Department of Communications Engineering, College of Engineering, University of Diyala

Digital Communication I

Lecture # 7

Digital Modulation Techniques

ASK, PSK, FSK, QPSK, DPSK, DEPSK, MSK, M-ary-FSK, M-ary-PSK, QAM, M-ary-QAM

Digital Modulation:

- provides **more information capacity**,
- High data security,
- Quicker system availability with great quality communication.
- Hence, digital modulation techniques have a greater demand, for their capacity to convey larger amounts of data than analog modulation techniques.

➢ There are many types of digital modulation techniques and their combinations, depending upon the need.

ASK – Amplitude Shift Keying

➢ The amplitude of the resultant output depends upon the input data whether it should be a **zero level** or a variation of positive and negative, depending upon the carrier frequency.

FSK – Frequency Shift Keying

➢ The frequency of the output signal will be either high or low, depending upon the input data applied.

PSK – Phase Shift Keying

The phase of the output signal gets shifted depending upon the input. These are mainly of two types, namely **B**inary **P**hase **S**hift **K**eying (**BPSK**) and **Q**uadrature **P**hase **S**hift **K**eying (**QPSK**), according to the number of **phase shifts**. The other one is **D**ifferential **P**hase **S**hift **K**eying (**DPSK**), which changes the phase according to the previous value.

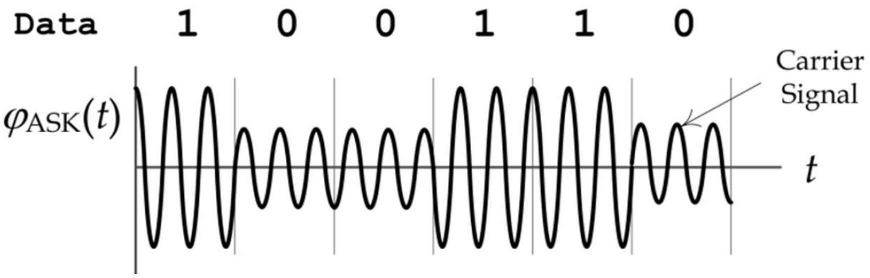
M-ary Encoding: *M*-ary Encoding techniques are the methods where more than two bits are made to transmit simultaneously on a single signal. This helps in the reduction of bandwidth.

The types of M-ary techniques are:-

1. M-ary ASK
2. M-ary FSK
3. M-ary PSK

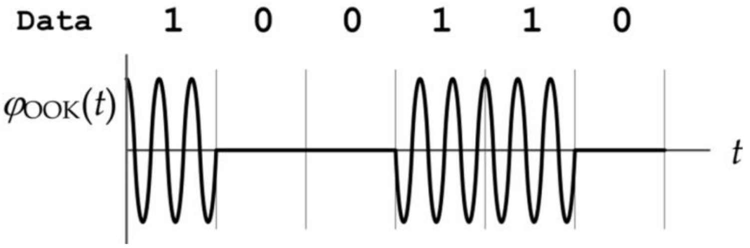
Amplitude-Shift Keying (ASK):

- ASK represents digital data *as variations in the amplitude of a carrier signal*.
- For example, the transmitter could send the carrier $2A\cos(\omega_c t)$ to represent a logic **1**,
- While using the carrier $A\cos(\omega_c t)$ to represent logic **0**.
- This is shown in the diagram below.
- The receiver detects the amplitude of the carrier to recover the original bit stream.

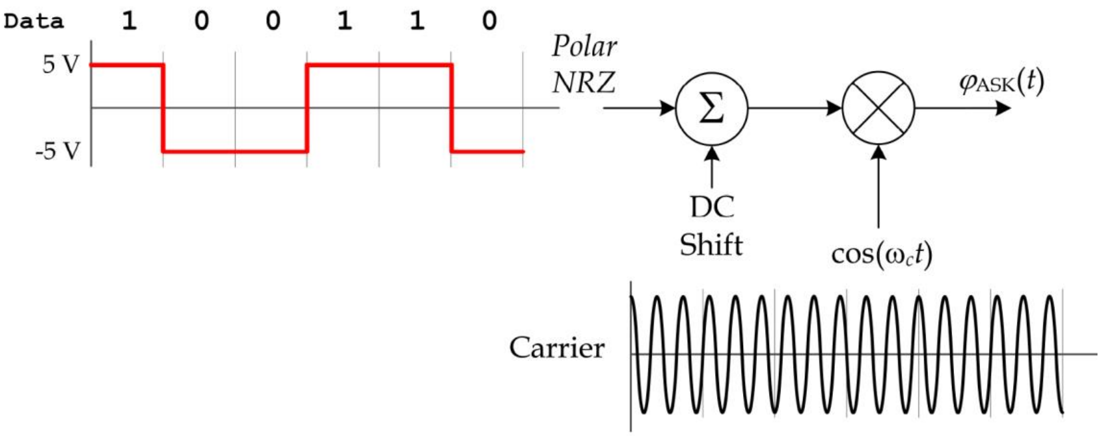


A special case of ASK is when a logic **1** is represented by $A\cos(\omega_c t)$ (i.e., the presence of a carrier) and a logic 0 is represented by a zero voltage (i.e., the absence of a carrier).

This special case is called **O**n-**O**ff **K**eying (**OOK**) and is shown below.

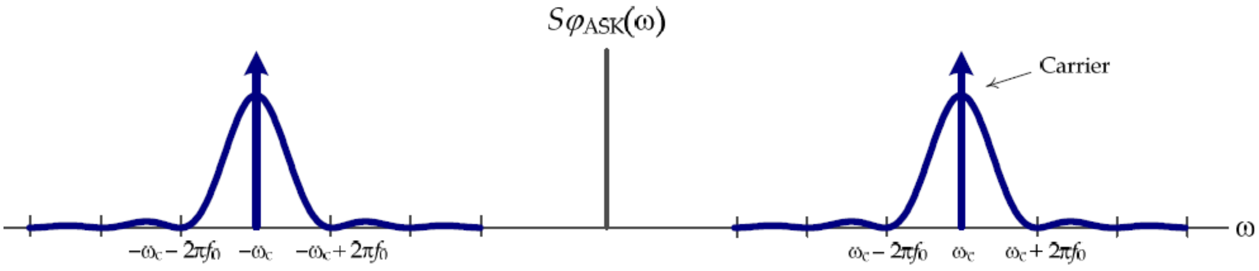


Notice that you can visualize ASK as the process of Amplitude Modulation (AM) using a "Polar NRZ" digital baseband message signal. In other words, we say that ASK is the result of multiplying a binary Polar NRZ signal $m(t)$ (with appropriate DC shift) times a sinusoidal carrier. This is shown in the diagram below:



- In addition, since **ASK** is a special case of AM modulation, **the bandwidth of ASK is $2B$** centered around the carrier frequency ω_c, where B is the bandwidth of the Polar NRZ signal.
- Since the bandwidth of Polar NRZ is equal to the data bit rate (f_0) of the bit stream to be sent, the **bandwidth of ASK is $2f_0$ (Hz)**.

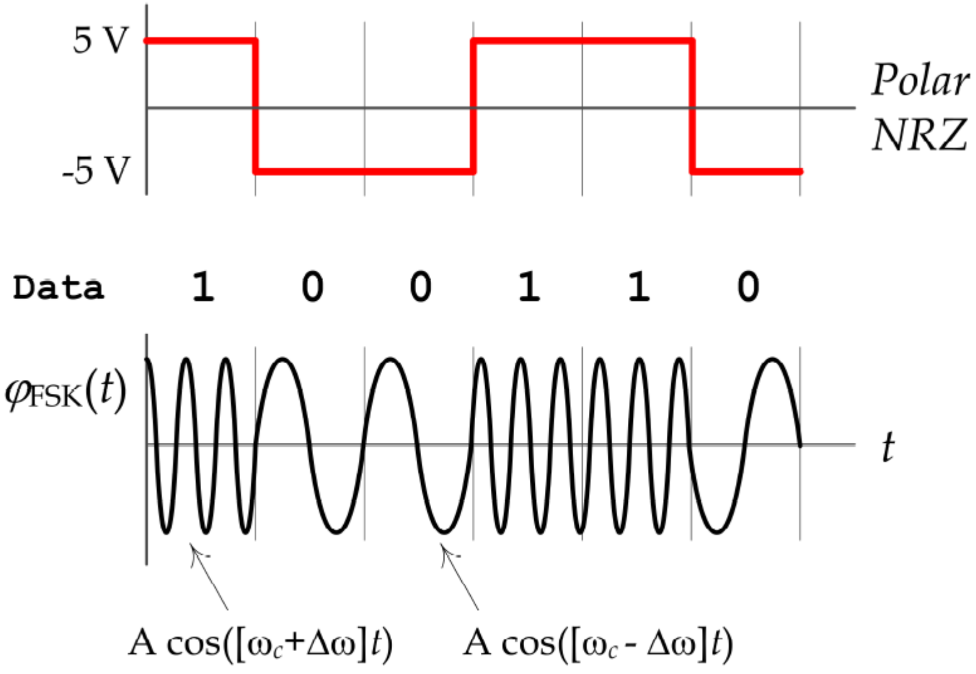
➢ The following is a sketch of the **PSD for an ASK signal**



Advantages	Disadvantages
• ASK is the simplest kind of modulation to generate and detect.	• It can be used only when the signal-to-noise ratio **(SNR) is very high**. • Its bandwidth is too big (equals **2f_0**).

Frequency-shift keying (FSK):

In FSK the instantaneous frequency of the carrier signal is shifted between two possible frequency values termed the mark frequency (representing a logic **1**) and the space frequency (representing a logic **0**). This is shown in the diagram below.



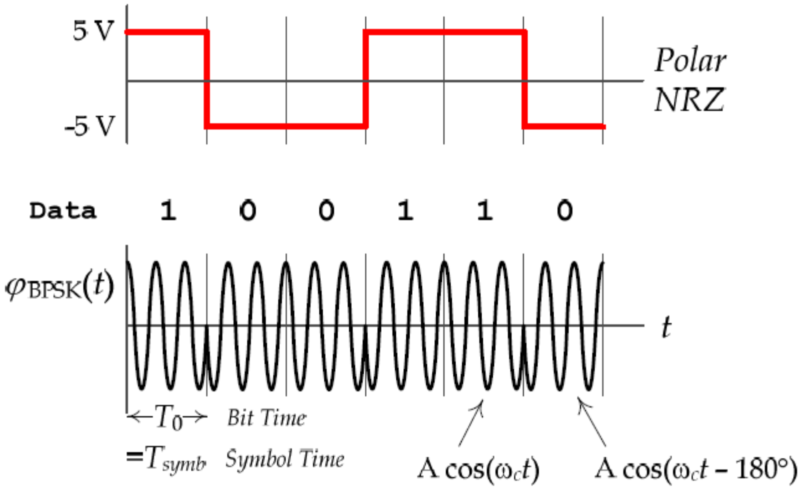
- Since **FSK** is a special case of FM modulation, the **bandwidth of FSK** is given by *Carson's rule* which says that $B_{FN} \approx 2\Delta f + 2B$, where B is the bandwidth of the Polar **NRZ** signal (equal to f_0 (*the bit rate*)).
- Hence, the bandwidth of **FSK** is $2\Delta f + 2f_0$ (Hz).
- In addition, all modulator and demodulator circuits for FM are still applicable for FSK.
- FSK has **several advantages over ASK** due to the fact that *the carrier has a constant amplitude*.
- These are the same advantages present in FM which include: immunity to non-linearities, immunity to rapid fading, immunity to adjacent channel interference, and the ability to exchange SNR for bandwidth.
- **FSK was used in early slow dial-up modems**.

Properties of FSK:

- Constant or non-constant envelope depends on filtering.
- Insensitive to channel fluctuations.
- Doppler and carrier phase error sensitive.
- Power efficient for the case of orthogonal M-FSK.
- Can be coherently and non-coherently detected.
- Currently most popular format.

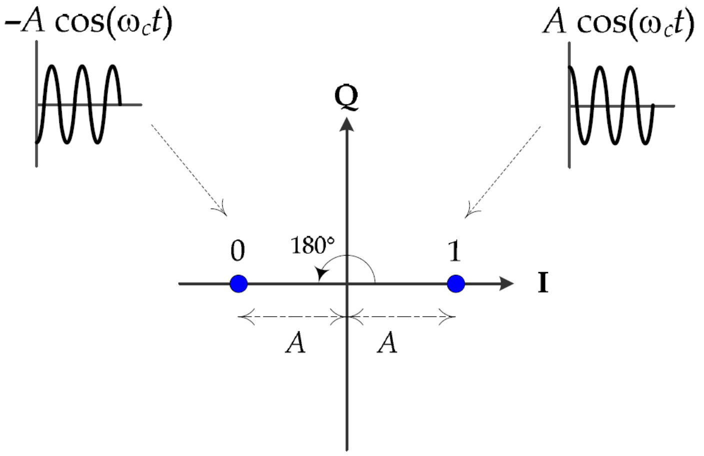
Phase-shift keying (PSK):

- In PSK, the data is conveyed by changing the phase of the carrier wave.
- One possible representation (called **B**inary **P**hase-Shift **K**eying or **BPSK**) is to send
  - **logic 1 as a cosine signal *with zero phase shift*** and a
  - **logic 0** as a **cosine signal but with a *180° phase shift***.
- We say in this case that the BPSK signal can assume one of two possible symbols: **0°** and **180°**. This case is shown in the following Figure.

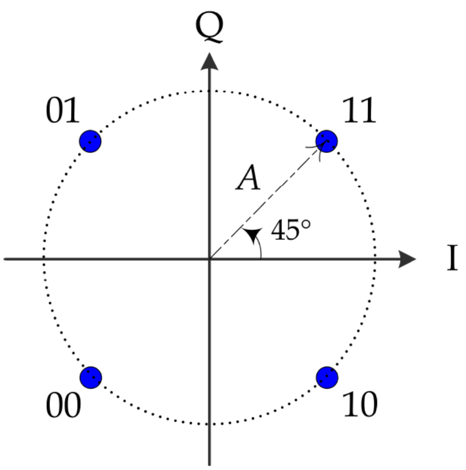


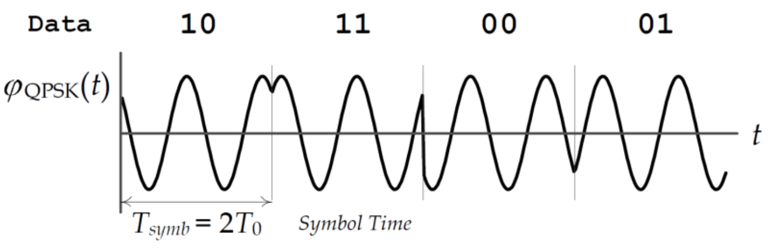
BPSK is a special case of **PM**, the **bandwidth of PSK is $2B + 2\Delta f$**, where B is the bandwidth for the polar NRZ signal and $\Delta f = 0$ since the sinusoidal carrier signal does not change its frequency. Hence, **the bandwidth of BPSK is $2f_0$** (Hz).

- A convenient way to represent **PSK** modulation is using a **constellation diagram**.
- A constellation diagram **consists of a group of points**.
- For example, for BPSK, in which each bit is represented by one symbol $A\cos(\omega_c)$ or $A\cos(\omega_c - 180^o)$),
- In this case, (**BPSK**) The constellation diagram consists of two points.
- These two points have the same amplitude A, but they are $180°$ apart.
    - **Logic 1** corresponds to $A\cos(\omega_c)$,
    - **Logic 0** corresponds to $A\cos(\omega_c - 180^o)$.

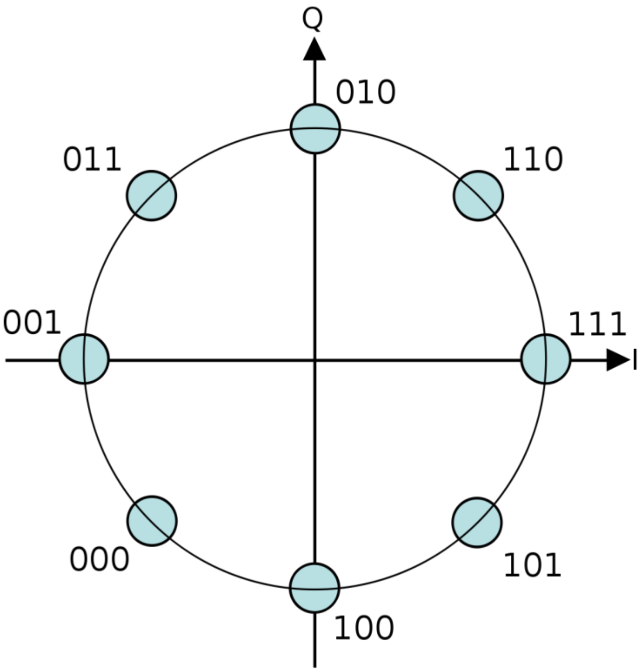


- Another common example of PSK is **Q**uadrature (or **Q**uaternary) **P**hase-**S**hift **K**eying (**QPSK**).
- QPSK uses **four possible phases** for the carrier (**45°, 135°, 225°, 315°**) but with the same carrier amplitude,
- With four phases, QPSK can encode **two bits per one symbol**





- ✓ Notice that **BPSK** can also be thought of as a special case of DSB-SC in which the Polar NRZ signal DSB-SC modulates a sinusoidal carrier. *This is because multiplying a carrier by positive and negative values switches its phase by 180°*.
- You can imagine **QPSK** as a special case of *Phase Modulation (PM)* in which the baseband message signal $m(t)$ is a digital ***M*-ary** signal (with ***M*** = 4).
- In this case, the bandwidth of the ***M*-ary** baseband signal is $\boldsymbol{B = Baud\ Rate = f_0 / 2}$, which means that the **bandwidth of the QPSK signal is** $\boldsymbol{2B + 2\Delta f \ = f_0}$ instead of $\boldsymbol{2f_0}$ for **BPSK**.
- Hence, **QPSK** can be used to double the data rate compared to a **BPSK** system while maintaining the same bandwidth of the modulated signal.
- ➢ Notice that **any number of phases** may be used to construct a **PSK** constellation.
- ➢ Usually, **8-PSK** is the highest order **PSK** constellation deployed in practice.
- ➢ See the following Figure; in this case, each carrier symbol represents three bits.



Example: Find the bandwidth of an **8-PSK** modulated signal if the data bit rate is **100 kbit/s**.

Solution:

For 8-PSK:

$$Bandwidth = 2B = 2 \times Baud\ Rate = 2 \times \frac{100\ kbps}{\log_2(8)}$$

$$Bandwidth = 2 \times \frac{100\ kbps}{3\ bits/symbol} = 66.67\ KHz$$

Quadrature Amplitude Modulation (QAM):

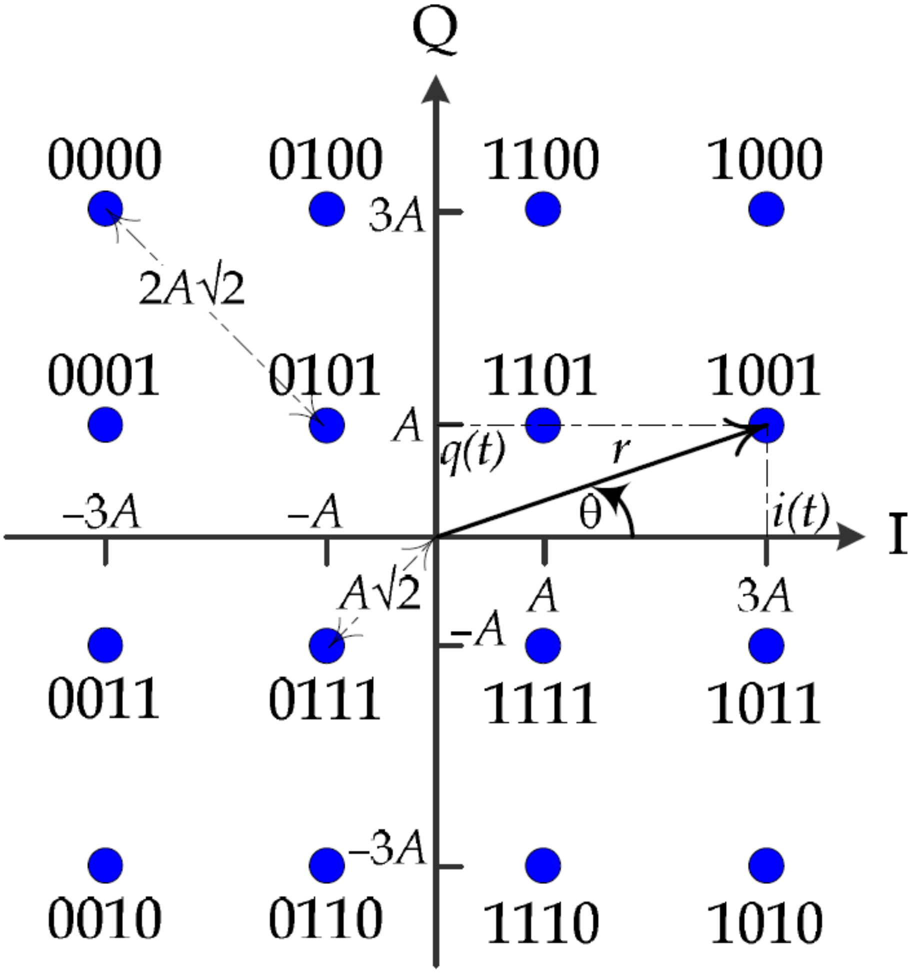
- QAM is a modulation scheme which conveys data by modulating the amplitude of two carrier waves.
- These two waves (a **cosine** and a **sine**) are out of phase with each other by 90° and are thus called quadrature carriers — hence the name of the scheme.
- Both analog and digital QAM are possible.
- **Analog QAM was used in NTSC and PAL television systems**, where the I- and Q-signals carry the components of chrominance (color) information.

❑ Digital QAM, on the other hand, is constructed using **two** ***M*-ary** baseband signals (called $\boldsymbol{i}(\boldsymbol{t})$ and $\boldsymbol{q}(\boldsymbol{t})$) modulating the two quadrature carriers.

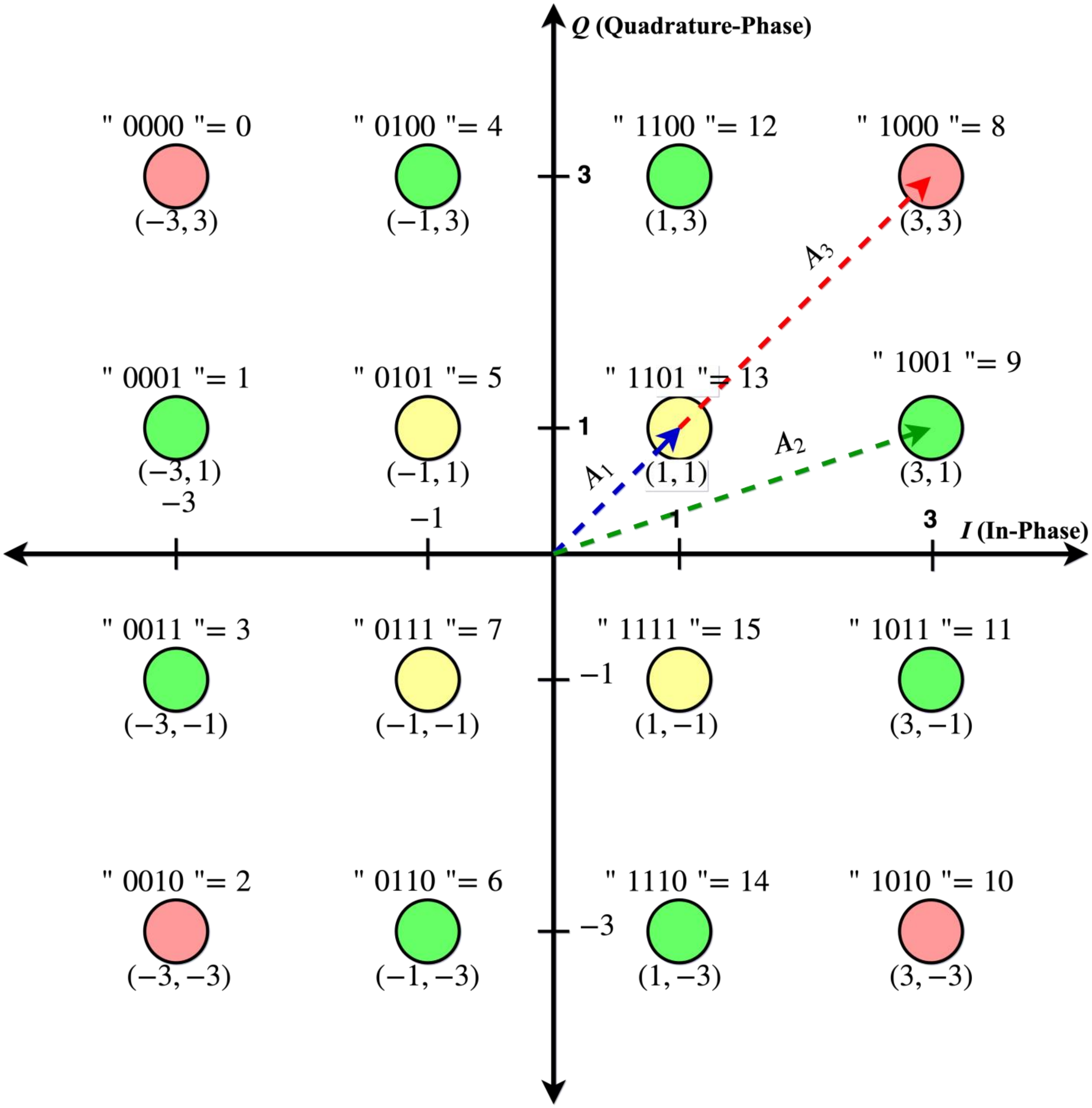
❑ For example, in **16-QAM** both $\boldsymbol{i}(\boldsymbol{t})$ and $\boldsymbol{q}(\boldsymbol{t})$ are **4-ary** digital baseband signals, which means each one of them can assume one of four possibilities.

❑ This results in **4×4 = 16** possible carrier symbols as shown in the constellation diagram below.

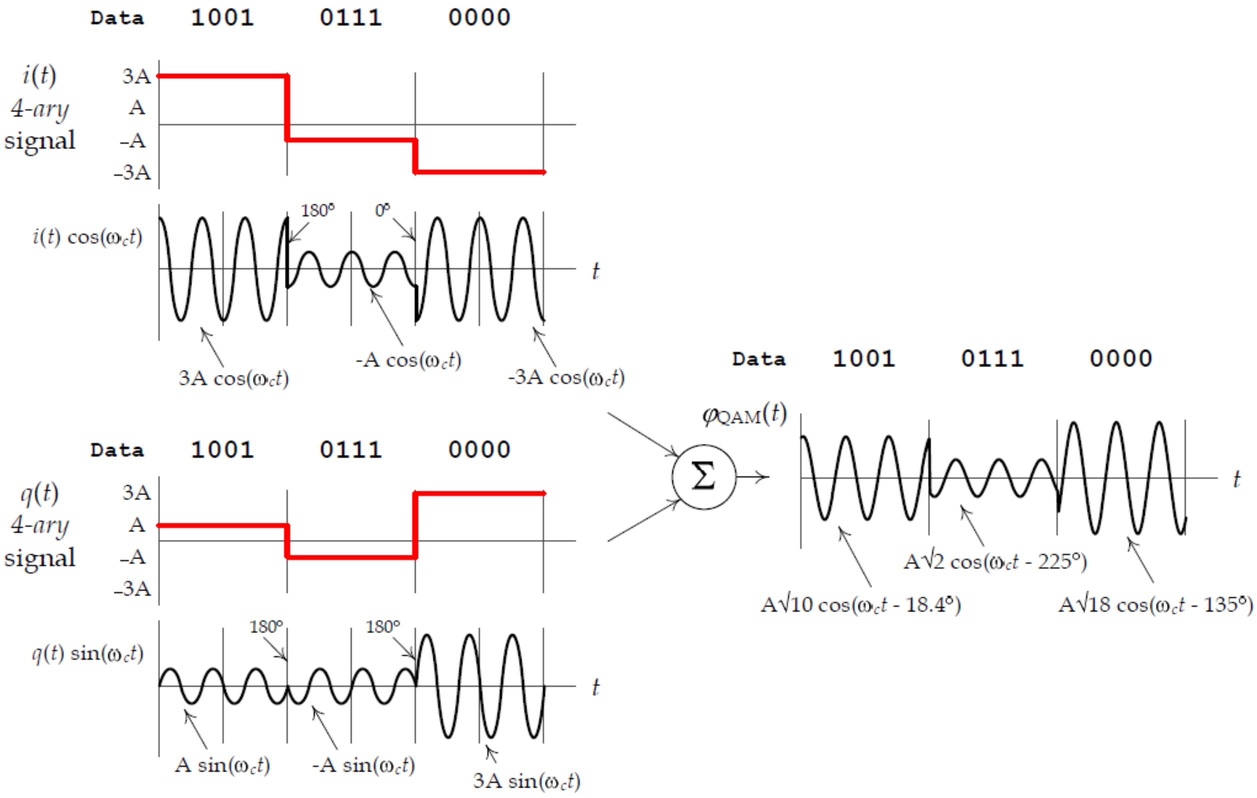
❑ Hence, **16-QAM** uses **16 symbols**, with each symbol representing a specific four-bit pattern.



Example: To send the bit sequence 100101110000 using **16-QAM**, draw the signal and wave voltage levels according to the following constellation diagram.



Solution: The bit stream is split into 4-bit groups, with each 4-bit pattern affecting $i(t)$ and $q(t)$ as shown in the figure below.



- Notice that the **baud rate** (***symbol rate***) of the resulting **16-QAM** signal is $^{1}/_{4}$ that of the data bit rate.
- This is why **the bandwidth of 16-QAM** is $\boldsymbol{2 \times Baud\ Rate = 2f_0/4 = f_0/2}$.
- You can see that this is correct because the bandwidth of each one of the **4-ary** signals is $\boldsymbol{B = f_0/4}$ (one symbol per four bits).
- Performing DSB-SC modulation for each one of these signals (i.e., **QAM**) results in a total bandwidth of $\boldsymbol{2B = 2(f_0/4) = f_0/2}$.

Example: Find the bandwidth of a **16-QAM** modulated signal if the data bit rate is **8 Mbit/s**.

Solution:

For **16-QAM:**

$$Bandwidth = 2 \times Baud\ Rate =$$

$$= 2 \times \frac{8\ Mbps}{\log_2(16)}$$

$$= 2 \times \frac{8\ Mbps}{4}$$

$$= 4\ MHz$$

- In QAM, the constellation points are usually arranged in a square grid with equal vertical and horizontal spacing called **rectangular QAM**.
- The **number of points** in the grid is usually a **power of 2** (2, 4, 8, 16...).
- The most common forms of **QAM** are **16-QAM**, **64-QAM**, **128-QAM** and **256-QAM**.
- By moving to *higher-order constellations*, it is *possible to transmit more bits per symbol*, which ***reduces bandwidth***.
- However, *if the mean energy of the constellation is to remain the same*, the points must be ***closer together*** and are thus ***more susceptible to noise***; this results in a *higher **b**it **e**rror **r**ate (**BER**)*.
- Hence, higher order **QAM** can deliver more data less reliably than lower-order **QAM** *unless, of course, the SNR is increased*.

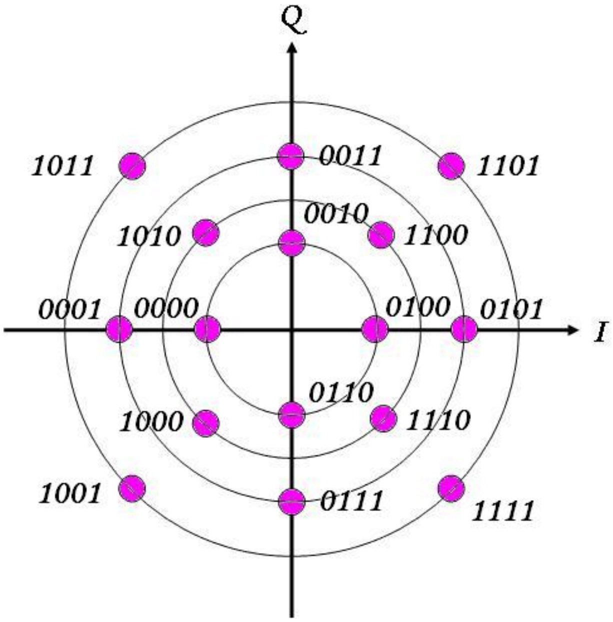
Example: Find the bandwidth of a **64-QAM** modulated signal if the data bit rate is **8 Mbit/s**.

Solution:

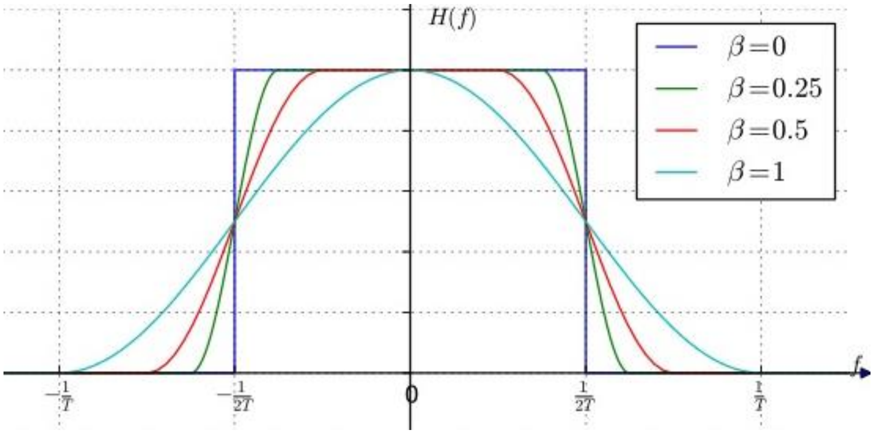
For 64-QAM: $Bandwidth\ = 2 \times Baud\ Rate\ = 2 \times \frac{8\ Mbps}{\log_2(64)}$

$$= 2 \times \frac{8\ Mbps}{6} = 1.33\ MHz$$

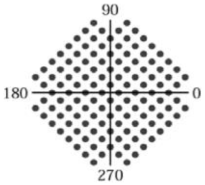
- Rectangular **QAM** constellations are, in general, ***sub-optimal*** in the sense that *they do not maximally space the constellation points* for a given energy.
- However, they have the considerable advantage that they are easier to generate and demodulated using **simple hardware**.
- **Non-square constellations** achieve marginally ***better performance*** **but** are harder to modulate and demodulate.



- In practical systems, ***M*-ary** signals are shaped using a ***Raised-Cosine Pulse*** before modulating the two-quadrature carriers.
- In such case, the bandwidth of **QAM** (or **PSK**) becomes $\boldsymbol{2 \times Baud \times (1+\beta)/2}$ instead of just $\boldsymbol{2 \times Baud}$
    - Here $\boldsymbol{\beta}$ is called **Roll-off factor** of the raised-cosine pulse.



Example: The constellation diagram shown below is the one used in the **V.32bis** *dial-up modem*. This modem provides **14.4** *kbps* using only **2400-baud** rate. Calculate the number of constellation points from these numbers. Assume there is one extra bit as redundancy for correction.



Solution:

$$\boldsymbol{baud\ rate} = symbol\ rate = \frac{bit\ rate}{bits\ per\ symbol}$$

This means that the number of data bits-per-symbol is

$$v = \frac{14400}{2400} = 6\ bits$$

Since there is one bit for redundancy, then, total number of bits

$$v_T = 6 + 1 = 7\ bits$$

Hence, constellation diagram points

$$M = 2^{v_T} = 2^7 = 128$$