# ELEC1323 Communications

# 4 Coherent detection

# Non-coherent vs coherent detection (CEP 3.6)

- In an AM signal, the sidebands contain all of the message information. The carrier contains none.
- However, in order to avoid overmodulation and allow non-coherent envelope detection, the carrier must use at least $2/3$ of the transmit power.
- If we want a more power-efficient AM scheme, we need to overmodulate the carrier and use coherent detection.
- However, this requires a more complicated receiver, which can obtain exact knowledge of the carrier frequency and phase.

# Coherent detection (CEP 3.5.2)

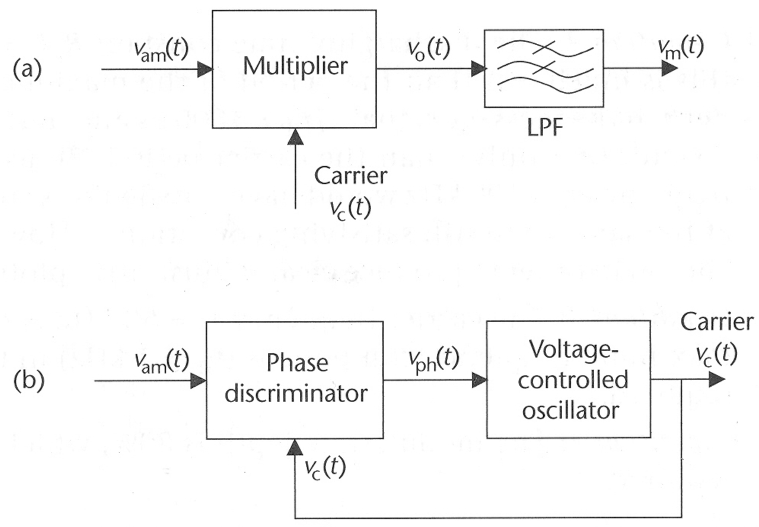



**Figure 3.20** (a) Coherent AM demodulator; (b) phase-locked loop (PLL).

- The VCO produces a sinusoid $v_c(t)$ having the frequency $f_c$ when its input $v_{ph}(t)$ is zero.
- This frequency is increased or decreased when the input is positive or negative, respectively.
- The output of the phase discriminator $v_{ph}(t)$ will be zero when $v_c(t)$ and $v_{am}(t)$ are in phase, otherwise it will be positive or negative as appropriate.
- The negative feedback loop keeps $v_c(t)$ and $v_{am}(t)$ in phase.

# Coherent detection (CEP 3.5.2)

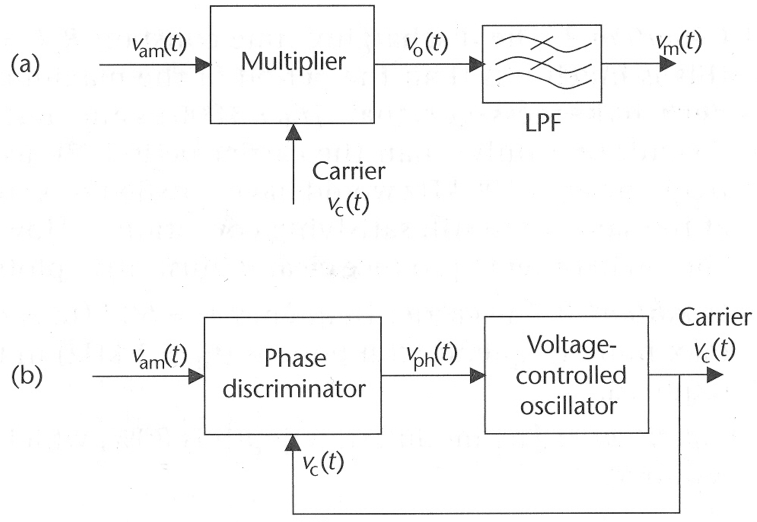
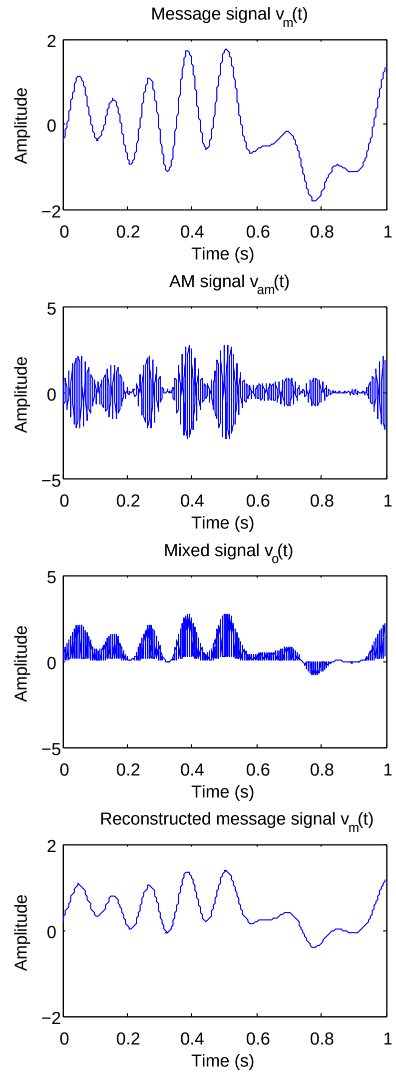



**Figure 3.20** (a) Coherent AM demodulator; (b) phase-locked loop (PLL).




$$
\begin{aligned}
v_{am}(t) &= (V_c + k_{am} \cdot v_m(t)) \cos(2\pi f_c t) \\
v_c(t) &= \cos(2\pi f_c t) \\
v_o(t) &= v_{am}(t) \cdot v_c(t) \\
&= (V_c + k_{am} \cdot v_m(t)) \cos^2(2\pi f_c t)
\end{aligned}
$$

# Coherent detection (CEP 3.5.2)

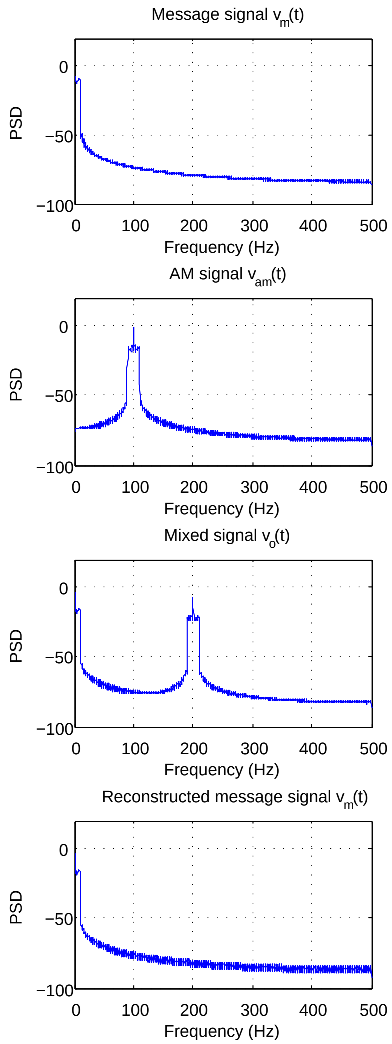
$$v_o(t) = (V_c + k_{am} \cdot v_m(t)) \cos^2(2\pi f_c t)$$

Using the trigonometric identity $\cos^2(2\pi f t) = \frac{1}{2} + \frac{1}{2}\cos(4\pi f t)$ from lecture 3, we get

$$\begin{aligned} v_o(t) &= (V_c + k_{am} \cdot v_m(t)) \left(\frac{1}{2} + \frac{1}{2}\cos(4\pi f_c t)\right) \\ &= \frac{1}{2}(V_c + k_{am} \cdot v_m(t)) + \frac{1}{2}(V_c + k_{am} \cdot v_m(t)) \cos(4\pi f_c t) \end{aligned}$$

The LPF removes the high frequency component, leaving

$$v'_m(t) = \frac{1}{2}(V_c + k_{am} \cdot v_m(t))$$



# Double SideBand Suppressed Carrier modulation (CEP 3.7.1.1)

DSBSC modulation is like AM modulation, but without the DC offset.

$$v_{dsb}(t) = v_m(t) \cdot V_c \cos(2\pi f_c t)$$

For a sinusoidal signal $v_m(t) = V_m \cos(2\pi f_m t)$ we have

$$\begin{aligned} v_{dsb}(t) &= V_m \cos(2\pi f_m t) \cdot V_c \cos(2\pi f_c t) \\ &= \frac{1}{2} V_m V_c \cos(2\pi [f_c - f_m] t) \\ &+ \frac{1}{2} V_m V_c \cos(2\pi [f_c + f_m] t) \end{aligned}$$

The lower and upper side frequencies are retained, but the carrier is suppressed, improving the power efficiency. However, the DSBSC signal bandwidth is still double that of the message signal.

Figure 3.29

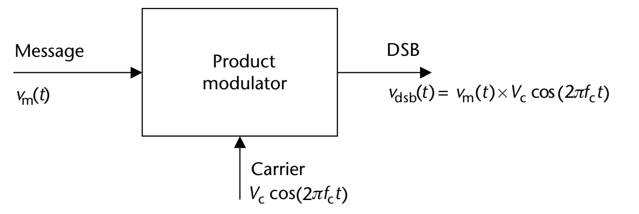



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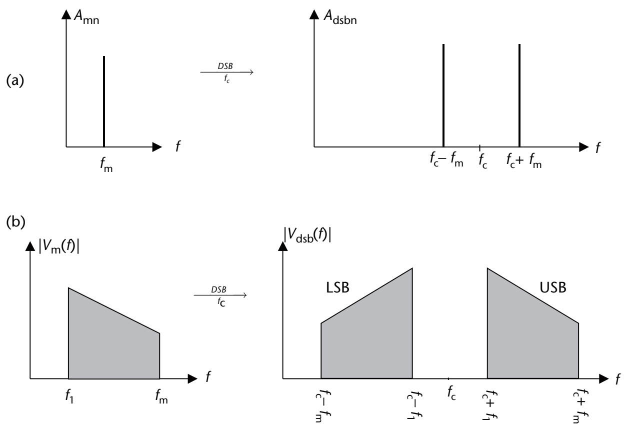
Figure 3.24

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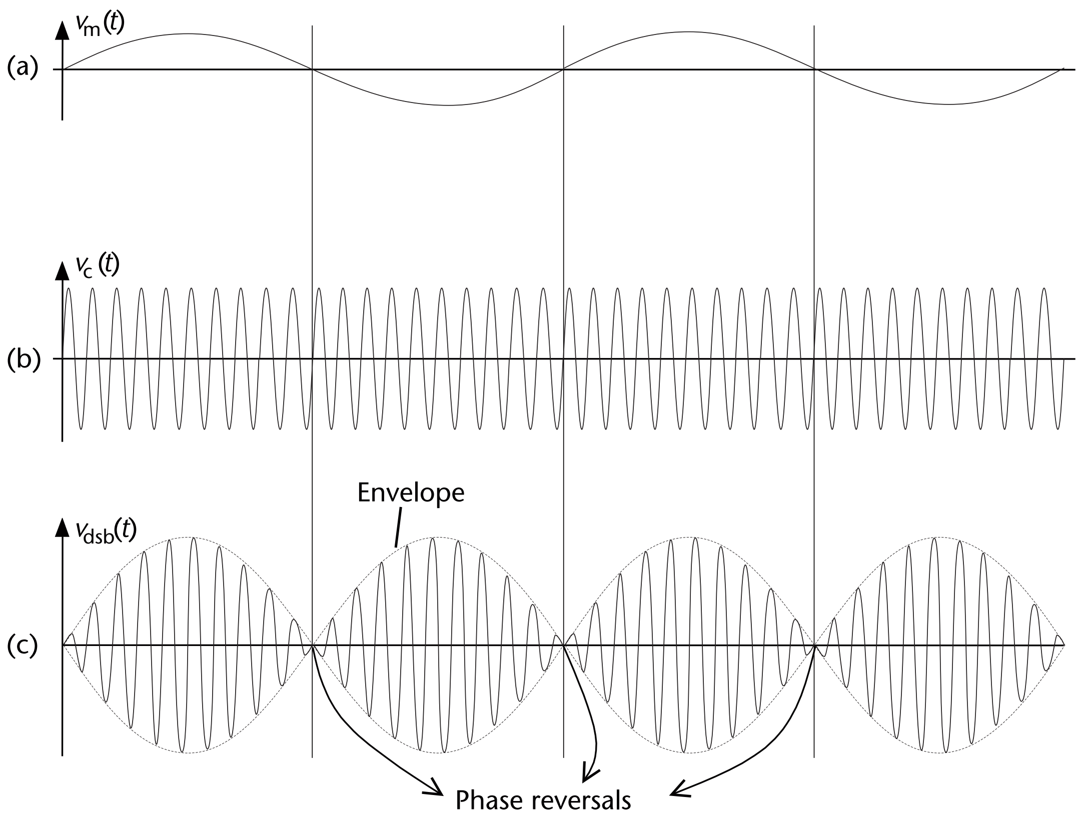
# Double SideBand Suppressed Carrier modulation (CEP 3.7.1.1)

In the time domain, the envelope crosses the x axis, causing phase reversals.

**Figure 3.23**



# DSBSC modulator (CEP 3.7.1.2)

Figure 3.25

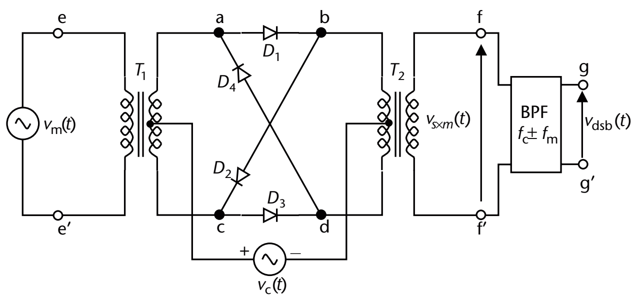



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Figure 3.27

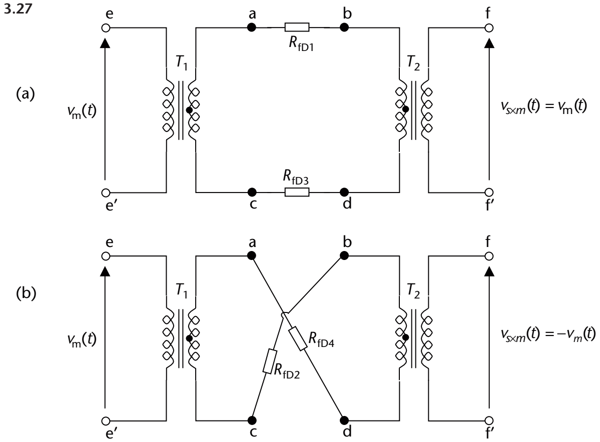


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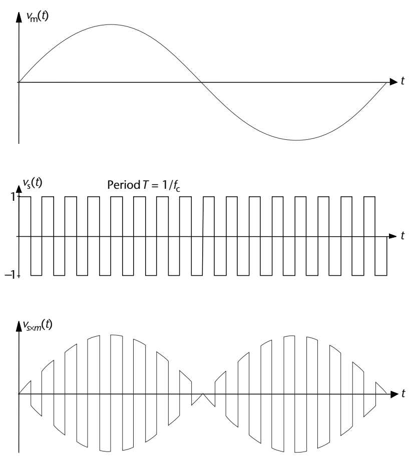
Figure 3.28

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- In a balanced modulator, a positive- and negative-going square wave $v_c(t)$ having the carrier frequency $f_c$ is used to bias the diodes.
- When the square wave has a positive voltage, D1 and D3 turn on, giving circuit (a). When the voltage is negative, D2 and D4 turn on, giving circuit (b).
- The BPF turns the enveloped square wave into an enveloped sinusoid.

# DSBSC demodulator (CEP 3.7.1.3)

Since the DSBSC signal is overmodulated, we must use coherent demodulation.

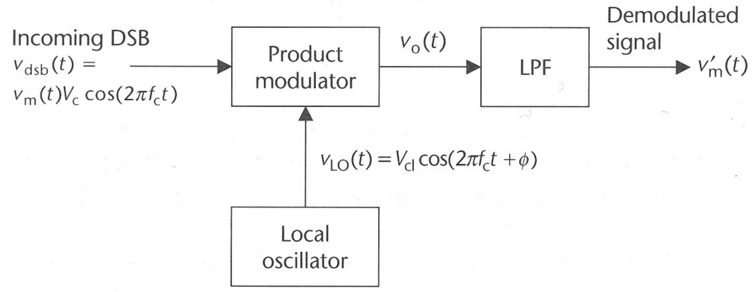



**Figure 3.30** Coherent demodulation of DSB.

$$v_o(t) = v_{dsb}(t) \cdot v_{LO}(t)$$

We can use trigonometric identity (1) from lecture 3 to see what happens when there is a phase difference $\phi$ between the local oscillator and the carrier.

$$\begin{aligned} v_o(t) &= v_m(t)V_c\cos(2\pi f_c t) \cdot V_{cl}\cos(2\pi f_c t + \phi) \\ &= \frac{1}{2}v_m(t)V_cV_{cl}\cos(\phi) + \frac{1}{2}v_m(t)V_cV_{cl}\cos(4\pi f_c t + \phi) \end{aligned}$$

After the LPF we get

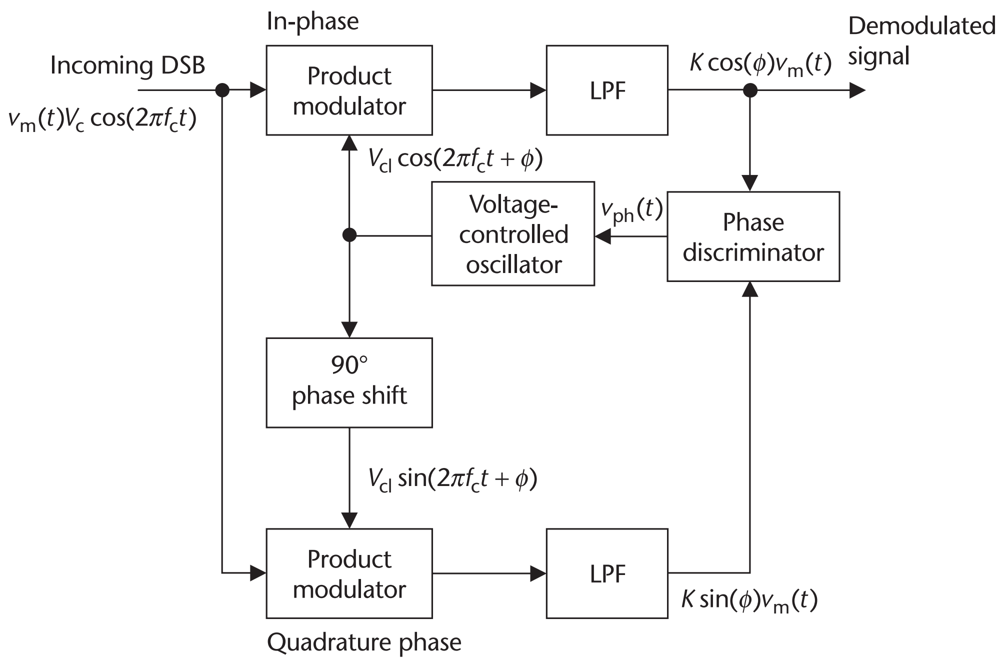
$$v'_m(t) = \frac{1}{2}v_m(t)V_cV_{cl}\cos(\phi)$$

Note that $v'_m(t)$ is attenuated altogether when $\phi = \pi/2$, which corresponds to a $90^\circ$ phase difference. This is the quadrature null effect.

# DSBSC demodulator (CEP 3.7.1.3)

The quadrature null effect motivates the Costas loop.

Figure 3.31

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This adjusts the local oscillator frequency until the signal $K\sin(\phi)v_m(t)$ is completely attenuated, leaving the desired signal $K\cos(\phi)v_m(t)$ completely unattenuated.

# Tuned receiver (CEP 3.5.3 and 3.5.3.1)

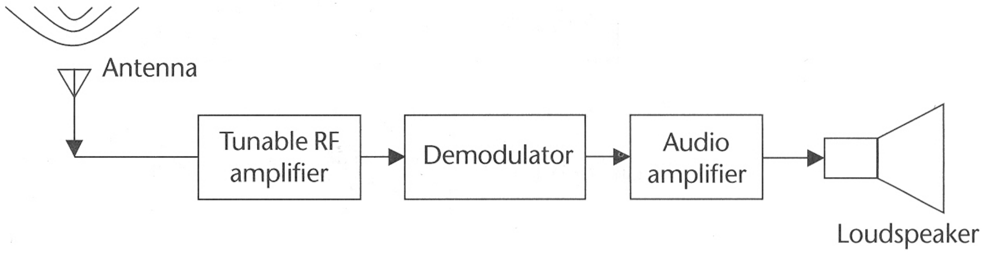



**Figure 3.21** Tunable radio frequency (TRF) receiver.

- The tunable RF amplifier rejects all signals except for the desired one.
- However, a very complex design is required to achieve the high-selectivity necessary to reject the unwanted adjacent signals owing to their high frequencies.

# Superheterodyne receiver (CEP 3.5.3.2)

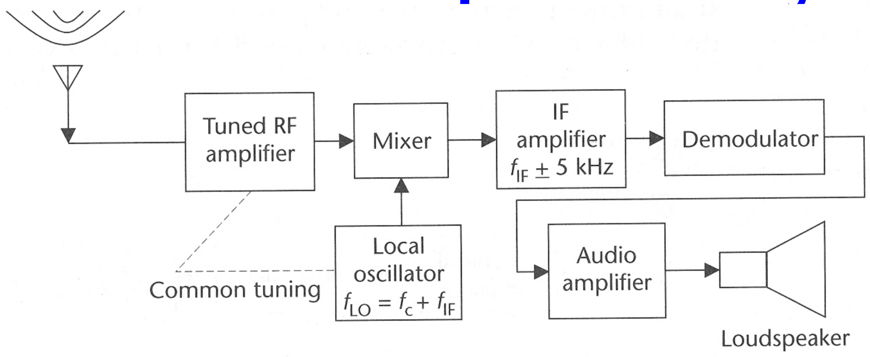
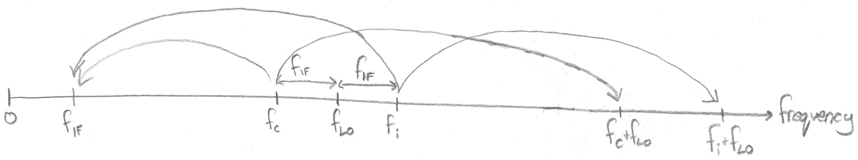



**Figure 3.22** The superheterodyne AM receiver.




- The mixer multiplies the AM signal by a sinusoid having a frequency $f_{LO} = f_c + f_{IF}$, where $f_{IF} \ll f_c$.
- The mixer moves the AM signal from being centred at $f_c$ to the difference $f_{LO} - f_c = f_{IF}$ and sum $f_{LO} + f_c = 2f_c + f_{IF}$ of the frequencies $f_{LO}$ and $f_c$.

- The high-selectivity IF amplifier removes the unwanted signals at low frequencies adjacent to $f_{IF}$, as well as the high frequency replica centred at the sum frequency $2f_c + f_{IF}$.

- However, the mixer will also move an unwanted image signal centred at $f_i = f_{LO} + f_{IF} = f_c + 2f_{IF}$ to $f_{IF}$. The low-selectivity tuned RF amplifier is therefore required to remove the high-frequency image signal before mixing takes place.

- A low complexity design results because high-selectivity is only used at low frequencies. At high frequencies, low-selectivity is used.

# Exercise

1. Sketch the amplitude spectrum of the message signal $v_m(t) = 3\cos(20\pi t + \pi/4) + 2\sin(60\pi t) - \cos(100\pi t)$.

2. Sketch the amplitude spectrum of the signal $v_{am}(t)$ that results when $v_m(t)$ is AM modulated onto a 1 kHz carrier using a DC offset of $V_c = 1$ and a modulation sensitivity of $k_{am} = 0.5$.

3. Calculate the fraction of the transmit power that is in the sidebands.

4. What kind of demodulation is required to recover the message signal $v_m(t)$ and why? Sketch the amplitude spectrum of the signal $v_o(t)$ obtained after the first step of the demodulator.

5. Sketch the phase spectra of the signals $v_m(t)$, $v_{am}(t)$ and $v_o(t)$.