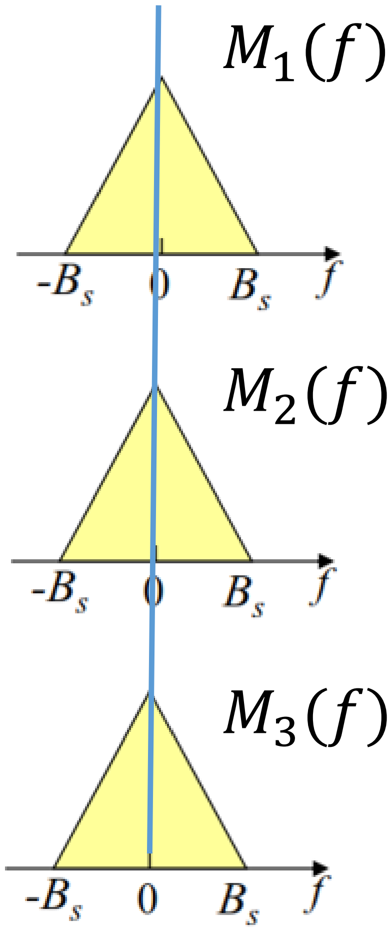
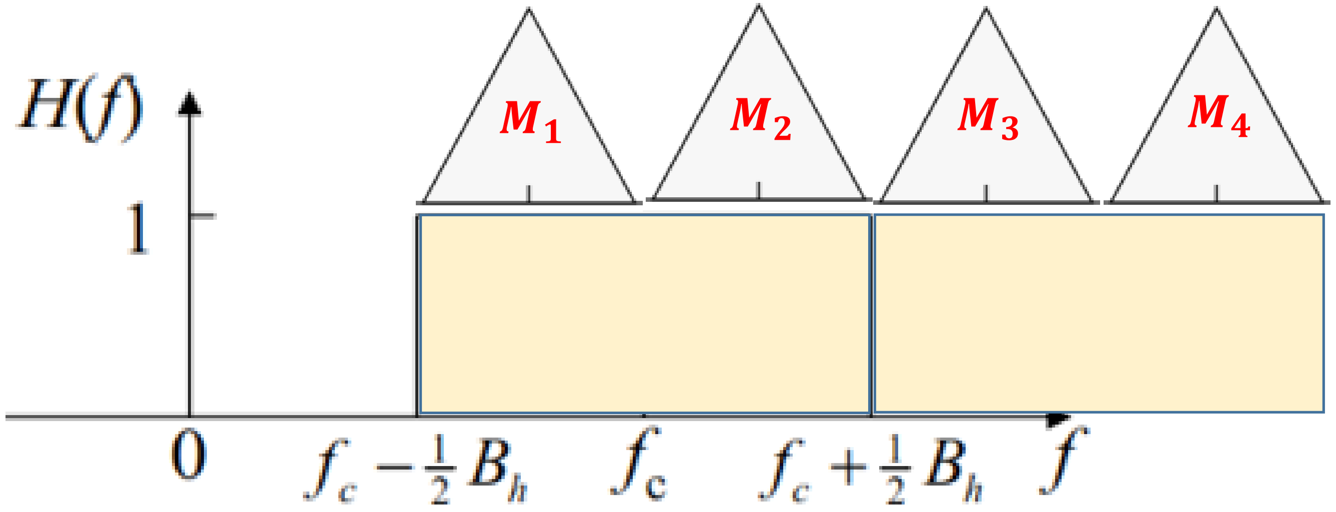
Frequency Division Multiplexing

- **Multiplexing**: A technique which allows multiple users to use the same channel at the same time by assigning each user a portion of the available bandwidth without interfering with other users.
- The main two topics of this lecture are quadrature carrier modulation and frequency division multiplexing**.**

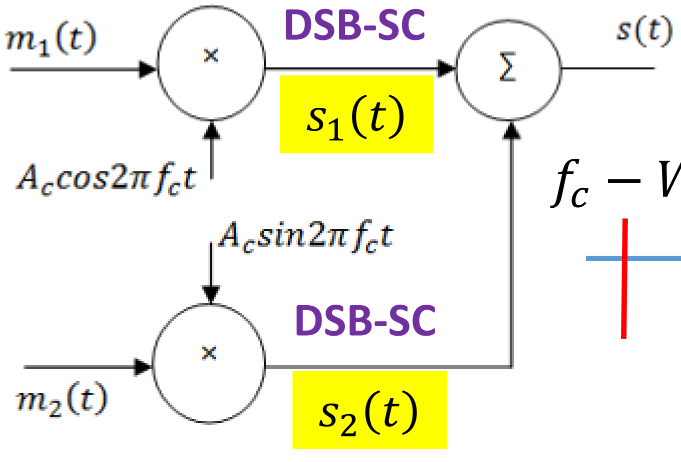




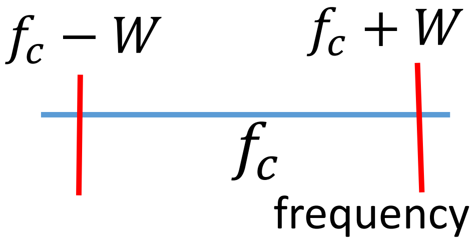
Band-pass Channel

Frequency Division Multiplexing

- **Quadrature Carrier Multiplexing:** This scheme enables two DSB-SC modulated signals to occupy the same transmission B.W and yet allows for the separation of the message signals at the receiver
- **Modulation**: $m_1(t)$ and $m_2(t)$ are low pass signals each with a B.W = W Hz .
- The composite signal is:
- $\boldsymbol{s(t) = A_c m_1(t) cos2\pi f_c t + A_c m_2(t) sin2\pi f_c t}$
- $\boldsymbol{S(f) = [A_c M_1(f - f_c) + A_c M_1(f + f_c)]/2}$
- $\boldsymbol{+ [A_c M_2(f - f_c) - A_c M_2(f + f_c)]/j2}$
- $s(t) = s_1(t) + s_2(t)$
- where $s_1(t)$ and $s_2(t)$ are both DSB-SC signals.
- B.W of $s_1(t)$ = 2W; B.W of $s_2(t)$ = 2W; B.W of $s(t)$ = 2W



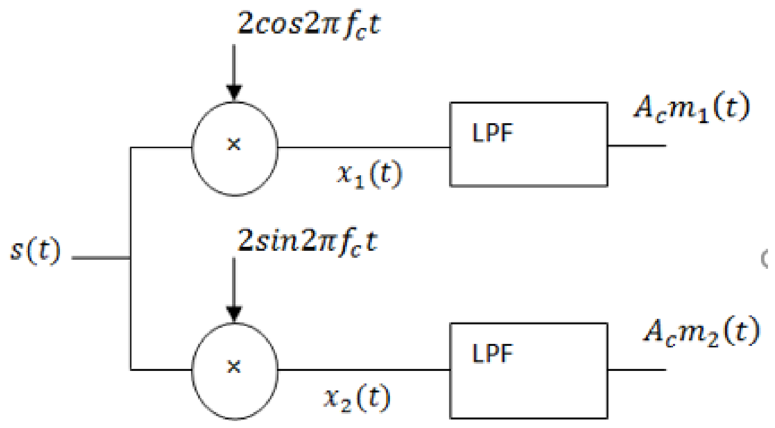
Modulation



- This method provides bandwidth conservation. That is, two DSB-SC signals are transmitted within the bandwidth of one DSB-SC signal. Therefore, this multiplexing technique provides bandwidth reduction by one half.

Frequency Division Multiplexing

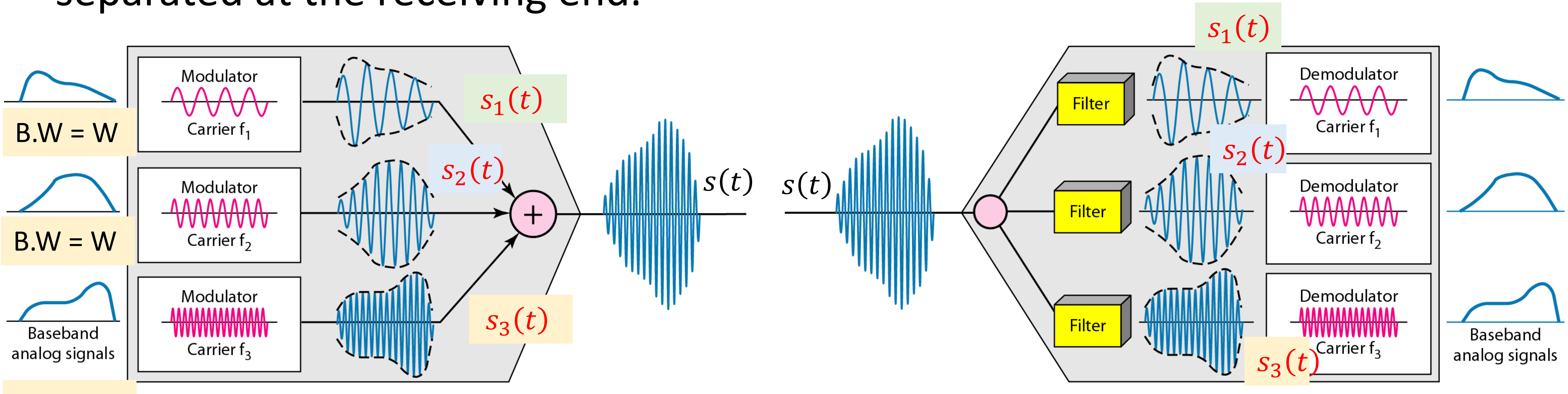
- **Quadrature Carrier Multiplexing (QAM)**
- **Demodulation:** Given $s(t)$, the objective is to recover $m_1(t)$ and $m_2(t)$ from $s(t)$. Consider first the in-phase channel
- $x_1(t) = 2cos2\pi f_c t \; s(t)$
  $= 2\cos 2\pi f_c t \,(A_c m_1(t)cos2\pi f_c t + A_c m_2(t)sin2\pi f_c t)$
- $= 2A_c m_1(t)cos^2 2\pi f_c t + 2A_c m_2(t)sin\omega_c t \; cos\omega_c t$
- $= 2A_c m_1(t)\left(\frac{1+cos2\omega_c t}{2}\right) + A_c m_2(t)sin2\omega_c t$
- $= A_c m_1(t) + A_c m_1(t)cos2\omega_c t + A_c m_2(t)sin2\omega_c t$
- After low pass filtering, the output of the in-phase channel is
- $\boldsymbol{y_1(t) = A_c m_1(t).}$
- Likewise, it can be shown that $\boldsymbol{y_2(t) = A_c m_2(t)}$.
- **Note:** Synchronization is a problem. That is to recover the message signals, it is important that the two carrier signals (the sine and the cosine functions) at the receiver should have the same phase and frequency as the signals at the transmitting side. A phase error or a frequency error will result is an interference type of distortion. That is, A component of $m_2(t)$ will appear in the in-phase channel in addition to the desired signal $m_1(t)$ and a component of $m_1(t)$ will appear at the quadrature output.



Demodulation

Frequency Division Multiplexing

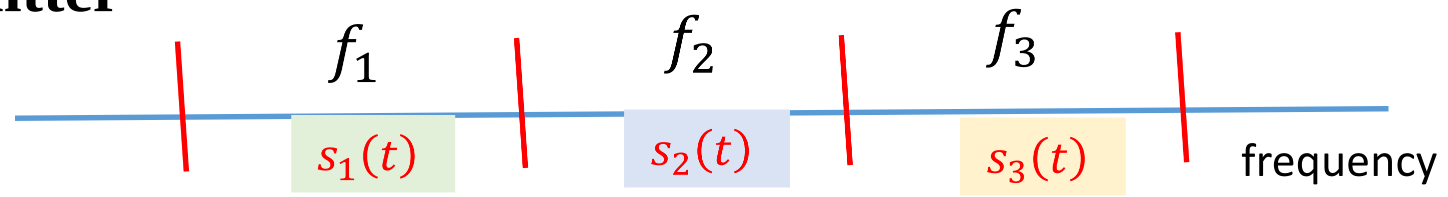
- A number of independent signals can be combined into a composite signal suitable for transmission over a common channel. The signals must be kept apart so that they do not interfere with each other and thus they can be separated at the receiving end.



$$s(t) = A_{c_1} m_1(t) cos 2\pi f_1 t + A_{c_2} m_2(t) cos 2\pi f_2 t + A_{c_3} m_3(t) cos 2\pi f_3 t$$

Receiver

Transmitter



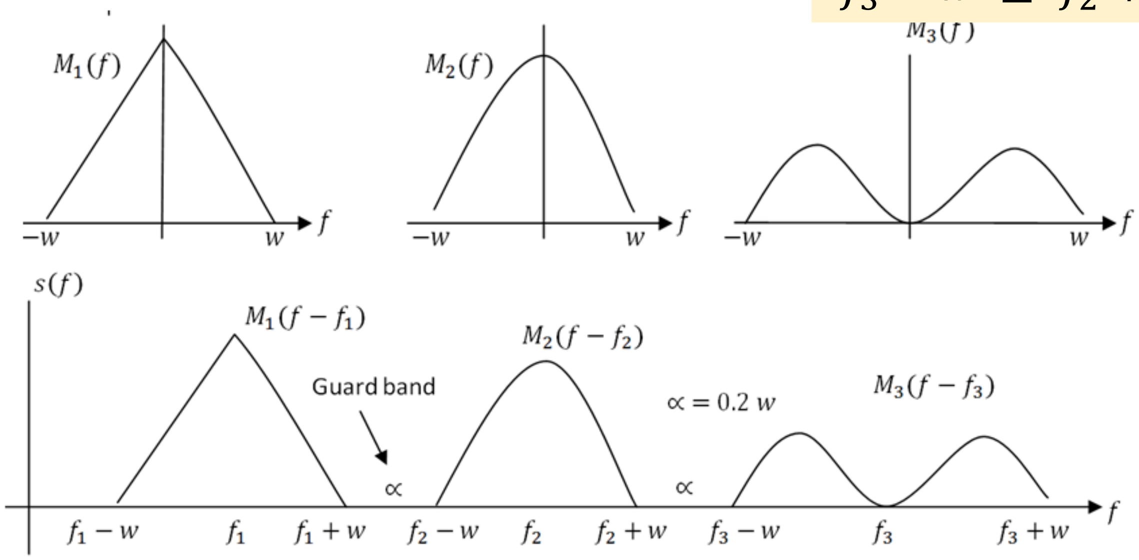
Reference: Data Communications and Networking: Forouzan

Example: Double Sideband Frequency Division Multiplexed Signals

- Let m_1, m_2 *and* m_3 be three baseband message signals each with a B.W = W.
- The composite modulated signal $s(t)$ is
- $s(t) = A_{c_1} m_1(t) cos2\pi f_1 t + A_{c_2} m_2(t) cos2\pi f_2 t + A_{c_3} m_3(t) cos2\pi f_3 t$
- $\quad\quad = s_1(t) + s_2(t) + s_3(t)$
- s_1, s_2 *and* s_3 are DSB-SC signals with carrier frequencies $f_1,\ f_2$ *and* f_3 , respectively. If the spectrum of $m_1(t),\ m_2(t)$ *and* $m_3(t)$ are as shown, the spectrum of $s(t)$ can be found as shown below.

$f_2 - w \geq f_1 + w \quad or \quad f_2 - f_1 \geq 2w$

$f_3 - w \geq f_2 + w \quad or \quad f_3 - f_2 \geq 2w$



Receiver