File name: tut331_04am_dem.pdf

References: Haykin: pp. 129–131, 136–138
Tutorial notes

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:

Name of detector	Type of det.	Circuit used	Suitable for
Envelope detector	Noncoherent	Diode with an RC filter	DSB, VSB
Product detector	Coherent	Analog multiplier	Every AM

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

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

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

Envelope of a band-pass signal

A signals $g(t)$ 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

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

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

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

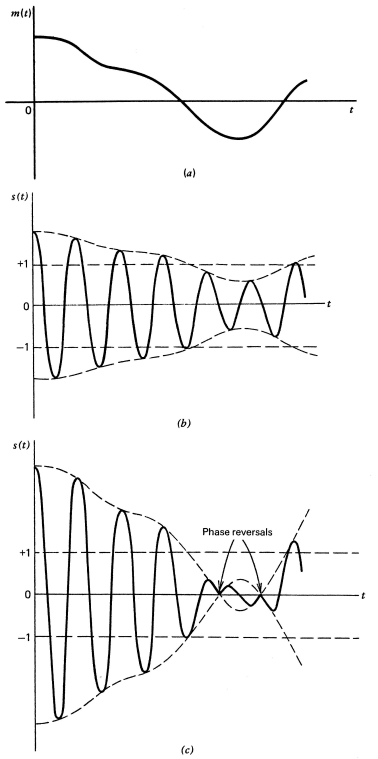
where the center frequency f_c is called carrier frequency.

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)

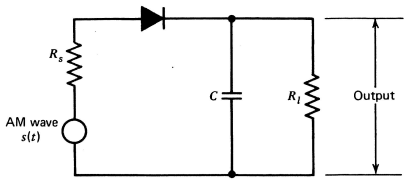


Note: Message signal may be recovered from the envelope only if DSB signal is a narrow-band signal ($W << f_c$) and if modulation factor is small enough ($\mu < 1$).

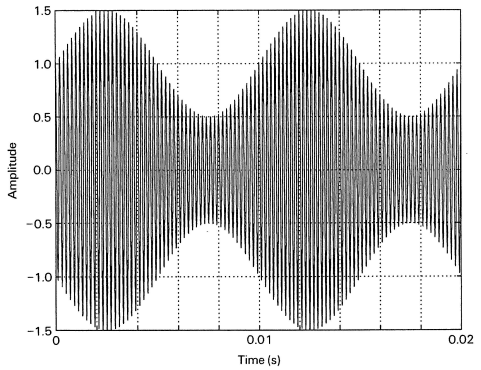
ENVELOPE DETECTOR

- 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

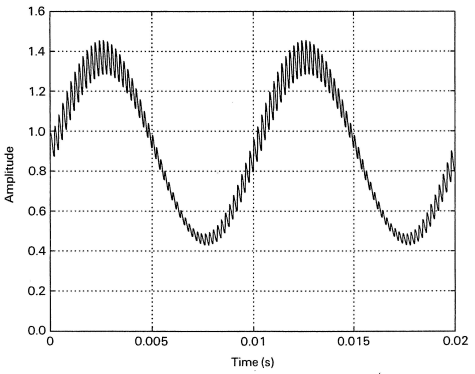
Circuit



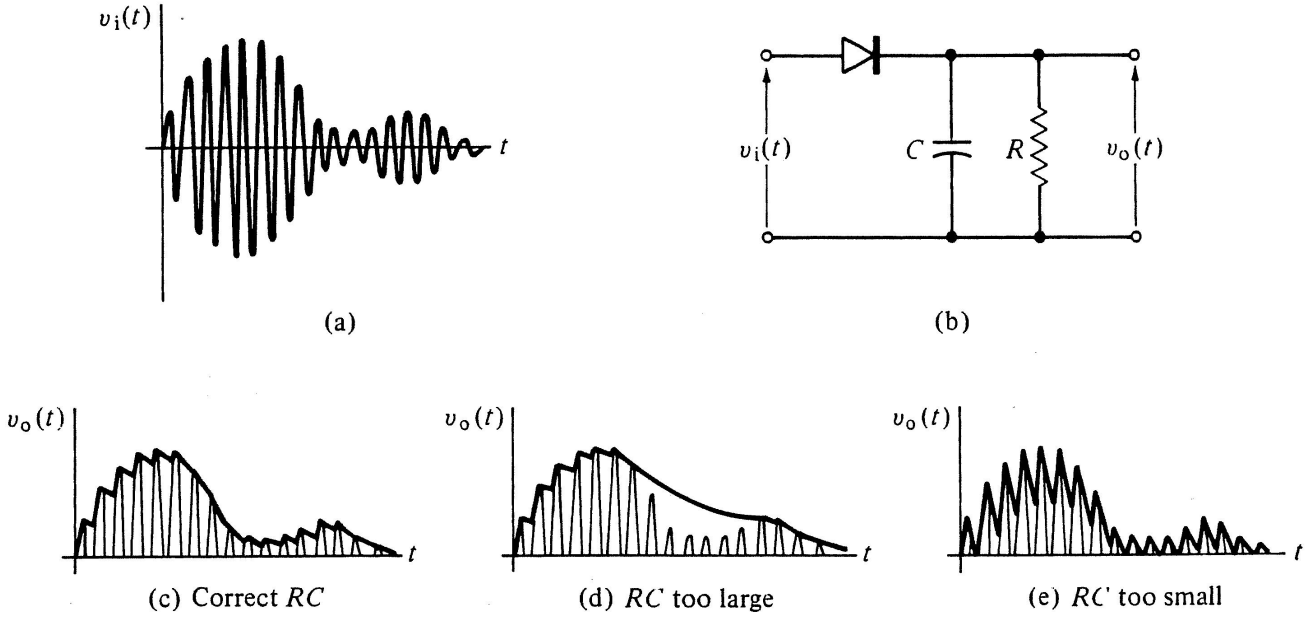
AM wave



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

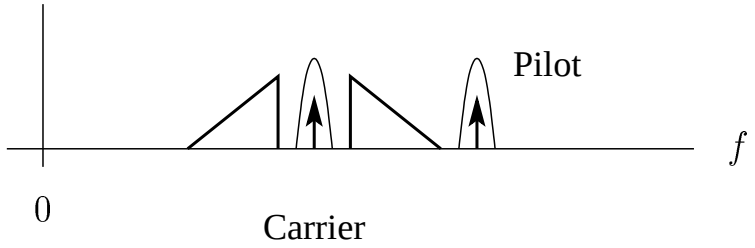
PRODUCT DETECTOR

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

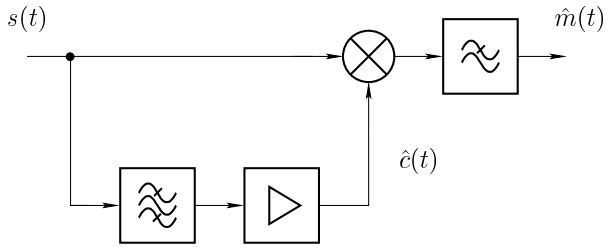
Spectrum of an AM signal (Only the positive-frequency side is shown)



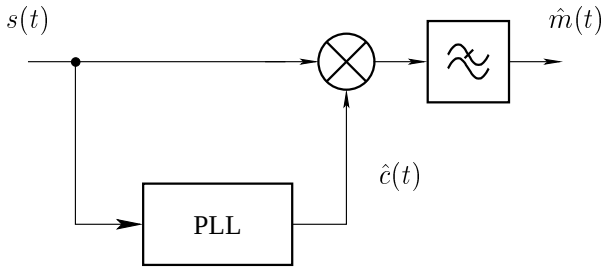
Note: Signals to be recovered are separated in the frequency domain (See frequency regions marked by curves) $\Longrightarrow$ Filtering is used

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

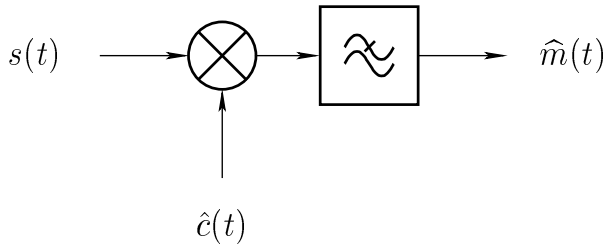
AM modulated input signal: $s(t) = A_c f[m(t)] \cos(2\pi f_c t)$

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

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

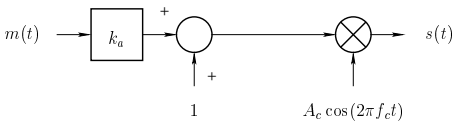
Note:
- The first term contains the message signal
- A low-pass filter is required to suppress the sum-frequency output

Block diagram of product detector

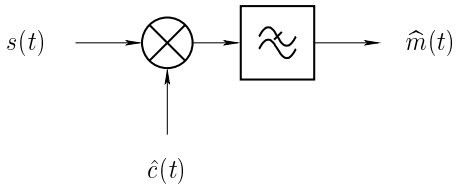


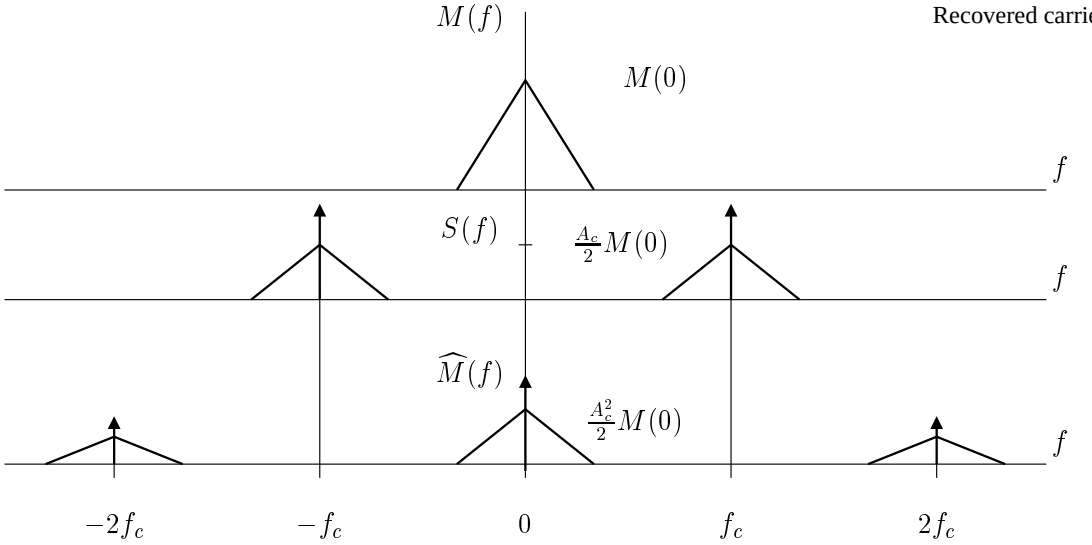
Demodulation of DSB signal by means of a product detector

DSB modulator



Coherent DSB demodulator

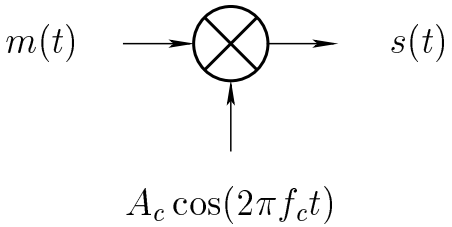




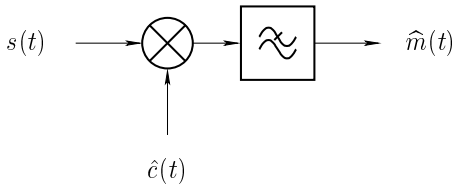
Remarks:
- For the sake of simplicity, $k_a = 1$ and $A_r = A_c$ have been chosen
- Low-pass filter at the detector output suppresses the sum-frequency output

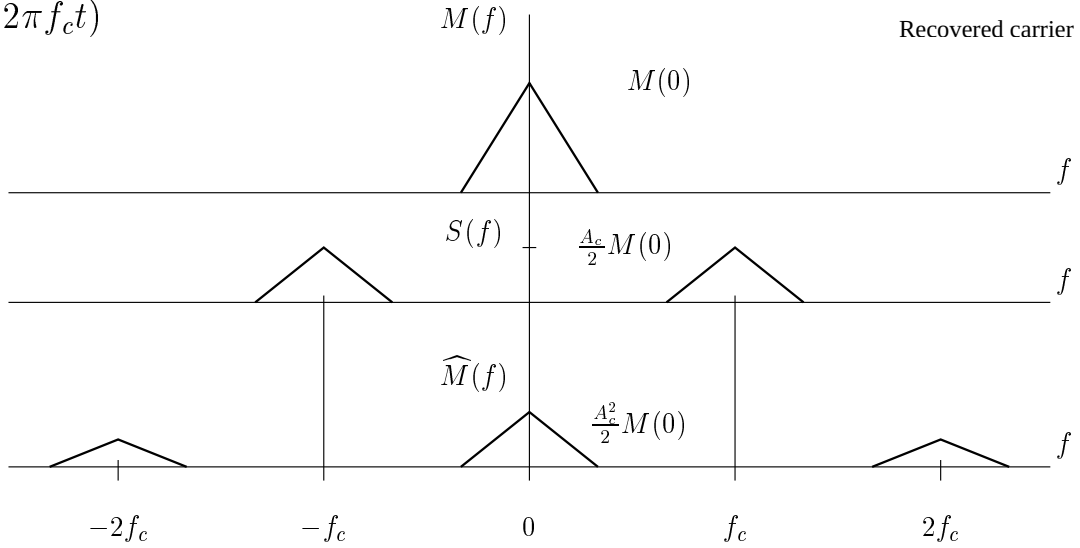
Demodulation of DSB–SC signal by means of a product detector

DSB-SC modulator



Coherent DSB-SC demodulator

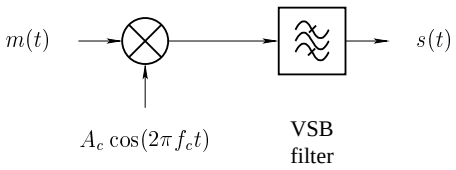




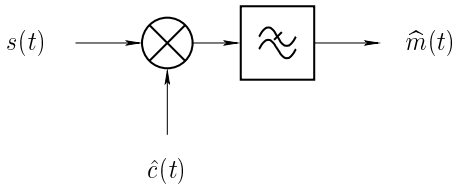
Remarks:
- As in the case of DSB, product detector recovers the message signal without any distortion

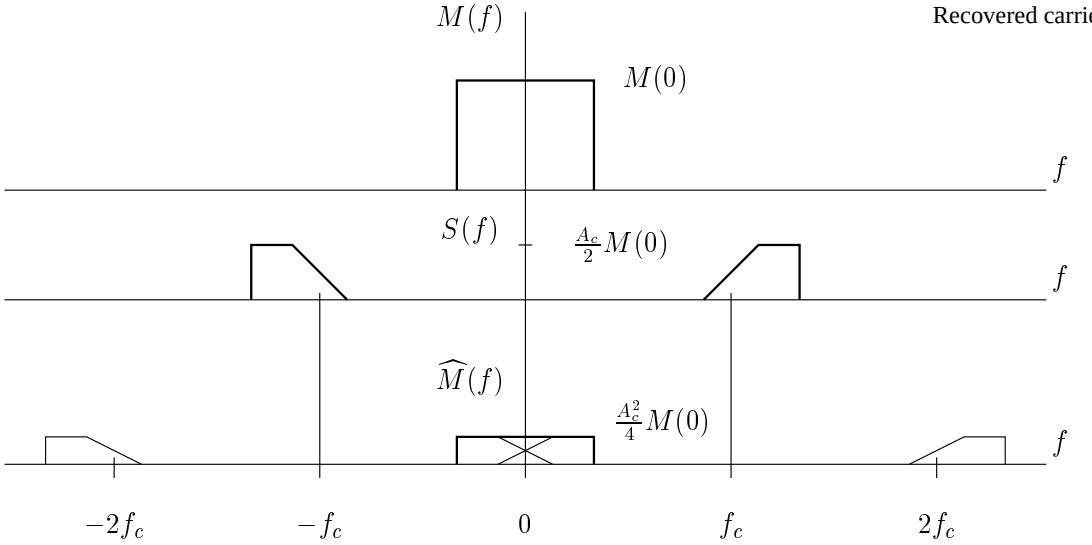
Demodulation of VSB signal by means of a product detector

VSB modulator



Coherent VSB demodulator

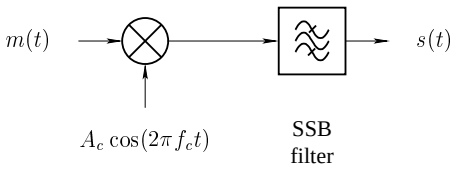




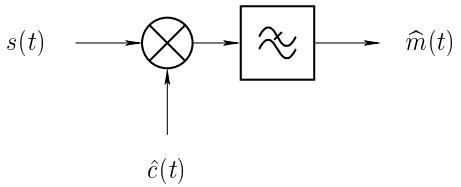
Remarks:
- Product detector recovers the message signal without any distortion
- Product detector is used exclusively in the TV receivers today

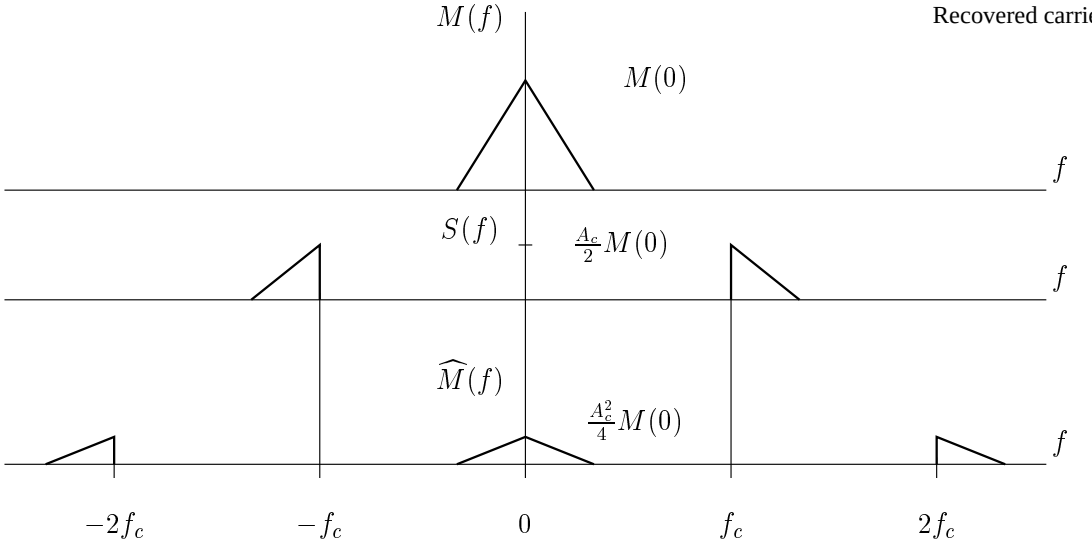
Demodulation of SSB signal by means of a product detector

SSB modulator



Coherent SSB demodulator





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.