Analog Communication

Short notes for B.Tech ECE · GATE EC

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1. Introduction

- **Communication system**: source → transmitter → channel → receiver → destination. Noise is added mainly in the channel.
- **Modulation** = changing a property (amplitude, frequency or phase) of a high-frequency **carrier** using the message signal.

➤ Why modulate?

1. Practical antenna size (antenna length is about λ/4; low frequencies need huge antennas).
2. Many signals can share the channel (frequency division multiplexing).
3. Less noise and interference, longer range.
4. Fits the signal to the channel band.

Type	What changes	Examples
Amplitude modulation	Carrier amplitude	AM, DSB-SC, SSB, VSB
Angle modulation	Carrier frequency or phase	FM, PM
Pulse modulation	Pulse amplitude, width or position	PAM, PWM, PPM

2. Amplitude Modulation (DSB-FC)

FORMULA $s(t) = A_c [1 + \mu \cos(\omega_m t)] \cos(\omega_c t)$, modulation index $\mu = A_m / A_c$.

- Spectrum: carrier at fc and two sidebands at fc + fm (USB) and fc − fm (LSB). Bandwidth = 2 fm.
- $\mu < 1$: normal. $\mu = 1$: 100% modulation. $\mu > 1$: **over-modulation**, envelope distorts (envelope detector fails).
- From the waveform: $\mu = (V_{max} - V_{min}) / (V_{max} + V_{min})$.

FORMULA Total power $P_t = P_c (1 + \mu^2 / 2)$. Each sideband power $= P_c \mu^2 / 4$. Current $I_t = I_c \sqrt{(1 + \mu^2 / 2)}$.

FORMULA Transmission efficiency $\eta = \mu^2 / (2 + \mu^2)$. Maximum = 33.3% at $\mu = 1$.

- Multi-tone: $\mu_t = \sqrt{(\mu_1^2 + \mu_2^2 + \ldots)}$.

➤ Solved example (AM power)

- Carrier power $P_c = 1000$ W, $\mu = 0.8$.
  - $P_t = 1000 (1 + 0.64 / 2) = 1000 \times 1.32 =$ **1320 W**
  - Total sideband power = 320 W, each sideband = 160 W
  - Efficiency $= 0.64 / 2.64 =$ **24.2%**
  - So about 76% of the power is in the carrier, which carries no information.

➤ AM generation and detection

- Generation: **square-law modulator** (low level), **collector modulator** (high level, class C).
- Detection: **envelope detector** (diode + RC). Condition: $1/f_c \ll RC \ll 1/f_m$. To avoid diagonal clipping: $RC \leq \sqrt{(1 - \mu^2)} / (\omega_m \mu)$.
- **Square-law detector**: for small signals, gives some distortion.

3. Suppressed Carrier Systems

System	Bandwidth	Power saving	Detection
DSB-FC (AM)	2 f_m	None	Envelope (simple)
DSB-SC	2 f_m	Carrier power saved	Coherent (synchronous)
SSB-SC	f_m	Carrier + one sideband saved	Coherent
VSB	$f_m < BW < 2 f_m$	Partial	Coherent / envelope with carrier (used in analog TV)

- **DSB-SC generation**: balanced modulator, ring modulator. $s(t) = m(t) \cos \omega_c t$.
- **SSB generation**: filter method, phase-shift method (uses Hilbert transform), Weaver's (third) method.

- **Coherent detection** error: phase error ϕ gives output $\propto m(t) \cos \phi$ (signal lost at $\phi = 90°$, called the quadrature null effect). Frequency error gives beating.
- **Costas loop** recovers the carrier for DSB-SC.

> **EXAM POINT** SSB-SC power saving vs AM at $\mu = 1$: carrier saves 66.7%, one sideband saves another 16.7%, total **83.3%**.

- **QAM (analog)**: two DSB-SC signals on cos and sin carriers share the same band (doubles capacity).

4. Angle Modulation (FM and PM)

- **FM**: instantaneous frequency $f_i = f_c + k_f m(t)$. **PM**: phase $\theta_i = \omega_c t + k_p m(t)$.
- FM and PM are related: FM of $m(t)$ = PM of the integral of $m(t)$.

> **FORMULA** Single-tone FM: $s(t) = A_c \cos(\omega_c t + \beta \sin \omega_m t)$, modulation index $\beta = \Delta f / f_m$, $\Delta f = k_f A_m$.

- **Narrowband FM** ($\beta << 1$, about $\beta < 0.3$): bandwidth $\approx 2 f_m$ (like AM).
- **Wideband FM** ($\beta > 1$): many sidebands at $f_c \pm n f_m$ with amplitudes $A_c J_n(\beta)$ (Bessel functions).
- Total power of FM = $A_c^2 / 2$, **constant** (does not depend on β).
- $J_0(\beta) = 0$ at $\beta = 2.405$ → carrier component vanishes.

> **FORMULA** Carson's rule: $BW \approx 2 (\Delta f + f_m) = 2 f_m (\beta + 1)$.

➤ Solved example (FM bandwidth)

- Commercial FM: $\Delta f = 75$ kHz, $f_m = 15$ kHz.
  - $\beta = 75 / 15 =$ **5** (wideband FM)
  - Carson $BW = 2 (75 + 15) =$ **180 kHz**
  - If f_m drops to 5 kHz (same Δf): $\beta = 15$, $BW = 2 (75 + 5) = 160$ kHz

➤ FM generation and detection

- **Direct method**: varactor diode or reactance modulator changes the oscillator frequency (needs AFC).
- **Indirect (Armstrong) method**: make NBFM, then use frequency multipliers to raise β and f_c. Very stable.

- Detection: slope detector, balanced slope detector, **Foster–Seeley discriminator**, **ratio detector** (also limits amplitude), **PLL detector**.

➤ AM vs FM

Point	AM	FM
Bandwidth	2 fm (small)	2 (Δf + fm) (large)
Noise immunity	Poor	Good (amplitude noise removed by limiter)
Transmitted power	Depends on μ	Constant
Circuit	Simple	Complex
Capture effect	No	Yes, stronger signal captures receiver

- **Pre-emphasis** (at transmitter) boosts high audio frequencies; **de-emphasis** (receiver) cuts them back. Improves SNR at high frequencies. Time constant 75 μs is common.

5. Radio Receivers

- **TRF receiver**: tunes several RF stages together; poor selectivity across the band.
- **Superheterodyne**: mixes incoming signal with a local oscillator to get a fixed **intermediate frequency (IF)**, then amplifies at IF.

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Antenna -> RF amp -> Mixer -> IF amp -> Detector -> Audio amp
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                Local oscillator (fLO = fs + IF)
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- Standard IF: AM broadcast ≈ 455 kHz, FM broadcast ≈ 10.7 MHz.

FORMULA Image frequency fsi = fs + 2 IF (when fLO = fs + IF). Image rejection ratio α = sqrt(1 + Q^2 ρ^2), ρ = fsi/fs − fs/fsi.

EXAMPLE fs = 1000 kHz, IF = 455 kHz: fLO = 1455 kHz, image = 1000 + 910 = 1910 kHz.

- Receiver qualities: **sensitivity** (weakest signal received), **selectivity** (reject nearby channels), **fidelity** (reproduce all audio frequencies), **image rejection**.
- **AGC** keeps output level steady when signal strength changes.

6. Noise

Noise	Cause	Note
Thermal (Johnson)	Random motion of electrons in a resistor	White, Gaussian
Shot	Random arrival of carriers across a junction	In = sqrt(2 q I B)
Flicker (1/f)	Surface defects	Strong at low frequencies
Partition	Current splitting between electrodes	In BJTs, tubes
External	Atmospheric, cosmic, man-made	Outside the receiver

FORMULA Thermal noise power Pn = k T B. Noise voltage Vn = sqrt(4 k T R B), k = 1.38 x 10^-23 J/K.

EXAMPLE R = 1 kΩ, T = 300 K, B = 10 kHz: Vn^2 = 4 x 1.38e-23 x 300 x 1000 x 10^4 = 1.656 x 10^-13, Vn ≈ 0.41 μV.

➤ Noise figure and temperature

FORMULA Noise figure F = (S/N)in / (S/N)out. Noise temperature Te = (F − 1) T0, T0 = 290 K.

FORMULA Friis formula: F = F1 + (F2 − 1)/G1 + (F3 − 1)/(G1 G2) + ...

- So the first stage (low noise amplifier) decides the overall noise figure.

➤ Noise performance (figure of merit γ = (S/N)o / (S/N)reference)

System	Figure of merit
DSB-SC (coherent)	1
SSB-SC (coherent)	1
AM (envelope, μ = 1)	μ^2 / (2 + μ^2) = 1/3
FM	(3/2) β^2

- FM shows a **threshold effect**: below a certain input CNR, output SNR falls sharply.

7. Random Processes (basics)

- **Autocorrelation** $R(\tau) = E[X(t)\,X(t+\tau)]$. **WSS process**: constant mean, R depends only on τ.
- **Wiener–Khinchin theorem**: power spectral density $S(f)$ = Fourier transform of $R(\tau)$.
- **White noise**: $S(f) = N0/2$ for all f, $R(\tau) = (N0/2)\,\delta(\tau)$.
- Through an LTI system: $Sy(f) = |H(f)|^2\,Sx(f)$.

8. Pulse Analog Modulation and Multiplexing

Type	What varies	Note
PAM	Pulse amplitude	Simple, noisy
PWM (PDM)	Pulse width	Better noise immunity, wastes power
PPM	Pulse position	Constant amplitude and width, best of three

- **FDM**: signals share frequency (separate bands, guard bands). **TDM**: signals share time (separate slots).

9. Most Asked Questions (practice)

1. Derive the power relation and efficiency of AM. Solve a power numerical.
2. Explain envelope detection and the condition on the RC time constant.
3. Compare DSB-FC, DSB-SC, SSB and VSB.
4. Explain SSB generation by the phase-shift method.
5. Derive the spectrum of single-tone FM using Bessel functions.
6. State Carson's rule and find bandwidth for given Δf and f_m.
7. Explain the Armstrong method of FM generation.
8. Draw a superheterodyne receiver; find the image frequency.
9. Define noise figure and derive the Friis formula.
10. Compare the noise performance of AM, DSB-SC, SSB and FM.

TIP GATE EC asks AM power and efficiency, Carson's bandwidth, image frequency, noise figure and coherent detection errors. Practise each with 2–3 numericals.