iq_comparison

November 11, 2025

1 IQ Comparison Notebook

2×8-bit IQ

$$\forall n:\ r[n] \in \mathbb{Z}_{256},\ \tilde{r}[n] = \frac{r[n] - 128}{128},\ \hat{r}[n] = \mathcal{H}\{\tilde{r}\}(n).$$

$$\tilde{s}[n] = (\tilde{r}[n] + j\hat{r}[n])\, e^{-j2\pi(f_c - f_0)n/f_s}.$$

$$\tilde{s} \xrightarrow{\downarrow M}\ s[m],\ I[m] = \Re\{s[m]\},\ Q[m] = \Im\{s[m]\}.$$

$$\mathcal{Q}_{u8}(x) = \mathrm{clip}\left(\left\lfloor (x+1)127.5 \right\rceil, 0, 255\right),$$

$$\mathcal{J}(m) = 2m,\ \mathcal{Q}(m) = 2m+1,$$

$$\forall m:\ b_{\mathcal{J}(m)} = \mathcal{Q}_{u8}(I[m]),\ b_{\mathcal{Q}(m)} = \mathcal{Q}_{u8}(Q[m]).$$

$$\Phi : \mathbb{B}_{256}^{2N} \to \mathbb{C}^N,\ \Phi(b)_m = \frac{(b_{2m} - 128) + j(b_{2m+1} - 128)}{128}.$$

$$\Phi^{-1}(s) = \mathrm{interleave}(\mathcal{Q}_{u8}(\Re s), \mathcal{Q}_{u8}(\Im s)).$$

$$\text{Receiver constraint: } f_s = \frac{2048\,\mathrm{kSa/s}}{1}.$$

$$\mathbf{x}_{\text{ref}} = \Phi(b^{(H)}),\ \mathbf{x}_{\text{conv}} = \Phi(b^{(F)}).$$

$$\sigma_I = \sqrt{\mathbb{E}[I^2] - \mathbb{E}[I]^2},\ \sigma_Q = \sqrt{\mathbb{E}[Q^2] - \mathbb{E}[Q]^2}.$$

$$\text{Compare } \mu_I, \mu_Q, \sigma_I, \sigma_Q, \text{RMS}(|\mathbf{x}|).$$

$$\text{Histogram bins} \to \rho_I, \rho_Q : \mathbb{R} \to \mathbb{R}_+.$$

$$\text{Time slice } \mathbf{x}[0:5000] \to \text{visual inspection of drift/bias.}$$

$$\text{Constellation } \{(I[k], Q[k])\} \to \text{energy symmetry.}$$

$$\text{PSD } \to 10\log_{10} S_{II}(f), S_{QQ}(f).$$

$$\text{CDF } \to F_{|x|}(\tau) = \mathbb{P}(|x| \le \tau).$$

$$\text{Let } r[n] \in \mathbb{Z}_{256},\ \tilde{r}[n] = \frac{r[n] - 128}{128}.$$

$$\mathcal{H}\{r\}(n) = \tilde{r}[n] + j\,\hat{r}[n].$$

$$\tilde{r}[n] \cdot e^{-j2\pi\Delta f n/f_s} \xrightarrow{\text{LPF}\downarrow} s[m].$$

$$I[m] = \Re\{s[m]\},\ Q[m] = \Im\{s[m]\}.$$

$$\mathcal{Q}_{u8}(x) = \text{clip}\left(\lfloor (x+1)127.5 \rceil, 0, 255\right).$$

$$\text{Interleave: } b[2m] = \mathcal{Q}_{u8}(I[m]),\ b[2m+1] = \mathcal{Q}_{u8}(Q[m]).$$

$$\mathbb{B}_{\text{repo}} = \{b_k \mid b_k \in \{0, 1, \ldots, 255\}\}.$$

$$\phi : \mathbb{B}_{\text{repo}}^{2N} \to \mathbb{C}^N, \quad \phi(b)_n = \frac{(b_{2n} - 128) + j(b_{2n+1} - 128)}{128}.$$

$$\phi^{-1}(s) = \text{interleave}(\mathcal{Q}_{u8}(\Re\{s_n\}), \mathcal{Q}_{u8}(\Im\{s_n\})).$$

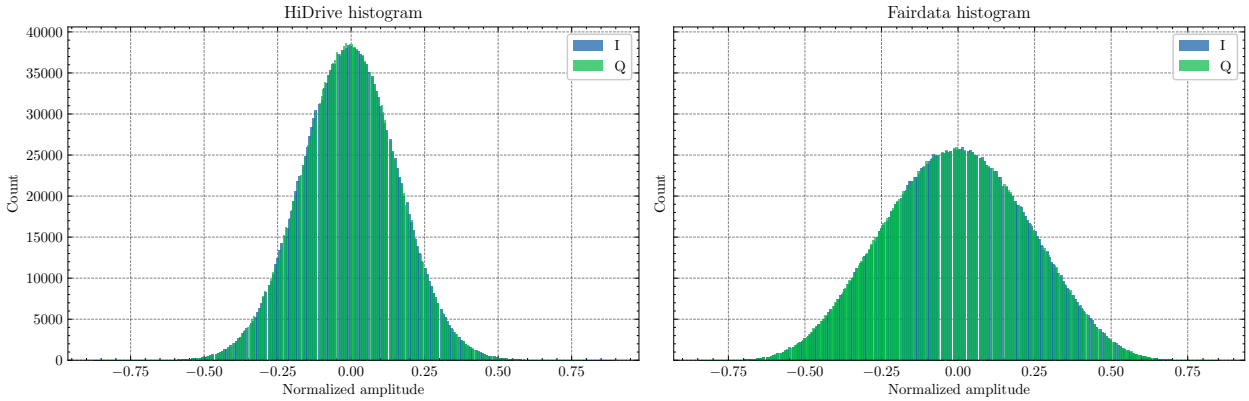
[1]:
```
from pathlib import Path
import numpy as np
import matplotlib.pyplot as plt
FS_HZ = 2_048_000

RAW_HIDRIVE = Path('../data/raw/230914_data_90s.bin')
RAW_FAIRDATA = Path('../data/processed/TGS_L1_E1_2p048Msps_iq_u8.bin')
SAMPLE_COUNT = 2_000_000
%config InlineBackend.figure_format = 'png'
import scienceplots
plt.style.use(['science','grid'])
```

[2]:
```
def load_iq(path: Path, count: int):
    if not path.exists():
        raise FileNotFoundError(path)
    data = np.fromfile(path, dtype=np.uint8, count=2 * count)
    if data.size < 2:
        raise RuntimeError(f'Not enough data read from {path}')
    data = (data.astype(np.float32) - 128.0) / 128.0
    i = data[0::2]
    q = data[1::2]
    return i + 1j * q

def describe_iq(data: np.ndarray, label: str):
    print(f'{label} stats (first {data.size} samples):')
    print(f'  Real  min/mean/max/std: {data.real.min(): .4f}, {data.real.mean():
 ↪ .4f}, {data.real.max(): .4f}, {data.real.std(): .4f}')
    print(f'  Imag  min/mean/max/std: {data.imag.min(): .4f}, {data.imag.mean():
 ↪ .4f}, {data.imag.max(): .4f}, {data.imag.std(): .4f}')
    print(f'  RMS magnitude: {np.sqrt(np.mean(np.abs(data)**2)):.4f}')
```

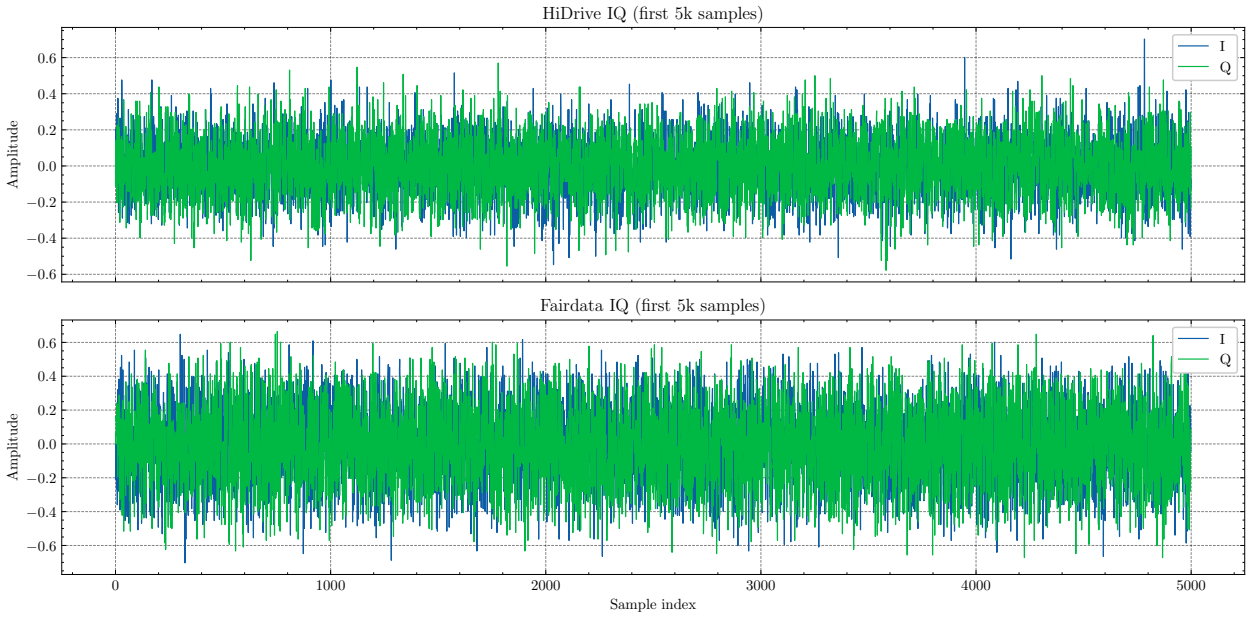
[3]:
```
iq_hidrive = load_iq(RAW_HIDRIVE, SAMPLE_COUNT)
describe_iq(iq_hidrive, 'HiDrive sample')

iq_fairdata = load_iq(RAW_FAIRDATA, SAMPLE_COUNT)
describe_iq(iq_fairdata, 'Fairdata converted')
```

```
HiDrive sample stats (first 2000000 samples):
  Real  min/mean/max/std: -0.8750, -0.0049,  0.8906,  0.1628
  Imag  min/mean/max/std: -0.8438, -0.0050,  0.7891,  0.1626
  RMS magnitude: 0.2302
Fairdata converted stats (first 2000000 samples):
  Real  min/mean/max/std: -0.8438, -0.0033,  0.8516,  0.2284
  Imag  min/mean/max/std: -0.8359, -0.0038,  0.8438,  0.2284
  RMS magnitude: 0.3230
```

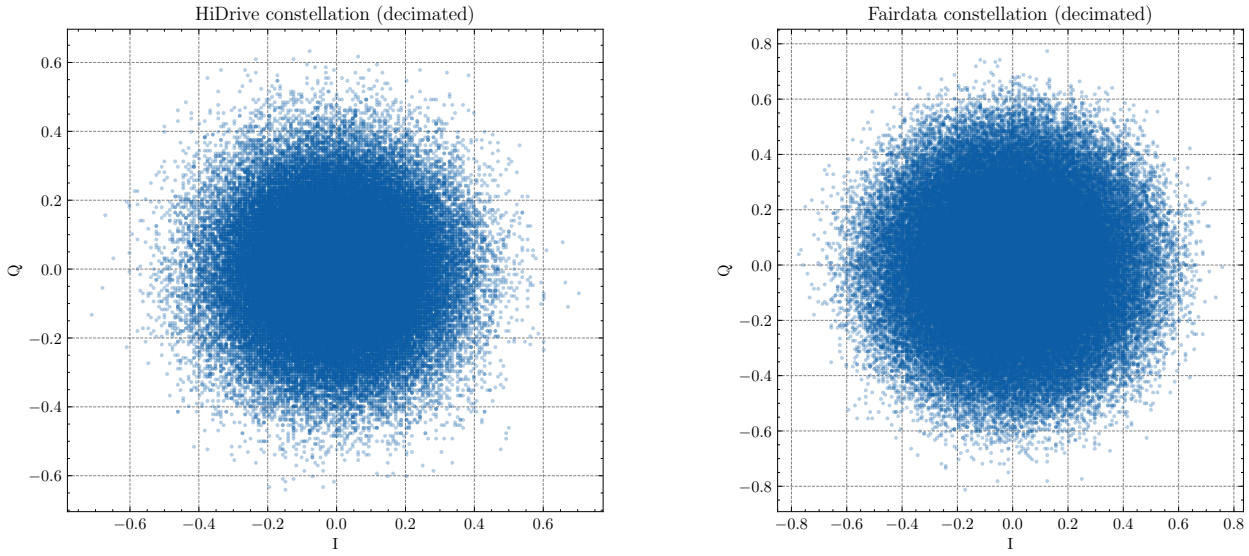
[4]:
```
fig, axes = plt.subplots(1, 2, figsize=(12, 4), sharey=True)
for ax, data, title in zip(axes, [iq_hidrive, iq_fairdata], ['HiDrive',␣
 ↪'Fairdata']):
    ax.hist(data.real, bins=256, alpha=0.7, label='I')
    ax.hist(data.imag, bins=256, alpha=0.7, label='Q')
    ax.set_title(f'{title} histogram')
    ax.set_xlabel('Normalized amplitude')
    ax.set_ylabel('Count')
    ax.legend()
fig.tight_layout()
```



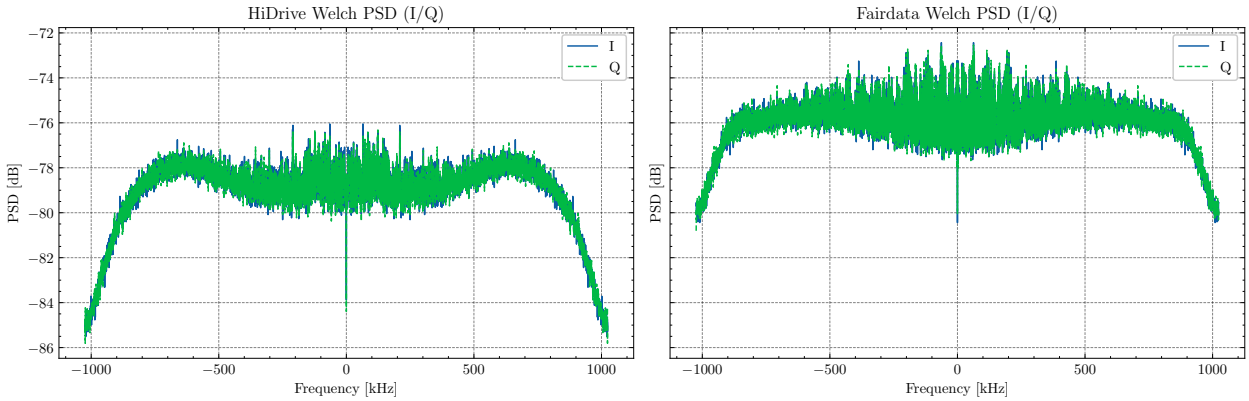
[5]:
```
window = slice(0, 5000)
fig, axes = plt.subplots(2, 1, figsize=(12, 6), sharex=True)
axes[0].plot(iq_hidrive.real[window], label='I', linewidth=0.8)
axes[0].plot(iq_hidrive.imag[window], label='Q', linewidth=0.8)
axes[0].set_title('HiDrive IQ (first 5k samples)')
axes[0].legend(loc='upper right')
axes[0].set_ylabel('Amplitude')
axes[1].plot(iq_fairdata.real[window], label='I', linewidth=0.8)
axes[1].plot(iq_fairdata.imag[window], label='Q', linewidth=0.8)
axes[1].set_title('Fairdata IQ (first 5k samples)')
axes[1].legend(loc='upper right')
axes[1].set_ylabel('Amplitude')
axes[1].set_xlabel('Sample index')
fig.tight_layout()
```



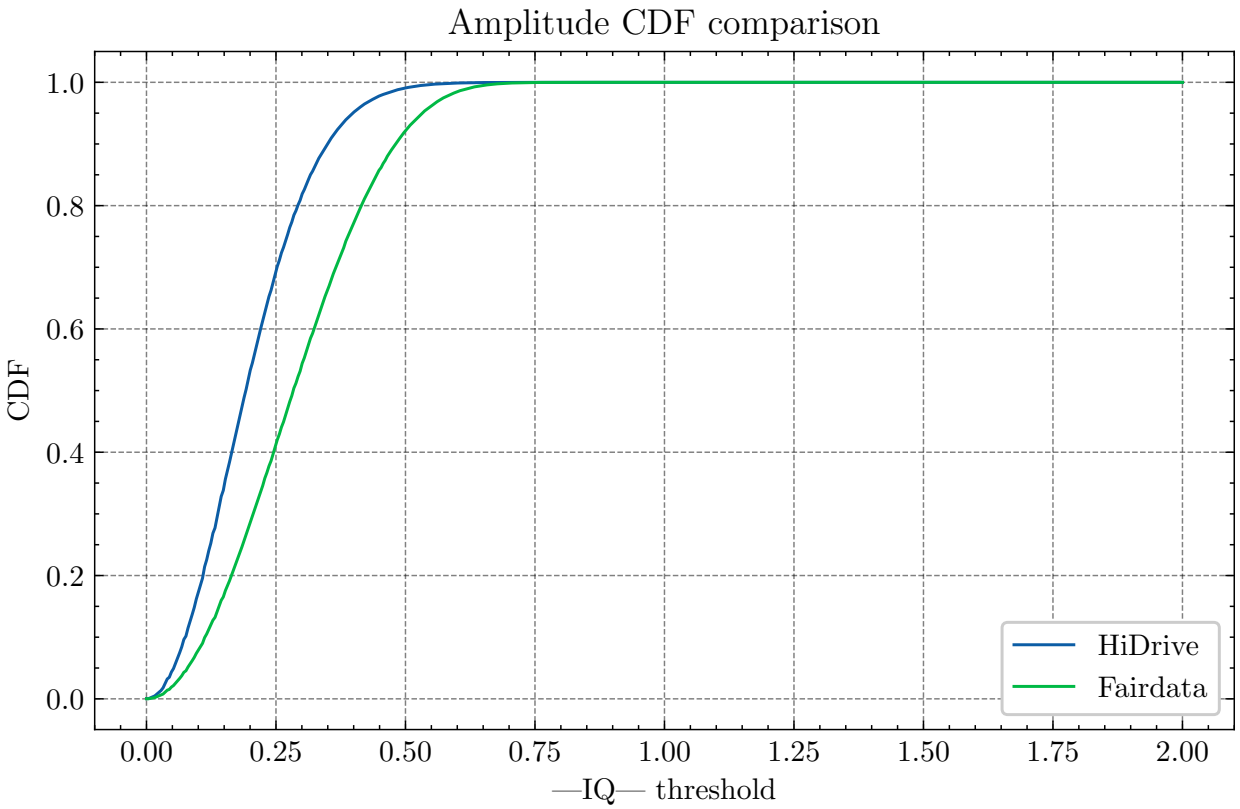
[6]:
```
fig, axes = plt.subplots(1, 2, figsize=(12, 5))
for ax, data, title in zip(axes, [iq_hidrive, iq_fairdata], ['HiDrive',␣
 ↪'Fairdata']):
    ax.scatter(data.real[::20], data.imag[::20], s=2, alpha=0.3)
    ax.set_title(f"{title} constellation (decimated)")
    ax.set_xlabel('I')
    ax.set_ylabel('Q')
    ax.set_aspect('equal', 'box')
fig.tight_layout()
```



[7]:
```
import scipy.signal as sig
win = sig.get_window('hann', 8192)
fig, axes = plt.subplots(1, 2, figsize=(12, 4), sharey=True)
for ax, data, title in zip(axes, [iq_hidrive, iq_fairdata], ['HiDrive',␣
 ↪'Fairdata']):
    f_i, pxx_i = sig.welch(data.real, fs=FS_HZ, window=win, nperseg=8192,␣
 ↪return_onesided=False, detrend='constant')
    f_q, pxx_q = sig.welch(data.imag, fs=FS_HZ, window=win, nperseg=8192,␣
 ↪return_onesided=False, detrend='constant')
    ax.plot(np.fft.fftshift(f_i)/1e3, 10*np.log10(np.fft.
 ↪fftshift(pxx_i)+1e-12), label='I')
    ax.plot(np.fft.fftshift(f_q)/1e3, 10*np.log10(np.fft.
 ↪fftshift(pxx_q)+1e-12), label='Q', linestyle='--')
    ax.set_title(f"{title} Welch PSD (I/Q)")
    ax.set_xlabel('Frequency [kHz]')
    ax.set_ylabel('PSD [dB]')
    ax.legend()
fig.tight_layout()
```



[8]:
```
mag_hidrive = np.abs(iq_hidrive)
mag_fair = np.abs(iq_fairdata)
thresholds = np.linspace(0, 2, 500)
cdf_h = [np.mean(mag_hidrive <= t) for t in thresholds]
cdf_f = [np.mean(mag_fair <= t) for t in thresholds]
fig, ax = plt.subplots(figsize=(6,4))
ax.plot(thresholds, cdf_h, label='HiDrive')
ax.plot(thresholds, cdf_f, label='Fairdata')
ax.set_xlabel('|IQ| threshold')
ax.set_ylabel('CDF')
ax.set_title('Amplitude CDF comparison')
ax.legend()
fig.tight_layout()
```


Amplitude CDF comparison
CDF
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
—IQ— threshold
HiDrive
Fairdata