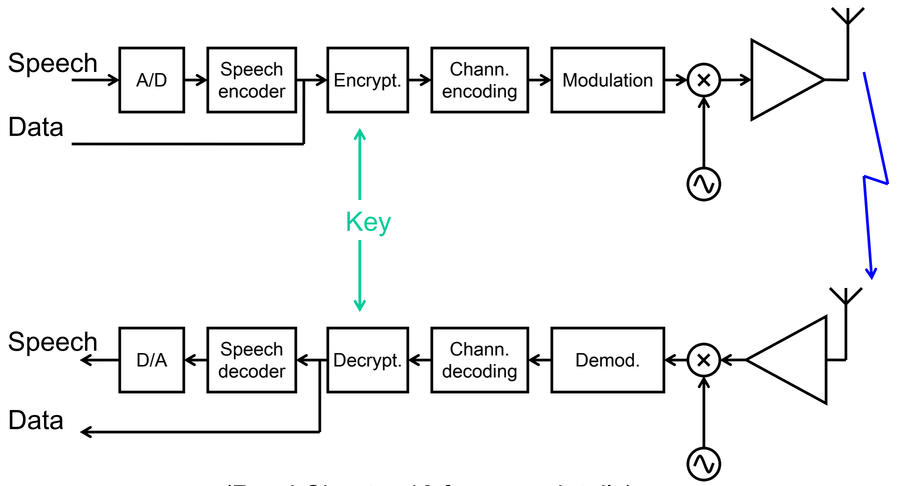
Lecture 3

EITN75 2018

STRUCTURE OF A WIRELESS COMMUNICATION LINK

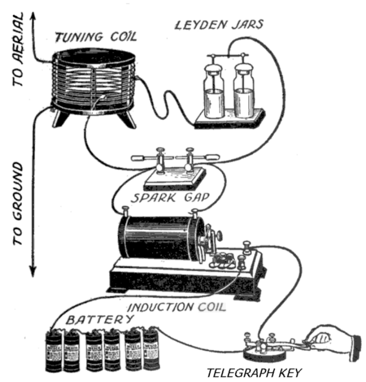
2

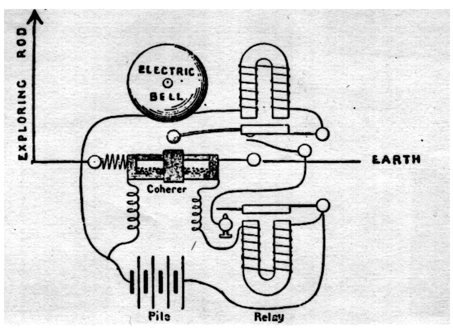
A simple structure



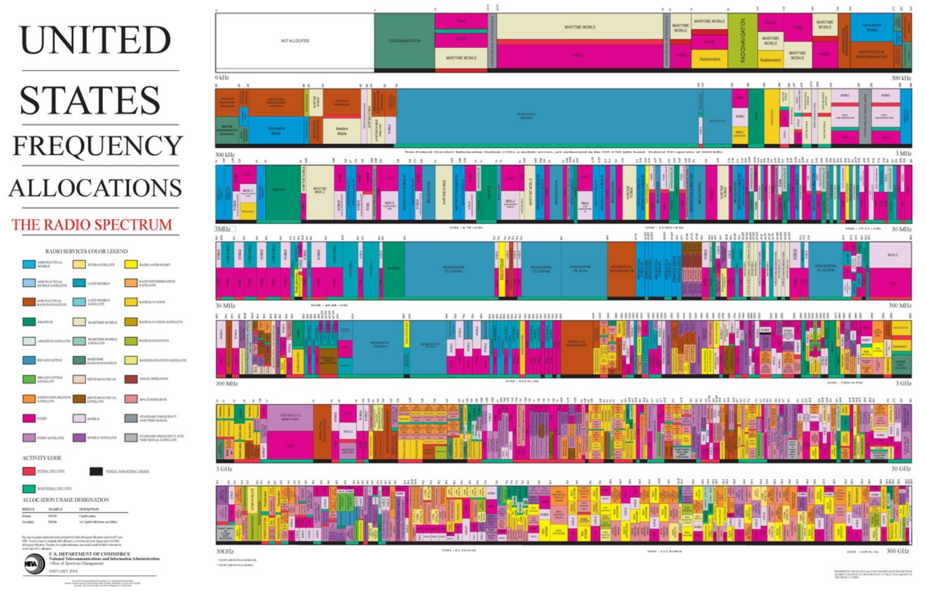
(Read Chapter 10 for more details)

Arc tranmsitter / coherer reciever

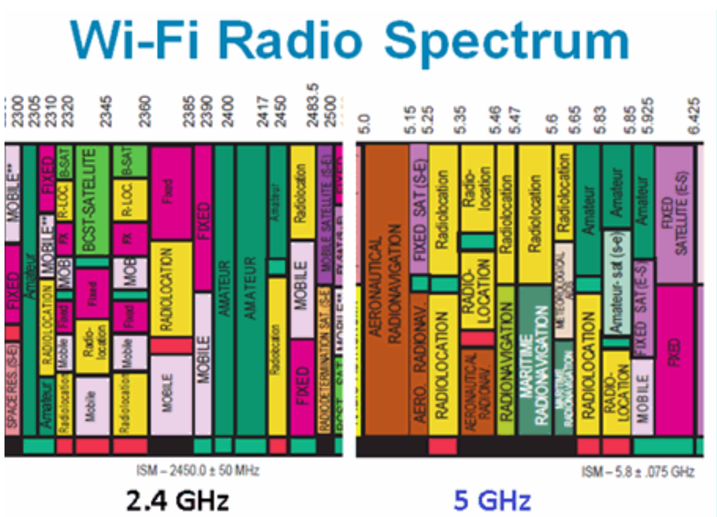




Frequency spectrum



ISM bands



Bandwidth

Shannon-Hartley Theorem

$C = B \times \log_2(1+S/N)$

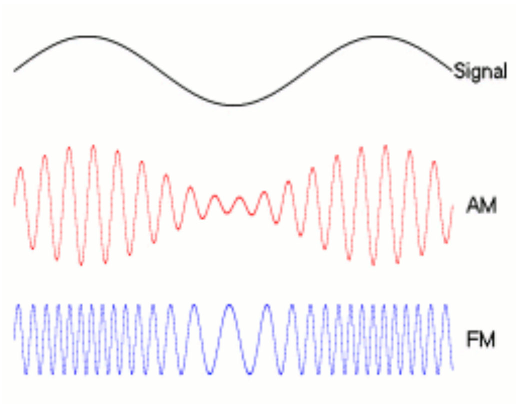
The capacity of a communication link is linearly dependent on the bandwidth(B), and logarithmically on the signal to noise level(S/N).

Classic modulation formats

Analog formats

- On-Off keying
- Amplitude modulation
- Frequency modulation

AM/FM



Simple model of a radio signal

•A transmitted radio signal can be written

$$s(t) = A\cos(2\pi f t + \phi)$$

Amplitude (A) — Frequency (f) — Phase (ϕ)

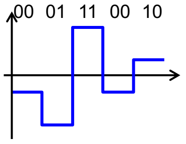
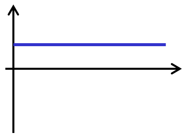
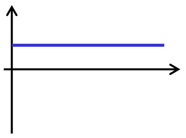
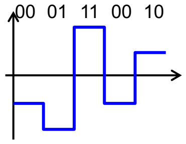
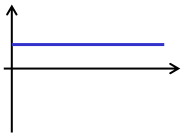
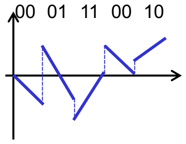
•By letting the transmitted information change the amplitude, the frequency, or the phase, we get the tree basic types of digital modulation techniques

–**ASK** (Amplitude Shift Keying)
–**FSK** (Frequency Shift Keying)
–**PSK** (Phase Shift Keying)

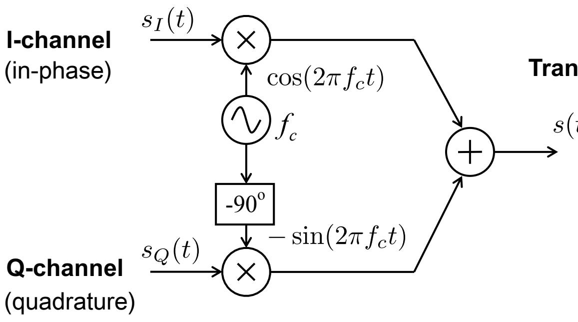
FSK, PSK: Constant envelope

Example: Digital amplitude, phase and frequency modulation

$$s(t) = A(t)\cos\left(2\pi f_c t + \phi(t)\right)$$

	$A(t)$	$\phi(t)$	Comment:
4ASK			- Amplitude carries information - Phase constant (arbitrary)
4PSK			- Amplitude constant (arbitrary) - Phase carries information
4FSK			- Amplitude constant (arbitrary) - Phase slope (frequency) carries information

The IQ modulator



Transmited radio signal

$$s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t)$$

Take a step into the complex domain:

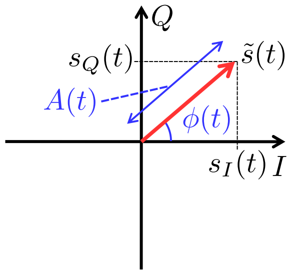
Complex envelope $\tilde{s}(t) = s_I(t) + js_Q(t)$

Carrier factor $e^{j2\pi f_c t}$

$\Rightarrow$ $s(t) = \mathrm{Re}\{\tilde{s}(t)e^{j2\pi f_c t}\}$

Interpreting the complex notation

Complex envelope (phasor)



Polar coordinates:

$$\tilde{s}(t) = s_I(t) + js_Q(t) = A(t)e^{j\phi(t)}$$

Transmitted radio signal

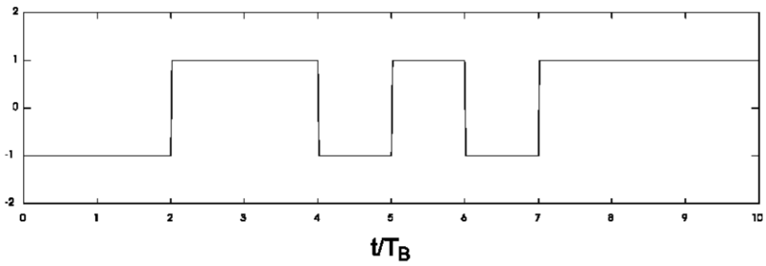
$$\begin{aligned} s(t) &= \mathrm{Re}\left\{\tilde{s}(t)e^{j2\pi f_c t}\right\} \\ &= \mathrm{Re}\left\{A(t)e^{j\phi(t)}e^{j2\pi f_c t}\right\} \\ &= \mathrm{Re}\left\{A(t)e^{j(2\pi f_c t + \phi(t))}\right\} \\ &= A(t)\cos\left(2\pi f_c t + \phi(t)\right) \end{aligned}$$

By manipulating the amplitude *A*(t) and the phase *Φ*(t) of the complex envelope (phasor), we can create any type of modulation/radio signal.

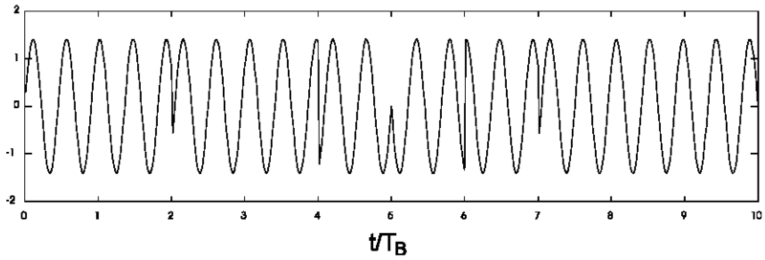
IMPORTANT MODULATION FORMATS

Binary phase-shift keying (BPSK)
Rectangular pulses

Base-band

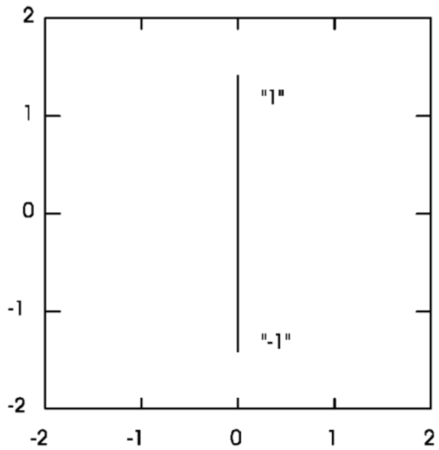


Radio
signal

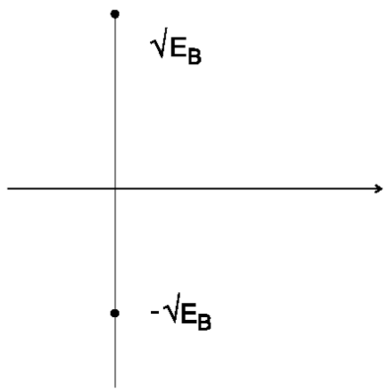


Binary phase-shift keying (BPSK)
Rectangular pulses

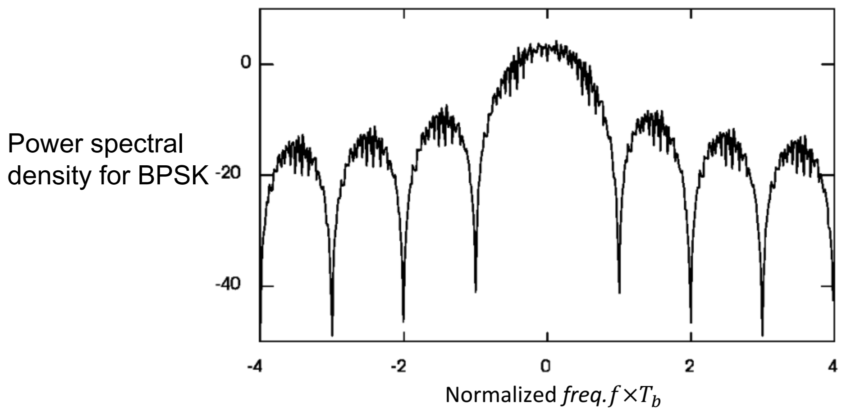
Complex representation



Signal constellation diagram

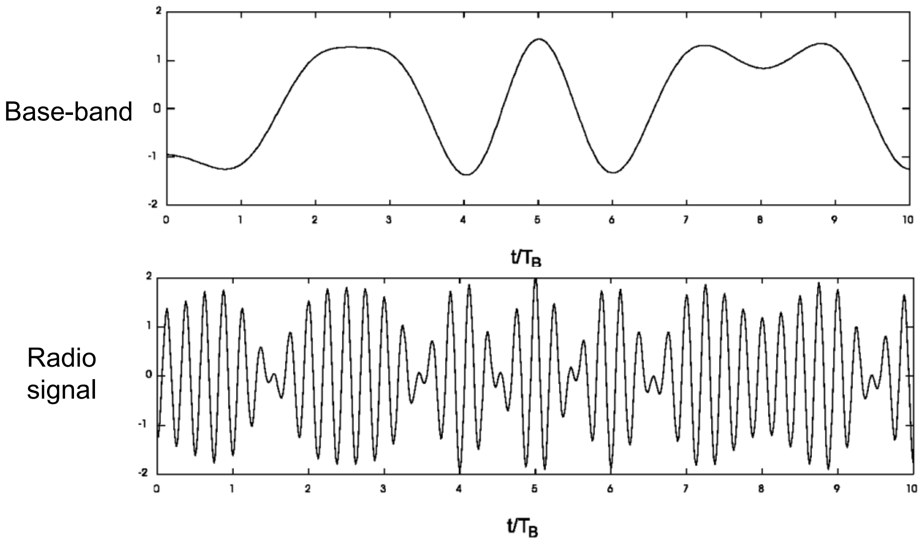


Binary phase-shift keying (BPSK)
Rectangular pulses



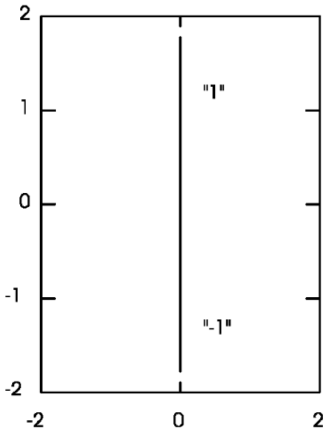
Contained percentage of total energy	spectral efficiency
90%	$0.59 Bit/s/Hz$
99%	$0.05 Bit/s/Hz$

Binary phase-shift keying (BPSK)
Raised-cosine pulses (roll-off 0.5)

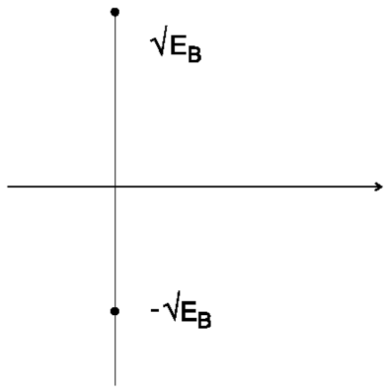


Binary phase-shift keying (BPSK) Raised-cosine pulses (roll-off 0.5)

Complex representation



Signal constellation diagram



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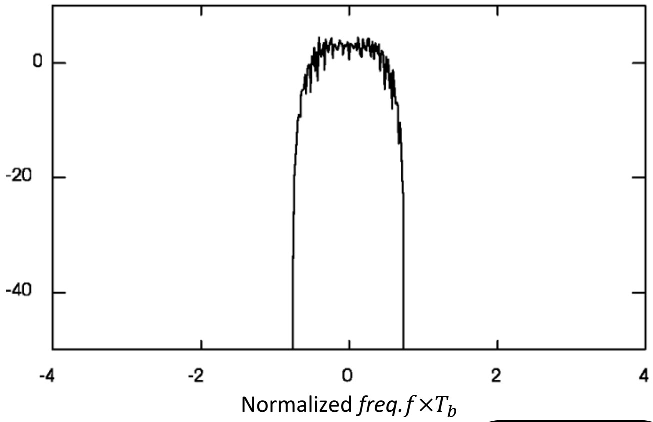
Binary phase-shift keying (BPSK) Raised-cosine pulses (roll-off 0.5)

Power spectral density for BAM



Contained percentage of total energy	spectral efficiency
90%	$1.02 Bit/s/Hz$
99%	$0.79 Bit/s/Hz$

Much higher spectral efficiency than BPSK (with rectangular pulses).

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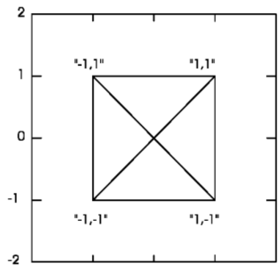
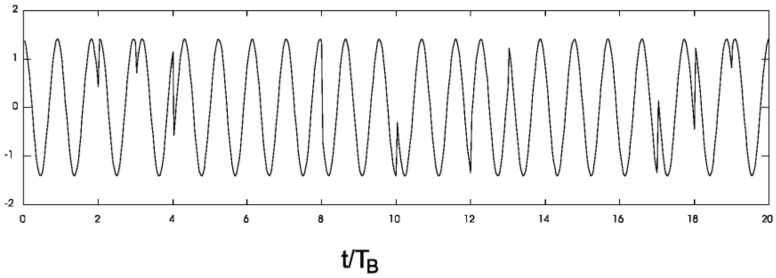
Quaternary PSK (QPSK or 4-PSK) Rectangular pulses

Complex representation

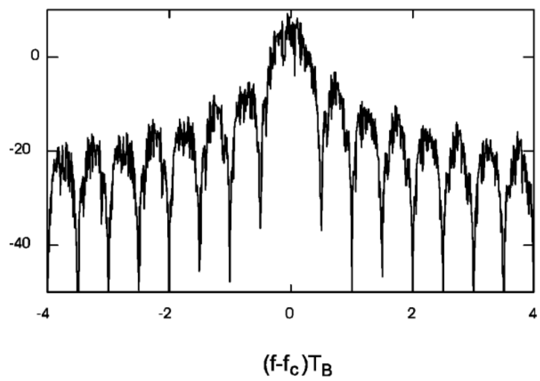


Radio signal



Quaternary PSK (QPSK or 4-PSK) Rectangular pulses

Power spectral density for QPSK

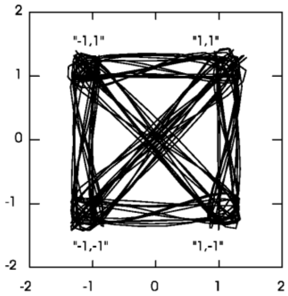


Contained percentage of total energy	spectral efficiency
90%	$1,18 Bit/s/Hz$
99%	$0.10 Bit/s/Hz$

Twice the spectrum efficiency of BPSK (with rect. pulses). TWO bits/pulse instead of one.

Quadrature ampl.-modulation (QAM)
Root raised-cos pulses (roll-off 0.5)

Complex representation



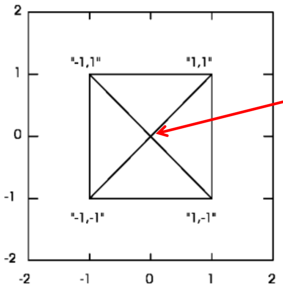
Contained percentage of total energy	spectral efficiency
90%	$2.04 Bit/s/Hz$
99%	$1.58 Bit/s/Hz$

Much higher spectral efficiency than QPSK (with rectangular pulses).

Amplitude variations
The problem

Signals with high amplitude variations leads to less efficient amplifiers.

Complex representation of QPSK

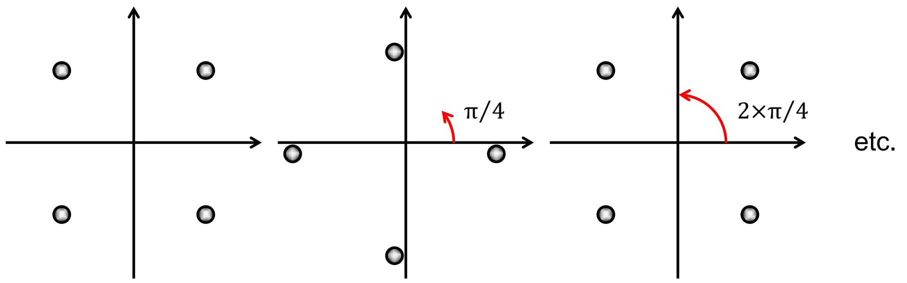


It is a problem that the signal passes through the origin, where the amplitude is ZERO.
(Infinite amplitude variation.)

Can we solve this problem in a simple way?

Amplitude variations
A solution

Let’s rotate the signal constellation diagram for each transmitted symbol!



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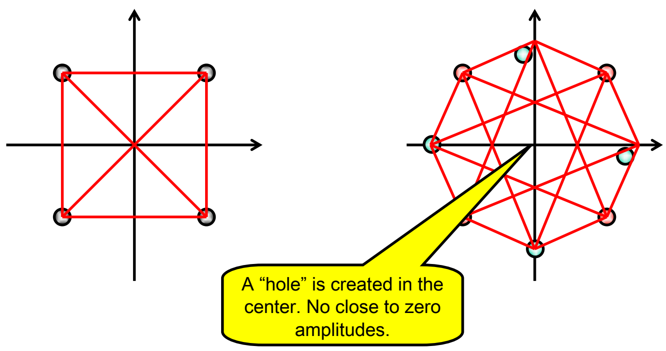
Amplitude variations
A solution

Looking at the complex representation ...

QPSK without rotation   QPSK with rotation



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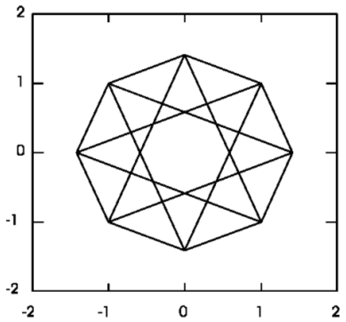
$\pi/4$- Differential QPSK (DQPSK)

Complex representation



Still uses the same rectangular pulses as QPSK - the power spectral density and the spectral efficiency are the same.

This modulation type is used in several standards for mobile communications (due to it's low amplitude variations).

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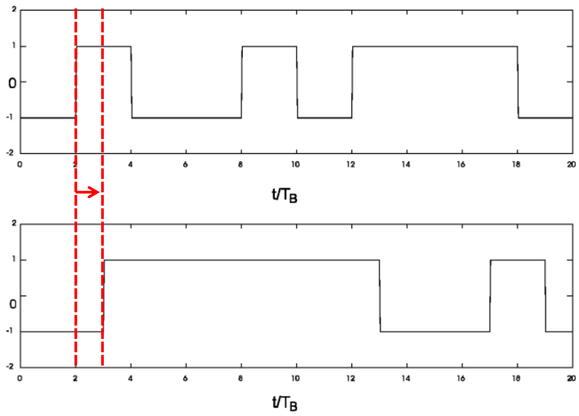
Offset QPSK (OQPSK) Rectangular pulses

In-phase signal

Quadrature signal



There is **one bit-time** offset between the in-pase and the quadrature part of the signal (a delay on the Q channel). This makes the transitions between pulses take place at different times!

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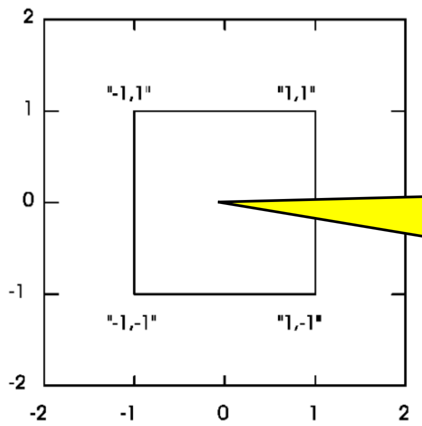
Offset QPSK
Rectangular pulses

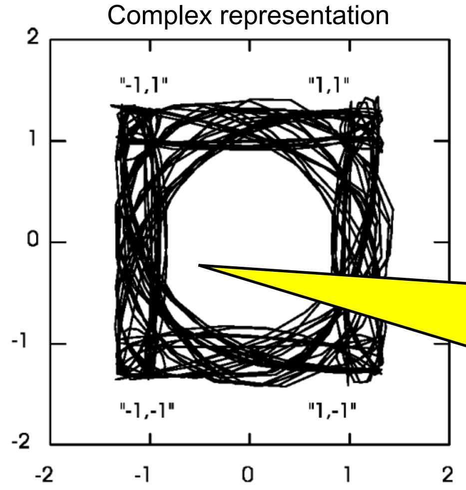
Complex representation



This method also creates a hole in the center, giving less amplitude variations.

Offset QAM (OQAM)
Raised-cosine pulses

Complex representation

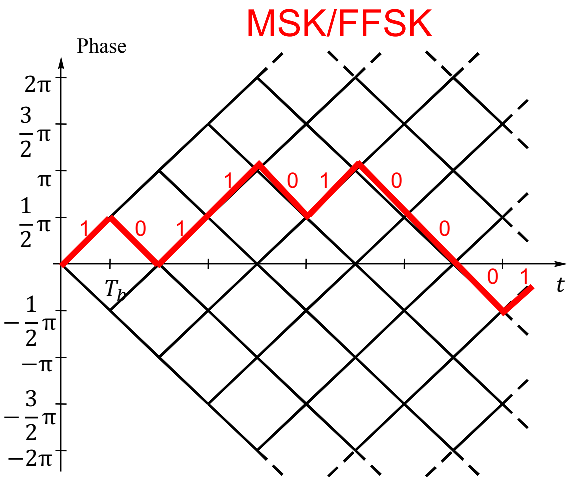


This method also creates a hole in the center, but has larger amplitude variations than OQPSK.

Continuous-phase modulation

Basic idea:
- Keep **amplitude constant**
- Change phase continuously

In this particular example we change the phase in a piecewise linear fashion by +/- $\pi/2$, depending on the data transmitted.



This type of modulation can be interpreted both as phase and frequency modulation. It is called **MSK** (minimum shift keying) or **FFSK** (fast frequency shift keying).

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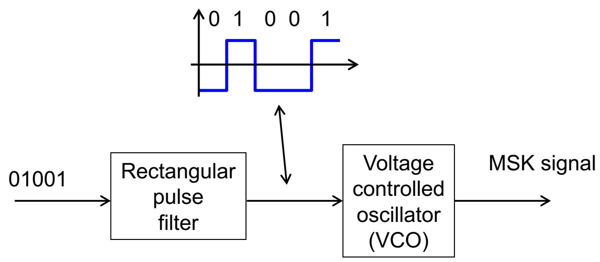
Minimum shift keying (MSK)

Simple MSK implementation



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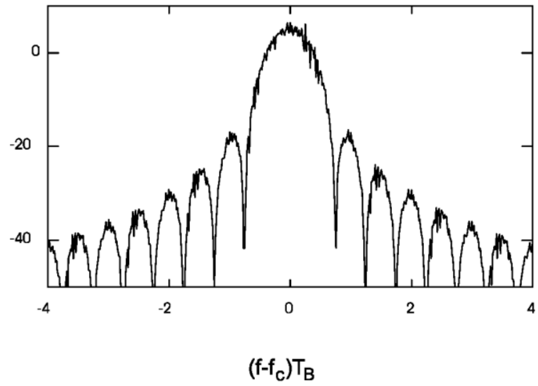
Minimum shift keying (MMSK)

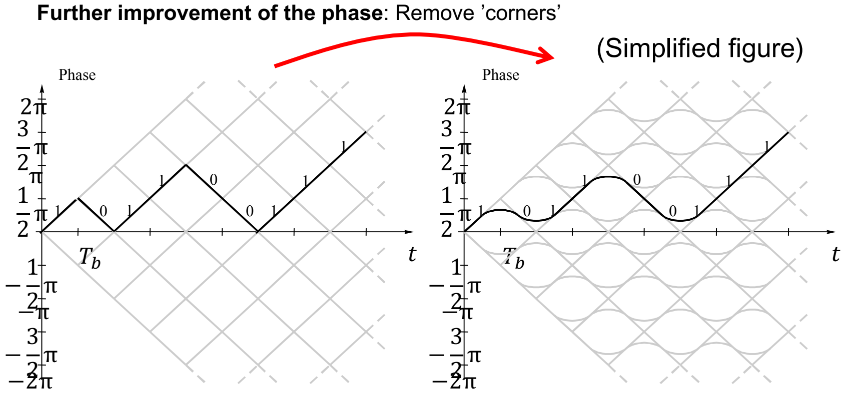
Power spectral density of MSK



Contained percentage of total energy	spectral efficiency
90 %	1,29 Bit / s / Hz
99 %	0,85 Bit / s / Hz

Gaussian filtered MSK (GMSK)

Further improvement of the phase: Remove 'corners'

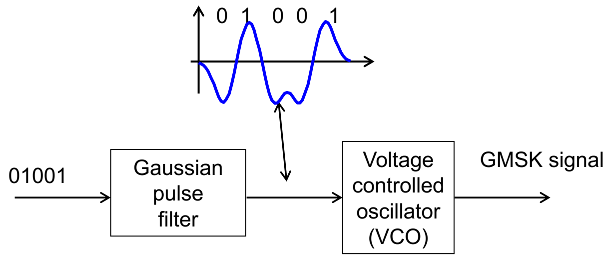


MSK
(Rectangular pulse filter)

Gaussian filtered MSK - GMSK
(Gaussian pulse filter)

Gaussian filtered MSK (GMSK)

Simple GMSK implementation

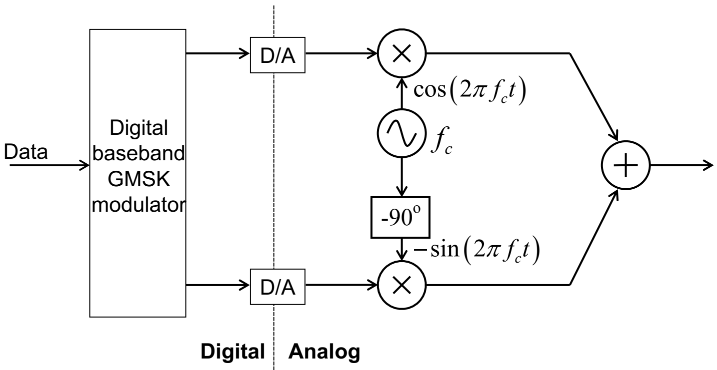


When implemented this "simple" way, it is usually called **G**aussian filtered frequency shift keying (GFSK).

GSFK is used in e.g. Bluetooth.

Gaussian filtered MSK (GMSK)

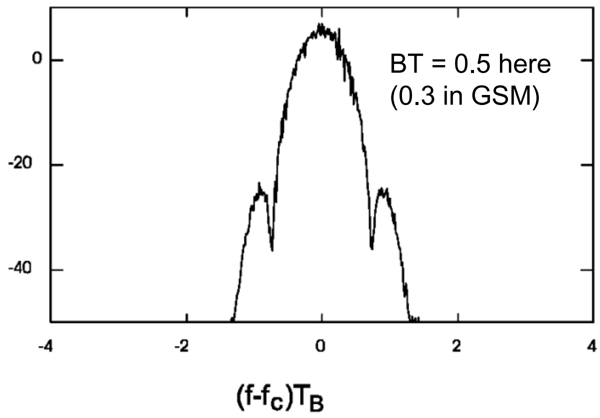
Digital GMSK implementation



This is a more precise implementation of GMSK, which is used in e.g. GSM.

Gaussian filtered MSK (GMSK)

Power spectral density of GMSK.



Contained percentage of total energy	spectral efficiency
90 %	1,45 Bit / s / Hz
99 %	0,97 Bit / s / Hz

How do we use all these spectral efficiencies?

Example: Assume that we want to use MSK to transmit 50 kbit/sec, and want to know the required transmission bandwidth.

Take a look at the spectral efficiency table:

Contained percentage of total energy	spectral efficiency
90 %	1,29 Bit / s / Hz
99 %	0,85 Bit / s / Hz

The 90% and 99% bandwidths become:

$$B_{90\%} = 50000/1.29 = 38.8 \text{ kHz}$$

$$B_{99\%} = 50000/0.85 = 58.8 \text{ kHz}$$

Summary

Modulation method	spectral efficiency for 90 % of total energy Bit / s / Hz	spectral efficiency for 99 % of total energy Bit / s / Hz
BPSK	0,59	0,05
BAM (α=0.5)	1,02	0,79
QPSK, OQPSK,	1,18	0,10
MSK	1,29	0,85
GMSK (B_G T= 0.5)	1,45	0,97
QAM (α = 0.5)	2,04	1,58

BPSK with root-raised cosine pulses → BAM (α=0.5)

TABLE 11.1 in textbook.

Another aspect:

802.11ax

- 4 – 1201 Mbit/s
- BPSK/QPSK/16-QAM/64-QAM/256-QAM/1024-QAM
- Coding rate ½, ¾, 2/3, 5/6,…
- Guard interval 800, 1600, 3200 ns
- Symbol duration 3.2, 6.4, 12.8 us
- OFDM
- MuMIMO
- Triggerbased random access, spatial frequency reuse,
- NAV, TWT, …