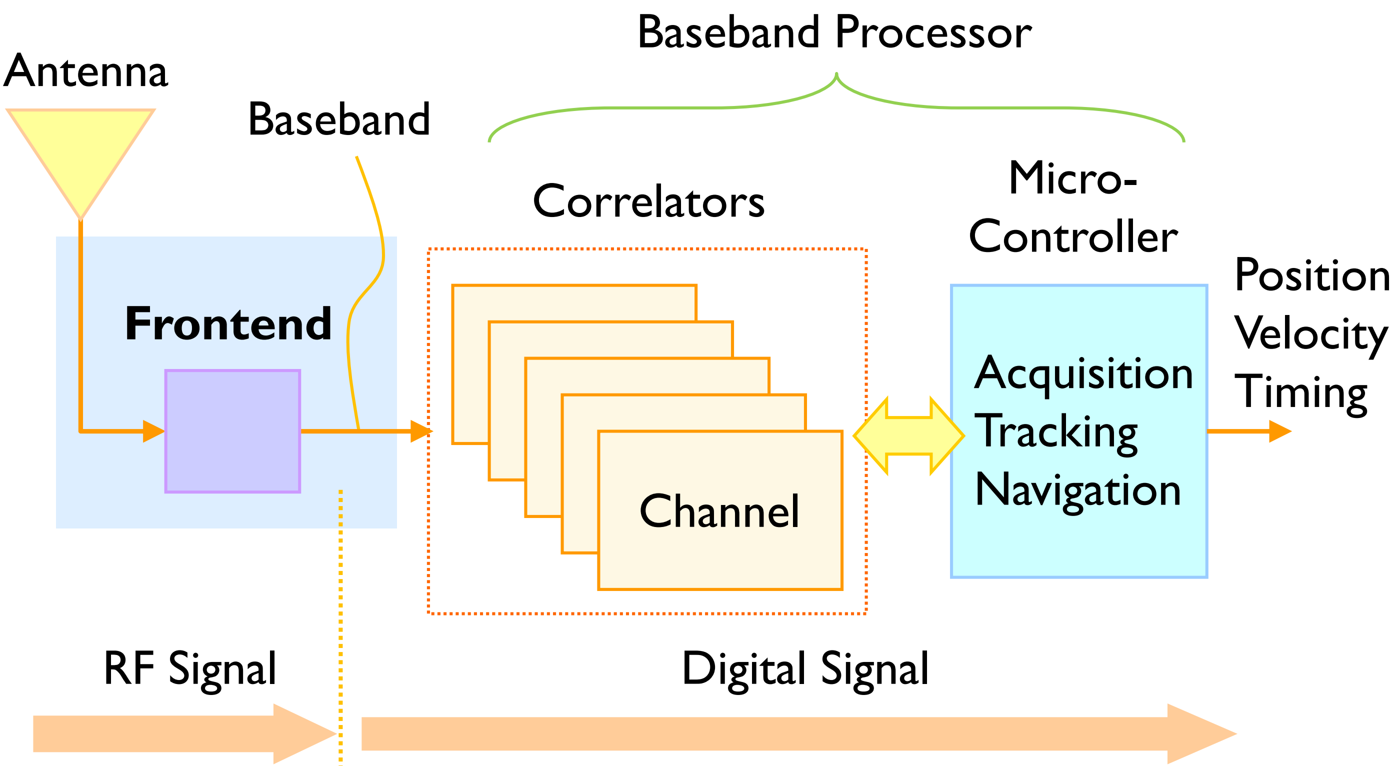
GNSS RF Frontend Architecture

GNSS Receiver Architecture



Modulation

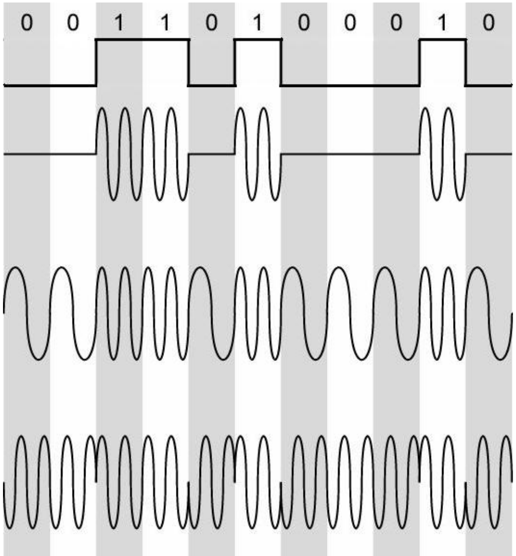
- Modulation is defined as the process of superimposing a low-frequency information signal on a high-frequency carrier wave.

$$s = \boldsymbol{A}\cos(2\pi \boldsymbol{f} t + \boldsymbol{\phi})$$

Amplitude Shift Keying

Frequency Shift Keying

Phase Shift Keying



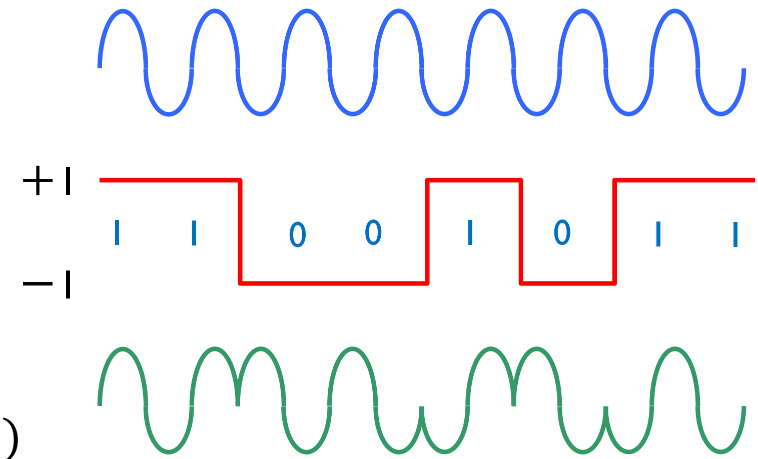
Binary Phase Shift Keying (BPSK)

- BPSK is a digital modulation scheme that conveys data by changing two different phases of the carrier wave.
- This gives maximum phase separation between adjacent points and thus the best immunity to corruption.

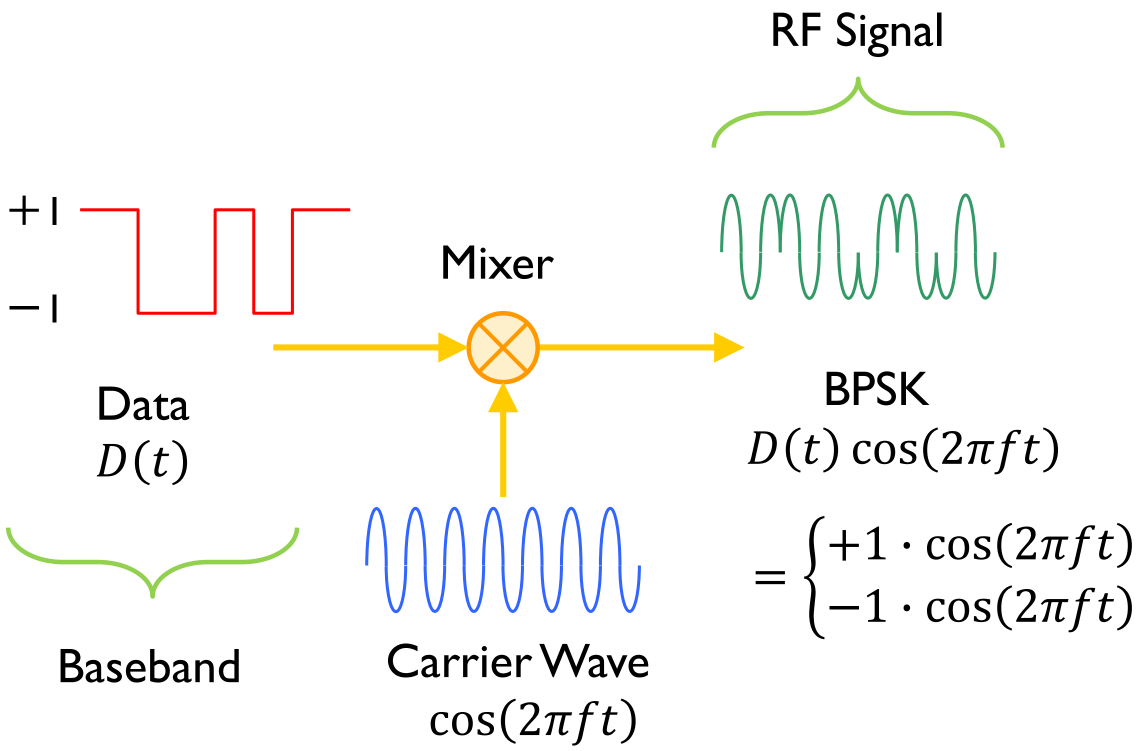
Carrier Wave
$\cos(2\pi f t)$

Data
$D(t)$

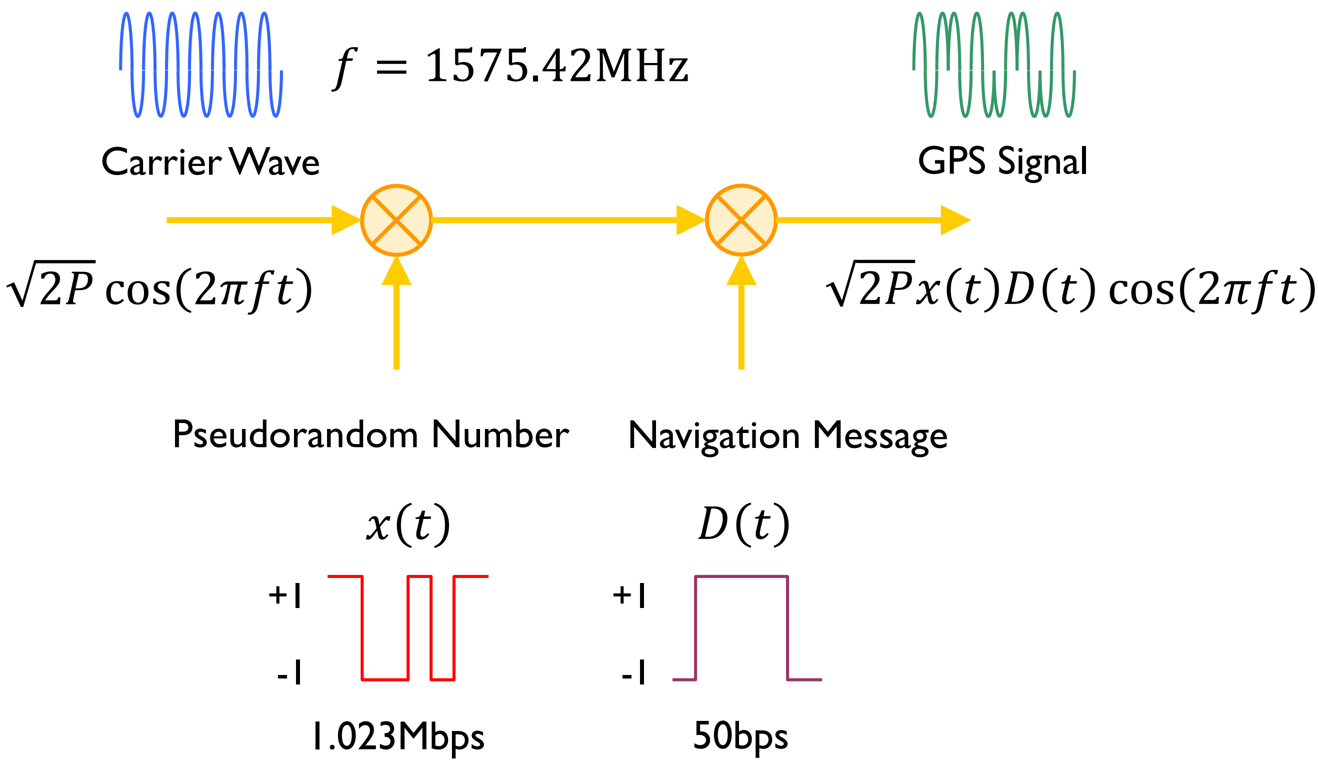
BPSK
$D(t)\cos(2\pi f t)$



Generating BPSK Signal

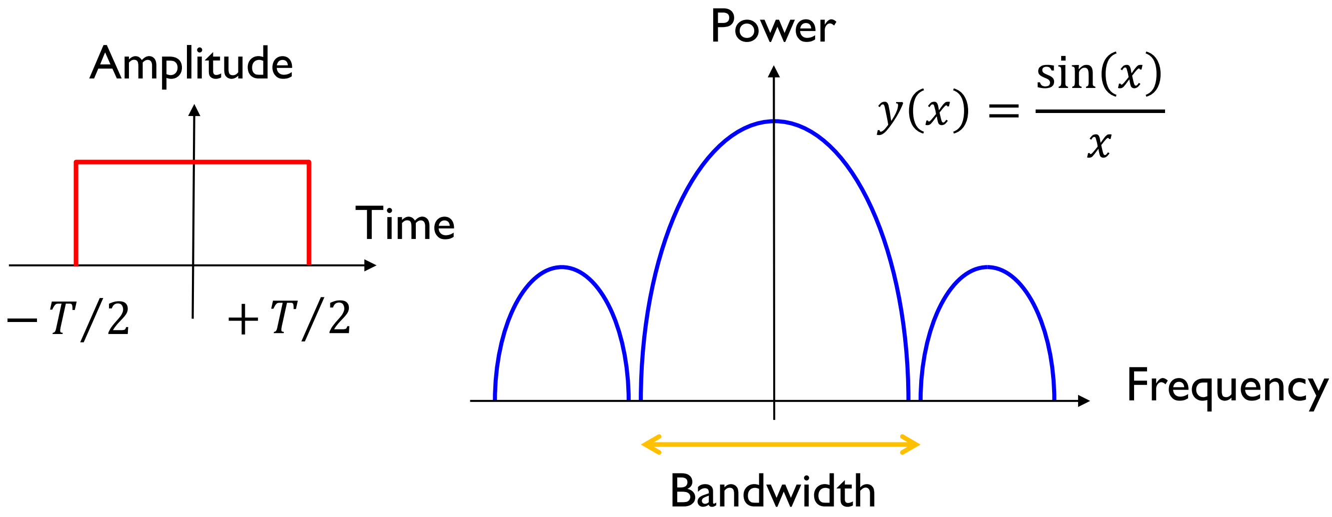


GPS Signal Architecture



GPS Signal Power Spectrum

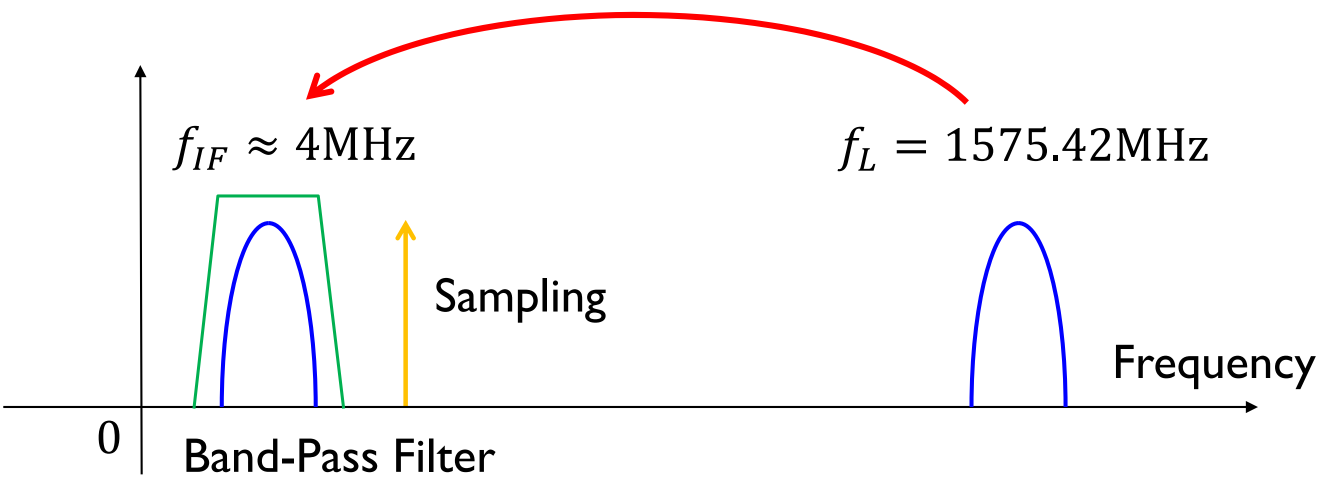
- The power spectrum of a rectangular chip is the well-known sinc function.



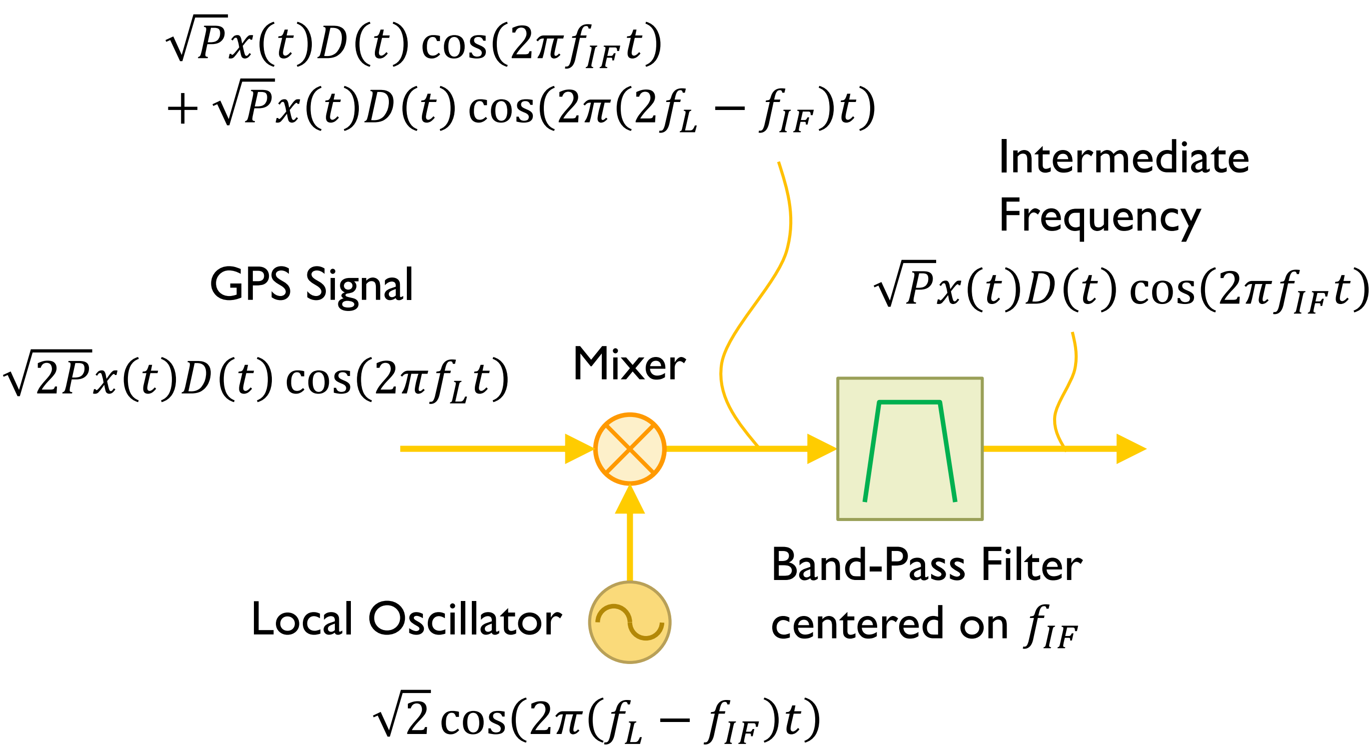
$$BW = \frac{2}{T} = 2.046\text{MHz}$$

Frequency Down Conversion

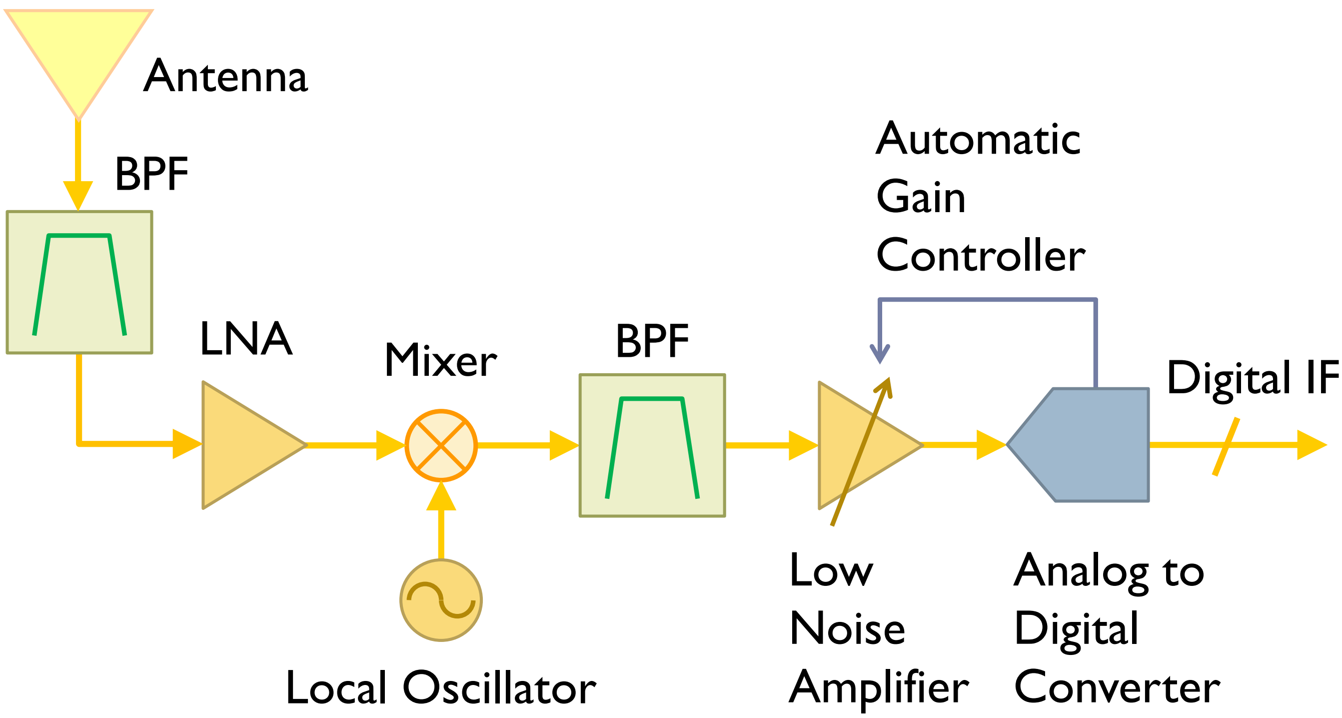
- The conversion of a high-frequency radio signal to a band-limited lower frequency (intermediate frequency) at a lower sampling rate.



Frequency Down Converter

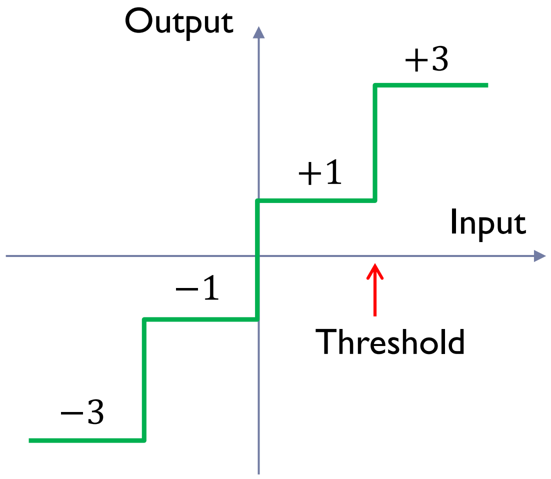


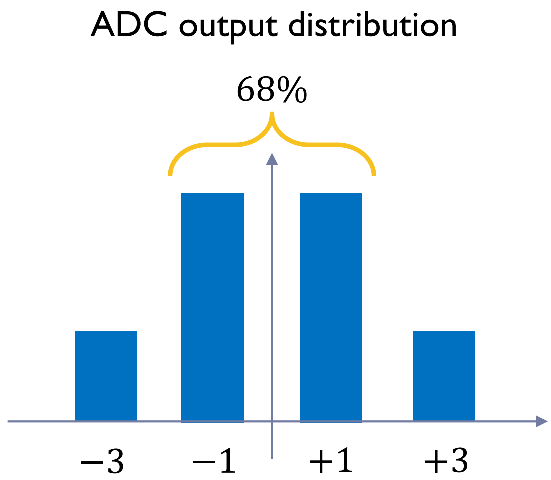
Heterodyne Frontend Architecture



Quantization

- Typical GNSS frontend utilizes two-bit ADC.
- AGC maintains an optimal signal level for the ADC input.
- Since GNSS signal is weaker than thermal noise, the observed ADC output distribution should be Gaussian.





Quadrature Modulation

- Any phase shift keying can be generated by changing the amplitudes of two carrier waves.
- The two carrier waves of the same frequency are out of phase with each other by $90°$, a condition known as orthogonality or quadrature.

$$s(t) = I(t)\cos(\omega t) + Q(t)\sin(\omega t)$$

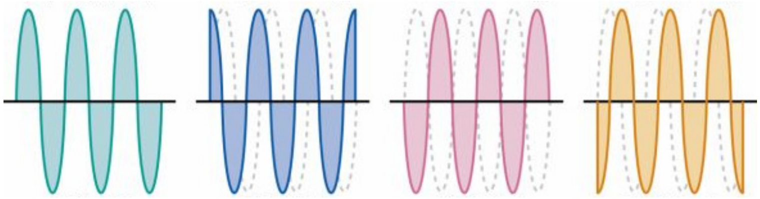
$$= \sqrt{I(t)^2 + Q(t)^2}\cos(\omega t - \phi)$$

where $\phi = \cos^{-1}\dfrac{I(t)}{\sqrt{I(t)^2 + Q(t)^2}} = \sin^{-1}\dfrac{Q(t)}{\sqrt{I(t)^2 + I(t)^2}}$

Quadrature Phase Shift Keying (QPSK)

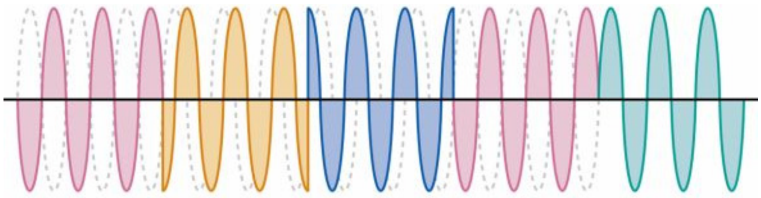
- QPSK modulates two bits at once by selecting one of four possible carrier phase shifts of $0°$, $90°$, $180°$, or $270°$.

Phase Shift	$0°$	$90°$	$180°$	$270°$



Symbol	00	01	10	11

Example:



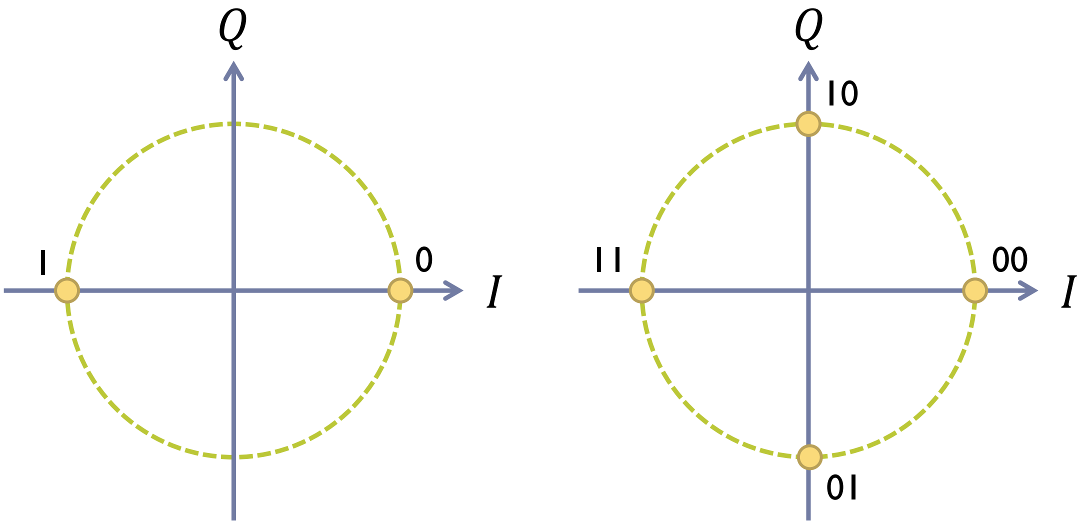
10 11 01 10 00

QPSK and Quadrature Modulation

Symbol	QPSK	Quadrature Modulation
00	$\cos(\omega t - 0°) =$	$+1 \cdot \cos(\omega t)$
01	$\cos(\omega t - 90°) =$	$+1 \cdot \sin(\omega t)$
10	$\cos(\omega t - 180°) =$	$-1 \cdot \cos(\omega t)$
11	$\cos(\omega t - 270°) =$	$-1 \cdot \sin(\omega t)$

Constellation Diagram

- A constellation diagram displays the signal as a two-dimensional I/Q-plane scatter diagram at symbol sampling instants.



BPSK (2PSK)   QPSK (4PSK)

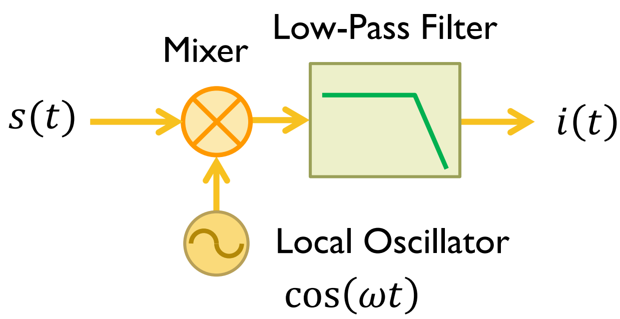
Coherent Demodulation

$$i(t) = s(t)\cos(\omega t)$$
$$= I(t)\cos(\omega t)\cos(\omega t) + Q(t)\sin(\omega t)\cos(\omega t)$$
$$= \frac{1}{2}I(t)\{1+\cos(2\omega t)\} + \frac{1}{2}Q(t)\sin(2\omega t)$$

LPF   LPF

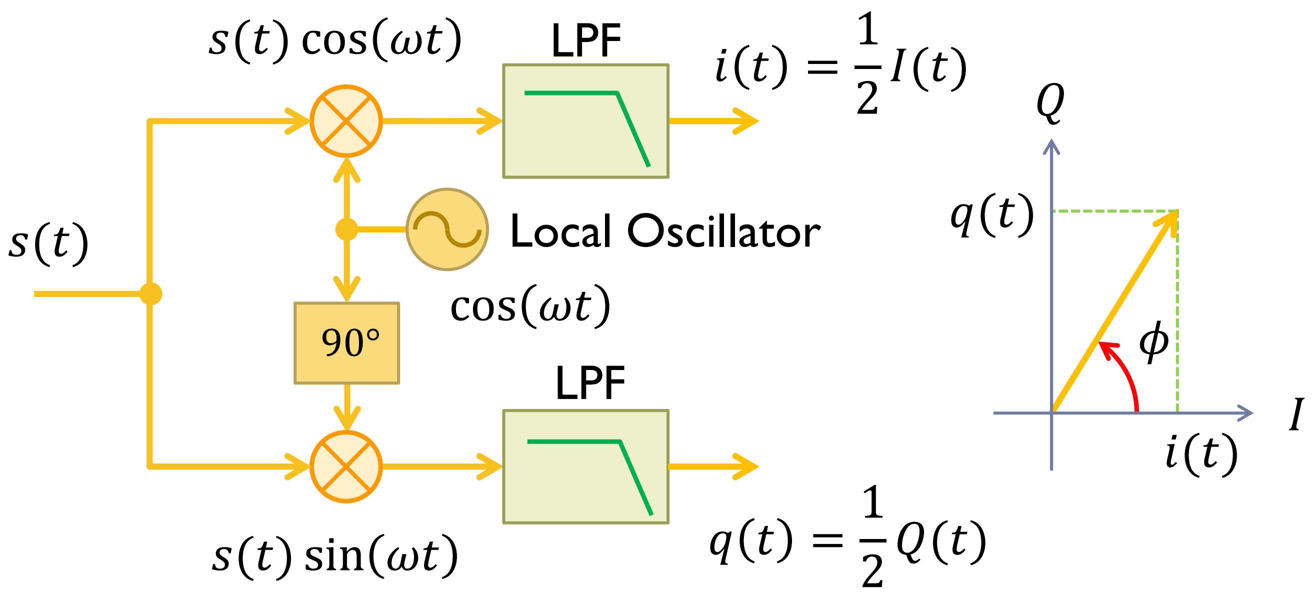
$$= \frac{1}{2}I(t)$$

$$q(t) = s(t)\sin(\omega t)$$
$$= \frac{1}{2}Q(t)$$

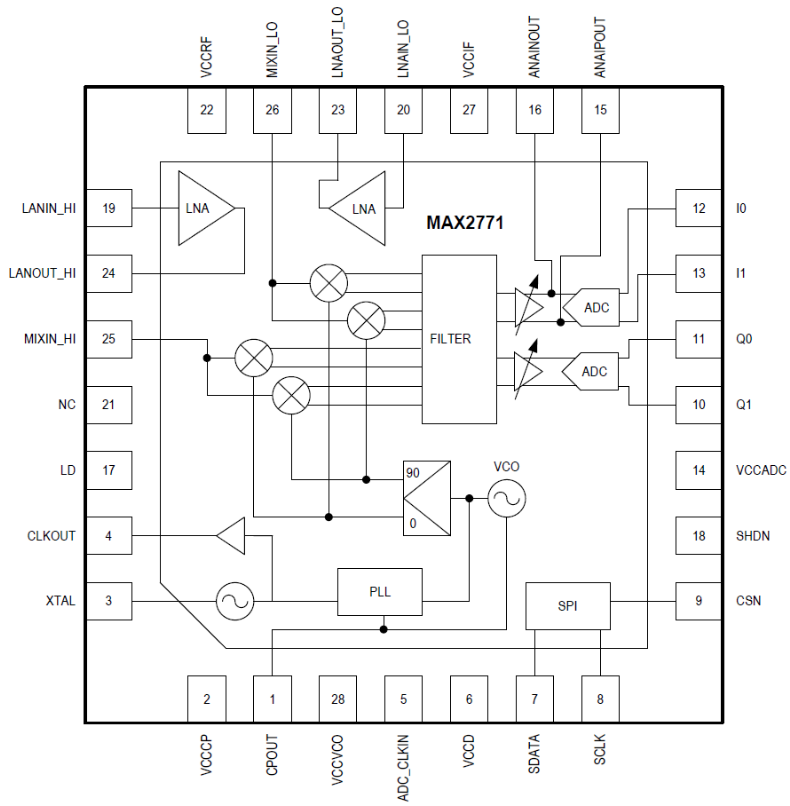


Coherent Demodulator

$$s(t) = I(t)\cos(\omega t) + Q(t)\sin(\omega t)$$

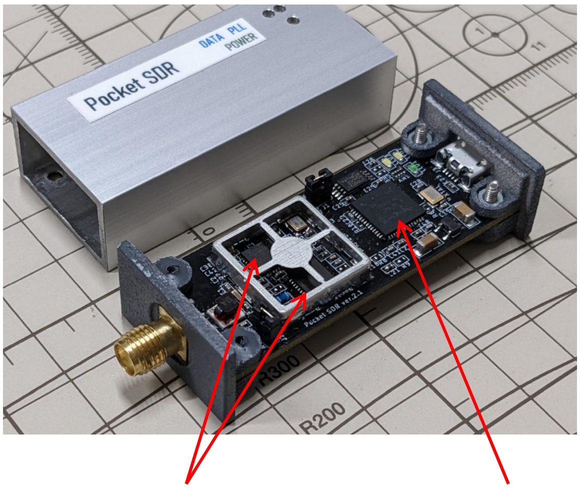


MAX2771 GNSS RF Frontend



PocketSDR

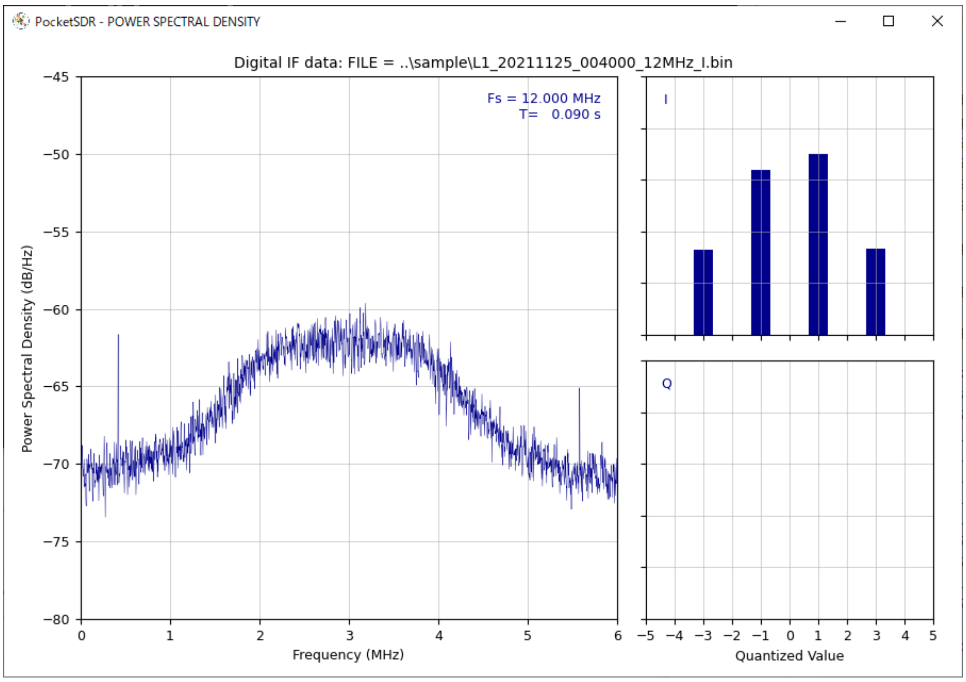
- An open-source dual-frequency GNSS frontend designed by Tomoji Takasu, the creator of RTKLIB.
  - https://github.com/tomojitakasu/PocketSDR



MAX2771 x 2 EZ-USB FX2LP

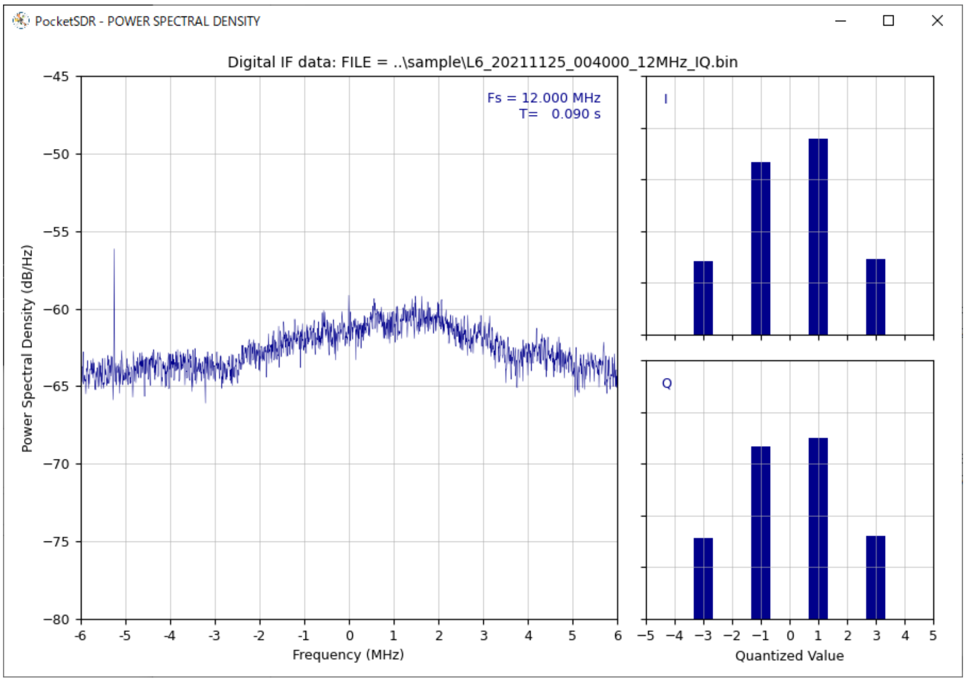
IF Signal Example

```
> python pocket_psd.py ..¥sample¥L1_20211125_004000_12MHz_I.bin -f 12 -h
```



I/Q Signal Example

```
> python pocket_psd.py ..¥sample¥L6_20211125_004000_12MHz_IQ.bin -f 12 -h -IQ
```



Configure PocketSDR

```
> pocket_conf ..¥conf¥pocket_L1L6_12MHz.conf
```

Pocket_L1L6_12MHz.conf

```
#
#  Pocket SDR device settings
#
#  [CH1] F_LO = 1572.420 MHz, F_ADC = 12.000 MHz (I ), F_FILT =  3.0 MHz, BW_FILT =  4.2 MHz
#  [CH2] F_LO = 1278.750 MHz, F_ADC =  0.000 MHz (IQ), F_FILT =  0.0 MHz, BW_FILT =  8.7 MHz

[CH1]
...
```

CH1: $f_{IF} = f_{L1} - f_{LO} = 1575.42\text{MHz} - 1572.42\text{MHz} = 3\text{MHz}$

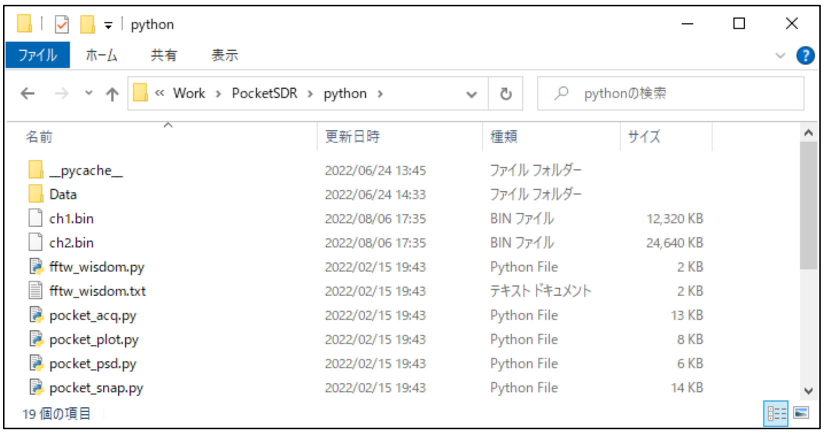
Capture GNSS Signals

```
> pocket_dump -t 1 ch1.bin ch2.bin
```

C:¥Windows¥System32¥cmd.exe

```
D:¥Work¥PocketSDR¥python>pocket_dump -t 1 ch1.bin ch2.bin
  TIME(s)    T   CH1(Bytes)   T   CH2(Bytes)   RATE(Ks/s)
      1.1    I     12615680  IQ     25231360      12014.9

D:¥Work¥PocketSDR¥python>_
```



GNSS Signal Acquisition

```
> python pocket_acq.py ch1.bin -f 12 -fi 3 -sig L1CA -prn 1-32
```

C:¥Windows¥System32¥cmd.exe

```
D:¥Work¥PocketSDR¥python>python pocket_acq.py ch1.bin -f 12 -fi 3 -sig L1CA -prn 1-32
SIG= L1CA, PRN=   1, COFF=  0.54658 ms, DOP=   -94 Hz, C/N0= 33.8 dB-Hz
SIG= L1CA, PRN=   2, COFF=  0.02075 ms, DOP=  3082 Hz, C/N0= 33.2 dB-Hz
SIG= L1CA, PRN=   3, COFF=  0.63433 ms, DOP=  1681 Hz, C/N0= 34.6 dB-Hz
SIG= L1CA, PRN=   4, COFF=  0.77025 ms, DOP=   998 Hz, C/N0= 33.9 dB-Hz
SIG= L1CA, PRN=   5, COFF=  0.22767 ms, DOP= -1030 Hz, C/N0= 34.0 dB-Hz
SIG= L1CA, PRN=   6, COFF=  0.10950 ms, DOP=    36 Hz, C/N0= 33.5 dB-Hz
SIG= L1CA, PRN=   7, COFF=  0.82458 ms, DOP=   129 Hz, C/N0= 33.9 dB-Hz
SIG= L1CA, PRN=   8, COFF=  0.41242 ms, DOP=   -81 Hz, C/N0= 33.8 dB-Hz
SIG= L1CA, PRN=   9, COFF=  0.55233 ms, DOP= -4479 Hz, C/N0= 33.7 dB-Hz
SIG= L1CA, PRN=  10, COFF=  0.52592 ms, DOP=  5000 Hz, C/N0= 34.0 dB-Hz
SIG= L1CA, PRN=  11, COFF=  0.19267 ms, DOP=  5000 Hz, C/N0= 33.6 dB-Hz
SIG= L1CA, PRN=  12, COFF=  0.36833 ms, DOP= -2041 Hz, C/N0= 33.7 dB-Hz
·[34mSIG= L1CA, PRN=  13, COFF=  0.47800 ms, DOP= -2293 Hz, C/N0= 50.2 dB-Hz·[0m
SIG= L1CA, PRN=  14, COFF=  0.80025 ms, DOP=  -409 Hz, C/N0= 36.5 dB-Hz
SIG= L1CA, PRN=  15, COFF=  0.71600 ms, DOP=  -380 Hz, C/N0= 33.7 dB-Hz
SIG= L1CA, PRN=  16, COFF=  0.95433 ms, DOP= -2438 Hz, C/N0= 33.6 dB-Hz
SIG= L1CA, PRN=  17, COFF=  0.59883 ms, DOP=  3005 Hz, C/N0= 33.8 dB-Hz
SIG= L1CA, PRN=  18, COFF=  0.03525 ms, DOP= -2074 Hz, C/N0= 34.3 dB-Hz
SIG= L1CA, PRN=  19, COFF=  0.40675 ms, DOP=  3971 Hz, C/N0= 33.4 dB-Hz
```

GNSS Signal Acquisition