4.4 QUADRATURE AMPLITUDE MODULATION (QAM)

The DSB signals occupy twice the bandwidth required for the baseband. This disadvantage can be overcome by transmitting two DSB signals using carriers of the same frequency but in phase quadrature, as shown in Fig. 4.14. In this figure, the boxes labeled $-\pi/2$ are phase shifters, which delay the phase of an input sinusoid by $-\pi/2$ rad. If the two baseband signals to be transmitted are $m_1(t)$ and $m_2(t)$, the corresponding QAM signal $\varphi_{QAM}(t)$, the sum of the two DSB-modulated signals, is

$$\varphi_{QAM}(t) = m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t$$

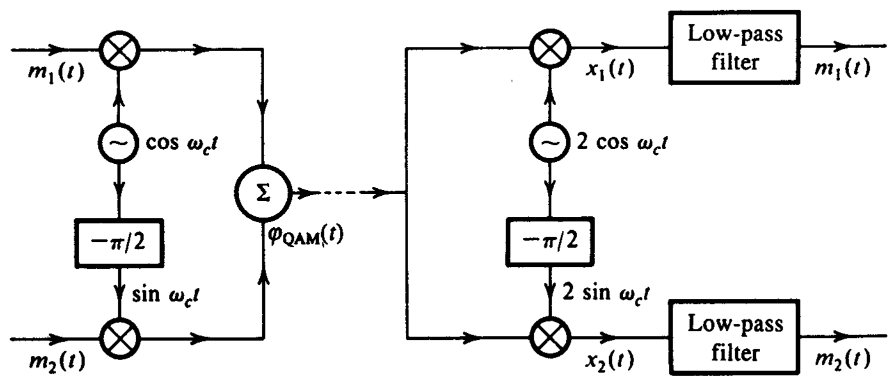

Figure 4.14 Quadrature amplitude multiplexing.

Both modulated signals occupy the same band. Yet two baseband signals can be separated at the receiver by synchronous detection using two local carriers in phase quadrature, as shown in Fig. 4.14. This can be shown by considering the multiplier output $x_1(t)$ of the upper arm of the receiver (Fig. 4.14):

$$\begin{aligned} x_1(t) &= 2\varphi_{QAM}(t)\cos\omega_c t = 2[m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t]\cos\omega_c t \\ &= m_1(t) + m_1(t)\cos 2\omega_c t + m_2(t)\sin 2\omega_c t \end{aligned}$$

The last two terms are suppressed by the low-pass filter, yielding the desired output $m_1(t)$. Similarly, the output of the lower receiver branch can be shown to be $m_2(t)$. This scheme is known as **quadrature amplitude modulation (QAM)** or **quadrature multiplexing.** Thus, two baseband signals, each of bandwidth B Hz, can be transmitted simultaneously over a bandwidth $2B$ by using DSB transmission and quadrature multiplexing. The upper channel is also known as the **in-phase** (I) channel and the lower channel is the **quadrature** (Q) channel.

QAM is somewhat of an exacting scheme. A slight error in the phase or the frequency of the carrier at the demodulator in QAM will not only result in loss and distortion of signals, but will also lead to interference between the two channels. To show this let the carrier at the demodulator be $2\cos(\omega_c t + \theta)$. In this case,

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

The low-pass filter suppresses the two signals with frequency $2\omega_c$, resulting in the output $m_1(t)\cos\theta - m_2(t)\sin\theta$. Thus, in addition to the desired signal $m_1(t)$, we also receive signal $m_2(t)$ in the upper branch. Similar argument shows that in addition to the desired signal $m_2(t)$, we receive signal $m_1(t)$ in the lower branch. This cochannel* interference is undesirable. Similar difficulties arise when the local frequency is in error (see Prob. 4.4-1). In addition, unequal attenuation of the USB and the LSB during transmission also leads to crosstalk or cochannel interference.

Quadrature multiplexing is used in color television to multiplex the so-called chrominance signals, which carry the information about colors. There the synchronization is achieved by periodic insertion of a short **burst of carrier signal** (called **color burst** in the transmitted signal, as explained in Sec. 4.9).