Modulation

Generalities

The carrier is a pure sinusoidal signal of constant amplitude, frequency and phase. This carrier must be modified to carry the signal we want to transmit. We say that the signal is modulated.

The carrier is described by the equation **y = a sin (2πFt + ϕ)** in which:

• a is the amplitude of the carrier,

• F is the frequency of the carrier,

• ϕ is the phase of the carrier.

To modulate the carrier, we will modify one of these three parameter as function of the signal to transmit.

Concept of envelope: The envelope of a signal is the external form of the modulated signal.

Baud rate: The baud expresses the number of modulation moments per second, this is the modulation rate. Each modulation moment being able to transmit one or more bits.

Connection flow: Produces the baud rate and the length of the symbol in bit.

Spectral efficiency: Ratio between flow rate (kb/s) and bandwidth (Hz)

Concept of symbol: Unit of information transmitted by moment of modulation. A symbol is a certain combined state of frequency, amplitude and/or phase that represents a number of bits. If a symbol represents one bit, it is the binary case. The single bit (k=1) can either be a logical 1 or 0, thus rendering two symbol possibilities (M=2). If a symbol consists of two bits (k=2), there is a total number of four symbols (00, 01, 10 and 11), therefore M=4. The relationship between the number of symbols and bits is:

M = 2k

Nyquist's theorem gives the upper limit of the bit rate for a system defined by the following equation:

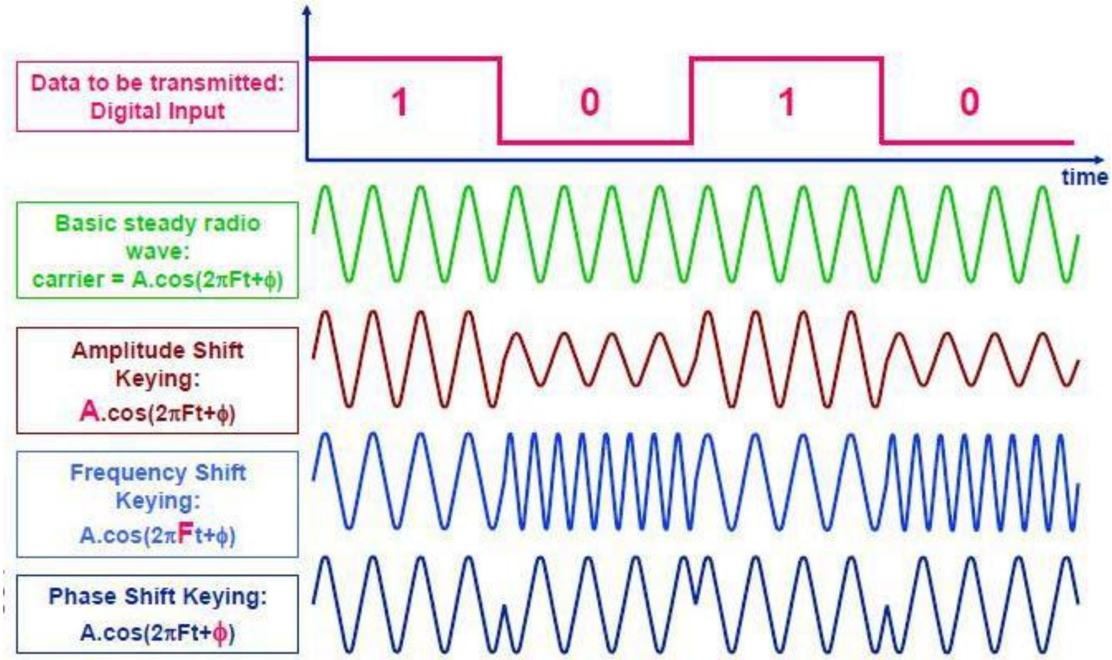
C = 2 B log2(2k)

C = 2 B log2(M)

C is the channel capacity in bps

B is the channel bandwidth in Hz

Numerical modulation



Modulation by amplitude shift keying (ASK)

This is a non-constant envelope modulation.

The introduction of amplitude modulation techniques requires the use of amplifiers of good quality, greatly increasing costs.

In ASK the baud rate and bit rate are the same

Also known as On-Off keying because depending on the information (1 or 0) the carrier signal is switched on or off.

But during the transmission of 0, the response is not ideal “off” signal, but there is a presence of noise which can be misinterpreted as data. To overcome this problem, '1' and ‘0’ are assigned to two different amplitudes. To get the maximum power it is possible to suppress the carrier and filter one of the side-bands to preserve the bandwidth.

Modulation by frequency shift keying (FSK)

Baud rate is the same as the bit rate

This modulation alleviates the problems associated with amplitude displacement modulation (clipping, greater amplification of weak signals and noises). This modulation is very used in broadcasting.

The frequency of the carrier is switched between two values, one representing the '1' and the other representing the '0'. The amplitude of the carrier remains constant. We talk about constant envelope modulation.

The system uses two different frequencies for the values 0 and 1 of each bit. If B is the base frequency (the carrier) and d the carrier deviation in frequency, each time a '0' is transmitted, a waveform of frequency B-d (a symbol), and to transmit a 1 it creates a waveform of frequency B+d. The receiver just needs to measure the deviation of the signal to the reference frequency B to know which value of the bit was transmitted. When the modulation rate increases, the difference between the two chosen frequencies also need to be higher, this has a restriction in the bandwidth.

2FSK is the simplest form of FSK, it uses one bit per symbol (‘1’ or ‘0’), but it is possible to use more bits per symbol.

4-FSK uses four different symbols and therefore needs 4 different carrier deviations; in this case each symbol is mapped as a combination of two bits (00, 01, 10, 11). This doubles the signaling rate, but requires a higher received Signal to Noise ratio due to the shorter distance between symbols, which makes the system more sensitive to noise and interferences between symbols.

Therefore, between 2-FSK and 4-FSK, the choice between a slow modulation which works even on weak signals and a high speed modulation which requires a stronger received signal. In other words, the higher the signaling rate, the shorter the range.

Gaussian Shift Keying (GFSK): Is a 2-FSK form shaped by a Gaussian filter with a roll off factor of 0.5. The parameters of the Gaussian filter determine how much the basic spectrum of the lateral bands will be narrowed,

Audio Frequency Shift Keying (**AFSK**): Is a special FSK modulation scheme using two tones, 2200 and 1200Hz, to modulate a binary signal into a carrier wave. It uses audible tones which can be transmitted through electronic circuits carrying sound, it is a simple system but less efficient in both power and bandwidth.

Minimum Shift Keying (MSK): Minimum Shift Keying is FSK with a modulation index of 0.5. Therefore, the carrier phase of an MSK signal will be advanced or retarded 90° over the course of each bit period to represent either a one or a zero. Due to this exact phase relationship MSK can be considered as either phase or frequency modulation. The result of this exact phase relationship is that MSK can’t practically be generated with a voltage controlled oscillator and a digital waveform. Instead, an IQ modulation technique, as for PSK, is usually implemented.

Coherent demodulation is usually employed for MSK due to the superior bit-error-rate (BER) performance. This is practically achievable, and widely used in real systems, due to the exact phase relationship between each bit.

In MSK, the difference between the high frequency and the low frequency is equal to half the bit rate in bits per second. Consequently, when transmitting a 0, exactly one more (or less) period in the output signal flows than when transmitting a 1. In this technique, the modulation index is 0.5: This is the smallest modulation index usable in FSK so that the signals for 0 and 1 are orthogonal. The minimum frequency-shift keying (MSK) is a very efficient form of FSK modulation in terms of spectrum occupancy.

Modulation by phase shift keying (PSK)

Here, the phase of the carrier is discretely varied with respect to either a reference phase or to the phase of the immediately preceding signal element in accordance with the binary data.

PSK systems with only two different phase angles are called Binary -PSK systems *(BPSK)*, in this, the bit rate equals the modulation rate.

Modulation with constant envelope, the amplitude of the carrier is not modified. There is no requirement for linear amplifiers in reception.

It is the phase of the carrier which is modulated by the binary data.

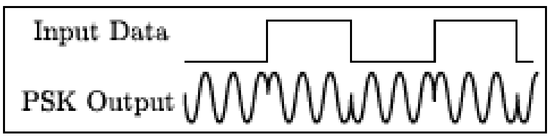
This modulation is very useful in data transmission.

There are two types:

- Binary PSK (BPSK): modulation that carries one-bit length symbols.

  - 1: the carrier phase is not phase shifted,
  - 0: the carrier phased is phase shifted of π.

  The phase of the carrier changes only on the 1/0 and 0/1 transition.



- PSK quadrature (QPSK): This modulation carries 2-bit length symbols.

  - 11: the carrier is phase shifted of π/4,
  - 01: the carrier is phase shifted of 3 π/4,
  - 00: the carrier is phase shifted of -3 π/4,

- 10: the carrier is phase shifted of - π/4.

QPSK (Quadrature phase shift keying) is one of the most used forms of PSK modulation, it consists of two BPSK systems operating in quadrature. The input bit stream is split in two bit streams, one containing the even numbered bits, and the other the odd numbered bits.

GMSK modulation:

GMSK is derived from the PSK modulations and acts on the phase of the carrier. It's a constant envelope modulation.

To transmit a "0", the phase of the carrier of + π / 2 is shifted.

To transmit a "1", the carrier of -π / 2 is shifted.

The length of the symbol is therefore 1 bit and the baud rate is equal to the bit rate in Kbits / s.

Unlike the PSK, each consecutive "1" or "0" applies a new phase shift of the carrier. Thus for the sequence 0010, the phase of the carrier (beginning with 0) will be successively π / 2, π, π / 2, π.

It is a popular alternative to QPSK. The RF bandwidth is controlled by the bandwidth of the Gaussian low-pass filter.

Comparison

Modulation format	Typical application
MSK,GMSK	GSM, CDPD
BPSK	Astronomic telemetry, cable modem
QPSK, DQPSK	Satellite, CDMA, NADC, TETRA, PHS, LMDS, DVB-S,TFTS
OQPSK	CDMA, satellite
FSK,GFSK	DECT, mobile data AM, AMPS, CT2, ERMES, public security
8,16 VSB	North American digital TV (ATV), hertzian cable
8PSK	Satellite, plane, telemetry pilots for monitoring broadband video systems
16 QAM	Digital microwave radio, modem, DVB-C, DVB-T
32 QAM	Terrestrial microwave
64 QAM	DVB-C, modem, Broadband decoder
256 QAM	Modem, DVB-C, Digital video

Numéroter le tableau.

Summary of modulations

In accordance with the annex n°…

The most commonly used modulation methods are GMSK, BPSK and AFSK. We have to choose the method according to the data rate required as well as the card used.

FSK signals are relatively easy to modulate and demodulate and provide adequate performance for satellite communication channels.

BPSK gives also a good performance and is more robust than FSK.

GMSK is more robust than BPSK but is more difficult to implement and need more power.

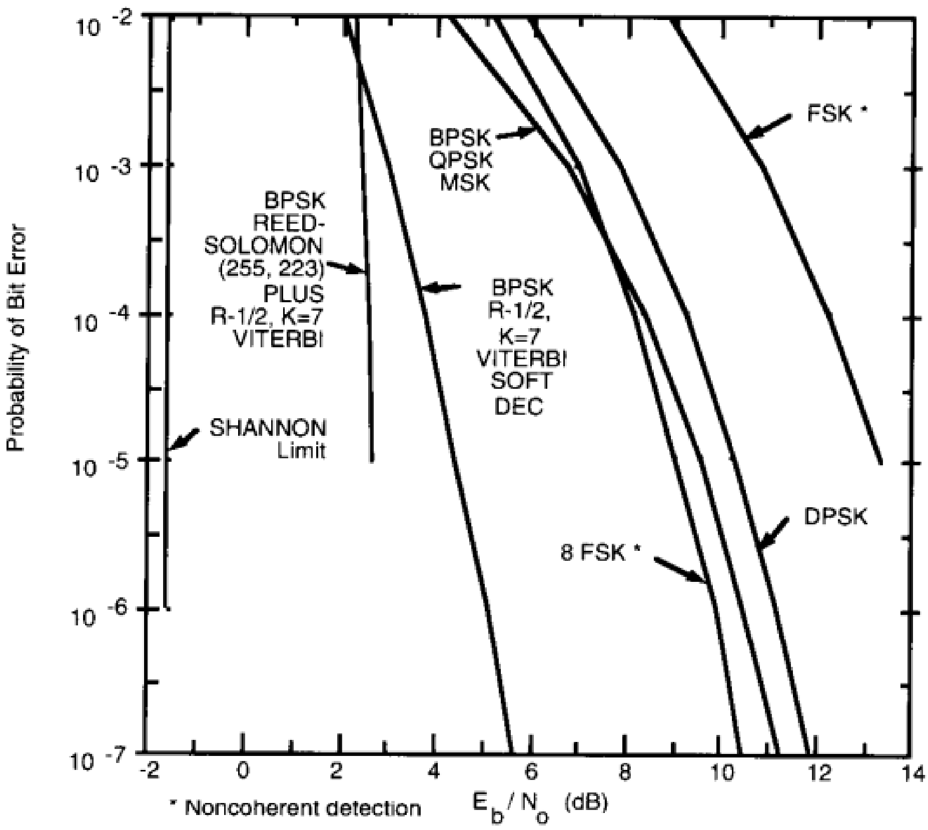
It appears that the BPSK is the best compromise between all off those technics.

BER comparison:

The probability of error is a function of the signal to noise ratio (SNR) and the number of bits per symbol used in a modulation scheme (M). The higher the modulation level, more energy per bit is needed, therefore the distance between symbols is smaller, making it more susceptible to inter symbol interferences and having a greater chance of having errors.

Eb/N0 is the energy per bit, it is a relation between the signal to noise ratio, the frequency of bit, and the bandwidth.

These parameters are useful when comparing techniques.



Comparison of the probability of bit error for the different most used techniques, BPSK, MSK and FSK.

The BER (Bit error code) increases as Eb/No decreases. A BER rate of 10−6 is generally considered an adequate value for digital communication. Which relates to a Eb/No value of 10.5 dB.

Eb/No gives an indication of how much stronger the signal is compared to the

background noise.

The expected bit rate for BPSK can be calculated. Assuming a baud rate of 4800, the following bit rate is achieved:

$$C = R\log_2(M)$$

$$C = 4800 \log_2(2)$$

$$C = 4800 \text{ bps}$$

The bit rate for QPSK with a baud rate of 4800 is as follows:

$$C = R\log_2(M)$$
$$C = 4800 \log_2(4)$$
$$C = 9600 \text{ bps}$$

QPSK's data rate is double that of BPSK, while using the same amount of bandwidth.
QPSK is a more efficient modulation technique compared to BPSK, but it is more difficult to implement.

FSK is the simplest technique to implement, but it has a wider spectrum than the other techniques. By increasing the number of bits per symbol, for example between 2-FSK and 4-FSK, to achieve the same probability of error, less energy is required, but also implementation becomes more complicated.

GFSK is as simple as FSK, and it has a smaller spectrum due to the Gaussian filtering, but it also has a worse noise immunity as compared to FSK.

MSK has the better noise immunity compared to 2FSK, 4FSK and GFSK, but the implementation of the modulator and demodulator is more complex.

http://claude.lahache.free.fr/mapage2/modulations-numeriques.pdf

http://www.forumatena.org/files/livresblancs/IntroductionALaradio.pdf

Master Thesis CubeCat-1: Implementation, testing and integration of the communication subsystem