Electrical Communications Systems
09433

Lecture 5

Ben Wu
ECE Department
Rowan University

Plan

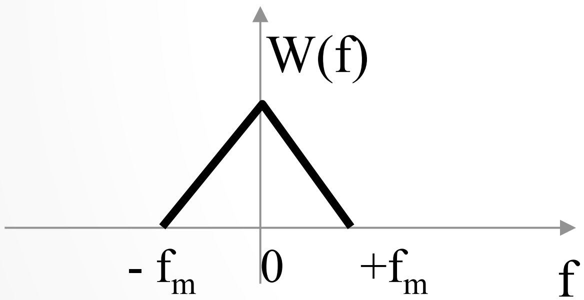
- 5.1 Baseband and Bandpass Signals
  - 5.1.1 Modulation
  - 5.1.2 Complex envelope representation of bandpass waveforms
- 5.2 Amplitude modulation
  - 5.2.1 Complex envelope of AM
  - 5.2.2 Spectrum
  - 5.2.3 Power and Efficiency
  - 5.2.4 AM detector
  - 5.2.5 AM standard
  - 5.2.6 Summary of AM

Why Modulate?

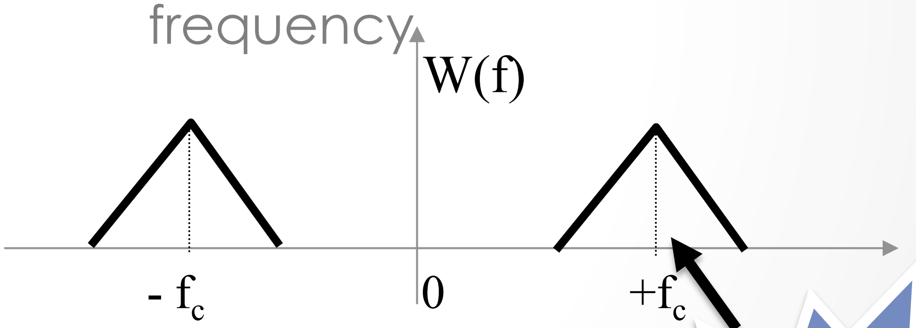
- Antenna size considerations
- Transparency
- Multiplexing (Frequency, wavelength)

Baseband and Bandpass Signals

- <u>Baseband signals</u>: spectral magnitude is non-zero only near the origin and is zero (or negligible) elsewhere
- <u>Bandpass signals</u>: spectral magnitude is non-zero only near the vicinity of f = ± f_c, were $f_c >> 0$
- f_c is called carrier frequency



AF (audio frequency) Signals



RF (radio frequency) Signals

Carrier Frequency

Modulation

What is it?

Modulation is the process of imparting the source information onto a bandpass signal with a carrier frequency f_c by introduction of amplitude or phase perturbations or both. This bandpass signal is called the modulated signal *s(t)*, and the baseband source signal is called the modulating signal *m(t)*.

Information

Modulating Signal
Message Signal
m(t)
(Baseband)

Modulated Signal
s(t)
(Bandpass)

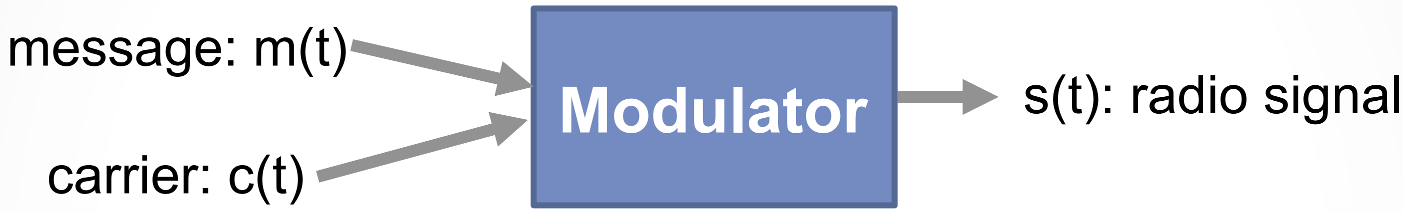
Modulation $\longleftrightarrow$ Frequency Translation

How is it done?

message: m(t) → **Modulator** → s(t): modulated signal

carrier: c(t) → **Modulator**

Complex Envelope Representation



- We want a common mathematical representation for
  - information transfer from baseband to bandpass
  - any bandpass signal
  - any time of modulation
  - signal/noise and signal+noise

Complex envelope representation of bandpass waveforms

Any physical bandpass waveform can be represented by

$$v(t) = \mathrm{Re}\{g(t)e^{j2\pi f_c t}\}$$

- *g(t)* is called the complex envelope of *v(t)*
- f_c carrier frequency (Hz)

$$v(t) = R(t)\cos[2\pi f_c t + \theta(t)]$$

$$v(t) = x(t)\cos(2\pi f_c t) - y(t)\sin(2\pi f_c t)$$

$$g(t) = x(t) + jy(t) = |g(t)|e^{j\angle g(t)} \equiv R(t)e^{j\theta(t)}$$

Complex envelope representation of bandpass waveforms

$$g(t) = x(t) + jy(t) = |g(t)|e^{j\angle g(t)} = R(t)e^{j\theta(t)}$$

$$x(t) = \mathrm{Re}\{g(t)\} = R(t)\cos\theta(t)$$

$$y(t) = \mathrm{Im}\{g(t)\} = R(t)\sin\theta(t)$$

$$R(t) = |g(t)| = \sqrt{x^2(t) + y^2(t)}$$

$$\theta(t) = \angle g(t) = \tan^{-1}\left(\frac{y(t)}{x(t)}\right)$$

Complex envelope representation of bandpass waveforms

- *g(t), x(t), y(t), R(t)*, and *θ(t)* are all baseband waveforms
- *g(t)* is complex
- *x(t), y(t), R(t)*, and *θ(t)* are all real waveforms
- *R(t)* is amplitude modulation is on *v(t), θ(t)* is phase modulation
- *x(t)* is in-phase modulation ***I***, *y(t)* is quadrature modulation ***Q***

Message Signal *m(t)* $\xrightarrow{\text{Mapping function}}$ Complex envelope *g(t)*

Amplitude modulation $g(t) = A_c[1 + m(t)]$

Plan

- 5.1 Baseband and Bandpass Signals
    - 5.1.1 Modulation
    - 5.1.2 Complex envelope representation of bandpass waveforms
- 5.2 Amplitude modulation
    - 5.2.1 Complex envelope of AM
    - 5.2.2 Spectrum
    - 5.2.3 Power and Efficiency
    - 5.2.4 AM detector
    - 5.2.5 AM standard
    - 5.2.6 Summary of AM

Amplitude Modulation

- Complex envelope $g(t) = A_c[1 + m(t)]$
  - A_c power level
  - $m(t)$ modulating signal
- AM signal $s(t) = A_c[1 + m(t)]\cos(2\pi f_c t)$
- Percentage of positive modulation

$$\%\text{positive modulation} = \frac{A_{\max} - A_c}{A_c} \times 100 = \max[m(t)] \times 100$$

$$\%\text{negative modulation} = \frac{A_c - A_{\min}}{A_c} \times 100 = -\min[m(t)] \times 100$$

$$\text{overall modulation percentage} = \frac{A_{\max} - A_{\min}}{2A_c} \times 100 = \frac{\max[m(t)] - \min[m(t)]}{2} \times 100$$

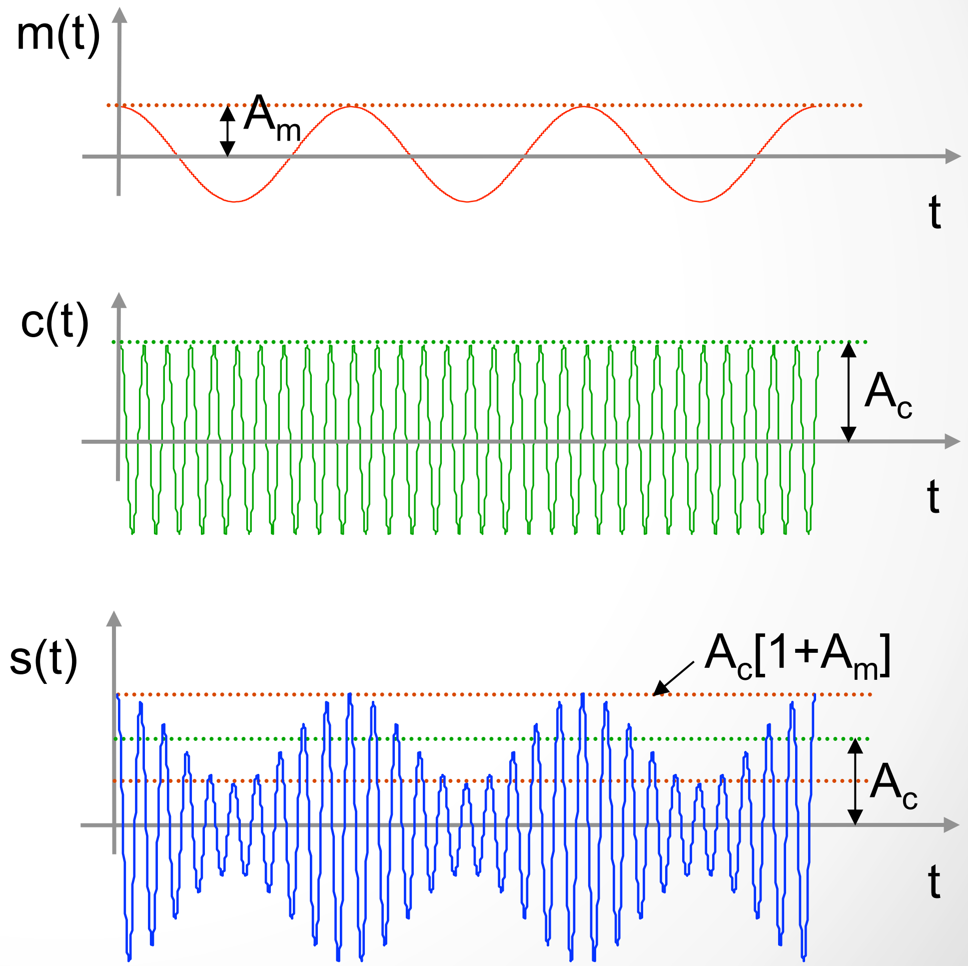
Where $$A_{\max} = \max[g(t)]$$
$$A_{\min} = \min[g(t)]$$

Single Tone AM

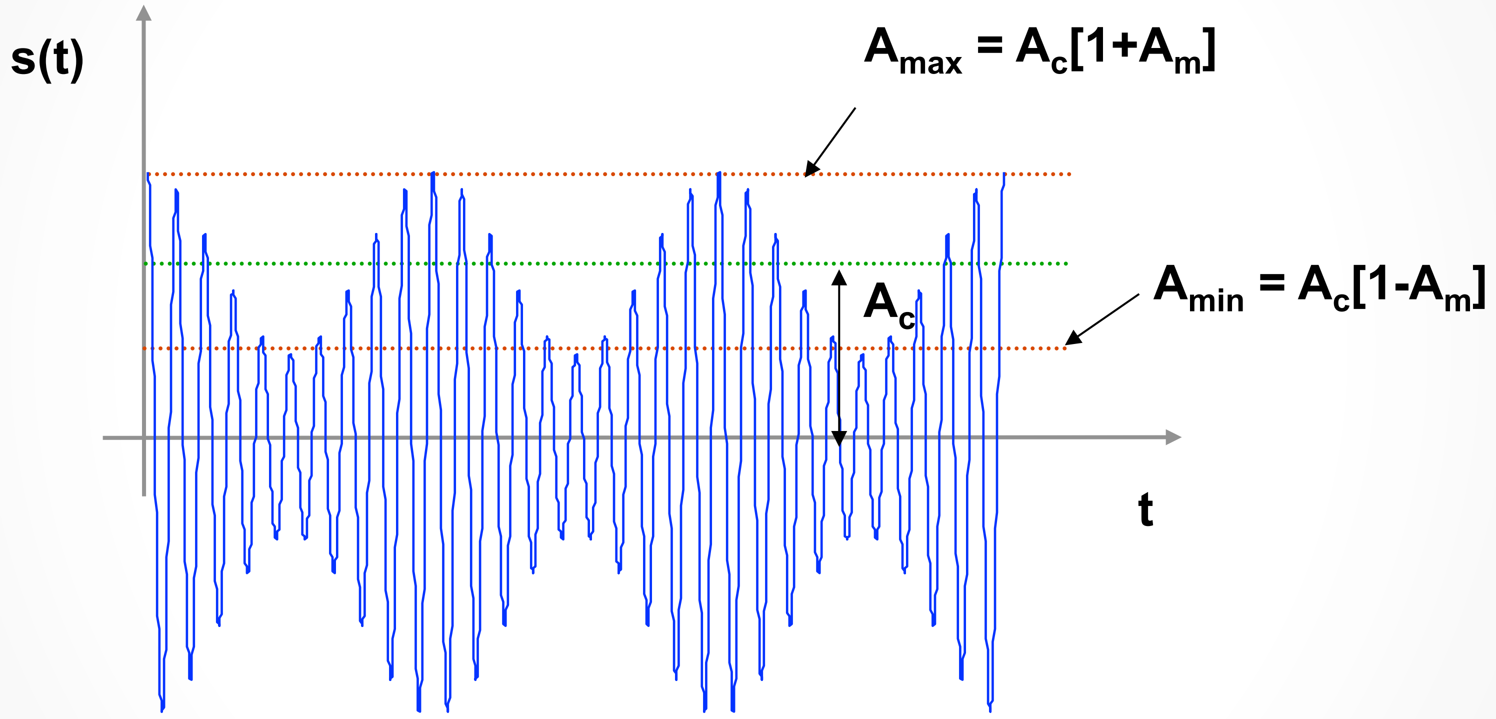
$m(t) = A_m \cos(2\pi f_m t)$

$c(t) = A_c \cos(2\pi f_c t)$

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

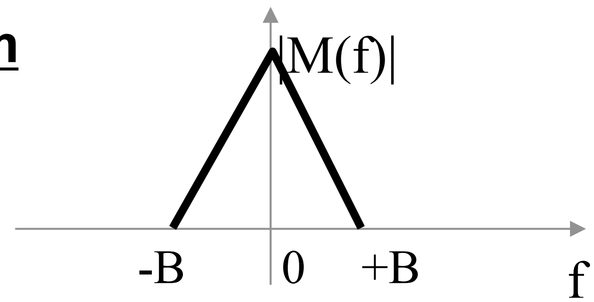


Percentage Modulation (AM)

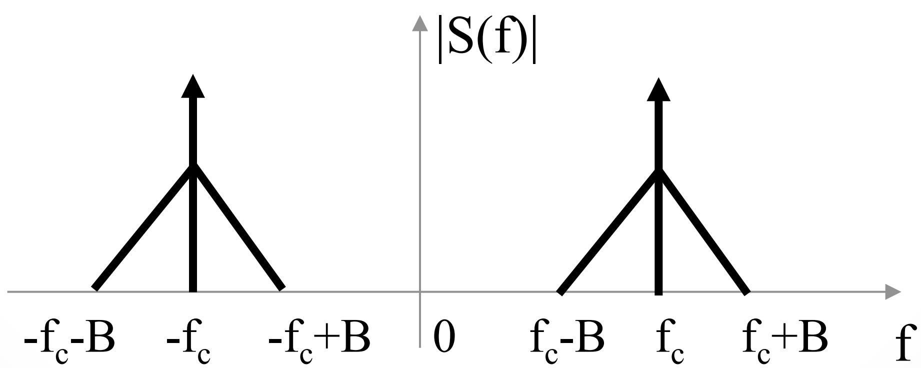


AM Spectrum

Message Spectrum



AM Spectrum



AM Spectrum

- Complex envelope $g(t) = A_c[1 + m(t)]$
- Spectrum of the complex envelope (Fourier Transform):

$$G(f) = A_c\delta(f) + A_c M(f)$$

$$S(f) = \frac{A_c}{2}[\delta(f - f_c) + M(f - f_c) + \delta(f + f_c) + M(f + f_c)]$$

AM Power & Efficiency

- Normalized average power of the AM signal
  - Normalized mean that the load is equivalent to one ohm
  - Total power.

$$\left\langle s^2(t) \right\rangle = \frac{1}{2}\left\langle |g(t)|^2 \right\rangle = \frac{1}{2} A_c \left\langle [1+m(t)]^2 \right\rangle$$

$$= \frac{1}{2} A_c^2 \left\langle 1 + 2m(t) + m^2(t) \right\rangle$$

$$= \frac{1}{2} A_c^2 + A_c^2 \left\langle m(t) \right\rangle + \frac{1}{2} A_c^2 \left\langle m^2(t) \right\rangle$$

If modulation has no DC level, $\left\langle m(t) \right\rangle = 0$

$$\left\langle s^2(t) \right\rangle = \frac{1}{2} A_c^2 + \frac{1}{2} A_c^2 \left\langle m^2(t) \right\rangle$$

Discrete carrier power

Sideband power

AM Power & Efficiency

- Modulation efficiency

  the percentage of the total power of the modulated signal that conveys information

$$E = \frac{\langle m^2(t) \rangle}{1 + \langle m^2(t) \rangle} \times 100\%$$

- The highest efficiency for AM modulation (without overmodulation)
  - 100%modulation
  - Square wave

$$E = \frac{1}{1+1} \times 100\% = 50\%$$

AM Power & Efficiency

- Peak envelope power (PEP)

the average power that would be obtained if $|g(t)|$ were to be held constant at its peak value.

$$P_{PEP} = \frac{1}{2}[\max|g(t)|]^2 = \frac{A_c^2}{2}\{1 + \max[m(t)]\}^2$$

AM Power & Efficiency

- Example
- 5,000W AM transmitter (no modulation) with 50Ω load

$$\frac{1}{2}A_c^2/50 = 5{,}000 \qquad A_c = 707V$$

- If the transmitter is 100% modulated by a 1kHz test tone, the total (carrier and sideband) average power is

$$\langle m^2(t)\rangle = 0.5$$

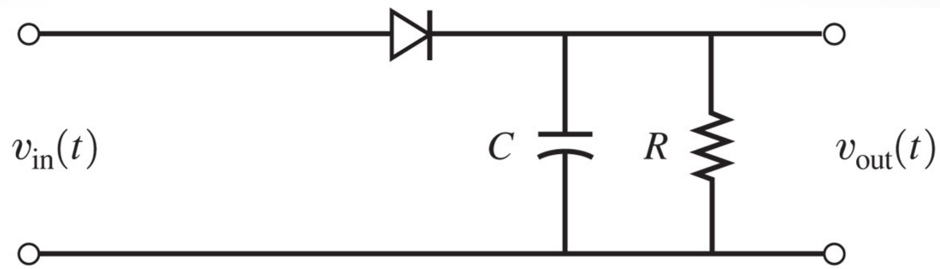
$$(1+0.5)\times\left(\frac{1}{2}A_c^2/50\right) = 7{,}500W$$

- PEP is (actual, not normalized)

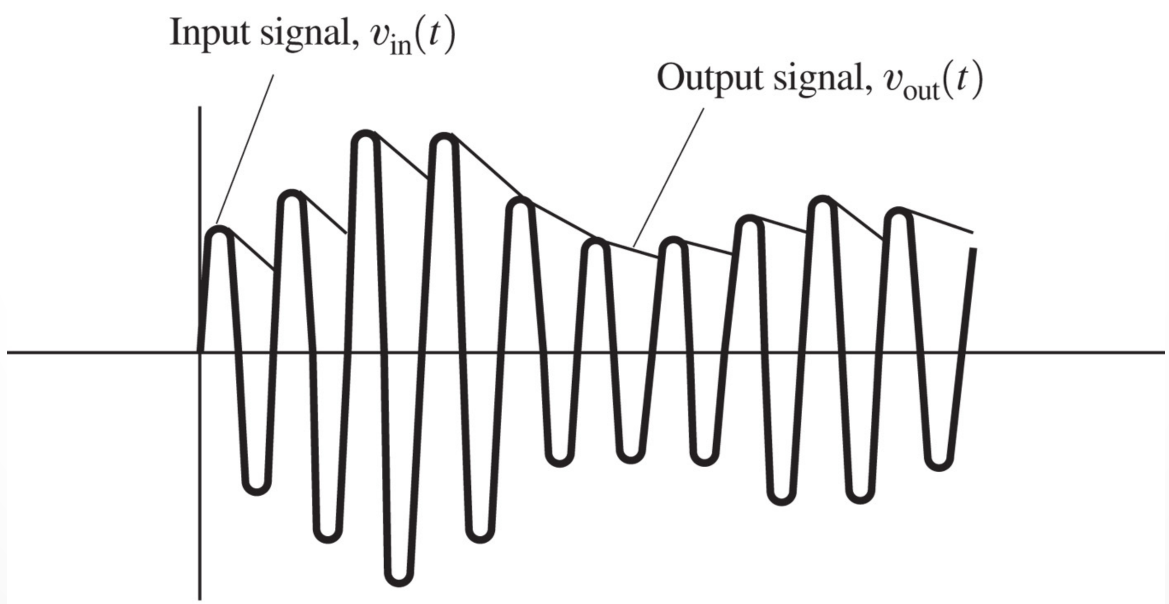
$$P_{PEP} = \frac{A_c^2}{2}\{1+\max[m(t)]\}^2\times\frac{1}{50} = 4\times\frac{1}{2}A_c^2/50 = 20{,}000W$$

- Modulation efficiency is 33% (0.5/1.5)

Envelope Detector

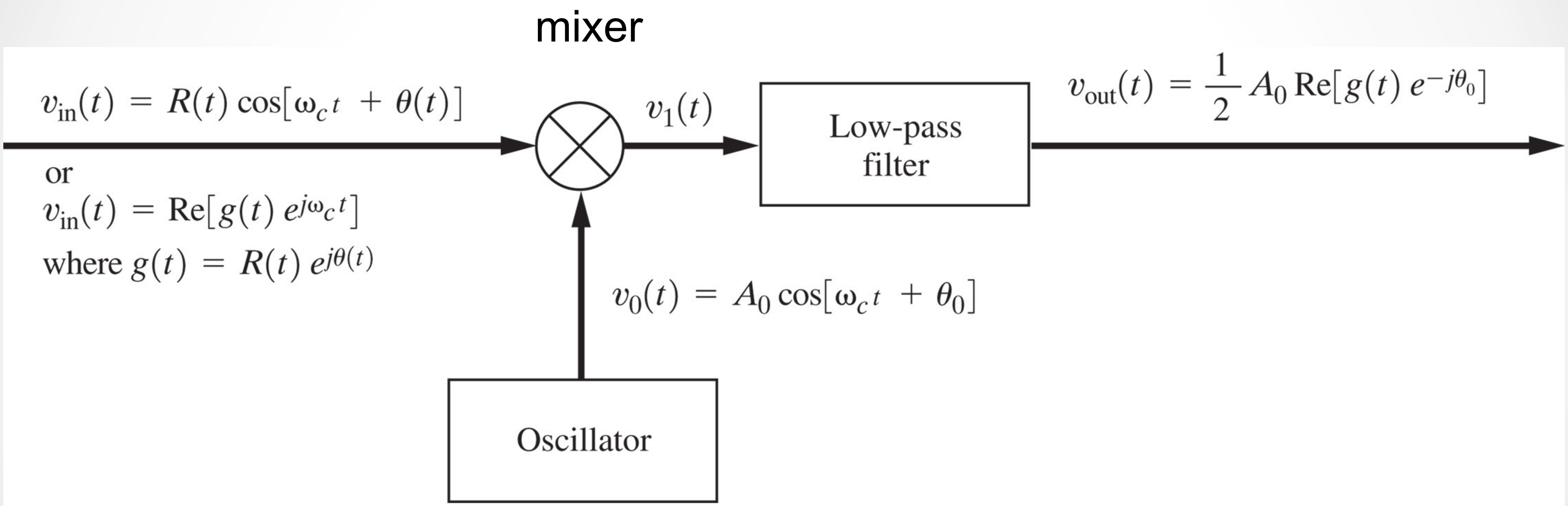


(a) A Diode Envelope Detector



(b) Waveforms Associated with the Diode Envelope Detector

Product Detector



Federal Communications Commission (FCC) AM Standards

TABLE 5–1 AM BROADCAST STATION TECHNICAL STANDARDS

Item	FCC Technical Standard
Assigned frequency, f_c	In 10-kHz increments from 540 to 1,700 kHz
Channel bandwidth	10 kHz
Carrier frequency stability	±20 Hz of the assigned frequency
Clear-channel frequencies (One Class A, 50-kW station) (Nondirectional)	640, 650, 660, 670, 700, 720, 750, 760, 770, 780, 820, 830, 840, 870, 880, 890, 1,020, 1,030, 1,040, 1,070, 1,100, 1,120, 1,160, 1,180, 1,200, and 1,210 kHz
Clear-channel frequencies (Multiple 50-kW stations) (Directional night)	680, 710, 810, 850, 1,000, 1,060, 1,080, 1,090, 1,110, 1,130, 1,140, 1,170, 1,190, 1,500, 1,510, 1,520, and 1,530 kHz
Clear-channel frequencies (For Bahama, Cuba, Canada, or Mexico)	540, 690, 730, 740, 800, 860, 900, 940, 990, 1,010, 1,050, 1,220, 1,540, 1,550, 1,560, 1,570, and 1,580 kHz
Local channel frequencies (1-kW stations)	1,230, 1,240, 1,340, 1,400, 1,450, and 1,490 kHz
Maximum power licensed	50 kW
Travelers' Information Radio (50 W maximum, usually 10 W)	In 10 kHz increments from 530 to 1,700 kHz

AM Standards

Class A (former I-A/I-B) stations

Freq. (kHz)	Callsign	City of license
540	CBK	Watrous, Saskatchewan
540	CBT	Grand Falls, Newfoundland and Labrador
540	XEWA	San Luis Potosí, San Luis Potosí
640	CBN	St. John's, Newfoundland and Labrador
640	KFI	Los Angeles, California
650	WSM	Nashville, Tennessee
660	WFAN	New York, New York
670	WSCR	Chicago, Illinois
680	KNBR	San Francisco, California
690	CKGM[a]	Montreal, Quebec
690	XEWW	Tijuana, Baja California
700	WLW	Cincinnati, Ohio
710	KIRO	Seattle, Washington
710	WOR	New York, New York
720	WGN	Chicago, Illinois
730	CKAC	Montreal, Quebec
730	XEX	Mexico City, D.F.
740	CFZM[b]	Toronto, Ontario
750	WSB	Atlanta, Georgia

https://en.wikipedia.org/wiki/Clear-channel_station#List_of_all_clear-channel_stations

AM Standards

HW (Do not need to be turned in)

- Find a AM radio, check what carrier frequencies are used and what are the intervals

AM: Features

- AM system is very cheap to build and maintain
- AM is wasteful of power - % modulation, single tone efficiency is 33%
- AM is wasteful of bandwidth - twice the message bandwidth is required

- AM Modifications:
  - DSB-SC
  - SSB
  - VSB