Amplitude Modulation

Tomasi, Chapter 3

1

Why AM?

- Need to insert message onto a higher frequency carrier
- Carriers assigned spectrum channels to allow spectrum sharing
- Modulation – allows us to put message signal onto carrier signal; result is a modulated signal

2

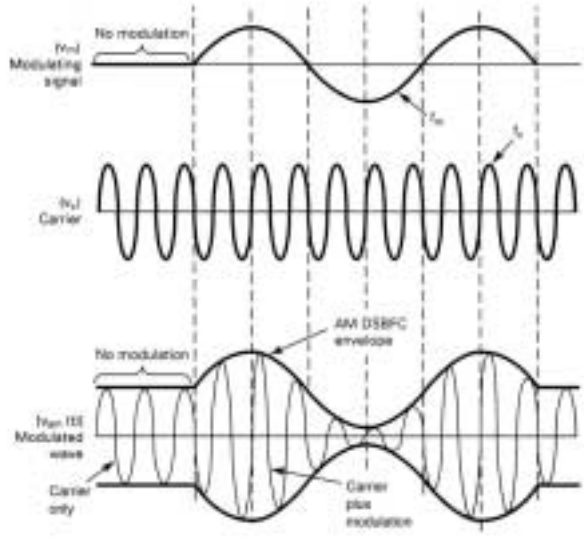
AM

- Change carrier amplitude to follow message
- Example –
  - Standard message test signal: single-frequency sinusoid
  - See next figure ("Double sideband full-carrier AM = DSBFC AM")

3

AM Wave (Sinusoid Message)

FIGURE 3-1 AM generation



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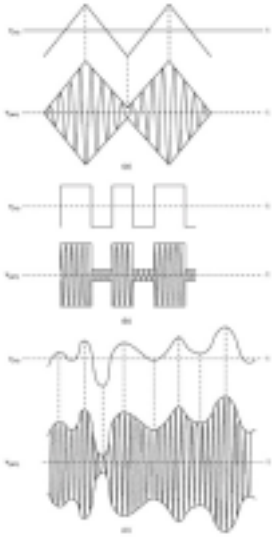
4

AM Waveforms

- Examples of non-sinusoid messages
  - Top: triangle wave (aka sawtooth wave)
  - Middle: Pulse train
  - Bottom: Arbitrary waveform (e.g., piece of speech, music, video from analog camera)

FIGURE 3-29 AM with complex modulating signal: (a) triangular wave modulation; (b) rectangular wave modulation; and (c) voice modulation



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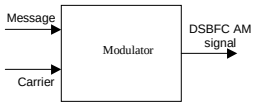
5

DSBFC AM

- In math,
  - Message: $v_m(t) = E_m \sin(2\pi f_m t)$
  - Carrier: $v_c(t) = E_c \sin(2\pi f_c t + \alpha_c)$
  - Modulated carrier:

$$v_{am}(t) = \left[1 + mE_m \sin(2\pi f_m t)\right] E_c \sin(2\pi f_c t + \alpha_c)$$



m is modulation index ($m \le 1$)

6

DSBFC AM with General Message

- General message:
  - Message: $v_m(t)$
  - Carrier: $v_c(t) = E_c \sin(2\pi f_c t + \alpha_c)$
  - Modulated carrier:

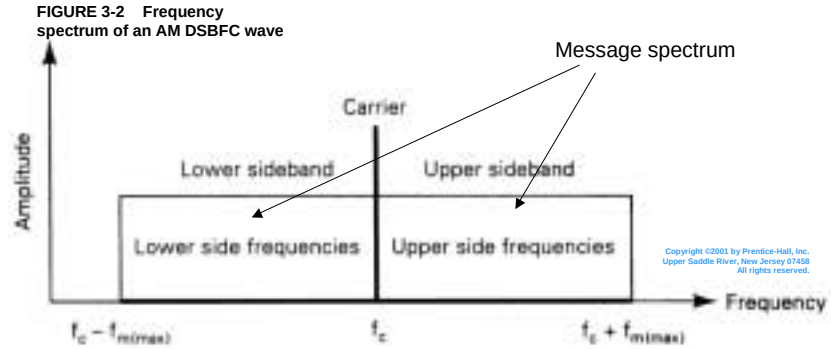
$$v_{am}(t) = \left[1 + mv(t)\right] E_c \sin(2\pi f_c t + \alpha_c)$$

m is modulation index ($m \le 1$)

7

Positive Frequency Spectrum of DSBFC AM with General Message

FIGURE 3-2 Frequency spectrum of an AM DSBFC wave



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Note: message is band-limited

- Message spectrum is frequency translated to f_c (USB); another copy of the spectrum is reflected around f_c (LSB).

8

Bandwidths

- Message is bandlimited: 0 to $f_{m\ max}$
- Modulated waveform from f_c- $f_{m\ max}$ to f_c+ $f_{m\ max}$
- The total bandwidth of AM signal: $2f_{m\ max}$

9

Modulation Index

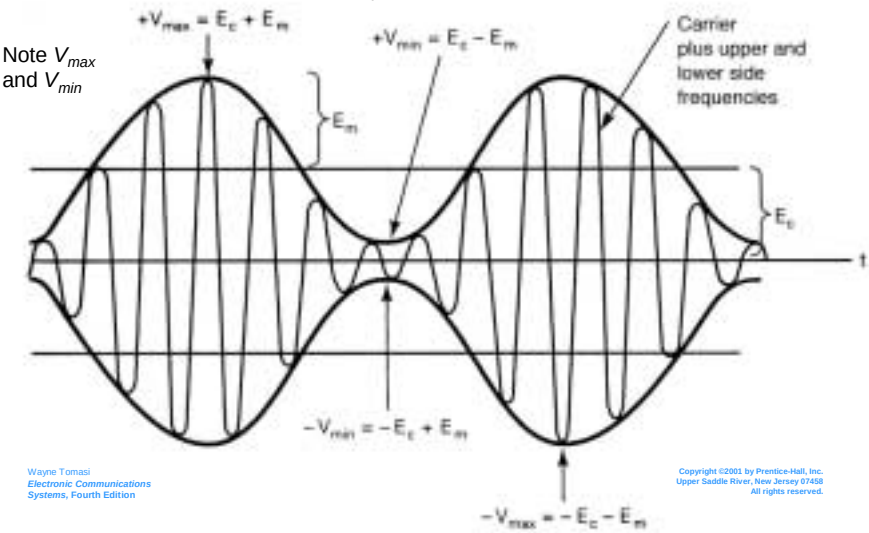
- Modulation index: $m = E_m / E_c$
- Percent modulation: $m \times 100\%$
- Describes depth of troughs in AM wave

10

AM Signal with Sinusoid Message

FIGURE 3-5 Modulation coefficient, E_m, and E_c

Note V_{max} and V_{min}



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Finding Math Expression from Waveforms

- Start by measuring V_{max} and V_{min}

$$E_m = \frac{1}{2}(V_{max} - V_{min})$$

$$E_c = \frac{1}{2}(V_{max} + V_{min})$$

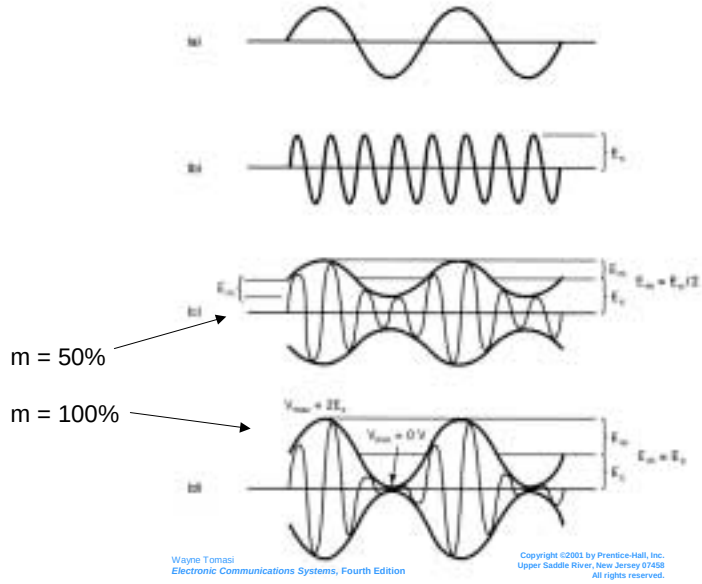
$$m = \frac{(V_{max} - V_{min})}{(V_{max} + V_{min})} \times 100\%$$

Peak amplitude of sideband

$$E_{usf} = E_{lsf} = \frac{E_m}{2} = \frac{1}{4}(V_{max} - V_{min})$$

Effect of *m* value

FIGURE 3-6 Percent modulation of an AM DSBFC envelope: (a) modulating signal; (b) unmodulated carrier; (c) 50% modulated wave; (d) 100% modulated wave



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Upper & Lower Sidebands

- Peak change in amplitude of output wave is sum of voltages from upper and lower sidebands

$$E_m = E_{usf} + E_{lsf}$$

where

$$E_{usf} = E_{lsf} = \frac{E_m}{2}.$$

Frequency-Domain Representation

- Consider sinusoid message,

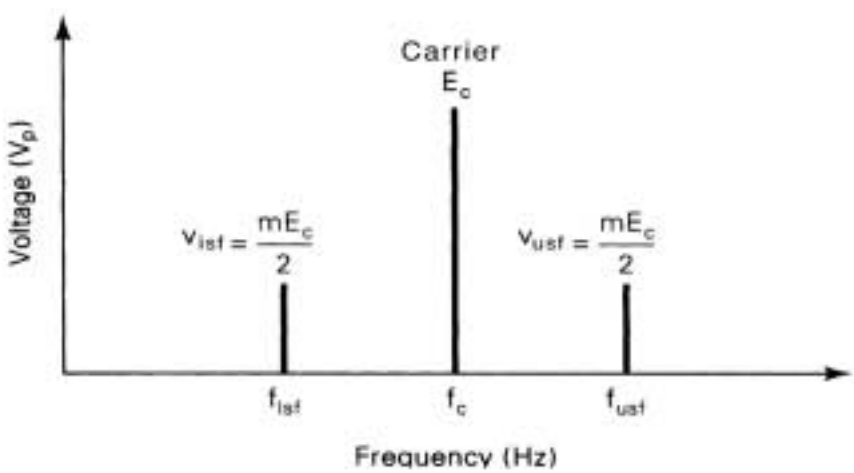
$$v_{am}(t) = \left[1 + m\sin(2\pi f_m t)\right]\left[E_c \sin(2\pi f_c t)\right]$$
$$= E_c \sin(2\pi f_c t) - \frac{mE_c}{2}\cos\left[2\pi(f_c + f_m)t\right]$$
$$+ \frac{mE_c}{2}\cos\left[2\pi(f_c - f_m)t\right]$$

- Spectrum…
  - Component at f_c
  - Component at f_c+f_m
  - Component at f_c-f_m
  - See graph on next page

15

Spectrum of Single-Frequency Message AM

FIGURE 3-8 Voltage spectrum for an AM DSBFC wave



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16

Properties of DSBFC AM Spectrum

- Value of carrier component is E_c (independent of modulation)
- Value of sideband depends on both…
  - The carrier amplitude and
  - The modulation index (or, equivalently, the strength of the message E_m)
    - Max strength is m = 100%
    - At 100% modulation…

$$V_{max} = E_c + \frac{E_c}{2} + \frac{E_c}{2} = 2E_c$$

$$V_{min} = E_c - \frac{E_c}{2} - \frac{E_c}{2} = 0 \qquad (\text{at } m = 1)$$

- The carrier is sine wave; the sidebands are a cosine wave (with different signs)
  - Hence 90˚ phase difference between carrier and sidebands
  - Hence, 180˚ phase difference between sidebands

17

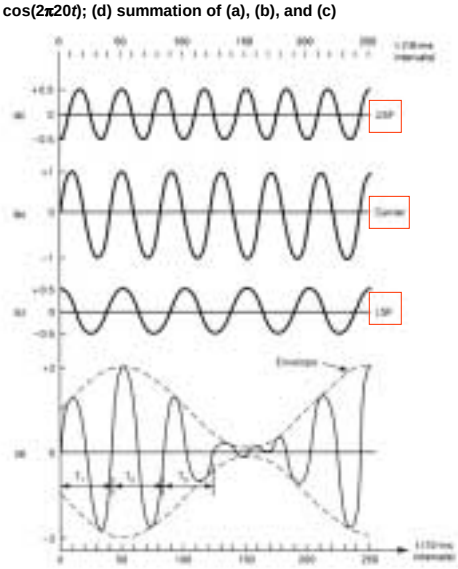
Time-domain Wave Summation

Note phase differences at left end of figures!

Carrier is ±90° from sidebands

Sidebands are 180° from each other.

FIGURE 3-9 Generation of an AM DSBFC envelope shown in the time domain: (a) –½ cos(2π30*t*); (b) sin(2π25*t*); + ½ cos(2π20*t*); (d) summation of (a), (b), and (c)



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18

Power Distribution

- Power is…
  - Voltage²/R (completely general)
  - If a sinusoid signal,

$$P = \frac{E_{\text{RMS}}^2}{R} = \frac{(0.707E)^2}{R} = \frac{E^2}{2R} \qquad \text{(sinusoid signal only!!)}$$

19

DSBFC AM Power Distribution

- Power in the carrier

$$P_c = \frac{E_c^2}{2R}$$

- Power in the sidebands

$$P_{usb} = P_{lsb}$$
$$= \frac{(mE_c/2)^2}{2R} = \frac{m^2E_c^2}{8R}$$
$$= \frac{m^2}{4}\left(\frac{E_c^2}{2R}\right) = \frac{m^2}{4}P_c$$

- Total power in AM signal

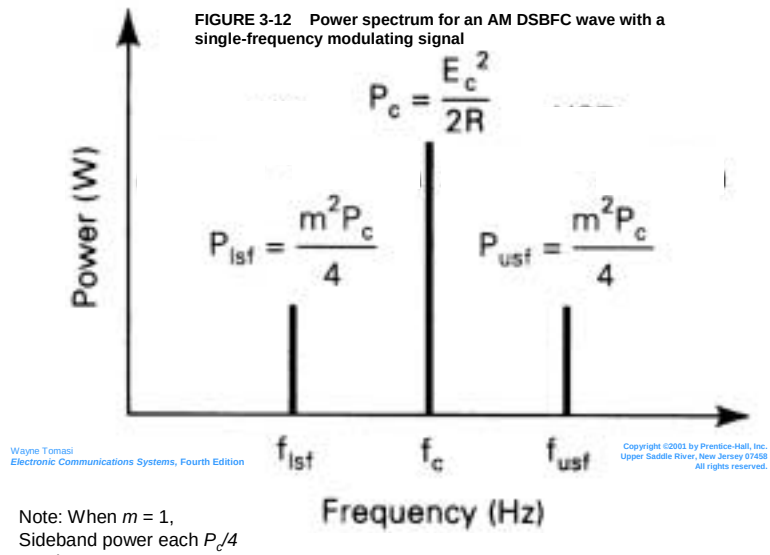
$$P_t = P_c + P_{lsb} + P_{usb}$$
$$= P_c + \frac{m^2P_c}{4} + \frac{m^2P_c}{4}$$
$$= \underbrace{P_c}_{\substack{\text{carrier}\\ \text{power}}} + \underbrace{\frac{m^2P_c}{2}}_{\substack{\text{sideband}\\ \text{power}}}$$
$$= P_c\left(1 + \frac{m^2}{2}\right)$$

- See following graph of power spectrum (sinusoid signal)

20

Power Spectrum for Sinusoidal Message

FIGURE 3-12 Power spectrum for an AM DSBFC wave with a single-frequency modulating signal



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Note: When $m = 1$,
Sideband power each $P_c/4$
Total power = 1.5 P_c
2/3 power in carrier, 1/3 in sidebands

21

DSBFC AM with General Message

- Consider two-frequency message…

$$v_{am}(t) = E_c \sin(2\pi f_c t) - \frac{m_1 E_c}{2}\cos\left[2\pi\left(f_c + f_{m_1}\right)t\right] + \frac{m_1 E_c}{2}\cos\left[2\pi\left(f_c - f_{m_1}\right)t\right] - \frac{m_2 E_c}{2}\cos\left[2\pi\left(f_c + f_{m_2}\right)t\right] + \frac{m_2 E_c}{2}\cos\left[2\pi\left(f_c - f_{m_2}\right)t\right].$$

- Consider an *n*-frequency message [e.g., the Fourier-series representation of a message *v(t)*]…

$$v_{am}(t) = E_c \sin(2\pi f_c t) - \frac{m_1 E_c}{2}\cos\left[2\pi\left(f_c + f_m\right)t\right] + \frac{m_1 E_c}{2}\cos\left[2\pi\left(f_c - f_{m_1}\right)t\right] - \frac{m_2 E_c}{2}\cos\left[2\pi\left(f_c + f_{m_2}\right)t\right] + \frac{m_2 E_c}{2}\cos\left[2\pi\left(f_c - f_{m_2}\right)t\right] \ldots - \frac{m_n E_c}{2}\cos\left[2\pi\left(f_c + f_{m_n}\right)t\right] + \frac{m_n E_c}{2}\cos\left[2\pi\left(f_c - f_{m_n}\right)t\right].$$

22

DSBFC AM with General Message

- Define a "total modulation index" as…

$$m_t = \sqrt{m_1^2 + m_2^2 + m_3^2 + \ldots + m_n^2}$$

Note: take care to keep $m_t \leq 1$!!

- Combined power in sidebands…

$$P_{\text{usb total}} = P_{\text{lsb total}} = \frac{P_c m_t^2}{4}$$

- Total power in AM signal…

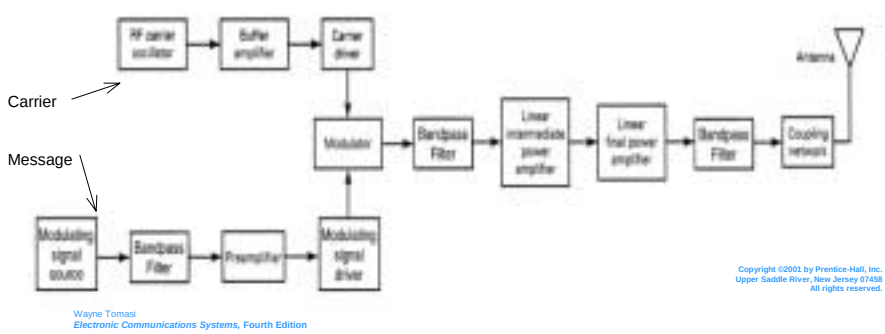
$$P_t = P_c + P_{\text{usb total}} + P_{\text{lsb total}} = P_c\left(1 + \frac{m_t^2}{2}\right)$$

23

Transmitter Block Diagram

- Low-level transmitter (e.g., wireless intercom, remote-control units, pagers, short-range radio)

FIGURE 3-23 Block diagram of a low-level AM DSBFC transmitter

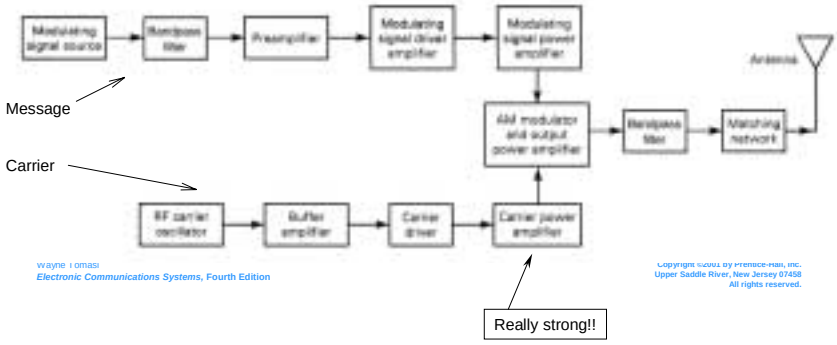


24

Transmitter Block Diagram

- High-level transmitter (e.g., broadcast radio, TV, satellite up- and down-links)

FIGURE 3-24 Block diagram of a high-level AM DSBFC transmitter



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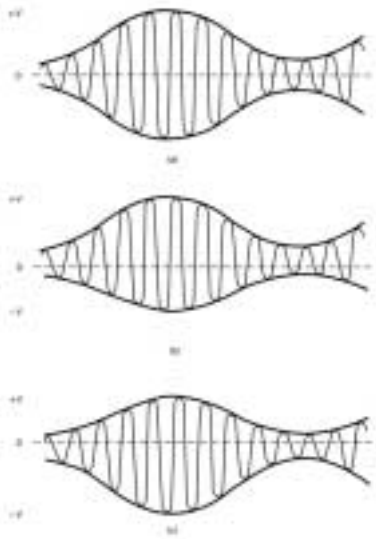
Carrier Shift

- "Carrier shift" – change in dc level of signal when message waveform is not symmetric in amplitude
- See figure-
  - Top: symmetric waveform
  - Middle: positive max bigger than negative max
  - Bottom: negative max bigger than positive max

FIGURE 3-28 Carrier shift: (a) linear modulation; (b) positive carrier shift; (c) negative carrier shift



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AM Summary

- Common form of modulation
- Inputs: Message and carrier
- Output: Modulated carrier
- Message: arbitrary waveform or sinusoid message
- Time-domain representation
  - Sinusoidal message: Eqs. 3.9a, 3.9b, 3.9c, and/or 3.10
  - Modulation index, *m*
  - Power relations: Eqs. 3.18, 3.19, and 3.20 (sinusoid message) and Eqs. 3.22, 3.23, and 3.25 (general message)

- Frequency-domain representation
  - Upper and lower sidebands plus carrier (Fig. 3.2)
  - Power relations: Fig. 3.12

- Implementations: Block diagrams of Figs. 3.23 and 3.24

27