P1: AM

**1. Significance of the Modulation Index in AM and Its Effect on the Waveform**

* **Modulation Index (m)** in **Amplitude Modulation (AM)** is a measure of how much the amplitude of the carrier wave is varied by the modulating signal. It is defined as:

m=Am/Ac

where:

* + Am = peak amplitude of the modulating signal
  + Ac = peak amplitude of the carrier signal
* **Significance:**
  + **m < 1 (Under-modulation):** The carrier is not fully modulated; the modulating signal's information is weakly transmitted.
  + **m = 1 (Ideal Modulation):** The carrier amplitude varies fully from max to zero — optimal modulation.
  + **m > 1 (Over-modulation):** Causes **distortion** due to envelope overlapping (envelope no longer matches the modulating signal).
* **Effect on Waveform:**
  + As the modulation index increases, the envelope of the AM waveform becomes more pronounced.
  + Over-modulation results in a distorted envelope, leading to potential information loss during demodulation.

**2. Key Differences Between Modulated and Demodulated Signals**

| **Feature** | **Modulated Signal (AM)** | **Demodulated Signal** |
| --- | --- | --- |
| **Frequency Content** | Contains **carrier** frequency fc and **sidebands** at fc±fm | Contains only the **baseband** (original) signal frequency fm |
| **Shape** | High-frequency carrier wave with an amplitude envelope matching the modulating signal | Low-frequency waveform resembling the original signal |
| **Purpose** | For efficient transmission over long distances via antennas | For retrieving the original message signal at the receiver |

**3. Distortion in the Demodulated Signal as an Indicator**

Distortion in the demodulated signal can indicate:

* **Improper Modulation:**
  + **Over-modulation (m > 1):** Causes clipping or inversion in parts of the envelope, resulting in waveform distortion after demodulation.
  + **Under-modulation (m ≪ 1):** The envelope is too weak, making it difficult to recover the original signal clearly.
* **Improper Filtering:**
  + **Insufficient Low-Pass Filtering:** Allows high-frequency carrier or noise components to pass through, causing distortion.
  + **Over-Aggressive Filtering:** May attenuate essential parts of the baseband signal, distorting the recovered waveform.
* **Other Causes:**
  + Nonlinearities in detection circuitry
  + Phase mismatch in synchronous detection
  + Noise interference during transmission

P2: FM

**1. Parameters that Determine the Bandwidth of an FM Signal**

The bandwidth of an **FM signal** is primarily determined by:

* **Frequency Deviation (Δf):** This refers to how much the carrier frequency deviates from its unmodulated value due to the modulating signal. Greater deviation means a wider bandwidth.
* **Modulation Frequency (fm ​)**: This is the frequency of the modulating signal. Higher modulation frequencies also contribute to a wider bandwidth.

**2. How Frequency Deviation Affects the Shape of the Modulated Waveform**

* **Frequency Deviation** determines the **extent** to which the carrier frequency varies in response to the modulating signal.
* A **larger frequency deviation** leads to a more **spread-out** and more pronounced **frequency modulation**. The waveform of the FM signal will exhibit:
  + **Wider Frequency Spectrum**: The carrier frequency swings further from its center point.
  + **Increased Bandwidth**: A higher deviation increases the number of sidebands, leading to a broader spectrum.
* On the waveform:
  + **Small Deviation**: The FM signal will resemble a **narrower** spectrum, with less variation.
  + **Large Deviation**: The signal will show a wider frequency spread and a more **complex** waveform.

**3. Methods Used for Demodulating FM Signals**

The common methods for demodulating **FM signals** include:

* In a **zero-crossing counter demodulator**, pulses are generated at each zero crossing of the FM signal. The pulse density varies with the signal's frequency, and a low-pass filter averages these pulses to recover the original message signal. This method is simple but less precise and more susceptible to noise.
* A **phase-locked loop (PLL)** demodulator compares the FM signal with the output of a voltage-controlled oscillator (VCO) using a phase detector. The PLL adjusts the VCO to lock its frequency and phase to that of the FM signal. The control voltage used to tune the VCO is the demodulated output, accurately representing the original message.

**4. Noise Immunity Comparison Between AM and FM Signals**

* **FM (Frequency Modulation)** generally offers **better noise immunity** compared to **AM (Amplitude Modulation)**. Here’s why:
  + **AM Signals**: In AM, the information is encoded in the **amplitude** of the carrier. Amplitude changes are highly susceptible to **noise** (like static or electrical interference) because noise typically affects the amplitude of the signal.
  + **FM Signals**: In FM, the information is encoded in the **frequency** deviation of the carrier. Noise affects the **amplitude** of the signal but has minimal effect on the frequency, which is where the actual information resides. The FM demodulator is less sensitive to amplitude variations, hence providing **immunity** to amplitude noise.

P3: PAM

**1. What is the Nyquist Criterion and How Does It Relate to PAM?**

The **Nyquist criterion** states that for a signal to be **perfectly reconstructed** from its samples, the sampling rate must be **at least twice the highest frequency** present in the signal. In **Pulse Amplitude Modulation (PAM)**, this means that the signal should be sampled at a rate that meets or exceeds **twice the bandwidth** of the signal. This ensures that the original analog message can be accurately recovered from the sampled pulses, avoiding **aliasing** or loss of information.

**2. What Are the Drawbacks of PAM in Practical Communication Systems?**

* **Bandwidth Usage**: PAM requires a higher bandwidth compared to some other modulation schemes like Frequency Modulation (FM), especially with higher-order PAM (more pulse levels).
* **Noise Sensitivity**: PAM is more vulnerable to **noise and interference**, especially in channels with low signal-to-noise ratio (SNR), as errors in pulse amplitude can lead to significant distortion.
* **Power Efficiency**: PAM is **inefficient in terms of power**, particularly when transmitting over long distances, since the signal's strength decreases rapidly with distance.

**3. How Can Reconstruction Filters Be Used to Recover the Original Message Signal?**

Reconstruction filters, typically **low-pass filters**, are used to smooth out the **discrete pulses** in PAM and convert them back into a continuous analog signal. When the pulses are sampled at or above the Nyquist rate, the reconstruction filter removes the high-frequency components of the signal (created by sampling) and effectively reconstructs the original analog waveform by **interpolating** between the pulses. This process recovers the original message signal, ideally with minimal distortion.

P4: ASK

**1. How Does ASK Differ from Standard AM in Terms of Modulation Technique?**

**Amplitude Shift Keying (ASK)** is a digital modulation technique where the **carrier amplitude is varied between fixed levels** (often on/off) based on digital data (e.g., 1 or 0).  
In contrast, **Amplitude Modulation (AM)** is an analog technique where the **amplitude of the carrier continuously varies** in proportion to the analog message signal.  
So, ASK transmits digital information using discrete amplitude levels, while AM transmits analog information using continuous amplitude variations.

**2. What Is the Effect of Noise on ASK Signals?**

ASK is highly **sensitive to noise**, especially **amplitude noise**, because the data is encoded in the signal's amplitude.  
Any fluctuation in amplitude caused by noise can lead to bit errors, such as mistaking a ‘1’ for a ‘0’.  
This makes ASK less reliable in noisy or long-distance communication channels.

**3. What Methods Are Used for Demodulating ASK Signals?**

1. **Synchronous ASK Demodulation (Coherent Detection)**

* **Carrier synchronization** is required.
* **Square-law detector**:
  + Squares the received ASK signal to enhance amplitude differences.
  + Output contains both high-frequency (2ωc) and low-frequency (DC) components.
* **Low-pass filter**:
  + Removes high-frequency components.
  + Retains DC term proportional to amplitude (binary 0 or 1).
* **Comparator**:
  + Compares filtered output with a threshold.
  + Output is binary 1 (above threshold) or binary 0 (below threshold).
* **Voltage limiter** (optional):
  + Standardizes voltage levels (e.g., 0V and 2V).

**✔ High accuracy, good noise performance.**

1. **Asynchronous ASK Demodulation (Non-Coherent Detection)**

* **No carrier synchronization** needed.
* **Rectifier**:
  + Converts signal to unipolar form, preserving amplitude variations.
* **Low-pass filter**:
  + Extracts the envelope (amplitude) of the signal.
* **Comparator**:
  + Compares filtered signal to a threshold.
  + Outputs binary 1 or 0 based on amplitude.

**✔ Simple and low-cost, but more affected by noise.**

P5: FSK

**1. How does FSK compare to ASK in terms of noise immunity?**

**Frequency Shift Keying (FSK)** has **better noise immunity** than **Amplitude Shift Keying (ASK)**.  
This is because FSK encodes data using **frequency changes**, which are **less affected by amplitude noise** like interference or signal fading.  
In contrast, ASK is sensitive to any amplitude variation, making it more vulnerable in noisy environments.

**2. What are practical applications of FSK in digital communication?**

FSK is widely used in applications that require **reliable digital data transmission**, including:

* **Modems** (e.g., early dial-up modems using binary or multi-level FSK)
* **Radio communication** (e.g., walkie-talkies, emergency systems)
* **RFID systems**
* **Low-speed telemetry and data links**
* **Paging systems** and **wireless sensors**

It is especially suitable for **low to moderate data rate** systems where **robustness and simplicity** are needed.

P6: Delta Modulation

**1. How does Delta Modulation differ from PCM in terms of complexity and bandwidth?**

* **Delta Modulation (DM)** is **simpler** than **Pulse Code Modulation (PCM)** because it encodes only the **change (Δ)** in signal amplitude, using **1-bit per sample**.
* DM typically uses **less bandwidth** than PCM, which requires **multiple bits per sample** to represent amplitude levels.
* However, DM may suffer from **slope overload** or **granular noise**, especially if the step size or sampling rate isn't well-chosen.

**2. How Can Adaptive Delta Modulation Improve Performance?**

**Adaptive Delta Modulation (ADM)** dynamically adjusts the **step size** based on the rate of change of the input signal:

* When the signal changes quickly, the step size increases to **track fast variations**.
* When the signal changes slowly, the step size decreases to **reduce granular noise**.  
  This adaptability helps ADM **improve accuracy** and **reduce distortion**, especially in signals with varying dynamics like speech or audio.

**3. How Does Step Size Affect the Accuracy of Delta-Modulated Signals?**

* If the **step size is too small**, the modulator cannot keep up with rapid signal changes, causing **slope overload distortion**.
* If the **step size is too large**, the signal approximation becomes coarse, leading to **granular noise** in slowly varying parts.
* Therefore, choosing the **right step size** (or adapting it, in ADM) is crucial for **accurate signal representation**.