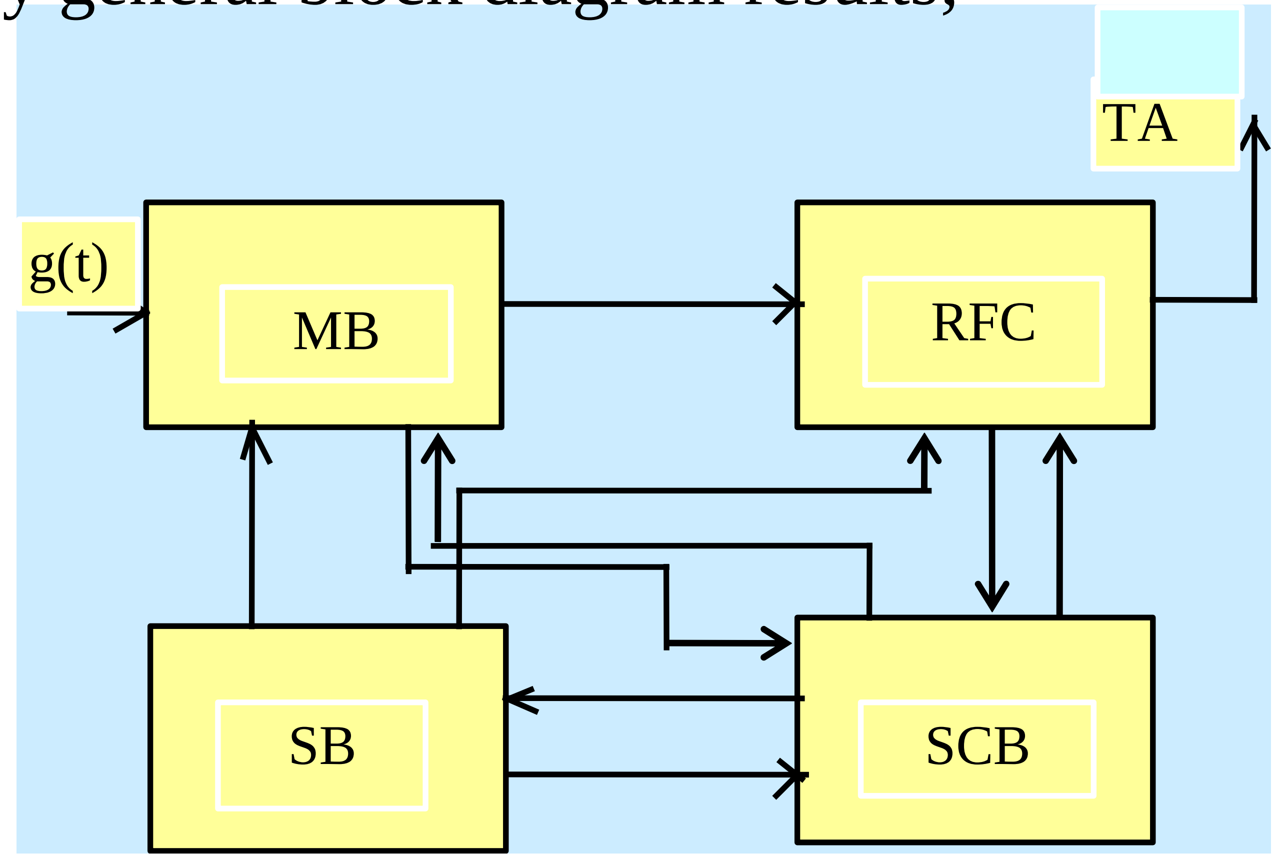
2. RT Equipment

2.1 The Radio Transmitter (RT) Functions

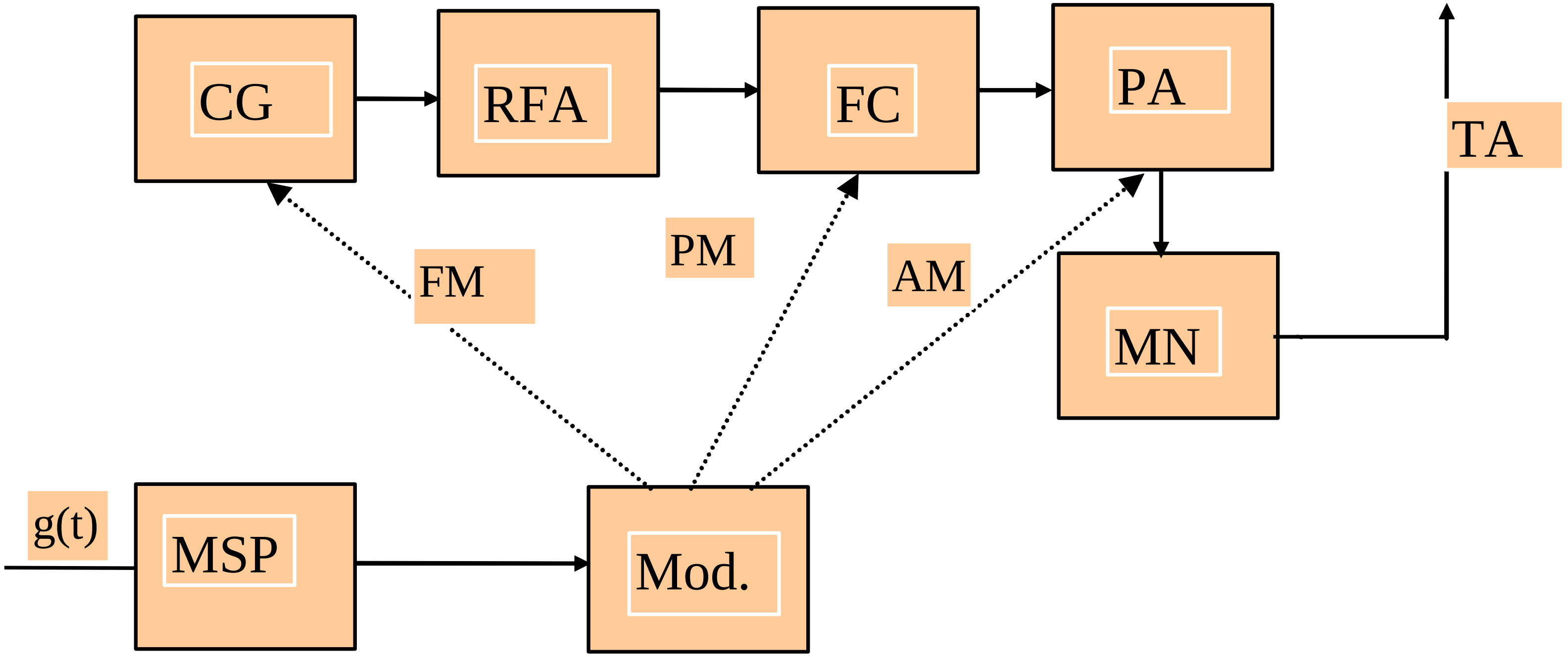
- The generation and processing of the carrier sine-wave;
- Final processing of the modulating signal (this signal must satisfy the modulation process requirements);
- Achieving (realizing) of the modulation;
- Modulated signal processing;
- Converting the modulated electrical signal to EMW.

- On the basis of the above mentioned functions a very general block diagram results;

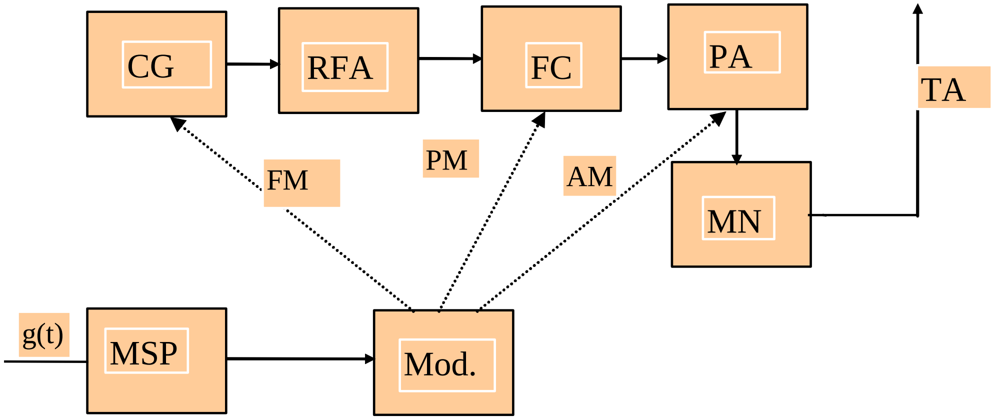


- As we see besides the main functioning blocks other auxiliary ones (such as power supplying, control, protection blocks) are necessary.

The general architecture of the Radio Frequency Chain (RFC)



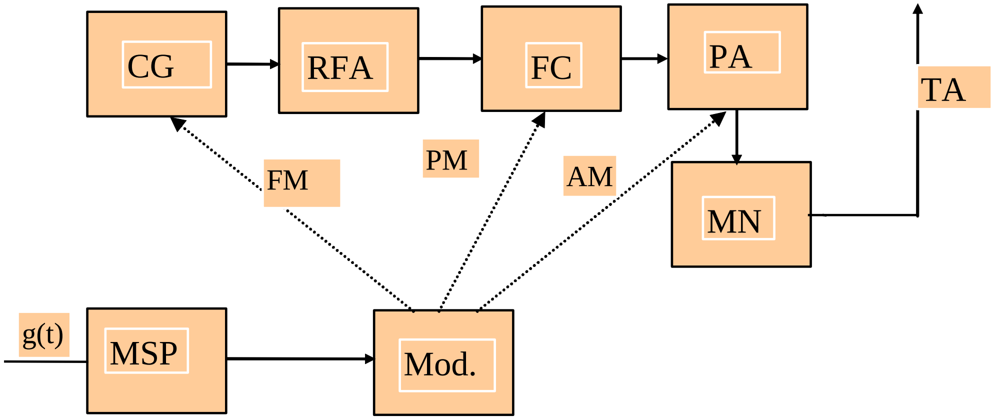
Radio Frequency Chain (RFC) – a block diagram



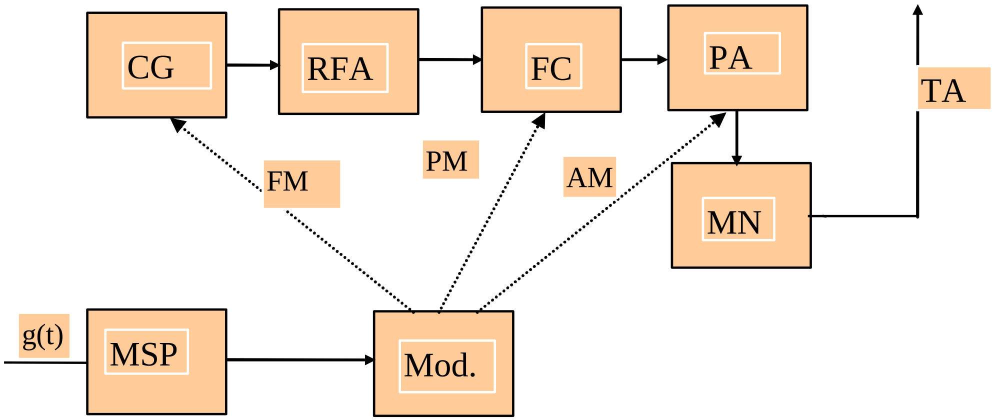
- *Carrier Generator (CG)*: has to assure the generation of a carrier sine-wave that must have the adequate stability imposed by the radio communication standards;

- Can be: a crystal controlled oscillator or a frequency synthesizer;

  - f_c, δf.

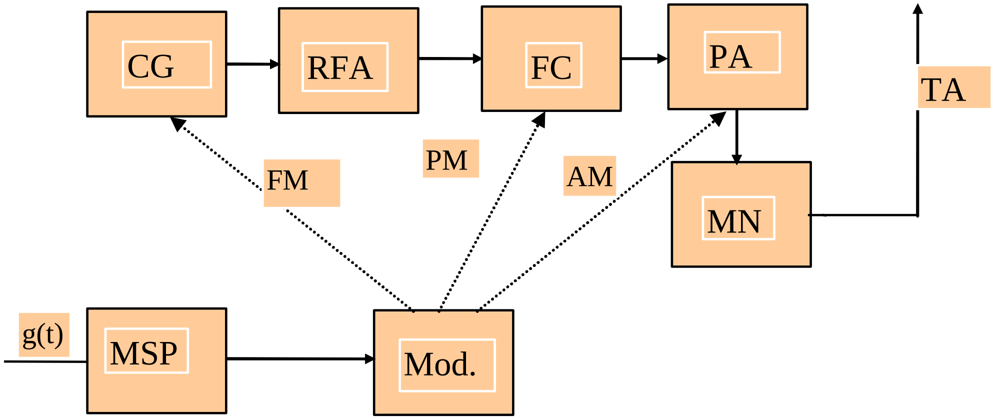


- *Frequency changer (FC)* is necessary for bringing the signal to the allocated frequency.
- It can be a: **frequency multiplier or a mixer**;
- A multiplier multiplies the instantaneous value of the frequency of the input signal (f_C becomes n x f_C);
- It is very convenient for analogue FM transmitters; in this case it will increase both the carrier frequency and the frequency deviation (see the TAD course);

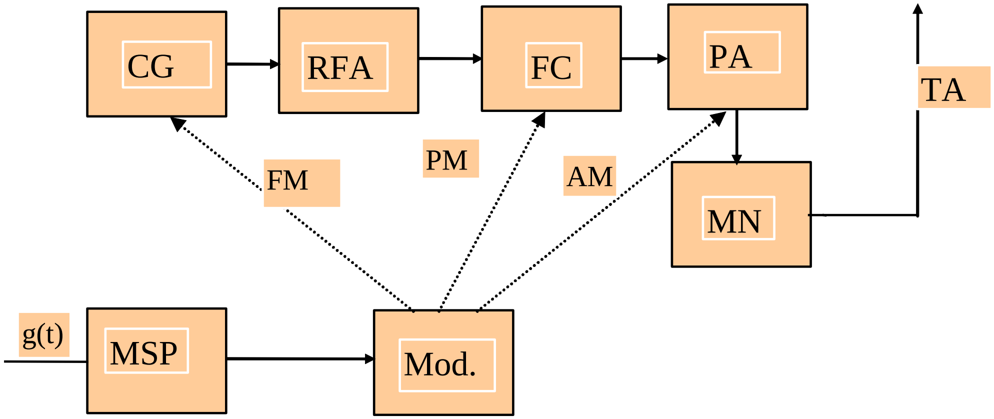


- It was used also for MA transmitters when the carrier frequency is relative low.
- It was necessary especially for RT that required a large output power, in order to avoid a global feedback that can destroy the RT.
- The multiplier changes the frequency value in a course way;
- In case of modern technologies it is used in a limited number of situations;

- **The Mixer** is a non-linear functional block who modifies the frequency value using an auxiliary block (an oscillator);
- Unlike the multiplier, the mixer doesn’t affect the modulation, both for amplitude and phase modulation;
- Because of this, it is used for processing signals with variable amplitude or in case when the final frequency value is large;
- The functioning principle will be discussed in a following paragraph;

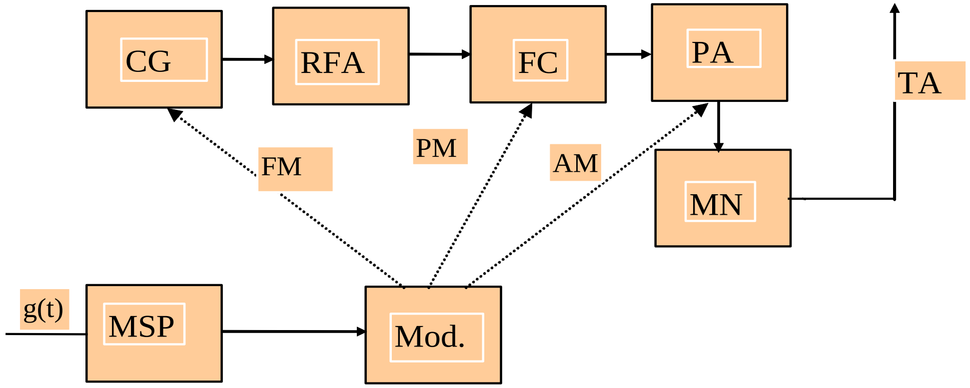


- *Power amplifier (PA):* is the block that has to provide the signal level necessary for establishing a radio link;
- It works at high power level, non-linear effects are inherent;
- Is decisive for the efficiency value that will characterize the RT;
- Because of its importance, a short paragraph will be dedicated to the PA in this chapter;

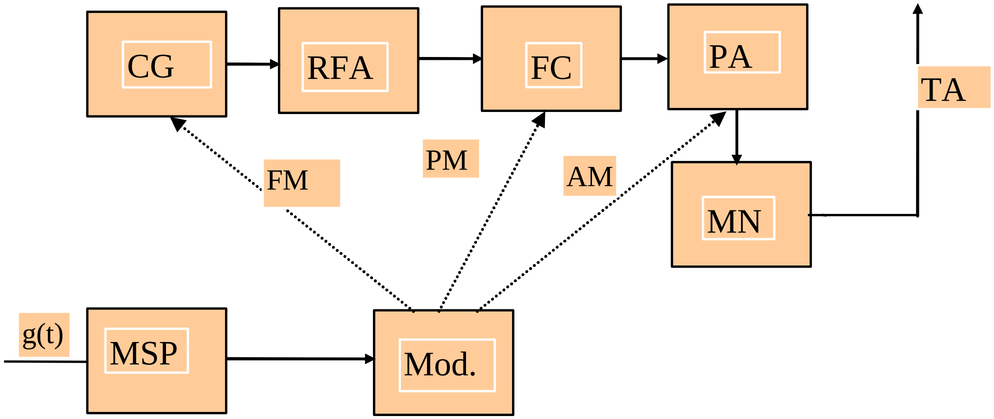


The Matching Network (MN)

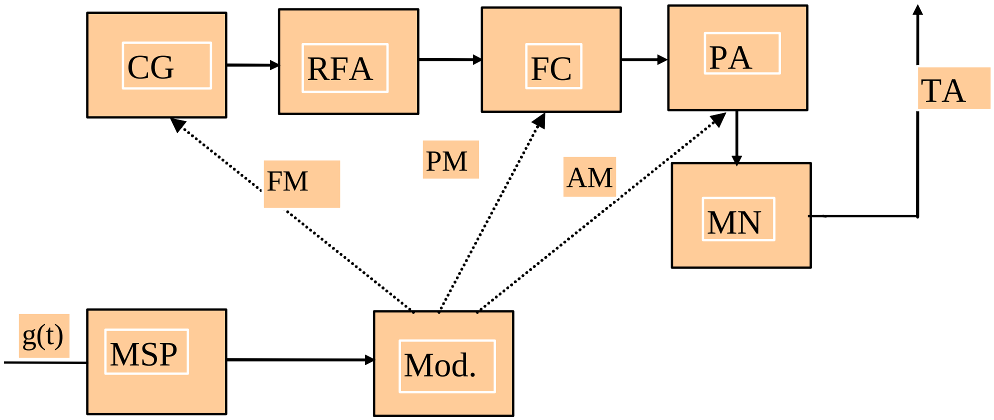
- The PA is characterized by an optimal load resistance, which as a rule differs from the antenna input resistance R_a. A matching is therefore necessary.
- Usually the MN is an LC circuit, with small losses.
- This block will also be analyzed in a following paragraph;



- Achieving modulation is another very important aspect for the performances of a RT;
- After a preliminary processing of the modulating signal (MSP) a final processing follows, which depends on the type of modulated signal.
- The effective modulation is realized in different points of the block diagram, depending on the modulation type.



- For example in case of a MF signal (analogue or digital), the modulation will be performed at a low power level, because the amplification can be easily obtained afterwards.
- In case of MA signals, the modulation is performed as close to antenna as possible, in order to avoid the necessity of linear PA, aso.



- The modern digital technologies use the IQ modulation technique (in phase and quadrature);
- This procedure will be also briefly discussed in a following subchapter;

2.2 RT specific aspects; specific parameters

- Some of the most important aspects that have to be taken care of when designing a radio transmitter are:

- ***Efficiency***
- ***Output power***
- ***Linearity***

- These aspects influence in a decisive manner the degree in which the RT complies to the requirements of operation imposed by licenses.

- It will be noticed that the block that influences in a great deal these parameters is the power amplifier (PA).

- The architecture of the RT is often determined by this block;

- The level of **power delivered by the transmitter** influences the distance covered at an adequate level of performance by the radio link;
- The transmitted power is defined at the input of the cable that feeds the antenna (feeder) or the *equivalent isotropically radiated power (EIRP).*
- The distance obviously also depends on the RR sensitivity:

$$d = f(P_e, S_r)$$

- A good **efficiency** is a key aspect in order to improve the autonomy of portable equipment from the battery point of view or to solve problems related to heat dissipation;
- The behavior from the **linearity** point of view represents a factor that limits the transmitted data rate and maintains the power spectral density in a predefined **spectral mask** in order to limit the interferences to the neighbor channels.
- The effect of linearity in cellular systems;

- Accordingly the following parameters will be briefly discussed:

- *Peak to average power ratio (PAPR)*
- *PA efficiency*
- *Non-linear effects in the PA*
- *Spectral mask*
- *Transitory phenomena in radio transmitters*
- *Spectral efficiency.*

- Comments

2.2.1 Peak to average power ratio (PAPR)

- In order to define this parameter the highest instantaneous power that can appear in the system will be denoted with P_v and the value obtained by averaging the transmitted power over a long period of time will be denoted P_a .
- The peak to average power ratio is defined by:

$$PAPR = \frac{P_v}{P_a}$$

and is usually expressed in dB.

- The evolution of the communication technologies highlighted the necessity to transmit in a certain frequency band an amount of data as high as possible, to increase the efficiency in the use of spectrum maintaining in the same time the capacity of working in electromagnetic hostile environments (for example multi-path propagation ones);

- Complex modulation techniques with dense constellations are necessary.

- Unfortunately, the corresponding signals exhibit envelopes that are characterized by high PAPR values.

- Let’s consider, for example, the WLAN 802.11a technology, using OFDM signals with 52 subcarriers QAM modulated for which the PAPR is 10dB.

- Even the narrowband radiotelephony technology TETRA (TErrestrial TRunked rAdio) using a π/4 DQPSK modulation is characterized by a PAPR of 2dB.

- The power that can be delivered by a PA stage is limited at it’s specific saturation level;

- Because of this, it results that the higher the PAPR value is, the lower the medium delivered power will be and the smaller the area that can be covered by the system.

2.2.2 Efficiency

- RF power amplifiers convert the DC power in RF power.
- In order to evaluate the efficiency of this process a parameter called efficiency is defined, denoted with η.
- This parameter, usually expressed in percent, represents the ratio between the average RF power delivered to the PA load and the DC power delivered by the DC power supply.
- Considering a finite time interval it can be written:

$$\eta = \frac{P_a}{V_{cc} I_a}$$

$$P_a = \frac{1}{T}\int_0^T P(t)\,dt \quad \text{respectiv} \quad I_a = \frac{1}{T}\int_0^T I(t)\,dt$$

where P(t) represents the instantaneous power delivered to the load, V_{cc} is the supply voltage of the PA and I(t) is the instantaneous current absorbed from the power supply.

- Obviously the current depends on the power P(t).
- The difference between the power absorbed from the power supply and the RF power delivered to the load is dissipated as heat in the final RF stages of the PA.

- Depending on the operating regime, the power amplifying stages using semiconductor devices can be classified into several classes: A, AB, B, C, D aso.
- It was proven that, without any additional measures, the efficiency increases, starting with the A class amplifiers (about 30%), C class (about 70%) and D class (about 90%).
- In case of the analog communication systems, solutions were found in order to use class C amplifiers for both AM and FM signals;

- In case of digital technologies, it was concluded that good performances can be obtained by using AB or B class amplifiers associated with some linearization methods.
- This is the only way to deliver high power together with a good linearity and efficiency.

- For the amplifiers from the above mentioned classes, the following reasonable hypotheses can be made:

1. As long as a safe functioning region is maintained, the higher the supply voltage, the higher is the power delivered by the PA to the load.

2. As long as the supply voltage is higher than the value necessary to deliver the instantaneous power, the current drawn from the DC power supply is not depending on the V_{cc} value.

- The last hypothesis is true considering the fact that if saturation is not reached, most RF devices are acting as current sources.

- Having in mind these hypotheses, it can be proven that the signals characterized by a high PAPR value will cause a low efficiency operation.

- According to these hypotheses, it can be deduced that if two signals (S_1 and S_2) have high PAPR values and PAPR1<PAPR2 , for a correct operation the power supply needs $V_{cc1}<V_{cc2}$.

- A high PAPR value means that the power peaks appear only for short periods of time and, as such, their contribution the overall current consumption is negligible.

- According to the 2nd hypotheses, the current is independent from V_{cc1} and V_{cc2}.

- Therefore, if both signals have the same average value, they consume approximatively the same average current from the power supply no matter what PAPR value they have.

- It follows that the DC power delivered for the S_1 signal is $V_{cc1}I_a$,and the one for the S_2 signal is $V_{cc2}I_a$.

- Therefore, for the S_2 signal more energy is consumed from the power supply, delivering the same average power on the load.

- **In conclusion, the S_2 signal is processed with a lower efficiency value.**

2.2.3 Nonlinear effects in PA

- RF power amplifiers convert the DC power in RF power.
- All the RF power amplifiers exhibit some nonlinear behavior which affects the modulated narrowband signals with the expression

$$s(t) = A(t)\cos(\omega_c t + \theta(t))$$

from two points of view:

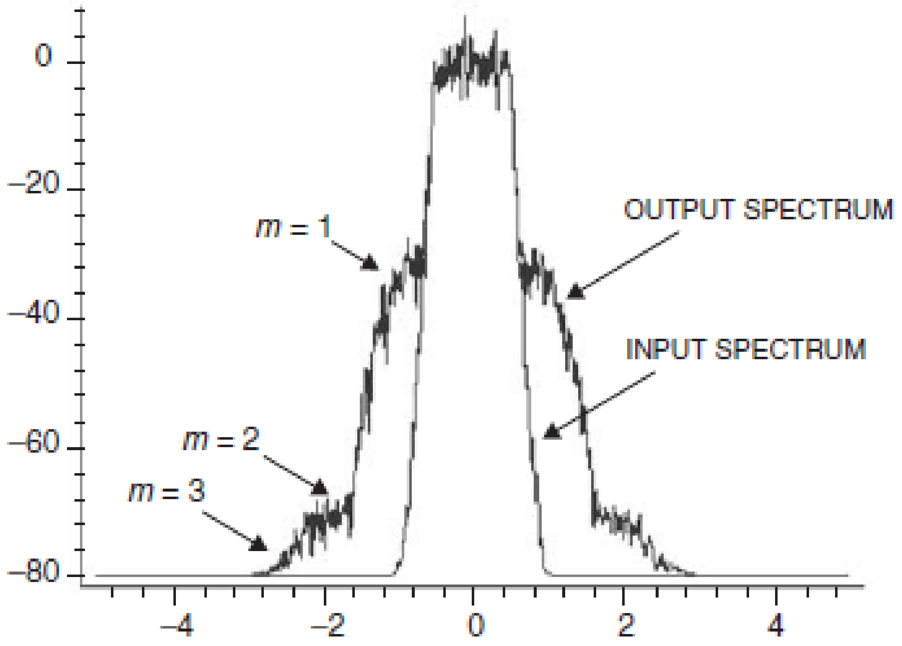
- envelope distortion (A(t)), known as AM to AM conversion;

- Phase distortion (θ(t)), known as AM to PM conversion;

- In case of the digital modulation techniques, the effect of these distortions are:

- The increase of the symbol error rate;

- The generation of a spreading of the signal outside of the allocated bandwidth, conducting to interferences in the neighbor channels;

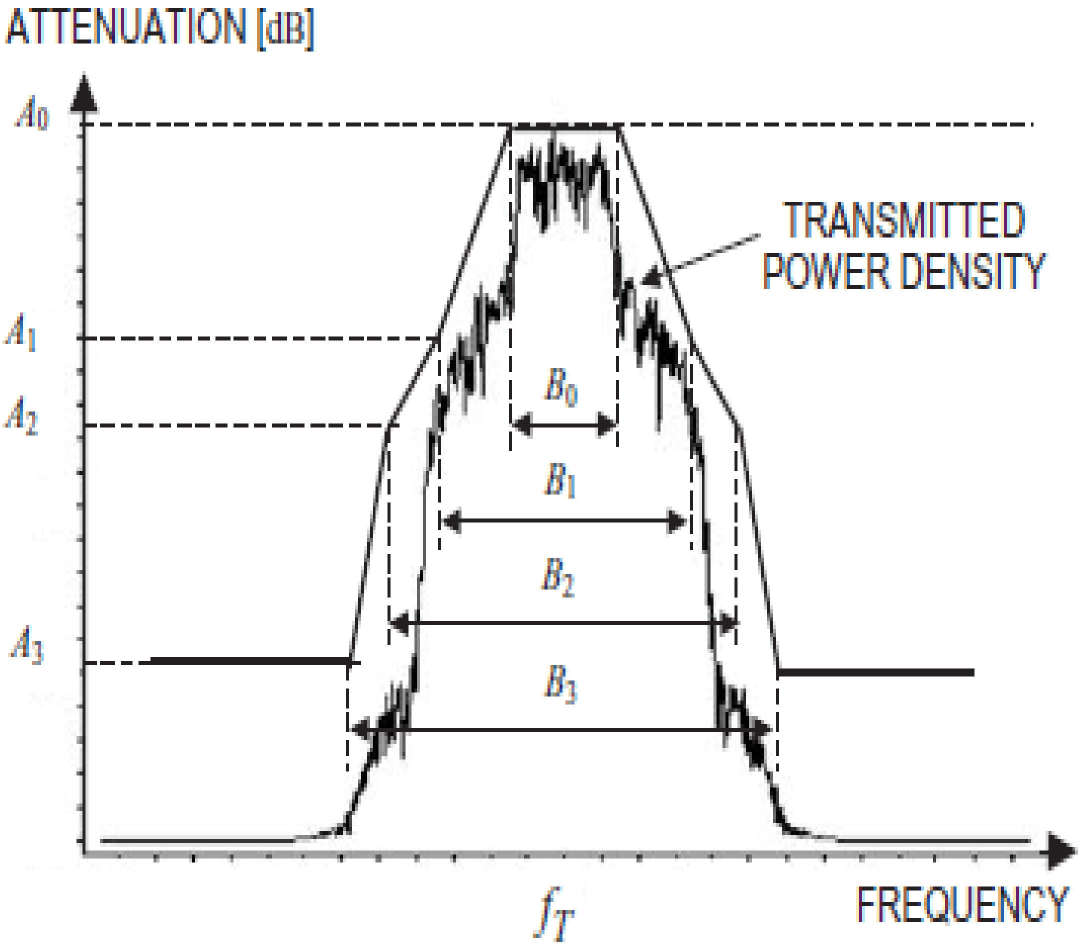


- The mechanism through which the amplitude is altered is relatively simple to understood; the mechanism through which the phase is altered is a lot more complex and difficult to be analyzed.

- The control of these phenomenon is done through specifying and verifying the observance of a so called **spectral mask**.

2.2.4 Spectral mask

- Through spectral mask a series of limits are defined, usually these are constraints imposed by the regulations made by national and international authorities, which have to be observed by the transmitted signal.


ATTENUATION [dB]
A_0
A_1
A_2
A_3
TRANSMITTED POWER DENSITY
B_0
B_1
B_2
B_3
f_T
FREQUENCY

- In order to be able to use it in a proper way, the spectral mask has to be defined for a set of parameters as:
    - Integration bandwidth,
    - Averaging method,
    - Switching sequence,
    - Modulation technique, aso.

2.2.5 Transient phenomena in transmitters

- Most modern radio communication equipment work intermittently;
- They switch periodically between transmission and reception;
- As soon as the transmitter is activated, a series of transient phenomena appear, like:

- The PA starts to draw a large current from the power supply.

- This sudden current variation through the supply lines from the circuit board produces parasite voltages either due to the series resistances of the conductors or through electromagnetic induction.

- The parasite voltages:
  - Can appear in series with components that are sensitive to high frequency signals, like the varicap diodes from the VCO,
  - Can be induced to the resonant circuit of the VCO or can appear as a result of the modification of the supply voltage of some stages sensitive to gain, like the modulating stages.

- The frequency and amplitude transitions generate unwanted components in the spectrum of the generated signal.

- These phenomena appear usually in a seldom way and therefore they are hard to identify and follow.

- Their correction is extremely difficult as it usually imply major redesign of the circuits.

- In most of the architectures, the synthesizer switches between a frequency necessary for transmission and one necessary for reception.

- If the transmission of the signal begins before the adequate stabilization of the frequency value then the system can be confronted with:

- Either the degradation of the channel performances because of the loss of some symbols;

- Or the decrease in sensitivity for the neighbor receivers because of the fact that the transmitted signal will flood into neighbor channels.

- These phenomena are easy to be noticed and measured and the correction can be often made only by some software interventions.

2.2.6 Spectral efficiency

- **Spectral efficiency** represents the quantity of information which can be transmitted in a second through the unit of bandwidth.
- If the spectral efficiency problem is not of importance, nonlinear amplifiers can be used which will process FM signals with a constant envelope, like in case of the GSM technology

- Unfortunately, nowadays this solution is not satisfactory, because the increase in the efficiency of spectrum usage, network management and the coexistence of several different technologies became of crucial importance;

- As such, the use of modulation techniques with variable envelope like OFDM imposed itself, combined with quadrature amplitude modulation (QAM).

- Such modulation techniques increase with a great deal the spectral efficiency;
- They could be used only when the technological evolution allowed the implementation of high speed processing systems.
- They lead to a considerable increase in spectral efficiency, even for environments characterized by multipath propagation;
- On the other side, they imply finding solutions for the linearization of the PA, solutions which often modify the whole signal processing chain of the transmitter.

2.2.7 Conclusion

- The requirements regarding the *transmitted power,* the *linearity* and the *efficiency* are contradictory and finding a convenient compromise is often difficult.
- For example, A class amplifiers have a good linearity but, because of the DC component which is large and independent of the RF signal, they have a low efficiency (about 30%) especially for signals with a high PAPR value.

- Class AB, B, C and D amplifiers exhibit better efficiency values, but introduce strong distortions that will affect wideband signals.

- For this kind of systems, a reasonable compromise is obtained by using B or AB class amplifiers, together with complex linearization methods.

2.3 Operating principles for some specific blocks of a RT

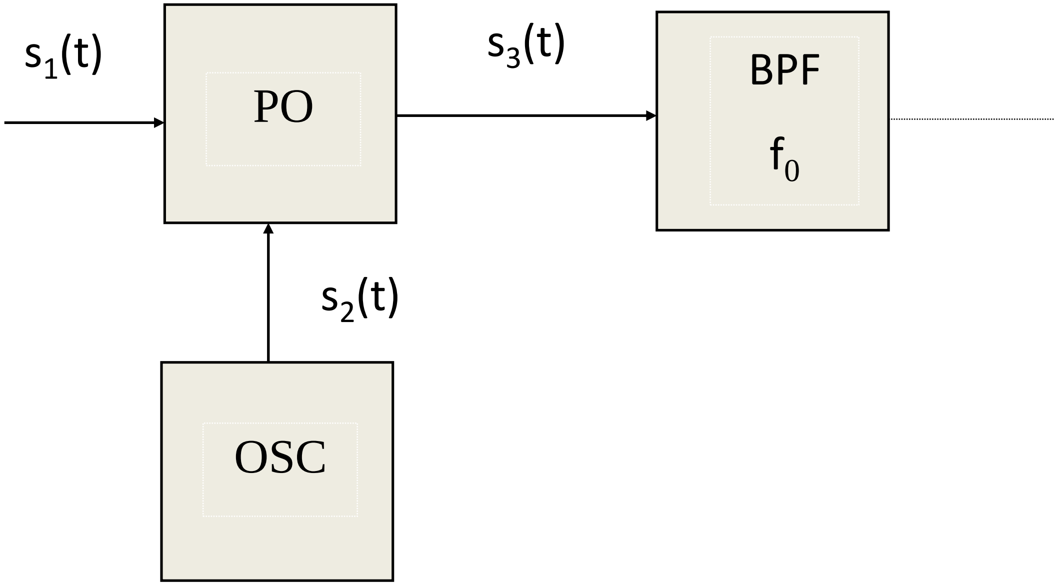
- In this subchapter we will discuss the principles necessary for performing:

- ➢ The frequency change;
- ➢ The matching between the power amplifier and the antenna (MN);
- ➢ The quadrature modulation.

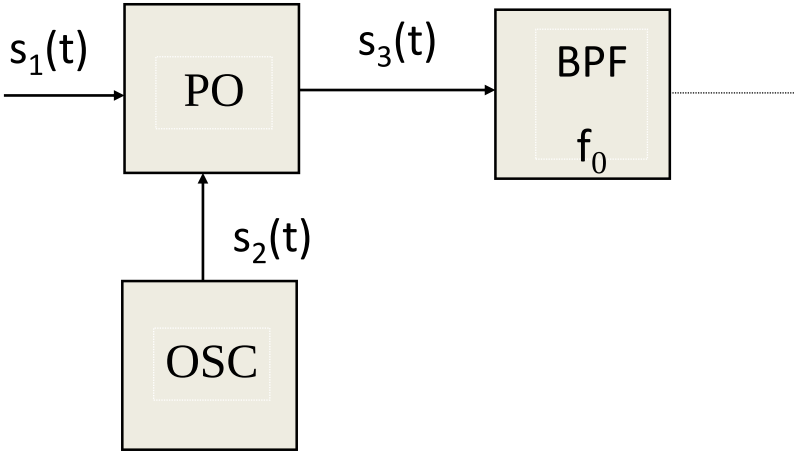
- The operating principles for PLL circuits will be also discussed

2.3.1 The frequency change

- The solution that imposed itself for changing the frequency of a modulated or unmodulated sine signal is illustrated using the block diagram from next slide;
- This solution ins used for both radio transmitters and radio receivers;
- In this chapter we will only analyze the aspects that are interesting regarding RT, we will present several other details in the RR chapter;



The principle of the frequency change;



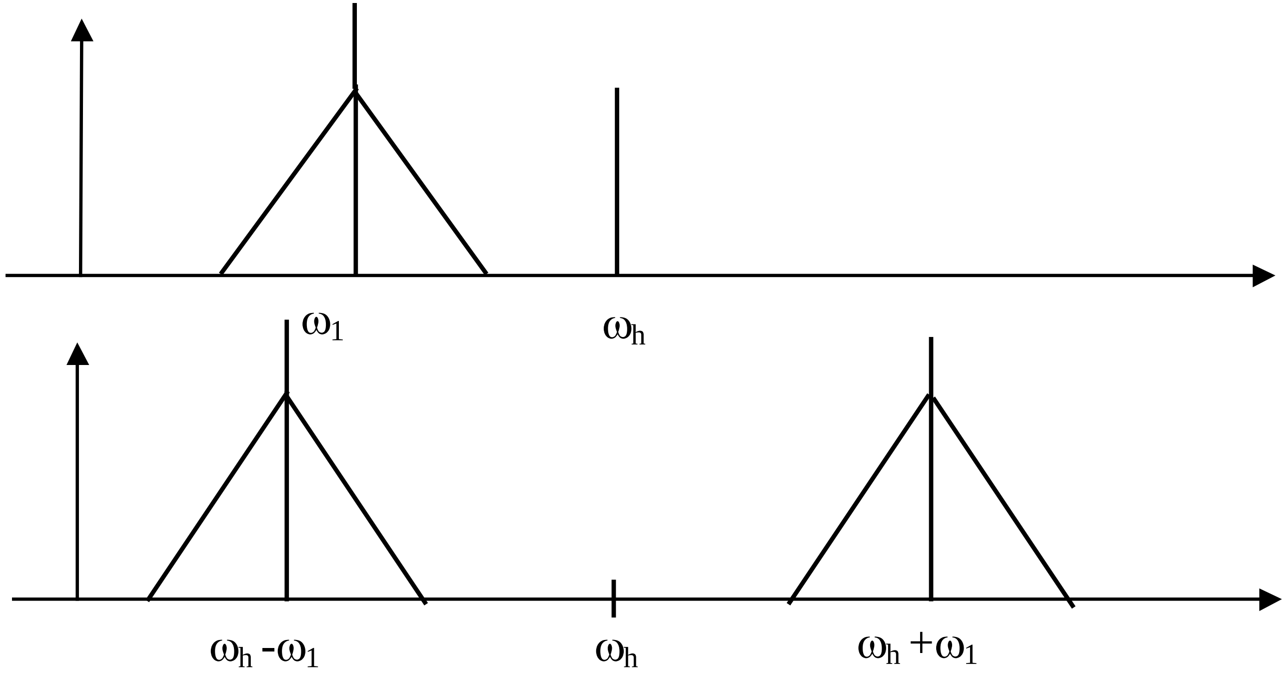
- The signals in the three marked points can be:

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

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

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

- Representing the amplitude spectrum of these signals will be obtained:



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

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

- Both terms from s_3 correspond to a frequency change, because they represent signals with a different frequency compared to the carrier frequency of the input signal.

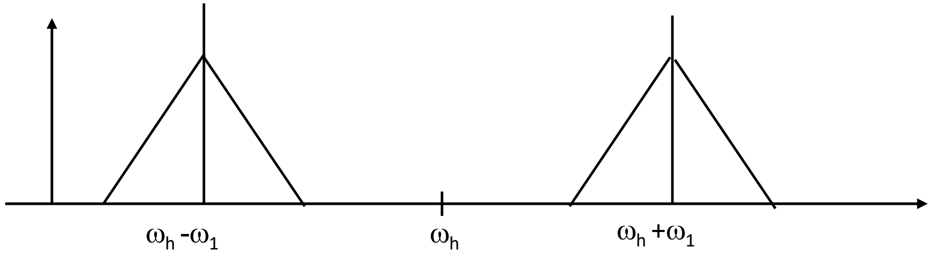
➢ The two options are frequency changes through:

  - ☐ difference
  - ☐ sum

- It can be noticed in both cases that:

- ☐ The modulation is preserved: $U(t), \varphi(t)$

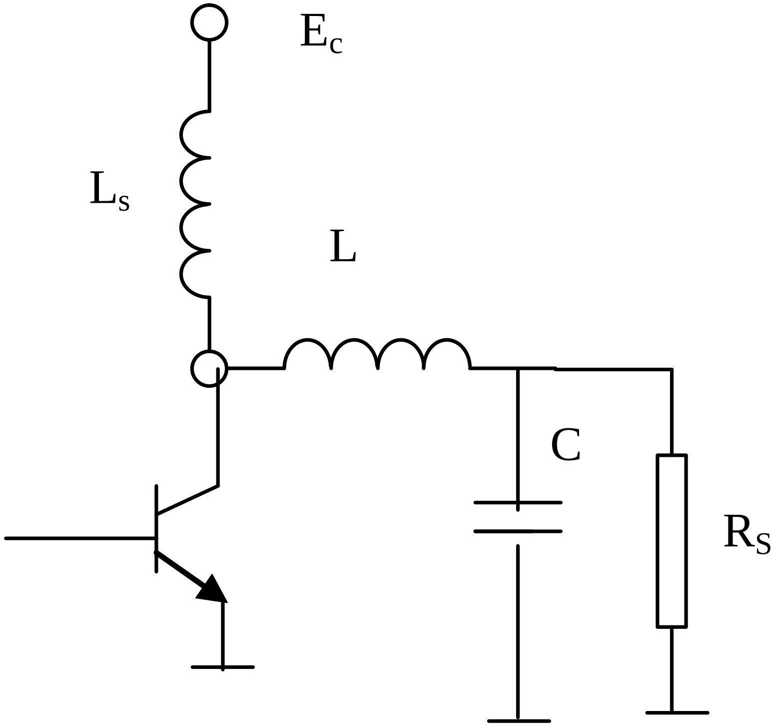
- ☐ Depending on the chosen term, some restrictions can occur in order to avoid the altering of the modulating signal.



- In different situations, for the frequency change one of the two terms is chosen;
- For RT is the sum option is usually chosen and for RR the difference option;
- The other term has to be eliminated, by using a BPF;
- The requirements imposed to the BPF are tougher, the closer the two terms are; in this case is important the way in which the values for the two components are chosen: *frequency plan*;

2.3.2 Matching networks

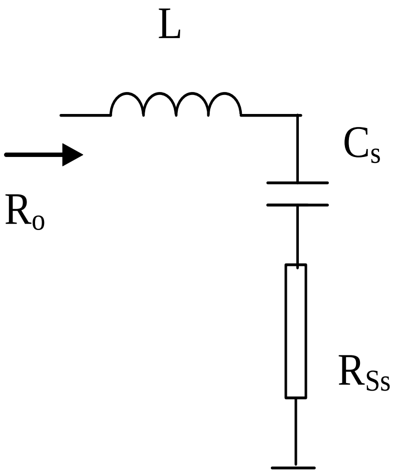
- One can identify several types of matching networks;
- Most frequently the L or Π LC networks are used.
- At the beginning we shall discuss the L network although it has not high performance; it helps giving the basic relations used to analyze the other one;


E_c
L_s
L
C
R_S

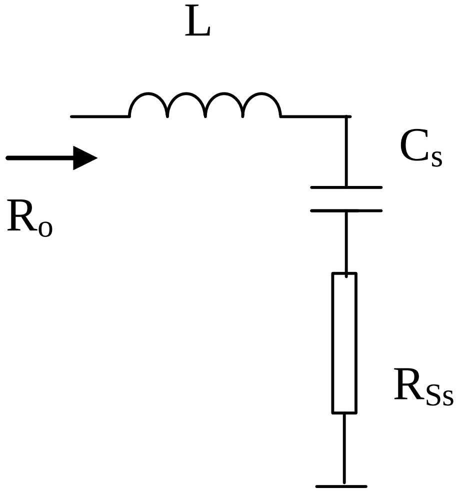
- The final amplifying stage optimum operating load can be evaluated if we know the RF power (*P*) to be delivered and the supply voltage (E_c): $U=E_c-V_{cesat}$

$$R_0=U^2/2P$$

- For simplicity at the beginning we shall neglect the intrinsic losses of the coil and capacitor;
- Let's convert the parallel group capacitor/load resistance into a serial one;
- It results the next equivalent circuit for which the specific relations are given in the next slide:

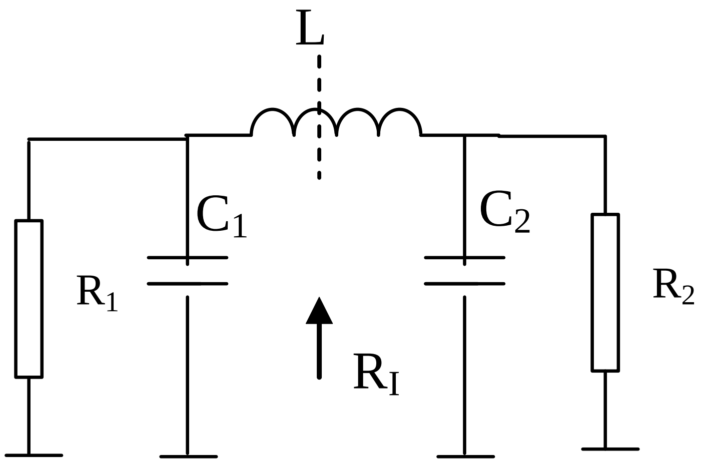


- $R_{Ss}=R_S/(Q^2+1);$



- For matching: $R_0=R_{Ss}= R_S/(Q^2+1)$
  So that: $Q=((R_S/R_0)-1)^{1/2}$
- The resonance condition: $X_L=X_{Cs}$
  - $Q= X_L/ R_0=R_s/X_C$
  - Combining the above expressions one can obtain
  - $X_L =R_0 ((R_S/R_0)-1)^{1/2}$
  - $X_C=R_sR_0 / X_L$
  - Knowing the central frequency (ω_0), we can compute the values for the inductance and capacitance.

- The use of an L network is limited having in mind that:
- 1. it requires that $R_S > R_0$
- 2. one has no possibility to independent set the overall circuit Q and bandwidth.

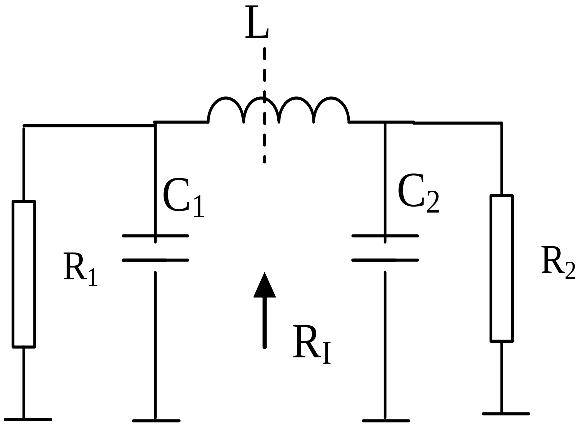


- One of the most frequently used matching networks is the Π matching network;

➢ We can notice that it can be considered as two L networks which transform the terminating resistances R_1 and R_2 into a common image resistance, R_I.

- It is obvious that the image resistance R_I must be lower both than R_1 and R_2, but R_1 and R_2 can take any values;

- The value chosen for R_I determines the network Q.



- The inductance L is split in two components L_1 and L_2 ($L_1 + L_2 = L$);

- The network Q will be the higher one between Q_1 and Q_2 evaluated for the two L branches;

- By using the results obtained above we can write;

$$Q_{1,2}=[(R_{1,2}/R_I)-1]^{1/2}$$

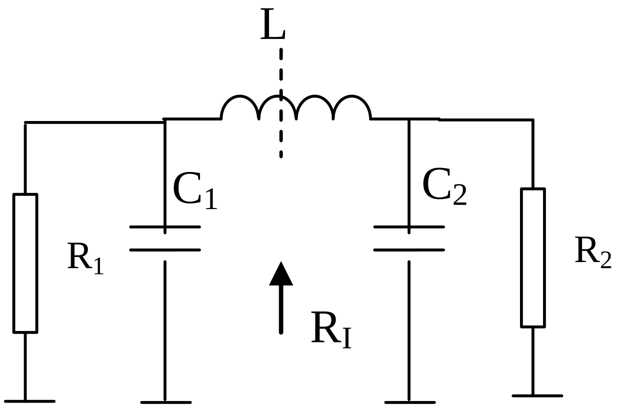
$$X_C = R_s R_0 \,/\, X_L \,; \qquad X_L = R_0\,((R_S/R_0)-1)^{1/2}$$

$$1/\omega_0 C = R_s R_I \,/ R_I\,((R_S/R_I)-1)^{1/2} = R_s \,/\, ((R_S/R_I)-1)^{1/2}$$

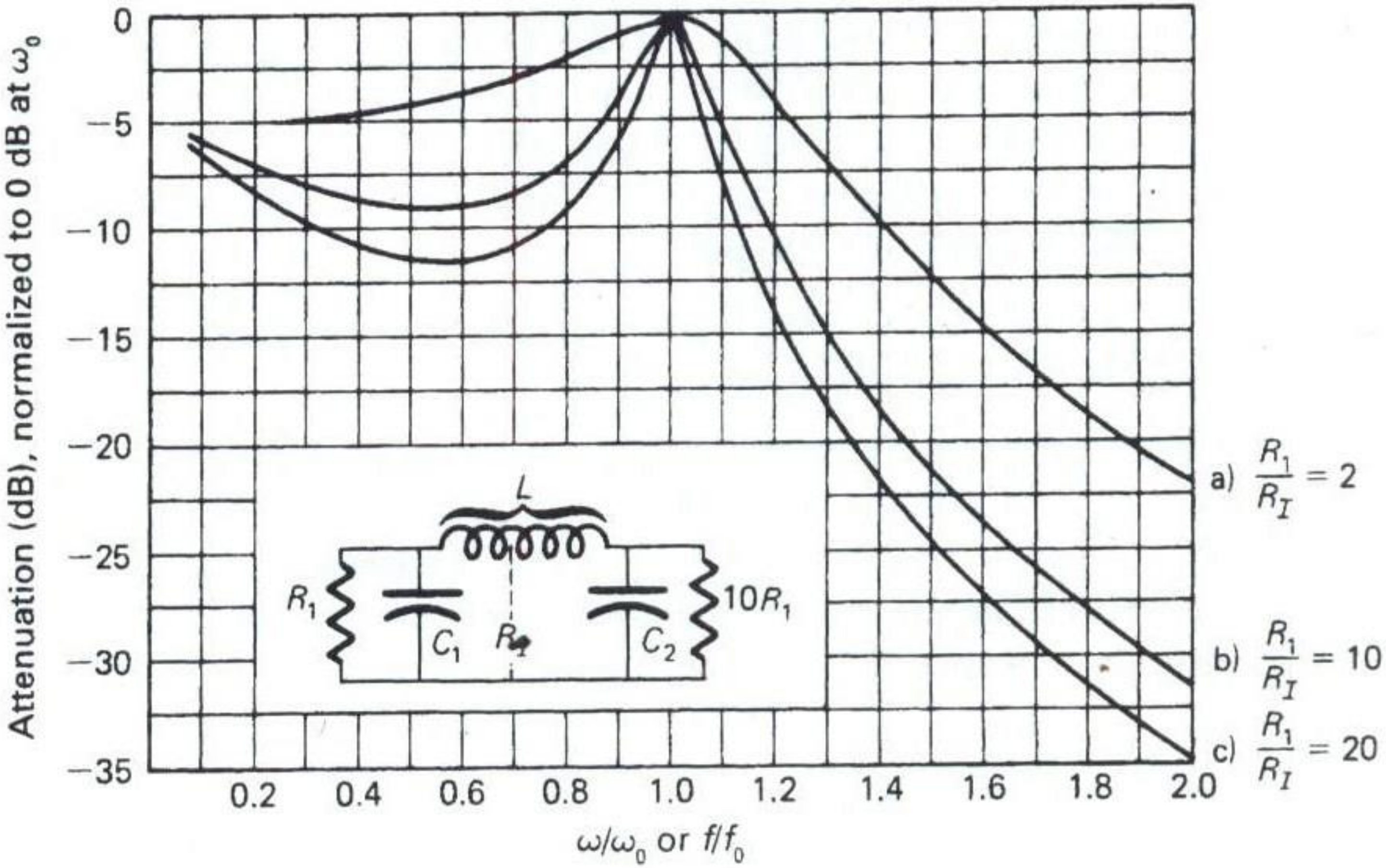
$$C_{1,2}=(1/\omega_0 R_{1,2})[(R_{1,2}/R_I)-1]^{1/2}$$

- and:

$$L=(R_I/\omega_0)[((R_1/R_I)-1)^{1/2} + ((R_2/R_I)-1)^{1/2}]$$

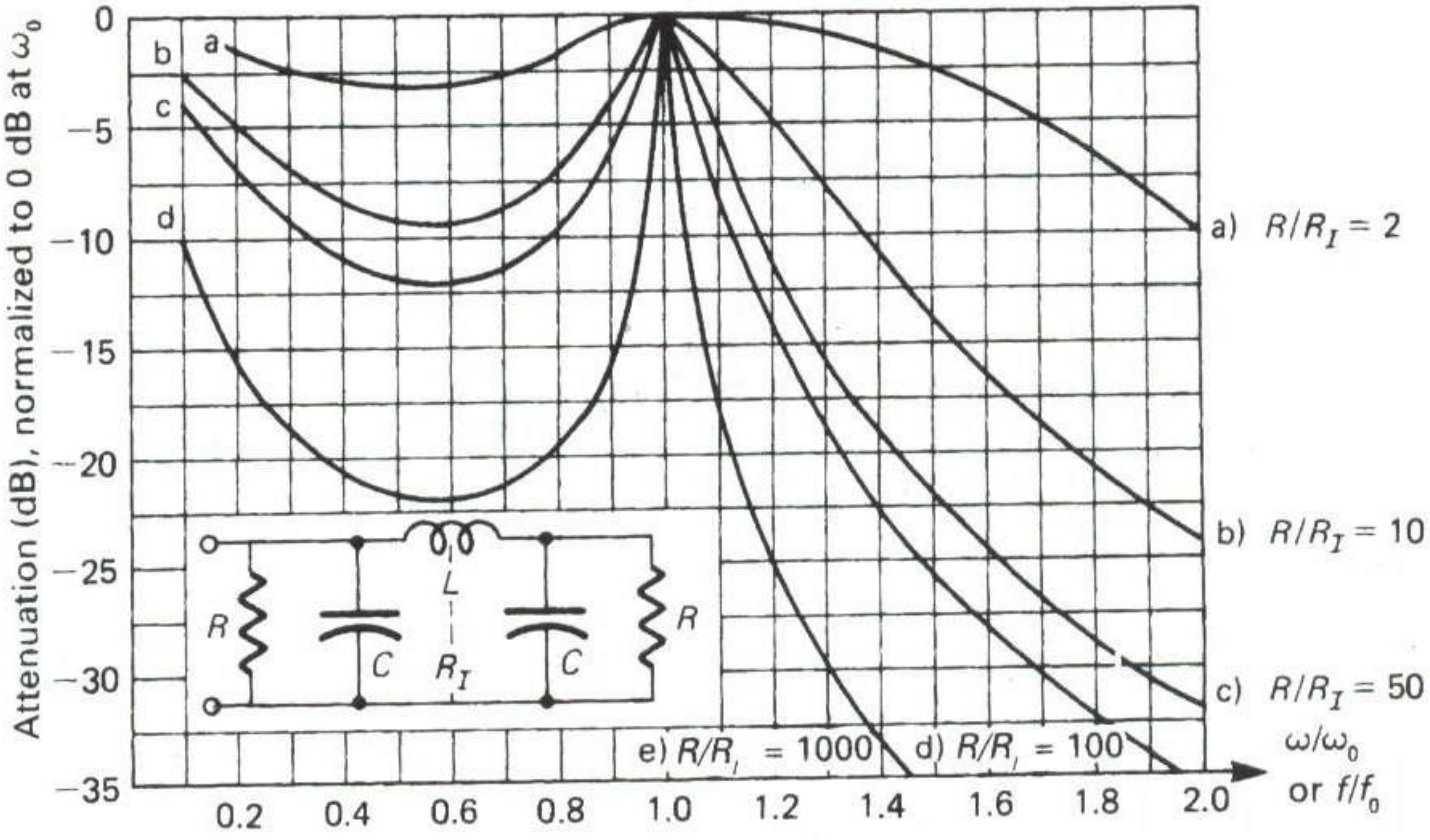


- To evaluate the selectivity of the network one should represent the curves of the attenuation normalized to 0 dB at ω_0 versus the normalised frequency.
- The ratio between the terminating resistances and the ratio between the image resistance and R_1 (or R_2) will be used as parameter;
- Let us notice two particular cases;



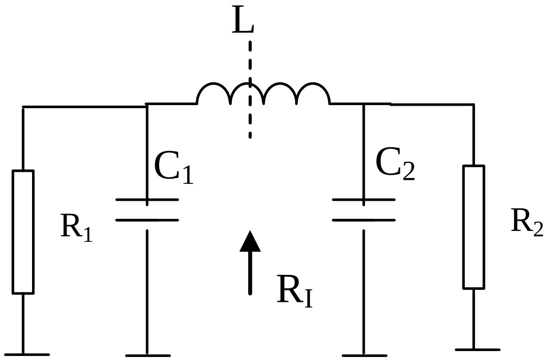
The normalized attenuation for unequal terminations:

R_2=$10R_1$

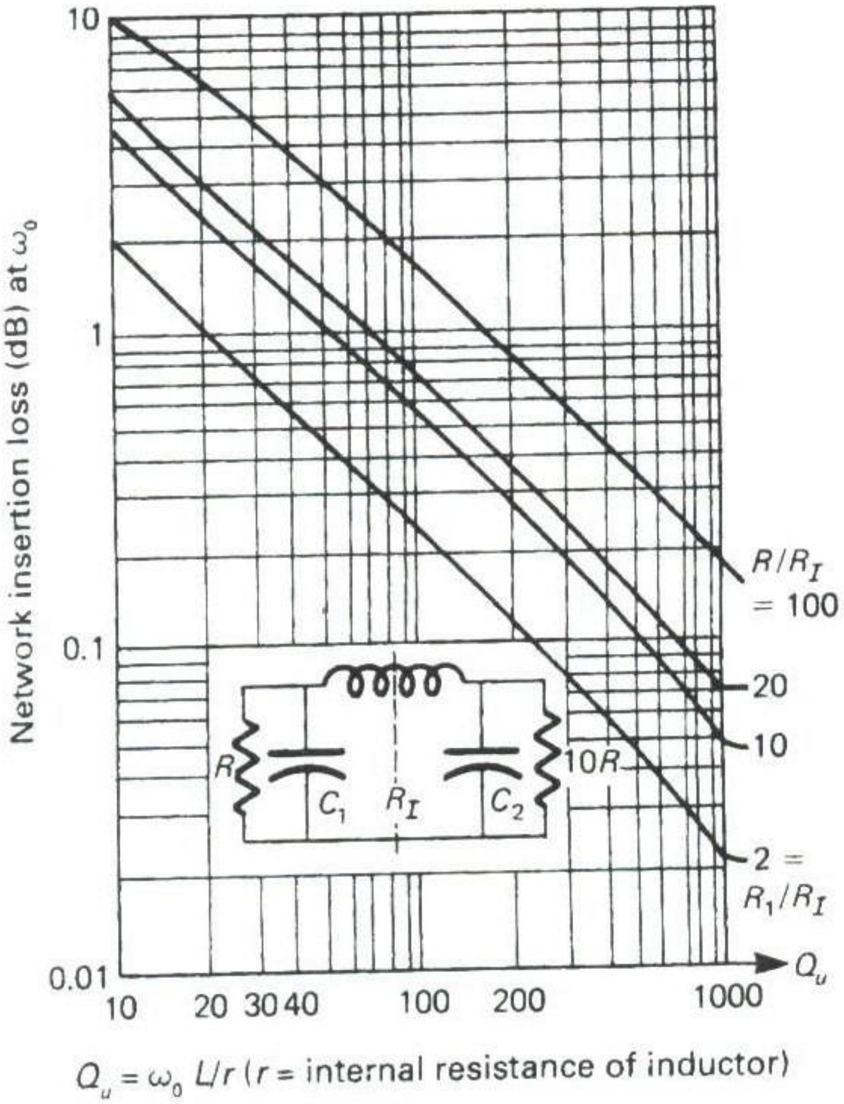


The normalized attenuation for equal terminations:

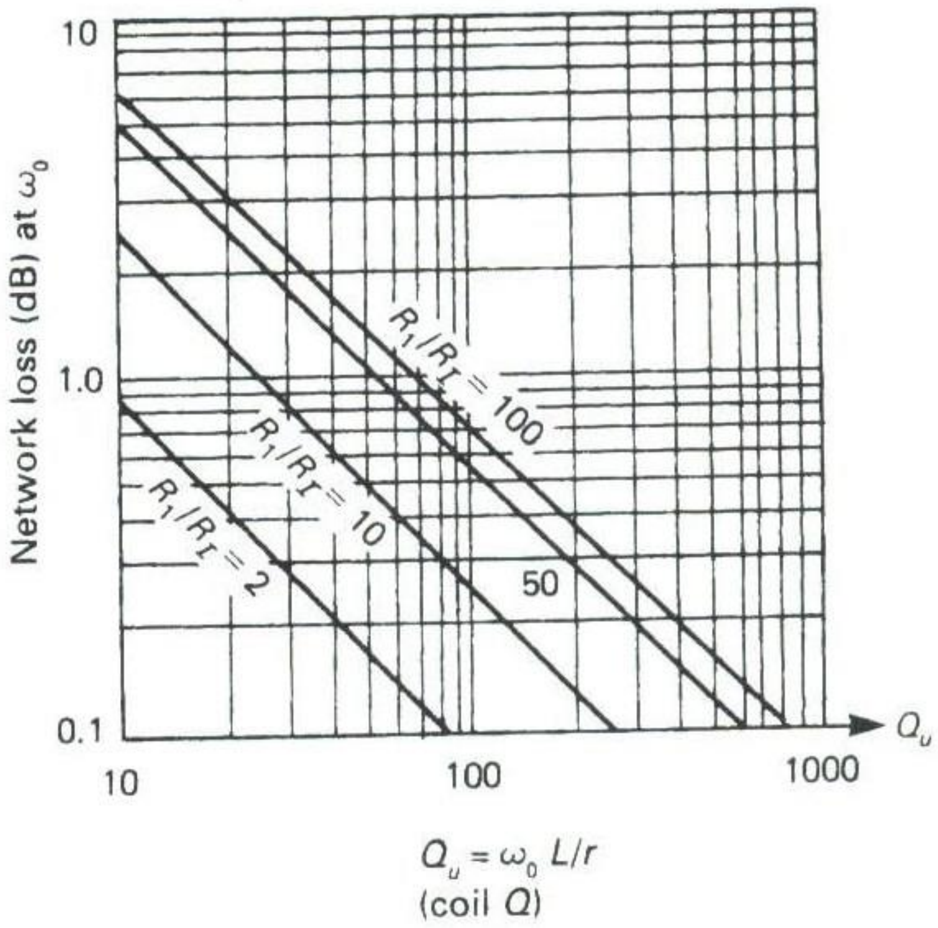
R_1=R_2



- Finally we can consider the effect of using a real inductor.
- To do that we have to sketch the curves of the insertion loss (frequency ω_0) versus the Q factor of the inductor;
- It is adequate to use the same parameters as in the previous case;



The insertion loss
for unequal
terminations
R_2=10R_1



The insertion loss for equal terminations $R_2=R_1$

2.3.3 Generation of digital modulation by IQ processing

- Let’s consider a RF modulated signal:

$$s_i(t) = S(t) \cdot \cos\left[2\pi f_c t + \varphi(t)\right]$$

- where:
  - S(t) - signal amplitude (can be variable),
  - f_c - carrier frequency,
  - φ(t) - instantaneous phase;

- The RF signal can be split into:

$$s(t) = s_I(t) + s_Q(t)$$

$$s_I(t) = S(t) \cdot \cos[\varphi(t)] \cdot \cos(2\pi f_c t)$$
$$s_Q(t) = S(t) \cdot \sin[\varphi(t)] \cdot [-\sin(2\pi f_c t)]$$

- It can be noticed that the amplitudes of the two components will vary, even if *S(t)* is constant.

- The two components are AM-SC signals and they can be produced in a very simple way;

- In order to highlight the I/Q way in which this signals are processed the term of complex envelope is introduced, u(t) which is a complex baseband signal:

$$\underline{s(t)} = S e^{j\varphi(t)} e^{j2\pi f_c t} = u(t) e^{j2\pi f_c t}$$

- Obviously, the real signal is given by:

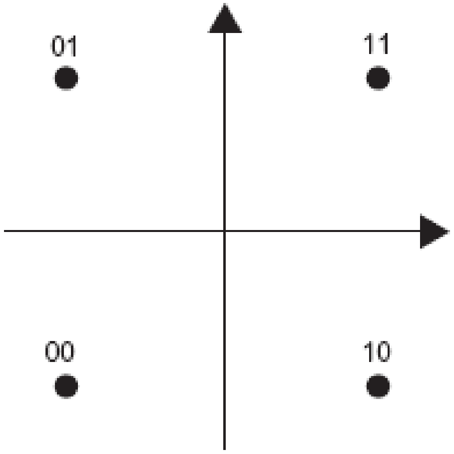
$$s(t) = \mathrm{Re}\{S e^{j\varphi(t)} e^{j2\pi f_c t}\}$$

- The complex envelope or the baseband equivalent signal is:

$$u(t) = S\,e^{j\varphi(t)} = S\cos[\varphi(t)] + jS\sin[\varphi(t)]$$

- The modulating signals can be, in turn, expressed as two components;
- One kind of representation which highlights this aspect is the complex plane digital signal representation;

- Let’s take for example the QPSK signal where the four symbols that can be transmitted are: (00,10,01,11);



(b) QPSK

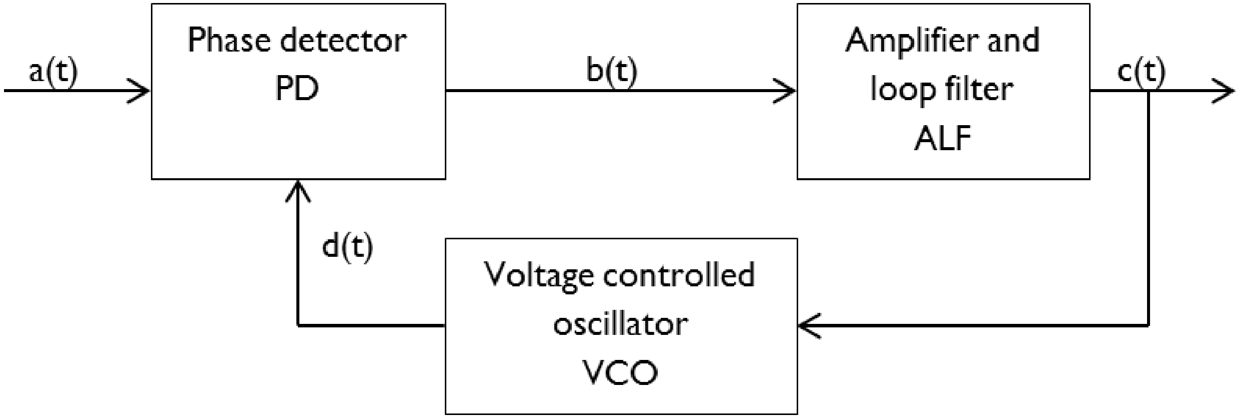
- For each symbol an I and a Q value can be defined, and they will be used to modulate the two carriers in such a way that the phase of the RF signal is the correct one;

- Consequenctly, using the I and Q signals two sine signals are modulated AM-SC, using simple modulators (for ex. ring modulators);

- The procedure is reversible, so the demodulation of these signals can be performed using an I/Q demodulator.

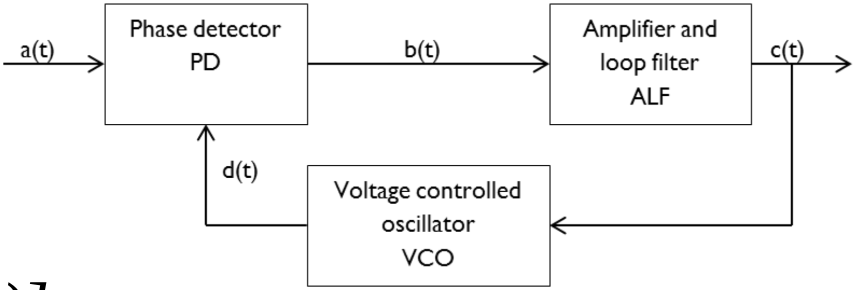
2.3.4 The functional principle of the PLL circuits

- PLL - *Phase Locked Loop* - 1932
- Applications
  - Coherent demodulation of LM signals
  - Frequency synthesis
  - Demodulation of FM signals



- the phase of a intern oscillator, *the voltage control oscillator (VCO),* is forced to follow the phase of the input signal.

- *The voltage controlled oscillator (OCT)*



a(t)

Phase detector PD

b(t)

Amplifier and loop filter ALF

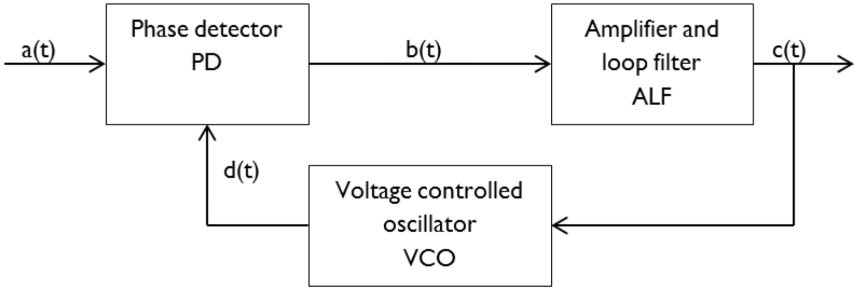
c(t)

d(t)

Voltage controlled oscillator VCO

$$d(t) = -\frac{2}{X_o}\sin[\omega_v t + \varphi_v(t)]$$

- $f_v=\omega_v/2\pi \Rightarrow (f_{v0}$ for $c(t)=0)$ is the central frequency of the VCO = the average value of the instantaneous frequency;
- $\varphi_v(t)$ – phase modulation of the VCO;
- X_o – amplitude of the a(t) signal;
- Operation law: $\frac{d}{dt}[\omega_v t + \varphi_v(t)] - \omega_{vo} = K_3 c(t)$



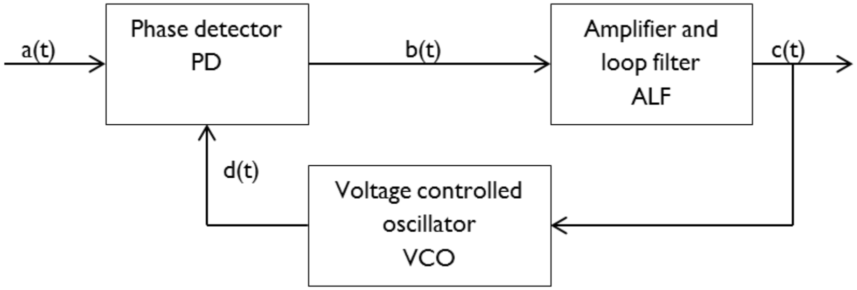
- *Amplifier and loop filter (ALF)*

- Transfer factor $K_2F(s)$, where K_2 is the gain of the amplifier;

- For most applications, $F(s)$ exists and $F(0)=1$;

- The filter is a LPF, usually with a simple configuration.

$$h_f(t) = \mathcal{L}^{-1}\{F(s)\}$$



Phase detector (DP):

- input signals: *a(t) and d(t)*

$$a(t) = X_o \cos[\omega_i t + \varphi_i(t)]$$

$$d(t) = -\frac{2}{X_o} \sin[\omega_v t + \varphi_v(t)]$$

- the output signal depends on the phase error

$$\varphi_e(t) = (\omega_i - \omega_v)t + \varphi_i(t) - \varphi_v(t)$$

PD variants:

a. analog multiplier,

b. modulo 2 adder preceded by limiters;

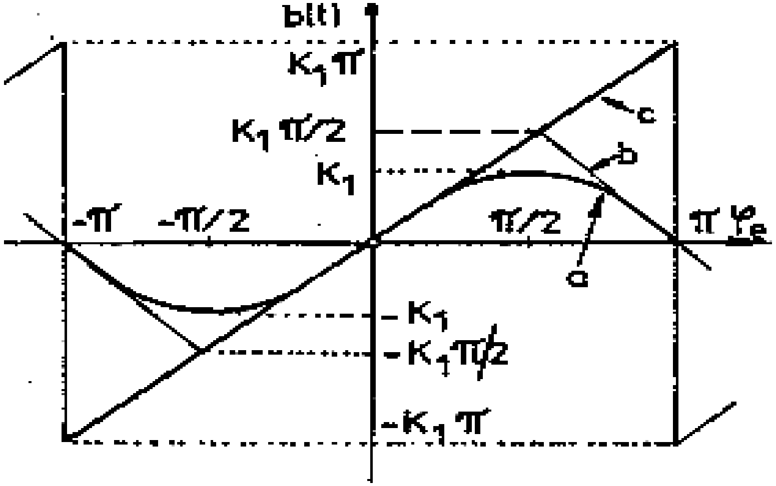
c. averaged output of a flip-flop commanded by the slopes of the limited signals.

a. PD implemented using an analog multiplier,

$$b(t) = K_1 a(t) d(t) = K_1 \sin \varphi_e(t) -$$

$$- K_1 \sin[(\omega_i + \omega_v)t + \varphi_i(t) + \varphi_v(t)]$$

- after the ALF: $b(t) = K_1 \sin \varphi_e(t)$
- if $\omega_i = \omega_v$ *for* $|\varphi_e(t)| << 1$ *then:* $b(t) \simeq K_1 \varphi_e(t)$

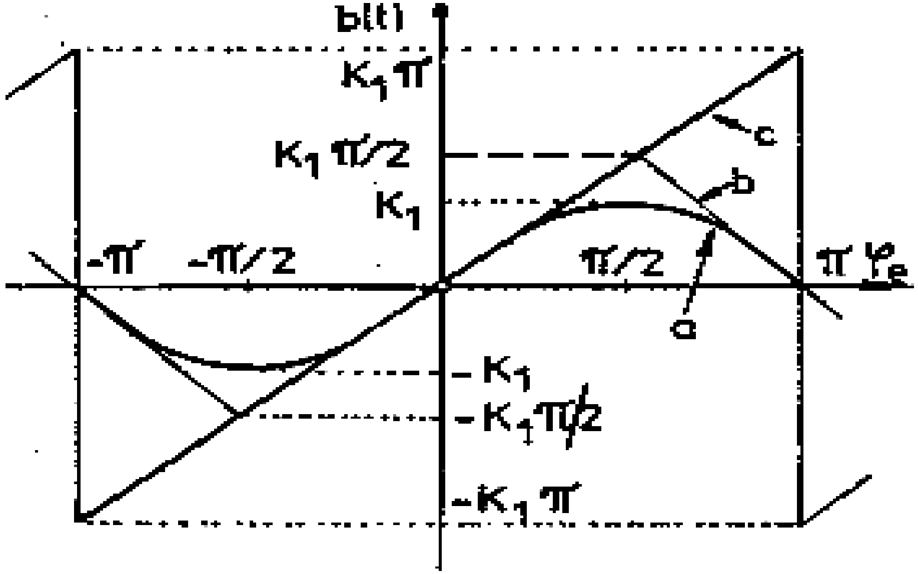


- the slope $K_1[\mathrm{V/rad}]$:

$$K_1 = \frac{\Delta b[\mathrm{V}]}{\Delta \varphi_e[\mathrm{rad}]}$$

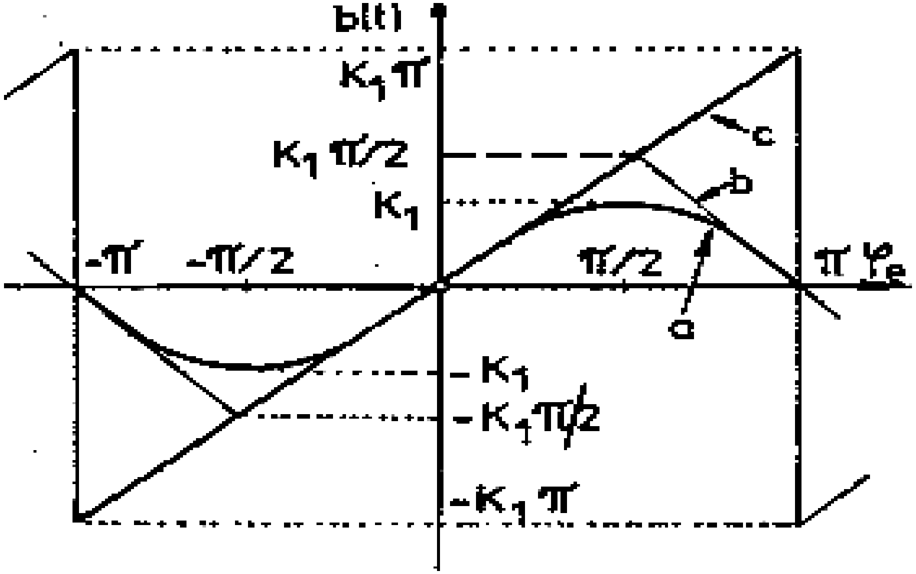
b. PD implemented using modulo 2 adder preceded by limiters;

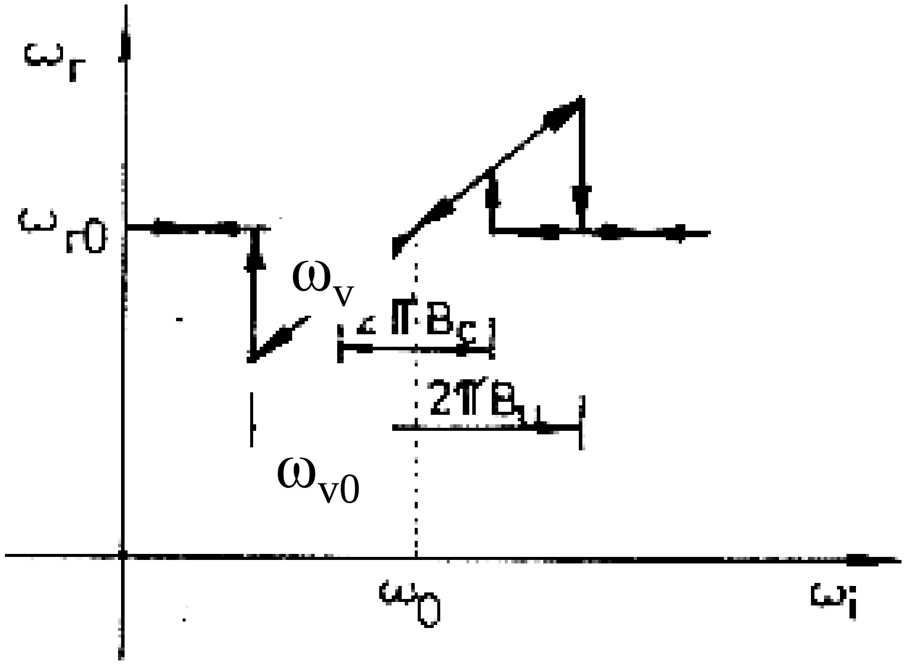
$$b(t) = K_1 \arcsin[\sin \varphi_e(t)]$$



c. PD implemented using the averaged output of a flip-flop commanded by the slopes of the limited signals.

$$b(t) = K_1[\varphi_e(t) - (2k+1)\pi], \quad \varphi_e \in [2k\pi, (2k+2)\pi]$$





B_u - the lock range/bandwidth of the loop

B_c – the *Capture range/bandwidth* – The frequency range the PLL is able to lock-in, starting from unlocked condition

2.4 Radio Transmitter topologies

- In order to commonly use some circuits and reduce the power consumption, the receiver and the transmitter have to be designed simultaneously.

- If a correct frequency planning is used, the design can be optimized in order to reduce the size of the equipment and obtain the requested performance parameters.

In the following analysis a arbitrary division of the transmitter in three sections will be used:

1. **The power amplifier (PA)** which includes all the amplifying chain with an input power level of more than 10dBm;

2. **The excitator** which includes the amplifying chain which brings the signal to the input of the power amplifier;

3. **The backend** which includes all the other circuits.

- From the modern transmitter architectures, in the following the most widely used ones will be discussed:

  a. Two transmitters designed for wide band applications;

    - *Two-Step Conversion Transmitter (TSCT);*
    - *Direct Launch Transmitter (DLT)*;

  b. A few types of *narrow band architectures* for FM transmissions;

- The first two types are used in most of the wide band applications.

- It will be noticed that they used IQ modulators and that they can be used for transmitters which process both constant envelope signals and variable envelope signals.

- The RF signal s(t) is generated by applying the *I(t)* and *Q(t)* components as input signals for the quadrature modulator.

- These components are obtained by processing the data by means of a digital signal processor that assures:
    - source coding,
    - filtering,
    - symbol generation,
    - Interleaving aso.

- ***Narrow band architectures*** are more simple, are used quite often and their intended use is for frequency modulated signals.

- A great number of possible architectures is available. Two of them will be briefly discussed.

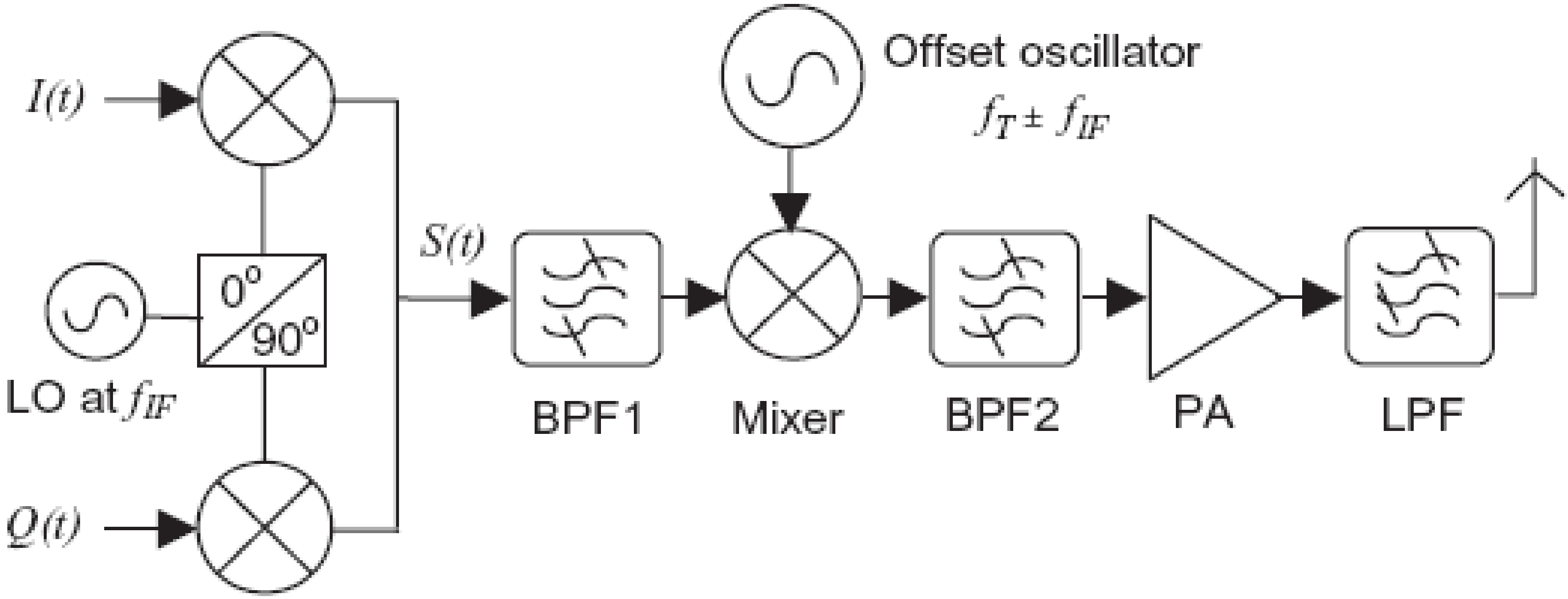
- In the end is useful to mention that one of the blocks that imply a great design and implementation effort is the RF power amplifier.

- In this case a reasonable compromise has to be done between power efficiency, linearity, RF output power level, power supply value.

- These aspects were treated in previous sections.

2.4.1. Two-step conversion transmitters (TSCT)

- This architecture includes a final IQ section and is suitable for implementing wideband radio transmitters or high performance narrowband radio transmitters.
- A simplified block diagram is presented in the next slide.



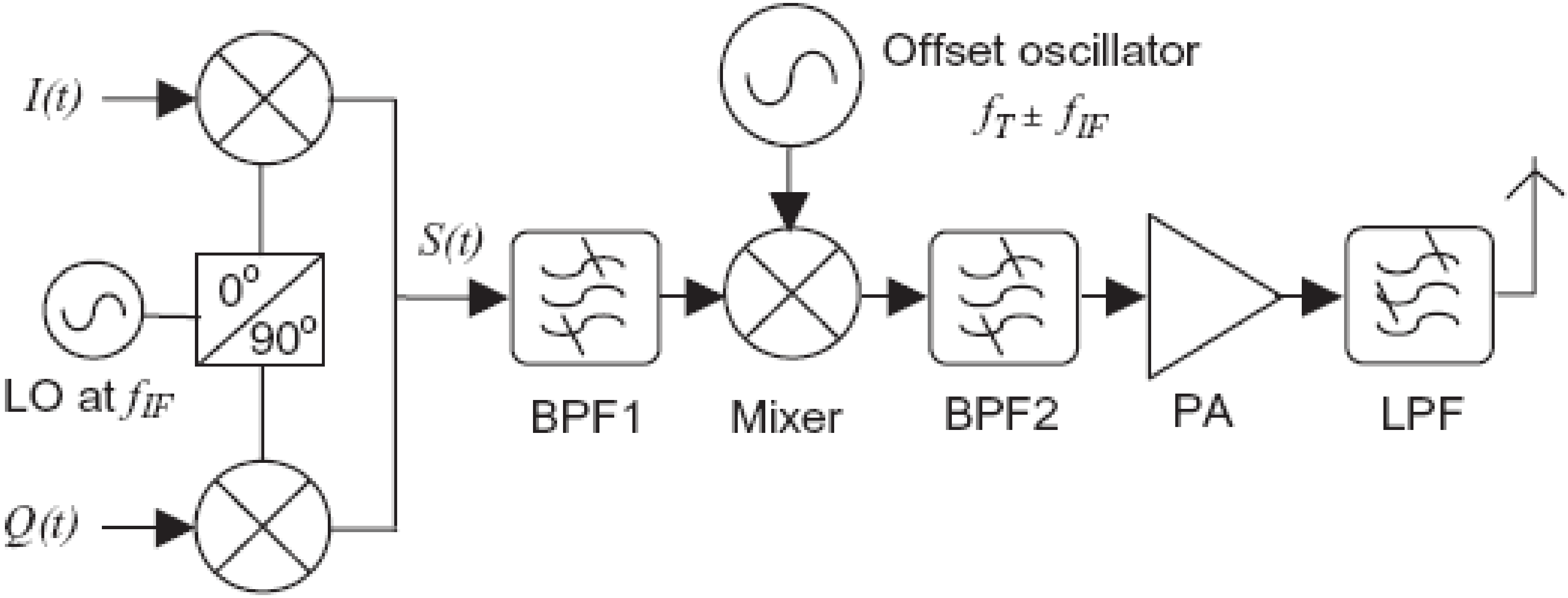
$I(t)$
$Q(t)$
0^o
90^o
LO at f_{IF}
$S(t)$
Offset oscillator
$f_T \pm f_{IF}$
BPF1
Mixer
BPF2
PA
LPF

- It can be noticed that the baseband signals $I(t)$ and $Q(t)$ generate, at the output of the modulator, a modulated signal on the intermediate frequency:

$$s(t) = I(t)\cos(\omega_{IF}\,t) - Q(\mathrm{t})\sin(\omega_{IF}\,t)$$

- The purpose of the band pass filter BPF1 is to reject all the unwanted signals located outside of the band occupied by the signal located on the intermediate frequency, like harmonics of the LO, noise on the image channel, aso.

- As such, the next mixer has a simple role, that is to translate the signal from the intermediate frequency to the working frequency of the radio transmitter, f_T.


I(t)
Q(t)
LO at f_{IF}
0°
90°
S(t)
Offset oscillator
$f_T \pm f_{IF}$
BPF1
Mixer
BPF2
PA
LPF

- The band pass filter BPF2 attenuates the image signal resulted after the second up-conversion.

- The last section realizes the power amplification, and the low pass filter eliminates the harmonics resulted after the power amplification.

- The matching network from the output of the power amplifier is designed to optimize the performances for aspects like the output power and linearity.

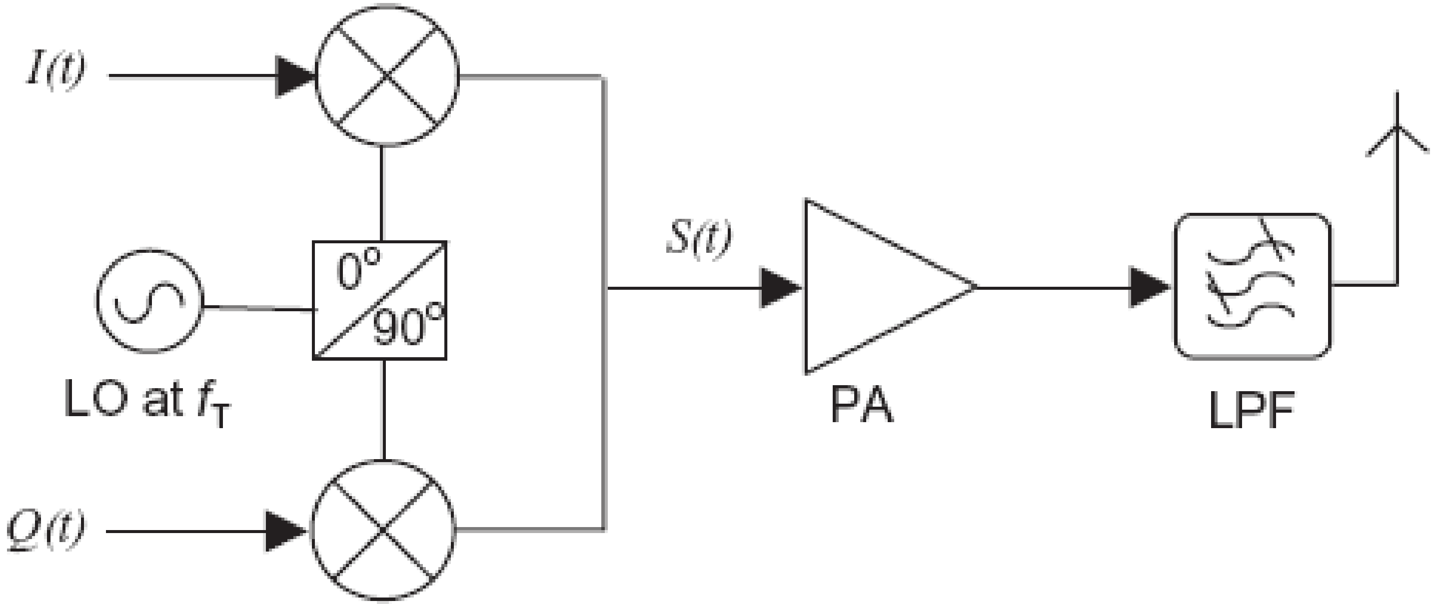
- To conclude, the TSCT architecture has a series of advantages like:
  - The IQ modulator works on a fixed frequency value, so a very good balance for the gain and phase of the two paths can be obtained; therefore, very good performances can be obtained with medium restrictions imposed to the components from the final stages;
  - Because of the fact that the two frequencies, the intermediate one and the RF carrier are very different in value, the phenomenon of “VCO injection pulling” by the signal generated after the power stages can be avoided.

- Unfortunately, the high level of performance is obtained at the cost of a complex equipment, with a high consumption, large size, aso.

- This architecture is not suitable for integration because of the existence of a large number of external concentrated components.

2.4.2 Direct Launch Transmitters (DLT)

- The DLT architecture also includes an IQ front end;
- It is very suitable for implementing wideband radio transmitters with a medium level of performance.
- Most of the Bluetooth or WiFi transmitters use this architecture and can be implemented using a single-on-chip (SoC) CMOS technology;


I(t)
Q(t)
LO at f_T
0°
90°
S(t)
PA
LPF

- The two *I*(*t*) and *Q*(*t*) components directly modulate the final frequency of the transmitter, obtaining a *s*(*t*) signal:

$$s(t) = I(t)\,cos(\omega_T\, t) - Q(\mathrm{t})\,sin(\omega_T\, t)$$

- Unlike the TSCT architecture, in this case there is no need for a BPF because there is no image signal or other unwanted products.

- As such, this signal can be directly applied to the input of the power amplifier.

- A low pass filter follows, in order to attenuate the harmonics produced during the amplification process;

- The matching network associated to the PA has the goal of optimizing the functioning of the final stage, realizing a compromise between the output power and the linearity, similar to the previously discussed architecture.

- A problem arises because of the fact that the power amplifier and the local oscillator work on the same frequency.

- Because of this fact, the transmitter is affected by an important source of interferences, known as „VCO injection pulling”

- The phenomenon of VCO injection pulling consists in the fact that the oscillator tends to follow the instantaneous frequency of the modulated signal received from the power amplifier.

- In this way a parasite modulation of the oscillator is produced if the radiation from the power amplifier reaches the oscillator.

- This modulation reduces the global performances, producing an expanse of the occupied spectrum.

- The phenomenon is known under the name of „remodulation” or „spectrum regrowth”.

- In most of the cases a good shielding of the VCO and of the area occupied by the synthesizer is necessary.

- Sometimes is indicated an additional filtering of the supply voltage and of the control lines.

- Also to be noticed is the fact that the IQ modulator works on a variable frequency and has to cover all the frequency band that is allocated to the communication system.

- Because of this, a consistent balancing of the two paths from the gain and phase points of view cannot be any more guaranteed.

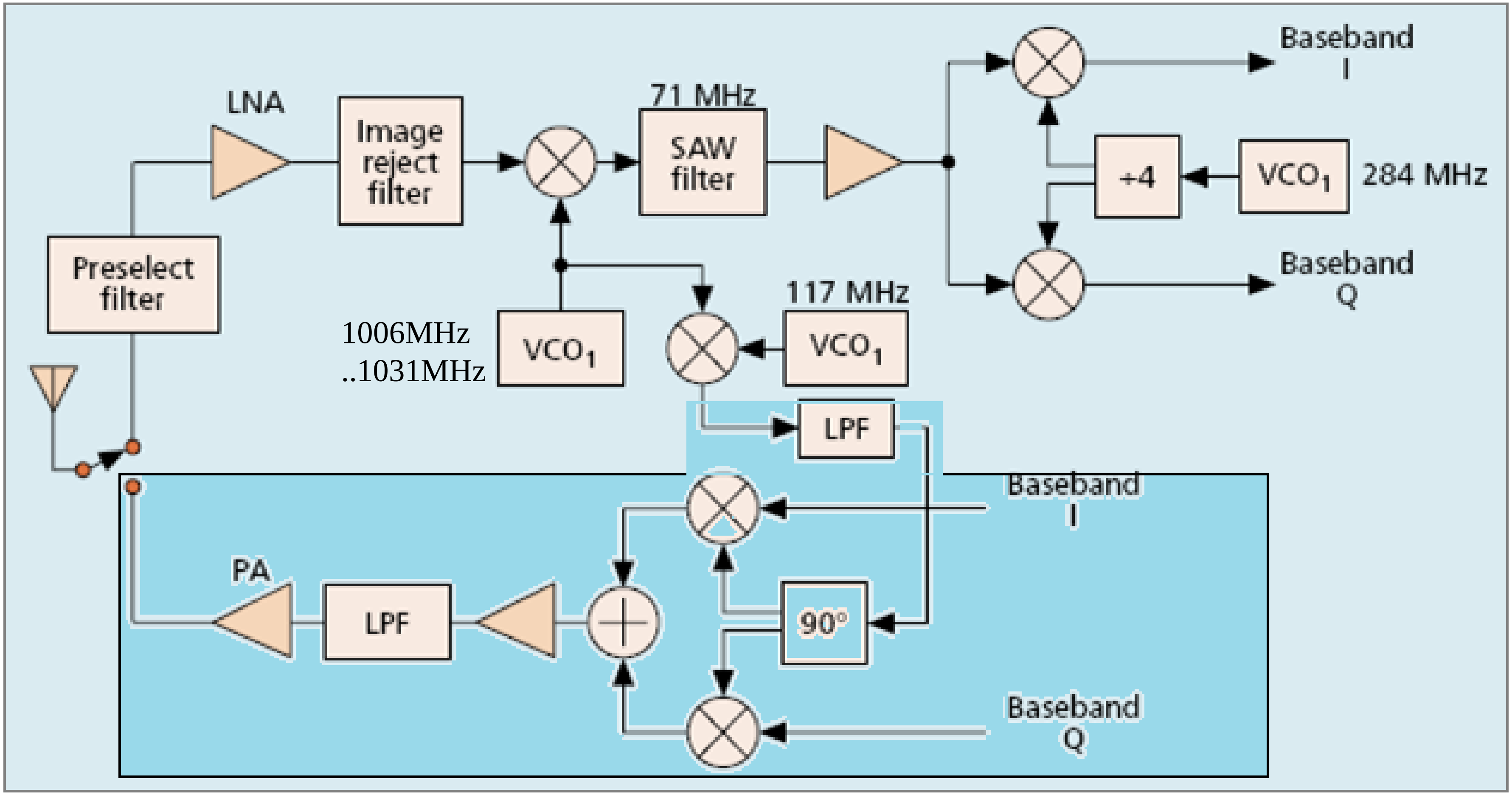
➢ Conclusion:

- ➢ The DLT arhitecture greatly simplifies the structure of the transmitter in comparison with the TSCT architecture : *a single local oscillator is necessary, there is no intermediate frequency stage any longer.*
- ➢ Substantial reduction in terms of size and cost can be obtained.
- ➢ However, the requirements regarding the linearity, spectral purity and IQ balancing imposed to the terminal section are much tougher.

- A great deal of attention has to be given to the shielding of the synthesizer in order to avoid the phenomenon of remodulation because of the radiation from the power amplifier.

- The DLT architecture is suitable for applications that use low transmit power.

- One example of using such an architecture in a GSM transceiver is given in the next slide.

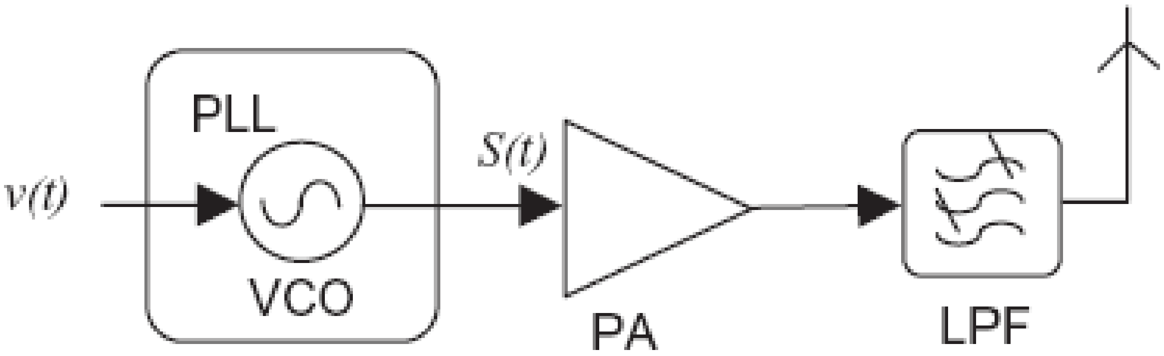

Baseband
I
LNA
Image
reject
filter
71 MHz
SAW
filter
+4
VCO$_1$
284 MHz
Preselect
filter
Baseband
Q
117 MHz
1006MHz
..1031MHz
VCO$_1$
VCO$_1$
LPF
Baseband
I
PA
LPF
90°
Baseband
Q

2.4.3 Direct FM transmitters

- The DFMT that is discussed in this paragraph is used only for FM signals.
- Narrowband FM signals are currently used for voice and data transmission in various applications: army, public safety, commercial communications, aso.
- The frequency bandwidth that is usually needed is 12,5 or 25 kHz, with the exception of the GSM system, where the bandwidth is 200kHz.

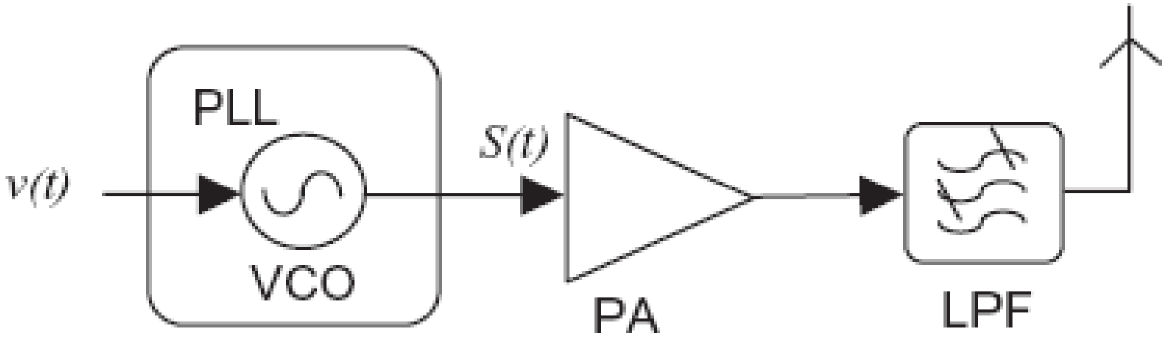
- FM signals are attractive because they are signals of constant envelope, which can be processed using solutions that are very power efficient;

- Because of this aspect, architectures that incorporate non-linear power amplifiers can be used; one can also use receivers with simple architectures which will lead to cheap products, with low size and consumption.



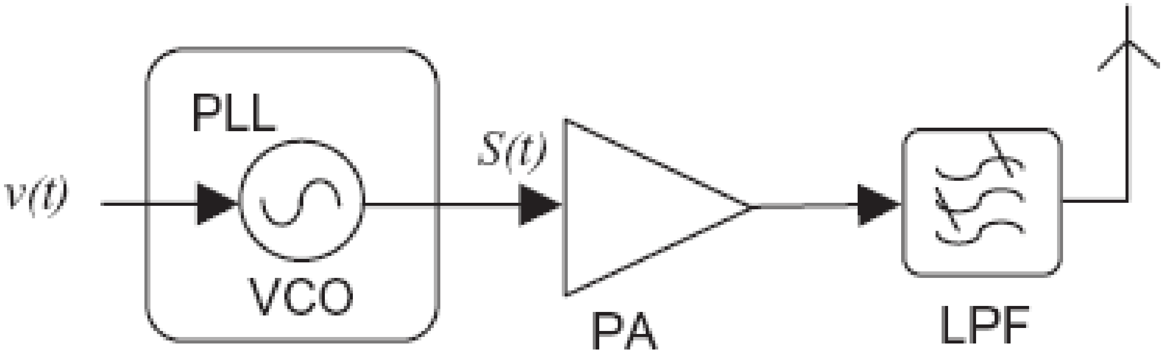
- The RF modulated signal *s(t) is obtained directly by controlling the frequency of the VCO by using the baseband signal.*

- The VCO is part of a synthesizer build using a PLL circuit.

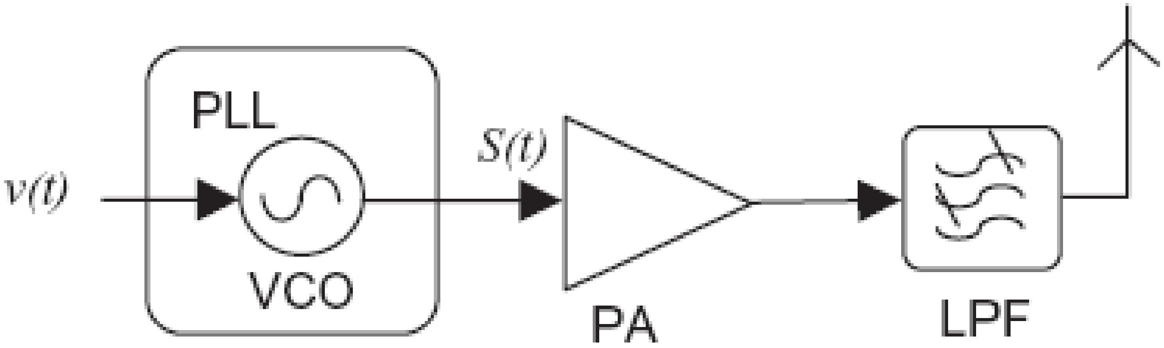


- The modulated signal is amplified and forwarded to the transmit antenna by means of a LPF that eliminates the harmonics generated by the non-linear power amplifier.

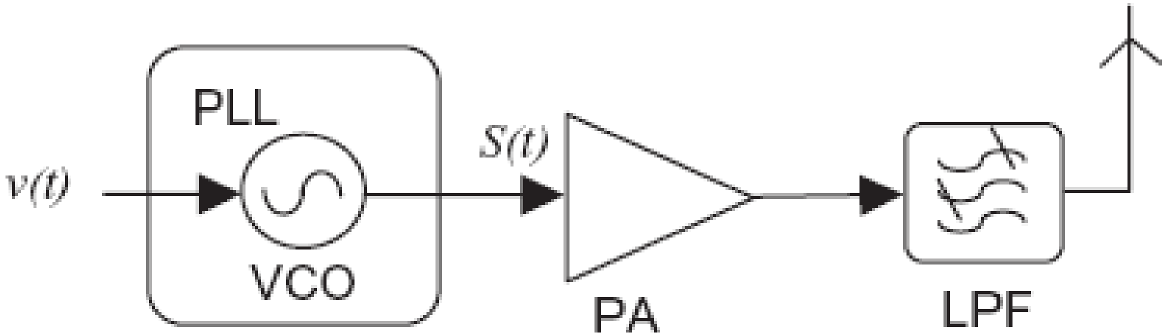
- The power amplifier can be implemented using C class stages, which will lead to a good power efficiency;



- Because of this, using this architecture it will be possible to obtain portable equipment with high autonomy and compact size (low amount of dissipated power).



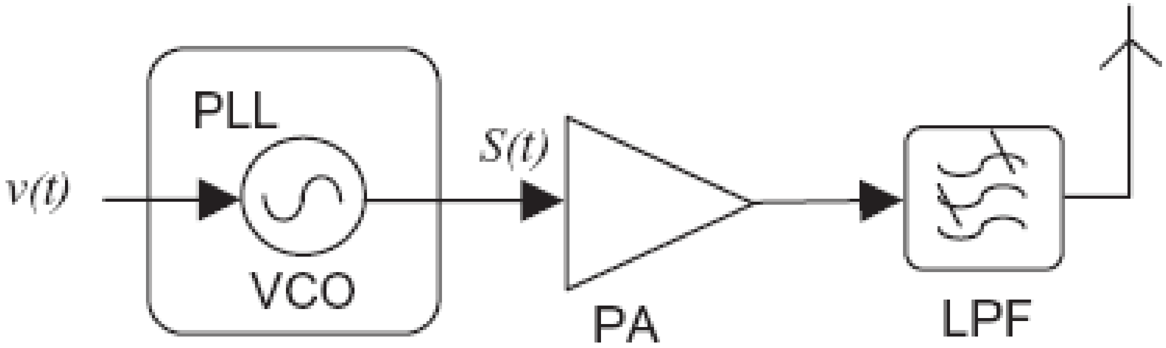
- Let’s go back to the PLL circuit containing the VCO circuit;
- Conform with the functioning principles of this circuit, at synchronism it will try to keep a constant frequency value for the signal generated by the VCO;



- If the frequency spectrum of the modulating signal is inside the band of the PLL circuit, the modulation will be canceled by the action of the loop;

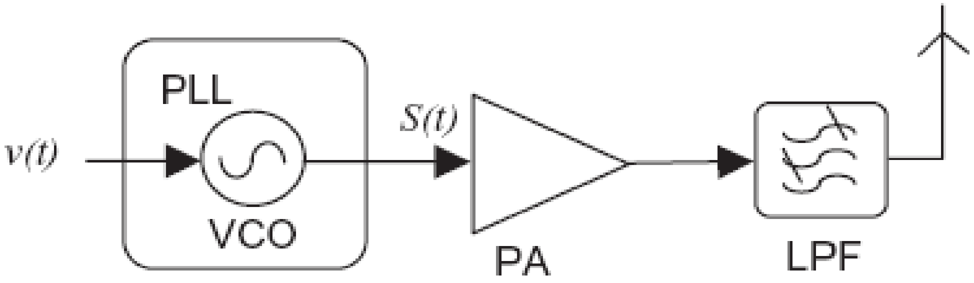
- This effect is known under the name of *modulation track-out*;

- In case of the DFMT architecture, the band of the PLL circuit is small, less than 300Hz.

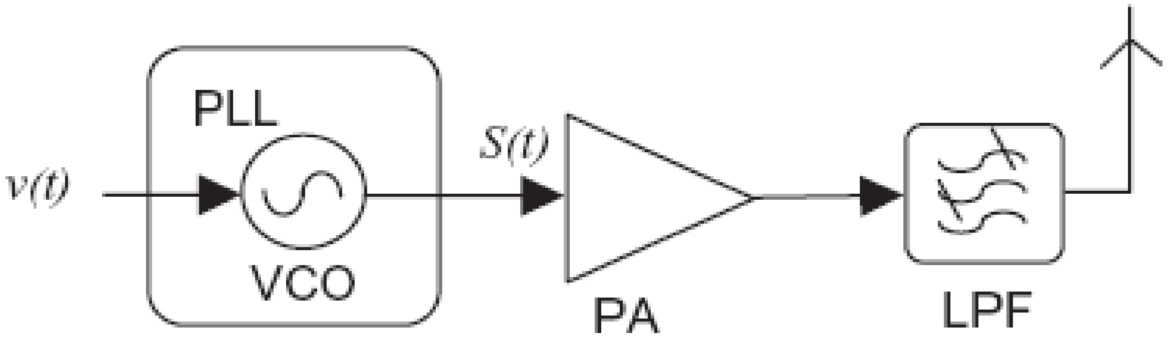


- Often, for example in radiotelephony where the signal has components between 300Hz and 3 kHz or in case of high speed data transmissions the modulated signal will not be affected.

- However, there are low speed data signals (for example NRZ control signals) which cannot be transmitted without a solution in order to avoid the before mentioned phenomenon;



- One possible action would be to reduce the band of the PLL circuit;
- This solution can be rarely accepted as the PLL band influences the acquisition time (the time necessary to reach the synchronism phase);
- Reducing the band – the loop becomes too slow to be used in systems that require a switching time as low as possible;



- It is to be noticed that the *modulation track-out* phenomenon has also positive effects, like the elimination of the modulation because of microphony (modulation on low frequencies due to mechanical vibrations);
- In conclusion, for data transmissions the solution presented in the following paragraph will be used, case in which the modulation acts on the PLL circuit through two paths;

Conclusion:

- The DFMT architecture is appropriate for RT with a simple RF chain, without mixers, IQ modulators, IF block;
- Is an architecture appropriate for applications that require low power equipment, low price, low consumption, low size;
- Unfortunately the DFMT architecture can be used only for signals with a constant envelope.

2.4.4 Dual-Port Direct FM transmitters - DDFMT

- The problem that had to be solved was in case of modulating signals that contain components at very low frequencies (around DC);
- The response of a PLL circuit to signals that are to modulate the VCO is a high pass one;

- It can be proven that the frequency modulation can be obtained also by controlling the division factor of the programmable divider, N ;

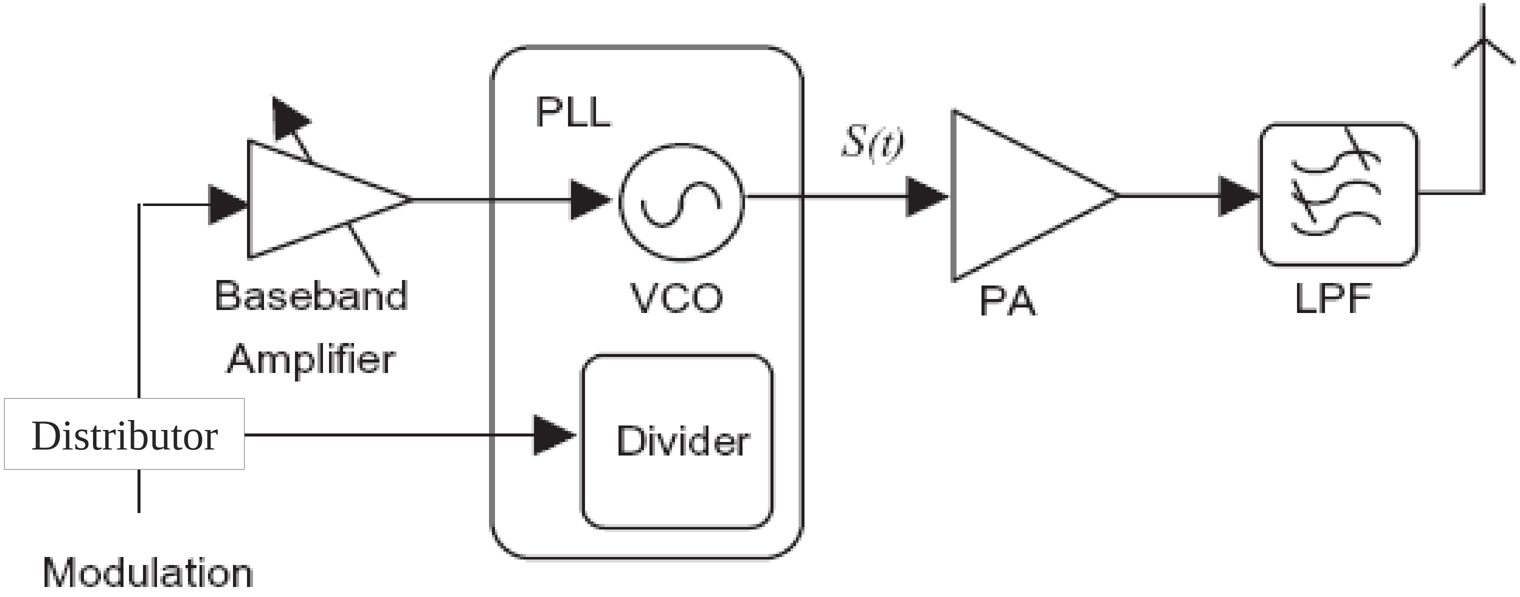
- As known, the VCO frequency is given by:

$$f_o = N\,f_r$$

- Moreover, it can be proven that in this case the response is a low pass one;

- In conclusion, if a wideband modulator is required, it is advisable to perform the modulation both directly at the VCO and through the control of the programmable divider.

- The block diagram from the next slide is obtained;



- ➢ The signal is applied to a distributor who sends the high frequency components to the VCO and the low frequency ones to the divider.