Signal Encoding Techniques

ITS323: Introduction to Data Communications

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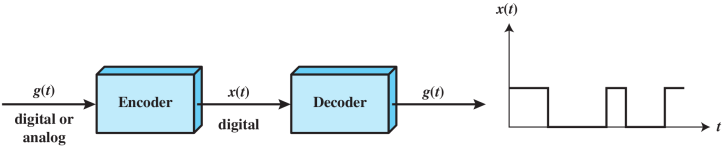
Contents

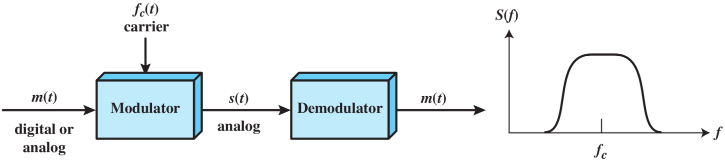
Signal Encoding Techniques

- Signals transmitted chosen to optimize use of transmission medium
  - E.g. conserve bandwidth, minimize errors
- Digital signaling: digital or analog data, $g(t)$, encoded into digital signal, $x(t)$
- Analog signaling: digital or analog data transmitted by analog carrier signal using modulation
  - Modulation: process of encoding source data onto a carrier signal with frequency f_c
  - Input signal, $m(t)$, is called baseband signal
  - Result of modulating carrier signal is called modulated signal, $s(t)$

Encoding and Modulation Techniques



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Reasons for Using Different Techniques

Digital data, digital signal: Equipment less complex/expensive than digital-to-analog modulation equipment

Analog data, digital signal: Permits use of digital transmission equipment

Digital data, analog signal: Some media only propagate analog signals, e.g. optical fibre, wireless

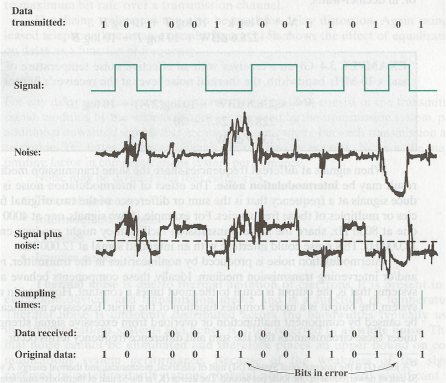
Analog data, analog signal: Some analog data can easily be transmitted as baseband signals, e.g. voice; enables multiple signals at different positions in spectrum to share transmission media

Contents

Digital Data, Digital Signals

- Digital signal: sequence of discrete voltage pulses
- Each pulse is a signal element
- Binary data transmitted by encoding each bit (data element) into signal elements
  - E.g. binary 1 represented by lower voltage level, binary 0 for higher level
- Data rate = data elements or bits per second; signaling or modulation rate = signal elements per second (baud)

Receiver Interpreting Incoming Signal



- Important factors for successful reception: SNR, data rate, bandwidth
  - Increase in data rate increases bit error rate (BER)
  - Increase in SNR decreases BER
  - Increase in bandwidth allows increase in data rate
- Also encoding scheme . . .

Definition of Digital Signal Encoding Formats

Nonreturn to Zero-Level (NRZ-L)
0 = high level
1 = low level

Nonreturn to Zero Inverted (NRZI)
0 = no transition at beginning of interval (one bit time)
1 = transition at beginning of interval

Bipolar-AMI
0 = no line signal
1 = positive or negative level, alternating for successive ones

Pseudoternary
0 = positive or negative level, alternating for successive zeros
1 = no line signal

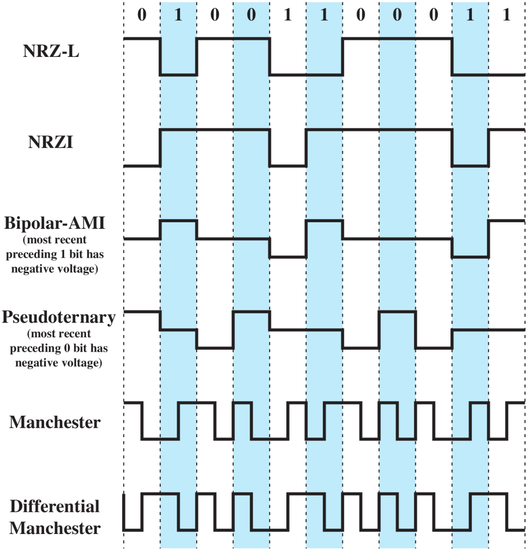
Manchester
0 = transition from high to low in middle of interval
1 = transition from low to high in middle of interval

Differential Manchester
Always a transition in middle of interval
0 = transition at beginning of interval
1 = no transition at beginning of interval

B8ZS
Same as bipolar AMI, except that any string of eight zeros is replaced by a string with two code violations

HDB3
Same as bipolar AMI, except that any string of four zeros is replaced by a string with one code violation

Digital Signal Encoding Formats



Comparing Different Encoding Schemes

Signal Spectrum

- Desire no high frequency components so less bandwidth is required
- Desire no dc component so ac coupling can be used (reduces bit error rate)
- Concentrate trasmitted power in middle of bandwidth

Clocking and Synchronization

- Transmitted signal can be used by receiver to synchronise bit timing

Comparing Different Encoding Schemes

Error Detection

- Receiver can detect some bit errors from the received signal

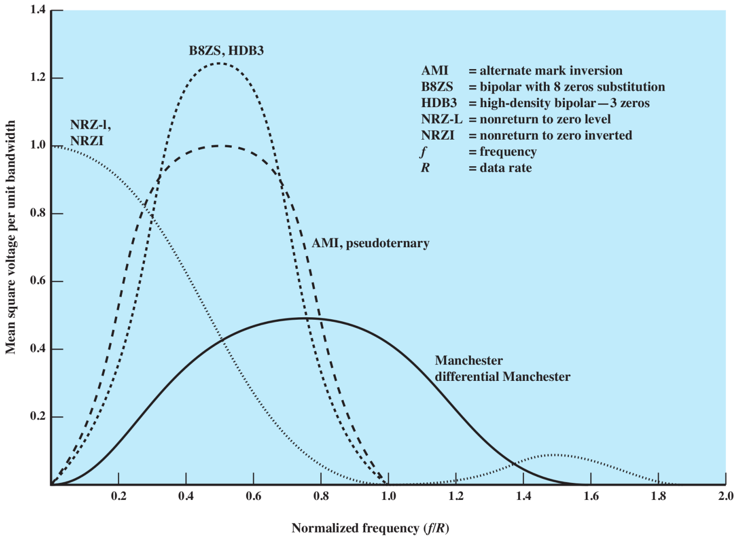
Signal Interference

- Provide good performance (few bit errors) in presence of noise

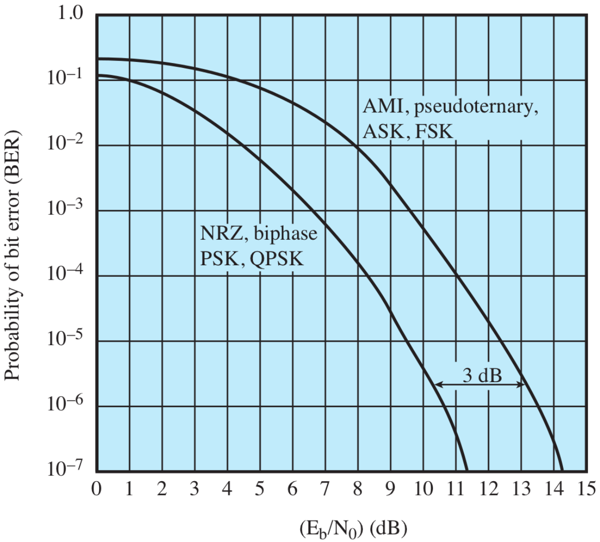
Cost and Complexity

- Desire smaller signaling rate to achieve a given data rate

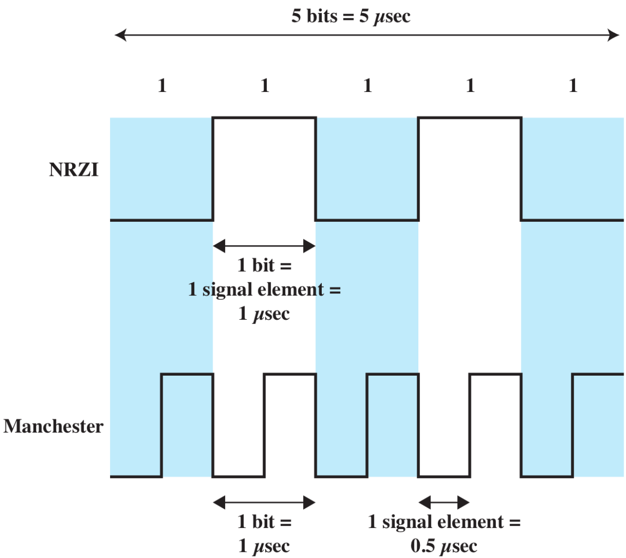
Spectral Density of Various Signal Encoding Schemes



Theoretical Bit Error Rate for Various Encoding Schemes



A Stream of Binary Ones at 1 Mbps



Improving on NRZ

Multilevel Binary Schemes

- Bipolar AMI, Pseudoternary
- Use more than two signal levels
- No dc component, simple error detection, no loss of synchronization (in some cases), small bandwidth needed
- Requires more transmit power for same level of BER as two-level schemes

Biphase Schemes

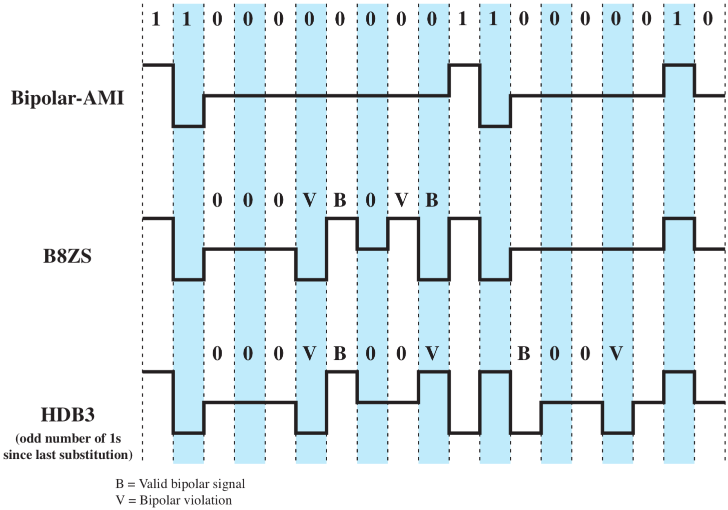
- Manchester, differential Manchester
- More than 1 transition per bit
- Similar features to multilevel schemes, but larger bandwidth required

Improving Synchronization

- In Bipolar AMI a long sequence of 0's makes it difficult for the receiver to synchronize
- Solution: if long sequence of same bit, replace with special sequence of bits
- B8ZS (Bipolar with 8-zeros substitution)
  - If 8 0's and last pulse was positive, replace 8 0's with $000 + -0 - +$
  - If 8 0's and last pulse was negative, replace 8 0's with $000 - +0 + -$
- HDB3 (High density bipolar 3-zeros)

	Number of Bipolar Pulses (ones) since Last Substitution	
Polarity of Preceding Pulse	**Odd**	**Even**
–	000–	+00+
+	000+	–00–

Encoding Rules for B8ZS and HDB3



Example Technologies using Encoding Schemes

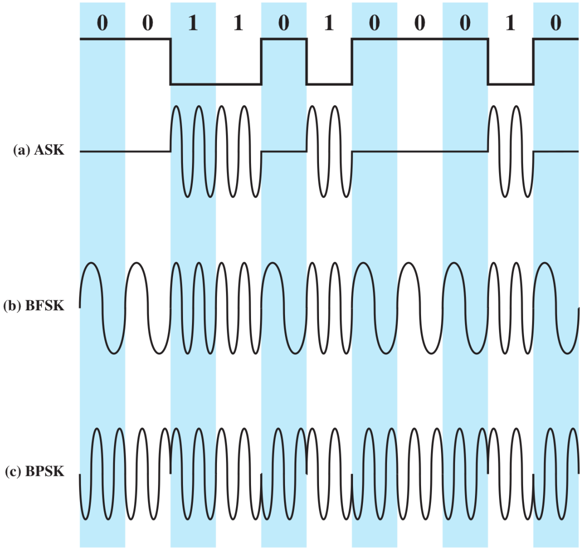
- NRZ/NRZI: RS-232, HDLC, USB, ...
- Manchester: Ethernet, Token Ring, ...
- Multilevel Binary: US T-carrier and European E-carrier telecommunication systems

Contents

Digital Data, Analog Signals

- Transmit digital data over media that only support analog signals, e.g. telephone network, microwave systems
  - Telephone network designed to transmit signals in voice-frequency (300 to 3400 Hz)
  - Modems (modulator-demodulator) convert digital data to signals in this frequency range
- 3 basic modulation techniques:
  1. Amplitude Shift Keying (ASK)
  2. Phase Shift Keying (PSK)
  3. Frequency Shift Keying (FSK)
- Resulting signal occupies bandwidth centred on carrier frequency

Modulation of Analog Signals for Digital Data



Comparing the Shift Keying Schemes

Amplitude Shift Keying

- Inefficient modulation technique
- Used on voice lines < 1200 bps and optical fibre

Frequency Shift Keying

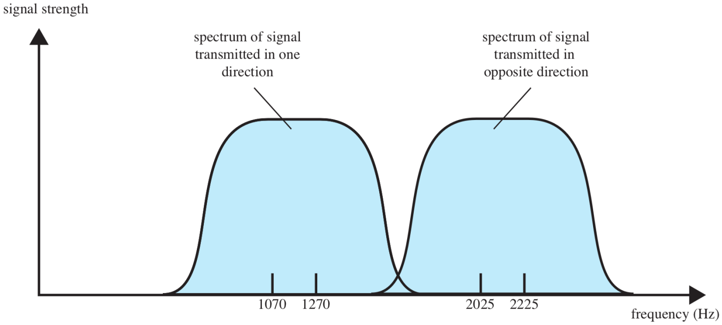
- Used on voice lines, coaxial cable, HF radio systems
- Extended with M frequencies: improve efficiency, higher error rate

Phase Shift Keying

- Used in wireless transmission systems
- Extended with M phases, e.g. QPSK ($M = 4$),
- Combined with ASK: Quadrature Amplitude Modulation (QAM); used in ADSL and wireless systems

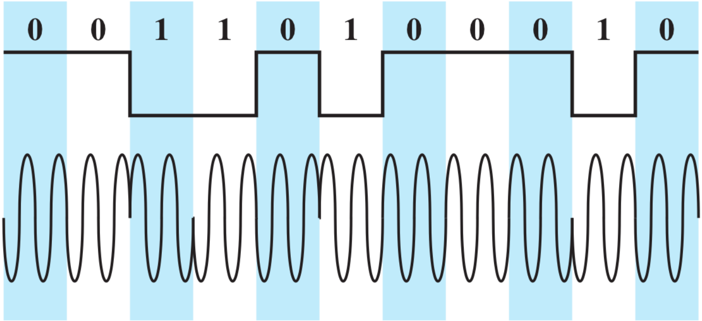
Example of FSK

Full-Duplex FSK Transmission on a Voice-Grade Line



Example of PSK

Differential Phase-Shift Keying



Example Technologies using Shift Keying

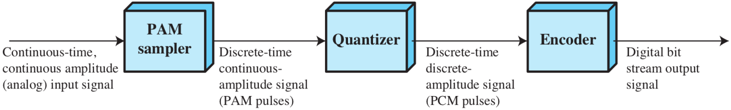
- ASK: Optical fibre, RFID
- FSK: HF/shortwave radio, UHF/VHF radio comms, RFID
- PSK and QAM: mobile phones, Wi-Fi, cable modems, xDSL, DVB, ...

Contents

Analog Data, Digital Signals

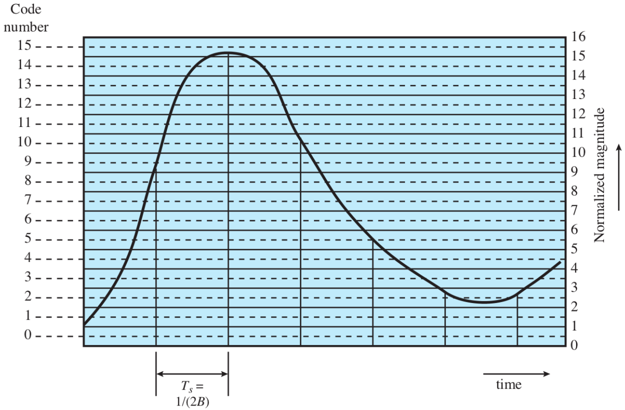
- Two options:
  1. Convert analog data to digital data; transmit digital data as digital signal (e.g. using NRZ)
  2. Convert analog data to digital data; modulate the data to transmit as analog signal (e.g. PSK)
- How to digitize analog data?
  - Codec converts analog to digital data, and recovers digital data from analog data
  - Consider two techniques used in codecs: Pulse Code Modulation and Delta Modulation

Pulse Code Modulation



1. Divide the normalised input magnitude into 2^n different levels, with corresponding code numbers
2. Sample analog input every T_s seconds $\rightarrow$ pulse amplitude modulation (PAM) value
3. Map PAM value to nearest code number
4. Convert code number to n-bit binary PCM code

Pulse Code Modulation Example



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

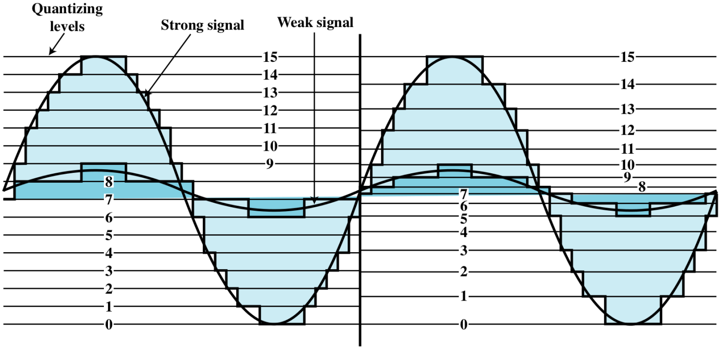
Sampling Theorem

If a signal $f(t)$ is sampled at regular intervals of time and at a rate higher than twice the highest signal frequency, then the samples contain all the information of the original signal

- Example: voice is between 0 and 4000 Hz; sampling at 8000 samples per second is sufficient to reproduce analog voice at receiver
- BUT . . . quantizing the PAM values introduces error (or noise); each additional bit increases SNR by 6 dB
- Good voice reproduction can be achieved with 128 quantization levels (7-bit coding)

Improving PCM with Nonlinear Coding

- Linear spacing of quantization levels can result in poor reproduction of weak signals
- Non-linear encoding: more steps for low amplitude, less steps at high amplitude
- Can lead to significant improvement for voice

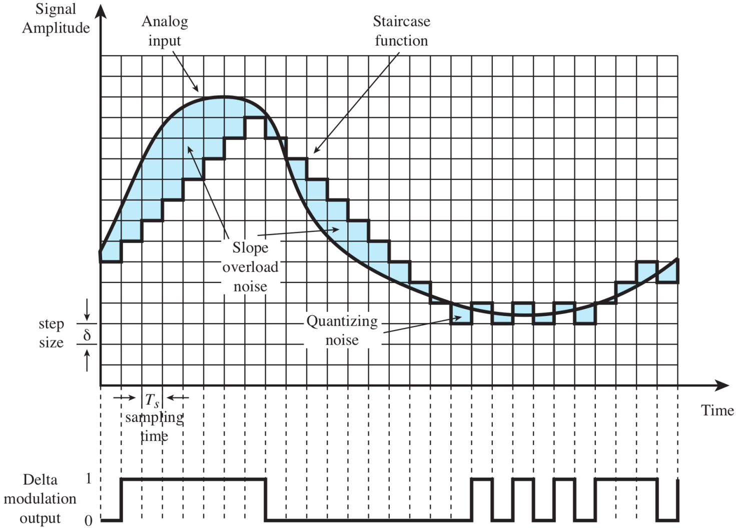


(a) Without nonlinear encoding (b) With nonlinear encoding

Delta Modulation

- Popular alternative to PCM
- Input analog data approximated by staircase function
- Moves up/down by one quantization level (δ) each sampling interval (T_s)
- If signal goes up, bit 1 is output; otherwise bit 0

Example of Delta Modulation

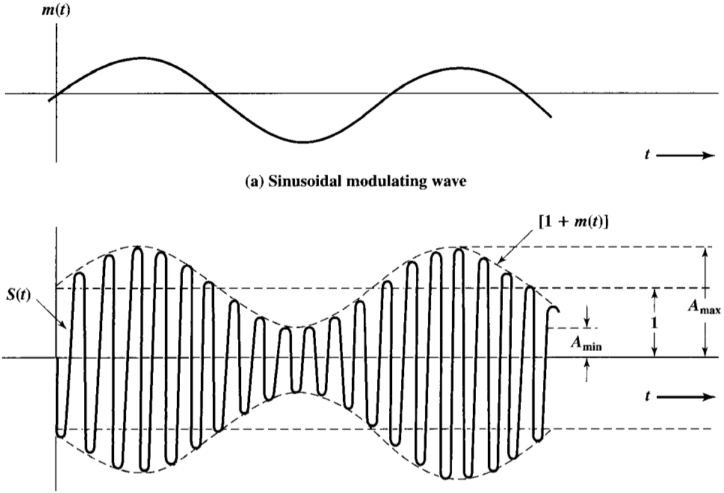


Contents

Modulating Signals

- Combine input signal, $m(t)$, and carrier at frequency f_c to produce signal $s(t)$ whose bandwidth is centered on f_c
- Why? If analog transmission systems ...
  - Digital data must be convereted to analog form (e.g. PSK, FSK)
  - Analog signals may need to be transmitted at higher frequency than analog data
  - Changing frequency of analog data allows for frequency division multiplexing (sending different ananlog data in one analog signal)
- Principal techniques: amplitude modulation (AM), frequency modulation (FM), phase modulation (PM)

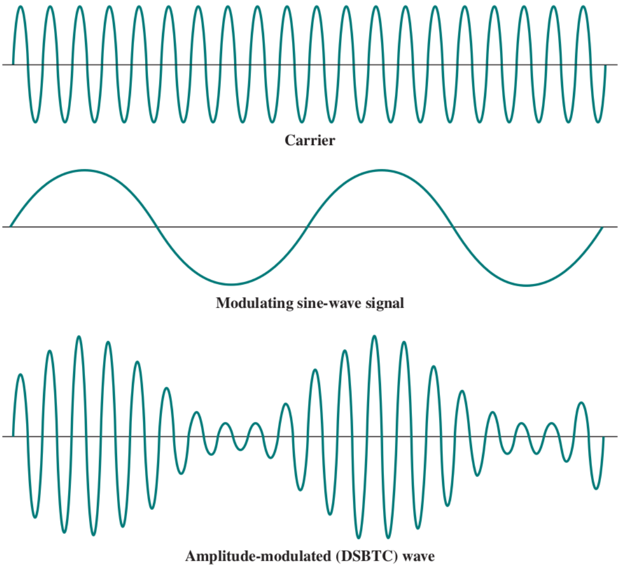
Amplitude Modulation



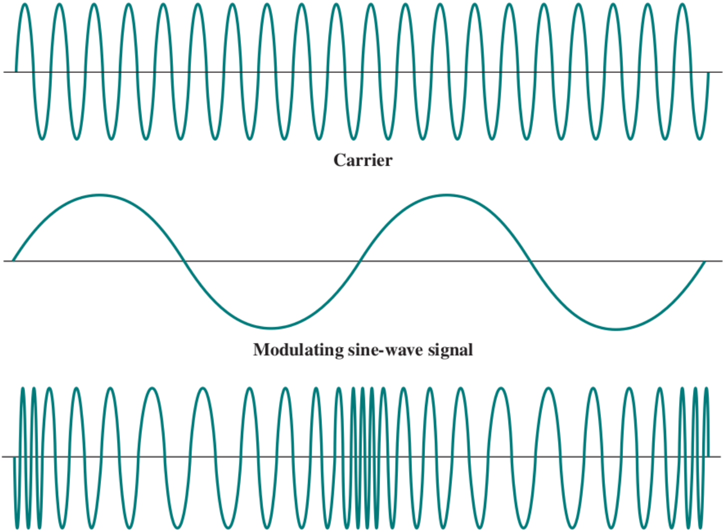
(a) Sinusoidal modulating wave

(b) Resulting AM signal

Amplitude Modulation of a Sine-Wave Carrier by a Sine-Wave Signal



Phase Modulation of a Sine-Wave Carrier by a Sine-Wave Signal



Frequency Modulation of a Sine-Wave Carrier by a Sine-Wave Signal