EEEN 322 PS 6 QUESTIONS

Q1

4.4-1 In a QAM system (Fig. 4.14), the locally generated carrier has a frequency error $\Delta\omega$ and a phase error δ; that is, the receiver carrier is $\cos[(\omega_c + \Delta\omega)t + \delta]$ or $\sin[(\omega_c + \Delta\omega)t + \delta]$. Show that the output of the upper receiver branch is

$$m_1(t)\cos[(\Delta\omega)t + \delta] - m_2(t)\sin[(\Delta\omega)t + \delta]$$

instead of $m_1(t)$, and the output of the lower receiver branch is

$$m_1(t)\sin[(\Delta\omega)t + \delta] + m_2(t)\cos[(\Delta\omega)t + \delta]$$

instead of $m_2(t)$.

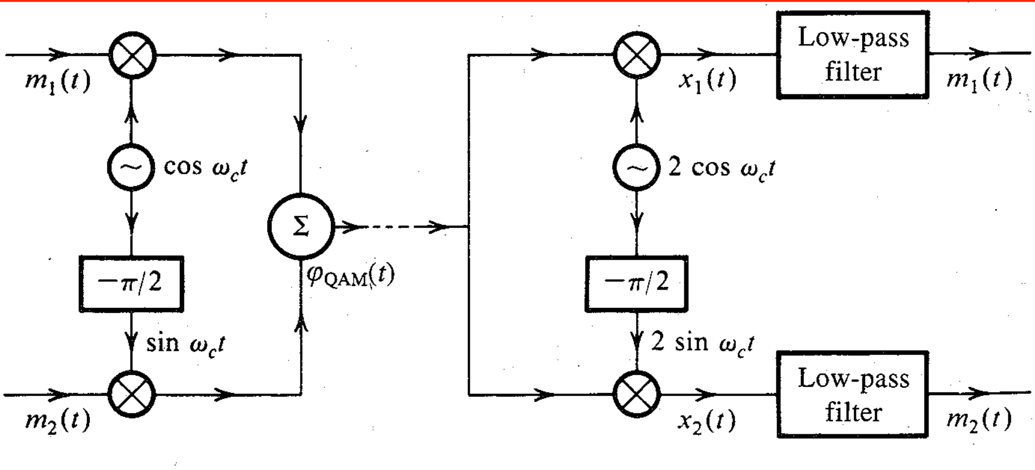

Figure 4.14 Quadrature amplitude multiplexing.

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Q2

4.5-5 An LSB signal is demodulated synchronously, as shown in Fig. P4.5-5. Unfortunately, the local carrier is not $2\cos\omega_c t$ as required, but is $2\cos[(\omega_c + \Delta\omega)t + \delta]$. Show that:

(a) When $\delta = 0$, the output $y(t)$ is the signal $m(t)$ with all its spectral components shifted (offset) by $\Delta\omega$. *Hint*: Observe that the output $y(t)$ is identical to the right-hand side of Eq. (4.17a) with ω_c replaced with $\Delta\omega$.

(b) When $\Delta\omega = 0$, the output is the signal $m(t)$ with phases of all its spectral components shifted by δ. *Hint*: Show that the output spectrum $Y(\omega) = M(\omega)e^{j\delta}$ for $\omega \geq 0$, and equal to $M(\omega)e^{-j\delta}$ when $\omega < 0$.

In each of these cases, explain the nature of distortion. *Hint*: For **(a)**, demodulation consists of shifting an LSB spectrum to the left and right by $\omega_c + \Delta\omega$, and low-pass filtering the result. For part **(b)**, use the expression (4.17b) for $\varphi_{LSB}(t)$ and multiply it by the local carrier $2\cos(\omega_c t + \delta)$, and low-pass filter the result.

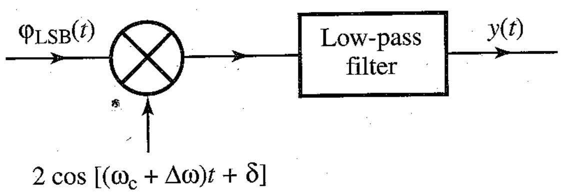

Figure P4.5-5

$$\varphi_{\text{USB}}(t) = m(t)\cos\omega_c t - m_h(t)\sin\omega_c t \tag{4.17a}$$

$$\varphi_{\text{LSB}}(t) = m(t)\cos\omega_c t + m_h(t)\sin\omega_c t \tag{4.17b}$$

$$\varphi_{\text{SSB}}(t) = m(t)\cos\omega_c t \mp m_h(t)\sin\omega_c t \tag{4.17c}$$

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Q3

4.8-1 A transmitter transmits an AM signal with a carrier frequency of 1500 kHz. When an inexpensive radio receiver (which has a poor selectivity in its RF-stage bandpass filter) is tuned to 1500 kHz, the signal is heard loud and clear. This same signal is also heard (not as strong) at another dial setting. State, with reasons, at what frequency you will hear this station. The IF frequency is 455 kHz.

EEEN 322 PS 6 SOLUTIONS

Q1

4.4-1 In Fig. 4.14. when the carrier is $\cos[(\Delta\omega)t + \delta]$ or $\sin[(\Delta\omega)t + \delta]$, we have

$$\begin{aligned} x_1(t) &= 2[m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t]\cos[(\omega_c + \Delta\omega)t + \delta] \\ &= 2m_1(t)\cos\omega_c t\cos[(\omega_c + \Delta\omega)t + \delta] + 2m_2(t)\sin\omega_c t\cos[(\omega_c + \Delta\omega)t + \delta] \\ &= m_1(t)\{\cos[(\Delta\omega)t + \delta] + \cos[(2\omega_c + \Delta\omega)t + \delta]\} + m_2(t)\{\sin[(2\omega_c + \Delta\omega)t + \delta] - \sin[(\Delta\omega)t + \delta]\} \end{aligned}$$

Similarly

$$x_2(t) = m_1(t)\{\sin[(2\omega_c + \Delta\omega)t + \delta] + \sin[(\Delta\omega)t + \delta]\} + m_2(t)\{\cos[(\Delta\omega)t + \delta] - \cos[(2\omega_c + \Delta\omega)t + \delta]\}$$

After $x_1(t)$ and $x_2(t)$ are passed through lowpass filter. the outputs are

$$\begin{aligned} m_1'(t) &= m_1(t)\cos[(\Delta\omega)t + \delta] - m_2(t)\sin[(\Delta\omega)t + \delta] \\ m_2'(t) &= m_1(t)\sin[(\Delta\omega)t + \delta] + m_2(t)\cos[(\Delta\omega)t + \delta] \end{aligned}$$

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Q2

4.5-5 The incoming SSB signal at the receiver is given by [Eq. (4.17b)]

$$\varphi_{LSB}(t) = m(t)\cos\omega_c t + m_h(t)\sin\omega_c t$$

Let the local carrier be $\cos[(\omega_c + \Delta\omega)t + \delta]$. The prodeuct of the incoming signal and the local carrier is $e_d(t)$. given by

$$\begin{aligned} e_d(t) &= \varphi_{LSB}(t)\cos[(\omega_c + \Delta\omega)t + \delta] \\ &= 2[m(t)\cos\omega_c t + m_h(t)\sin\omega_c t]\cos[(\omega_c + \Delta\omega)t + \delta] \end{aligned}$$

The lowpass filter suppresses the sum frequency component centered at the frequency $(2\omega_c + \Delta\omega)$. and passes only the difference frequency component centered at the frequency $\Delta\omega$. Hence, the filter output $e_0(t)$ is given by

$$e_0(t) = m(t)\cos(\Delta\omega)t + \delta) - m_h(t)\sin(\Delta\omega)t + \delta)$$

Observe that if both $\Delta\omega$ and δ are zero. the output is given by

$$e_0(t) = m(t)$$

as expected. If only $\delta = 0$. then the output is given by

$$e_0(t) = m(t)\cos(\Delta\omega)t - m_h(t)\sin(\Delta\omega)t$$

This is an USB signal corresponding to a carrier frequency $\Delta\omega$ as shown in Fig. S4.5-5b. This spectrum is the same as the spectrum $M(\omega)$ with each frequency component shifted by a frequency $\Delta\omega$. This changes the sound of an audio signal slightly. For voice signals, the frequency shift within ± 20 Hz is considered tolerable. Most US systems. however restrict the shift to ± 2 Hz.

(b) When only $\Delta\omega = 0$. the lowpass filter output is

$$e_0(t) = m(t)\cos\delta - m_h(t)\sin\delta$$

We now show that this is a phase distortion, where each frequency component of $M(\omega)$ is shifted in phase by amount δ. The Fourier transform of this equation yields

$$E_0(\omega) = M(\omega)\cos\delta - M_h(\omega)\sin\delta$$

But from Eq. (4.14b)

$$M_h(\omega) = -j\,\mathrm{sgn}(\omega)M(\omega) = \begin{cases} -jM(\omega) & \omega > 0 \\ M(\omega) & \omega < 0 \end{cases}$$

and

$$E_0(\omega) = \begin{cases} M(\omega)\, e^{jk} & \omega > 0 \\ M(\omega)\, e^{-jk} & \omega < 0 \end{cases}$$

It follows that the amplitude spectrum of $e_0(t)$ is $M(\omega)$, the same as that for $m(t)$. But the phase of each component is shifted by k. Phase distortion generally is not a serious problem with voice signals, because the human ear is somewhat insensitive to phase distortion. Such distortion may change the quality of speech, but the voice is still intelligible. In video signals and data transmission, however, phase distortion may be intolerable.

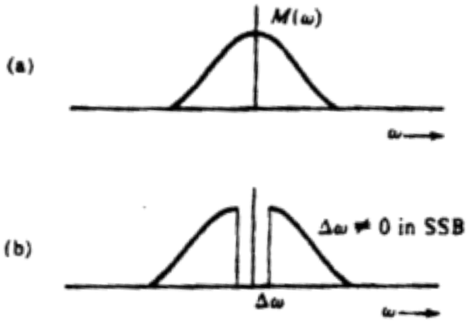

Fig. S4.5-5

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Q3

4.8-1 A station can be heard at its allocated frequency 1500 kHz as well as at its image frequency. The two frequencies are $2f_{\mathrm{IF}}$ Hz apart. In the present case, $f_{\mathrm{IF}} = 455$ kHz. Hence, the image frequency is $2 \times 455 = 910$ kHz apart. Therefore, the station will also be heard if the receiver is tuned to frequency $1500 - 910 = 590$ kHz. The reason for this is as follows. When the receiver is tuned to 590 kHz, the local oscillator frequency is $f_{\mathrm{LO}} = 590 + 455 = 1045$ kHz. Now this frequency f_{LO} is multiplied with the incoming signal of frequency $f_c = 1500$ kHz. The output yields the two modulated signals whose carrier frequencies are the sum and difference frequencies, which are $1500 + 1045 = 2545$ kHz and $1500 - 1045 = 455$ kHz. The sum carrier is suppressed, but the difference carrier passes through, and the station is received.