ELEC1323 Communications

5 Variants of AM

Pros and cons of undermodulated AM (CEP 3.6)

Advantages:

- Simple non-coherent demodulator circuit.

Disadvantages:

- Wasteful of power since the carrier consumes lots of transmit power but conveys no information (information is conveyed by the sidebands).

- Wasteful of bandwidth since the AM signal bandwidth is double that of the message.

Pros and cons of DSBSC modulation (CEP 3.6)

Advantages:

- Power efficient since the carrier is suppressed and all power is consumed by the sidebands.

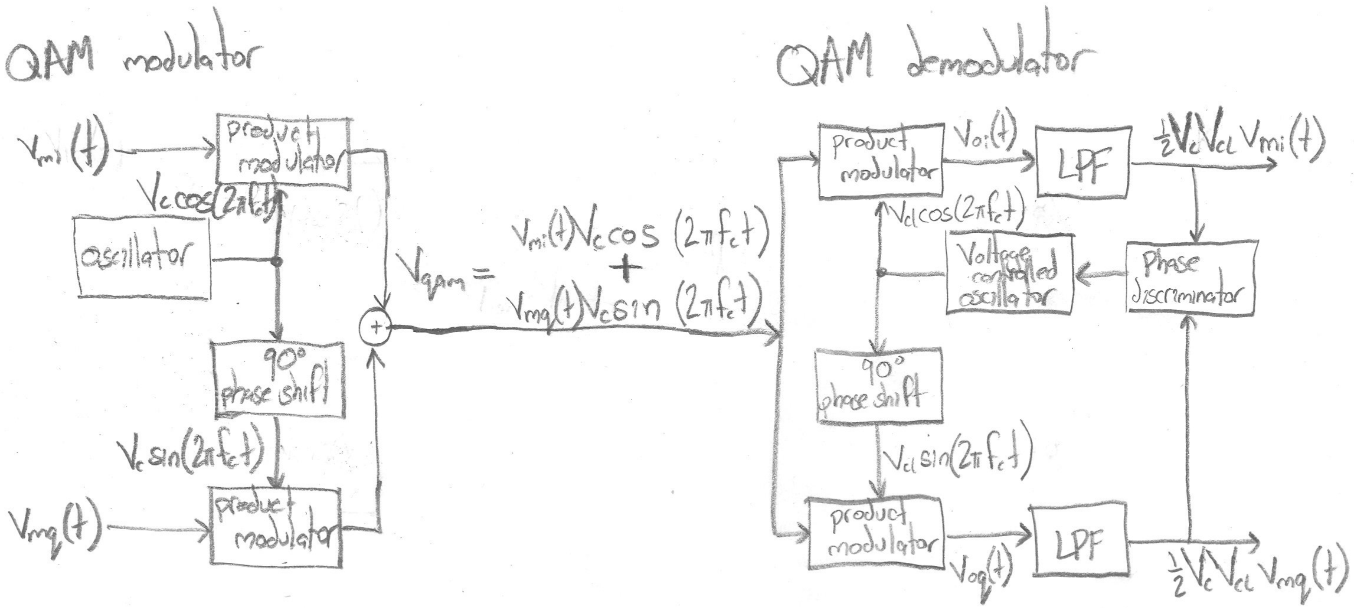
Disadvantages:

- More complex coherent demodulator circuit is required to obtain carrier phase.
- Attenuation occurs if carrier phase is estimated incorrectly.
- Wasteful of bandwidth since the AM signal bandwidth is still double that of the message.

Quadrature Amplitude Modulation (CEP 3.7.1.3)

• QAM improves the bandwidth efficiency of DSBSC by transmitting two message signals $v_{mi}(t)$ and $v_{mq}(t)$ in the same band, by using in-phase and quadrature-phase carriers having the same frequency.

• The QAM signal bandwidth is double the maximum of the two message signal bandwidths.



• The quadrature message signal $v_{mq}(t)$ must be initially turned off in order to allow the Costas loop to perform carrier recovery.

Mathematics

We need some more trigonometric identities

$$\cos\left(A - \frac{\pi}{2}\right) = \sin(A) \tag{1}$$

$$\cos(A - \pi) = -\cos(A) \tag{2}$$

Using trigonometric identity (1) from Lecture 3 and the identities above, we can derive even more identities

$$\cos^2(2\pi ft) = \frac{1}{2} + \frac{1}{2}\cos(4\pi ft) \tag{3}$$

$$\sin^2(2\pi ft) = \frac{1}{2} - \frac{1}{2}\cos(4\pi ft) \tag{4}$$

$$\cos(2\pi ft)\sin(2\pi ft) = \frac{1}{2}\sin(4\pi ft) \tag{5}$$

Mathematics

In QAM we have

$$v_{qam}(t) = v_{mi}(t)V_c \cos(2\pi f_c t) + v_{mq}(t)V_c \sin(2\pi f_c t)$$

Using identities (3) and (5) from above we can see how the in-phase carrier is demodulated

$$\begin{aligned} v_{oi}(t) &= v_{qam}(t) \cdot V_{cl} \cos(2\pi f_c t) \\ &= [v_{mi}(t)V_c \cos(2\pi f_c t) + v_{mq}(t)V_c \sin(2\pi f_c t)] \cdot V_{cl} \cos(2\pi f_c t) \\ &= \frac{1}{2}V_c V_{cl} v_{mi}(t) + \frac{1}{2}V_c V_{cl} v_{mi}(t) \cos(4\pi f_c t) + \frac{1}{2}V_c V_{cl} v_{mq}(t) \sin(4\pi f_c t) \end{aligned}$$

The LPF gives

$$v'_{mi}(t) = \frac{1}{2}V_c V_{cl} v_{mi}(t)$$

Mathematics

Similarly, the quadrature-phase carrier is demodulated using identities (4) and (5)

$$
\begin{aligned}
v_{oq}(t) &= v_{qam}(t) \cdot V_{cl}\sin(2\pi f_c t) \\
&= [v_{mi}(t)V_c\cos(2\pi f_c t) + v_{mq}(t)V_c\sin(2\pi f_c t)] \cdot V_{cl}\sin(2\pi f_c t) \\
&= \frac{1}{2}V_c V_{cl} v_{mq}(t) - \frac{1}{2}V_c V_{cl} v_{mq}(t)\cos(4\pi f_c t) + \frac{1}{2}V_c V_{cl} v_{mi}(t)\sin(4\pi f_c t)
\end{aligned}
$$

The LPF gives

$$v'_{mq}(t) = \frac{1}{2}V_c V_{cl} v_{mq}(t)$$

Effect of phase error

Suppose the receiver's estimate of the carrier includes a phase error ϕ

$$
\begin{aligned}
v_{oi}(t) &= v_{qam}(t) \cdot V_{cl}\cos(2\pi f_c t + \phi) \\
&= [v_{mi}(t)V_c\cos(2\pi f_c t) + v_{mq}(t)V_c\sin(2\pi f_c t)] \cdot V_{cl}\cos(2\pi f_c t + \phi) \\
&= \frac{1}{2}V_c V_{cl} v_{mi}(t)\cos(\phi) + \frac{1}{2}V_c V_{cl} v_{mi}(t)\cos(4\pi f_c t + \phi) \\
&\quad -\frac{1}{2}V_c V_{cl} v_{mq}(t)\sin(\phi) + \frac{1}{2}V_c V_{cl} v_{mq}(t)\sin(4\pi f_c t + \phi)
\end{aligned}
$$

The LPF gives the following result for the demodulated in-phase message signal

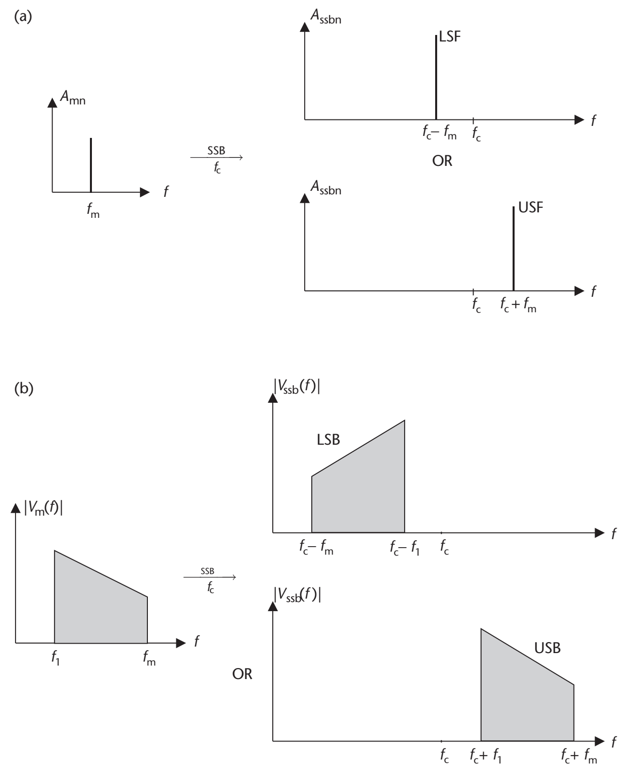
$$v'_{mi}(t) = \frac{1}{2}V_c V_{cl} v_{mi}(t)\cos(\phi) - \frac{1}{2}V_c V_{cl} v_{mq}(t)\sin(\phi)$$

The quadrature-phase signal has imposed interference upon the in-phase signal. Likewise, the in-phase signal imposes interference upon the quadrature-phase signal.

Single SideBand Suppressed Carrier (CEP 3.7.2)

- In DSBSC, the sidebands are mirror images of each other. SSBSC transmits only one sideband in order to improve spectral efficiency.
- The SSBSC signal bandwidth is equal to the message bandwidth.
- A tighter band-pass filter can be used to reject noise, improving the signal to noise ratio.
- Also, a lower bandwidth implies less sensitivity to frequency-selective fading.

Figure 3.33



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SSBSC frequency discrimination modulator (CEP 3.7.2.2)

• A filter can be used to remove the unwanted sideband.
• This only works if the lowest frequency f_1 in the message signal is somewhat higher than 0 Hz.
• To remove the upper sideband, the filter must retain the frequencies below $f_c - f_1$, but reject the frequencies above $f_c + f_1$.
• A highly-selective filter having a high complexity will be required if f_1 is low and f_c is high.
• Low-complexity filters can be used if the modulation is performed in stages.

Figure 3.35

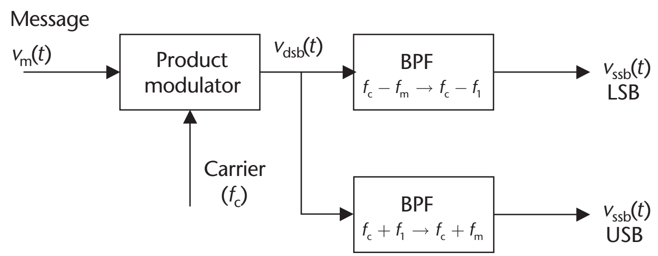

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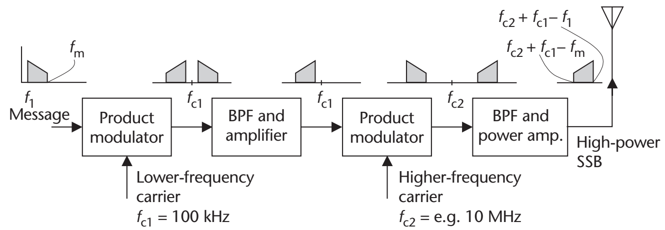
Figure 3.36



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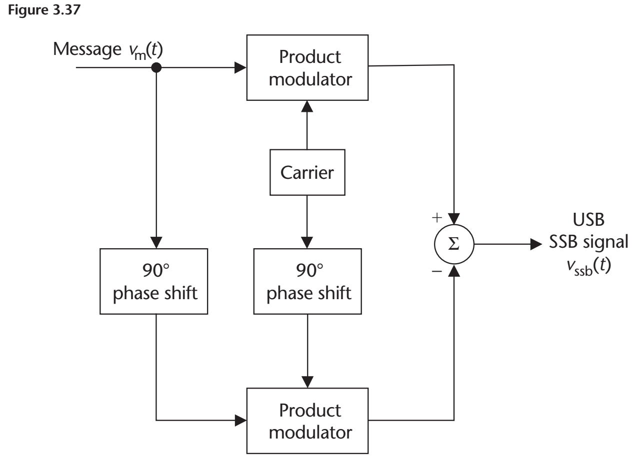
SSBSC phase discrimination modulator (CEP 3.7.2.2)

This uses QAM modulation of the message signal and a version in which every frequency component has its phase shifted by $90°$.
Consider a sinusoidal message signal

$$v_m(t) = V_m \cos(2\pi f_m t)$$



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We need the trigonometric identities

$$\cos(2\pi f_1 t)\cos(2\pi f_2 t) = \frac{1}{2}\cos(2\pi|f_1 - f_2|t) + \frac{1}{2}\cos(2\pi|f_1 + f_2|t) \quad (6)$$

$$\sin(2\pi f_1 t)\sin(2\pi f_2 t) = \frac{1}{2}\cos(2\pi|f_1 - f_2|t) - \frac{1}{2}\cos(2\pi|f_1 + f_2|t) \quad (7)$$

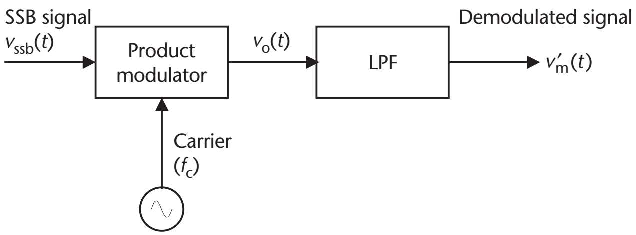
We have

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

Adding the two product modulator outputs gives the lower sideband.

SSBSC demodulator (CEP 3.7.2.3)

Figure 3.38



Coherent demodulation uses a local oscillator signal $v_{LO}(t) = V_{cl}\cos(2\pi f_c t)$ to demodulate the SSBSC signal $v_{ssb}(t) = V_m V_c \cos[2\pi(f_c + f_m)t]$

We get

$$\begin{aligned} v_o(t) &= v_{ssb}(t) \cdot v_{LO}(t) \\ &= V_m V_c \cos[2\pi(f_c + f_m)t] \cdot V_{cl}\cos(2\pi f_c t) \\ &= \frac{1}{2} V_m V_c V_{cl} \cos[2\pi f_m t] + \frac{1}{2} V_m V_c V_{cl} \cos[2\pi(2f_c + f_m)t] \end{aligned}$$

The LPF recovers the sinusoidal message signal

$$v'_m(t) = \frac{1}{2} V_m V_c V_{cl} \cos(2\pi f_m t)$$

SSBSC demodulator (CEP 3.7.2.3)

Suppose there is a phase error ϕ in the local oscillator signal

$$v_{LO}(t) = V_{cl}\cos(2\pi f_c t + \phi)$$

In this case we get

$$\begin{aligned} v_o(t) &= v_{ssb}(t) \cdot v_{LO}(t) \\ &= V_m V_c \cos[2\pi(f_c + f_m)t] \cdot V_{cl}\cos(2\pi f_c t + \phi) \\ &= \frac{1}{2} V_m V_c V_{cl} \cos[2\pi f_m t - \phi] + \frac{1}{2} V_m V_c V_{cl} \cos[2\pi(2f_c + f_m)t + \phi] \end{aligned}$$

There will be a corresponding phase error in the recovered message signal

$$v'_m(t) = \frac{1}{2} V_m V_c V_{cl} \cos(2\pi f_m t - \phi)$$

In DSBSC, a phase error causes attenuation of the recovered message signal, which is not very harmful and is easy to fix.

In SSBSC, a phase error shifts the phase of every frequency component in the message signal by ϕ, which is very harmful and is difficult to fix.

Independent SideBand Modulation (CEP 3.7.3 and 3.7.3.1)

- Independent messages are transmitted on the two sidebands of a carrier.
- Modulation is achieved by adding the outputs of two frequency or phase discrimination SSBSC modulators.

Figure 3.39

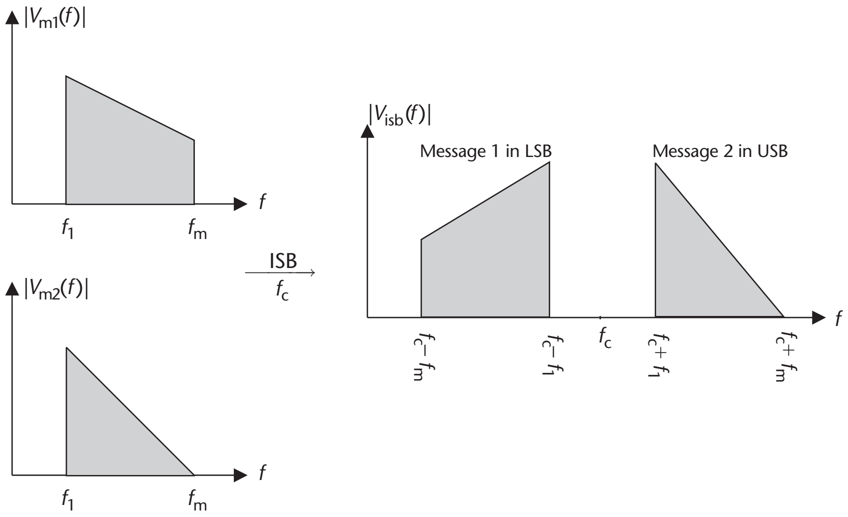


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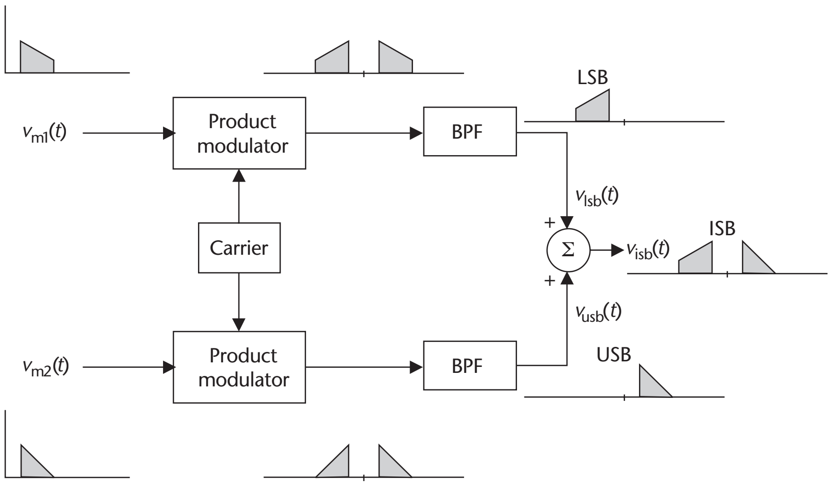
Figure 3.40



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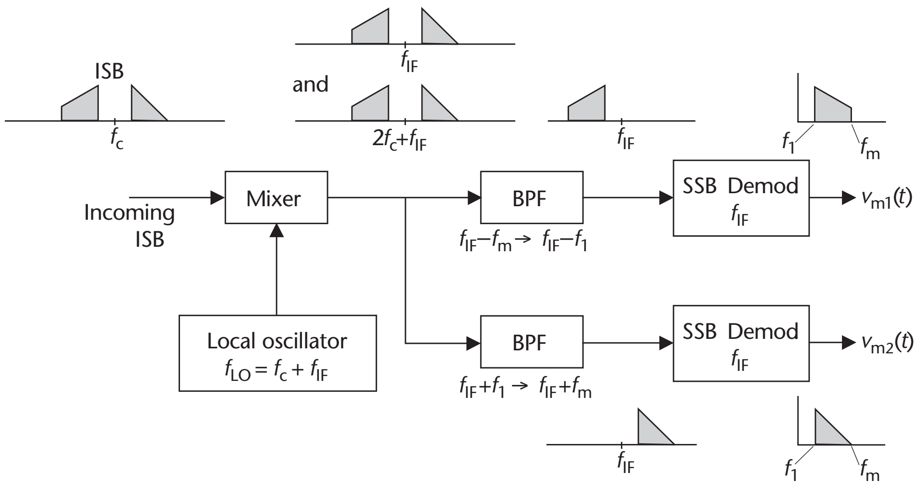
Independent SideBand Demodulation (CEP 3.7.3.2)

- Filtering is required to discriminate between the upper and lower sidebands during demodulation.

- A superheterodyne receiver is typically used to avoid the requirement for high selectivity filtering at high frequencies.

Figure 3.41



Vestigial SideBand Modulation (CEP 3.7.4)

- All but a vestige of the lower sideband is filtered away before transmission.
- The filter response is such that $H_{vsb}(f_c - f) + H_{vsb}(f_c + f) = 1$ for $0 \leq f \leq B_v$.
- As a result during coherent demodulation, the vestige of the lower sideband compensates for the attenuated frequencies in the upper sideband.
- The VSB signal bandwidth is given by $f_m + B_v$.

Figure 3.43

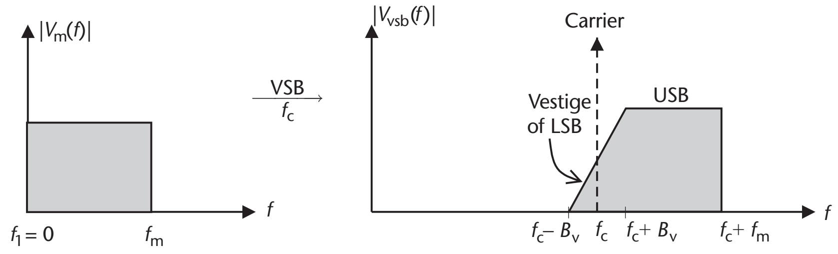


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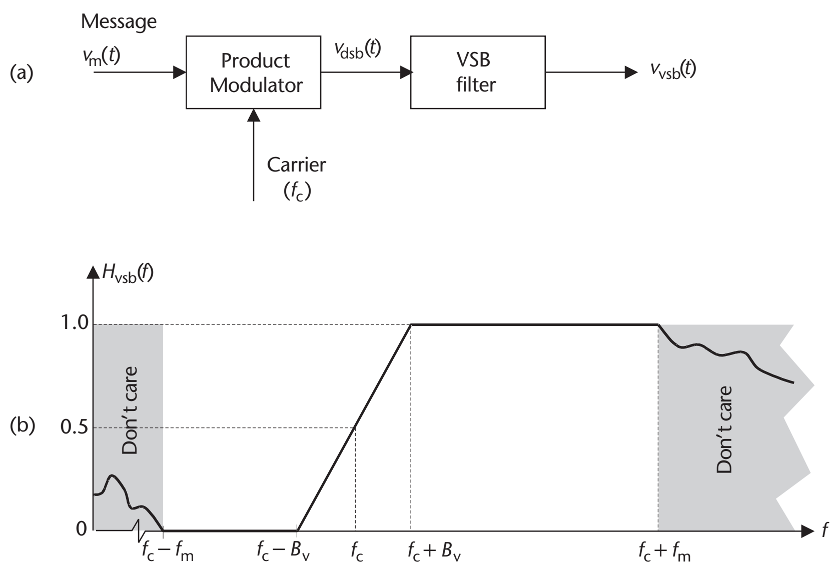
Figure 3.44



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Summary of AM variants

Variant	Number of signals	Bandwidth	bandwidth efficient?	Power efficient	non-coherent?	effect of phase error
Full AM	1	$2B$	No	No	Yes	N/A
DSBSC	1	$2B$	No	Yes	No	attenuation
QAM	2	$2\max(B_1, B_2)$	Sort of	Yes	No	interference
SSBSC	1	B	Yes	Yes	No	phase error
ISM	2	$B_1 + B_2$	Yes	Yes	No	phase error
VSM	1	$B +$ a bit	Sort of	Yes	No	phase error

Exercise

$$\begin{aligned} v_{m1}(t) &= 2 + \sin(40\pi t) + 3\cos(60\pi t) \\ v_{m2}(t) &= 3\cos(20\pi t + \pi/4) + 2\sin(60\pi t) - \cos(100\pi t) \end{aligned}$$

1. Sketch the amplitude and phase spectrum of the signal $v_{dsb}(t)$ that results when the signal $v_{m1}(t)$ is DSBSC modulated onto a 1 kHz carrier having an amplitude of $V_c = 1$.

2. Sketch the amplitude and phase spectrum of the VSB signal $v_{vsb}(t)$ that results when the DSBSC signal $v_{dsb}(t)$ is filtered according to

$$H_{vsb}(f) = \begin{cases} 0 & \text{if } f < 975 \\ 1 & \text{if } f > 1025 \\ (f - 975)/50 & \text{otherwise} \end{cases}$$

3. Sketch the amplitude and phase spectrum of the signal $v_{ssb}(t)$ that results when phase discrimination is used to SSBSC modulate the signal $v_{m2}(t)$ onto the upper sideband of a 1 kHz carrier having an amplitude of $V_c = 1$.

Exercise continued

4. Sketch the amplitude and phase spectrum of the signal $v_{isb}(t)$ that results when the signals $v_{m1}(t)$ and $v_{m2}(t)$ are respectively ISB modulated onto the lower and upper sidebands of a 1 kHz carrier having an amplitude of $V_c = 1$.

5. Sketch the amplitude and phase spectrum of the signal $v_{qam}(t)$ that results when the signals $v_{m1}(t)$ and $v_{m2}(t)$ are respectively QAM modulated onto in-phase and quadrature-phase 1 kHz carriers having amplitudes of $V_c = 1$.

6. For each case above, state the signal bandwidth.

7. For the cases in questions 1 to 3, sketch the amplitude and phase spectrum of the signal $v_o(t)$ obtained after the first step of the coherent demodulator.

8. For the case in question 5, sketch the amplitude and phase spectrum of the signals $v_{oi}(t)$ and $v_{oq}(t)$ obtained during the coherent demodulation of the in-phase and quadrature-phase carriers, respectively.