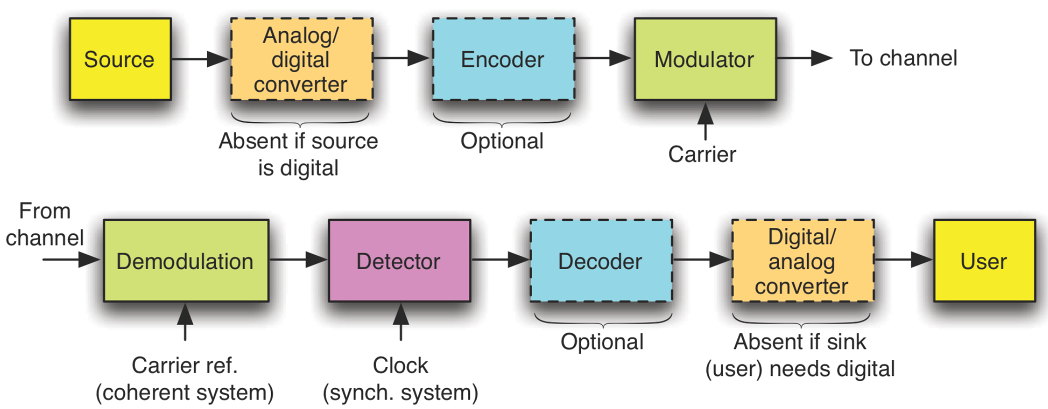
Signal Processing and Communications Hands-On Using scikit-dsp-comm Part 3

Communications Theory & Practice

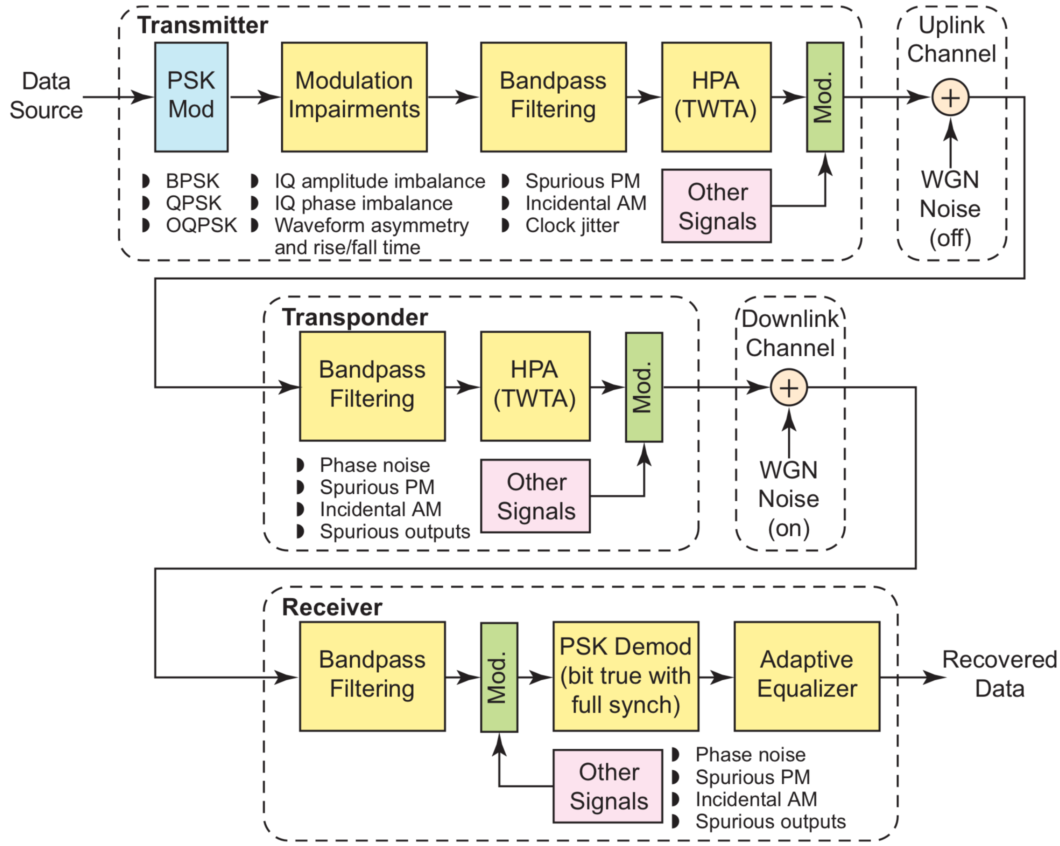
- In this part of the tutorial the focus is on signal processing for communications
- The Labs will involve the use of the RTL-SDR or optionally archived captures found in the tutorial repository

Top Level Block Diagram



- Communication system modeling and simulation are woven throughout all of the `scikit-dsp-comm` package
- The flavors of communication are *analog* and *digital* modulation
    - The above block diagram is digital as bits flow into the encode block and out the decoder block
    - To analog is a misnomer as the channel is waveform based, which is also analog signal processing too
    - In analog communications the message or information signal is directly *modulated* on to the channel

Use Case: Modeling Satellite Commnunications Systems



Wideband Sat-Comm simulation model

Baseband or Carrier Based

- The signals or waveforms that carry communication information are either *baseband* or *carrier* based
- Wired Ethernet is an example of baseband, as are interconnects within our devices
- Wireless communications uses a radio frequency (RF) carrier to allow free space propagation to serve as the channel to carry the signal from the transmitter (tx) to the receiver (rx)
  - There is also free space optical and optical fiber

Carrier Modulation

- A modulated carrier can be represented as

$$x_c(t) = A(t)\cos\left[2\pi f_c t + \phi(t)\right] \tag{1}$$

where $A(t)$ is linear modulation, f_c the carrier frequency, and $\phi(t)$ is phase modulation

- Amplitude modulation is where radio started, and still is in use today in both analog and digital communications
- Phase modulation encompasses frequency modulation (FM) as well, since the two are related by differentiation/integration, e.g.,

$$\phi(t) = \text{Phase Deviation of the Carrier in radians} \tag{2}$$

$$\frac{1}{2\pi}\cdot\frac{d\phi(t)}{dt} = \text{Frequency Deviation in Hz of the carrier} \tag{3}$$

Carrier Demodulation in Python with the RTL-SDR

- > **Demodulation**: Undoing at the receiver what was done at the transmitter to recover the data bits or analog signal
- As a quick review, an FM modulated carrier applies the message signal $m(t)$ to the carrier signal $x_c(t)$ such that the derivative of the phase deviation, $d\phi(t)/dt$, (also the frequency deviation) is proportional to the message:

$$x_c(t) = A_c \cos\left[2\pi f_c t + \phi(t)\right] = A_c \cos\left[2\pi f_c t + 2\pi k_d \int^t m(\alpha)d\alpha\right], \tag{4}$$

  where k_d is the modulator frequency deviation constant.

- To demodulate FM you first consider the ideal discriminator which takes in $x_c(t)$ and operates on the phase deviation to produce

$$y_D(t) = \frac{1}{2\pi}K_D\frac{d\phi(t)}{dt} \tag{5}$$

  where K_D is the discriminator gain constant

- Notice that for FM, that is $\phi(t) = 2\pi f_D \int^t m(\alpha)d\alpha$ as defined above,

$$y_D(t) = \underbrace{K_D}_{\text{v/Hz}} \cdot \underbrace{f_D}_{\text{v/Hz}} \cdot \underbrace{m(t)}_{\text{v}} \tag{6}$$

- To demodulate FM, the *complex baseband discriminator*, also known as the *quadricorrelator*, has a convenient DSP implementation
- At complex baseband $x_c(t)$ is of the form

$$\tilde{x}_c(t) = \cos[\underbrace{2\pi\Delta f t + \phi(t)}_{\theta(t)}] + j\sin[\underbrace{2\pi\Delta f t + \phi(t)}_{\theta(t)}] = x_I(t) + jx_Q(t), \tag{7}$$

  where I have assumed a small frequency error Δf in the frequency translation of $x_c(t)$ to baseband

- The frequency discriminator obtains $d\theta(t)/dt$ where in terms of the I and Q signals

$$\theta(t) = \tan^{-1}\left(\frac{x_Q(t)}{x_I(t)}\right) \tag{8}$$

- The derivative of $\theta(t)$ is

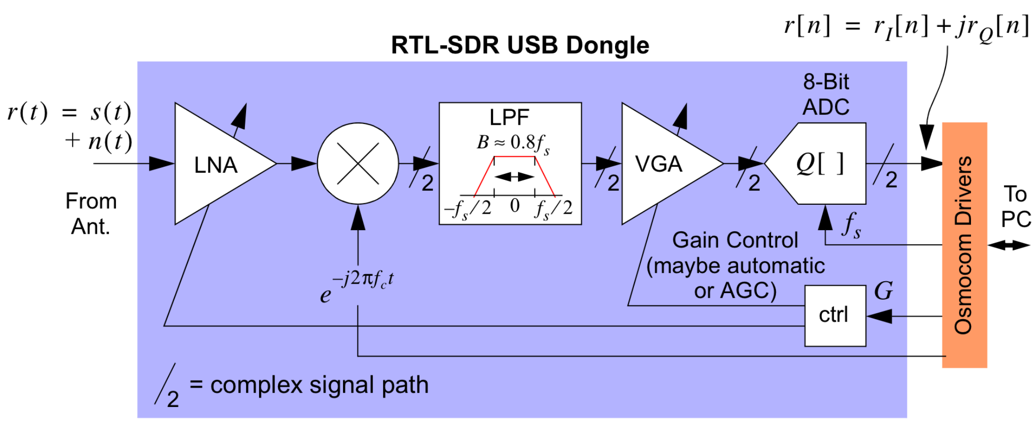
$$\frac{d\theta(t)}{dt} = \frac{x_I(t)x'_Q(t) - x'_I(t)x_Q(t)}{x_I^2(t) + x_Q^2(t)} \tag{9}$$

- In DSP $x_I(t) \Rightarrow x_I(nT) = x_I[n]$ and $x_Q(t) \rightarrow x_Q(nT) = x_Q[n]$, where T is the sample spacing and $1/T = f_s$ is the sampling rate. The derivatives, $x'_I(t)$ and $x'_Q(t)$, are approximated by the *backwards difference* $x_I[n] - x_I[n-1]$ and $x_Q[n] - x_Q[n-1]$ respectively
- Inside `rtlsdr_helper` this is impolkemented in `y = discrim(x)` as:

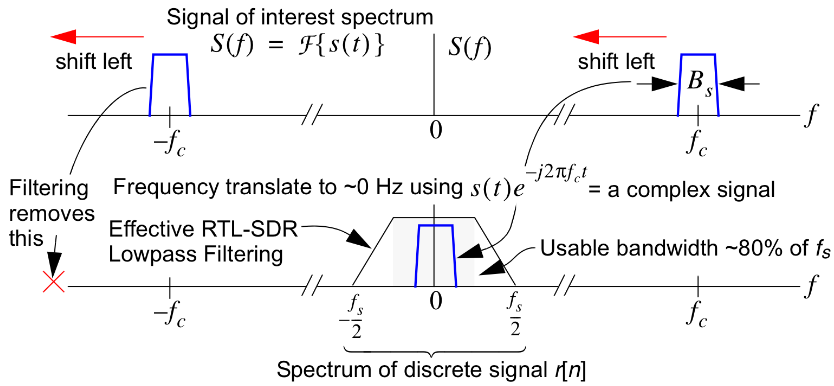
```
def discrim(x):
    """
    function disdata = discrim(x)
    where x is an angle modulated signal in complex baseband form.

    Mark Wickert
    """
    X=np.real(x)        # X is the real part of the received signal
    Y=np.imag(x)        # Y is the imaginary part of the received signal
    b=np.array([1, -1]) # filter coefficients for discrete derivative
    a=np.array([1, 0])  # filter coefficients for discrete derivative
    derY=signal.lfilter(b,a,Y)  # derivative of Y,
    derX=signal.lfilter(b,a,X)  #    "          X,
    disdata=(X*derY-Y*derX)/(X**2+Y**2)
    return disdata
```

RTL-SDR Architecture

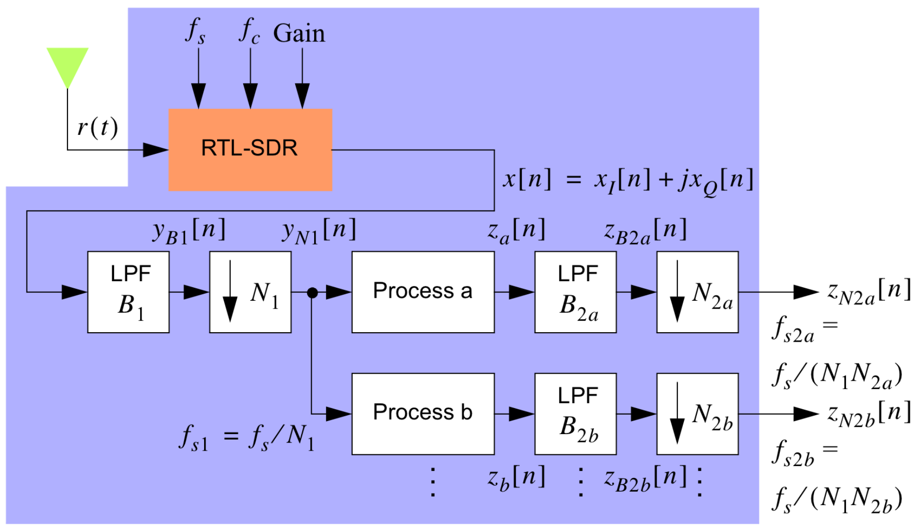
Inside the Dongle



Moving the Signal from the Carrier to Complex Baseband

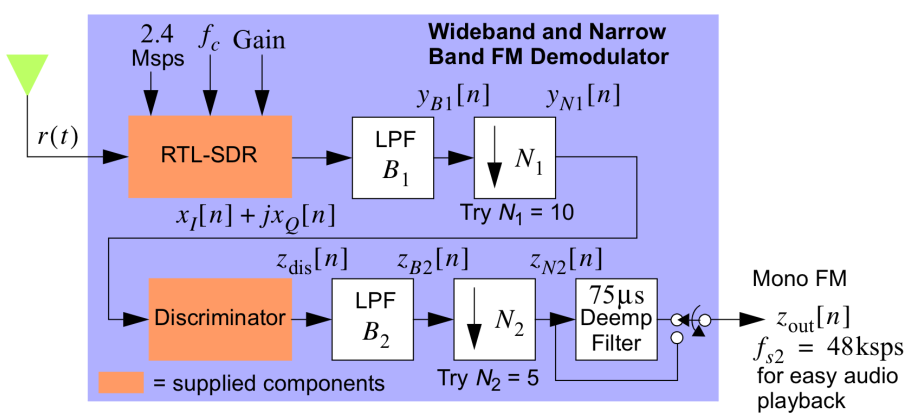


Generic Demodulation Algorithm

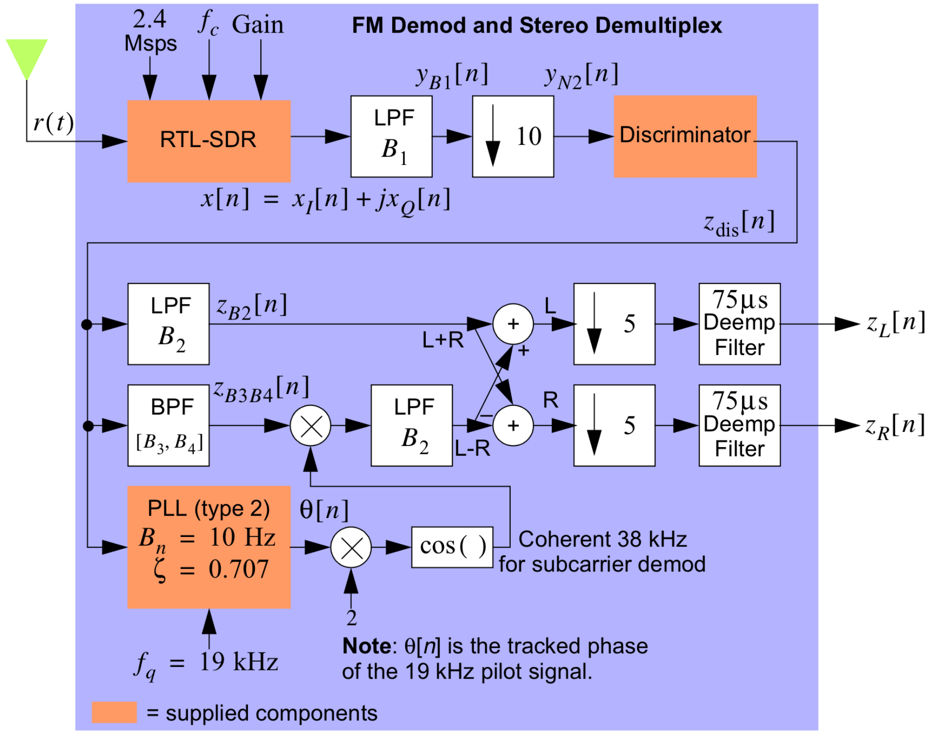


Signals Of Interest in the Tutorial

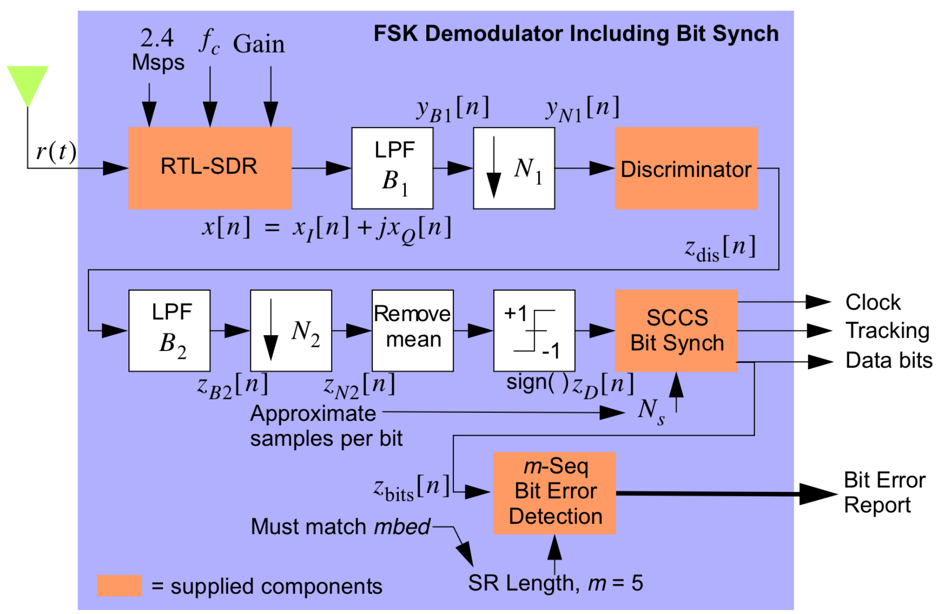
Broadcast FM Mono



Broadcast FM Stereo



Frequency Shift Keying Demod (Arduino-based FM/FSK Stereo tx)



> Move to working with the hardware using various Jupyter notebooks