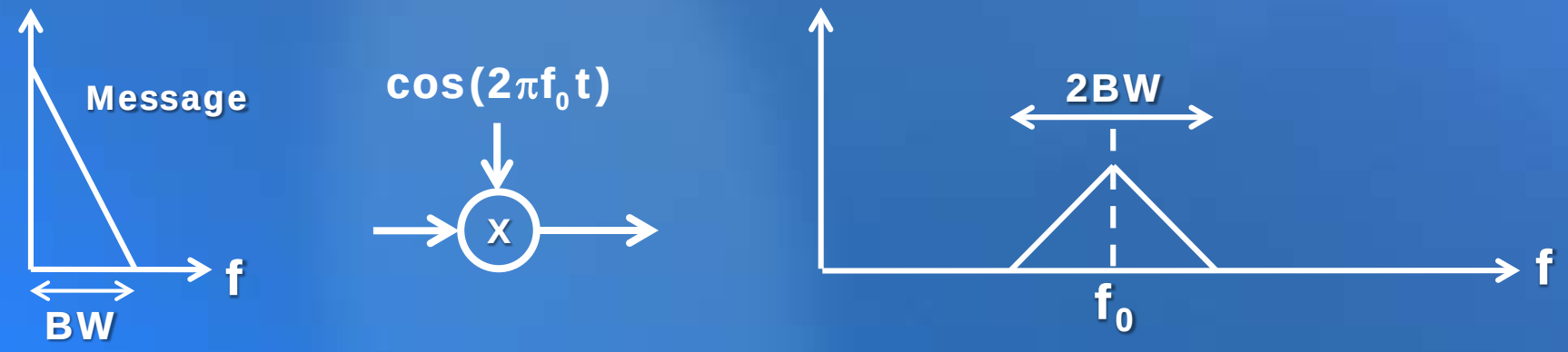
I/Q Modulation

Inefficient Use of Bandwidth

Modulating by a cosine results in a signal that uses twice the bandwidth of the original.



This is inefficient use of the radio spectrum.

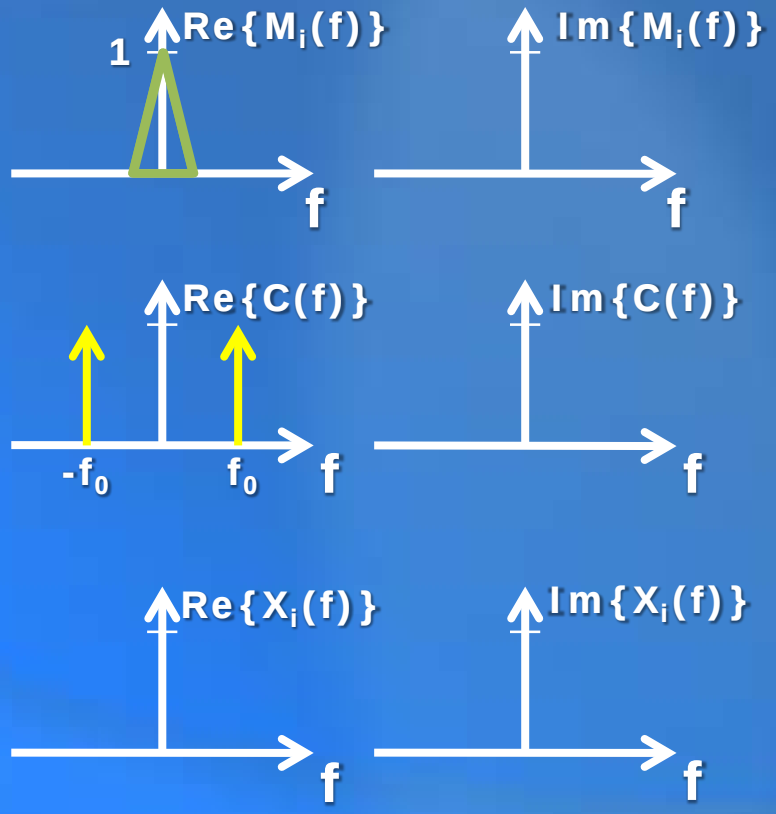
I/Q Modulation

- I/Q modulation takes two different signals ($m_i(t)$ and $m_q(t)$) with the same bandwidth BW and
  - Modulates one by a cosine carrier with frequency f_0
    - This is called the in-phase component (I)
  - Modulates the other by a sine carrier with the same frequency f_0
    - The sine carrier has a one quarter period (90 degree) phase shift with the cosine.
    - This is called the quadrature component (Q)
- Both components occupy a bandwidth of 2BW centered at f_0
- However, they can be transmitted at the same time and recovered without interfering with each other.

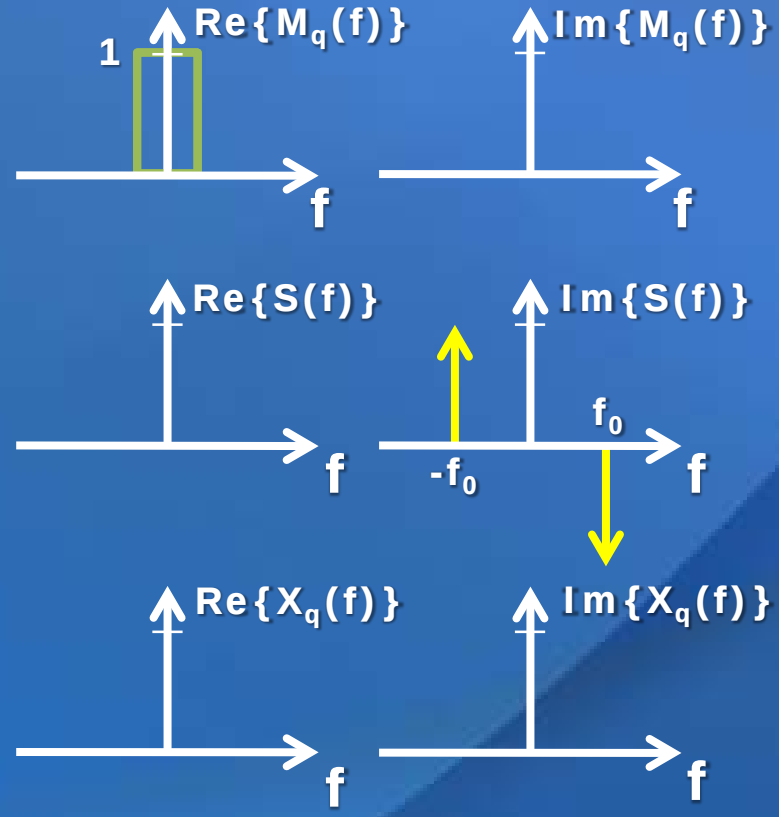
- I/Q modulation transmits two signals in the same space previously occupied by one, solving the inefficient use of bandwidth!

Modulating by Cosine / Sine

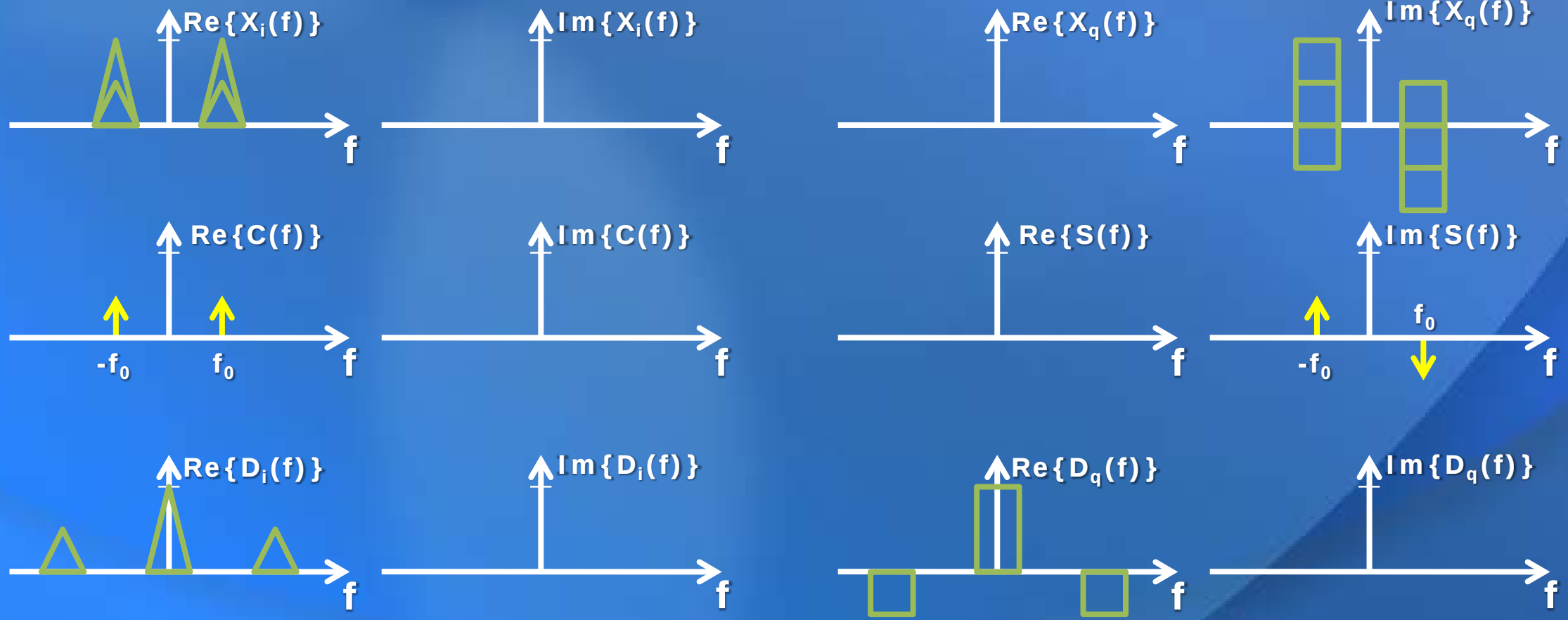
$$x_i(t) = m_i(t) \times 2\cos(2\pi f_0 t)$$



$$x_q(t) = m_q(t) \times 2\sin(2\pi f_0 t)$$

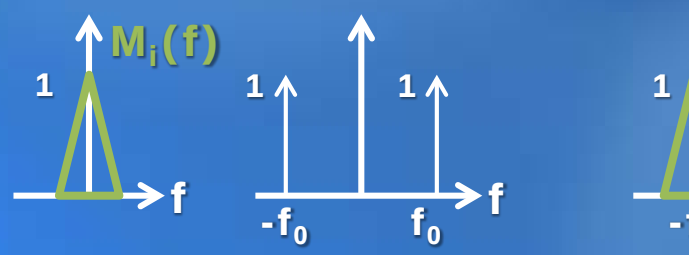


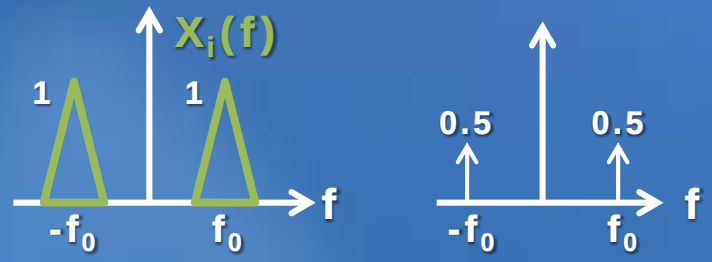
Mixing

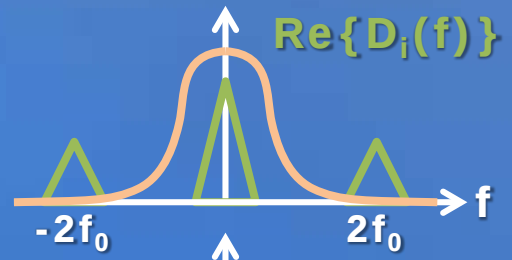

Re{X_i(f)}
Im{X_i(f)}
Re{X_q(f)}
Im{X_q(f)}
Re{C(f)}
Im{C(f)}
Re{S(f)}
Im{S(f)}
-f_0
f_0
-f_0
f_0
Re{D_i(f)}
Im{D_i(f)}
Re{D_q(f)}
Im{D_q(f)}
f

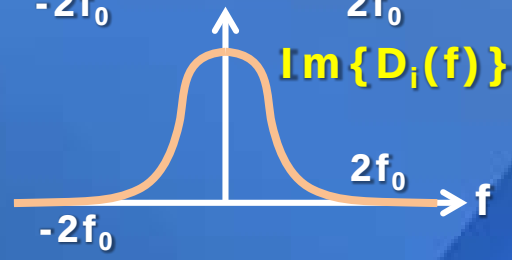
I / Q Modulation

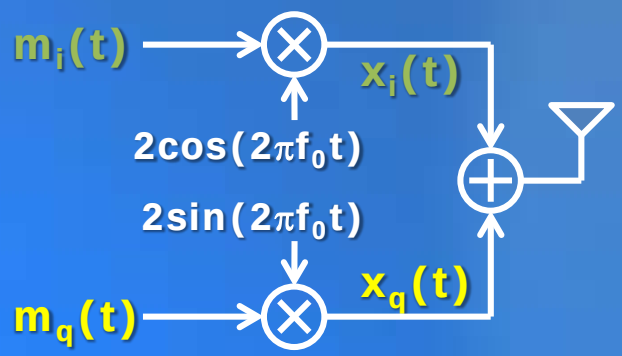
Coherent Demodulation

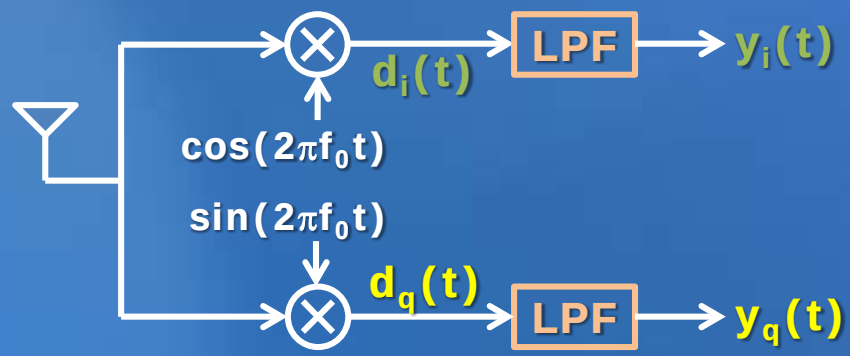




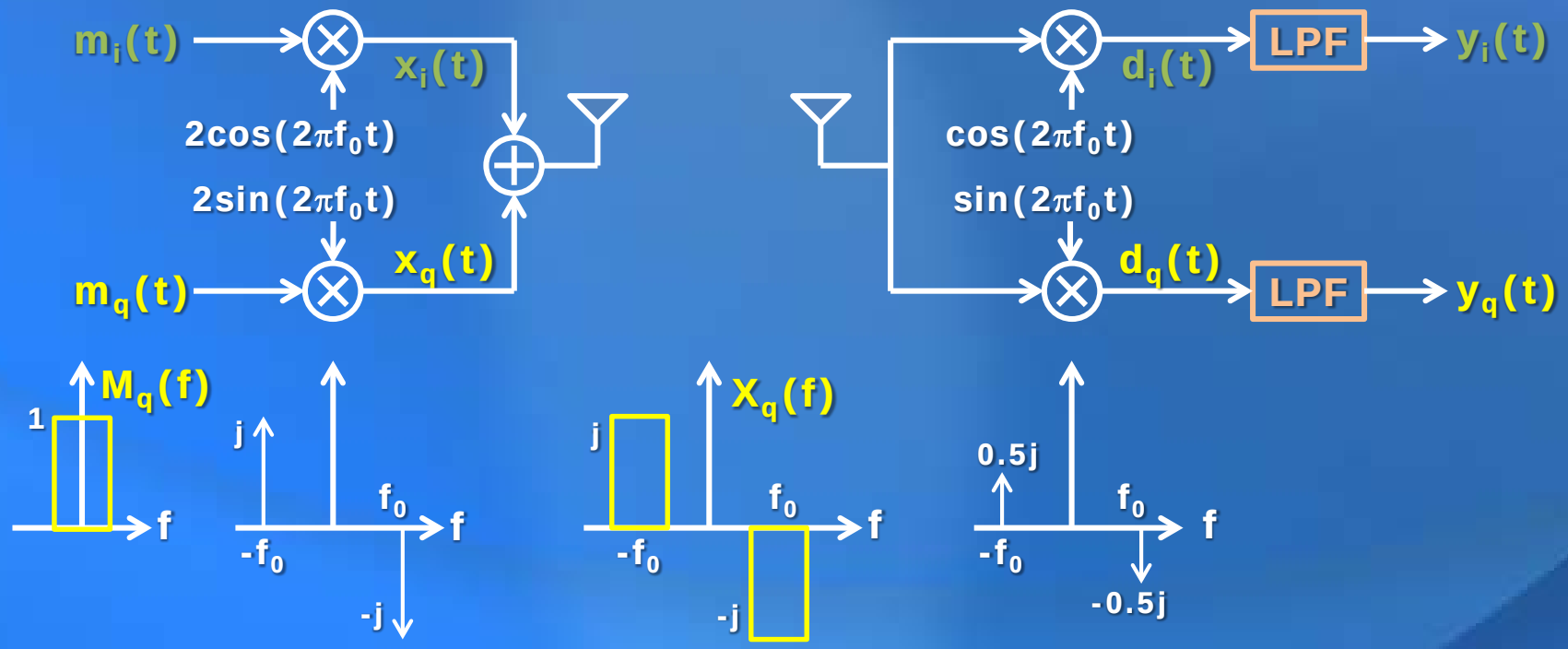


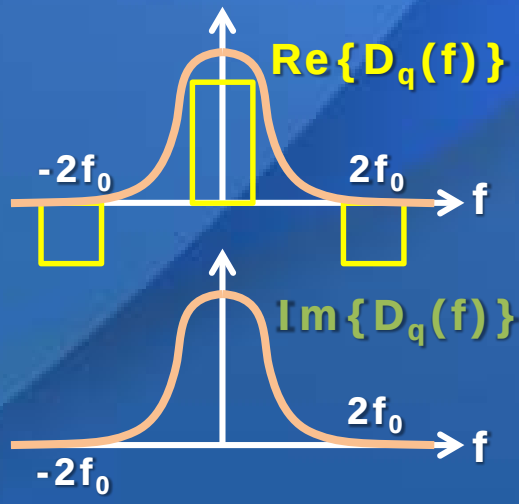




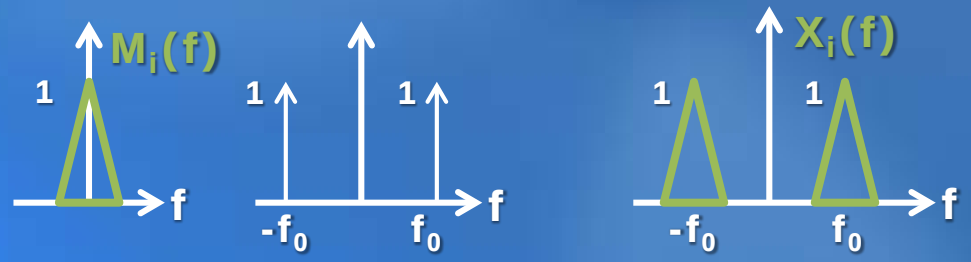


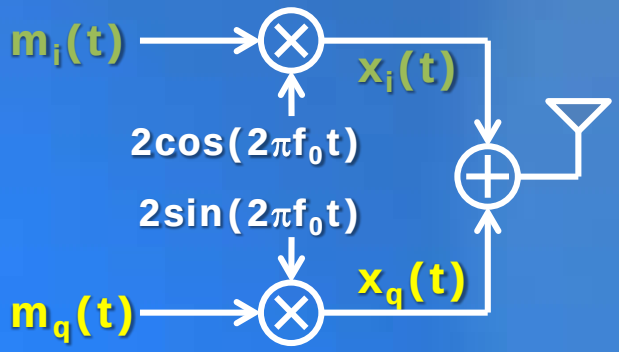
Coherent Demodulation

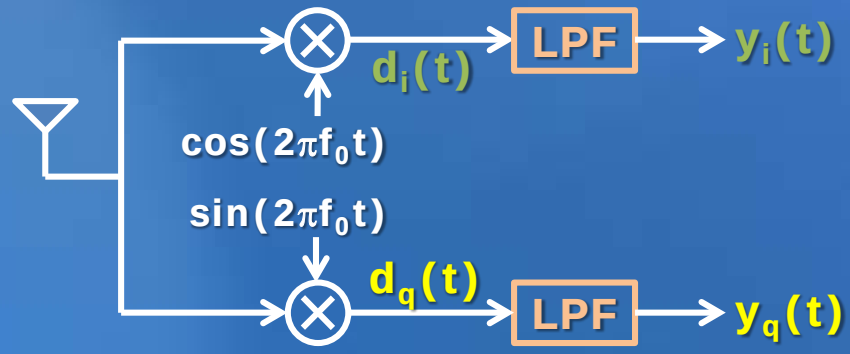


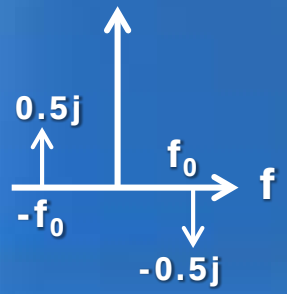


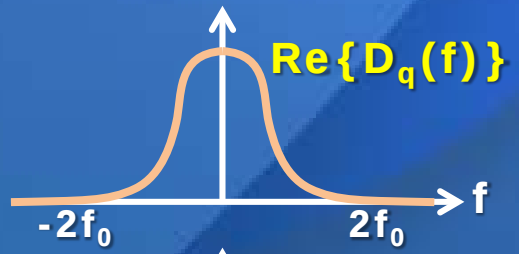
Quadrature Phase Shift

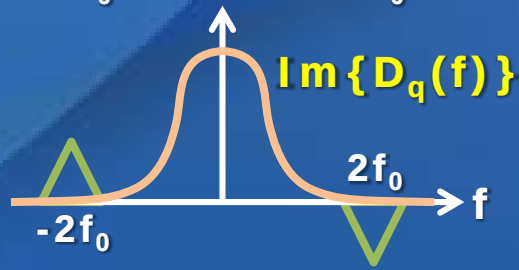




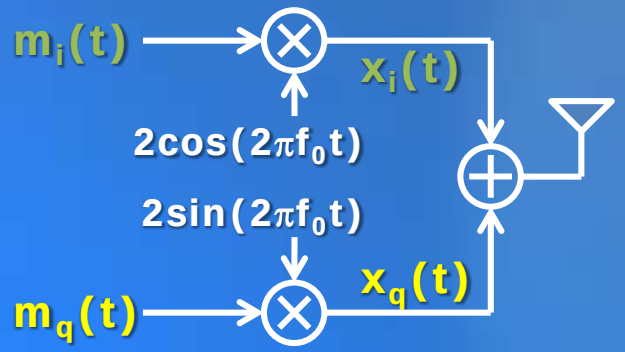


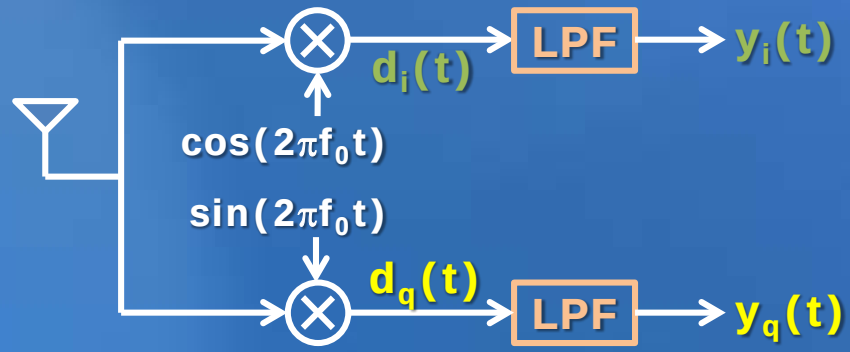


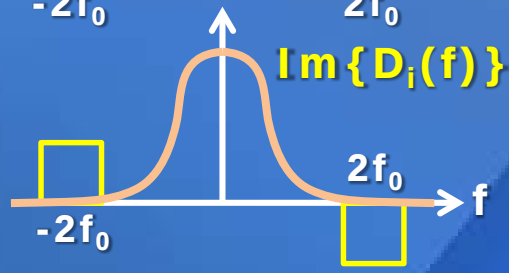


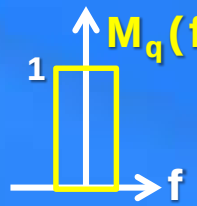


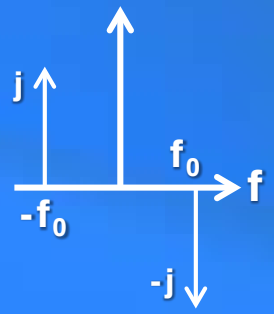
Quadrature Phase Shift

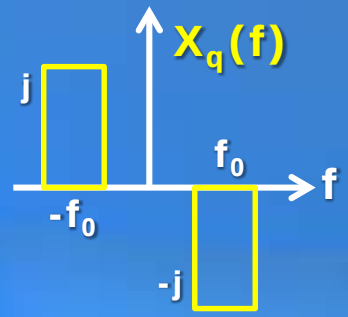




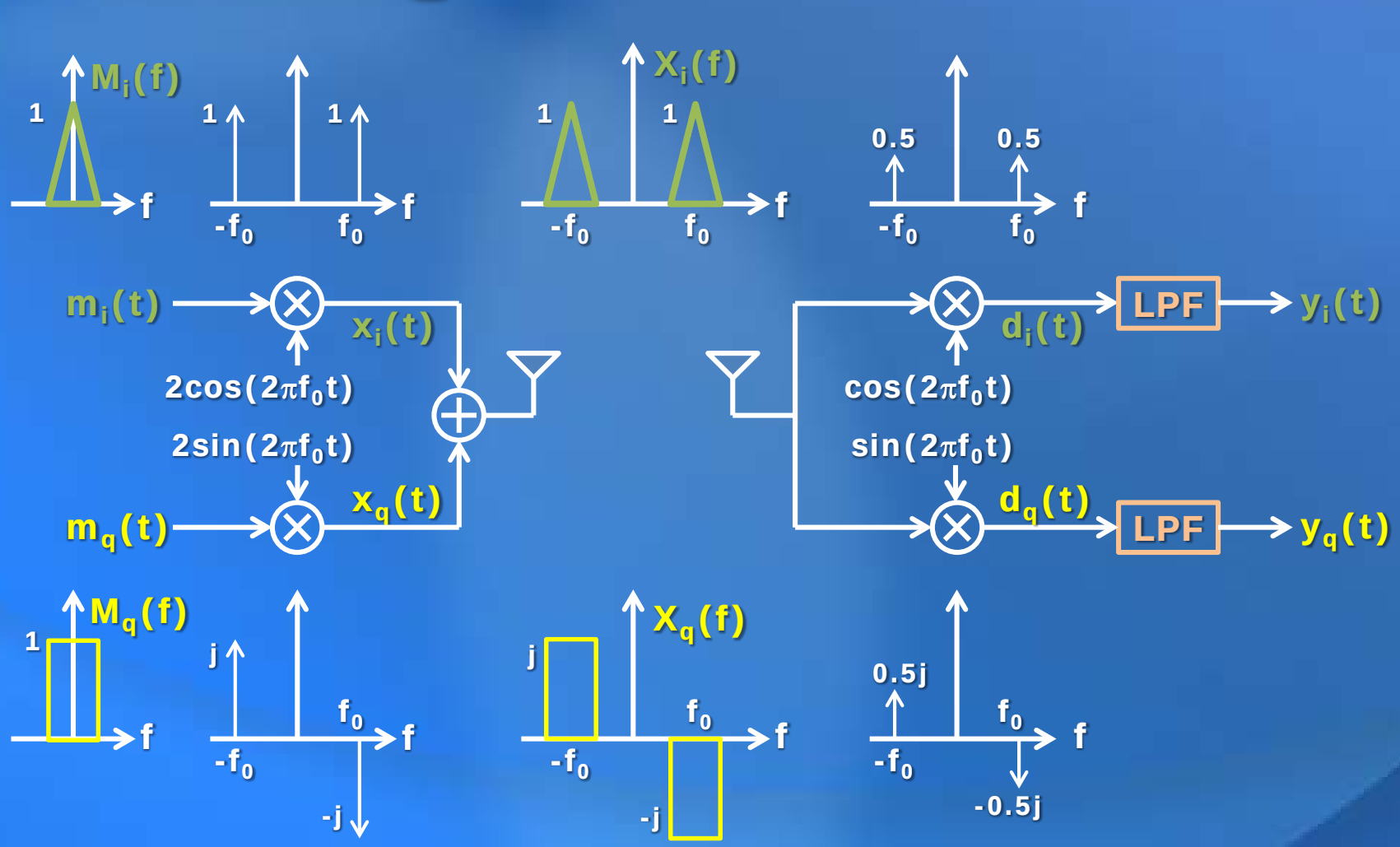


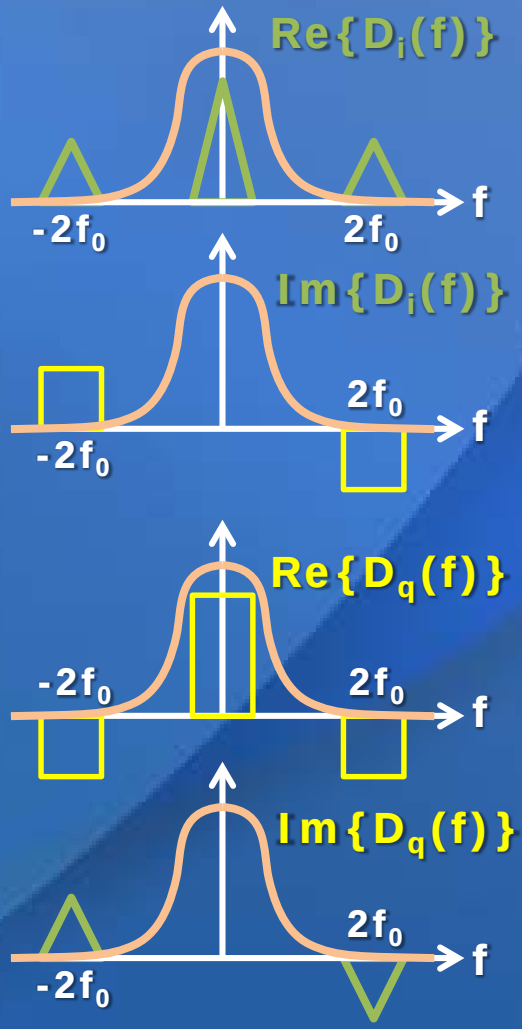




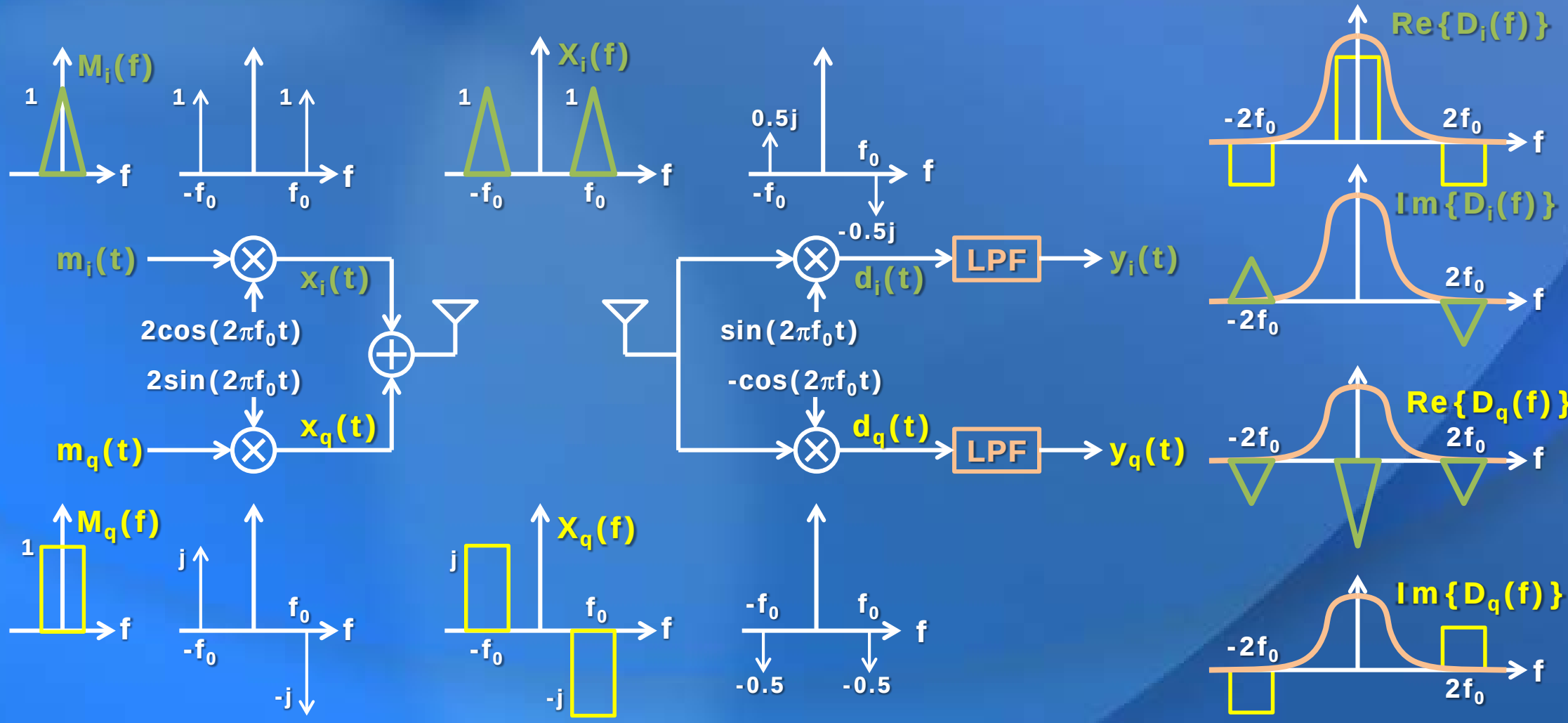


I-Q Communication





Impact of 90° Phase Shift



Impact of 90° Phase Shift

- I and Q channels get swapped at receiver
  - I input appears at Q output with change in sign
  - Q input appears at I output.
- Key observation: no information is lost!
- For intermediate phase shifts, the I and Q signals are mixed.