DEMODULATION OF AM SIGNALS

Demodulation: Restoring (or recovering) the message signal from the received modulated waveform that is generally corrupted by noise

Types of AM detectors:

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Coherent detection:

- Both phase and frequency of carrier are known at the demodulator.
- Amplitude of carrier is not important since it influences only the demodulated signal level which may be changed by a simple amplifier.

Key element of coherent detector is an analog multiplier. For example, consider a DSB–SC signal

\[ s(t) = m(t) A_c \cos(2\pi f_c t) \]

A well-known trigonometrical identity

\[ \cos \alpha \cos \beta = \frac{1}{2} [\cos(\alpha - \beta) + \cos(\alpha + \beta)] \]

Output of analog multiplier

\[ s(t) \hat{c}(t) = m(t) A_c \cos(2\pi f_c t) A_r \cos(2\pi f_c t) = \frac{A_c A_r}{2} m(t) (1 + \cos[2\pi (2f_c) t]) \]

- Noise performance of a coherent detector is always better than that of a noncoherent counterpart.
Envelope of a band-pass signal

A signal $g(t)$ is a band-pass signal if its Fourier transform is non-negligible only in a band of frequencies of total extent $2W$ centered about $f_c$. Each band-pass signal may be expressed as

$$g(t) = \Re \{ \tilde{g}(t) \exp(j2\pi f_c t) \} = \Re \{ a(t) \exp[j\phi(t)] \exp(j2\pi f_c t) \}$$

where by definition

$$\tilde{g}(t) = g_I(t) + jg_Q(t) = a(t) \exp[j\phi(t)]$$

is the complex envelope. The complex envelope is a generalization of phasor concept discussed in Basic Electronics.

By definition $a(t)$ is the envelope and $\phi(t)$ is the phase of a band-pass signal. With these parameters the continuous wave (CW) modulations may be described easily

$$g(t) = a(t) \cos[2\pi f_c t + \phi(t)] \iff s(t) = a(t) \cos[\theta_i(t)]$$

where the center frequency $f_c$ is called carrier frequency.
DSB waveforms \[ s(t) = A_c[1 + k_a m(t)] \cos(2\pi f_c t) \]

(a) Message signal \( m(t) \)

(b) AM waveform for \( \mu < 1 \)

(c) Overmodulated \( (\mu > 1) \) AM signal (Note the phase reversals and envelope distortion)

**Note:** Message signal may be recovered from the envelope only if DSB signal is a narrow-band signal \( (W \ll f_c) \) and if modulation factor is small enough \( (\mu < 1) \).
ENVELOPE DETECTOR

- On positive half-cycle of RF input signal $s(t)$ the diode is forward biased and the capacitor $C$ charges up rapidly to the peak value of RF input signal.
- When RF input falls below the output voltage then the diode becomes reverse-biased and the capacitor $C$ discharges slowly through the load resistor $R_l$.
- If $\frac{1}{f_c} << R_l C << \frac{1}{W}$ then the average value of output voltage is equal to the message signal.

Circuit

AM wave

Demodulated output
Distortion in envelope detector caused by the wrong time constant

Question: Why the frequency domain was not used in the analysis of envelope detector?

Recall: Envelope detector can be used to demodulate only DSB (no distortion) and VSB (little distortion) signals
PRODUCT DETECTOR

In *coherent detection* or *synchronous demodulation* both the phase and frequency of carrier must be known at the detector. Carrier is recovered by the **carrier recovery circuit** at the receiver.

**Techniques for providing the carrier signal:**

1. Carrier is transmitted
2. A pilot signal is transmitted outside the pass-band of modulated signal

Spectrum of an AM signal (Only the positive-frequency side is shown)

![Spectrum of an AM signal](image)

**Note:** Signals to be recovered are separated in the frequency domain (See frequency regions marked by curves) \(\implies\) Filtering is used
Techniques for recovering the carrier signal:

1. Recovery of carrier by a band-pass filter

2. Recovery of carrier by *phase-locked loop* (PLL)

**Note:** The demodulator contains a carrier recovery circuit [its output is the recovered carrier $\hat{c}(t)$] and a product detector (see the analog multiplier and low-pass filter)
Product detector

AM modulated input signal: \[ s(t) = A_c f[m(t)] \cos(2\pi f_c t) \]

Recovered carrier: \[ \hat{c}(t) = A_r \cos(2\pi f_c t) \]

Output of analog multiplier: \[ \hat{m}(t) = s(t)\hat{c}(t) = \frac{A_c A_r}{2} f[m(t)] (1 + \cos[2\pi(2f_c)t]) \]

Note: • The first term contains the message signal
• A low-pass filter is required to suppress the sum-frequency output
Demodulation of DSB signal by means of a product detector

DSB modulator

Coherent DSB demodulator

Remarks:  
- For the sake of simplicity, $k_a = 1$ and $A_r = A_c$ have been chosen
- Low-pass filter at the detector output suppresses the sum-frequency output
Demodulation of DSB–SC signal by means of a product detector

DSB-SC modulator

\[ m(t) \xrightarrow{\times} s(t) \]

\[ A_c \cos(2\pi f_c t) \]

Coherent DSB-SC demodulator

\[ s(t) \xrightarrow{\times} \hat{m}(t) \]

\[ \hat{c}(t) \]

Recovered carrier

Remarks: • As in the case of DSB, product detector recovers the message signal without any distortion
Demodulation of VSB signal by means of a product detector

VSB modulator

\[ m(t) \rightarrow A_w \cos(2\pi f_c t) \rightarrow \text{VSB filter} \rightarrow s(t) \]

Coherent VSB demodulator

\[ s(t) \rightarrow \hat{c}(t) \rightarrow \hat{m}(t) \]

Remarks:
- Product detector recovers the message signal without any distortion
- Product detector is used exclusively in the TV receivers today
Demodulation of SSB signal by means of a product detector

SSB modulator

\[ m(t) \rightarrow A \cos(2\pi f_c t) \rightarrow s(t) \]

SSB filter

Coherent SSB demodulator

\[ s(t) \rightarrow \hat{c}(t) \rightarrow \hat{m}(t) \]

**Remarks:**
- Product detector recovers the message signal without any distortion
- Generally a low-level pilot signal is transmitted for the carrier recovery circuit
CONCLUSIONS:

• Noise performance of a coherent detector is always better than that of a noncoherent detector

• Due to the frequency shifting property of analog multiplier, it can be used to implement each AM modulator and demodulator

• Low-pass filter is used in each detector, its duty is to suppress the high-frequency output

• The product detector is capable of restoring the message signal carried by each AM modulation scheme

• Until the carrier is available at the detector, there is no need for the transmission of carrier at least at a high power level. Recall: Transmission of carrier is a waste of power since it does not carry information except its phase and frequency.