Direct Down-Conversion vs. 2-Stage Down-Conversion

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- Review.
  - Demodulation can be understood as an operation that extracts the complex envelope of the desired bandpass part from the received signal.
  - In particular, an I-Q demodulator is a one real-valued bandpass input and two real-valued baseband output system that recovers the real and the imaginary parts of the complex envelope.

- Preview.
  - I-Q imbalance problem may occur in a direct down-conversion receiver.
  - So, 2- or multi-stage down-conversion is devised.

- Fig. quadrature modulator and quadrature demodulator

- Fig. homodyne transmitter and homodyne receiver

- Is a **homodyne receiver** enough?
  - Was a homodyne transmitter enough?
    - To mitigate I-Q imbalance problem, a heterodyne transmitter was devised.
    - Similar to a homodyne Tx, it may not be easy to have very small phase noise in the I-Q demodulator when f_c is large.
  - We may devise a **heterodyne receiver**.
    - First, we down-convert the RF signal to an IF signal.
    - Then, we down-convert the IF signal to two baseband signals
    - Fig. Block diagram with LO_1 and LO_2

- Q. Design a heterodyne receiver.
- Simplify. Ignore interference and noise to have $y(t) = x(t)$.
  - Fig. In FD, ...

  - The pre-envelope $y_{\mathrm{IF},+}(t)$ of the IF signal $y_{\mathrm{IF}}(t)$ is given by

$$y_{\mathrm{IF},+}(t) = \mathrm{BPF}\{y(t) \cdot 2e^{-\mathrm{j}(2\pi(f_c - f_{\mathrm{IF}})t + \phi_1)}\},$$

where the impulse response of the BPF is real-valued.

- The IF signal $y_{\mathrm{IF}}(t) = \mathrm{Re}\{y_{\mathrm{IF},+}(t)\}$ is given by

$$\begin{aligned}
\mathrm{Re}\{y_{\mathrm{IF},+}(t)\} &= \mathrm{Re}\left[\mathrm{BPF}\{y(t) \cdot 2e^{-\mathrm{j}(2\pi(f_c - f_{\mathrm{IF}})t + \phi_1)}\}\right] \\
&= \ldots \\
&= \mathrm{BPF}\left[\mathrm{Re}\{y(t) 2e^{-\mathrm{j}(2\pi(f_c - f_{\mathrm{IF}})t + \phi_1)}\}\right] \\
&= \mathrm{BPF}\left[y(t)\mathrm{Re}\{2e^{-\mathrm{j}(2\pi(f_c - f_{\mathrm{IF}})t + \phi_1)}\}\right] \\
&= \mathrm{BPF}\{y(t) \cdot 2\cos(2\pi(f_c - f_{\mathrm{IF}})t + \phi_1)\}
\end{aligned}$$

- This IF signal can be down-converted by a quadrature demodulator to obtain the real and the imaginary parts of $x_l(t)e^{\mathrm{j}\phi_3}$.
- Fig. 2-stage down-conversion without interference and noise

– Similar to upper-side tuning and lower-side tuning, we can down-convert to IF as

$$y_{\mathrm{IF},+}(t) = \mathrm{BPF}\{y(t) \cdot 2e^{-\mathrm{j}(2\pi(f_c+f_{\mathrm{IF}})t+\phi_1)}\},$$

where the impulse response of the BPF is real-valued.

– Fig. In FD, ...

– The IF signal $y_{\text{IF}}(t)$ is given by

$$\text{Re}\{y_{\text{IF},+}(t)\} = ... = \text{BPF}\{y(t) \cdot 2\cos(2\pi(f_c + f_{\text{IF}})t + \phi_1)\}.$$

– This IF signal can be down-converted by a quadrature demodulator to obtain the real and the imaginary parts of $x_l^*(t)e^{\mathrm{j}\phi_3}$.

– Fig. 2-stage down-conversion without interference and noise

- With interference and noise, the above simplified 2-stage down-conversions suffer from **the image-band problem**.
  - Fig.
  - Unless the image band is filtered out before mixing, the IF signal contains the signal component from the image band.
    * The center frequency of the image band is $f_c - 2f_{\text{IF}}$ when mixed with $2\cos(2\pi(f_c - f_{\text{IF}})t + \phi_1)$.
    * The center frequency of the image band is $f_c + 2f_{\text{IF}}$ when mixed with $2\cos(2\pi(f_c + f_{\text{IF}})t + \phi_1)$.
  - Thus, a real-valued BPF is placed before the down-conversion mixer. This filter is called an **image reject (IR) filter**.

- The down-conversion mixer output may contain interference and noise. So, the output is need to be further filtered.
- Fig.
- Thus, a real-valued BPF is placed after the down-conversion mixer. This filter is called a **channel select (CS) filter**.
- Fig. Heterodyne receiver