Direct Up-conversion vs. 2-Stage Up-conversion

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- Review. A real bandpass signal can be generated by

$$x(t) = x_c(t)\cos(2\pi f_c t + \theta) - x_s(t)\sin(2\pi f_c t + \theta).$$

- Preview. There are pros and cons for direct up-conversion and 2- or multi-stage up-conversion transmitters. The key is to understand the upper-side tuning and the lower-side tuning in 2-stage up-conversion both in the FD and in the TD.

- Direct (Homodyne) Up-conversion Transmitter
  - Fig.

  - Pro. Simple structure
  - Con. DC leakage
  - Con. phase imbalance with a high frequency

- 2-Stage (Heterodyne) Up-conversion Transmitter
- DC leakage and phase imbalance problem may be lessened by mixing with a lower frequency sinusoidal signal.
- Fig.

- intermediate frequency (IF)
- Q. How to generate $x(t)$ from $x_{\mathrm{IF}}(t)$?

- IF to RF up-conversion
  - If difficult in TD, then think in FD.
  - Fig.

  - If the IF frequency is large enough, then the BPF can be easily designed.

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– Q. The RF signal can be generated by

$$x(t) = \mathrm{BPF}\{x_{\mathrm{IF}}(t)\cos(2\pi f_{\mathrm{LO}}t + \phi)\}.$$

Design BPF and choose the local oscillator frequency f_{LO} properly.

– A. Mixing the IF signal with $\cos(2\pi f_{\mathrm{LO}}t + \phi)$ generates an upper sideband signal and a lower sideband signal.

$$\begin{aligned} & x_{\mathrm{IF}}(t) \times 2\cos(2\pi f_{\mathrm{LO}}t + \phi) \\ =& \frac{x_l(t)e^{\mathrm{j}2\pi f_{\mathrm{IF}}t} + x_l^*(t)e^{-\mathrm{j}2\pi f_{\mathrm{IF}}t}}{2} \times 2\frac{e^{\mathrm{j}(2\pi f_{\mathrm{LO}}t+\phi)} + e^{-\mathrm{j}(2\pi f_{\mathrm{LO}}t+\phi)}}{2} \\ = & \\ =& \underbrace{\mathrm{Re}\{x_l(t)e^{\mathrm{j}(2\pi(f_{\mathrm{LO}}+f_{\mathrm{IF}})t+\phi)}\}}_{\text{upper sideband}} + \underbrace{\mathrm{Re}\{x_l^*(t)e^{\mathrm{j}(2\pi(f_{\mathrm{LO}}-f_{\mathrm{IF}})t-\phi)}\}}_{\text{lower sideband}} \end{aligned}$$

* There are two ways to convert IF to RF.

$$\begin{cases} \text{upper-side tuning:} \\ \quad f_{\text{LO}} = f_c - f_{\text{IF}} \text{ with BPF that passes upper sideband signal} \\ \text{lower-side tuning:} \\ \quad f_{\text{LO}} = f_c + f_{\text{IF}} \text{ with BPF that passes lower sideband signal} \end{cases}$$

* The upper-side tuning generates $x(t)$ given

$$x_{\text{IF}}(t) = \text{Re}\{x_l(t)e^{\text{j}2\pi f_{\text{IF}}t}\}.$$

* The lower-side tuning generates $x(t)$ given

$$x_{\text{IF}}(t) = \text{Re}\{x_l^*(t)e^{\text{j}2\pi f_{\text{IF}}t}\}.$$

* Which one to choose depends on situation.

- Fig.

  – Pro. reduced DC leakage
  – Pro. reduced I-Q imbalance
  – Pro. suitable to digital IF transmitter
  – Con. complicated structure ← multiple mixers, BPF