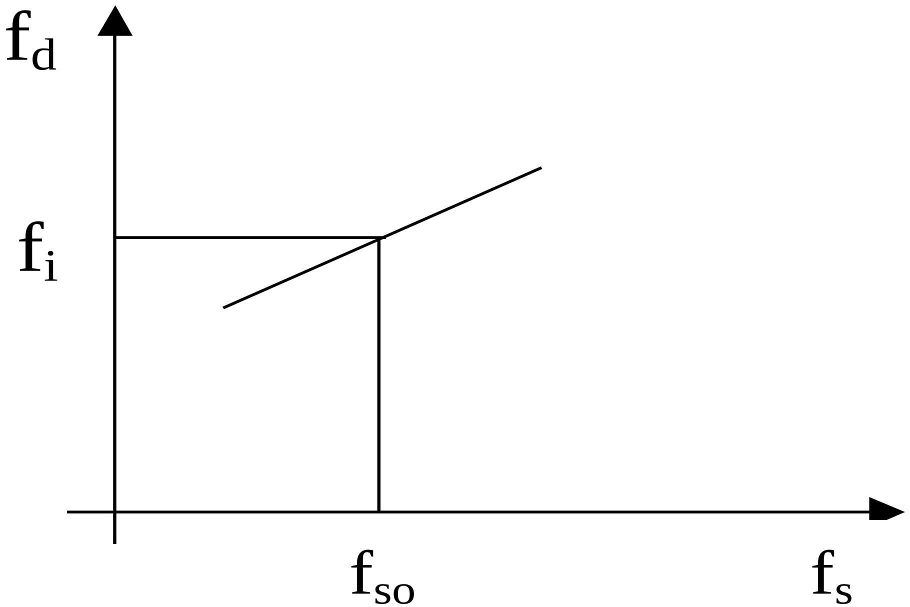


$$f_{rs} = \frac{1}{2\pi\sqrt{C_v L_s}}; \qquad f_h = \frac{1}{2\pi\sqrt{C_v L_h}} \qquad (2)$$

$$f_d = f_h - f_{rs} = \frac{1}{2\pi\sqrt{C_v L_s}}\left(\sqrt{\frac{L_h}{L_s}} - 1\right) = f_{rs}\ a$$

- It would be convenient that $f_d = f_i$ no matter the value of the received signal frequency f_s.

- If the capacitance is changing in order to tune the RF circuits on the received signal frequency it can be observed the moment when $f_d = f_i$;



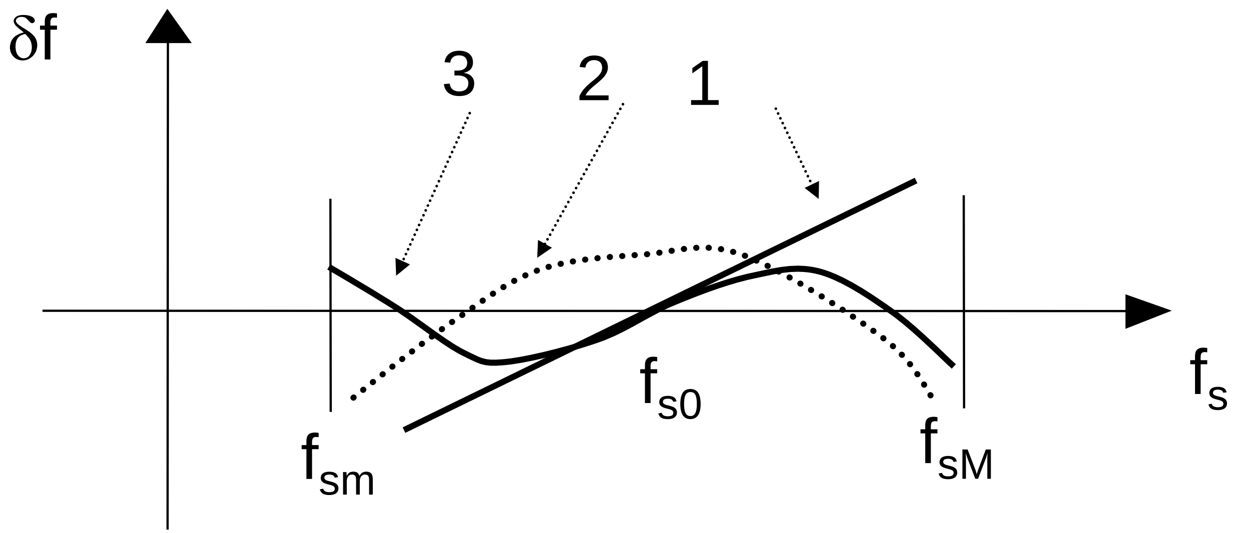
- Conclusion: f_d is linearly changing as f_{rs} (that is f_s) is changing and the condition $f_d = f_i$ is fulfilled only for $f_s = f_{so}$.

- We can define the **alignment error** :

$$\delta f = f_d - f_i = af_{rs} - f_i$$

- It can be stated that the signal with the central frequency f_{so} is correctly received, in other words the tuned circuits from the RFA and from the IFA are correctly aligned.

- All the other signals are processed with a **alignment error** equal to δf.


δf
3
2
1
f_{sm}
f_{s0}
f_{sM}
f_s

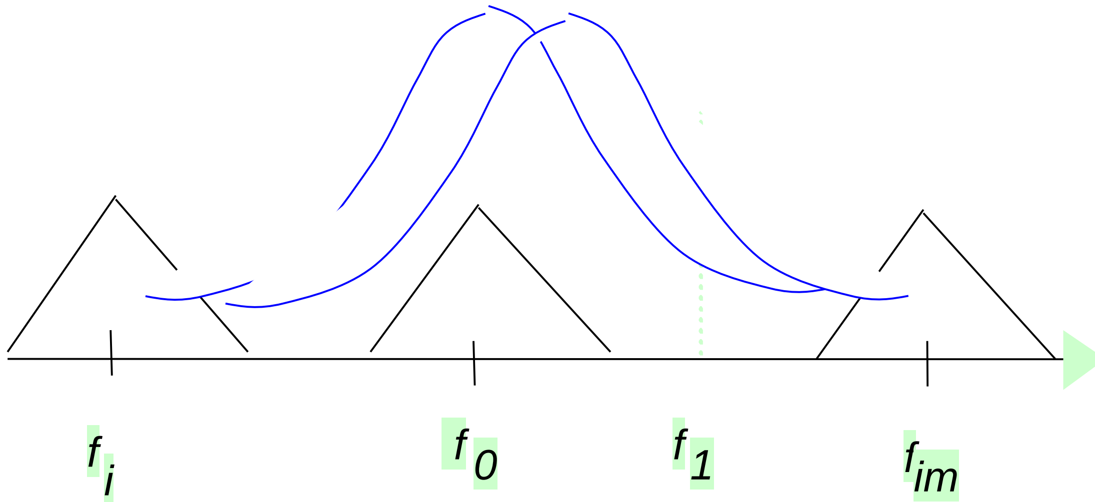
What consequences has such an error?

- It is distributed as mismatch of the RFA tuning and of the IFA.

- Let's consider that all this error is materialized as mismatch of the RFA.

- For $\delta f=0$ the useful signal spectra is centred on the resonance frequency of the tuned circuit.

- For δf≠0 the useful signal spectra is centred on another frequency and it will be attenuated;



- This way the gain limited sensitivity of the receiver diminishes;

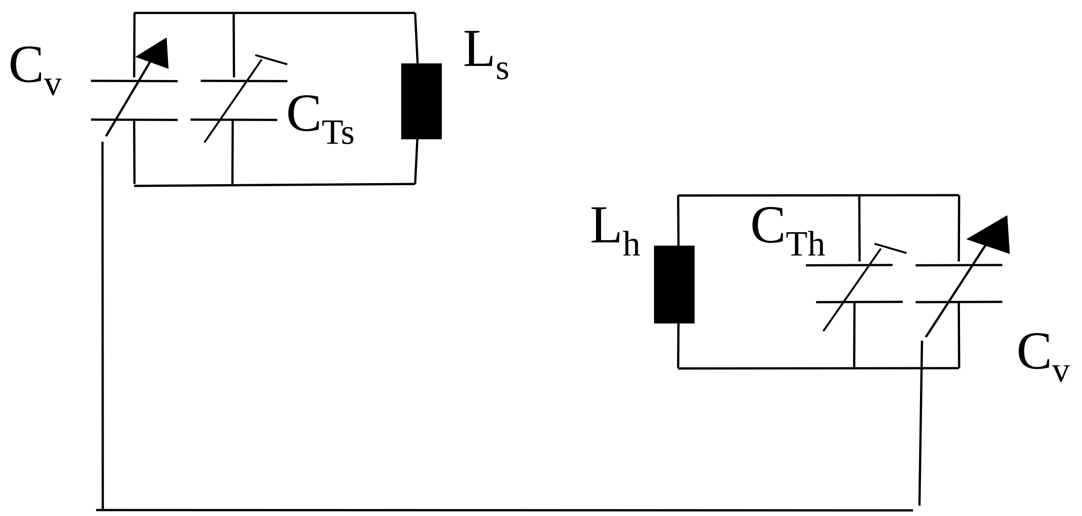
- At the same time the noise power is not modified so that the noise limited sensitivity diminishes too.

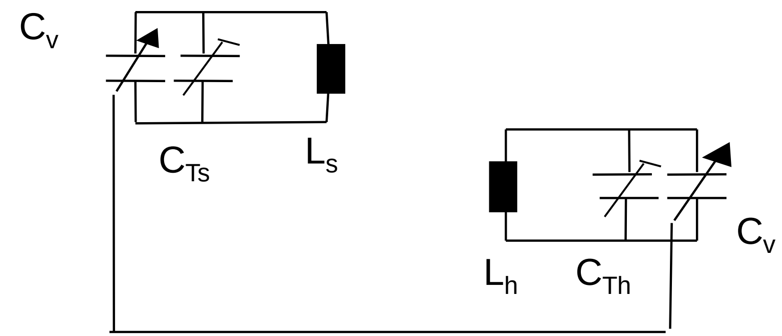
- It can be demonstrated that the lack of symmetry of the frequency characteristic causes nonlinear distortion also;
- Conclusion: it is desirable a zero value of the error δf;
- If this is not possible it must be as low as possible.

- Different solution have been proposed;
- One of them consisted in using multiple sections gang capacitors; the sections used in RFA have a capacitance depending on the position given by a law; this law is different from the one governing the capacitance of the section used in LO;
- The second one could be obtained on the basis of the condition that $f_d = f_i$ all the time;
- It was remarked that such capacitors can be used only in a **given** frequency range and for a **given** value of the intermediate frequency , f_i.
- Consequently this solution had not so many applications;

- Another solution consists in adding auxiliary components to the two circuits: by means of the value of those components one can create additional frequencies correctly received (aligned) and can decrease the alignment error.

- For example a second correctly aligned frequency can be obtained if we use the next schematic diagram which includes two more trimmer capacitors.


C_v
L_s
C_{Ts}
L_h
C_{Th}
C_v



- The relations (2) become:

$$f_{rs} = \frac{1}{2\pi\sqrt{L_s(C_v + C_{Ts})}}; \qquad f_{rh} = \frac{1}{2\pi\sqrt{L_h(C_v + C_{Th})}} \quad (3)$$

- The design consists in computing the values of: L_s, L_h C_{Ts} and C_{Th} in order to cover the required frequency range and to fulfil the conditions for a correct reception of two frequencies;

- The conditions to cover the required frequency range can be written as:

$$f_{rs\min} = f_{s\min} = \frac{1}{2\pi\sqrt{L_s(C_{vM} + C_{Ts})}}$$

$$f_{rs\max} = f_{s\max} = \frac{1}{2\pi\sqrt{L_s(C_{vm} + C_{Ts})}} \qquad (4)$$

- we have two equations with two unknown quantities:

$$C_{Ts} = \frac{C_{vM} - k^2 C_{vm}}{k^2 - 1}; \qquad k = \frac{f_{s\max}}{f_{s\min}}$$

$$L_s = \frac{1}{4\pi^2 f^2{}_{sm}(C_{vM} + C_{Ts})} \qquad (5)$$

- We introduced the notation:

$$k = f_{s\max} / f_{s\min}$$

- This is the so-called frequency coverage ratio.

- There are two more unknown quantities : L_h and C_{Th} ;

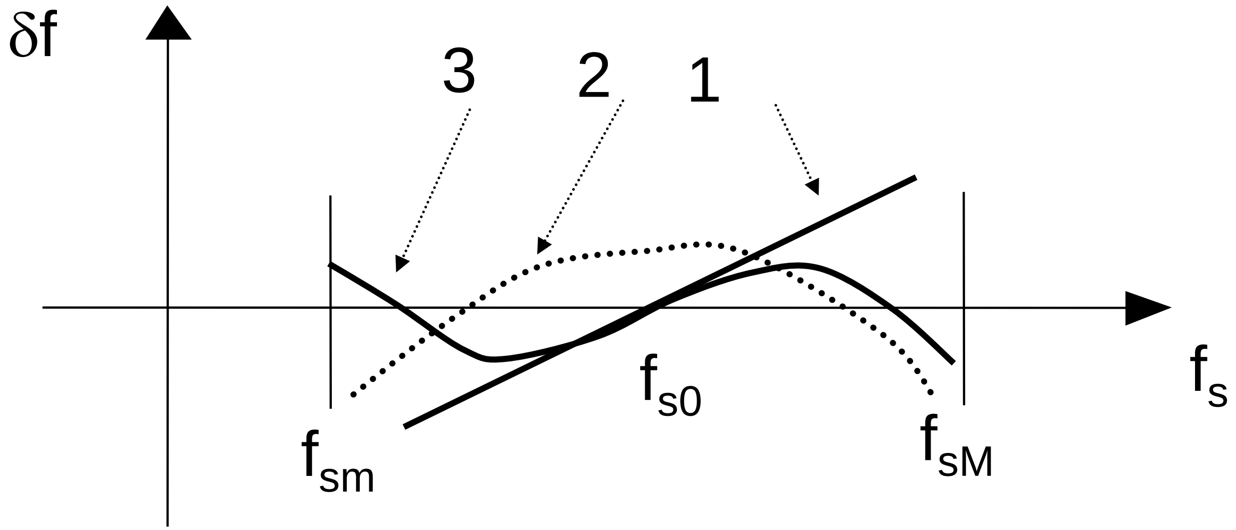
- One can write:

$$f_d = \frac{1}{2\pi\sqrt{L_h(C_{vn}+C_{Th})}} - \frac{1}{2\pi\sqrt{L_s(C_{vn}+C_{Ts})}} = f_i \qquad (6)$$

- Let’s choose two convenient values for f_{rs}; using them we can calculate the adequate values for the variable capacitor C_{vn} (C_{v1} , C_{v2});

- It results another two equations which allow the computing of the necessary values of L_h şi C_{th}.

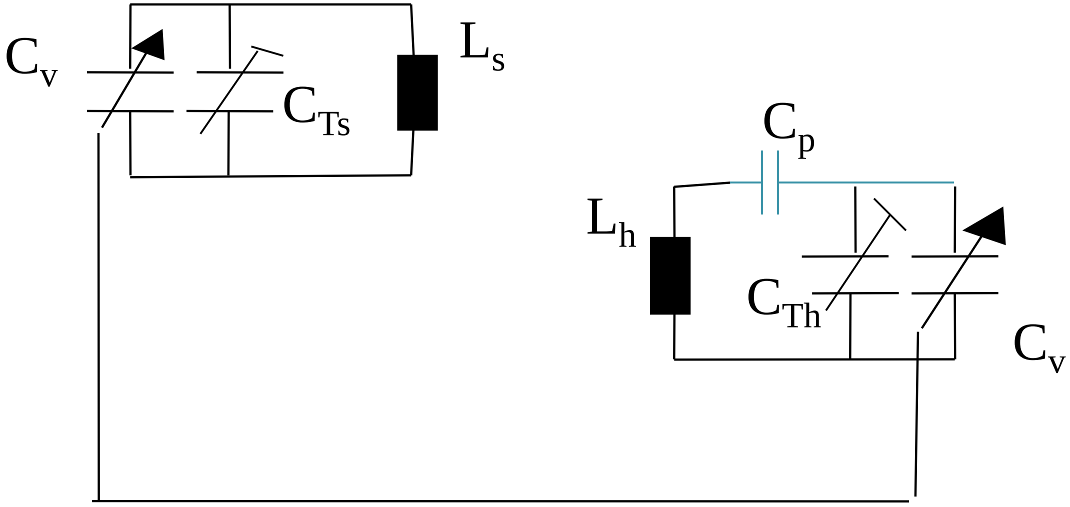
- Finally, by plotting the alignment error versus the useful signal frequency one obtains the curve number 2 in the next diagram.

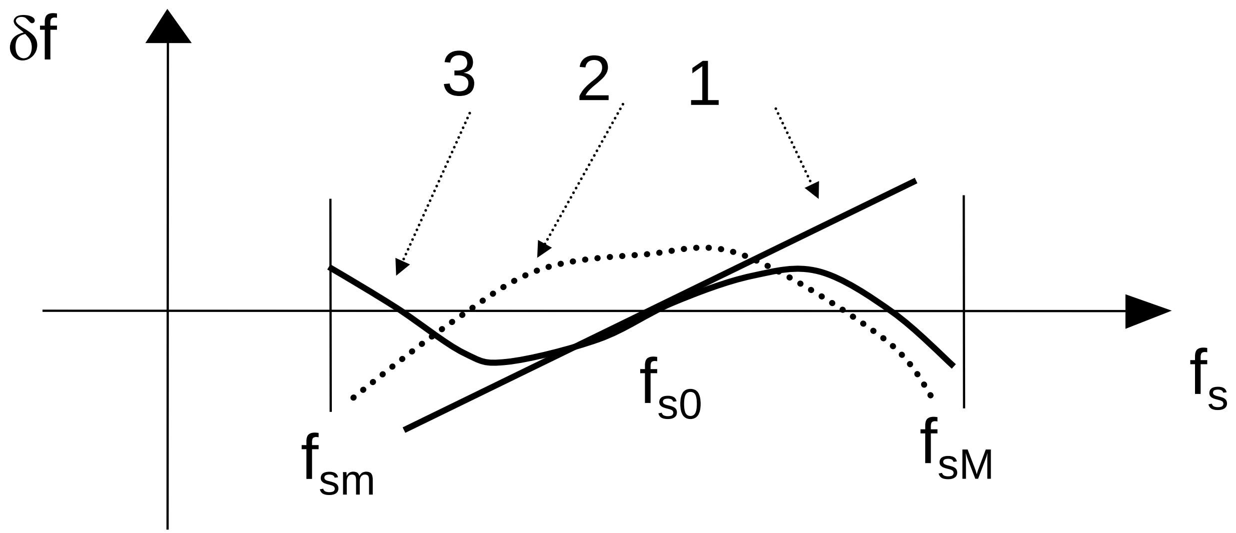


- It can be observed that if we conserve the values of required frequency range, intermediate frequency and the variable capacitor the new circuits ensure a lower alignment error than the first ones;

- The procedure can be continued by adding one more component in the tuned circuit controlling LO frequency;

- This way we shall have three correctly received frequencies;


C_v
C_{Ts}
L_s
C_p
L_h
C_{Th}
C_v



- It was demonstrated that no more than 3 correctly received frequency can be obtained;

- In the case of commercial broadcast receivers and in the case of frequency ranges with small extent ($k=f_{smax}/f_{smin} \Rightarrow 1$) the alignment issue is not critical.
- In some frequency ranges we can use two alignment frequencies (USW, SW) while in other ones (LW, MW) we must use three such frequencies.
- Anyway, it was proven that if the frequency range limits and the intermediate frequency value are adequately chosen, the alignment error can be reduced down to a level that does not noticeably affect the overall performance of the receiver.

- Before ending this section let mention that the necessity of alignment represents the second important negative aspect of the single conversion receiver;
- Remember that the first one was the necessary trade-of in choosing the value of the intermediate frequency between a high value in order to reject the image frequency interference and a low one in order to get a high performance IFA.