Introduction to Telecommunications and Computer Engineering

Unit 4: Principles of Modulation

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Acknowledgements

These notes contain material from the following sources:

[1] *Data Communications and Networking,* by B.A.Forouzan, McGraw Hill, 2003.

[2] *Communication Systems*, by R.Palit, CSE Department, North South University, 2005.

Modulation

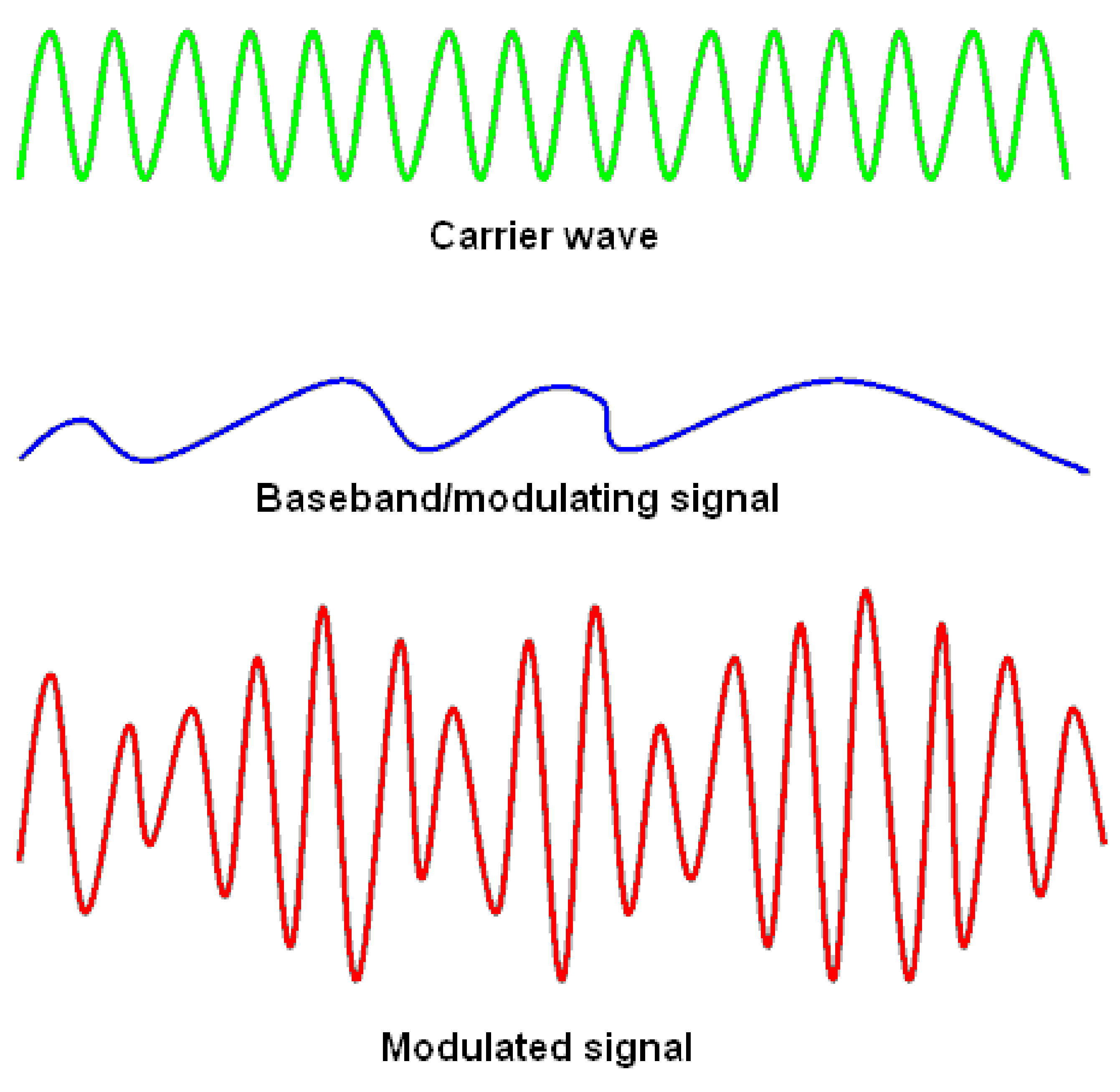
Modulation is the process of encoding information from a message source in a manner suitable for transmission. Generally the message source is a low frequency signal, which changes one of the characteristics of a high frequency carrier signal.

Message Signal/Modulating signal/Baseband signal: This is the signal that we are intending to encode and transmit.

Carrier signal: The high frequency analog signal that carries the message signal is known as carrier signal.

Modulated signal: The carrier signal modulated (changed) by the modulating signal is called modulated signal (also called bandpass signal).

Modulated signal = carrier signal + modulating signal


Carrier wave
Baseband/modulating signal
Modulated signal

From [2]

Modulation Types and Techniques

Types of Modulation -

- **Analog Modulation:** When the message is analog then the modulation is called analog modulation.
  - **Amplitude modulation (AM)**
  - **Frequency modulation (FM)**
  - **Phase modulation (PM)**
- **Digital Modulation:** When the modulating signal is digital then the modulation is called digital modulation.
  - **Amplitude Shift Keying (ASK)**
  - **Frequency Shift Keying (FSK)**
  - **Phase Shift Keying (PSK)**
  - **Quadratic Amplitude Modulation (QAM)** – A combination of ASK and PSK

Analog Modulation

For the description of Frequency, Amplitude and Phase Modulation, let us assume that the message signal is represented by $s_m(t)$ where

$$s_m(t) = A_m\, Sin(2\pi f_m t)$$

which will modulate a carrier signal $s_c(t)$ using FM, AM or PM modulation where

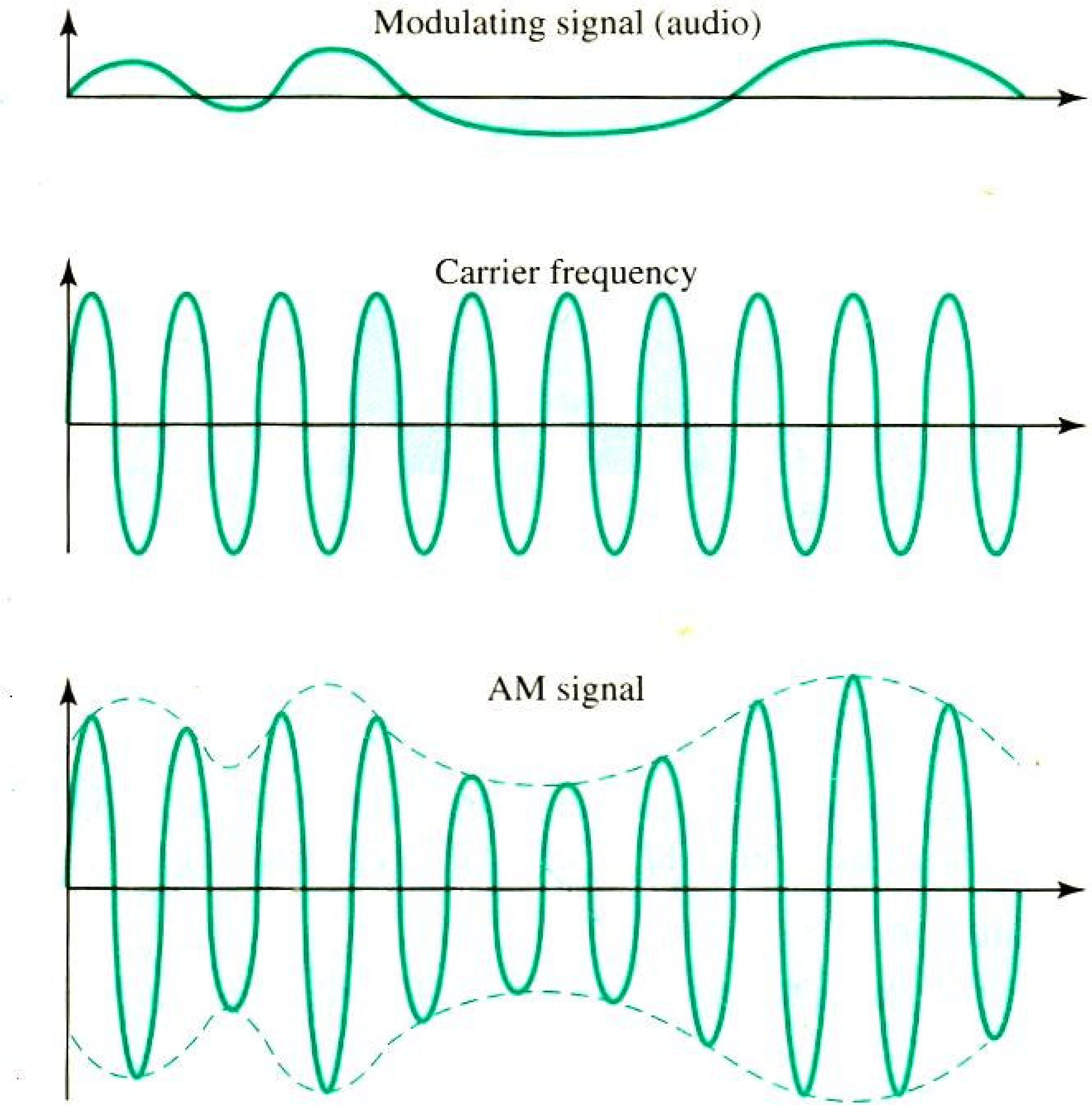
$$s_c(t) = A_c\, Sin\,(2\pi f_c t)$$

The bandwidth of the message signal is usually written as BW_m and that of the modulated (i.e. transmitted) signal is written as BW_t

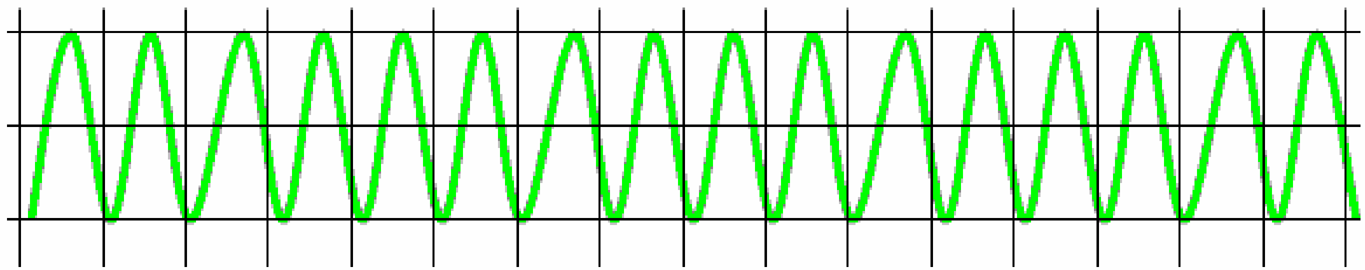
Amplitude modulation (AM)

Amplitude modulation is the process of varying the amplitude of a carrier wave in proportion to the amplitude of a baseband signal. The frequency of the carrier remains constant. This is the most simple and well-known modulation technique used in ***radio broadcast***.

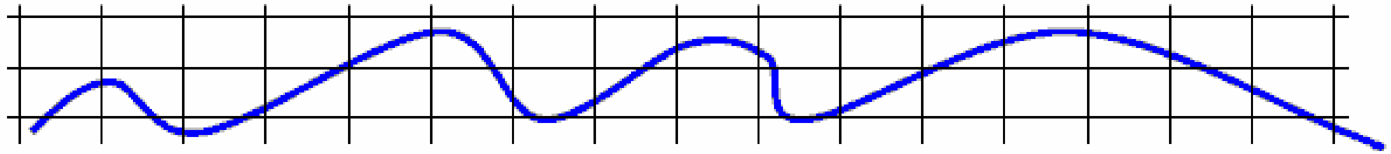
The bandwidth of an audio signal (speech and music) is usually 5KHz and therefore an AM station needs a minimum bandwidth of 10KHz. The FCC (Federal Communications Commission) in USA allocates 10KHz to each AM station.



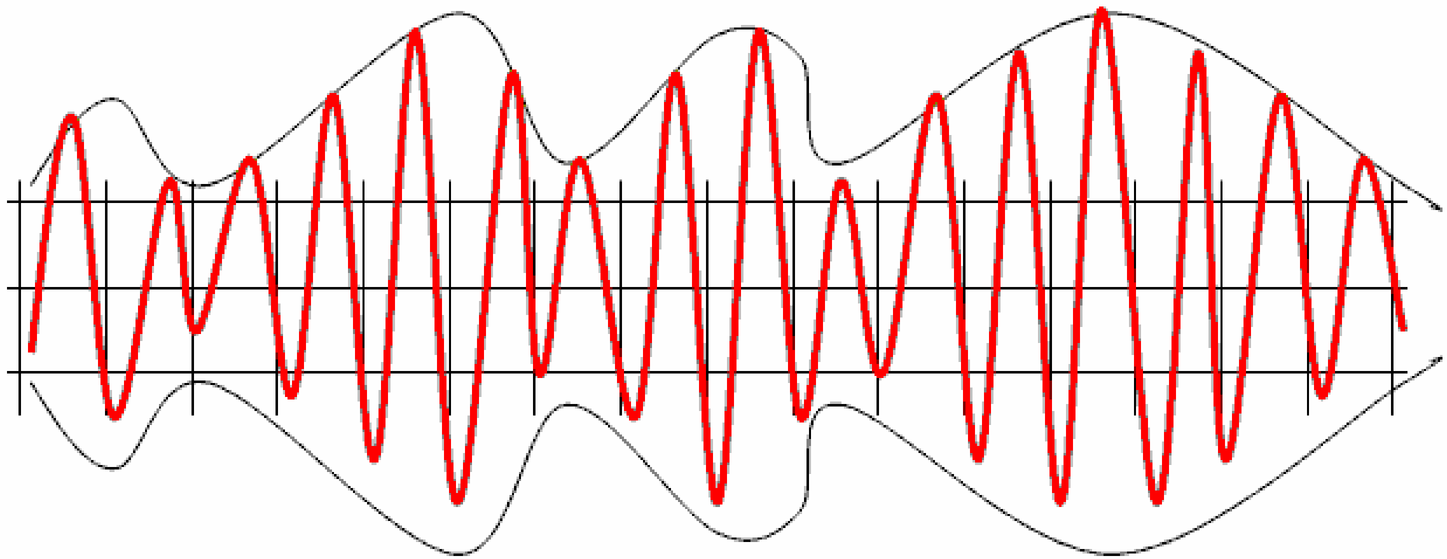
From [1]



Carrier wave



Baseband signal or modulating signal



Amplitude modulated signal

From [2]

Amplitude modulation (AM)

The bandwidth requirement of AM:

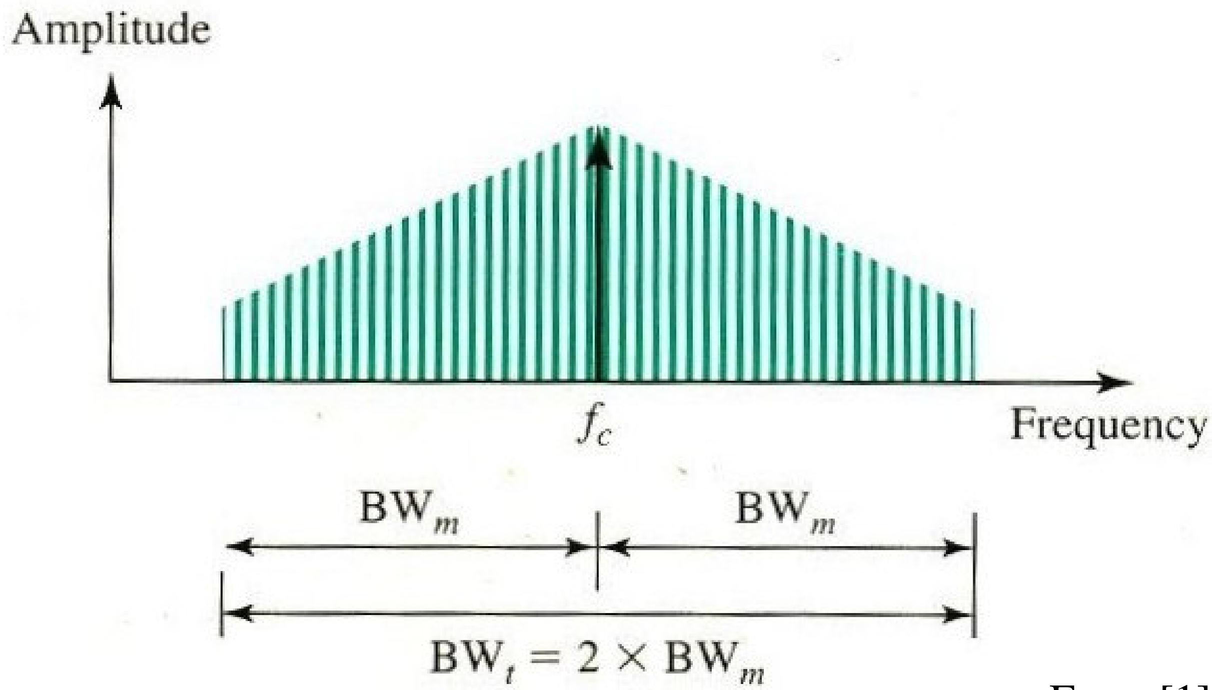
In the amplitude modulated signal we find two side bands having frequency $(f_c - f_m)$ and $(f_c + f_m)$. So the bandwidth required to send the signal is: $f_{max} - f_{min} = (f_c + f_m) - (f_c - f_m) = 2f_m$

That is, the total bandwidth required for AM can be determined from the bandwidth of the message signal

$\boldsymbol{BW_t = 2 \times BW_m}$

$\boldsymbol{m}$ **= modulation index**

$\boldsymbol{= A_m/A_c}$



From [1]

Frequency Modulation (FM)

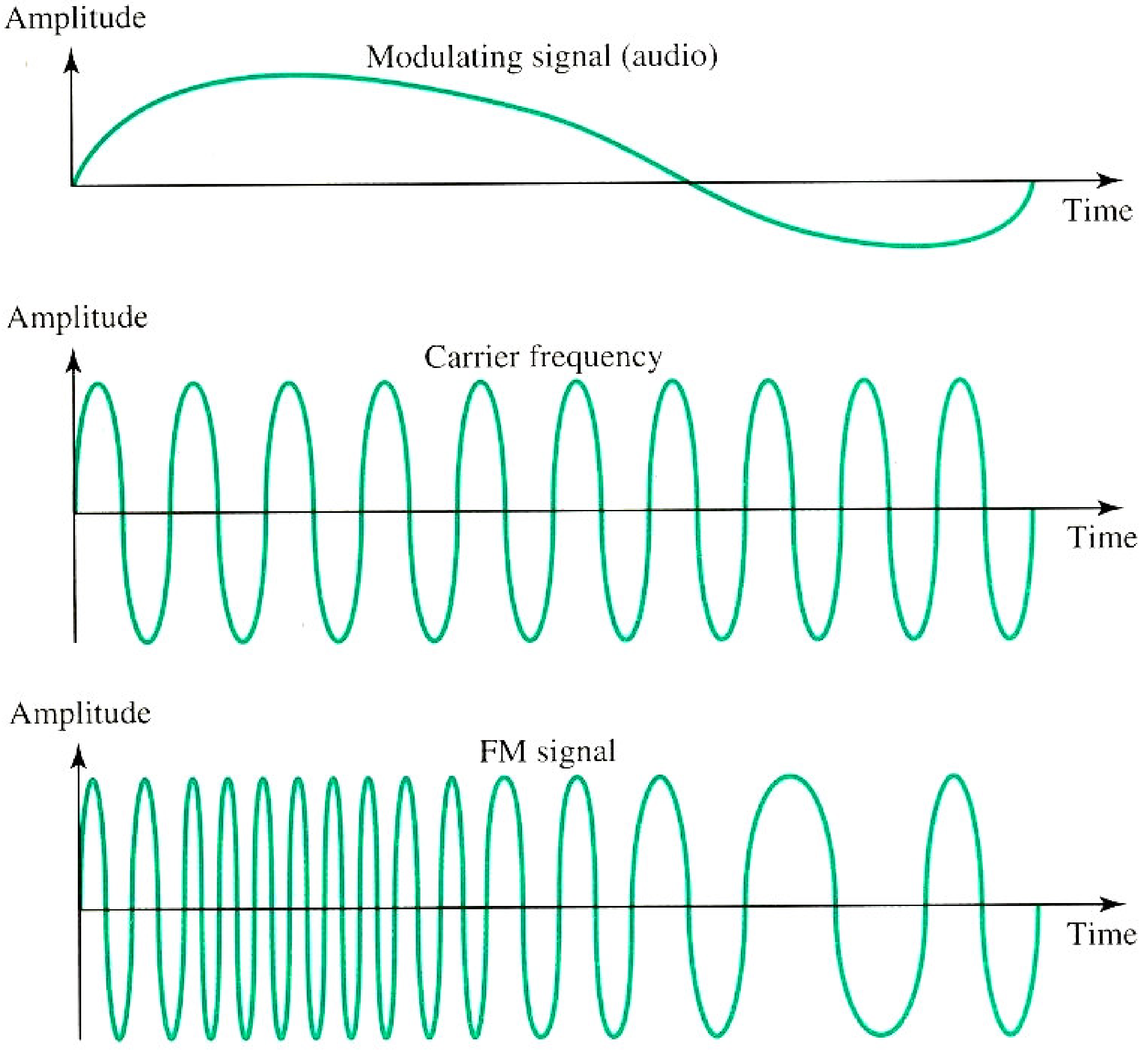
Frequency modulation is the process of varying the frequency of a carrier wave in proportion to the amplitude of a baseband signal. The amplitude of the carrier remains constant.

Let assume that the message signal is represented by $s_m(t)$ and the carrier signal by $s_c(t)$. Suppose the signals are measured by voltage. Now in frequency modulation the $s_m(t)$ will be used to vary the frequency of carrier signal (f_c).

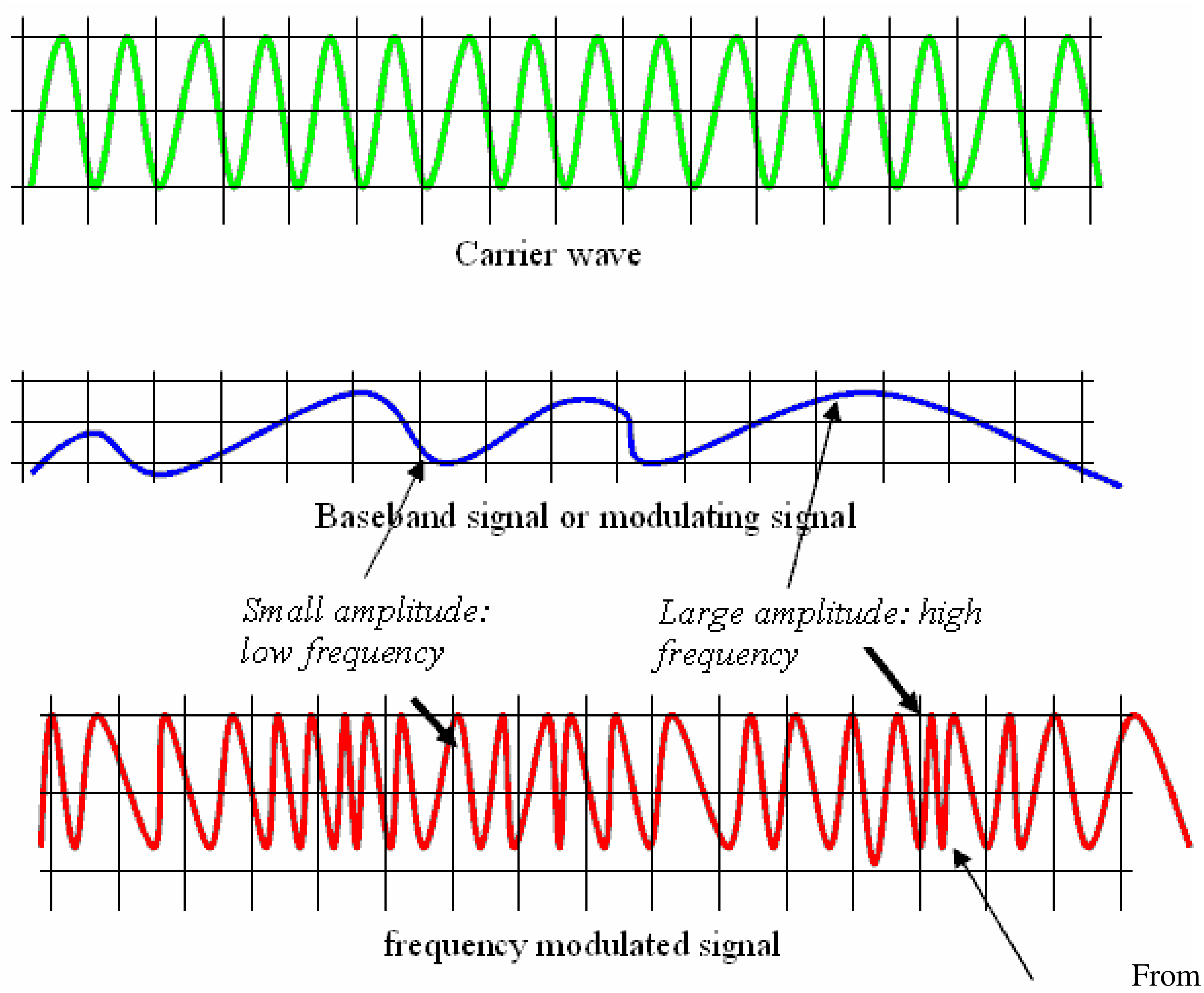
The change in the f_c will be proportional to the $v_m(t)$ and can be represented by $k\, s_m(t)$, where k is a constant know as **frequency deviation constant** and measured by unit hertz/volts. Here:

$\Delta f = k\, A_m$ = peak frequency deviation.

$\Delta f / f_m$ is called the modulation index of frequency modulation and expressed by β.


Amplitude
Modulating signal (audio)
Time
Amplitude
Carrier frequency
Time
Amplitude
FM signal
Time

From [1]


Carrier wave
Baseband signal or modulating signal
Small amplitude: low frequency
Large amplitude: high frequency
frequency modulated signal

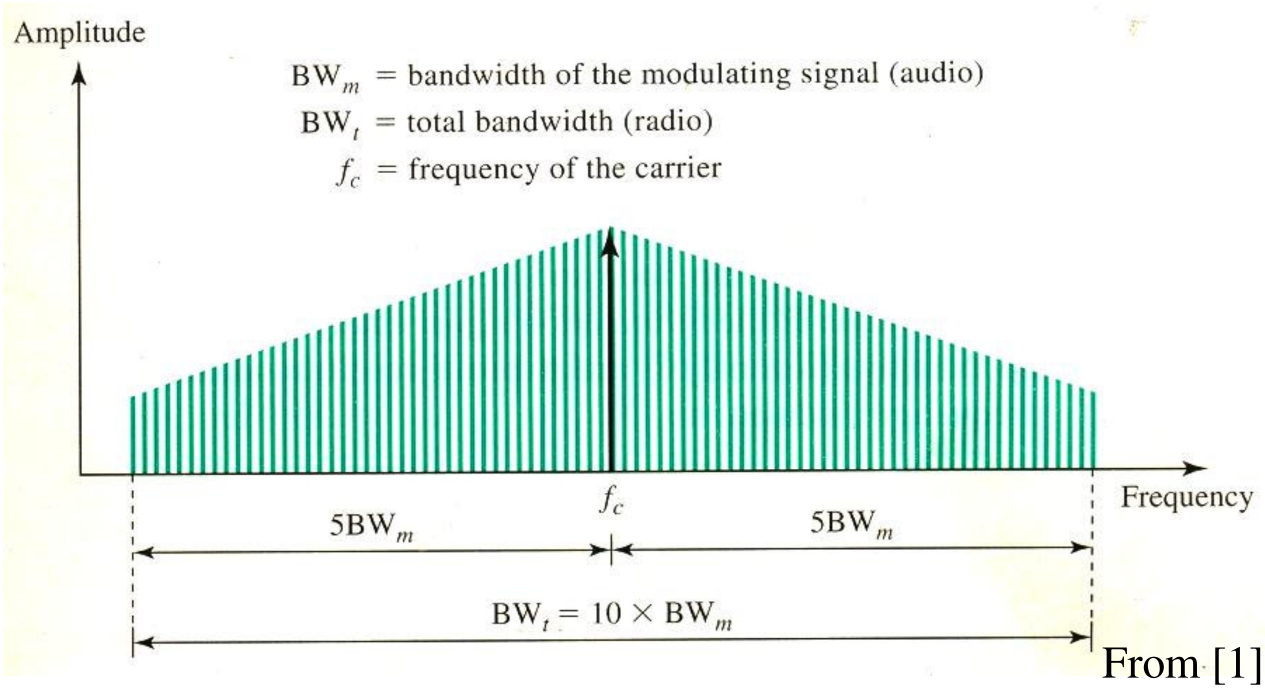
From [2]

Frequency modulation (FM)

The bandwidth requirement of FM:

In the amplitude modulated signal we find two side bands having frequency $(f_c - 5f_m)$ and $(f_c + 5f_m)$. So the bandwidth required to send the signal is: $f_{max} - f_{min} = (f_c + 5f_m) - (f_c - 5f_m) = 10f_m$

That is, the total bandwidth required for FM can be determined from the bandwidth of the message signal $BW_t = 10 \times BW_m$



Carson's Rule:

$BW_t = 2(\Delta f + f_m)$

From [1]

Phase Modulation (PM)

Phase modulation is the process of encoding the message signal by changing the phase of the carrier signal.

In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the message signal.

The peak amplitude and frequency of the carrier remain constant but as the amplitude of message signal changes, the phase of the carrier changes correspondingly

Digital Modulation

Digital modulation can be used to transmit digital data using a analog signals. This process is used to transmit computer (digital) data through (analog) telephone lines via a ***modem*** (Modulator/Demodulator) which is then converted back into digital data on the receiving end.

Two terms related to data transmission and modulation:

Bit rate: the number of bits per second

Baud rate: number of signal units per second

Baud rate is always less than or equal to the bit rate.

Amplitude Shift Keying (ASK)

In Amplitude Shift Keying (**ASK**), the amplitude of the carrier signal is varied to represent binary 0 or 1 as they appear on the message signal. Frequency and phase however remain constant.

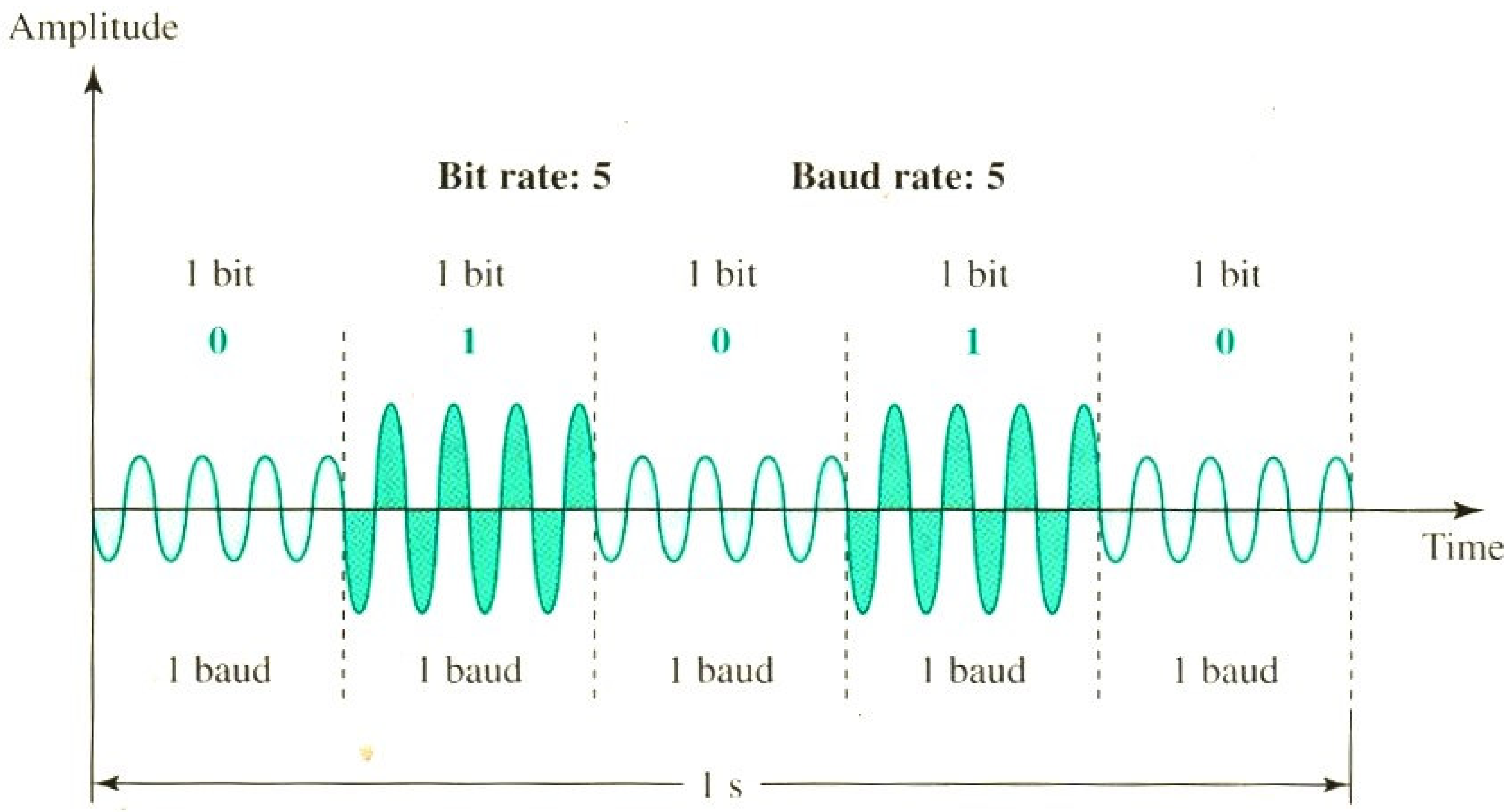
A ***bit duration*** is the period of time that defines a bit.

The peak amplitude during each bit duration is constant and its value depends on the bit (0 or 1).

Since noise affects the amplitude of a wave, ASK is most susceptible to noise.

Amplitude Shift Keying – An Example

For ASK, $n = N_{baud}$ (where n = bit rate and N_{baud} = baud rate)



From [1]

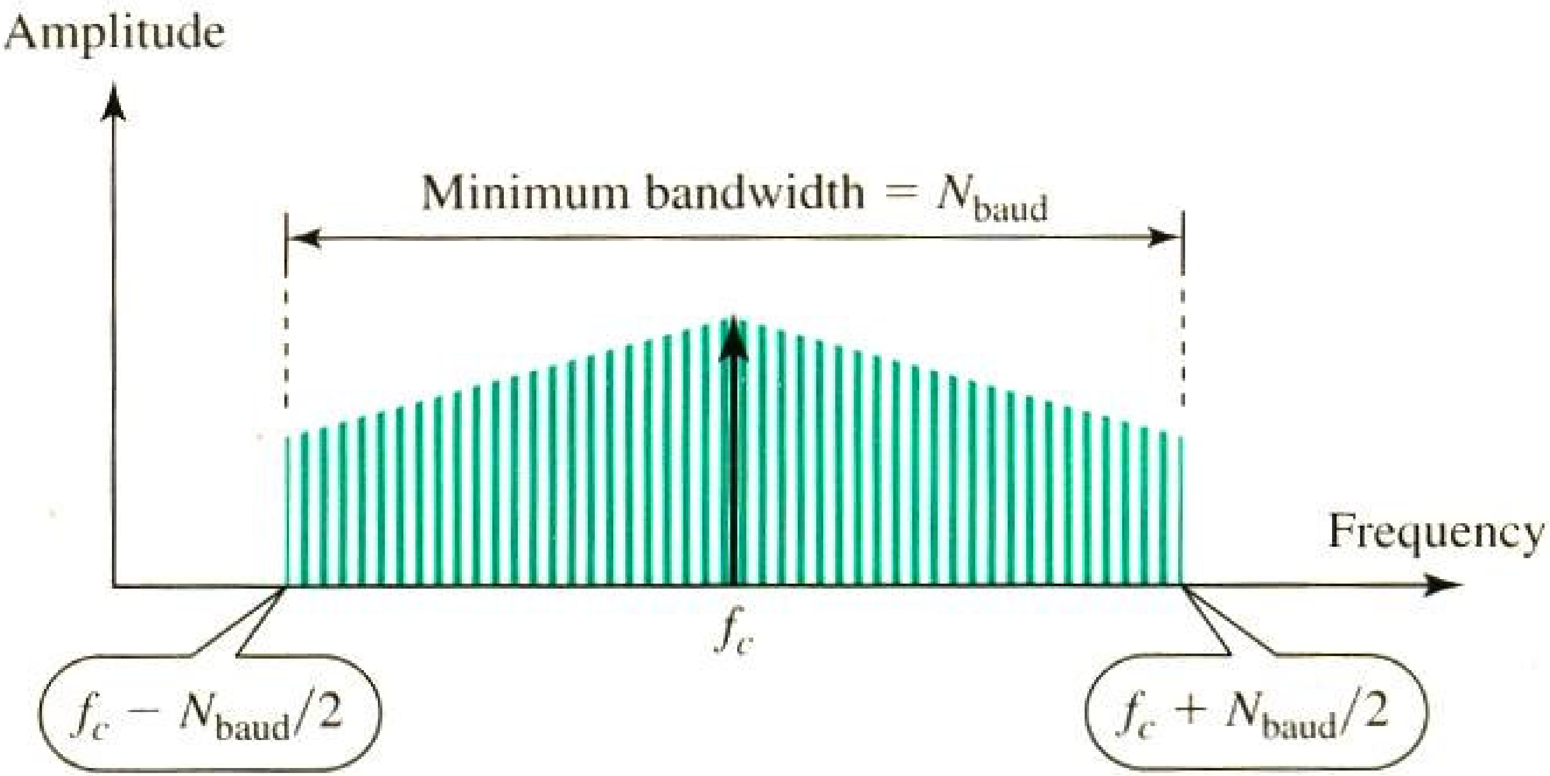
Amplitude Shift Keying - Bandwidth

Bandwidth requirements for ASK are calculated as:

$$BW_t = (1 + d) \times N_{baud}$$

where d is a modulation factor (with a minimum value of 0)

i.e. minimum bandwidth = N_{baud}



From [1]

Frequency Shift Keying (FSK)

In Frequency Shift Keying (**FSK**), the frequency of the carrier signal is varied to represent binary 0 or 1 as they appear on the message signal. Amplitude and phase however remain constant.

A ***bit duration*** is the period of time that defines a bit.

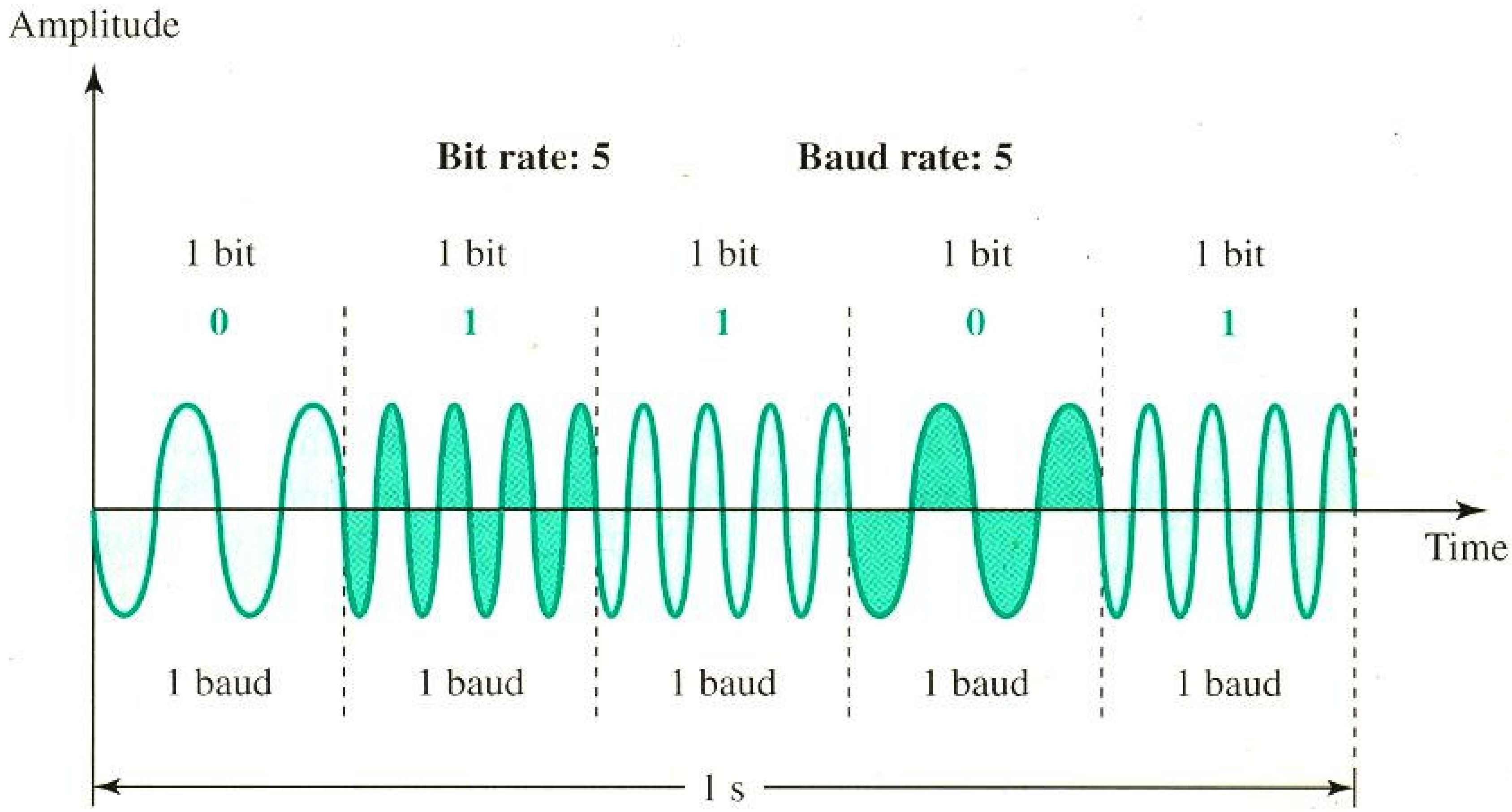
The frequency during each bit duration is constant and its value depends on the bit (0 or 1).

FSK is not susceptible to noise since the voltage spikes caused by noise do not affect the frequency of the signal.

However FSK has bandwidth limitations as shown later.

Frequency Shift Keying - An Example

For FSK, $n = N_{baud}$ (where n = bit rate and N_{baud} = baud rate)



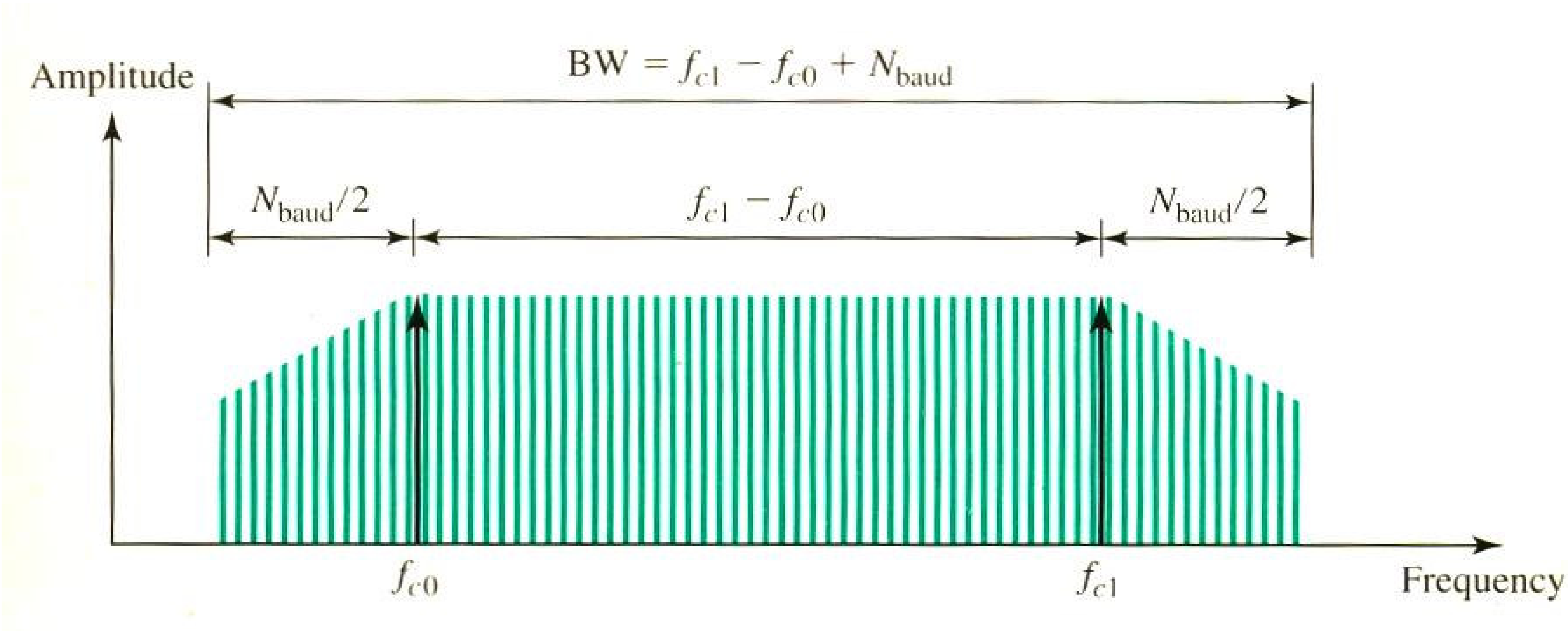
From [1]

Frequency Shift Keying - Bandwidth

Bandwidth requirements for FSK are calculated as:

$$BW_t = f_{c1} - f_{c0} + N_{baud}$$

where f_{c1} and f_{c0} are the frequencies for bits 1 and 0 respectively



From [1]

Phase Shift Keying (PSK)

In Phase Shift Keying (**PSK**), the phase of the carrier signal is varied to represent binary bits 0 or 1 (or a pair or trio of bits) as they appear on the message signal. Amplitude and frequency however remain constant.

The phase during each signal unit is constant and its value depends on the bit (0 or 1), dibit or tribit (see 4-PSK/8-PSK). Bit rate and baud rate are not always the same.

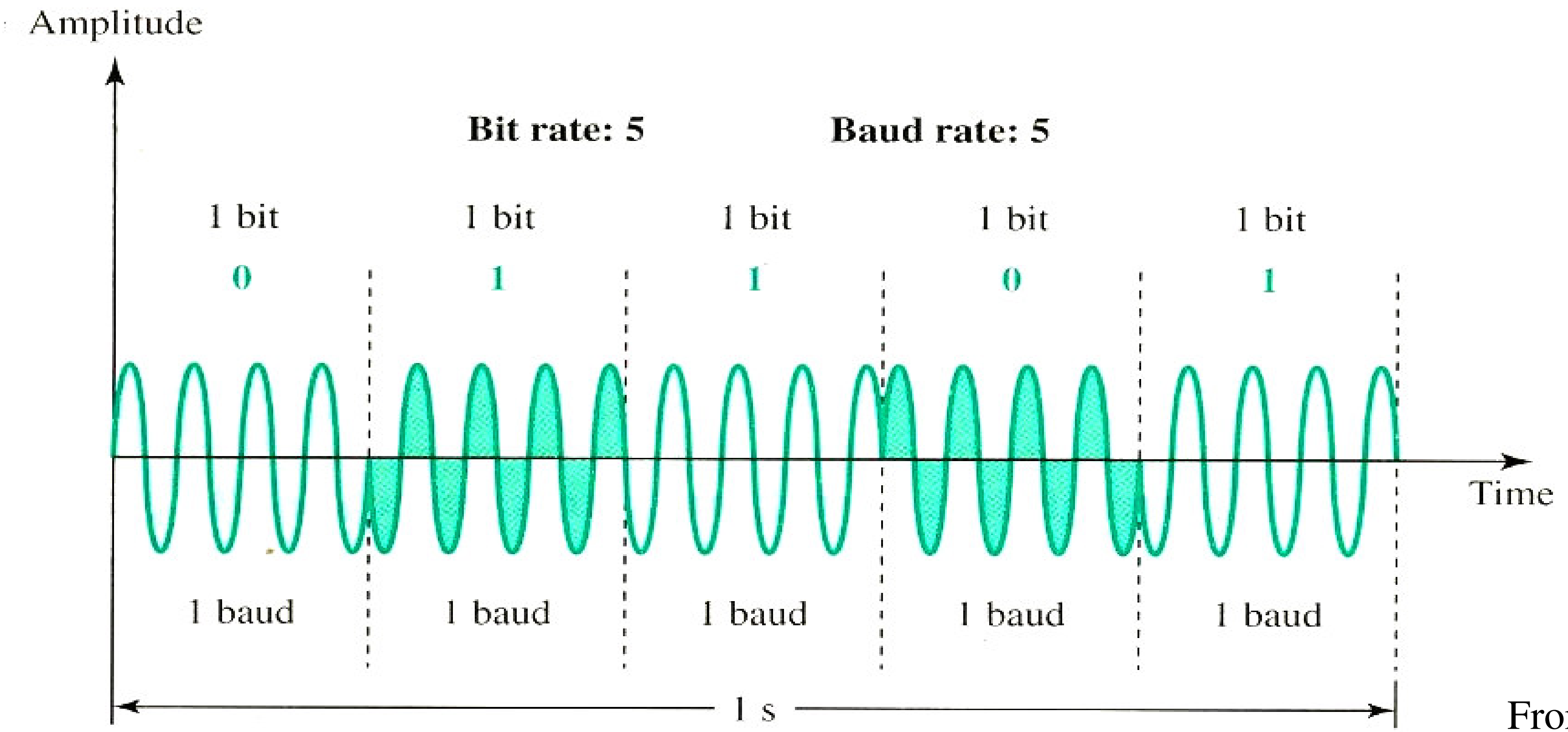
PSK is not susceptible to noise or bandwidth limitations.

It is however limited by the ability of the equipment to distinguish small difference in phase. This factor limits its potential bit rate.

Binary PSK (BPSK or 2-PSK)

2-PSK uses two different phases, i.e. one signal unit per bit (0^0 for bit 0 and 180^0 for bit 1)

For 2-PSK, $n = N_{baud}$ (n = bit rate, N_{baud} = baud rate)

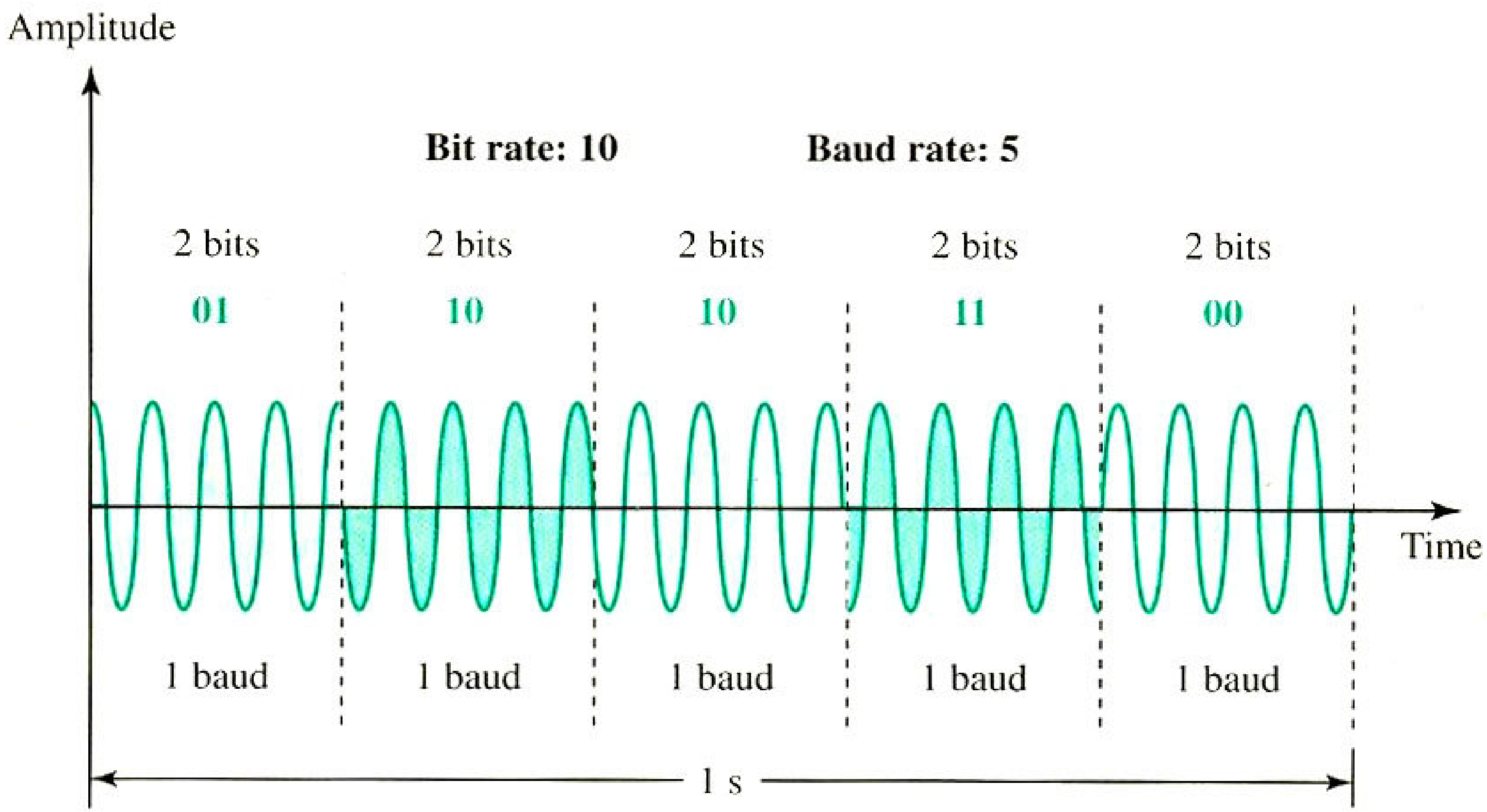


From [1]

Quaternary PSK (QPSK or 4-PSK)

4-PSK uses four different phases, i.e. 1 signal unit per 2 bits (0^0 for bits 00, 90^0 for 01, 180^0 for 10, 270^0 for 11)

For 4-PSK, $n = 2 \times N_{baud}$ (n = bit rate, N_{baud} = baud rate)



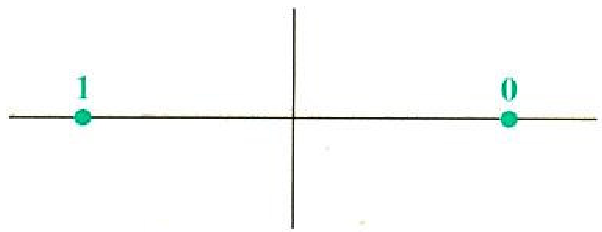
From [1]

PSK and Constellation Diagrams

Constellation diagrams are often used to show the relation between binary values and phases in PSK systems.

Bit	Phase
0	0
1	180

Bits

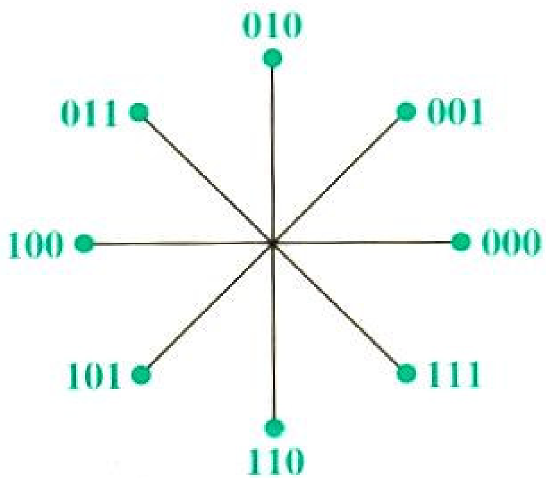


Constellation diagram

2-PSK

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

Tribits
(3 bits)

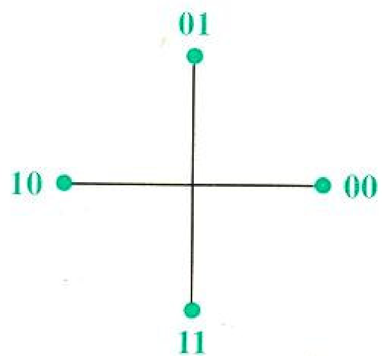


Constellation diagram

8-PSK

Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)



Constellation diagram

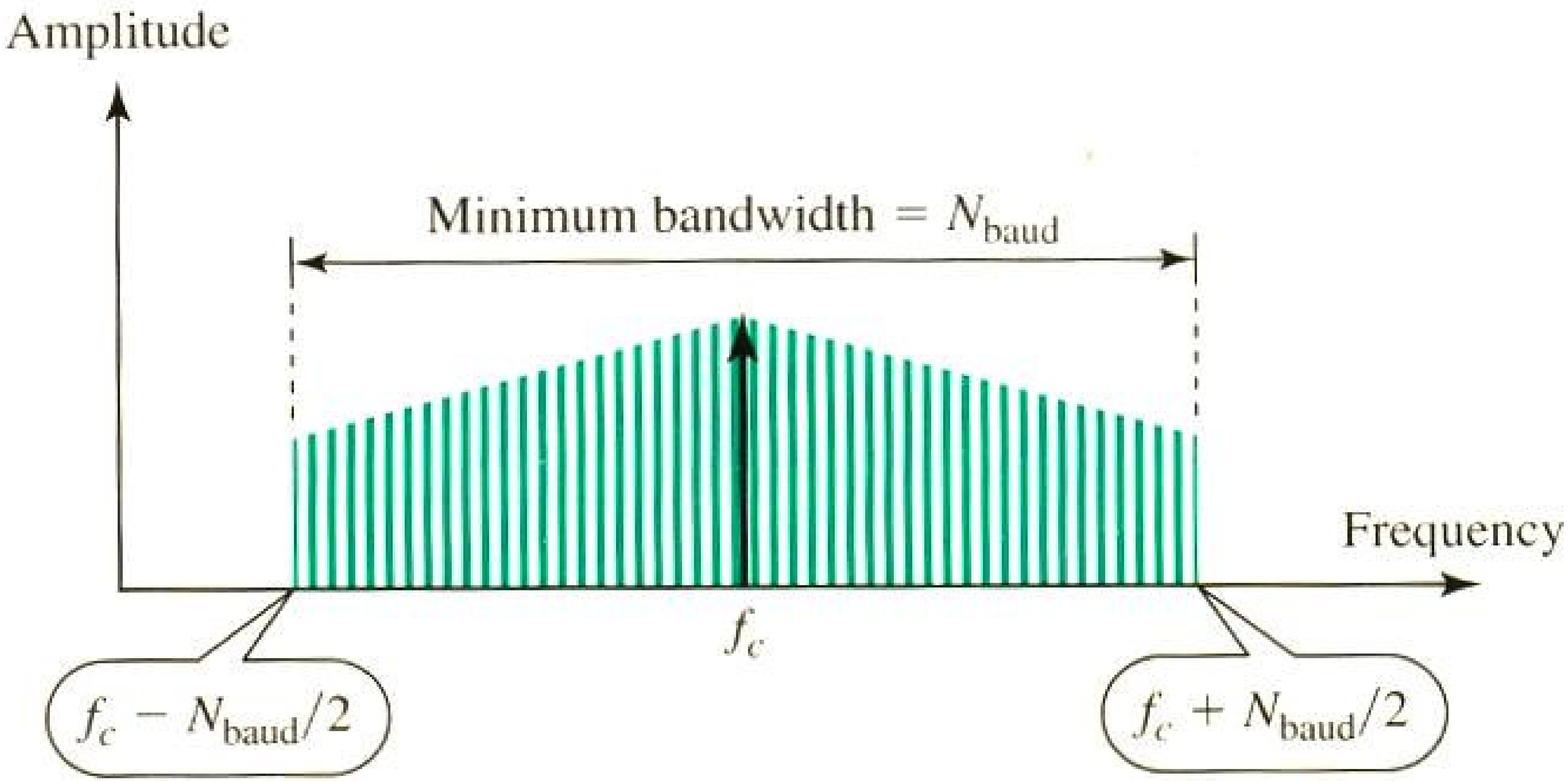
4-PSK

From [1]

Phase Shift Keying - Bandwidth

Bandwidth requirements for ASK are calculated as:

$$BW_t = N_{baud}$$



From [1]

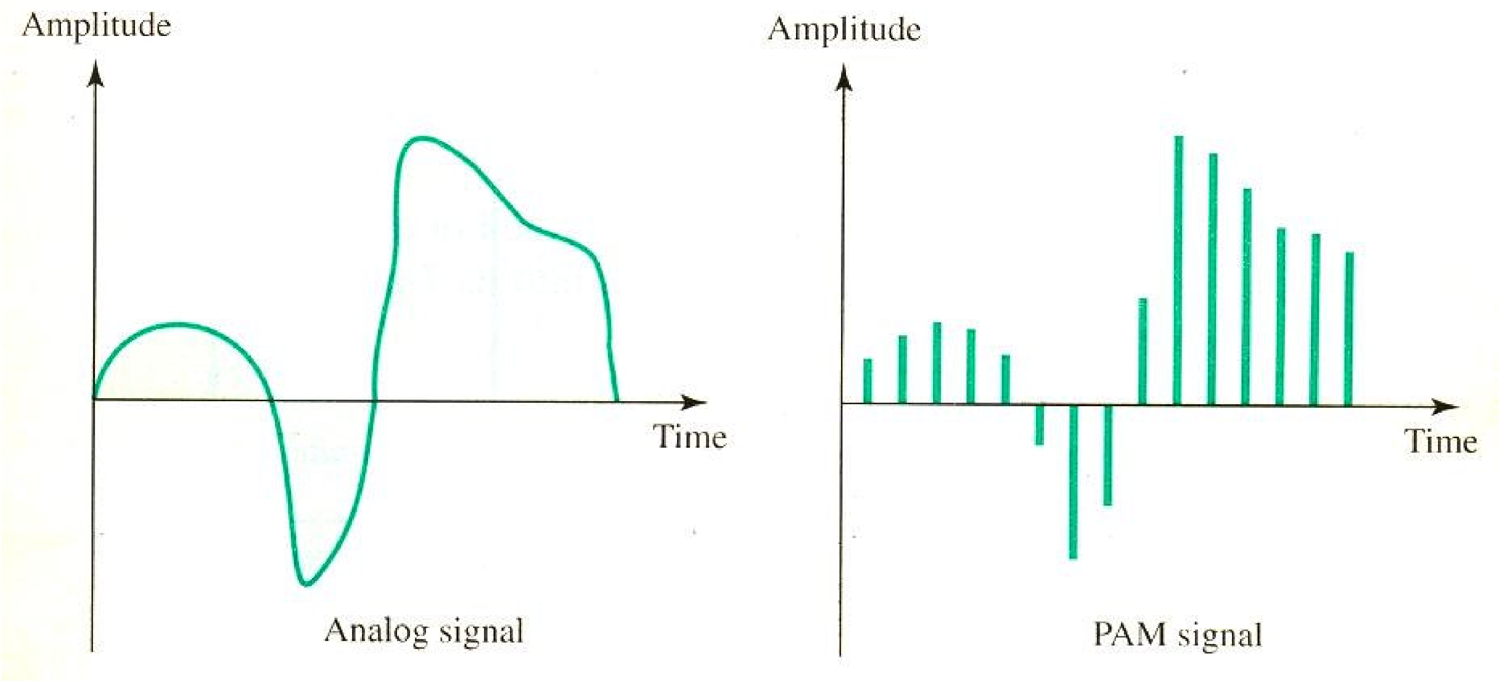
Pulse Code Modulation (PCM)

Pulse-Code Modulation (PCM) is the digital conversion or representation of an analog signal where the magnitude of the signal is sampled regularly at uniform intervals, then quantized to a series of symbols in a digital (usually binary) code.

Another technique **Pulse Amplitude Modulation** (**PAM**) is used as the first step in achieving PCM. PAM has some applications but it is not used itself in data communication.

Pulse Amplitude Modulation

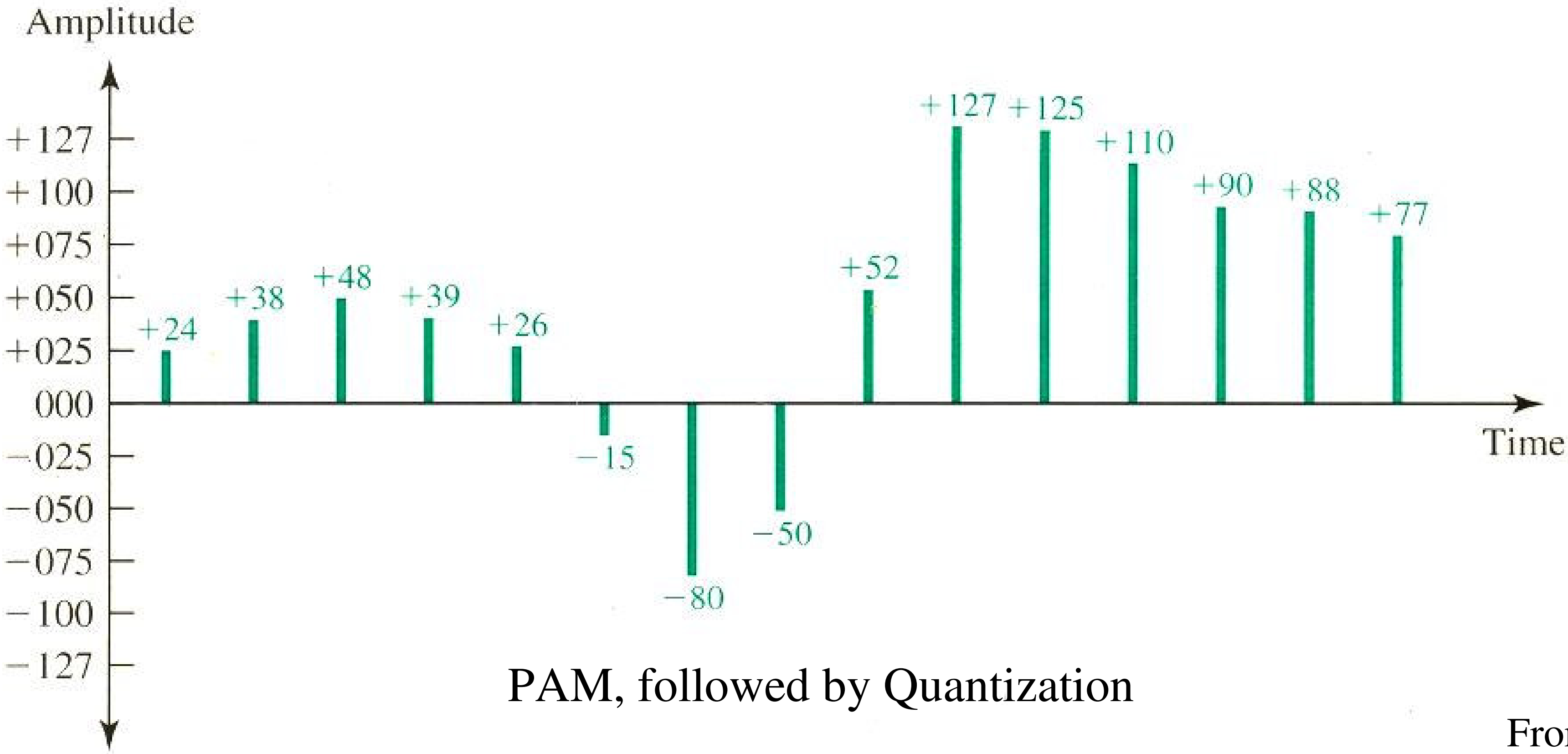
PAM takes a analog signal, samples it and generates a series of pulses based on the results of this sampling. The term **sampling** means measuring the amplitude of the signal at regular equal intervals. PAM uses a technique of **pulse and hold**, whereby the signal level is read, then held briefly. Although the new waveform is a series of pulses they are still of any amplitude i.e. analog.



From [1]

Quantization and Encoding

Quantization is the method integral values in a specific range to sampled instances. Each pulse is then assigned its corresponding value and converted to binary via **encoding**.



PAM, followed by Quantization

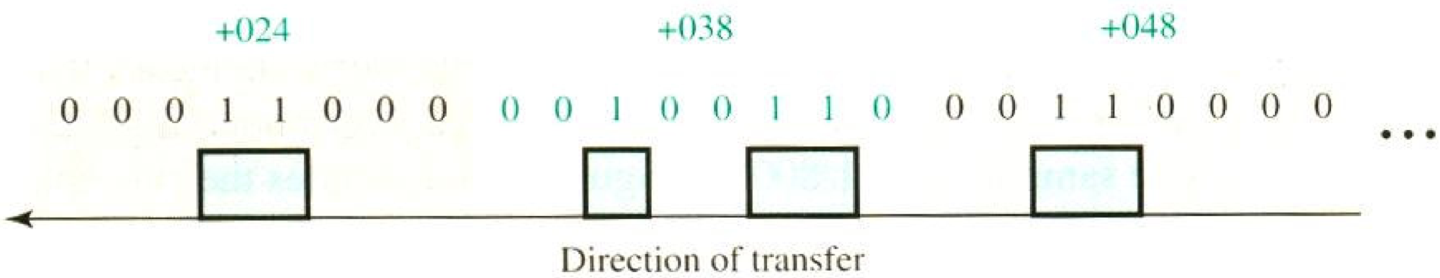
From [1]

Quantization and Encoding

+024	00011000	−015	10001111	+125	01111101
+038	00100110	−080	11010000	+110	01101110
+048	00110000	−050	10110010	+090	01011010
+039	00100111	+052	00110110	+088	01011000
+026	00011010	+127	01111111	+077	01001101

Sign bit
+ is 0   − is 1

PAM, Quantization, followed by Encoding



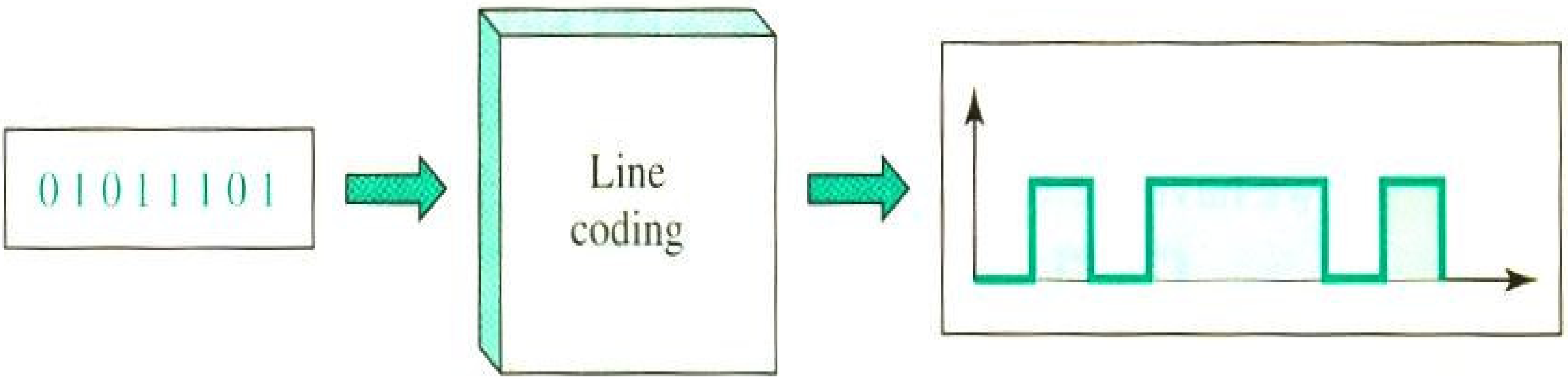
After Line Coding

From [1]

Line Coding

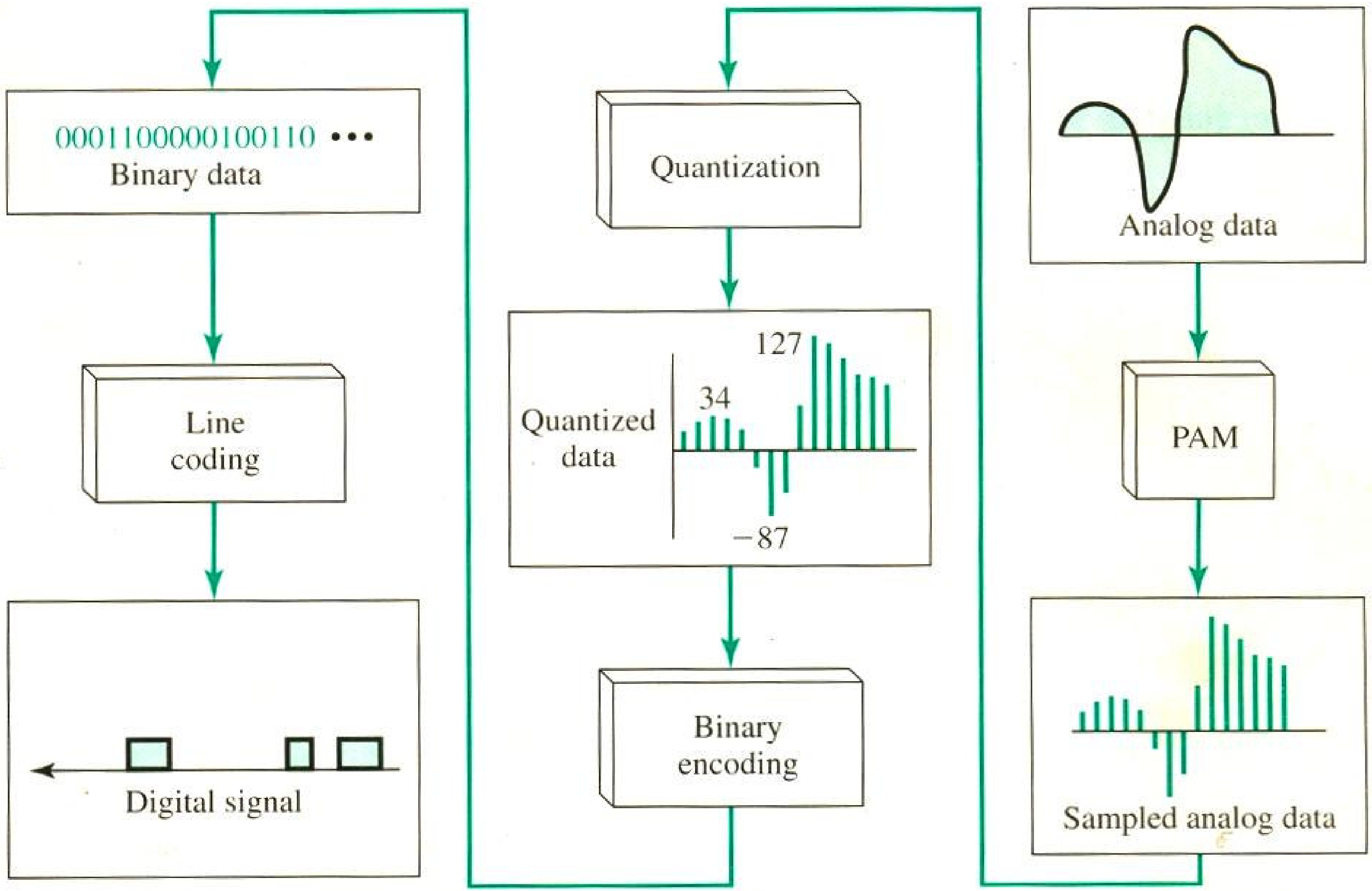
Line coding is the process of converting binary data, i.e. a sequence of bits, to a digital signal.

Methods of line coding include unipolar encoding, polar encoding, bipolar encoding, Manchester encoding etc.



From [1]

Analog Signal to Digital Signal via PCM



From [1]