

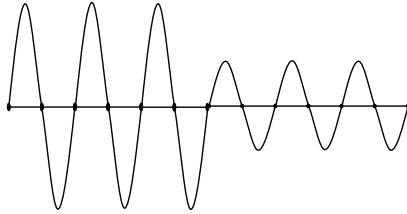
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Modulation technique

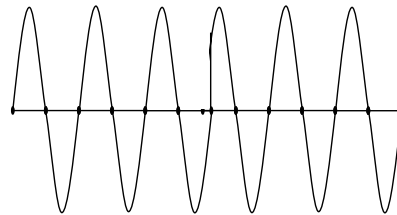
Politecnico di Torino
2006



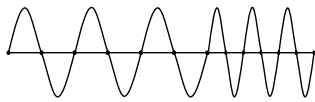
Amplitude, frequency and phase-based modulations



Amplitude shift keying



Phase shift keying



Frequency shift keying

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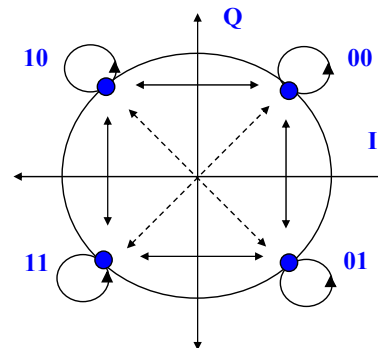
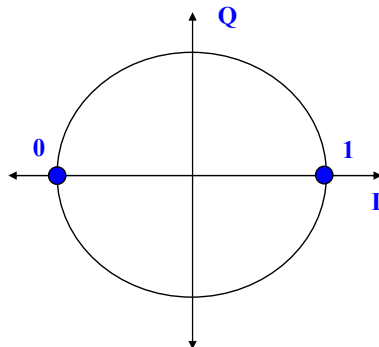
The digital modulation resolves the problem of transporting over the radio carrier the sequence of bits generated by the source of information.

The modulation is realised by varying the carrier characteristics according to the digital signal to be transmitted over the air. The modified characteristics may be:

- Amplitude (Amplitude Modulation; Amplitude Shift Keying)
- Frequency (Frequency Modulation; Frequency Shift Keying)
- Phase (Phase Modulation; Phase Shift Keying).

Phase modulation techniques

Binary Phase Shift Keying



Quadrature Phase Shift Keying

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The carrier can be represented through a rotating vector in the I/Q plane (*In phase/Quadrature*). The vector runs 1 full revolution per each period of the carrier waveform. It reproduces the cosine function and the sin function on the I and Q axes respectively.

Binary Phase Shift Keying (BPSK) modulation is a two-level modulation scheme, where each symbol represents a single bit (M is the number of possible symbols that can be represented during a cycle period).

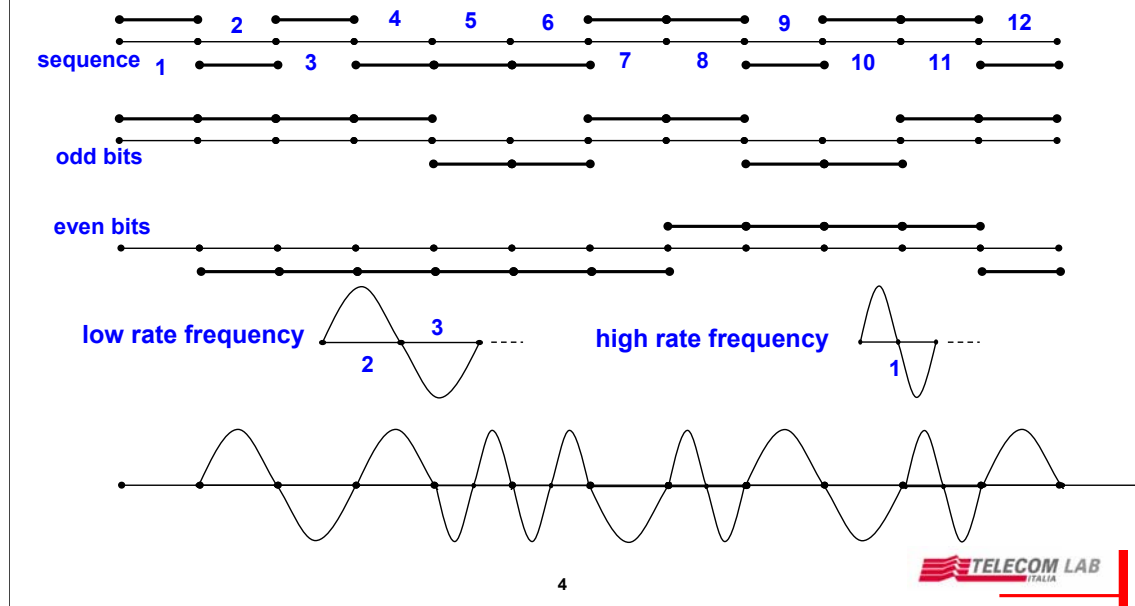
$$M = 2^1$$

Quadrature Phase Shift Keying (QPSK) modulation is a 4-level modulation scheme, each symbol represents a couple of bits.

$$M = 2^2$$

The changes between subsequent symbols, may imply a significant modification of the amplitude during the shift time (the higher is the phase shift, the lower the amplitude during the shift time) as well as of the bandwidth spreading. This poses strict linearity requirements to the amplifiers. In order to limit this requirements, it may be useful to avoid direct transactions between states that are in phase opposition (see dotted cases in figure for QPSK). In this case, we have an *offset* QPSK, which avoids the emitted power to go to zero while passing between symbols phase-opposite (π rad.).

Minimum Shift Keying modulation



For the GSM, the chosen modulation is the *Gaussian Minimum Shift Keying* (GMSK). It avoids changes of amplitude between symbols and, accordingly, does not induces stringent requirements on the amplifiers at the receiving side, that can work with high efficiency.

The figure represents the modulation named *Minimum Shift Keying* (MSK). This is a particular type of the *Frequency Shift Keying* (FSK) modulation. It is based on a couple of frequencies (*low*, *high* in the figure). The original bit sequence is split in two sequences, composed by the even and odd bits respectively.

In the first sequence, each bit maintains its value (1 or -1) for two consecutive bit periods. Similarly for the odd sequence.

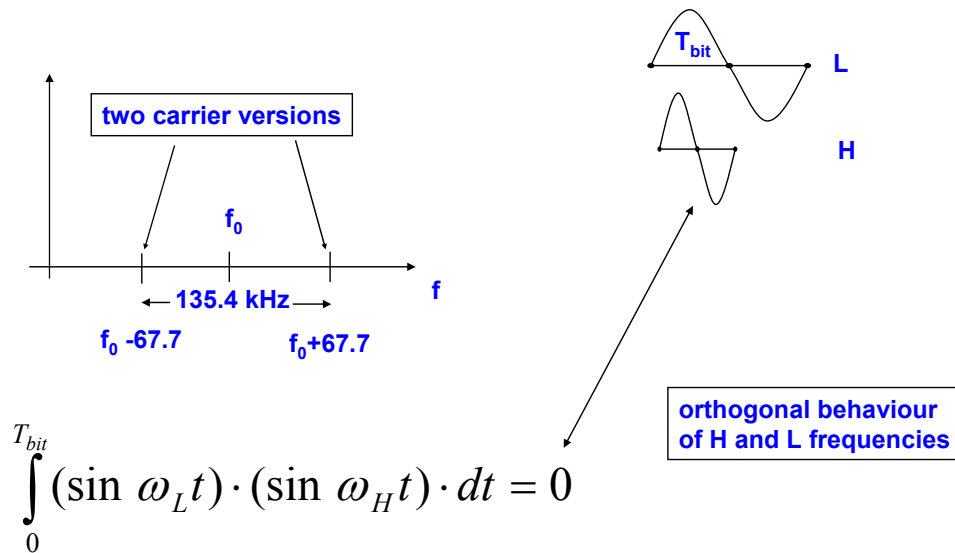
If the two sequences are considered, the couples of values they present in each bit period, correspond to passages between the symbols of a modulator of the kind *Offset Quadrature Shift Keying*, namely a modulator where subsequent symbols differ for one only bit.

The MSK modulator chooses between the two frequencies H (*high*) and L (*low*) by following the even/odd sequences according to the scheme of this table:

odd	even	frequency
1	1	H
-1	1	-L
1	-1	L
-1	-1	-H

Where the prefix - indicates a shifting of π radians for that specific frequency.

Minimum Shift Keying modulation (II)



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The two frequencies (H e L) are allocated symmetrically with respect to the central frequency of any GSM radio channel and their spectral distance reflects the frequency of the digital signal to be modulated. The digital signal is either the *odd* or the *even* sequence previously introduced, which is characterised by a bit rate of $270.833/2 = 135.4$ bit/s.

The distance in frequency between H and L is then 134.5 kHz. If f_0 is the central frequency of the carrier, then:

$$H = f_0 + 67.7 \text{ kHz}$$

$$L = f_0 - 67.7 \text{ kHz}$$

The two frequencies are orthogonal over the bit period T_{bit} , as indicated in the figure. This allows for an easy detection of the frequencies on the receiving side.

Minimum Shift Keying modulation (III)

$$C(t) = V \cdot \cos \left[\omega_0 t + \int_0^t k \cdot v(\tau) d\tau \right] + \varphi_a$$

φ_a arbitrary phase

$v(\tau)$ modulating signal (frequency f_m)

ω_0 cycle rate

k constant

frequency variation in t: $\frac{k \cdot v(t)}{2\pi}$

modulation index m

$$m = \frac{\max \left| \int_0^t k \cdot v(\tau) d\tau \right|}{f_m}$$

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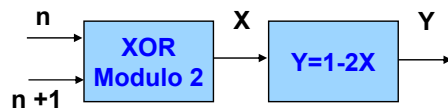
The modulation just described has a *modulation index* equal to 0.5, being this index m the ratio between the maximum frequency excursion with respect to the central frequency and the frequency of the signal to be modulated (the base band signal).

For a frequency modulated signal $C(t)$, the argument of the sinusoidal function, can vary linearly with the variations of the signal to be transmitted (the modulating signal) $v(t)$. The modulation index m of the GSM is defined as reported in the figure.

For the GSM, the product $B \cdot T_{\text{bit}}$ is 0.3. Being the *bit rate* 270.833 kbit/s, the T_{bit} is 3.7 μs .

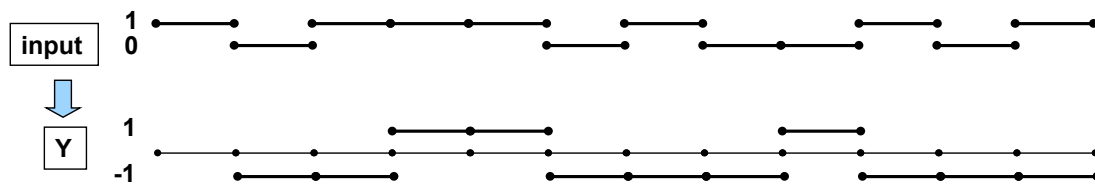
The bandwidth of the modulating signal is then limited to 81.3 kHz. This limitation is fulfilled through a Gaussian filter limiting the modulating frequency to 81.3 kHz at 3dB.

Gaussian Minimum Shift Keying modulation



Differential encoding:

- the receiver has no need of having his reference phase (no need of coherent demodulation)
- signal Y bears a polarity (+1,-1)



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The GMSK modulator utilises a differential encoder acting directly on the original bit stream.

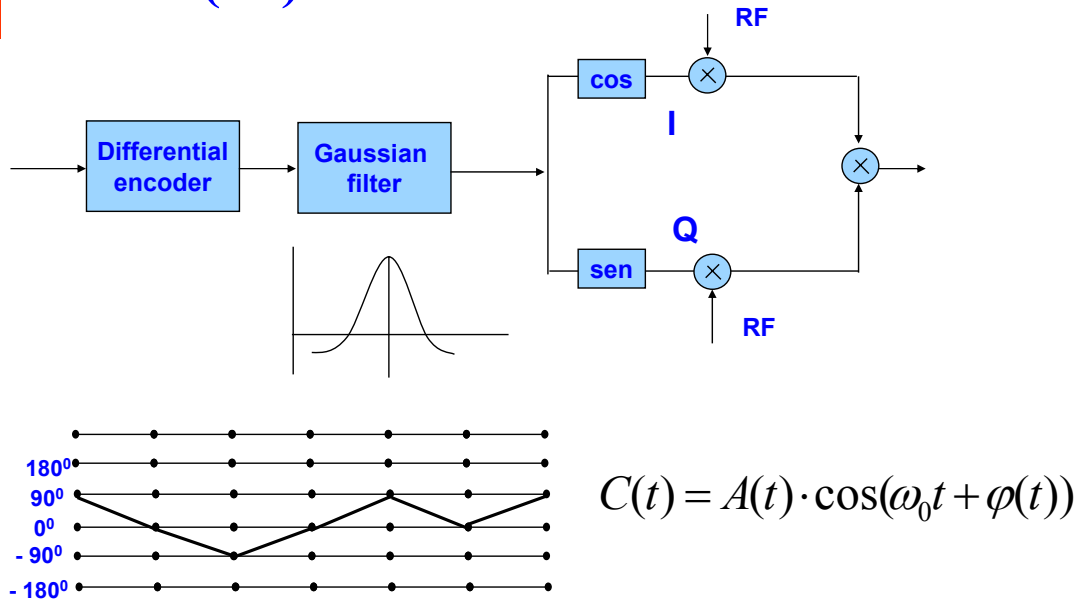
The outcome of this operation maps the original signal over the levels +1, -1 and performs a modification on the original signal which is similar to that previously described for the two *odd* and *even* flows of the MSK modulator.

The resulting bit stream (y) assumes the value -1 in the n^{th} bit period (of the original sequence) whenever this changes with respect to the $(n-1)^{\text{th}}$ bit.

Conversely, y assumes the value 1 in the n^{th} bit period (of the original sequence) whenever this remains un-changed with respect to the $(n-1)^{\text{th}}$ bit.

The differential encoding allows the receiver to work on phase changes rather than on the real phase values.

GMSK (IV)



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The signal y generated by the differential encoder allow to trigger the frequency modulator in function of the phase changes. The phase trajectory is limited in the frequency spectrum by the Gaussian filter.

The figure represents an example of GSMK modulator and the typical function of the phase changes.

The resulting modulated signal $C(t)$ depends on the central frequency f_0 and on the phase $\varphi(t)$ introduced through the above mechanism.

The amplitude $A(t)$ varies in function of the power control mechanism already described for the GSM system.

The GMSK modulation has a constant envelope, avoids sharp phase shifts that could limit the spectral efficiency with undesired effects on bandwidth-limited systems like the GSM.