EEEN 462 – ANALOGUE COMMUNICATION

VESTIGIAL SIDEBAND MODULATION (VSB) STUDY GUIDE

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1. CORE CONCEPT & DEFINITION

- **What it is VSB:** VSB is a bandwidth-efficient modulation technique derived from Amplitude Modulation (AM). It transmits **one full sideband + a "vestige" (fragment) of the other sideband + the carrier**.
- **Key Motivation:** Achieve bandwidth savings over Double Sideband (DSB) while overcoming the practical challenges (complex filters, carrier recovery) of Single Sideband (SSB).
- **"Vestigial" Meaning:** Refers to the intentionally transmitted small portion of the suppressed sideband.
- **Primary Application:** Dominated **analogue television broadcasting** (NTSC, PAL, SECAM). Still relevant in parts of **digital TV (ATSC)** and some data communication systems.

2. WHY DO WE NEED VSB?

- **DSB-SC (Suppressed Carrier):**
    - *Bandwidth:* 2B (where B = baseband signal bandwidth). Inefficient.
    - *Demodulation:* Requires coherent detection (precise carrier recovery), complex for broadcasting.
- **SSB (Single Sideband):**
    - *Bandwidth:* B (most efficient).
    - *Problem:* Requires extremely sharp cutoff filters to isolate one sideband without distortion near the carrier frequency (impractical for signals with significant low-frequency content like video). Carrier recovery for demodulation is also challenging.

3. VSB MODULATION: HOW IT WORKS

1. **Generation:** Start with a **DSB-SC signal** (Message m(t) * Carrier cos(ω_ct)).
2. **Filtering:** Pass the DSB-SC signal through a **Vestigial Sideband Filter (VSB Filter)**. This filter's key characteristic is its *asymmetrical* frequency response around the carrier frequency (f_c).
    - **Filter Shape (Crucial):**

- At f_c: |H(f_c)| = 0.5 (typically).
- Over a small range (f_c - f_v < f < f_c + f_v): The filter has a *gradual, controlled roll-off*.
- One sideband (e.g., USB) is passed almost completely.
- The other sideband (e.g., LSB) is attenuated but **not completely eliminated**. A small "vestige" of width f_v is allowed to pass.

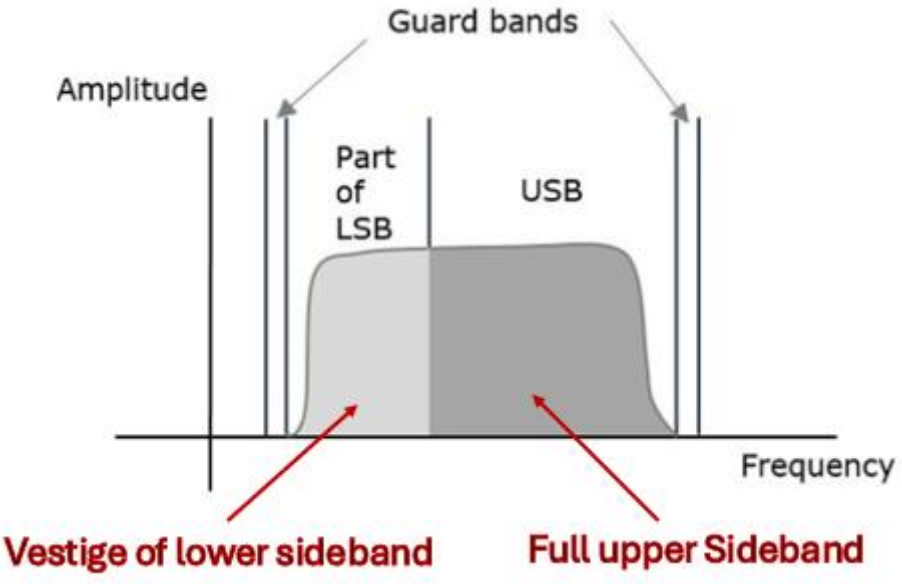

Figure 1. Frequency spectrum of VSB signal

IV. VSB TRANSMISSION & BANDWIDTH

- **Transmitted Signal Spectrum:** Contains:
  - A nearly full Upper Sideband (USB) *or* Lower Sideband (LSB).
  - A vestige (fragment) of the Lower Sideband (LSB) *or* Upper Sideband (USB).
  - The Carrier (often partially suppressed, but present).
- **Bandwidth:**
  - Bandwidth_VSB ≈ B + f_v
  - Where B = Baseband signal bandwidth, f_v= Width of the vestigial band (roll-off region).
  - **Significantly less than DSB (2B), slightly more than SSB (B).** (e.g., Analog TV: B ~ 4.2 MHz, f_v~ 0.75 MHz, BW_VSB ~ 6 MHz channel).
- **Carrier Level:** Often transmitted at a higher level than in DSB-SC to simplify receiver design (envelope detection possible), but less than full-carrier AM. This is called **VSB+C**.

5. VSB DEMODULATION

- **Key Insight:** The vestigial sideband "fills in" the gap created by the filter roll-off on the other side.

- **Methods:**
    1. **Coherent Detection (Ideal):**
        - Multiply received VSB signal s_vsb(t) by a locally generated carrier $\cos(\omega_c t)$ perfectly synchronized in phase and frequency.
        - Pass the result through a **Low-Pass Filter (LPF)**.
        - *Why it works:* The coherent mixing process shifts the spectrum. The vestige and the corresponding attenuated part of the full sideband combine to reconstruct the original baseband spectrum M(f) faithfully *provided the VSB filter satisfies the distortionless condition* (see VI).
    2. **Envelope Detection (Practical for VSB+C):**
        - **Requires a strong carrier component (VSB+C).**
        - Pass the received VSB+C signal through an **Envelope Detector** (simple diode-RC circuit).
        - *Why it works (simplified):* The strong carrier acts similarly to a carrier in standard AM. The envelope of the VSB+C signal closely approximates the original baseband message m(t), especially if f_v is chosen correctly relative to B. **This simplicity was crucial for cheap TV receivers.**

6. THE DISTORTION LESS CONDITION

- **Requirement:** For perfect demodulation (especially with coherent detection), the VSB filter H(f) must satisfy:
  $H(f - f_v) + H(f + f_v) = \text{Constant for } |f| < B$
- **Interpretation:** The *sum* of the filter's gain at frequencies symmetrically located f Hz above *and* below the carrier frequency f_v must be constant across the entire baseband bandwidth B.
- **Practical Implication:** This condition dictates the precise shape of the filter's roll-off region (the vestige). The gradual roll-off is designed to meet this requirement as closely as possible.

7. ADVANTAGES & DISADVANTAGES

Advantages:

a) **Bandwidth Efficiency:** Better than DSB ($\approx B + f_v$ vs 2B).

b) **Simpler Filtering:** Compared to the near-impossible sharp cutoff filters needed for SSB. VSB filters with gradual roll-off are realizable.

c) **Good Low-Frequency Response:** Preserves low-frequency components well (critical for video signals), unlike SSB which struggles near f_v.

d) **Simplified Demodulation:** Allows use of envelope detection (with carrier) for cost-sensitive applications (TV receivers).

Disadvantages:

a) **Slightly Less Efficient than SSB:** Uses more bandwidth (B+f_v vs B).

b) **Filter Design Critical:** Requires careful design of the asymmetrical VSB filter roll-off to meet the distortion-less condition.

c) **Carrier Needed for Envelope Detection:** Requires transmitting carrier power (reducing power efficiency for the message).

d) **Susceptibility to Nonlinear Distortion:** Similar to AM.

8. KEY APPLICATIONS

1. **Analog Television Broadcasting:** The defining application. NTSC (US), PAL (Europe/Africa), SECAM (France/Russia) all used VSB-AM (VSB+C) for video transmission. (6 MHz or 8 MHz channels).
2. **Digital Television (ATSC 1.0):** Uses **8-VSB** modulation (8-level Vestigial Sideband). While digital, it leverages the VSB spectrum shape (8 MHz channel, significant roll-off) for terrestrial broadcast robustness and compatibility with analogue channel allocations/filters.
3. **Some Data Modems & Cable Systems:** Used in specific scenarios requiring bandwidth efficiency without SSB complexity.

9. COMPARISON TO OTHER AM TECHNIQUES

Feature	DSB-SC	SSB-SC	VSB-SC/VSB+C	Conventional AM
Bandwidth	2B	B	≈ B + f_v	2B
Carrier Tx	Suppressed	Suppressed	Partial/Full	Full
Rx Complexity	High (Coher)	High (Coher)	Low (Env) / Med (Coher)	Very Low (Env)
Filter Complexity	Low	Very High	Medium	Low
Power Eff.	High	Highest	High/Medium	Low
Low-Freq Resp.	Good	Poor	Good	Good

X. IMPORTANT FORMULAS & REPRESENTATIONS

1. **DSB-SC Signal:** s_dsb(t) = m(t) * cos(ω_c t)
2. **VSB Signal (After Filtering):** s_vsb(t) = [s_dsb(t)] * h_vsb(t) (Convolution) or S_vsb(f) = S_dsb(f) * H_vsb(f) (Frequency Domain)
3. **Coherent Demodulation Output (Ideal LPF):** y(t) = (1/2) * m(t) (Provided distortion-less condition holds)
4. **Distortion-less Condition:** H(f - f_c) + H(f + f_v) = K for |f| < B (K constant, often 1 or 2)

XI. Self-Test Questions

1. What does "vestigial" refer to in VSB modulation?
2. Why was SSB impractical for analogue TV transmission?
3. Draw a sketch of a typical VSB filter magnitude response |H(f)| around the carrier frequency f_v. Labelf_v .
4. Calculate the approximate bandwidth of a VSB signal if the baseband bandwidth is 5 MHz and the vestige width is 1.25 MHz.
5. Name the two main methods for demodulating VSB. Which one requires a transmitted carrier?
6. What is the key requirement (distortion-less condition) a VSB filter must satisfy for perfect coherent demodulation?
7. What is the primary advantage of VSB over DSB? What is the primary advantage of VSB over SSB?
8. What was the dominant historical application of VSB? Name one modern digital standard that uses a form of VSB.
9. If a VSB filter passes the USB almost completely and a vestige of the LSB, what would its response look like for negative frequencies relative to f_c?
10. Explain why envelope detection can be used with VSB+C but not with VSB-SC.

XII. Key Terms to Remember

- Vestigial Sideband (VSB)
- Vestigial Band (f_v)
- VSB Filter (Asymmetrical Roll-off)
- DSB-SC (Double Sideband Suppressed Carrier)
- SSB-SC (Single Sideband Suppressed Carrier)
- Coherent Detection
- Envelope Detection
- VSB+C (VSB with Carrier)
- Distortionless Condition (H(f-fc) + H(f+fc) = K)
- Bandwidth Efficiency
- NTSC/PAL/SECAM (Analog TV)
- ATSC 8-VSB (Digital TV)

HOW TO USE THIS GUIDE:

1. **Start with Concepts (I, II, VII):** Understand the "why" before the "how".

2. **Master the Spectrum & Filter (III, IV, VI):** Visualize the filter shape and resulting spectrum. The distortionless condition is key.
3. **Understand Demodulation (V):** Know the differences between coherent and envelope detection and their requirements.
4. **Contextualize with Applications (VIII):** See how theory translates to real-world systems (TV).
5. **Compare & Contrast (IX):** Use the table to solidify differences between AM techniques.
6. **Practice Math (X):** Work through the formulas. Try generating/demodulating simple signals conceptually.
7. **Test Yourself (XI):** Answer the self-test questions without looking. Explain concepts aloud.
8. **Memorize Key Terms (XII):** Ensure you can define each term precisely.