Amplitude and Frequency Modulation

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9/4/2021

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EE 421

- Instructor: Dr. Anas Al-Hussayen, ahussayen@ksu.edu.sa
- Office Hours: By appointment, Room 2C27 Engineering Building
- Grading:
  - 40% Lab reports
  - 20% Quizzes
  - 40% Final exam (20% written, 20% practical)

Reporting Activities

- Summary: A succinctly written single paragraph given a general description of objective, methodology and main conclusion of the experiment.
- Introduction: Provide some background material about the nature of the experiment and the significance of the questions to be answered by the experiment design.
- Theory: Key mathematical formulas underpinning the reported results, e.g., SNR, channel capacity, etc. Your theory section should be a recapitulation, not a regurgitation of textbook material. Formulas described fully in the textbook can be referenced by their numbers in the textbook, but key formulas most relevant to the measurements/results described in the report should be included in a concise form.
- Equipment: A list of the modules used in the experiment should be provided.

Reporting Activities

- Procedure: This should reflect the Procedure given in the Lab Manual. The report should include documentation from your lab notebook summarizing your observations (e.g. oscilloscope screen shots) associated with each step.
- Results: A concise summary of the measurements in table and/or figure form should be included. The figures and/or tables should give the reader an idea about the mean and variance of specific measurements.
- Discussion: The report should give the reader an idea about any anomalies in the observations or measurements. Give a brief statement about possible reasons and significance. If significant, speculate on possible mitigations even if there is no time to test them in the lab.
- Conclusions: Summarize the main results, margins or statistics of error, significant discrepancies (if any) and possible mitigations.

Reporting Activities

- Grading:
  - 20% Summary, introduction, theory, equipment and procedure
  - 60% Results, analysis, and discussion
  - 20% Conclusions

List of Experiments

- Amplitude and Frequency Modulation
- Pulse Code Modulation
- Shift Keying
- Phase-Locked-Loop
- Demonstration of Wireless Communications

Quiz #1

1) In AM, the message modulates the carrier's frequency.
2) When $|K_a\, m(t)| < 1$, the AM signal is over-modulated.
3) The massage can not be recovered from under-modulated AM signals.
4) AM provides better noise discrimination than FM.
5) AM requires more transmission BW than FM.

Why Modulation?

- Upconvert Baseband signal to a passband signal
- Frequency Division Multiplexing (FDM)
- Smaller Antennas
  - For audio (20 KHz) → λ = 15 Km → antenna size = 1.5 Km
- Carrier signal

$$c(t) = A(t) cos(w_c t + \theta(t))$$

Amplitude Modulation

$$\Theta_{AM}(t) = (A + m(t))cos(w_c t)$$

$$\Phi_{AM}(f) = \frac{1}{2}[M(f+f_c) + M(f-f_c)] + \frac{A}{2}[\delta(f+f_c) + \delta(f-f_c)]$$

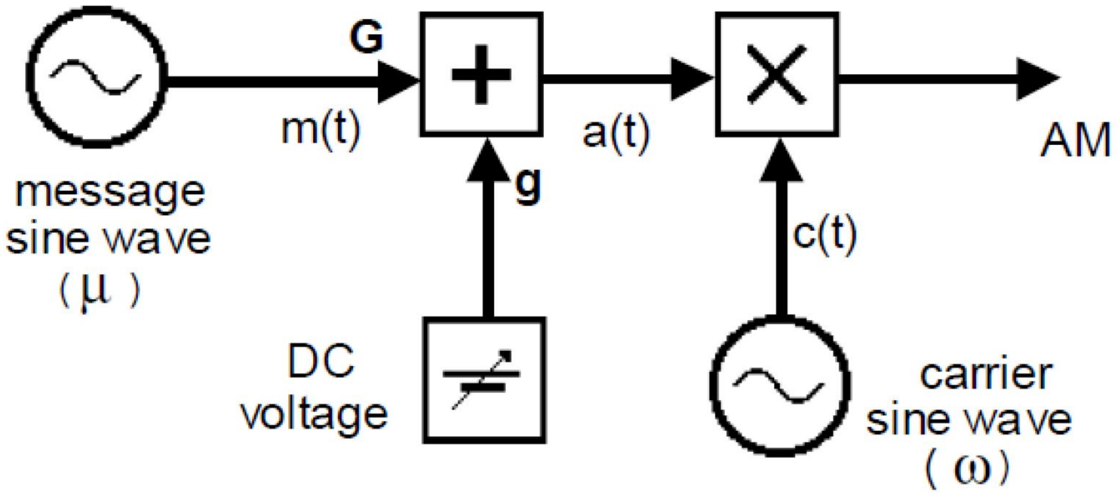

Fig. 1: Conventional AM generator.

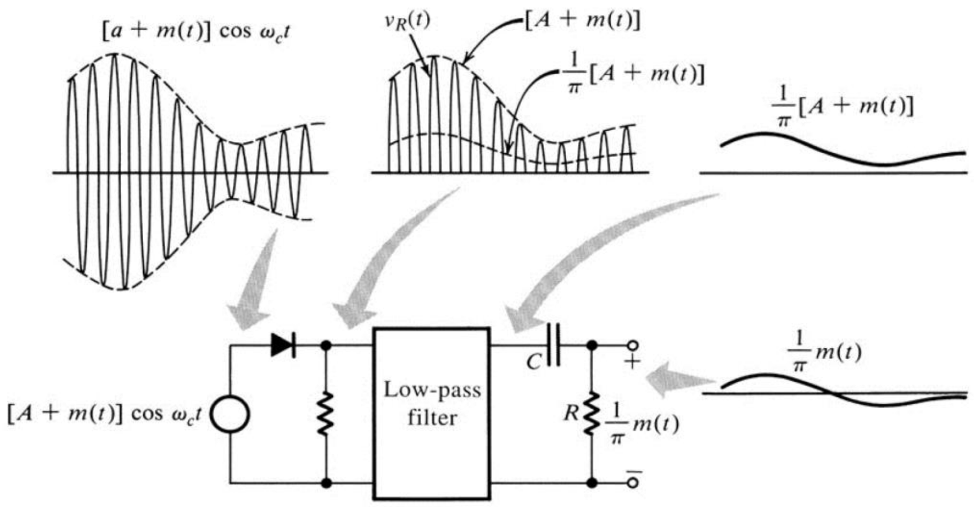

Fig. 2: Envelope detection.

Modulation Index

$$A + m(t) \geq 0$$

$$\Rightarrow A \geq -m_{min}$$

$$\mu = \frac{m_p}{A} \Rightarrow 0 \leq \mu \leq 1$$

- For nonzero offset

$$\mu = \frac{m_{max} - m_{min}}{2A + m_{max} + m_{min}}$$

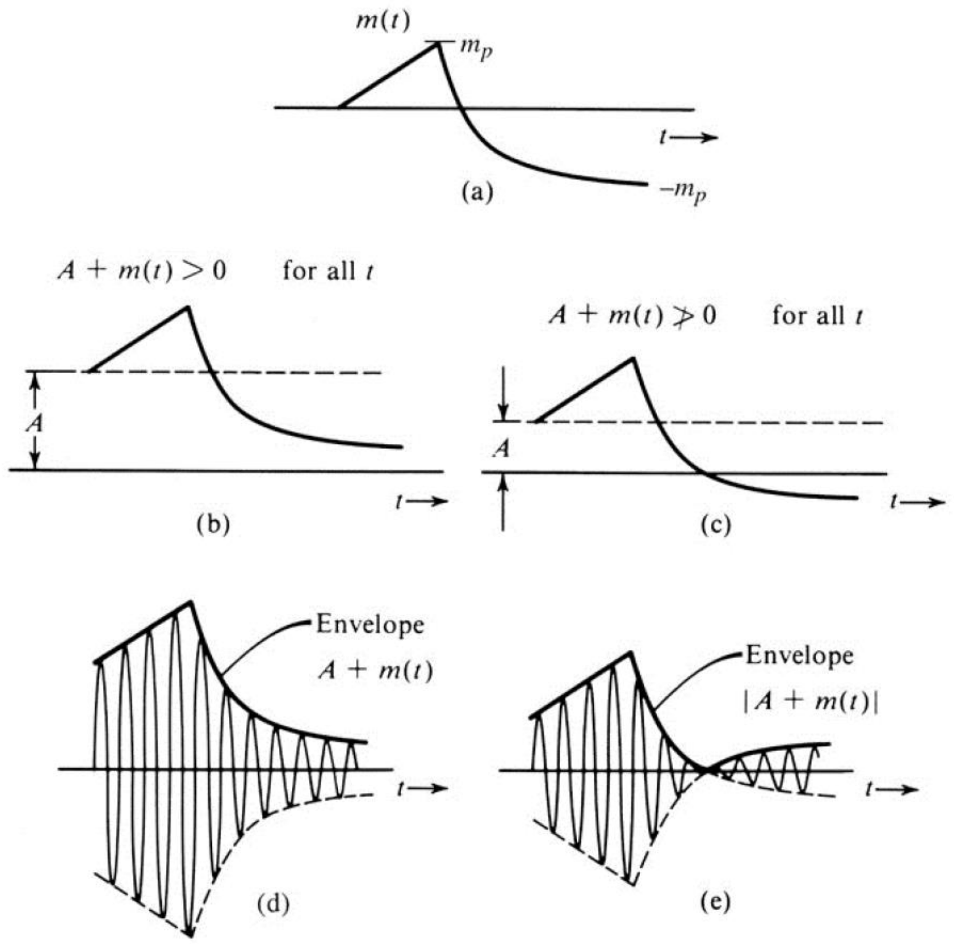

Fig. 3: Illustration of the role of A in AM.

Double Side Band-Suppressed Carrier (DSB-SC)

$$\Theta_{DSB-SC}(t) = m(t)cos(w_c t)$$

$$\Phi_{DSB-SC}(f) = \frac{1}{2}[M(f + f_c) + M(f - f_c)]$$

Bandwidth of AM Signals

- For a single-tone message:

$$B_{AM} = 2\, f_m$$

- For an arbitrary message with bandwidth *W*

$$B_{AM} = 2W$$

Frequency Modulation

- Carrier signal

$$c(t) = A(t)cos(w_c t + \theta(t))$$

- Angular Frequency (Instantaneous Angle)

$$\phi(t) = w_c t + \theta_0 \qquad = \int w(t)dt$$

- Instantaneous Frequency

$$w(t) = \frac{d\phi(t)}{dt}$$

$$f(t) = \frac{w(t)}{2\pi}$$

Frequency Deviation

- Frequency Deviation *Δf* : the maximum difference between instantaneous frequency and carrier frequency.

$$\Delta f = max\left|\frac{1}{2\pi}\frac{d\theta(t)}{dt}\right|$$

- Range of instantaneous frequency: *2Δf* around f_c

$$[f_c - \Delta f,\ f_c + \Delta f]$$

Frequency Modulation

- In FM, the instantaneous frequency is varied linearly with the message signal, i.e.

$$f(t) = f_c + k_f m(t)$$

- The instantaneous phase:

$$\phi(t) = 2\pi \int_0^t f(t)dt = 2\pi f_c t + 2\pi k_f \int_0^t m(t)dt$$

- The FM wave is then:

$$\Theta_{FM}(t) = A_c cos(2\pi f_c t + 2\pi k_f \int m(t)dt + \theta_0)$$

Frequency Modulation

- The frequency deviation becomes

$$\Delta f = max\left|\frac{1}{2\pi}\frac{d\theta(t)}{dt}\right| = k_f \, max\,|m(t)|$$

- Modulation index

$$\beta \triangleq \frac{\Delta f}{f_m}$$

Single-Tone FM

$$\Theta_{FM}(t) = A_c cos\left(2\pi f_c t + \beta sin(2\pi f_m t)\right)$$

$$\Theta_{FM}(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\, 2\pi\, cos\left(2\pi(f_c + n f_m)t)\right)$$

$$\Phi_{FM}(f) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\left[\delta\left(f - (f_c + n f_m)\right) + \delta\left(f + (f_c + n f_m)\right)\right]$$

Single-Tone FM

- A property of Bessel functions:

$$\lim_{n\to\infty} J_n(\beta) = 0$$

- BW of single-tone FM: separation between two frequencies beyond which all

$$|J_n(\beta) < 0.01|$$

- The corresponding BW

$$B = 2\, n_{max}\, f_m$$

Carson’s Rule

- For a single-tone message:

$$B_{FM} \approx 2(f_m + \Delta f) = 2(\beta + 1)f_m$$

- For an arbitrary message with bandwidth *W*

$$B_{FM} \approx 2(W + \Delta f) = 2(\beta + 1)W$$