Shift Keying

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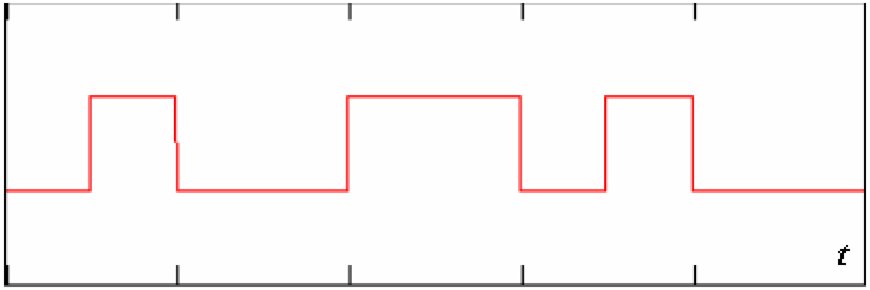
For the course "Communications"

ESKİŞEHİR OSMANGAZİ UNIVERSITY

Basic PAM

Binary 1 is represented by voltage A

Binary 0 is represented by voltage B

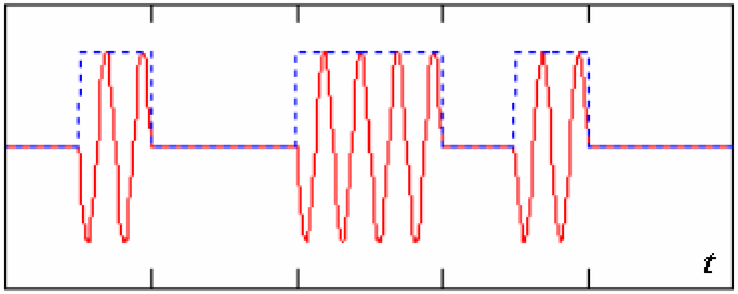


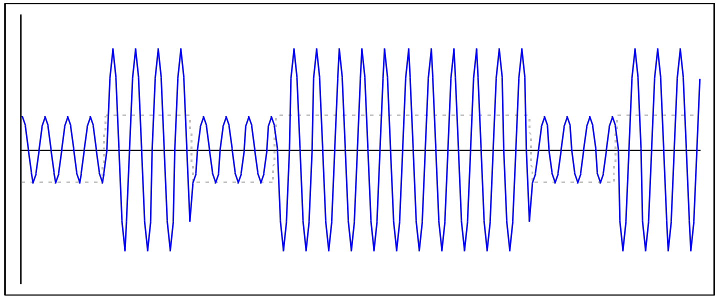
Amplitude Shift Keying (ASK)

Binary - ASK case

$$ASK(t) = x(t)\cos(2\pi f_c t)$$

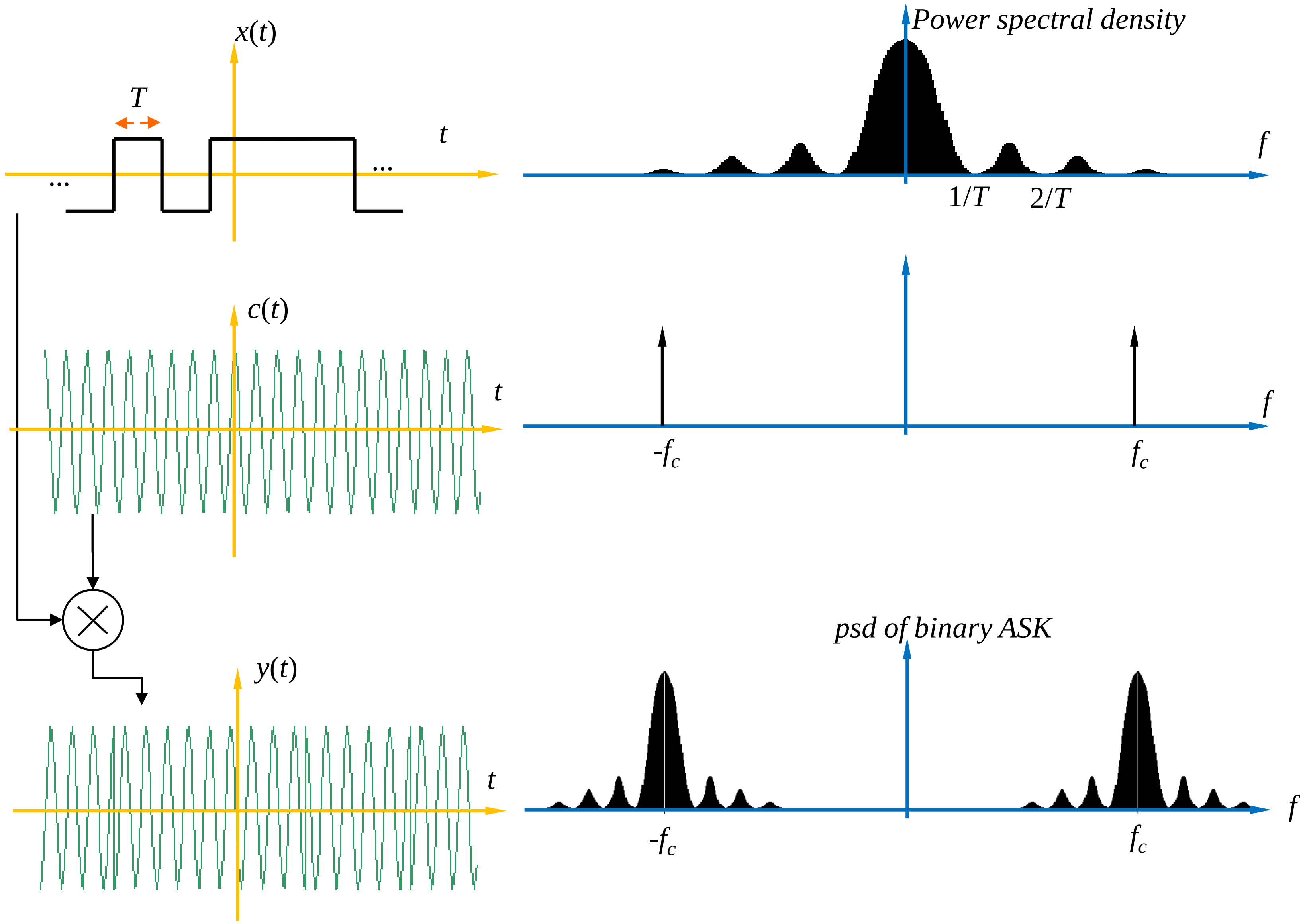
carrier



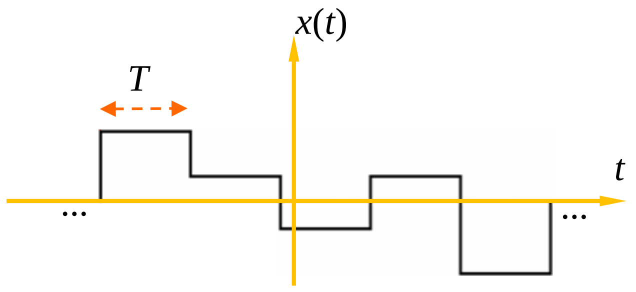


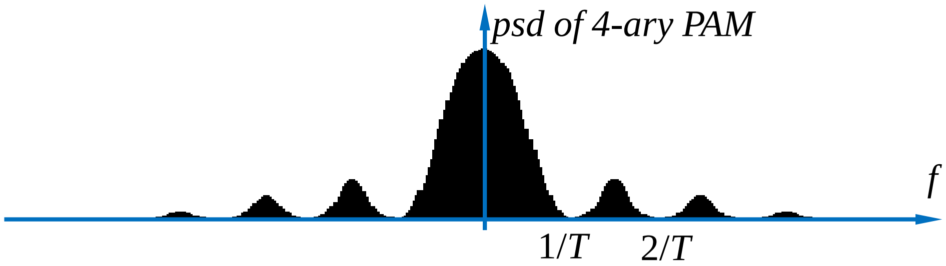
If A and B has opposite signs then there will be a phase jumps at bit-value changes

Spectrum of ASK

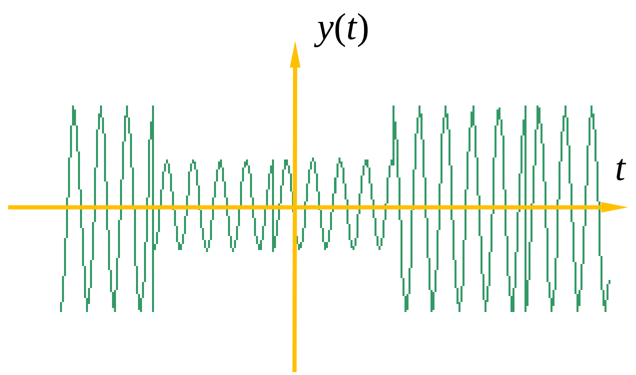


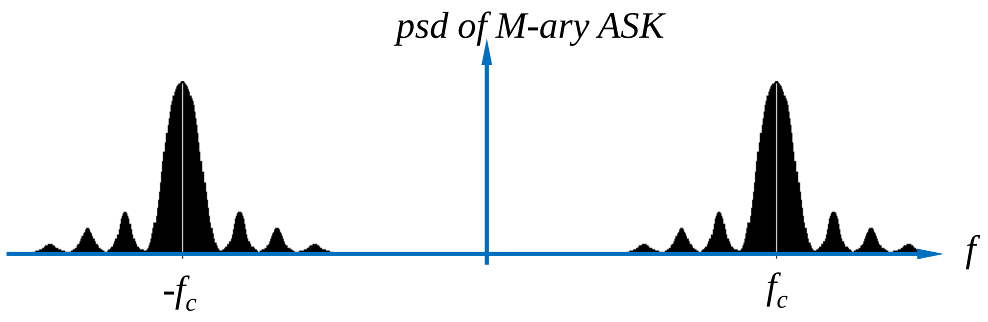
M=4





How? : 4-ary PAM can be thought of a sum of two 2-ary PAM





Same argument follows when $M=2^k$ (k:integer)

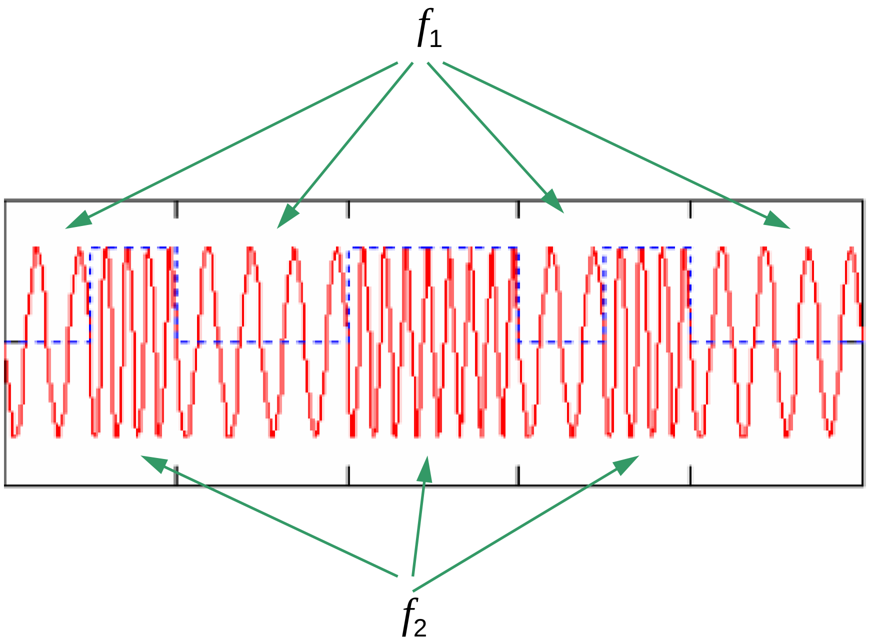
Frequency Shift Keying (FSK)

Use different frequency values (finite number of) instead of different amplitudes

Example : Binary FSK

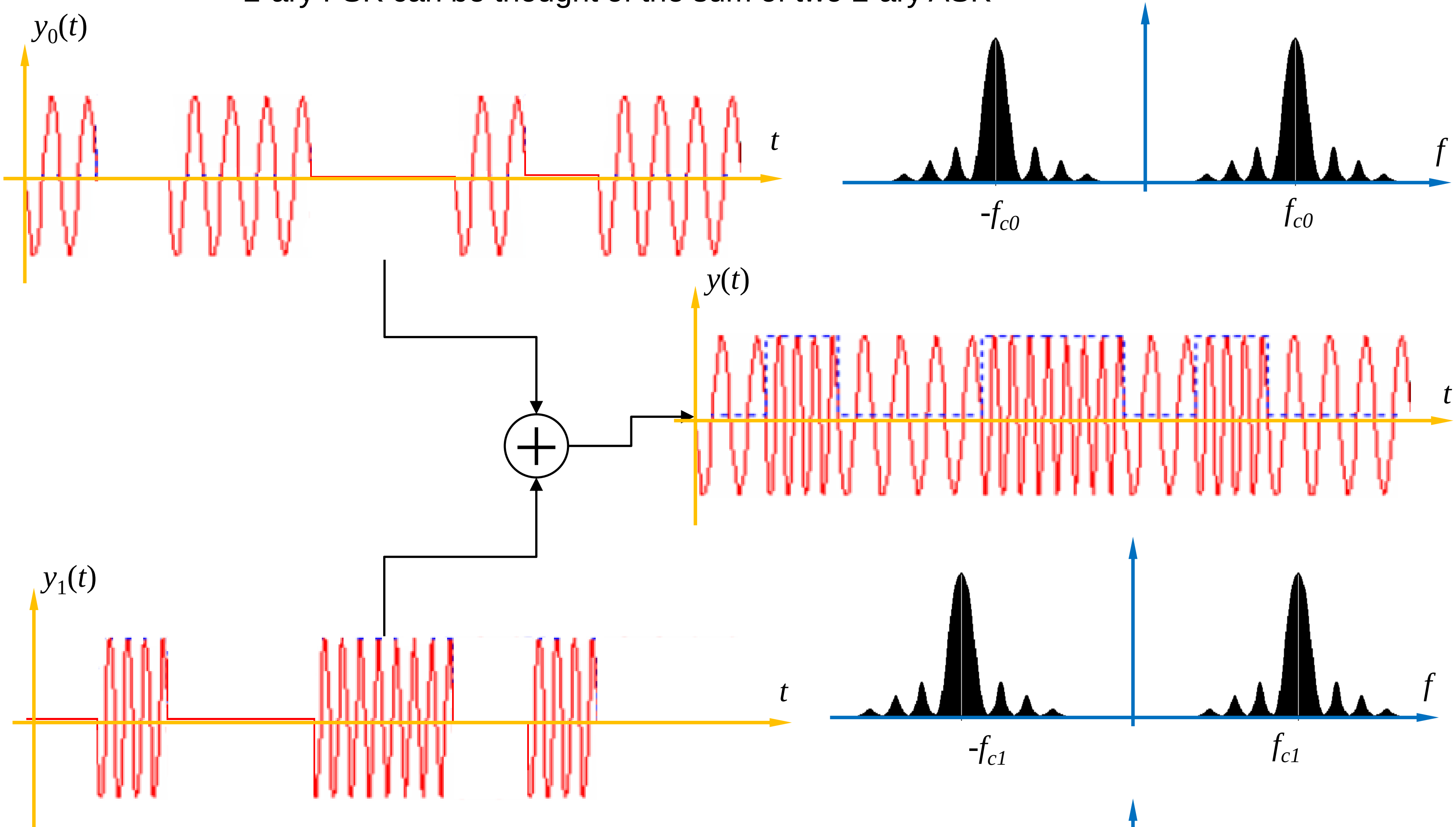
Binary 1 is represented by a sinusoid with frequency f_1

Binary 0 is represented by a sinusoid with frequency f_2

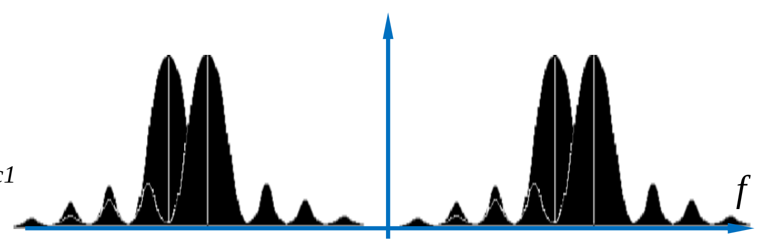


Note: Amplitude does not change, phase is not an issue

2-ary FSK can be thought of the sum of two 2-ary ASK



spectrum very much dependent on the choices of f_{c0} and f_{c1}

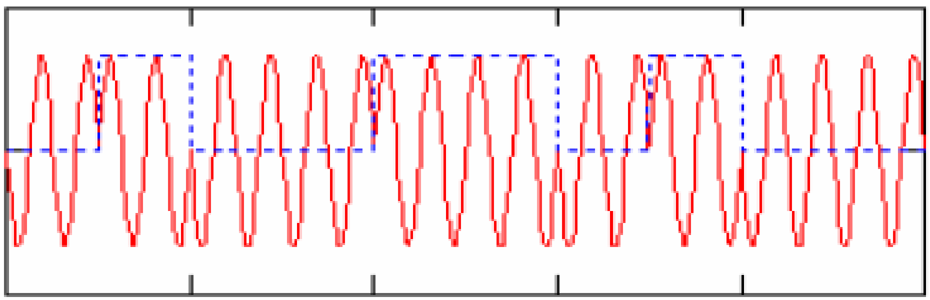


Phase Shift Keying (PSK)

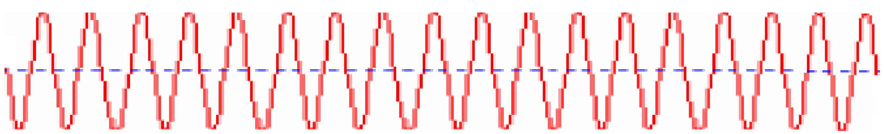
Use different phase values (finite number of), and we get PSK

Example : Binary PSK (BPSK)
Binary 1 is represented by a sinusoid with 0 phase
Binary 0 is represented by a sinusoid with phase π

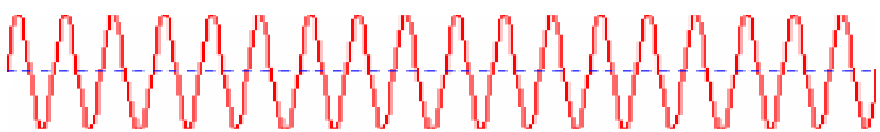
$$BPSK(t) = Acos(2\pi ft + \varphi + s(t))$$



$$s(t) = \begin{cases} 0 & for binary 0 \\ \pi & for binary 1 \end{cases}$$



Carrier with phase φ

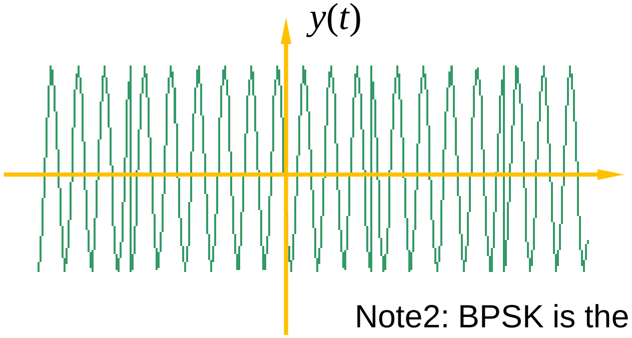


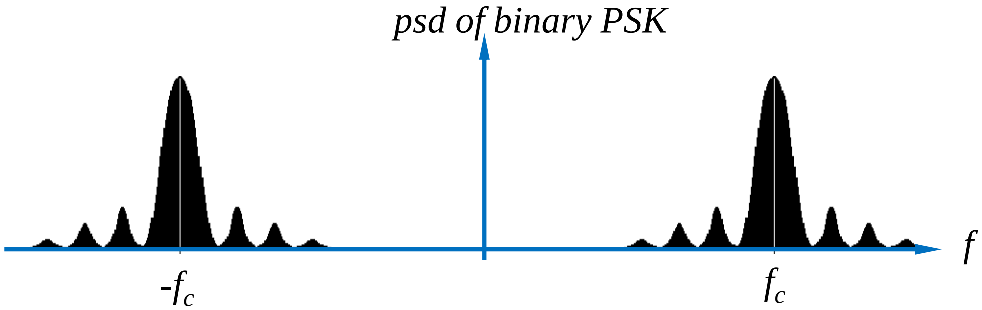
Carrier with phase $\varphi+\pi$

Note: Amplitude and frequency do not change

Note2: BPSK is the same as Binary ASK when amplitudes are $-A$ and $+A$

Spectrum of 2-ary PSK



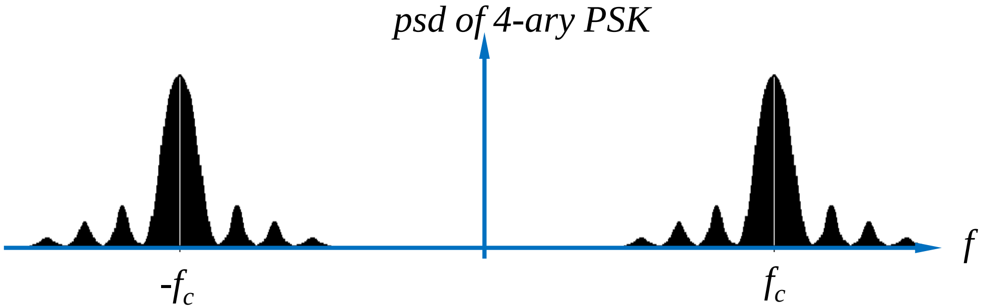


Note2: BPSK is the same as Binary ASK when amplitudes are $-A$ and $+A$

Spectrum of 4-ary PSK

That is, there are 4 phases ($\pi/2$ apart) instead of 2 (π apart)

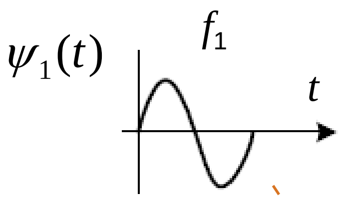
Think of 4-ary PSK as the sum of two 2-ary PSK and verify the following

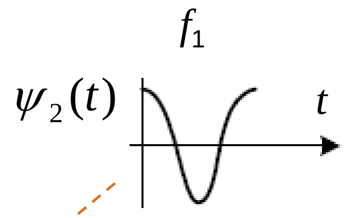


It seems that this sinc spectrum will always be with us in communication

Hmw : Check the spectrum of PSK of a general $M=2^k$ (k:integer)

Cosine and Sine are Orthonormal

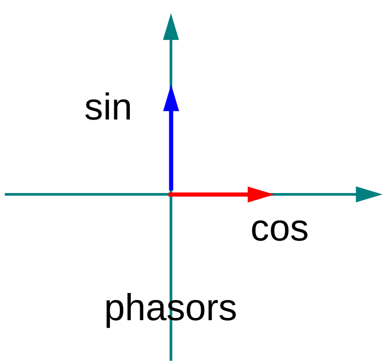


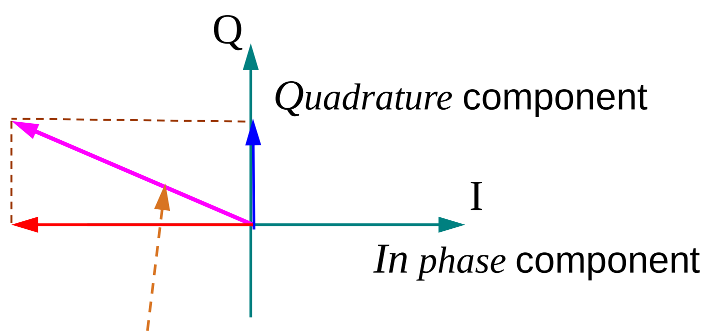


same frequencies

$$\int_{-\infty}^{\infty} \psi_1(t)\psi_2(t)dt = 0$$

A sinusoidal signal with any phase (at frequency f_1) can be obtained by a weighted sum of these basis waveforms $\psi_1(t)$ and $\psi_2(t)$

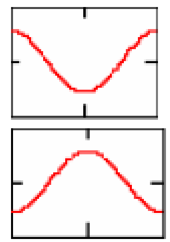


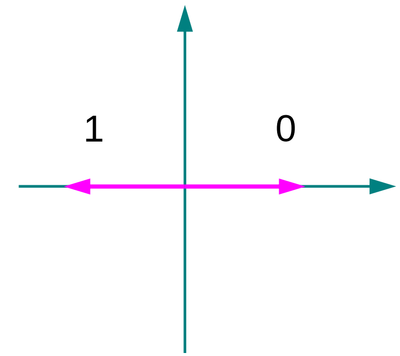


$$s(t) = -2\cos(2\pi f_1 t) + \sin(2\pi f_1 t)$$

BPSK

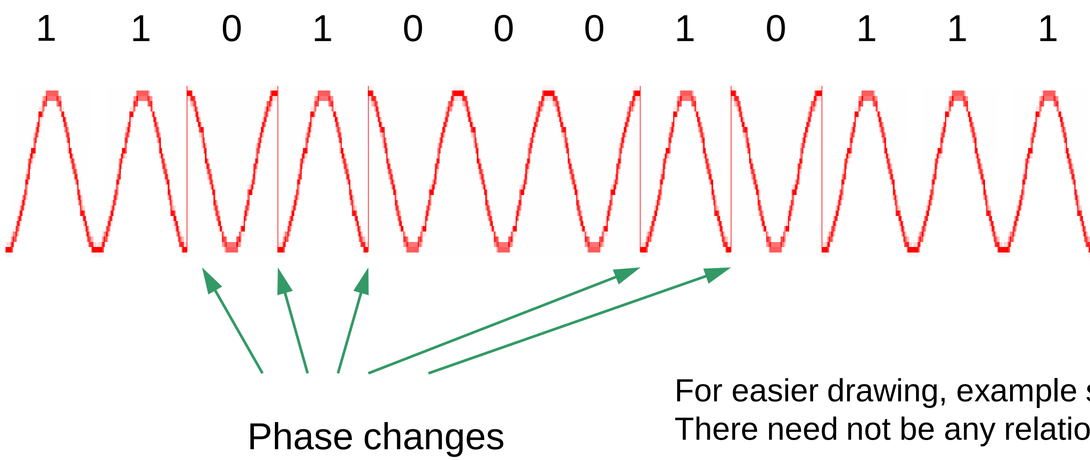
Symbol	Binary	Signal	I	Q
S1	0	$\cos(2\pi f_c t)$	1	0
S2	1	$\cos(2\pi f_c t + \pi)$	-1	0





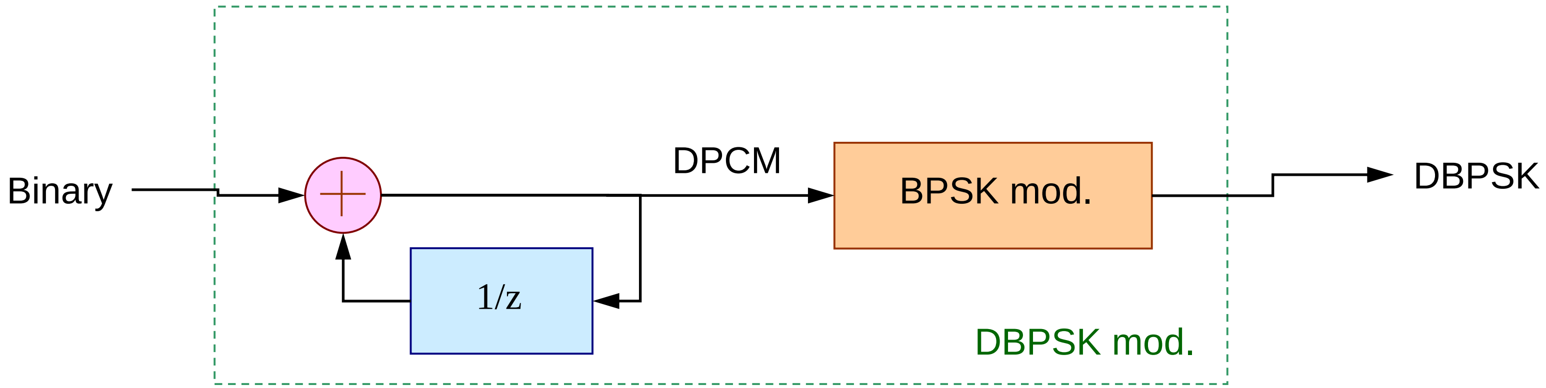
2D constellation diagram

A binary stream

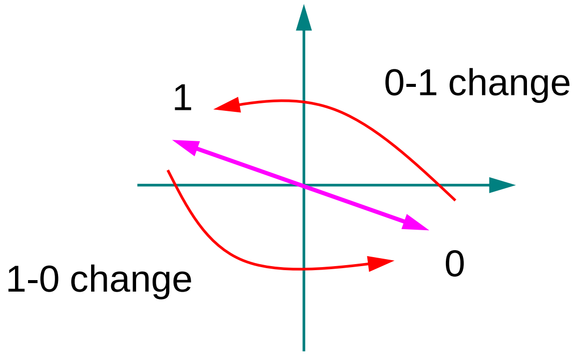


For easier drawing, example shows 1 carrier period per bit.
There need not be any relation between them.

Differential BPSK



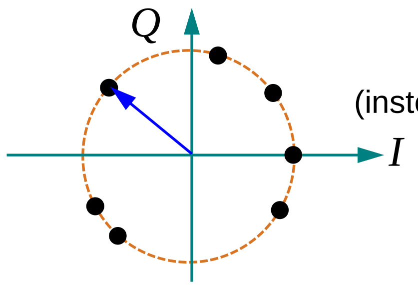
Advantage : Non-Coherent Detection is possible



Changes can be easily detected even when there is no reference carrier

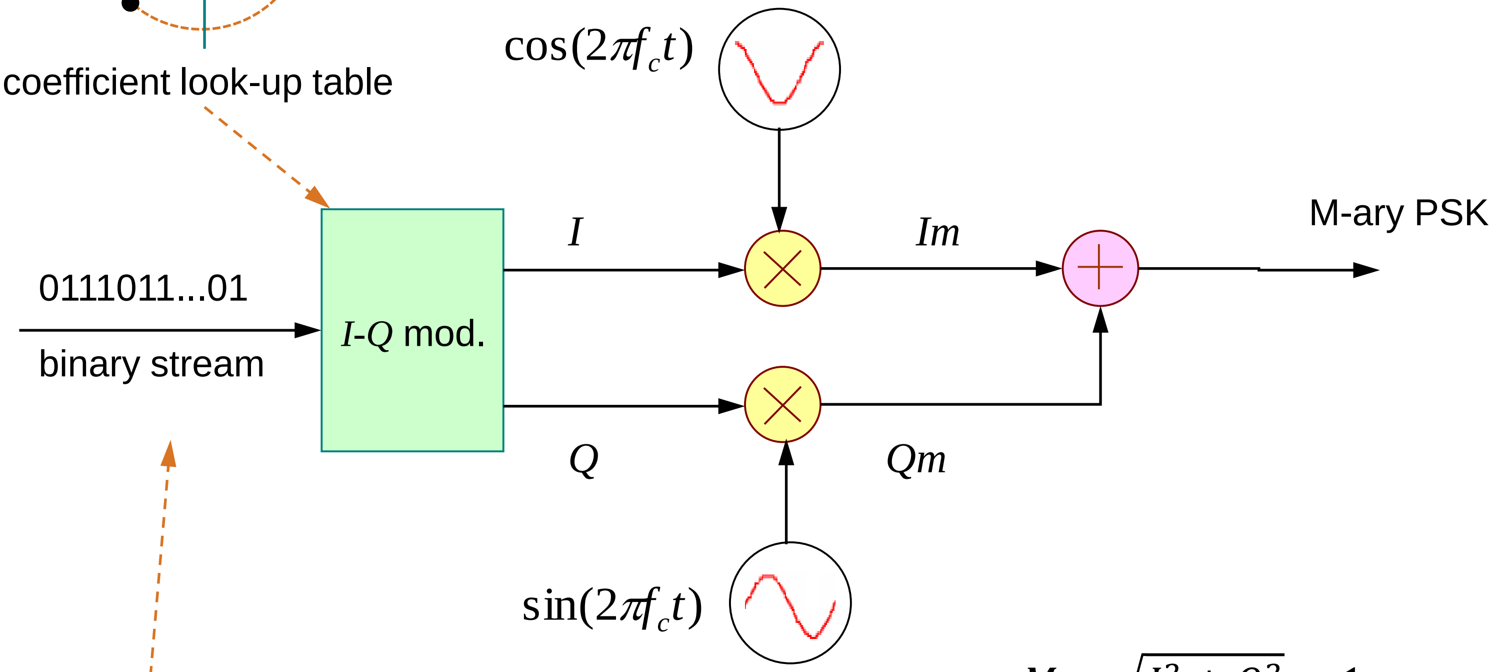
Disadvantage : A bit error affects detection of all remaining bits

Generation of M-PSK



(instead of vectors, we just use points at tip of the vectors)

coefficient look-up table

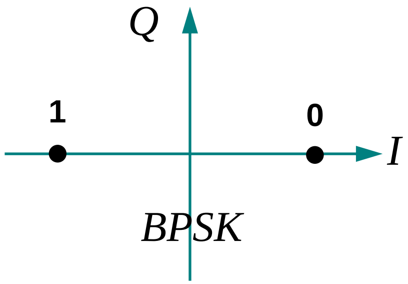


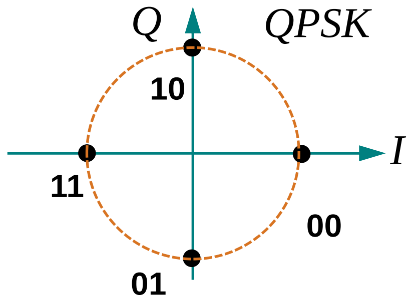
$$M = \sqrt{I^2 + Q^2} = 1$$

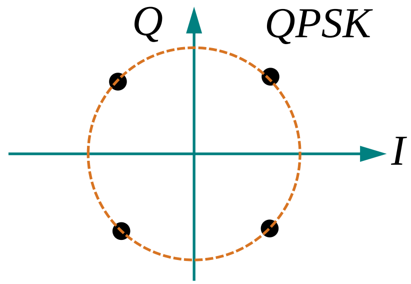
$$\varphi_i = \tan^{-1}\left(\frac{I}{Q}\right)$$

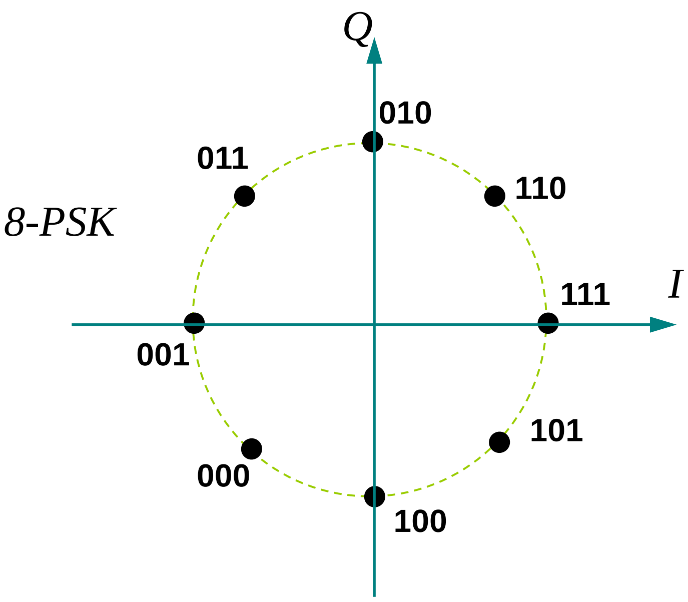
M=2^k k: number of bits in a symbol

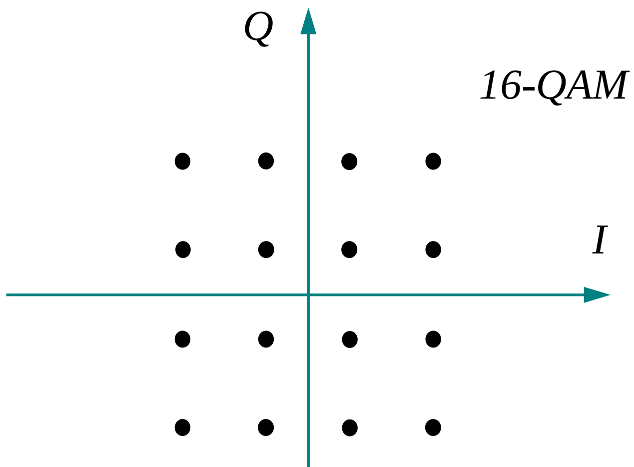
Remember the efficiency statement in the baseband receiver block diagrams







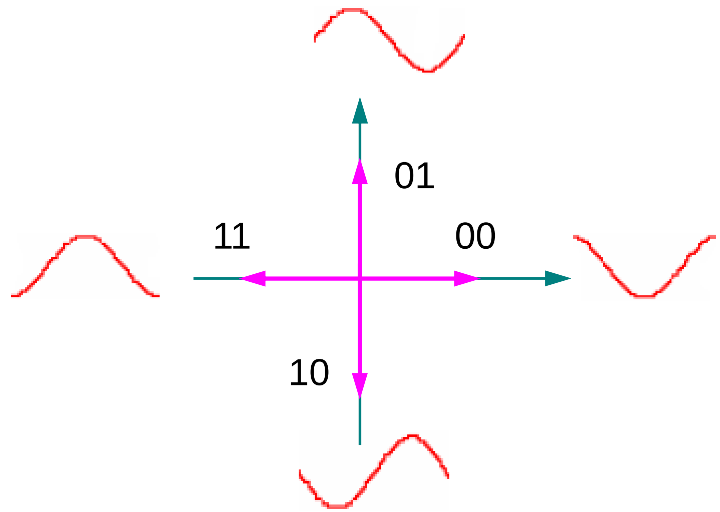


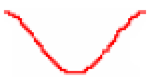
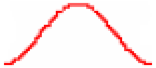
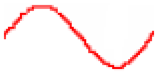
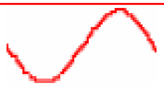


In QAM, both amplitude and phase are used to represent a symbol

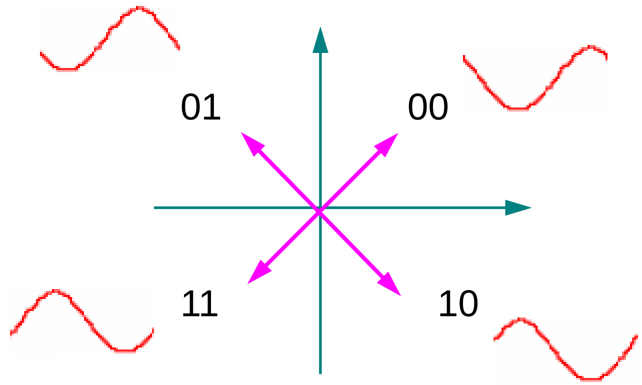
(to be continued)

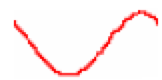
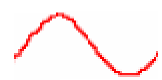
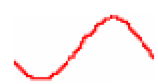
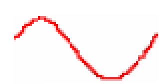
Quadrature PSK



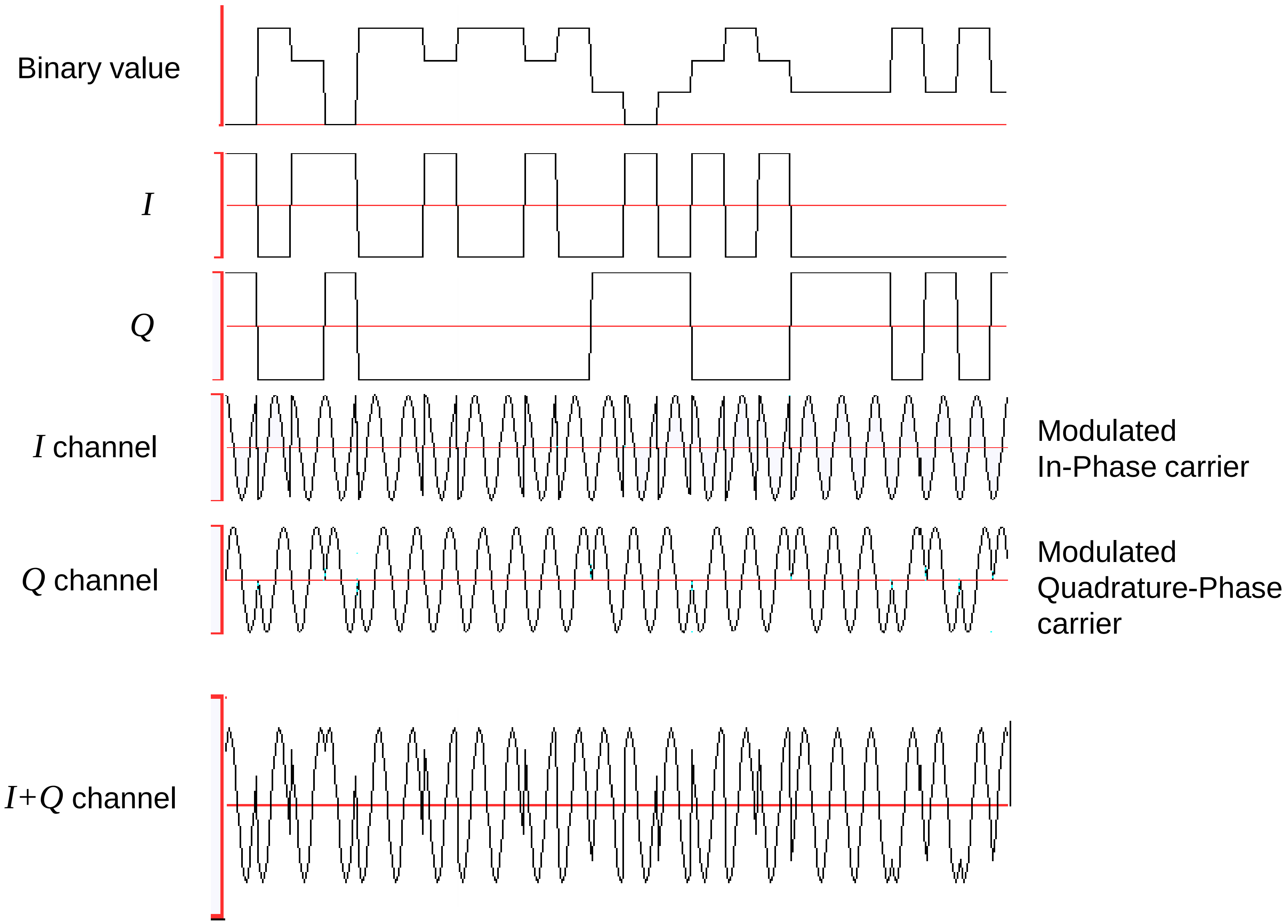
Symbol	Binary	Signal		I	Q
S1	00	$\cos(2\pi f_c t)$		1	0
S2	11	$\cos(2\pi f_c t + \pi)$		-1	0
S3	01	$\cos(2\pi f_c t + \pi / 2)$		0	1
S4	10	$\cos(2\pi f_c t - \pi / 2)$		0	-1

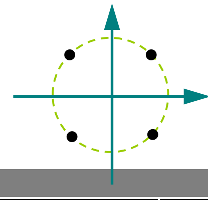
QPSK



Symbol	Binary	Signal		I	Q
S1	00	$\cos(2\pi f_c t + \pi / 4)$		0.707	0.707
S2	11	$\cos(2\pi f_c t + 5\pi / 4)$		-0.707	-0.707
S3	01	$\cos(2\pi f_c t + 3\pi / 4)$		-0.707	0.707
S4	10	$\cos(2\pi f_c t - 3\pi / 4)$		0.707	-0.707

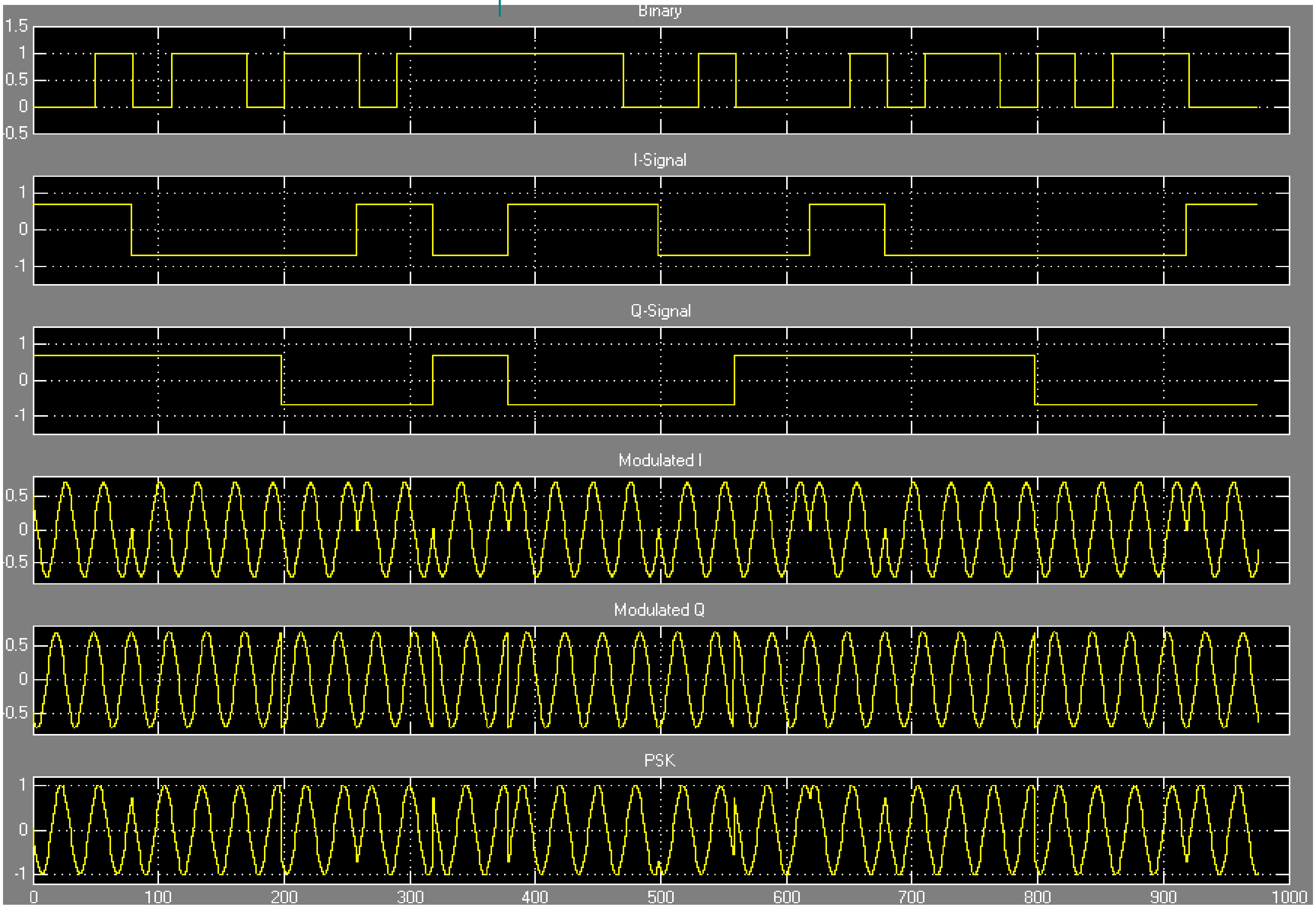
QPSK (sum of two BPSKs)

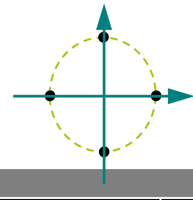




QPSK

```
Ir = [ 0.7071 -0.7071 -0.7071  0.7071 ]
Qr = [ 0.7071  0.7071 -0.7071 -0.7071 ]
```

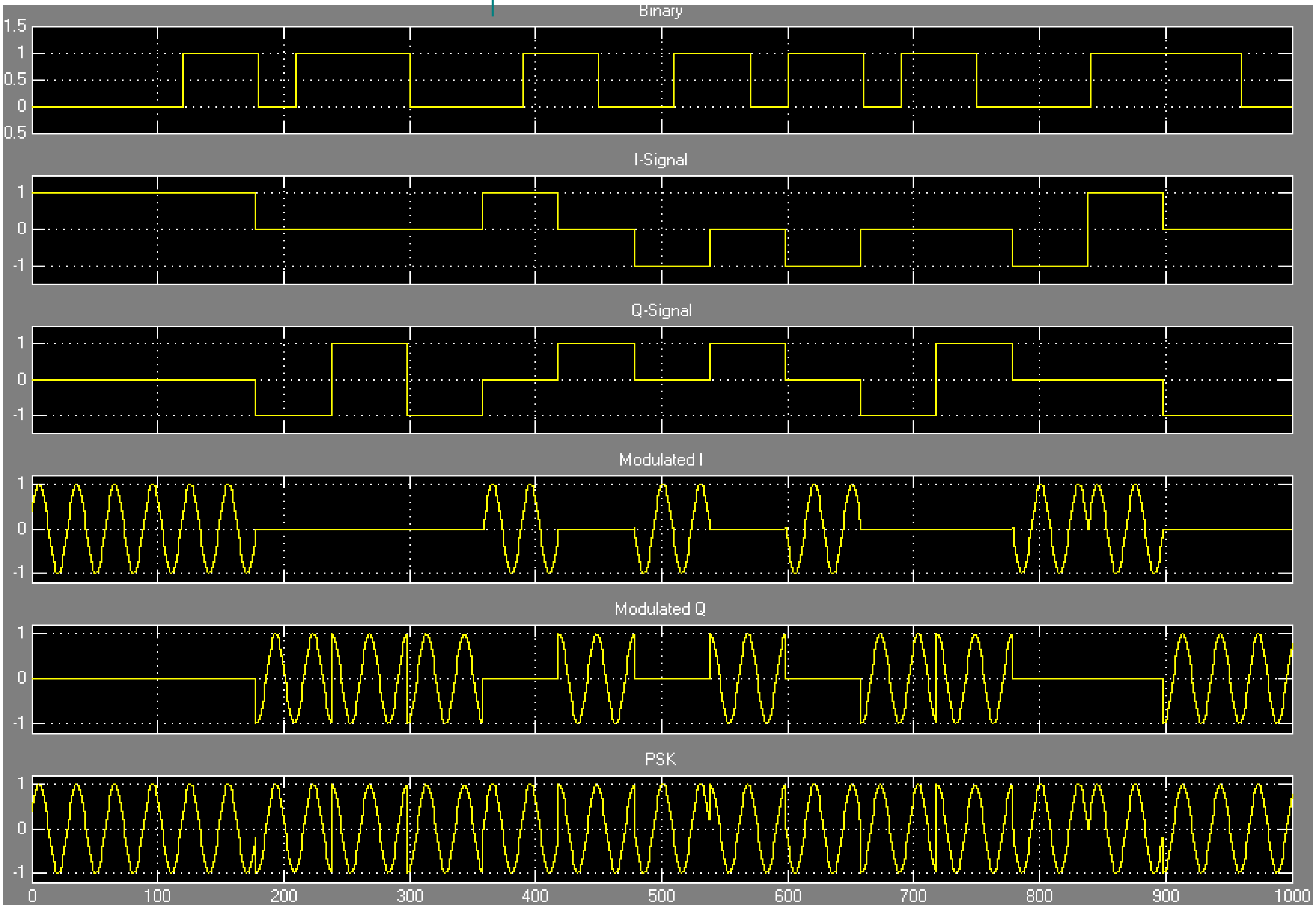




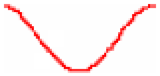
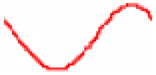
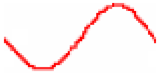
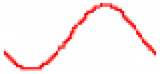
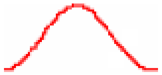
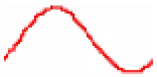
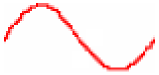
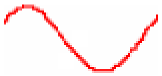
QPSK

Ir = [1 0 -1   0]

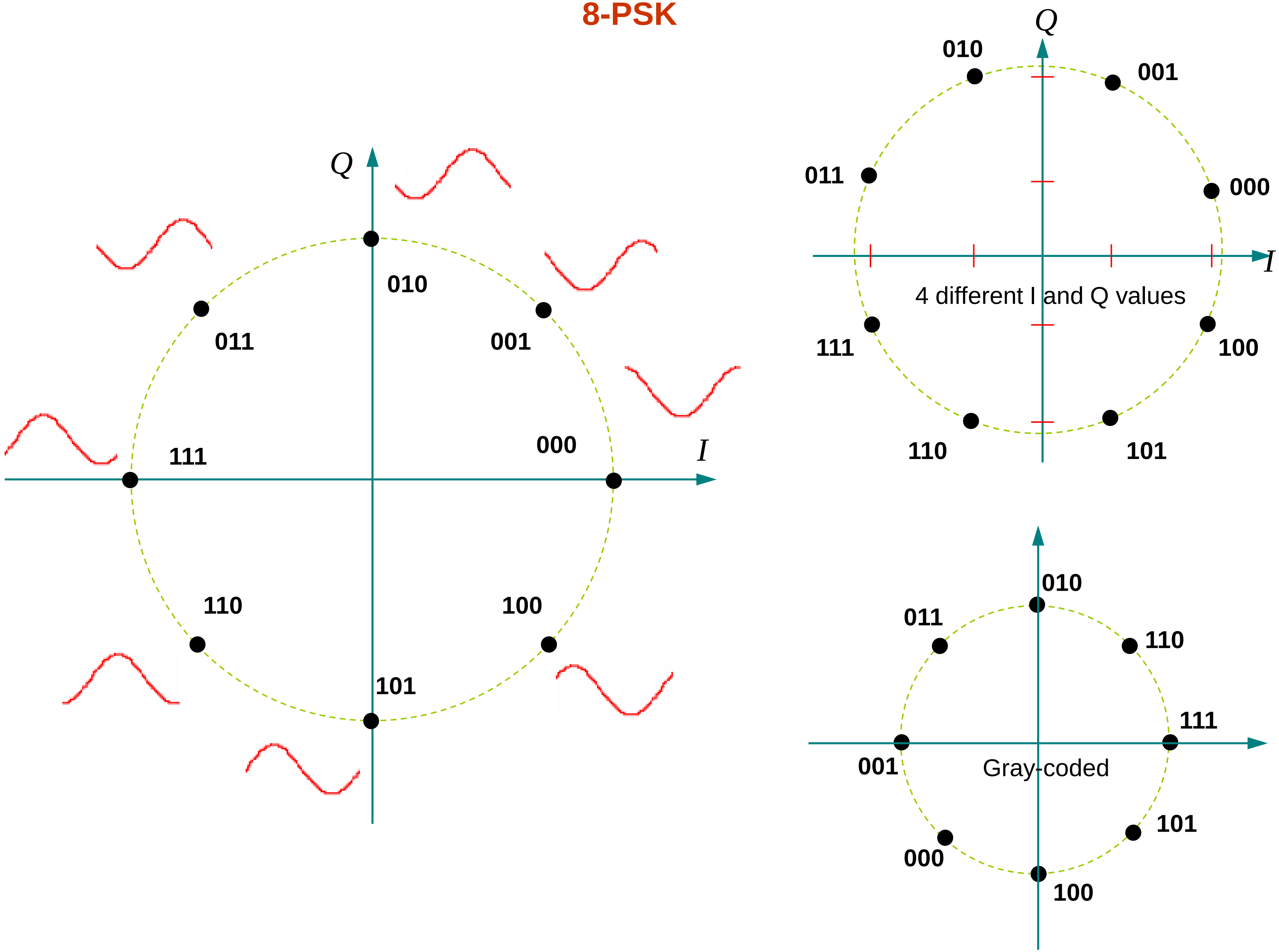
Qr = [0 1   0 -1]



8-PSK

Binary	Signal		I	Q
000	$\cos(2\pi f_c t)$		1	0
001	$\cos(2\pi f_c t + \pi / 4)$		0.707	0.707
011	$\cos(2\pi f_c t + \pi / 2)$		0	1
010	$\cos(2\pi f_c t + 3\pi / 4)$		-0.707	0.707
110	$\cos(2\pi f_c t + 5\pi / 8)$		-1	0
111	$\cos(2\pi f_c t + 7\pi / 8)$		-0.707	-0.707
101	$\cos(2\pi f_c t + 9\pi / 8)$		0	-1
100	$\cos(2\pi f_c t + 11\pi / 8)$		0.707	-0.707

8-PSK

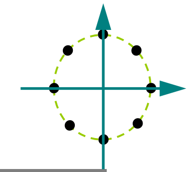


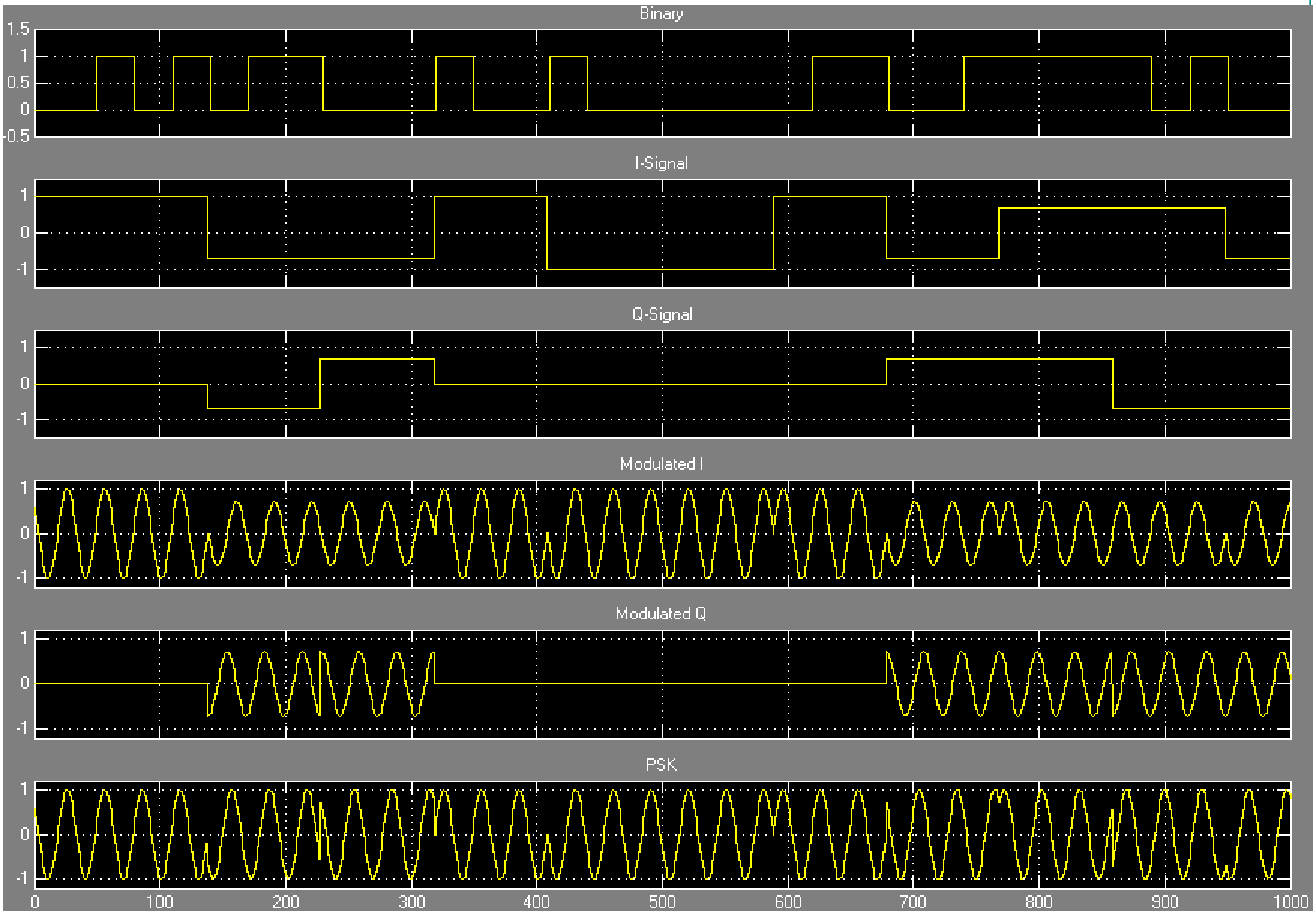
Q
I
010
001
011
000
111
110
100
101
Q
I
010
001
011
000
4 different I and Q values
111
100
110
101
010
011
110
111
001
Gray-coded
101
000
100

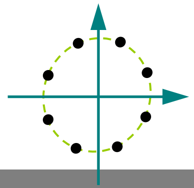
8-PSK

(bit assignments are different than shown in previous slide)

```
Ir = [1 0.7071 0 -0.7071 -1 -0.7071  0  0.7071 ]
Qr = [0 0.7071 1  0.7071  0 -0.7071 -1 -0.7071 ]
```

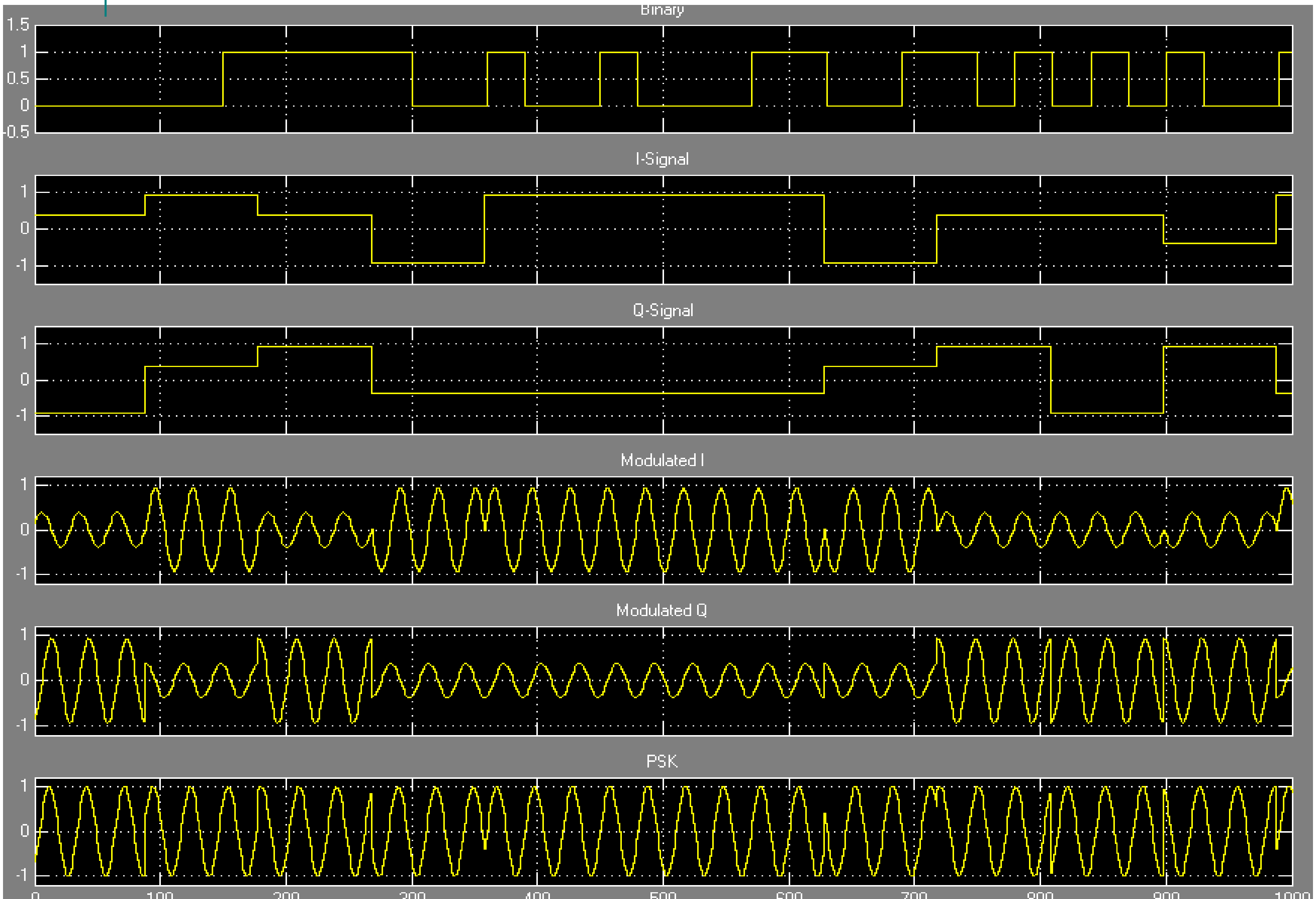






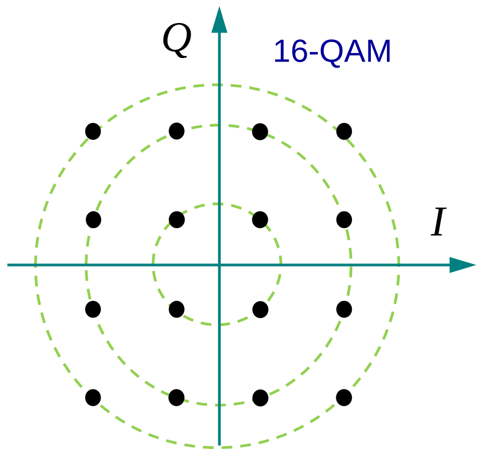
8-PSK

```
Ir = [0.9239 0.3827 -0.3827 -0.9238  0.9238  0.3827 -0.3827 -0.9238]
Qr = [0.3827 0.9238  0.9238  0.3827 -0.3827 -0.9238 -0.9238 -0.3827]
```



QAM

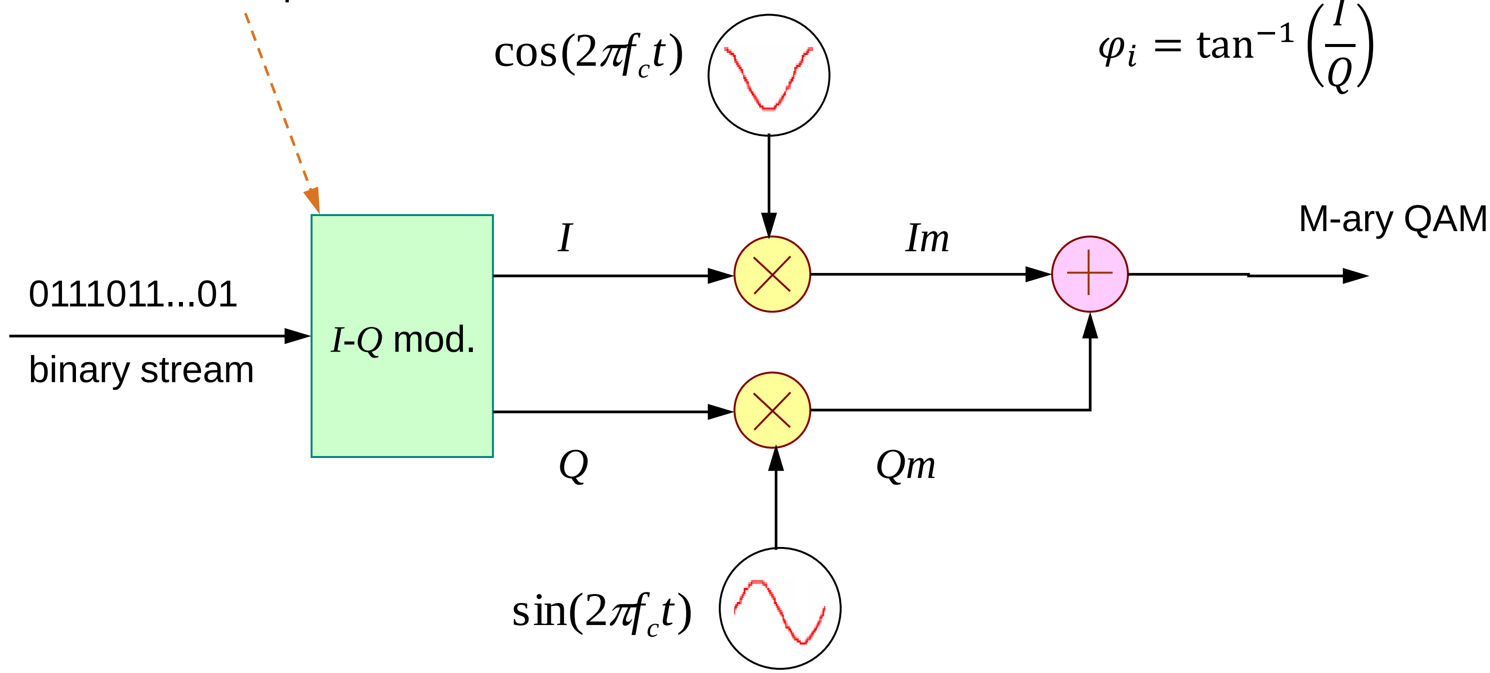
Both phase & amplitude are used



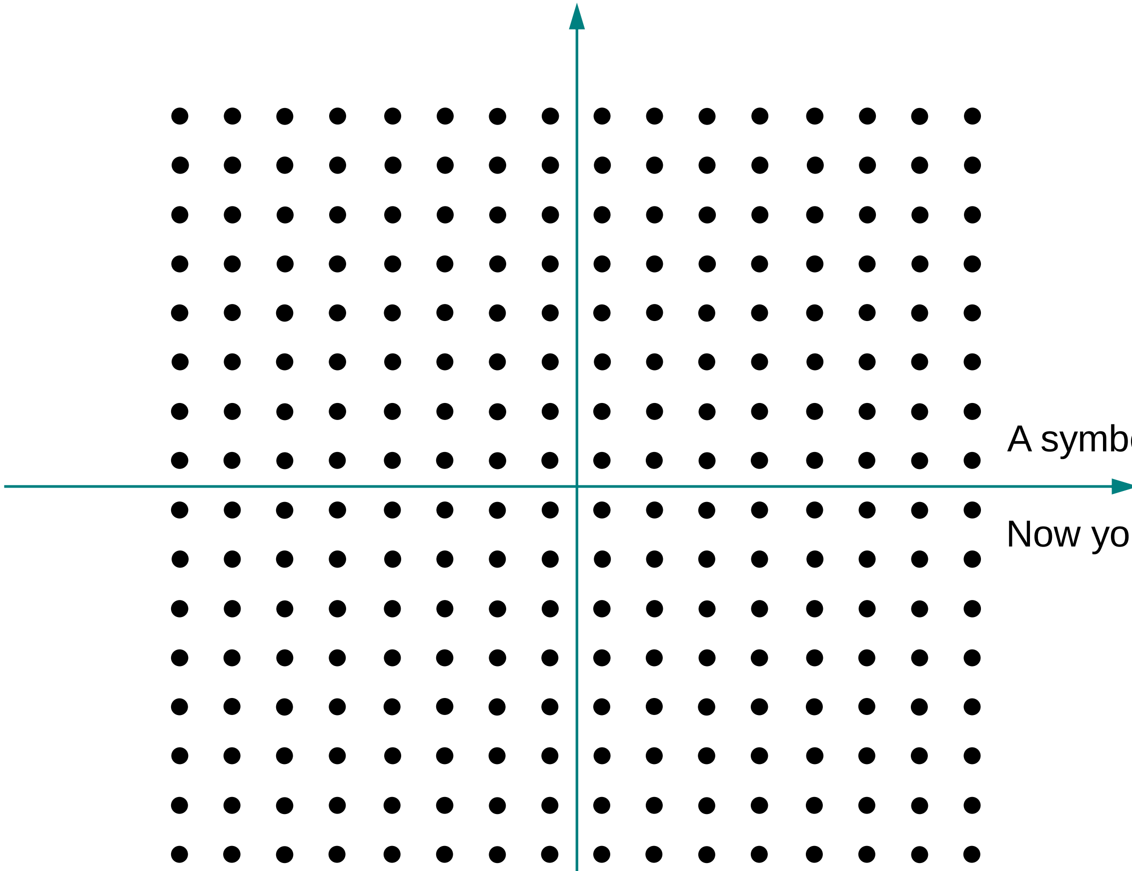
coefficient look-up table

$$A_i = \sqrt{I^2 + Q^2}$$

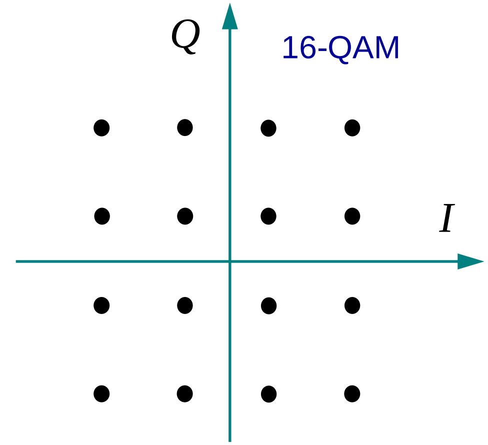
$$\varphi_i = \tan^{-1}\left(\frac{I}{Q}\right)$$



1024-QAM



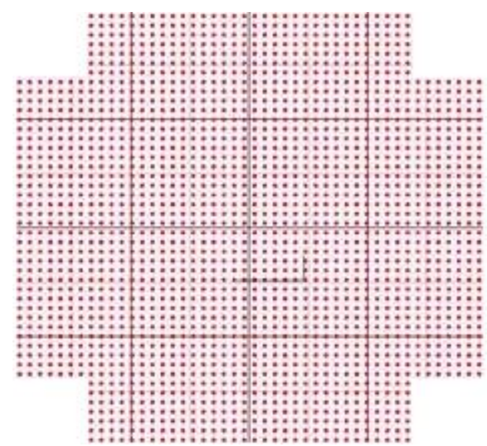
Spectrum is the same as BPSK. So, why not use 64536-QAM and transmit 16 bits with each symbol? Caveat : The receiver must distinguish each symbol, and symbols will be closer, unless the voltage is increased.



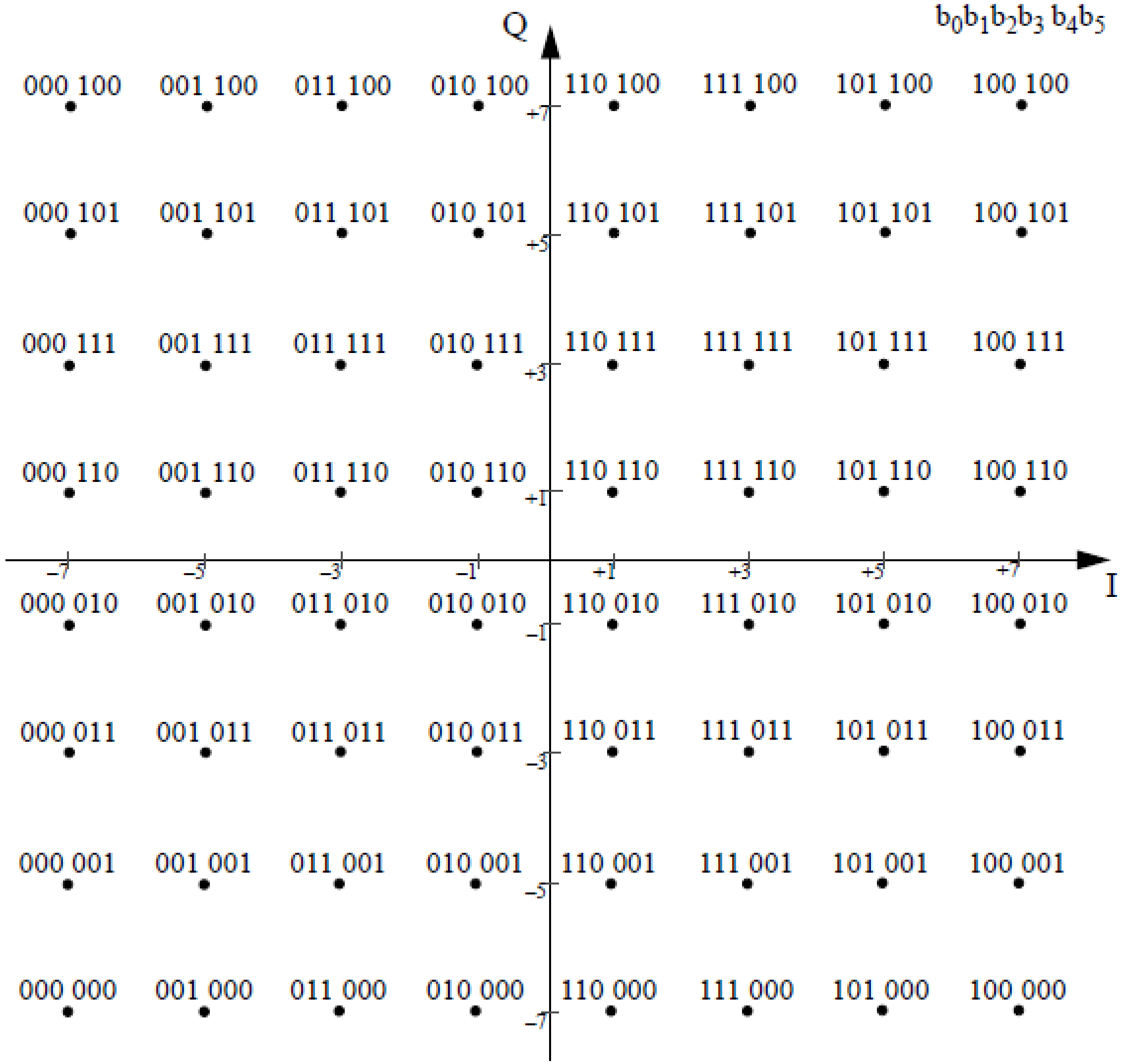
A symbol is 10 bits.

Now you know the sky is the limit.

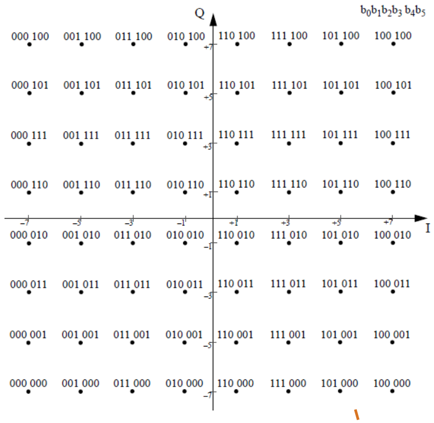
2048-QAM



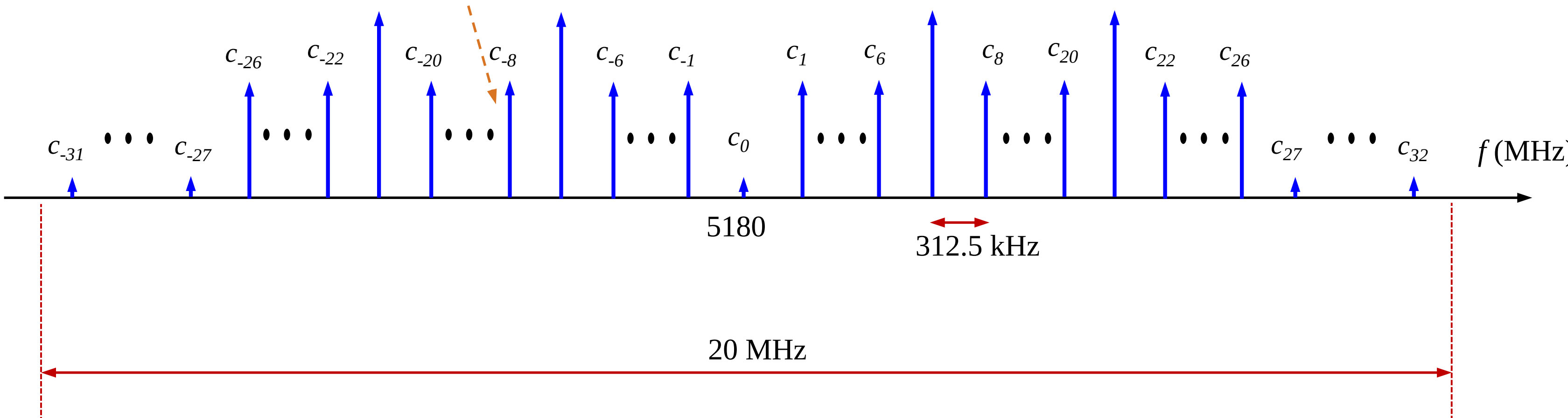
64-QAM (from IEEE-802.1a-1999)



Placement of 64 Carriers in IEEE-802.1a-1999)



48 carriers use BPSK, QPSK, 16-QAM or 64-QAM



How these signals are generated will be discussed in OFDM

END