(Digital Modulation)

مدولاسیون دیجیتال

1

مقدمه

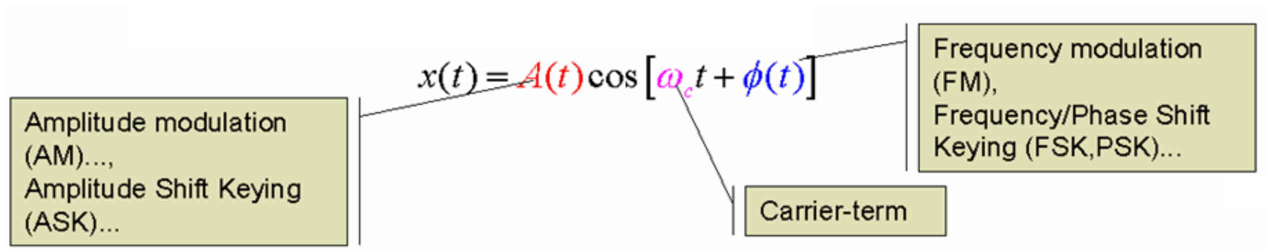
- انگیزهٔ اصلی استفاده از مدولاسیون، بهره مندی کامل از محیطهای انتقال بوده و لذا میتوان عوامل تاثیر گذار بر این بهره مندی را که ملاک انتخاب روشهای مدولاسیون میگردد، بصورت زیر طبقه بندی نمود:

1. بر اساس نوع پیام مورد نظر برای ارسال:
    - voice/video (analog source)
    - data (digital source, machine-to-machine communications)
    - traffic statistics
2. میزان تاخیری که مجاز هستیم.
3. نوع محیط انتقالی که در اختیار داریم.
4. در کاربردهای شبکه ائی ، نوع شبکهٔ مورد استفاده ، نظیر:
    - cellular wireless networks (GSM, AMPS*)
    - Wi-Fi
    - wire-line local area networks (Ethernet LANs)
    - public switched telephone network (PSTN)

2

انواع شیوه های مدولاسیون دیجیتال

- با ملاحظه سیگنال رادیوئی حامل در فرم کلی میتوان شیوه های مختلفی از مدولاسیون دیجیتال نظیر آنچه در آنالوگ داشتیم طبق شکل زیر تعریف نمائیم:

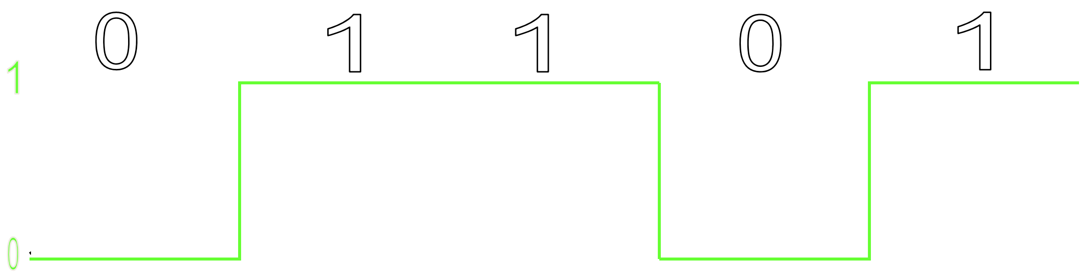


مدولاسیون دامنهٔ دیجیتال ASK (۱)

- در مدولاسیون دامنهٔ یا **ASK**، اطلاعات مدوله کننده داده های باینری **0** و **1** بوده و چون کاریر وابسته به وضعیت داده **0** یا **1** بین دو وضعیت سوئیچ میشود بنام "مدولاسیون کلیدزنی **on/off**" نیز شناخته میشود.

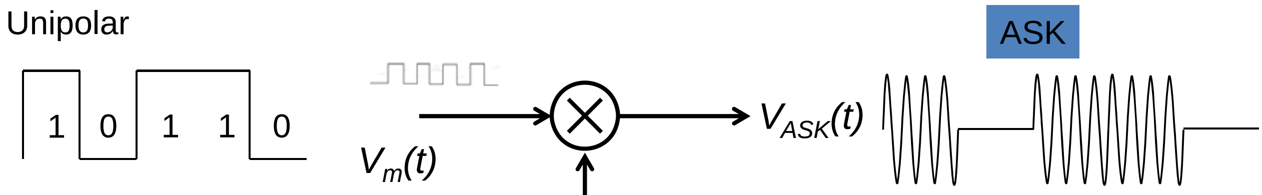
$$x_C(t)=\begin{cases}+A_C\cos 2\pi f_C t & :\text{"1"}\\ -A_C\cos 2\pi f_C t & :\text{"0"}\end{cases}\quad ;\; x_C(t)=\begin{cases}+A_C\cos 2\pi f_C t & :\text{"1"}\\ 0 & :\text{"0"}\end{cases}$$

"*RZ Data input*" "*RZ Data input*"



Amplitude Shift Keying (ASK) , On Off Keying (OOK)

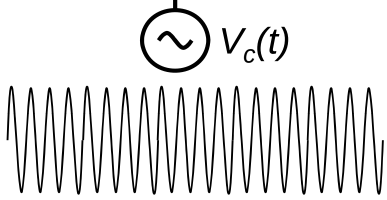
مدولاسیون دامنهٔ دیجیتال ASK (۲)



$V_m(t)$: input signal (digital)

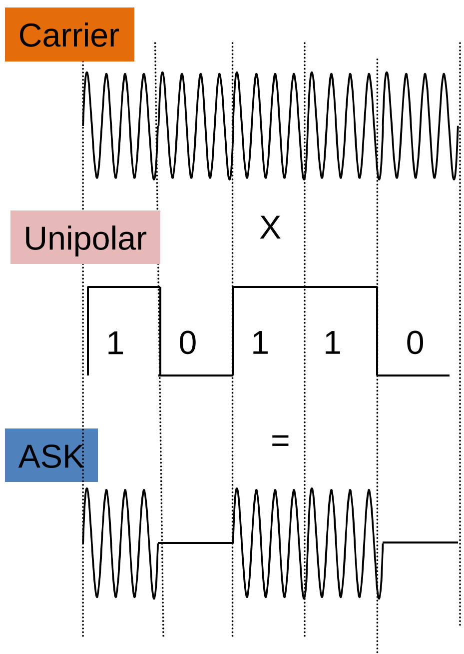
$V_c(t)$: carrier signal

$V_{ASK}(t)$: output signal

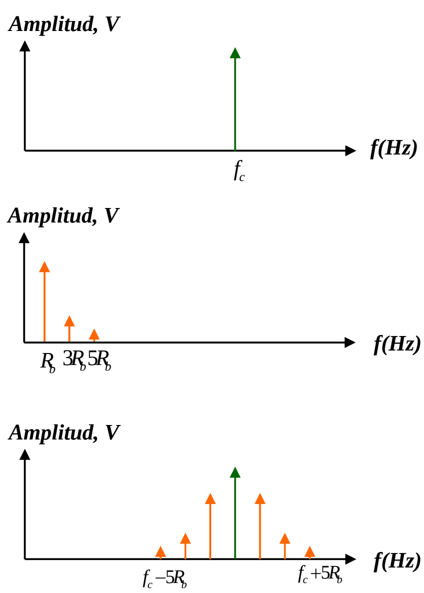


مدولاسیون دامنهٔ دیجیتال ASK (۳)

حوزه زمان



حوزه فرکانس



پهنای باند مدولاسیون دامنهٔ دیجیتال ASK

برای سیگنالهای غیر پریودیک:

$BW_{ASK} = R_S = R_b = 2f_m$

f_m : *Max Frequency of* input signal (Analogue)

$f_S = 2 f_m$: *Min Sampling Frequency of* input signal

$R_b = 1bit \times f_S = 2f_m$: *Min Bit Rate of* input signal after 1 bit quantization (digital)

ارزیابی سیستم ASK

مزیتها

- آسانی انجام مدولاسیون
- بطور وسیعی در انتقال بوسیله فیبر نوری استفاده میشود.

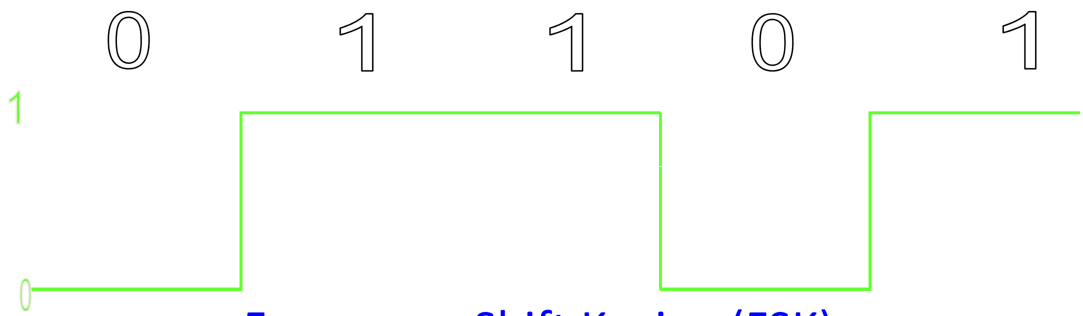
معایب

- حساس در برابر تضعیف سیگنال (ناکارآمدی در ارتباط دهی بین نقاط دور از هم).
- محدودیت نرخ بیت

مدولاسیون فرکانس دیجیتال FSK

- در مدولاسیون فرکانس یا FSK، فرکانس کاریر وابسته به وضعیت داده ورودی **0** یا **1** بین دو وضعیت فرکانسی مختلف $f_{Hi}=f_C+\Delta f$ و $f_{Low}=f_C-\Delta f$ (حول کاریر)سوئیچ میشود :

$$x_C(t)=\begin{cases} A_C\cos 2\pi f_{Hi}t & :"1" \\ A_C\cos 2\pi f_{Low}t & :"0" \end{cases}$$



Frequency Shift Keying (FSK)

پهنای باند مدولاسیون دامنهٔ دیجیتال FSK

برای سیگنالهای غیر پریودیک: $BW_{FSK}=2(R_b+\Delta f)$

f_m : *Max Frequency of* input signal (Analogue)

$f_S=2f_m$: *Min Sampling Frequency of* input signal

$R_b=1bit \times f_S=2f_m$: *Min Bit Rate of* input signal after 1 bit quantization (digital)

مثال

سیگنال FSK ائی با دو فرکانس 51kHz و49kHz سیگنال مدوله شده دیجیتالی را ایجاد می کند،نرخ بیت را 2kbps فرض نمایید، مطلوبست:

1. محل فرکانس کاریر
2. میزان انحراف فرکانس
3. پهنای باند

1. f_C = |(49 kHz + 51 kHz)|/2 = 50 **kHz**

2. Δf:

Δ **f** = |(49 kHz – 51 kHz)|/2 = **1 kHz**

3. bandwidth:

BW = 2[2+1] = **6 kHz**

$BW_{FSK} = 2(R_b + \Delta f)$

کاربردهای متداول شیوه FSK

- مدم ها(Modulator/demodulator)
- مخابرات موبایل(سلولی)
- ارتباطات HF(در رنج 3-30 MHz)
- انتقال دیتا بر روی خطوط قدرت
- شبکه های خانگی دیتا با نرخ بیت بالای 14Mbps

ارزیابی سیستم FSK

مزیتها

- برخورداری از تضعیف کمتر سیگنال در مقایسه با شیوه ASK
- تاثیر پذیری کمتری از نویز نسبت به ASK دارد.

معایب

- غلبه بر نویز(prone to noise) در استفاده این شیوه برای ارتباطات دور(حدود 1km به بالا)
- توانایی صرفا برای انتقال با نرخ بیت نسبتا پایین(baud rate 4800bps)

انواع هم خانواده های مدولاسیون FSK

- MFSK (Multi or M-Array FSK)
- DFSK (Double or Binary FSK)
- DFSK (distributed)
- GFSK (Gaussian)

این شیوه مدولاسیون FSK ائی است که از فیلترهای گاوسی شکلی بمنظور شکل دهی پالسهای FSK و در نهایت آرام نمودن شکل نهایی حوزه زمان موج نهایی و در نهایت کاهش موثر پهنای باند، بهره میبرد(چراکه بطور تئوری پهنای باند FSK نامحدود است).مدارات مجتمع بلوتوث موجود از شیوه مدولاسیون GFSK استفاده می کنند.

مقایسه مدولاسیونهای ASK و FSK

دلایل توجیهی و مواردی که توصیه میشود شیوه ASK انتخاب شود:

- کاربردهای قدرت پایین
- کاربردهای که ارزانی قیمت ملاک است.
- مواردی که سادگی ساخت مد نظر است(مصارف عمومی و غیر نظامی)

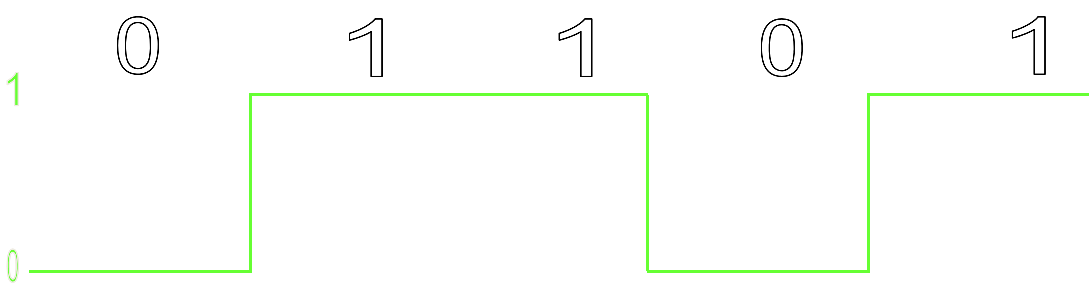
دلایل توجیهی و مواردی که توصیه میشود شیوه FSK انتخاب شود:

- کاربردهای فرکانس بالا
- امکان بروز تداخل با سایر سیگنالها/ آلودگی نویز بالا

- **ضرورت بکارگیری کریستال در FSK و معایب آن** (نیاز به سیستم پایدار کنندهٔ حرارتی و شکنندگی) **سبب برتری نسبی ASK گردیده است.**
- **گیرنده FSK از آستانه حداقل حساسیتی در مقابل ASK از نظر عملکرد خوب نویز برخوردار بوده که البته بهای آنرا با اشغال پهنای باند پانزده برابر بیشتر از ASK پرداخته است.**

مدولاسیون فاز دیجیتال PSK

- **در مدولاسیون فاز یا PSK، کاریر وابسته به وضعیت داده ورودی 0 یا 1 بین دو وضعیت فازی مختلف**(بهترین و ایمن ترین از نظر تشخیص در گیرنده دو فاز متقابل 0 و 180^{o} میباشد) **سوئیچ میشود بطوریکه اگر بیت وارده به مدولاتور تغییر حالت نداد فاز کاریر بدون تغییر باقی میماند، ولی با تغییر بیت** (حال از 1 به 0 یا از 0 به 1 باشد) **فاز کاریر تغییر می کند :**



Phase-Shift Keying

پهنای باند مدولاسیون دامنهٔ دیجیتال PSK

برای سیگنالهای غیر پریودیک: $BW_{PSK} = R_b = 2BW_{baseband}$

$BW_{baseband}$: *Max Frequency of* input signal (Analogue)

$f_S = 2\ BW_{baseband}$: *Min Sampling Frequency of* input signal

$R_b = 1bit \times f_S = 2\ BW_{baseband}$: *Min Bit Rate of* input signal after 1 bit quantization (digital)

مثال

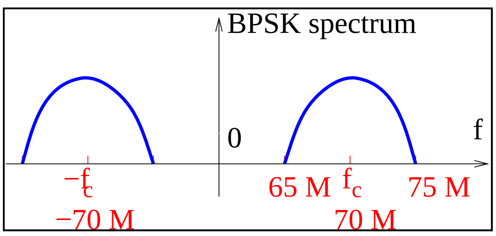
سیگنال **PSK** ائی با فرکانس کاریر **70MHz** و نرخ بیت ورودی **10Mbps** مفروض است، مطلوبست:

۱) مینیمم پهنای باند ۲) ماکزیمم و مینیمم فرکانسهای باند کناری

$$B_{\text{baseband}} \geq \frac{R_b}{2} = 5 \text{ MHz.} \quad \text{Minimum } W_{\text{BPSK}} = 2B_{\text{baseband}} = 10 \text{ MHz.}$$

$$\text{Maximum side frequency: } f_c + \frac{W_{\text{BPSK}}}{2} = 75 \text{ MHz.}$$

$$\text{Minimum side frequency: } f_c - \frac{W_{\text{BPSK}}}{2} = 65 \text{ MHz.}$$



ویژ گیهای BPSK

▪ **BPSK**

باینری **PSK**، در این نوع چنانچه بیت ورودی "**0**" باشد یک موج سینوسی در خروجی مدولاتور ایجاد شده و برای بیت "**1**" سینوسی با دامنه منفی **(inverted sine wave)** تولید می گردد.

از ویژگی های بارز این نوع میتوان به موارد زیر اشاره نمود:

- ساده ترین نوع **PSK**
- راندمان طیف پایین
- مناسب برای سیستمهایی نظیر ارتباطات ماهواره ائی

ارزیابی سیستم BPSK

مزیتها

- مصونیت بالا در برابر نویز، فیدینگ، تداخل
- برای اینکه گیرنده یک تصمیم اشتباه بگیرد منوط به بروز یک اعوجاج شدید میباشد.

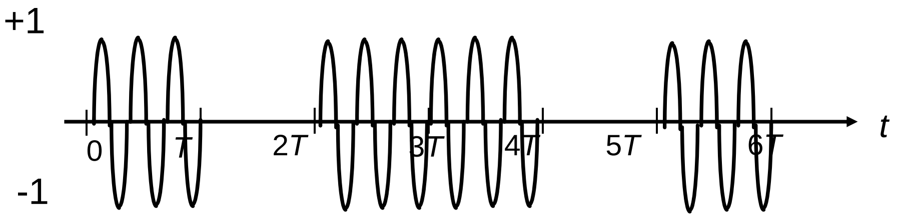
معایب

- تنها قادر است یک بیت بر نمونه را مدوله سازد.
- نامناسب برای کاربردهای با نرخ بیت بالا
- گرانی اجراء این تکنولوژی

Amplitude Modulation and Frequency Modulation

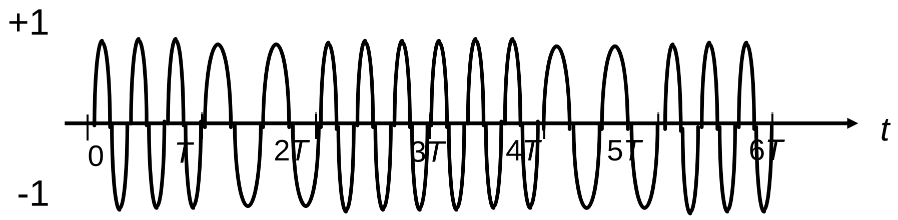
Information 1 0 1 1 0 1

Amplitude Shift Keying



Map bits into amplitude of sinusoid: “1” send sinusoid; “0” no sinusoid
Demodulator looks for signal vs. no signal

Frequency Shift Keying

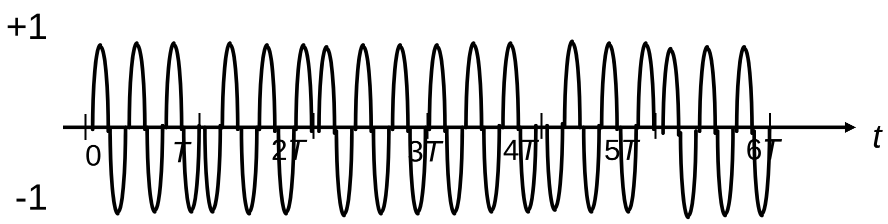


Map bits into frequency: “1” send frequency $f_c + \delta$; “0” send frequency $f_c - \delta$
Demodulator looks for power around $f_c + \delta$ or $f_c - \delta$

Phase Modulation

Information 1 0 1 1 0 1

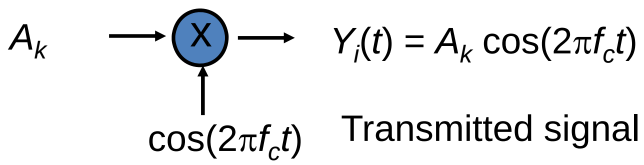
Phase Shift Keying



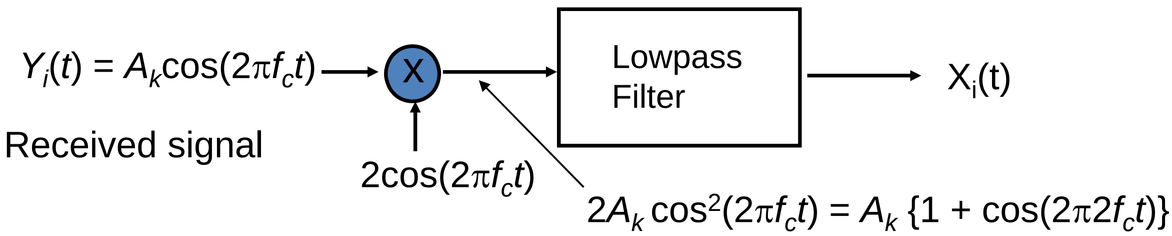
- Map bits into phase of sinusoid:
  - “1” send A $\cos(2\pi ft)$, i.e. phase is 0
  - “0” send A $\cos(2\pi ft+\pi)$, i.e. phase is π
- Equivalent to multiplying $\cos(2\pi ft)$ by +A or -A
  - “1” send A $\cos(2\pi ft)$, i.e. multiply by 1
  - “0” send A $\cos(2\pi ft+\pi)$ = - A $\cos(2\pi ft)$, i.e. multiply by -1

Modulator & Demodulator

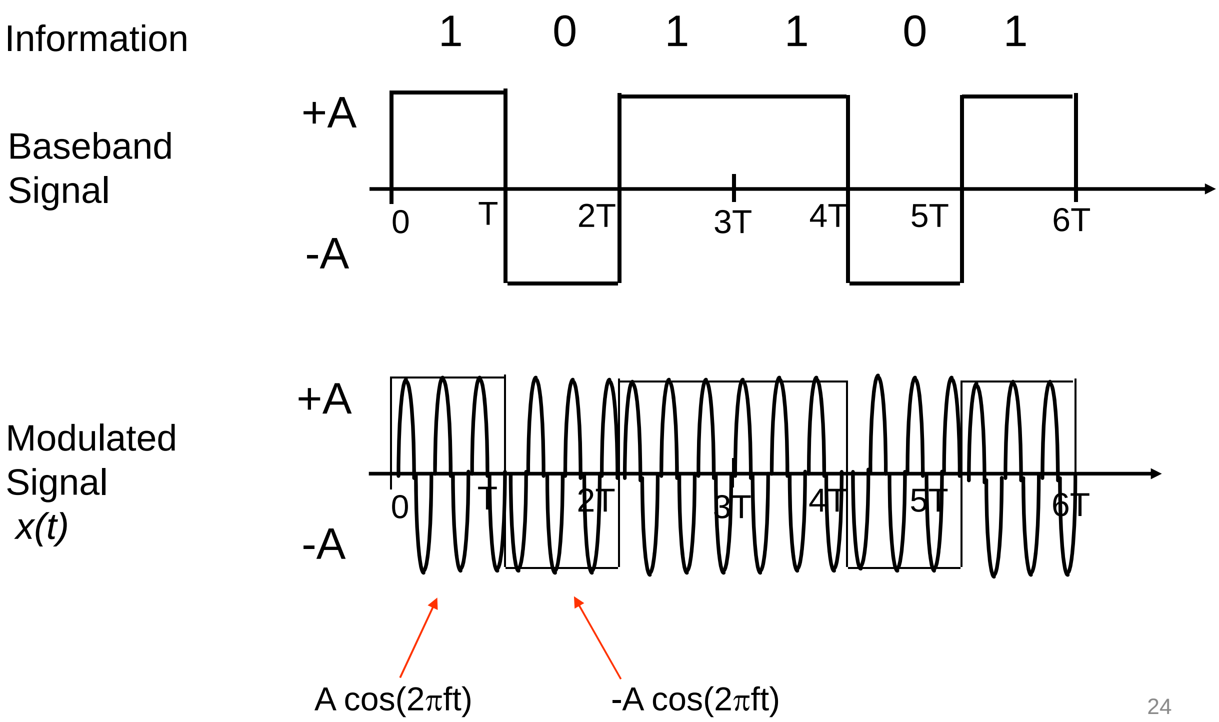
Modulate $\cos(2\pi f_c t)$ by multiplying by A_k for T seconds:



Demodulate (recover A_k) by multiplying by $2\cos(2\pi f_c t)$ for T seconds and lowpass filtering (smoothing):

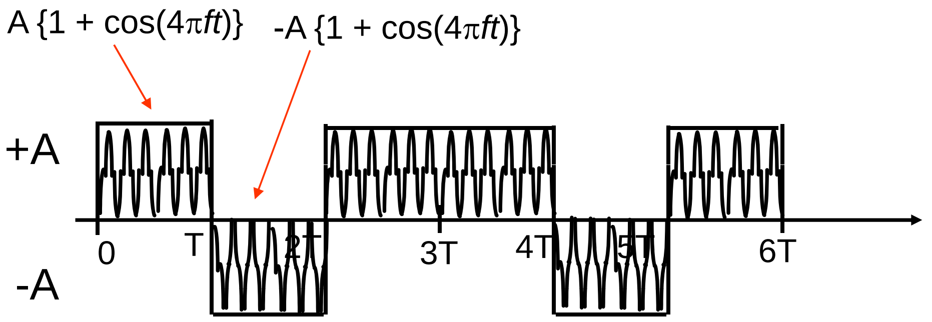


Example of Modulation

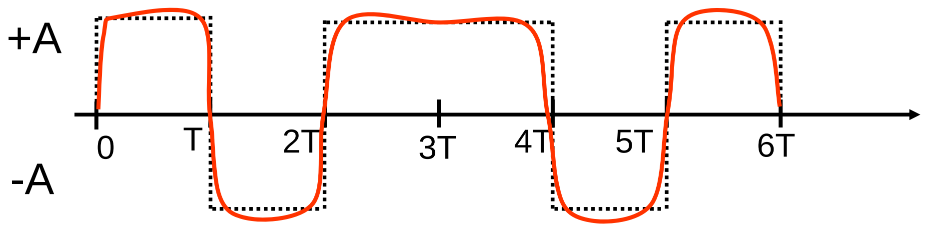


Example of Demodulation

After multiplication at receiver $x(t) \cos(2\pi f_c t)$



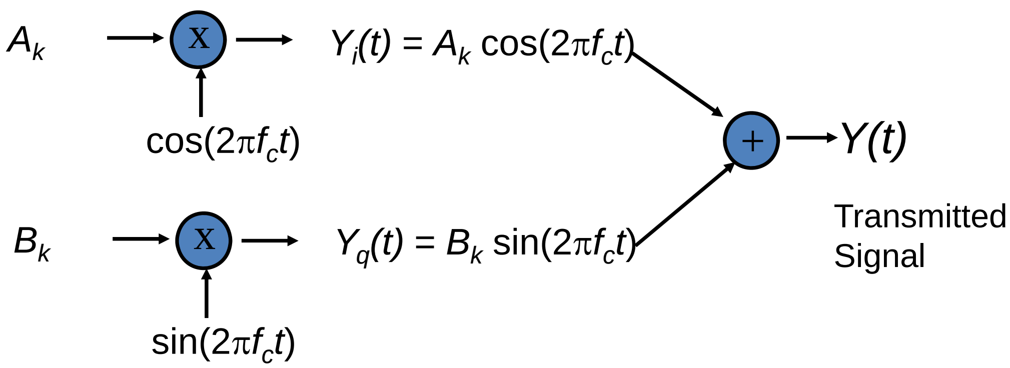
Baseband signal discernable



Recovered Information   1   0   1   1   0   1

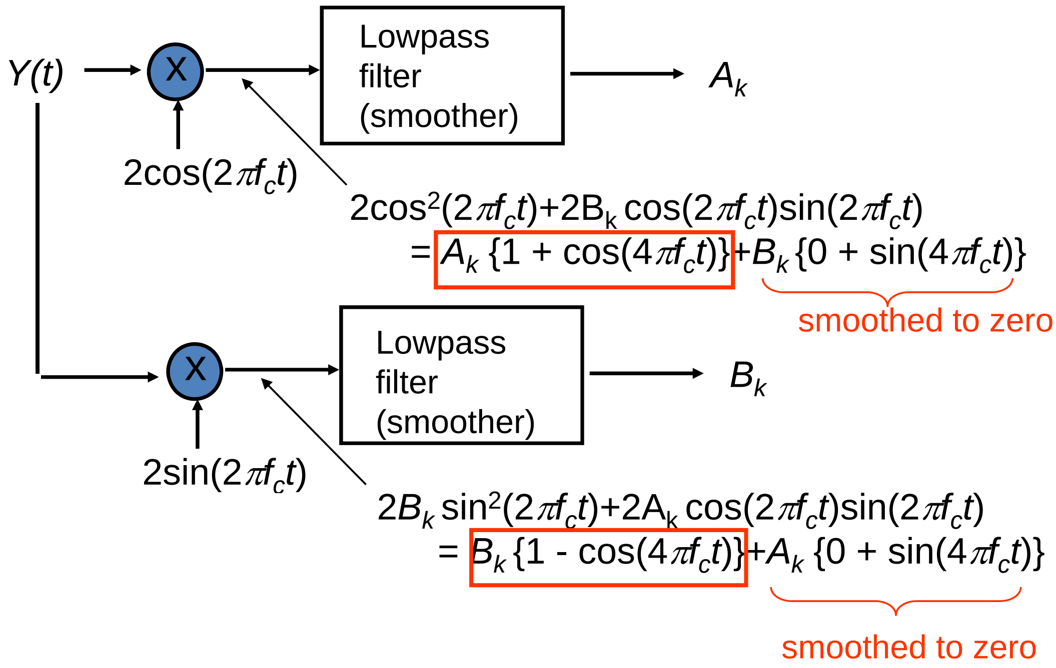
Quadrature Amplitude Modulation (QAM)

- QAM uses two-dimensional signaling
  - A_k modulates in-phase $\cos(2\pi f_c t)$
  - B_k modulates quadrature phase $\cos(2\pi f_c t + \pi/4) = \sin(2\pi f_c t)$
  - Transmit sum of inphase & quadrature phase components



- $Y_i(t)$ and $Y_q(t)$ both occupy the bandpass channel
- QAM sends 2 pulses/Hz

QAM Demodulation



Why Digital-to-analog modulation ?

- Digital signals can be transmitted directly at baseband.
- For wireless RF transmission some form of modulation is required to shift the spectra.
- Here key concerns are bandwidth efficiency and implementation complexity. These are affected by:
  - base band pulse shape
  - phase transition characteristics

Example

A signal has a spectrum with frequencies between 1000 and 2000 Hz (bandwidth of 1000 Hz). A medium can pass frequencies from 3000 to 4000 Hz (a bandwidth of 1000 Hz). Can this signal faithfully pass through this medium?

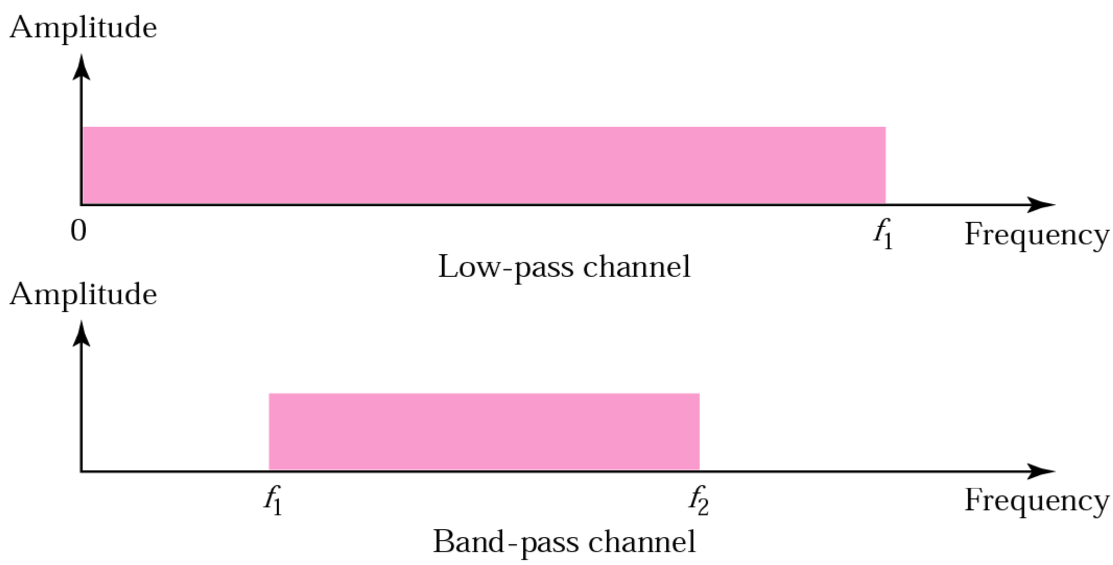
Example

A signal has a spectrum with frequencies between 1000 and 2000 Hz (bandwidth of 1000 Hz). A medium can pass frequencies from 3000 to 4000 Hz (a bandwidth of 1000 Hz). Can this signal faithfully pass through this medium?

Solution

The answer is definitely no. Although the signal can have the same bandwidth (1000 Hz), the range does not overlap. The medium can only pass the frequencies between 3000 and 4000 Hz; the signal is totally lost.

Low-pass and band-pass



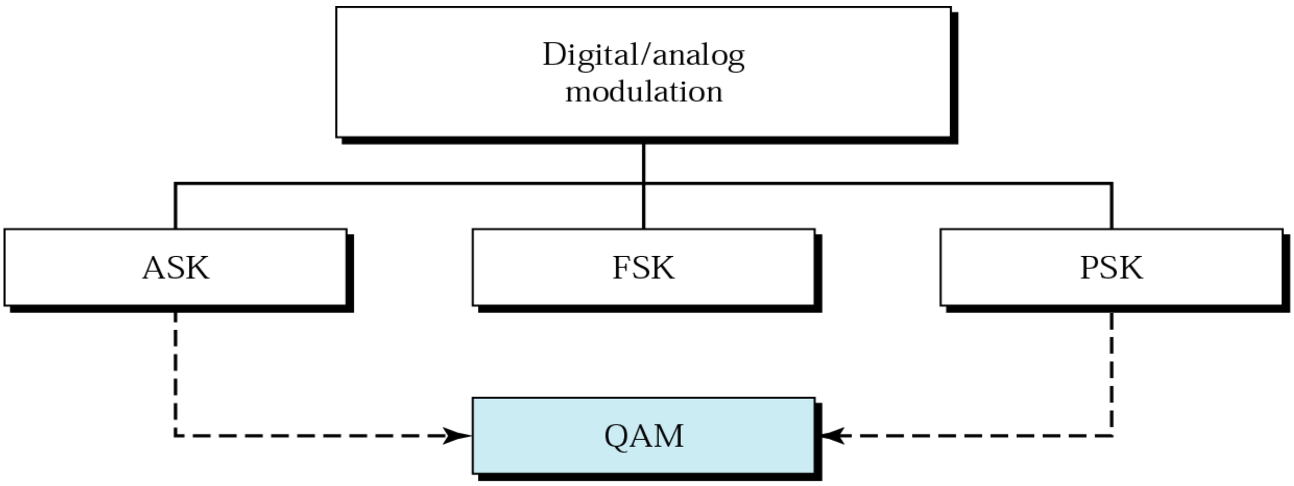
Digital transmission needs a low-pass channel.

Analog transmission can use a band-pass channel.

What are the different Types of Digital-to-analog modulation ?

- ASK involves turning a carrier on and off to represent the binary values.
- FSK involves switching between two frequencies that represent the binary values.
- PSK involves switching between two phases that represent the binary values
- QAM is a combination of both ASK and PSK

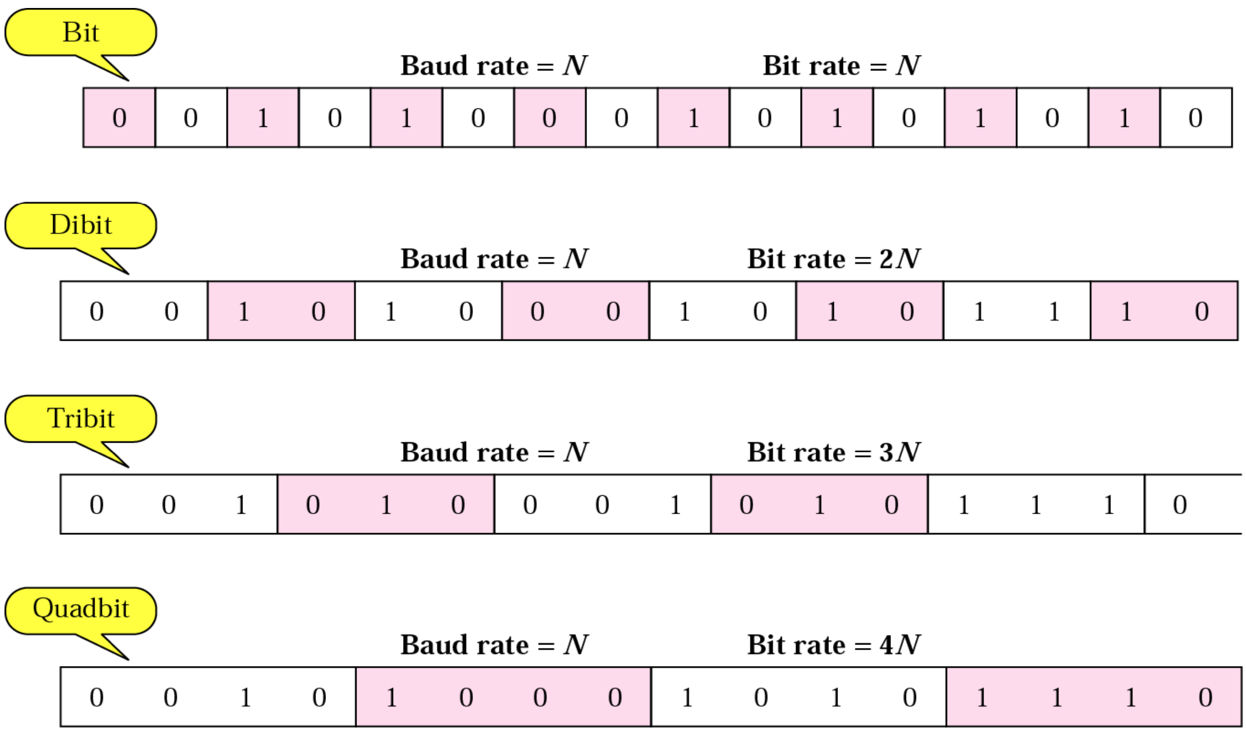
Types of digital-to-analog modulation



What is the difference between Baud rate and Bit rate

Bit rate is the number of bits per second. Baud rate is the number of signal units per second. Baud rate is less than or equal to the bit rate.

Bit and Baud



Example

An analog signal carries 4 bits in each signal unit. If 1000 signal units are sent per second, find the baud rate and the bit rate

Solution

Baud rate = 1000 bauds per second (baud/s)
Bit rate = 1000 x 4 = 4000 bps

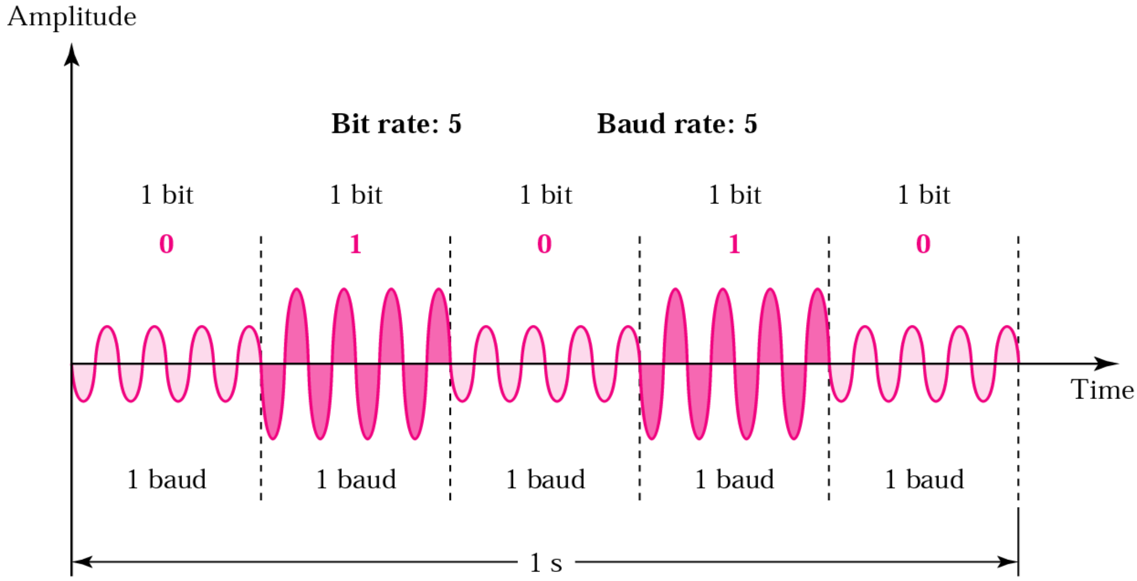
Example

The bit rate of a signal is 3000. If each signal unit carries 6 bits, what is the baud rate?

Solution

Baud rate = 3000 / 6 = 500 baud/s

Describe Amplitude Shift Keying

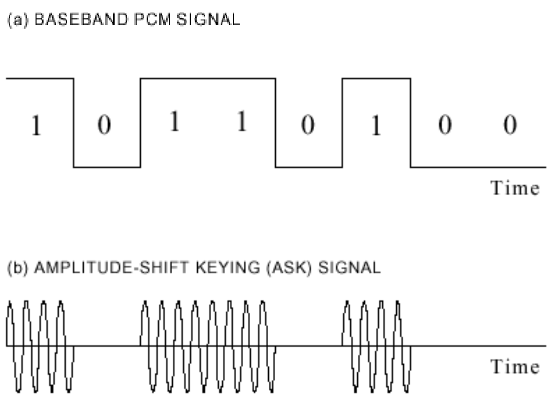


Amplitude-shift keying (**ASK**) is a form of modulation that represents digital data as variations in the amplitude of a carrier wave.

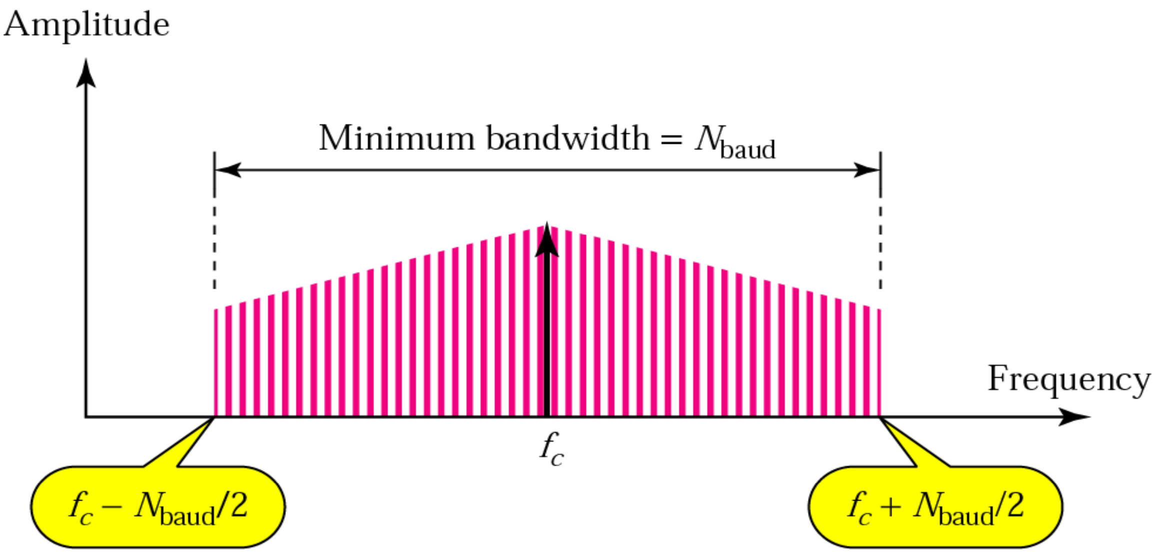
The simplest and most common form of ASK operates as a switch, using the presence of a carrier wave to indicate a binary one and its absence to indicate a binary zero.

This type of modulation is called **on-off keying**,

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases}$$



What is Relationship between baud rate and bandwidth in ASK



Example

Find the minimum bandwidth for an ASK signal transmitting at 2000 bps. The transmission mode is half-duplex.

Example

Find the minimum bandwidth for an ASK signal transmitting at 2000 bps. The transmission mode is half-duplex.

Solution

In ASK the baud rate and bit rate are the same. The baud rate is therefore 2000. An ASK signal requires a minimum bandwidth equal to its baud rate. Therefore, the minimum bandwidth is 2000 Hz.

Example

Given a bandwidth of 5000 Hz for an ASK signal, what are the baud rate and bit rate?

Example

Given a bandwidth of 5000 Hz for an ASK signal, what are the baud rate and bit rate?

Solution

In ASK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But because the baud rate and the bit rate are also the same for ASK, the bit rate is 5000 bps.

Example

Given a bandwidth of 10,000 Hz (1000 to 11,000 Hz), draw the full-duplex ASK diagram of the system. Find the carriers and the bandwidths in each direction. Assume there is no gap between the bands in the two directions.

Example

Given a bandwidth of 10,000 Hz (1000 to 11,000 Hz), draw the full-duplex ASK diagram of the system. Find the carriers and the bandwidths in each direction. Assume there is no gap between the bands in the two directions.

Solution

For full-duplex ASK, the bandwidth for each direction is

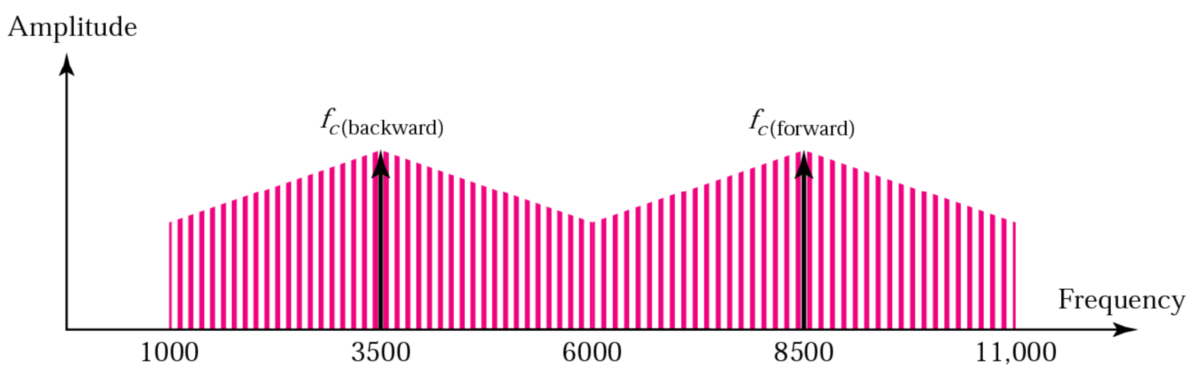
BW = 10000 / 2 = 5000 Hz

The carrier frequencies can be chosen at the middle of each band

fc (forward) = 1000 + 5000/2 = 3500 Hz

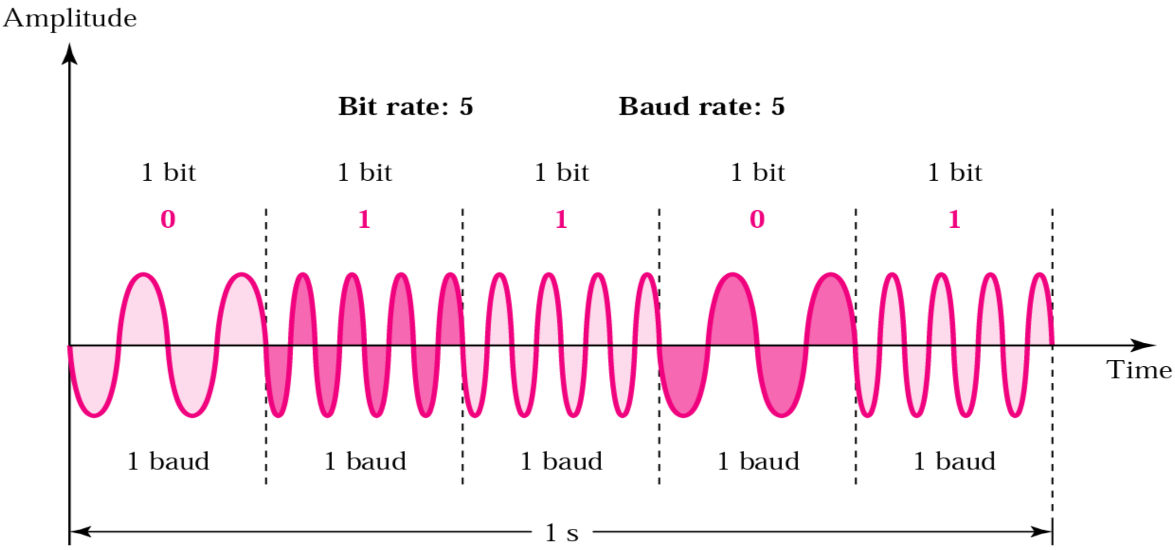
fc (backward) = 11000 – 5000/2 = 8500 Hz

Solution to Example



Describe Frequency Shift Keying

Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier wave. The simplest FSK is *binary FSK* (BFSK).

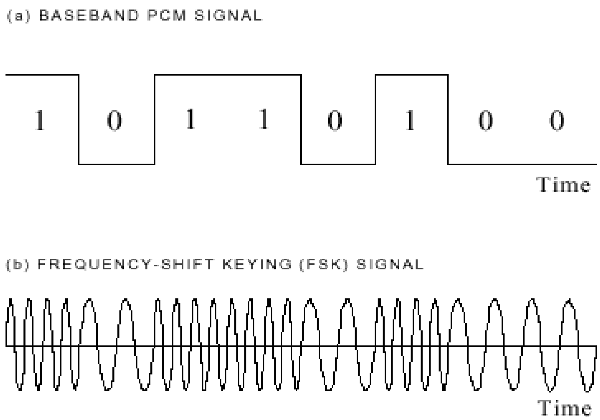


Frequency Shift Keying (FSK)

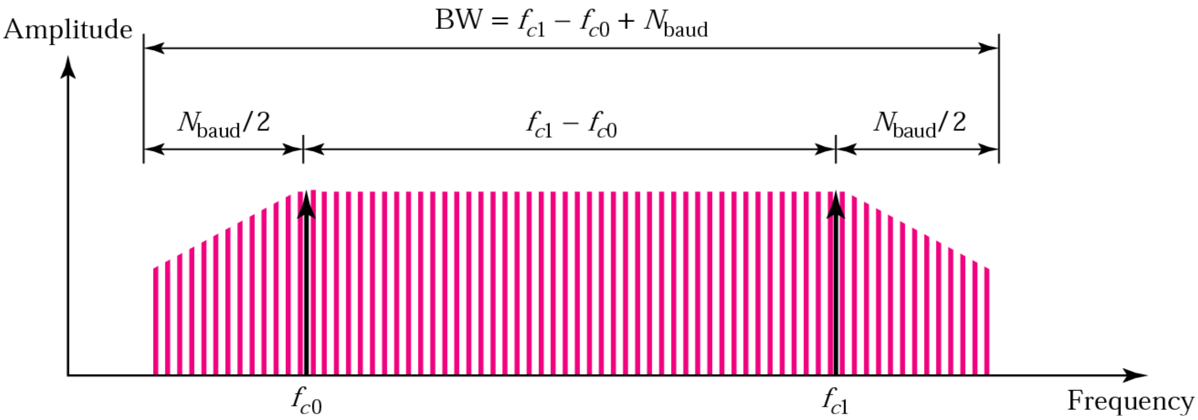
Two binary digits represented by two different frequencies near the carrier frequency

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

where f1 and f2 are offset from carrier frequency *fc* by equal but opposite amounts



what is the Relationship between baud rate and bandwidth in FSK ?



Example

Find the minimum bandwidth for an FSK signal transmitting at 2000 bps. Transmission is in half-duplex mode, and the carriers are separated by 3000 Hz.

Solution

For FSK

BW = baud rate + $f_{c1} - f_{c0}$

BW = bit rate + fc1 – fc0 = 2000 + 3000 = 5000 Hz

Example

Find the maximum bit rates for an FSK signal if the bandwidth of the medium is 12,000 Hz and the difference between the two carriers is 2000 Hz. Transmission is in full-duplex mode.

Solution

Because the transmission is full duplex, only 6000 Hz is allocated for each direction.

BW = baud rate + fc1 – fc0

Baud rate = BW – (fc1 – fc0) = 6000 – 2000 = 4000

But because the baud rate is the same as the bit rate, the bit rate is 4000 bps.

Minimum frequency-shift keying

Minimum frequency-shift keying or *minimum-shift keying* (MSK) is a particularly spectrally efficient form of coherent FSK. In MSK the difference between the higher and lower frequency is identical to half the bit rate.

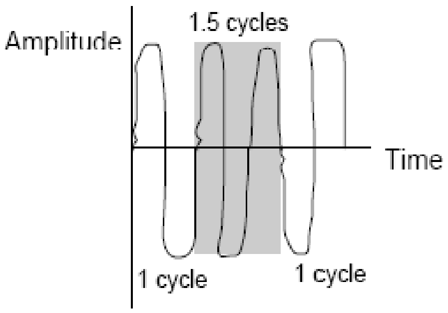
As a result, the waveforms used to represent a 0 and a 1 bit differ by exactly half a carrier period. This is the smallest FSK modulation index that can be chosen such that the waveforms for 0 and 1 are orthogonal.

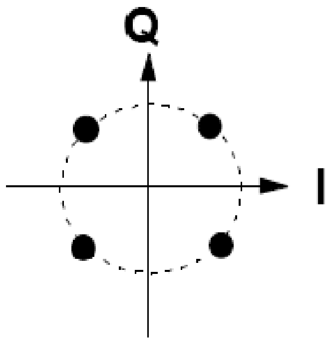
A variant of MSK called GMSK is used in the GSM mobile phone standard.

Minimum frequency-shift keying

- Special form of (continuous phase) frequency shift keying
  - Minimum spacing that allows two frequencies states to be orthogonal
  - Spectrally efficient, easily generated

Minimum Shift Keying (MSK)





Phase continuity at the bit transitions

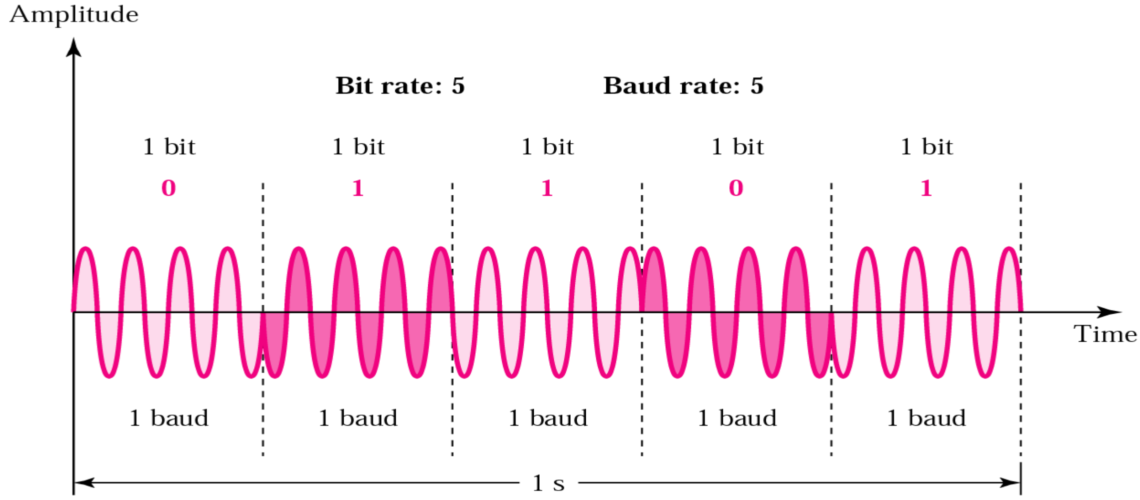
Gaussian Minimum frequency-shift keying

❑**Gaussian minimum shift keying** or **GMSK** is a continuous-phase frequency-shift keying modulation scheme.

❑It is similar to standard **minimum-shift keying** (MSK); however the digital data stream is first shaped with a Gaussian filter before being applied to a frequency modulator.

❑This has the advantage of reducing sideband power, which in turn reduces out-of-band interference between signal carriers in adjacent frequency channels.

Describe Phase Shift Keying



Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave).

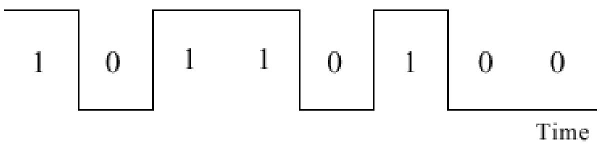
Binary Phase Shift Keying (BPSK)

Uses two phases to represent binary digits

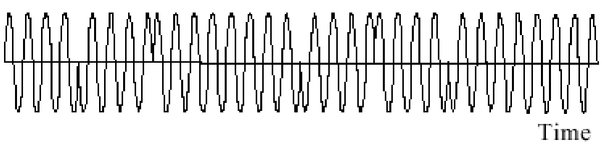
$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ A\cos(2\pi f_c t + \pi) & \text{binary } 0 \end{cases}$$

$$= \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ -A\cos(2\pi f_c t) & \text{binary } 0 \end{cases}$$

(a) BASEBAND PCM SIGNAL



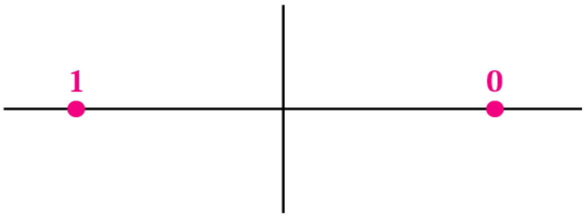
(b) BINARY PHASE-SHIFT KEYING (BPSK) SIGNAL



Draw BPSK constellation

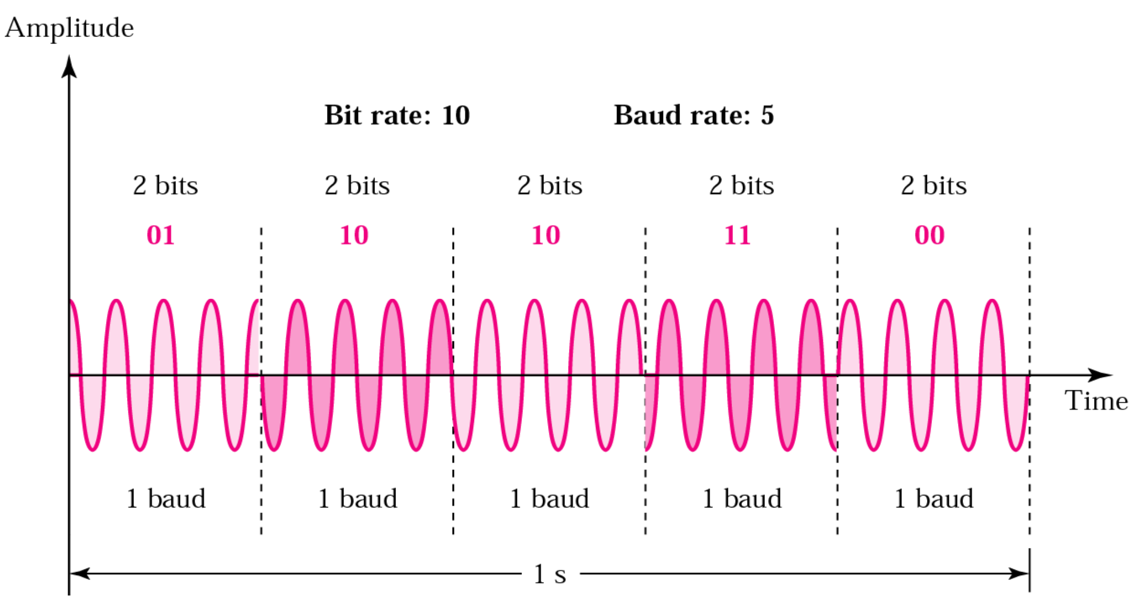
Bit	Phase
0	0
1	180

Bits



Constellation diagram

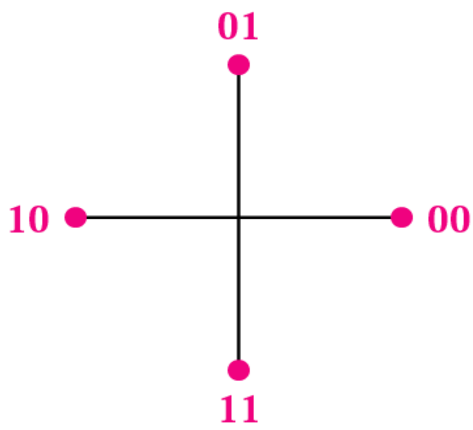
Quadrature phase-shift keying (QPSK or 4-PSK)



QPSK constellation

Dibit	Phase
00	0
01	90
10	180
11	270

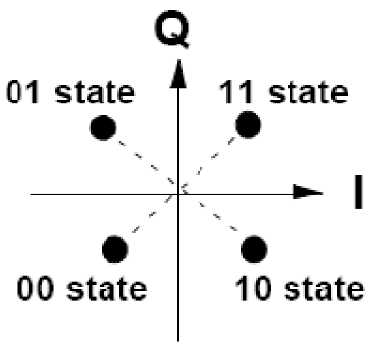
Dibit
(2 bits)



Constellation diagram

QPSK = 4-PSK

- Quadrature Phase Shift Keying (QPSK)
  - Multilevel modulation technique: 2 bits per symbol
  - More spectrally efficient, more complex receiver



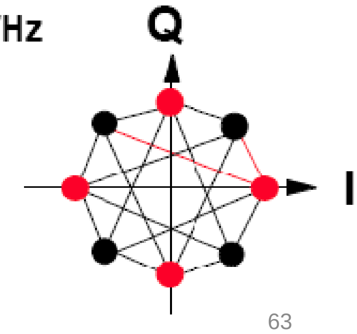
Phase of carrier:
$\pi/4$, $3\pi/4$, $5\pi/4$, $7\pi/4$

Output waveform is sum of modulated ± Cosine and ±Sine wave

2x bandwidth efficiency of BPSK

π/4 QPSK

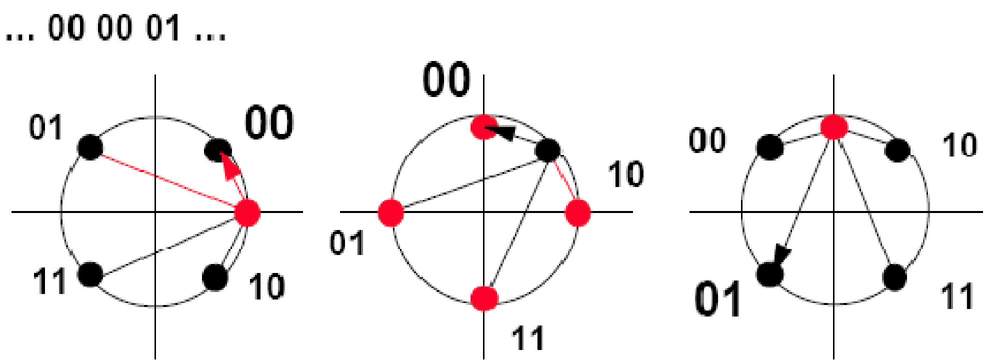
- Variation on QPSK
  - Restricted carrier phase transition to +/- π/4 and +/- 3π/4
  - Signaling elements selected in turn from two QPSK constellations, each shifted by π/4
  - Maximum phase change is ±135˚ vs. 180˚ for QPSK, thus maintaining constant envelope (i.e., amplitude of QPSK signal not constant for short interval during 180˚ phase changes)
- Popular in Second Generation Systems
  - North American Digital Cellular (IS-54): 1.62 bps/Hz
  - Japanese Digital Cellular System: 1.68 bps/Hz
  - European TETRA System: 1.44 bps/Hz
  - Japanese Personal Handy Phone (PHP)



π/4 QPSK

- Advantages:
  - Two bits per symbol, twice as efficient as GMSK
  - Phase transitions avoid center of diagram, remove some design constraints on amplifier
  - Always a phase change between symbols, leading to self clocking

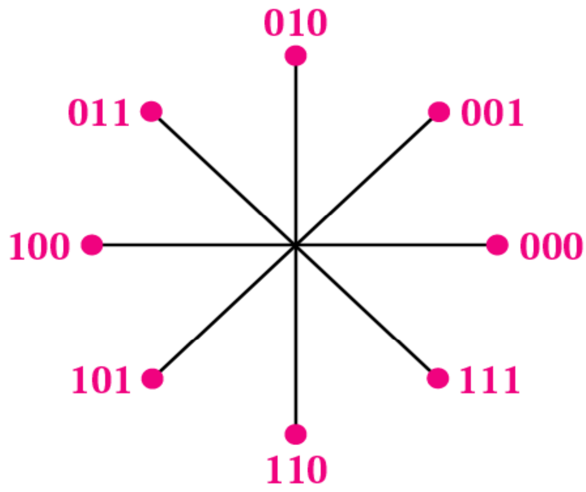
Data	Phase Change
00	45°
01	135°
10	-45°
11	-135°



8 - PSK constellation

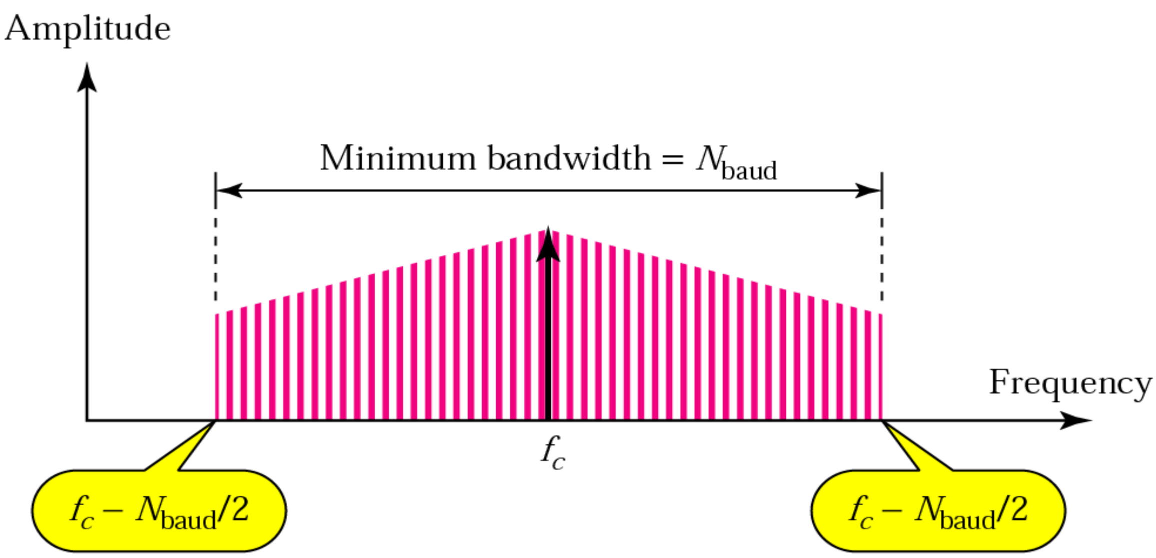
Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)



Constellation diagram

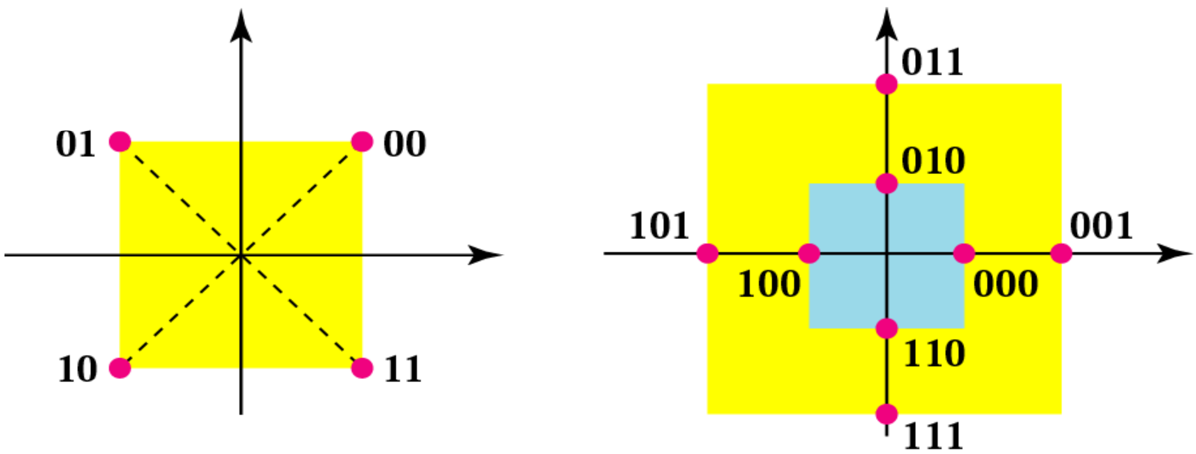
What is the Relationship between baud rate and bandwidth in PSK



What is the QAM ?

Quadrature amplitude modulation is a combination of ASK and PSK so that a maximum contrast between each signal unit (bit, dibit, tribit, and so on) is achieved.

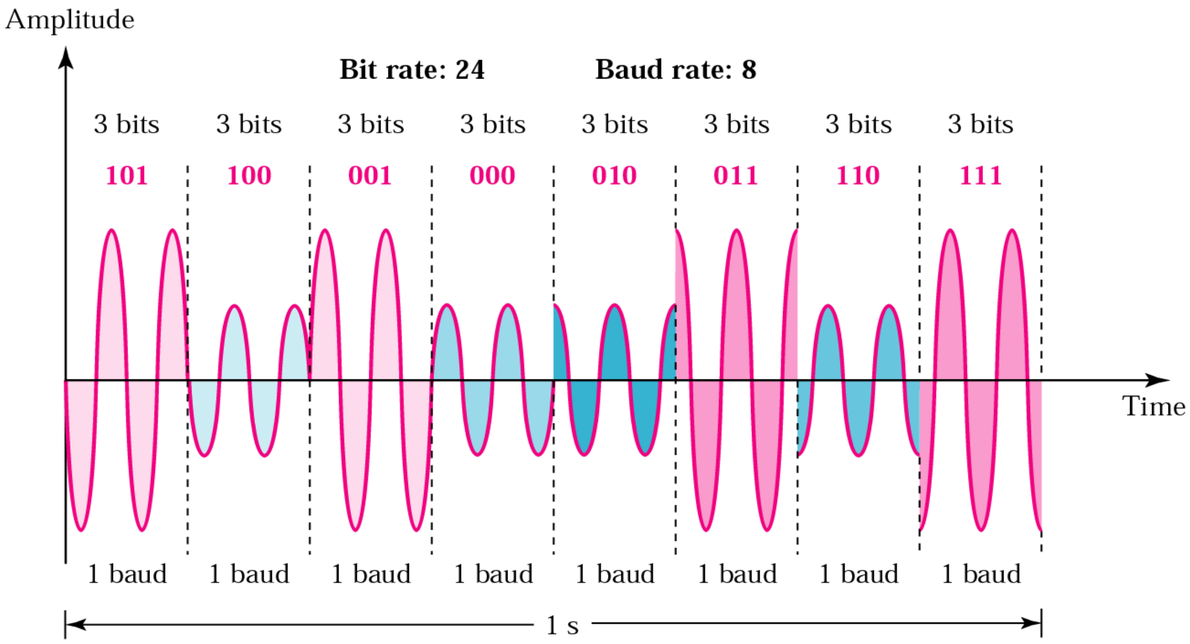
4 – QAM and 8 -QAM constellations



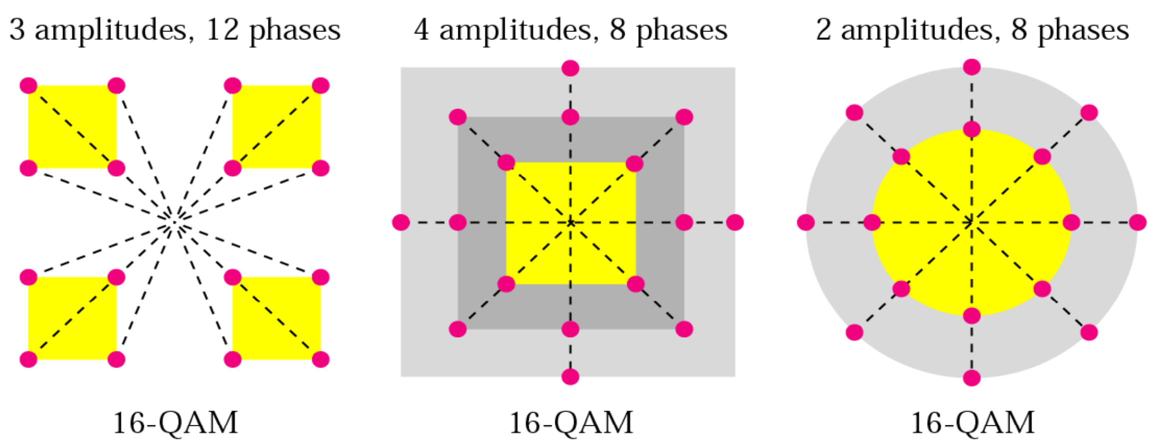
4-QAM
1 amplitude, 4 phases

8-QAM
2 amplitudes, 4 phases

8 – QAM in Time Domain

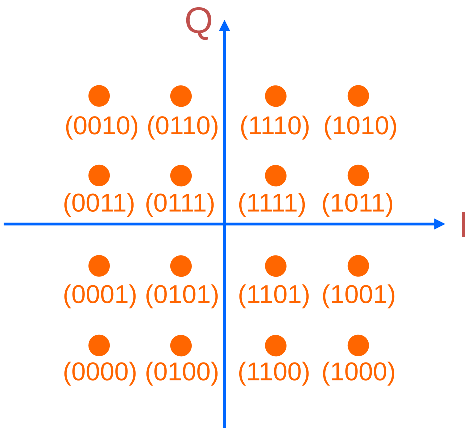


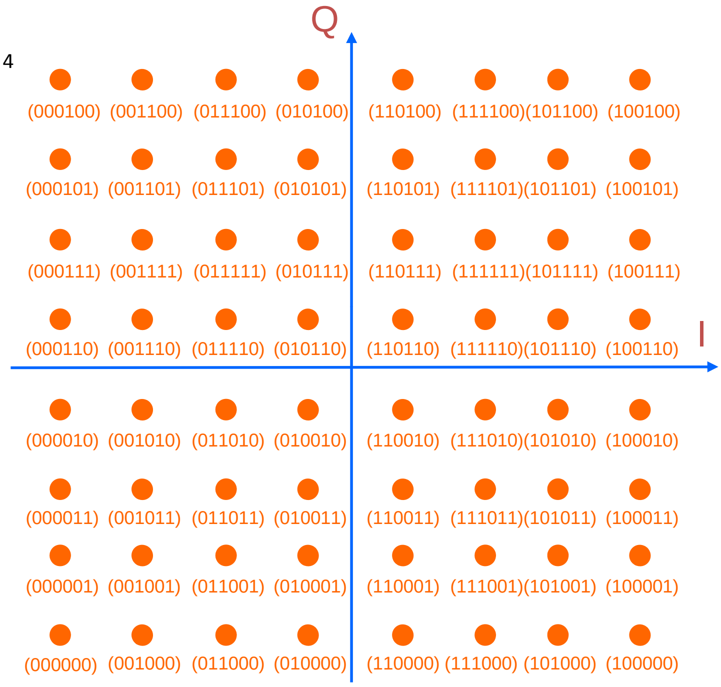
16 – QAM constellations



More Higher Order Modulation

- 6QAM(16-Quadrature Amplitude Modulation)
  - Each IQ symbol location is represented by 4 data bits
- 64QAM (64-Quadrature Amplitude Modulation)
  - Each symbol is now 1worth 5 bits





Bit and baud rate comparison

Modulation	Units	Bits/Baud	Baud rate	Bit Rate
ASK, FSK, 2-PSK	Bit	1	N	N
4-PSK, 4-QAM	Dibit	2	N	2N
8-PSK, 8-QAM	Tribit	3	N	3N
16-QAM	Quadbit	4	N	4N
32-QAM	Pentabit	5	N	5N
64-QAM	Hexabit	6	N	6N
128-QAM	Septabit	7	N	7N
256-QAM	Octabit	8	N	8N

Example

A constellation diagram consists of eight equally spaced points on a circle. If the bit rate is 4800 bps, what is the baud rate?

Solution

Example

A constellation diagram consists of eight equally spaced points on a circle. If the bit rate is 4800 bps, what is the baud rate?

Solution

The constellation indicates 8-PSK with the points 45 degrees apart. Since $2^3 = 8$, 3 bits are transmitted with each signal unit. Therefore, the baud rate is

$$4800 / 3 = 1600 \text{ baud}$$

Example

Compute the bit rate for a 1000-baud 16-QAM signal.

Solution

Example

Compute the bit rate for a 1000-baud 16-QAM signal.

Solution

A 16-QAM signal has 4 bits per signal unit since

$$\log_2 16 = 4.$$

Thus,

$$(1000)(4) = 4000 \text{ bps}$$

Example

Compute the baud rate for a 72,000-bps 64-QAM signal.

Solution

Example

Compute the baud rate for a 72,000-bps 64-QAM signal.

Solution

A 64-QAM signal has 6 bits per signal unit since

$$\log_2 64 = 6.$$

Thus,

$$72000 / 6 = 12{,}000 \text{ baud}$$

Example Modulation Schemes for Wireless

- FM — AMPS
- MSK (minimum-shift keying) — CT2
- GMSK (Gaussian MSK) — GSM, DCS 1800, CT3, DECT
- QPSK — NADC (CDMA) - base transmitter
- OQPSK — NADC (CDMA) - mobile transmitter
- $\pi/4$-DQPSK — NADC (TDMA), PDC (Japan), PHP (Japan)
- M-ary PSK (some wireless LANs)

Example Modulation Schemes for Wireless

Digital Modulation — Classification

Constant-envelope methods: Allow use of less expensive amplification (not dependent on signal amplitude) at the expense of out-of-band emissions. Limited to a spectral efficiency of about 1 bit/sec/Hz.

Examples: MSK, GMSK

Linear methods: Higher spectral efficiency, but must use linear amplifiers to maintain performance and to limit out-of-band emissions.

Examples: PSK, QAM

Example Modulation Schemes for Wireless

State of the technology:

Bandwidth efficiency: $1 < n < 2$

Speech encoder rate: $R_d \approx 4 - 8$ kb/sec

Oscillator stability: $\approx 1 \times 10^{-6}$/year implying $\Delta f \leq 1$ kHz at 900 MHz (long-term)

Examples:

- NADC (TDMA): 48.6 kbps in 30 kHz
- GSM: 34 kbps in 25 kHz