5G PHY Layer – RF Processing

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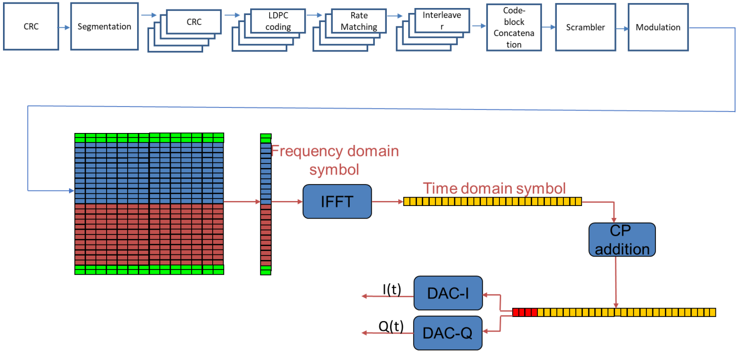
Simulation-Based Design of 5G Wireless Standard (EE698H)

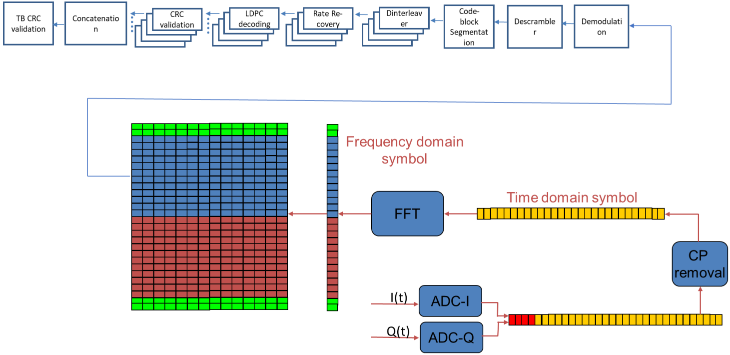
Agenda for today

- Finish discussing scrambler
- Discuss 5G radio RF transmitter and receiver
  - Any basic digital communications textbook

5G transmit chain

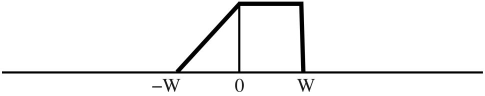


5G receive chain



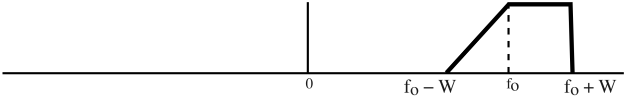
Baseband - passband system model

- Transmit complex waveform $s(t) = I(t) + jQ(t)$ is called as baseband signal
- $s(t)$ will have asymmetric spectrum around origin with bandwidth $-W$ to W



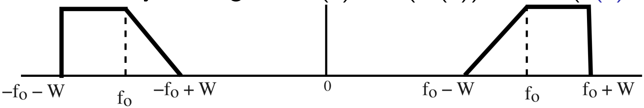
- Upconvert the baseband signal to desired center frequency f_o with $\omega_o = 2\pi f_o$

$$s_1(t) = s(t)\sqrt{2}e^{j\omega_0 t}$$



Transmit passband system model

- We can transmit only real signals $s^o(t) = \Re(s_1(t)) = \sqrt{2}\Re(s(t)e^{j\omega_0 t})$



- $s_1(t)$ is called passband/RF/upconverted transmit signal.
- Real transmit signal can equivalently be written as

$$\begin{aligned} s^o(t) &= \Re(s_1(t)) = \sqrt{2}\Re(s(t)e^{j\omega_0 t}) \\ &= \sqrt{2}\Re([I(t) + jQ(t)]e^{j\omega_0 t}) \\ &= \sqrt{2}I(t)\cos(\omega_0 t) - \sqrt{2}Q(t)\sin(\omega_0 t) \end{aligned}$$

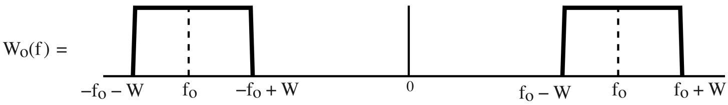
- Architecture is called balanced homodyne transmitter
- We assume that channel is not faded for today's discussion

Receive passband system model (2)

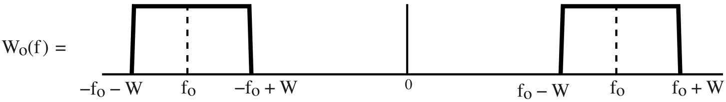
- Received signal is:

$$
\begin{aligned}
r_1(t) &= s^o(t) + n_w(t) \\
&= \sqrt{2}I(t)\cos(\omega_0 t) - \sqrt{2}Q(t)\sin(\omega_0 t) + n_w(t)
\end{aligned}
$$

- First step in recovering baseband signal – limit the bandpass noise $n_w(t)$.
- Filter the receive signal $r_1(t)$ using a band pass filter $W_0(f)$.



Receive passband system model (2)



- Received equivalent signal is

$$\begin{aligned} r(t) &= r_1(t) \circledast w_0(t) \\ &= (s^o(t) + n_w(t)) \circledast w_0(t) \\ &= s^o(t) + (n_w(t) \circledast w_0(t)) \\ &= s^o(t) + n(t) \end{aligned}$$

Receive baseband system model (1)

- Demodulate inphase signal $I(t)$

$$\begin{aligned}
r_c(t) &= \left[r(t)\sqrt{2}\cos(\omega_0 t)\right]_{lpf} \\
&= \left[\left\{\sqrt{2}I(t)\cos(\omega_0 t) - \sqrt{2}Q(t)\sin(\omega_0 t) + n(t)\right\}\sqrt{2}\cos(\omega_0 t)\right]_{lpf} \\
&= \left[2I(t)\cos^2(\omega_0 t) - Q(t)\sin(2\omega_0 t) + \sqrt{2}n(t)\cos(\omega_0 t)\right]_{lpf} \\
&= \left[I(t) + I(t)\cos(2\omega_0 t) - Q(t)\sin(2\omega_0 t) + \sqrt{2}n(t)\cos(\omega_0 t)\right]_{lpf} \\
&= I(t) + n_c(t)
\end{aligned}$$

Receive baseband system model (2)

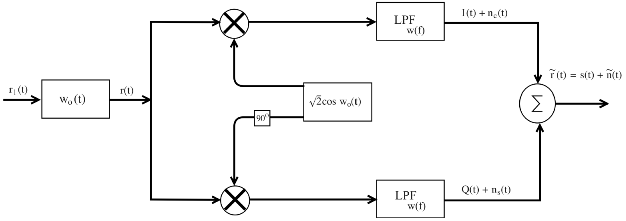
- Demodulate quadrature signal $Q(t)$ (multiply $r(t)$ with $-\sqrt{2}\sin(\omega_0 t)$)

$$
\begin{aligned}
r_s(t) &= -[r(t)\sqrt{2}\sin(\omega_0 t)]_{lpf} \\
&= -\left[I(t)\cos(2\omega_0 t) - Q(t)\sin^2(\omega_0 t) + \sqrt{2}n(t)\sin(\omega_0 t)\right]_{lpf} \\
&= Q(t) + n_s(t)
\end{aligned}
$$

Demodulator block diagram

- Demodulated complex baseband receive signal

$$
\begin{aligned}
\tilde{r}(t) &= r_c(t) + jr_s(t) \\
&= I(t) + jQ(t) + n_c(t) + jn_s(t) \\
&= s(t) + \tilde{n}(t)
\end{aligned}
$$



- Homodyne receiver architecture