Costa receiver: has built-in phase tracking to cancel any small phase error.

Lecture 6: Quadrature-carrier multiplexing.

Transmitter: modulate 2 separate message signals.

Receiver.
Quadrature-carrier multiplexing is used to send 2 separate baseband (message) signals on the same bandwidth and still allows for the recovery of each signal at Rx output.  
\[ S(t) = A_c m_1(t) \cos(2 \pi f c t) + A_c m_2(t) \sin(2 \pi f c t) \]

- Receiver must maintain synchronization with the original carrier → can use Costa receiver.
- Alternatively, can send a separate pilot signal outside the 2W bandwidth for the purpose of carrier synchronization. The pilot is usually a low-power sinusoidal tone with freq. and phase related to \( C(t) \).

- Output: for the upper branch,
\[ 2 S(t) \cos(2 \pi f c t) = A_c m_1(t) + A_c \left[ m_1(t) \cos(2 \pi f c t) + m_2(t) \sin(2 \pi f c t) \right] \]

  similarly for lower branch, we get \( A_c m_2(t) \).

- What happens if there is a phase error?

  upper branch output will be
  \[ n(t) = 2 S(t) \cos(2 \pi f c t + \phi) \]
  \[ = A_c m_1(t) \cos \phi - A_c m_2(t) \sin \phi + A_c \left[ m_1(t) \cos(2 \pi f c t + \phi) + m_2(t) \sin(2 \pi f c t + \phi) \right] \]

  After LPF we get
  \[ A_c \left[ m_1(t) \cos \phi - m_2(t) \sin \phi \right] \]

  co-channel interference similar interference if there is frequency error or unequal attenuation.
of upper-sideband and lower-sideband. Thus quadrature-carrier multiplexing requires accurate synchronization at the receiver.

- Quadrature multiplexing is used in analog color TV to "mix" colors (chrominance signals).

- **Single-sideband (SSB) modulation.**

  Since quadrature multiplexing requires exact synchronization, we look into other techniques that may be less stringent.

- SSB modulation is a good technique when the baseband signal (mit) has little energy at very low frequencies, as in the case of analog voice, (no voice < 300 Hz).

- **Generation of SSB signals:**
  - First generate a DS& signal
  - Then apply a bandpass filter to keep only one sideband (either the upper or the lower).

- Because practical filters cannot have sharp cutoffs, this method works well only when the desired sideband lies inside the passband of the filter, i.e., there is not a significant content around zero frequency (see figure).

  ![Diagram showing SSB modulation](image)
Demodulation of SSB signals requires coherent detection with accurate synchronization.

Again, synchronization can be achieved by either sending pilot signals or using highly stable oscillators at both Tx and Rx.

SSB by phase-shift method

\[ m(t) \]
\[ \rightarrow \]
\[ s_1(t) \]
\[ \cos(2\pi f_c t) \]
\[ 90^\circ \]
\[ \sin(2\pi f_c t) \]
\[ s_2(t) \]
\[ \rightarrow \]
\[ s(t) \] (SSB)

This is a phase-shift network; it does not change the amplitude of signals but only reverse the phase of the signal (positive or negative).

The phase-shift network, however, is difficult to realize accurately in practice. It requires careful control of phases and amplitudes and the circuit design can be difficult.
Vestigial - sideband (USB) modulation.

When the message signal does not have an energy gap at the origin, then we use the practical technique USB.

USB transmits one sideband and a small amount (vestige) of the other sideband as well.

The BPF for USB has a nonzero transition band.

We are interested in the conditions on this BPF to allow accurate recovery of the message signal.

Spectrum of the modulated signal

\[ S(f) = \frac{1}{2} \left[ M(f - fc) + M(f + fc) \right] H(f) \]

In coherent detection:

\[ v(t) = s(t) \cos(2\pi f_c t) \rightarrow V(f) = \frac{1}{2} \left[ S(f - fc) + S(f + fc) \right] \]
Thus \( V_0(f) = \frac{1}{4} M(f) \left[ H(f+fc) + H(f-fc) \right] \)
\[ + \frac{1}{4} \left[ M(f-2fc) H(f-fc) + M(f+2fc) H(f+fc) \right] \]

After LPF, we get
\[ V_0(f) = \frac{1}{4} M(f) \left[ H(f-fc) + H(f+fc) \right] \]

We then require
\[ H(f-fc) + H(f+fc) = \text{constant} \quad -W \leq f \leq W. \]

This condition, in fact, is quite flexible and allows a variety of filters \( H(f) \).

**Example:**

- Response: flip around \( f_c \)
- The sum here is constant
- \( H(f) \)

VSB is used in analog and digital TV broadcasting (but not suppressed carrier, to keep receiver simple).

**HDTV Spectrum using VSB:**

\( f_c = 57.155 \text{ MHz} \)

\( \text{BW} = 6 \text{ MHz} \)

Frequency division multiplexing (FDM)

SSB is a form of frequency translation, also called "mixing" or "heterodyning."
FDM allows different signals to be combined into a composite signal to transmit over a common channel. Each signal will occupy a separate band of the channel.