Lecture 14

Frequency Translation, Frequency Division Multiplexing, Superheterodyne Receivers
Frequency Translation

- Suppose we have a modulated wave $s_1(t)$ whose spectrum is centered around frequency $f_1$ and we wish to move it upward in frequency, so that its spectrum is centered around $f_2$.
- This can be accomplished by multiplying $s_1(t)$ by $\cos 2\pi (f_2-f_1) t$ and passing it through a BPF.
Frequency Translation

\[ s_1(t) \times x(t) \xrightarrow{\text{BPF @ } f_2} s_2(t) \]

\[ \cos 2\pi (f_2 - f_1)t \]

\[ X(f) = 0.5S_1(f-f_2+f_1) + 0.5S_1(f+f_2-f_1) \]
Frequency Translation

\[f_1 - f_2 - (f_2 - 2f_1) - f_2\]
Downward Frequency Translation (Downconversion)

- We can also decrease the frequency of a modulated signal by multiplying by \( \cos(2\pi (f_2-f_1)t) \) and then filtering out the higher frequency (sum) component, and using the lower frequency (difference) component.
Frequency Division Multiplexing

- When multiple signals are to be transmitted they can be multiplexed in frequency by assigning different carrier frequencies that are sufficiently spaced.
- For example, in a DSB-SC system the messages $m_1(t)$, $m_2(t)$ and $m_3(t)$ can be multiplexed by assigning carriers $A_{c1}\cos 2\pi f_1 t$, $A_{c2}\cos 2\pi f_2 t$ and $A_{c3}\cos 2\pi f_3 t$.
- The signal that is transmitted on the common channel is $s(t) = A_{c1} m_1(t) \cos 2\pi f_1 t + A_{c2} m_2(t) \cos 2\pi f_2 t + A_{c3} m_3(t) \cos 2\pi f_3 t$.
- The spectrum of the signals are:
Frequency Division Multiplexing
Signal Separation

• In the previous example, we can demodulate $m_1(t)$, for example, by multiplying by $\cos 2\pi f_1 t$ and using an LPF.
• But in conventional AM or FM demodulation, the detector requires 1 AM or 1 FM signal at its input.
• Filtering is required.
  - Multiple RF filters?
  - Tunable RF filters?
  - Downconversion?
• Superheterodyne Receiver combines tunable RF filters with downconversion to produce a unique AM or FM signal at the input to the detector
• RF filter must be able to remove the image frequencies.
Superheterodyne Receiver

- Most popular type of a radio receiver so far.
- Used for AM/FM & TV broadcasting, cellular & satellite systems, radars, GPS etc.
- Main idea: downconvert RF signal to some fixed lower (intermediate) frequency, then amplify it and detect.
Superheterodyne Receiver

- **RF amplifier:** amplifies a weak RF signal coming out of the antenna. Rejects the image frequency. Bandwidth: much wider than the signal bandwidth.
- **Mixer:** together with the local oscillator downconverts the RF signal to the IF frequency band.
- **IF amplifier:** amplifies the IF signal significantly (up to $10^6$) and rejects adjacent channel signals and interference (frequency selectivity). Its bandwidth is the same as the signal bandwidth.
- **Detector (demodulator):** demodulates (recovers) the message signal.
- **AGC:** adjusts the IF amplifier gain according to the signal level (to keep the average signal amplitude almost constant)
- **Local oscillator:** allows tuning the receiver to a desired channel (frequency).