Analog data, analog signals

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Question

The process of combining an input signal m(t) and a carrier at frequency f_c to produce a signal s(t) whose bandwidth is (usually) centered on f_c is:

(A) multiplexing

(B) modulation

(C) sampling

(D) companding

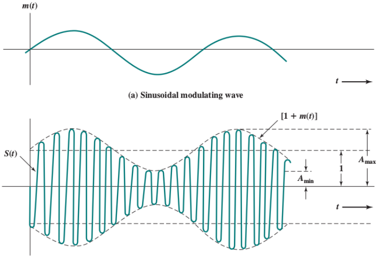
Analog data, analog signals

- When only analog transmission facilities are available, modulation is required to convert digital data to analog form
- Voice signals are transmitted over telephone lines at their original spectrum (referred to as baseband transmission)
- Why must analog data be modulated ?
  1. A higher frequency may be needed for effective transmission (low frequency transmission requires long antennas)
  2. Modulation permits frequency-division multiplexing
- Principal modulation techniques: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM)

An example: radio

- The government assigns a narrow bandwidth to each radio station
- The analog signal produced by a radio station is a low-pass signal, each in the same range
- To be able to listen to different stations, the low-pass signals need to be shifted, each to a different range

Amplitude Modulation



(a) Sinusoidal modulating wave

(b) Resulting AM signal

$$s(t) = [1 + n_a x(t)] \cos 2\pi f_c t$$

$\cos 2\pi f_c t$: the carrier, x(t): the input signal carrying data, both normalized to an amplitude of 1. Modulation index $n_a =$ amplitude of the input signal / amplitude of the carrier.

$$m(t) = n_a x(t)$$

This scheme: double sideband transmitted carrier (DSBTC).

Amplitude Modulation

$$s(t) = [1 + n_a x(t)] \cos 2\pi f_c t$$

Suppose the modulating signal $x(t) = \cos 2\pi f_m t$

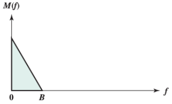
$$s(t) = [1 + n_a \cos 2\pi f_m t] \cos 2\pi f_c t$$

$$s(t) = \cos 2\pi f_c t + n_a \cos 2\pi f_m t \cos 2\pi f_c t$$

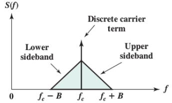
$$s(t) = \cos 2\pi f_c t + \frac{n_a}{2} \cos 2\pi (f_c - f_m) t + \frac{n_a}{2} \cos 2\pi (f_c + f_m) t$$

- a component at the original carrier frequency
- plus a pair of components each spaced f_m Hz from the carrier.
- AM involves the multiplication of the input signal by the carrier
- The envelope of the resulting signal is $[1 + n_a x(t)]$

Amplitude Modulation



(a) Spectrum of modulating signal

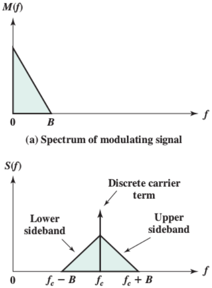


(b) Spectrum of AM signal with carrier at f_c

Both the upper and lower sidebands are replicas of the original spectrum M(f), with the lower sideband being frequency reversed

- voice signal with a bandwidth that extends from 300 to 3000 Hz
- being modulated on a 60-kHz carrier
- s(t): upper side band: 60.3 to 63 kHz, lower side band: 57 to 59.7 kHz, and the 60-kHz carrier
- Amplitude of carrier: 50 V, amplitude of signal: 20 V
- $n_a = 20/50 = 0.4$

Amplitude Modulation



(a) Spectrum of modulating signal

(b) Spectrum of AM signal with carrier at f_c

- s(t) contains unnecessary components, because each of the sidebands contains the complete spectrum of m(t)
- single sideband (SSB) : sends only one sideband
  - Only half the bandwidth is required, $B_T = B$, where B is the bandwidth of the original signal. (For DSBTC, $B_t = 2B$)
  - Less power is required because no power is used to transmit the carrier or the other sideband

Amplitude Modulation

Double Sideband Suppressed Carrier (DSBSC):filters out the carrier frequency and sends both sidebands.
This saves some power but uses as much bandwidth as DSBTC

Vestigial Side Band

The carrier can be used for synchronization

- Suppose the original analog signal is an ASK waveform encoding ______ data
- The receiver needs to know the starting point of each bit time to interpret the data correctly.
- compromise: vestigial sideband (VSB), which uses one sideband and a reduced- power carrier

Question

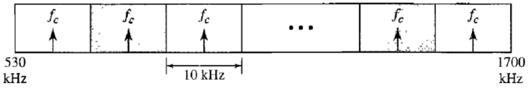
The bandwidth of an audio signal (speech and music): 5kHz Therefore an AM radio station (using DSBTC) needs a bandwidth of ______

(A) 5KHz

(B) 10kHz

(C) 3.4 kHz

AM Radio



- Carrier frequencies: between 530 and 1700kHz
- Carrier frequencies of each station is separated by 10 kHz
- Being phased out in many parts of the world (overtaken by digital broadcasting, radio over the internet etc.). Useful in disaster situations
- Another use of AM! : https://www.mattblaze.org/blog/neinnines/

Angle Modulation

FM and PM are special cases of angle modulation

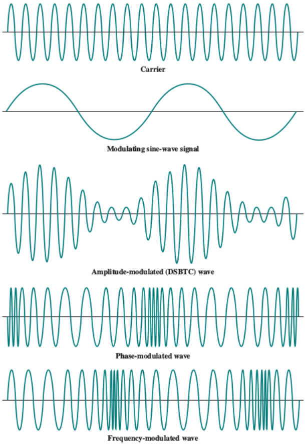
$$s(t) = A_c \cos[2\pi f_c t + \phi(t)]$$

- For phase modulation, $\phi(t) = n_p m(t)$, where n_p is the modulation index
- For Frequency Modulation (FM), the instantaneous frequency of the carrier wave deviates from f_c in proportion to the amplitude of the modulating signal.
- Equivalently, for FM, $\phi'(t) = n_f m(t)$ where n_f is the frequency modulation index and $\phi'(t)$ is the derivative of $\phi(t)$.
- The peak deviation of frequency from f_c

$$\Delta F = \frac{1}{2\pi} n_f A_m$$

A_m is the maximum value of $m(t)$

Angle Modulation



FM:Observations

- The peak deviation of frequency from f_c

$$\Delta F = \frac{1}{2\pi} n_f A_m$$

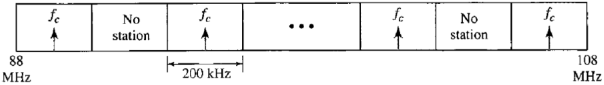
  A_m is the maximum value of $m(t)$
- An increase in magnitude of m(t) will increase the peak deviation of frequency, which increases B_T
- This will not increase the average power level of the FM signal, which is ${A_c}^2/2$ (A_c: peak amplitude of the carrier signal)
- But in AM, the level of modulation affects the power in the AM signal but does not affect its bandwidth.

Observations

- Angle modulation causes a wide range of frequencies
- s(t) will contain components at $f_c + f_m$, $f_c + 2f_m$ and so on for a modulating sinusoid of frequency f_m
- Therefore for the most general analog signal, infinite bandwith is required
- Carson's rule for angle modulation: $B_T = 2(\beta + 1)B$ where
  - $\beta = n_p A_m$ for PM and
  - $\beta = \frac{\Delta F}{B} = \frac{n_f A_m}{2\pi B}$ for FM.

  A_m is the maximum value of m(t). B is the bandwidth of the original signal (modulating signal)
- We can re-write the formula for FM as $B_T = 2(\frac{\Delta F}{B} + 1)B = 2\Delta F + 2B$
- Thus FM and PM require more bandwidth than AM

FM Radio



- Audio signal: bandlimited at 15kHz
- Carrier frequencies: between 88 and 108 MHz
- The carrier frequency of each station is separated by at least 200 kHz
- Popular for short range broadcasts