Efficient Band Occupancy and Modulation Parameter Detection

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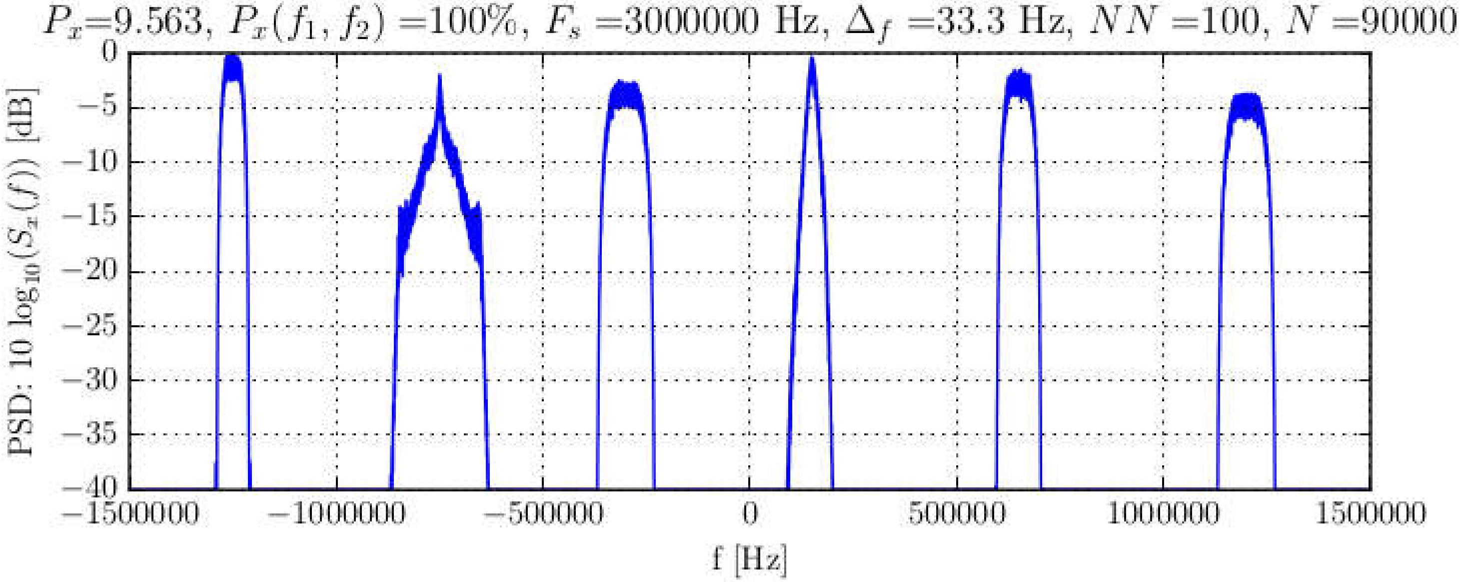
The Problem: Unknown Signals in Freq. Band

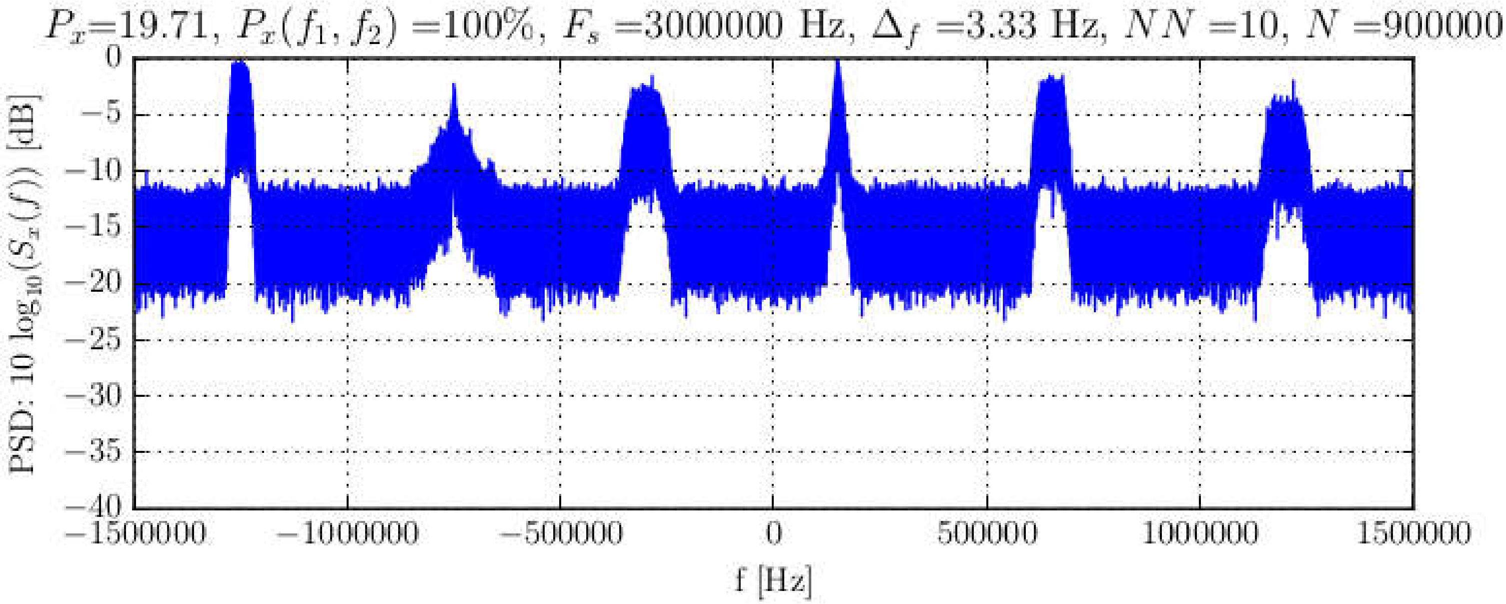


PSD of Noiseless Signals in a 3 MHz Band

Question: How to Find Parameters Efficiently?

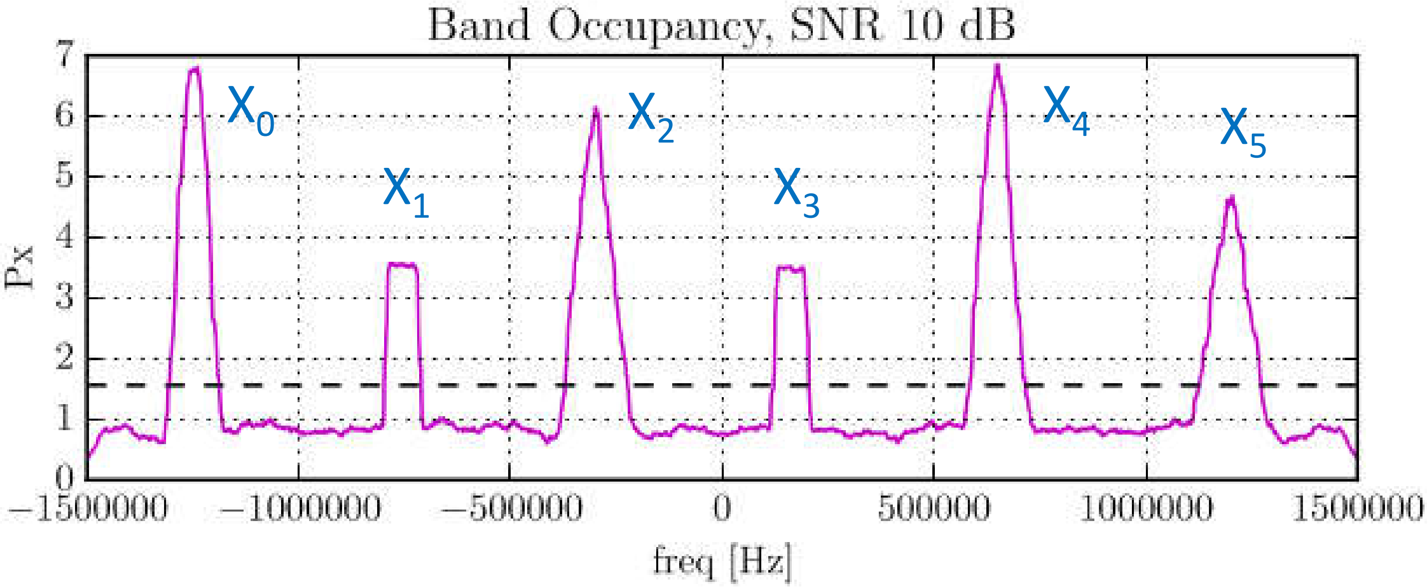
- Intelligent radios: Understand and characterize signals to infer the conditions of the local RF environment (from DARPA's SC2).
- The goal of SC2 (Spectrum Collaboration Challenge) is to find ways to share the RF spectrum dynamically and collaboratively among many users.
- One of the SC2 hurdles asked to "Develop a classifier that can identify the occupied range and type of six simultaneous non-overlapping signals within a 3 MHz bandwidth channel."
- We look at BPSK, QPSK, 8-PSK, 16-QAM, and analog FM signals.

In Real Life Signals are Of Course Noisy



PSD of Signals with SNR~10 dB in 3 MHz Band

Conventional Method: Find Bands, Center Frequencies and Extract Signals Individually



Can use Welch modified periodogram method

Individual Signal Extraction for Finding F_B

- Shift desired signal with center frequency fc to baseband.

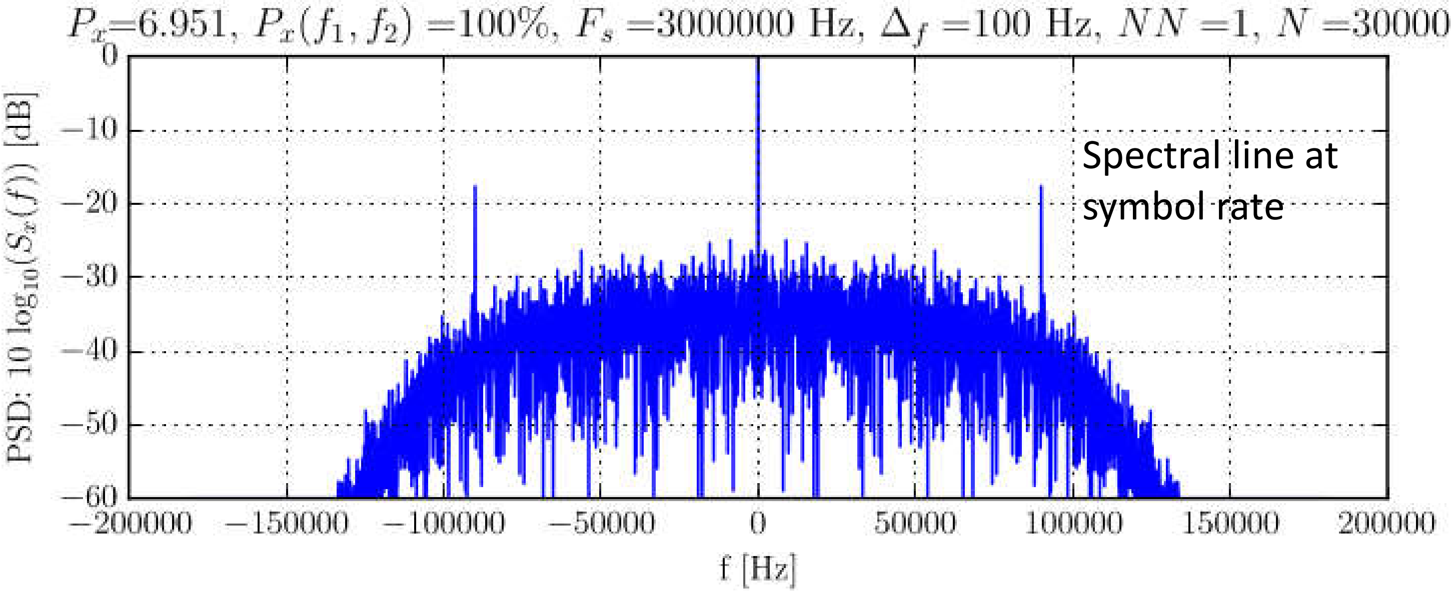
$$x_{BB}(t) = x(t)\, e^{-j2\pi f_c t}$$

- Apply lowpass filtering to remove all other signals

$$s(t) = LPF\{x_{BB}(t)\}$$

- Cannot use polyphase filter bank if symbol rate is unknown because that reduces frequency resolution.
- Then look at PSD of $|s(t)|^2$ to obtain symbol rate F_B.

Example: PSD of Magnitude Squared Signal X_5



$$x_5(t) = s_5(t)\, e^{j2\pi f_{c5} t} \quad \Longrightarrow \quad |x_5(t)|^2 = |s_5(t)|^2$$

Fourier Transform of $|x(t)|^2 = x(t)\, x^*(t)$

$$\int_{-\infty}^{\infty} x(t)\, x^*(t)\, e^{-j2\pi f t}\, dt =$$

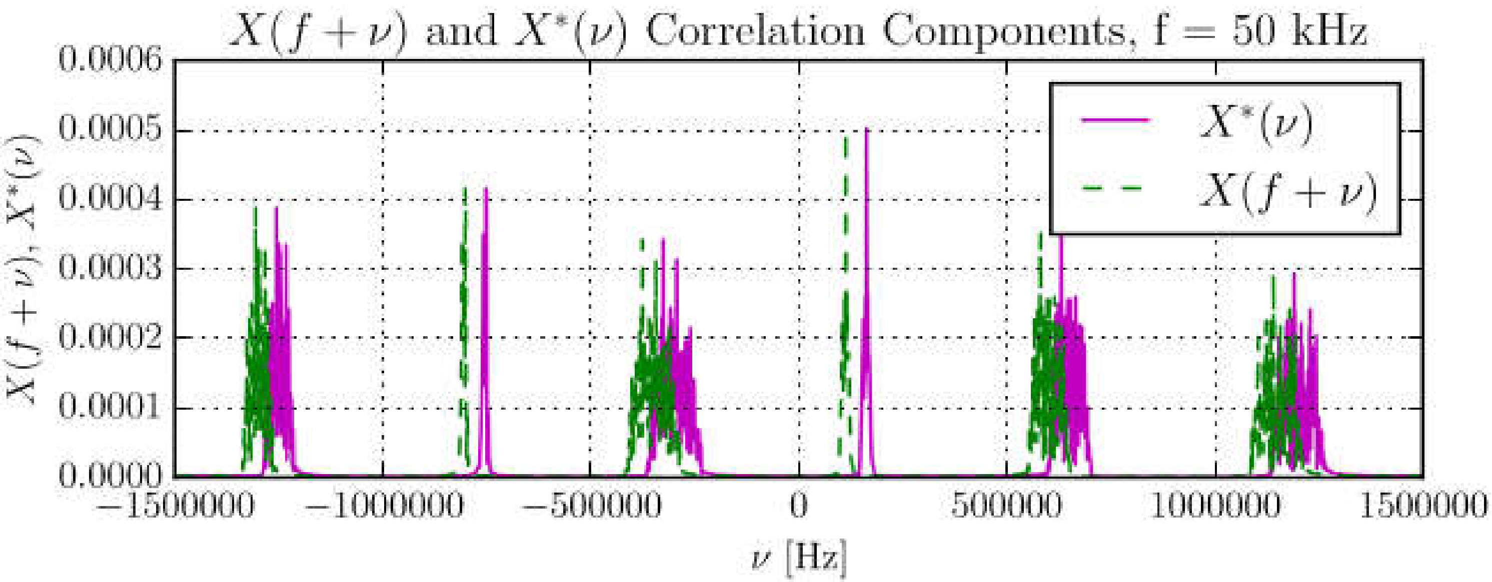
$$= \int_{-\infty}^{\infty} x(t) \int_{-\infty}^{\infty} X^*(\nu)\, e^{-j2\pi\nu t}\, d\nu\, e^{-j2\pi f t}\, dt$$

$$= \int_{-\infty}^{\infty} X^*(\nu) \int_{-\infty}^{\infty} x(t)\, e^{-j2\pi(f+\nu)t}\, dt\, d\nu$$

$$= \int_{-\infty}^{\infty} X(f+\nu)\, X^*(\nu)\, d\nu$$

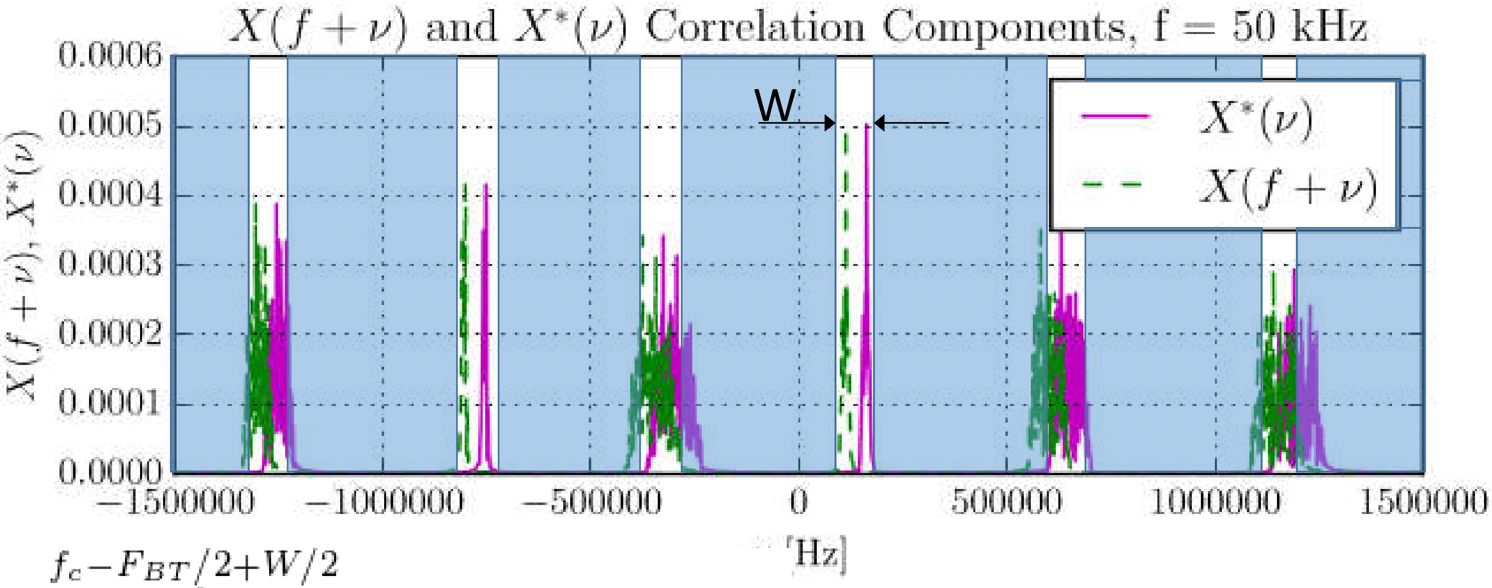
Autocorrelation in frequency domain

Component Spectra for Freq Domain Correlation



$$\int_{-\infty}^{\infty} X(f+\nu)\, X^*(\nu)\, d\nu$$

Bandlimited to W Freq Domain Correlation

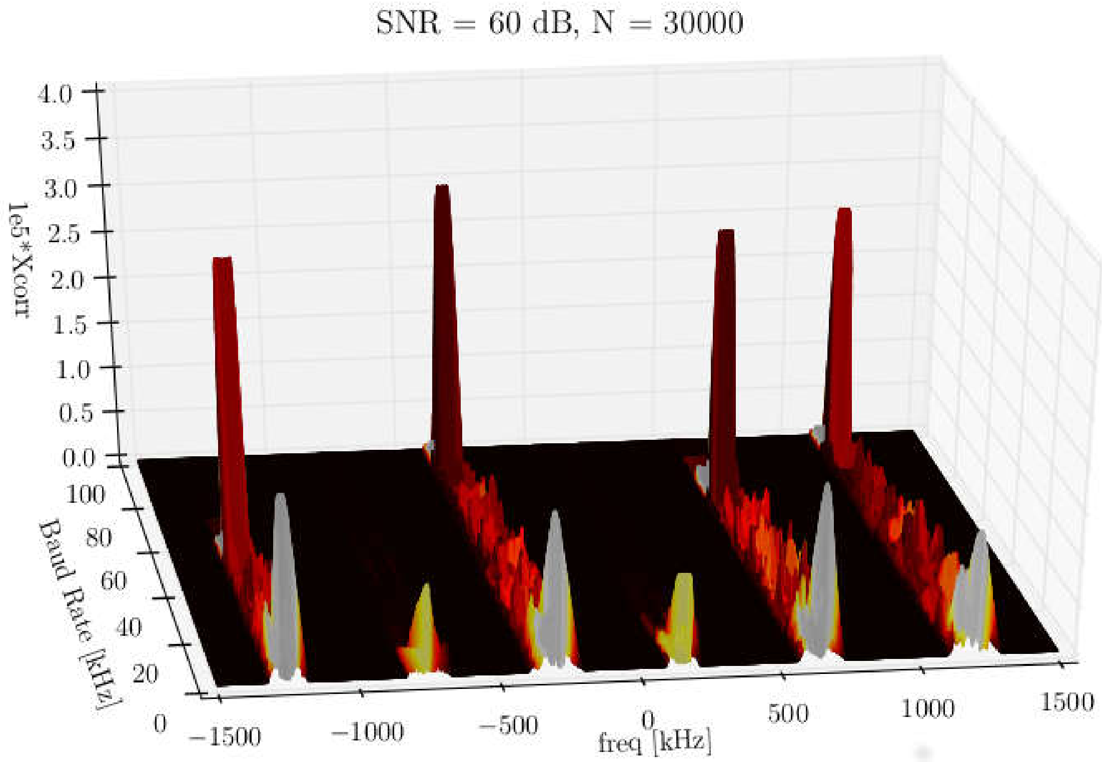


$$\int_{f_c - F_{BT}/2 - W/2}^{f_c - F_{BT}/2 + W/2} X(F_{BT}+\nu)\, X^*(\nu)\, d\nu$$

$f = F_{BT}$

Trial Baud Rate

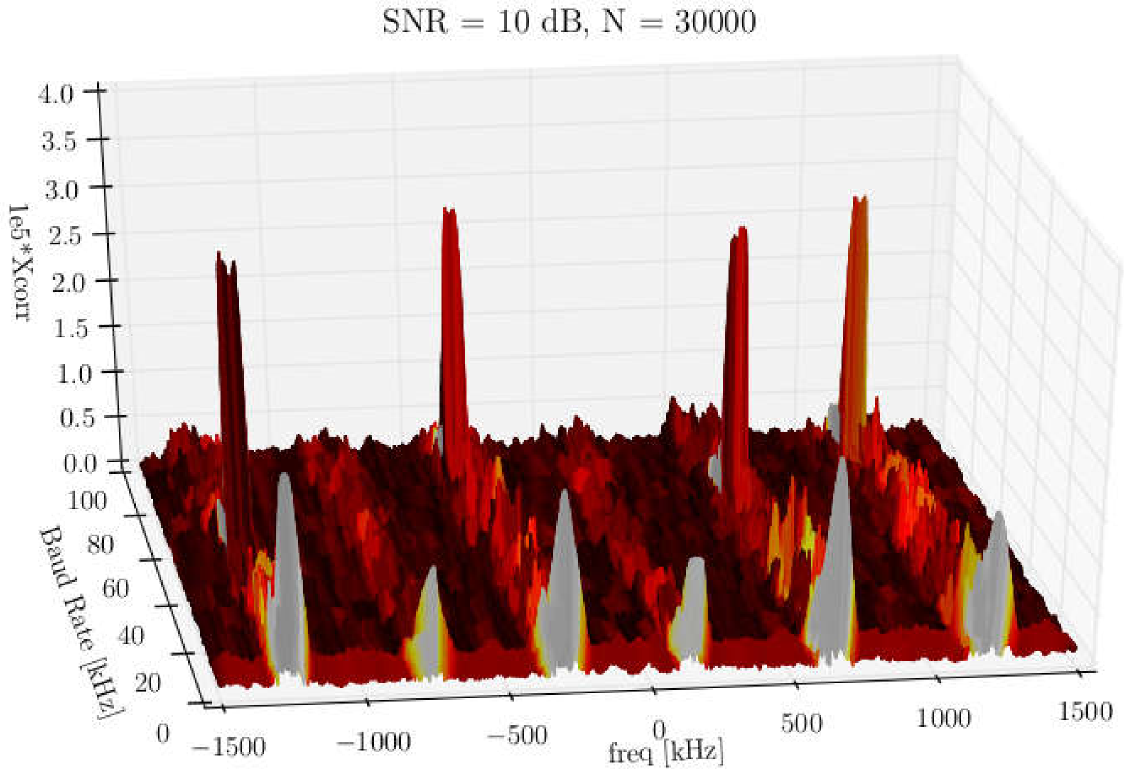
Bands and Symbol Rates, Noiseless Case



F_{BT} (y-axis) is varied from 0 to 100 kHz.

z-axis is correlation

Bands and Symbol Rates, SNR~10 dB

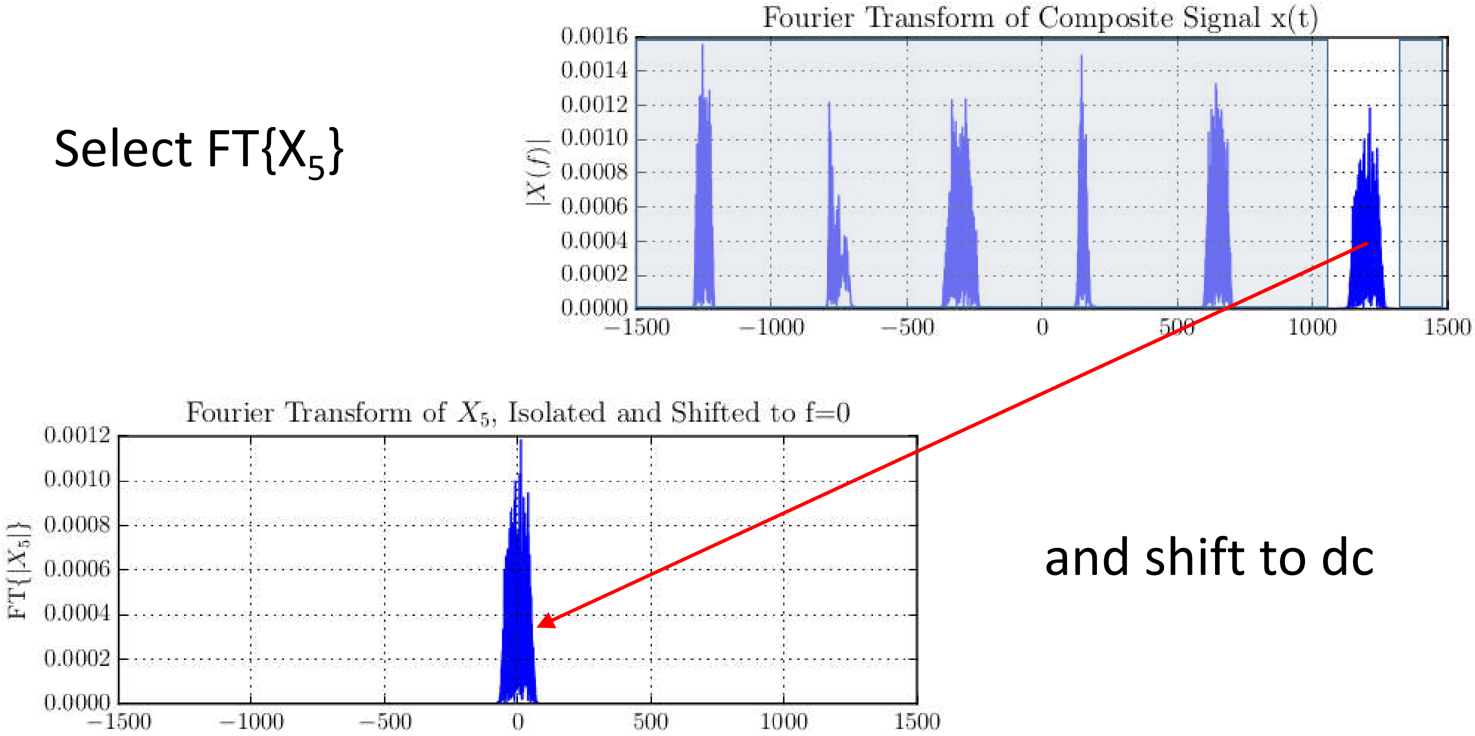


F_{BT} (y-axis) is varied from 0 to 100 kHz.

z-axis is correlation

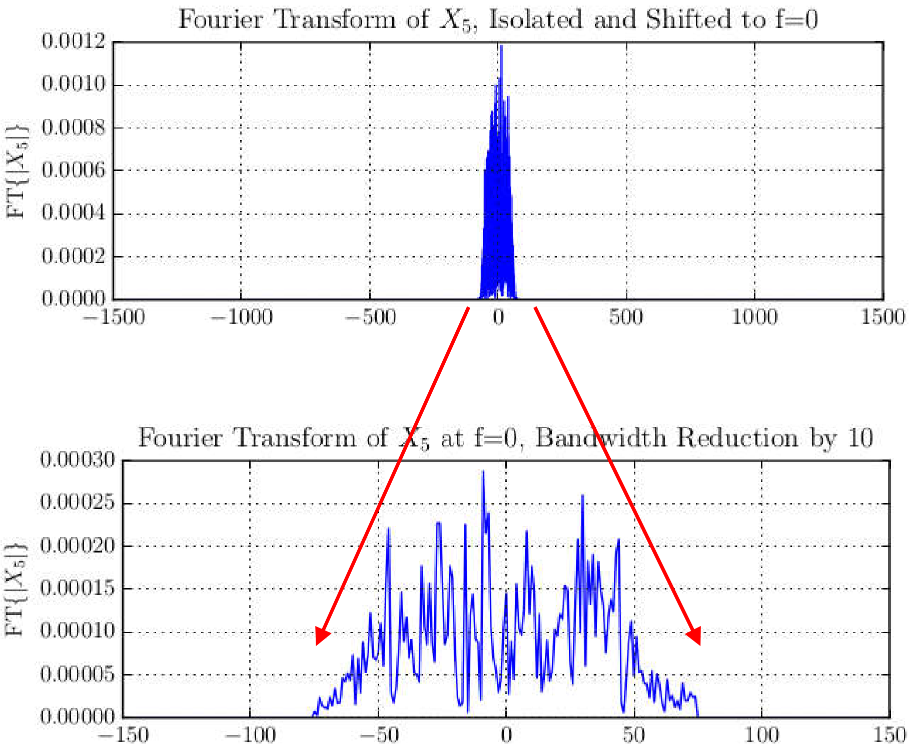
More Modulation Parameters

Select FT{X_5}

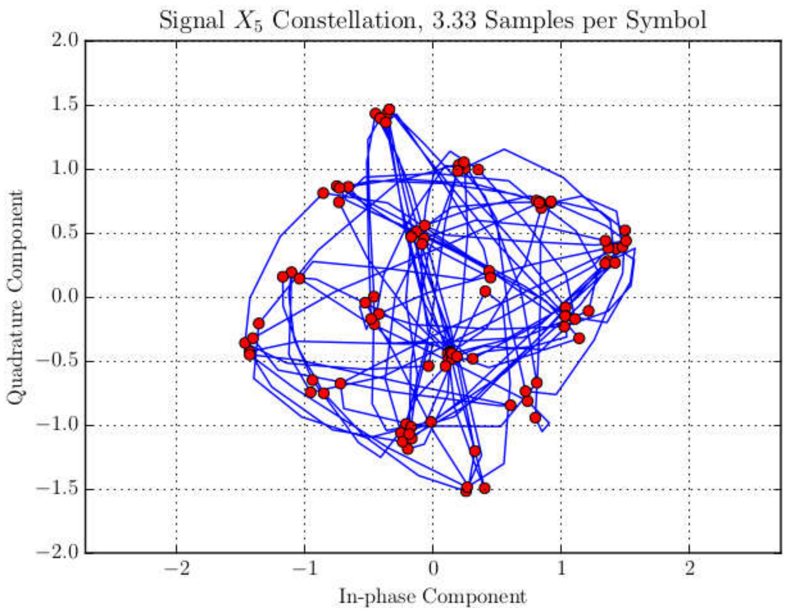


and shift to dc

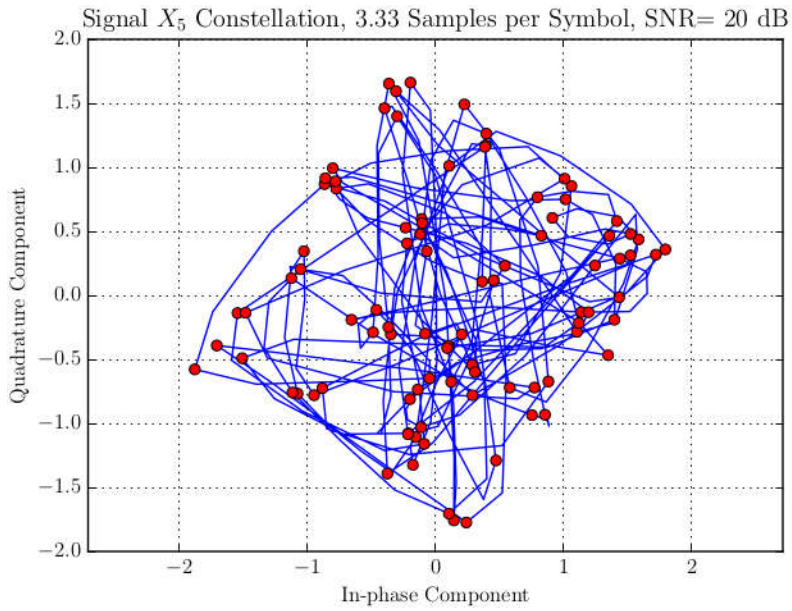
Reduce Bandwidth by Factor of 10



Use IFT to obtain Signal X_5 and its Constellation



Noiseless (RRCf ISI)



20 dB SNR

Computational Effort Comparison

- **Assumptions:**
- Sampling rate F_s = 3 MHz
- Frequency resolution Δf = 100 Hz
- FFT blocklength N = 30000
- Signal bandwidth BW = 100 kHz
- Units of measurement: MAC (multiply-accumulate) instructions
- Both conventional and frequency domain methods require initial FFT of length N to estimate f_{ci} and BW_i of i-th signal

Computational Effort Comparison

Conventional Method

- Shift each signal to baseband

$$x(t)\,e^{-j2\pi f_{ci} t}$$

- Lowpass filter, FIR, cutoff BW/2, $4N^2\Delta_f/BW$ (3.6e6) MACs per signal
- Square each individual baseband signal and compute FFT, $N\log_2 N$ (0.45e6) MACs per signal

Proposed Frequency Domain Method

- Compute

$$\int_{f_x - F_{BT}/2 - W/2}^{f_x - F_{BT}/2 + W/2} X(F_{BT} + \nu)\, X^*(\nu)\, d\nu$$

- Use W = BW, $F_{BT} = BW_i \pm 0.1BW$, $f_x = f_{ci} \pm 0.1 f_{ci}$
- Requires $1.2 \times 0.2 \times (BW/\Delta_f)2$ (2.4e5) MACs per signal
- Note: 4.05e6 = 16.9x2.4e5

Improvement by factor of 16.9

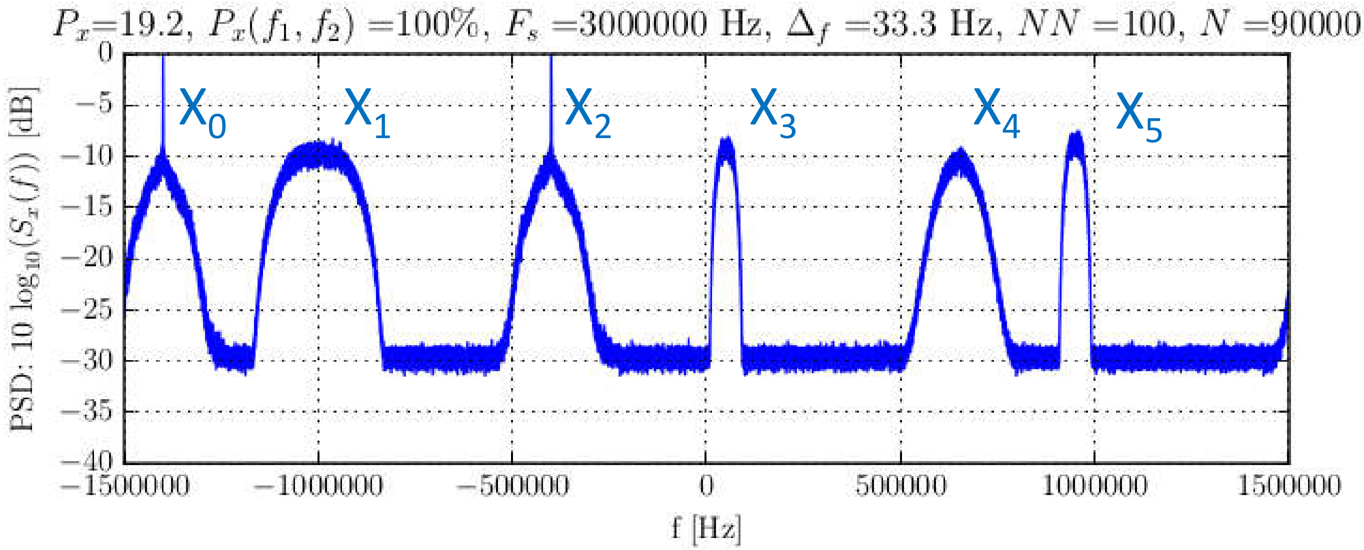
Limitations

- For 100 Hz frequency resolution 10 ms of data is needed. For 20 MHz frequency band, FFT of length >=200,000 needed for either method.
- Conceptual difference:
  - Conventional method produces spectral line at symbol rate F_{Bi}
  - Frequency domain method produces spectral line at $f_{ci} \pm F_{BT}/2$ only if trial symbol rate F_{BT} is close enough to actual rate F_{Bi}.
- Constant envelope modulation (CPM, CPFSK, GMSK) produces signals

$$x(t) = Ae^{j(2\pi f_c t + \phi(t))}$$

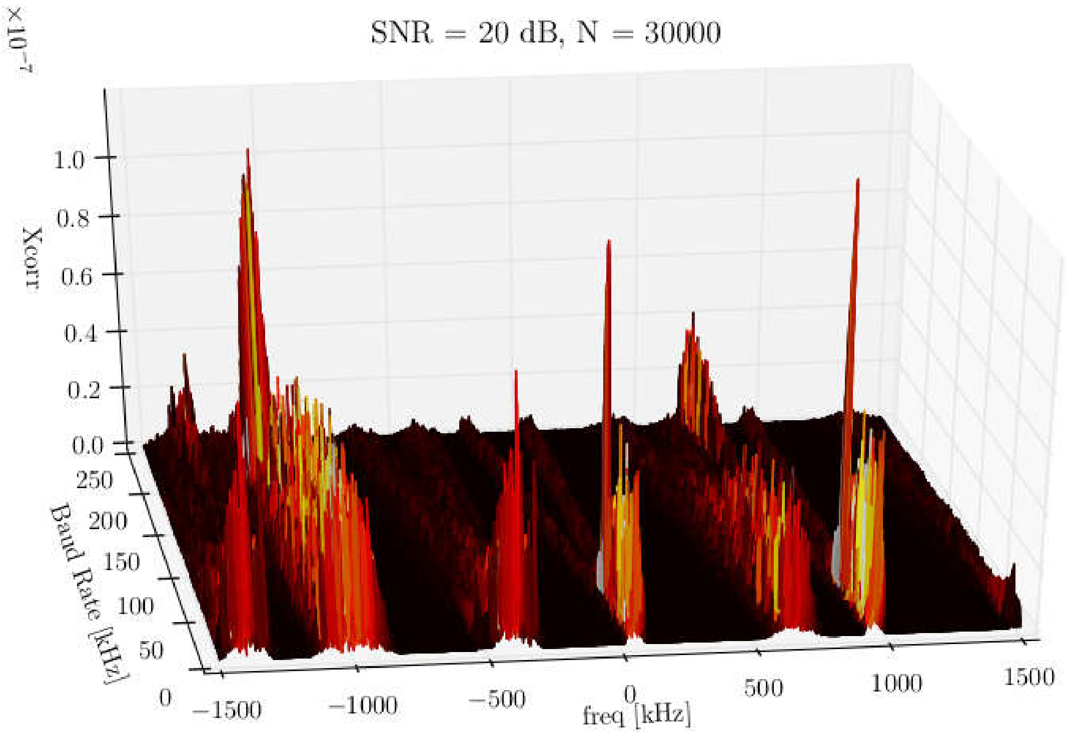
- Magnitude squaring results in $|x(t)|^2 = A^2$ which has no symbol rate information.

Example: Analog FM, QPSK, GMSK Signals



SNR approx. 20 dB

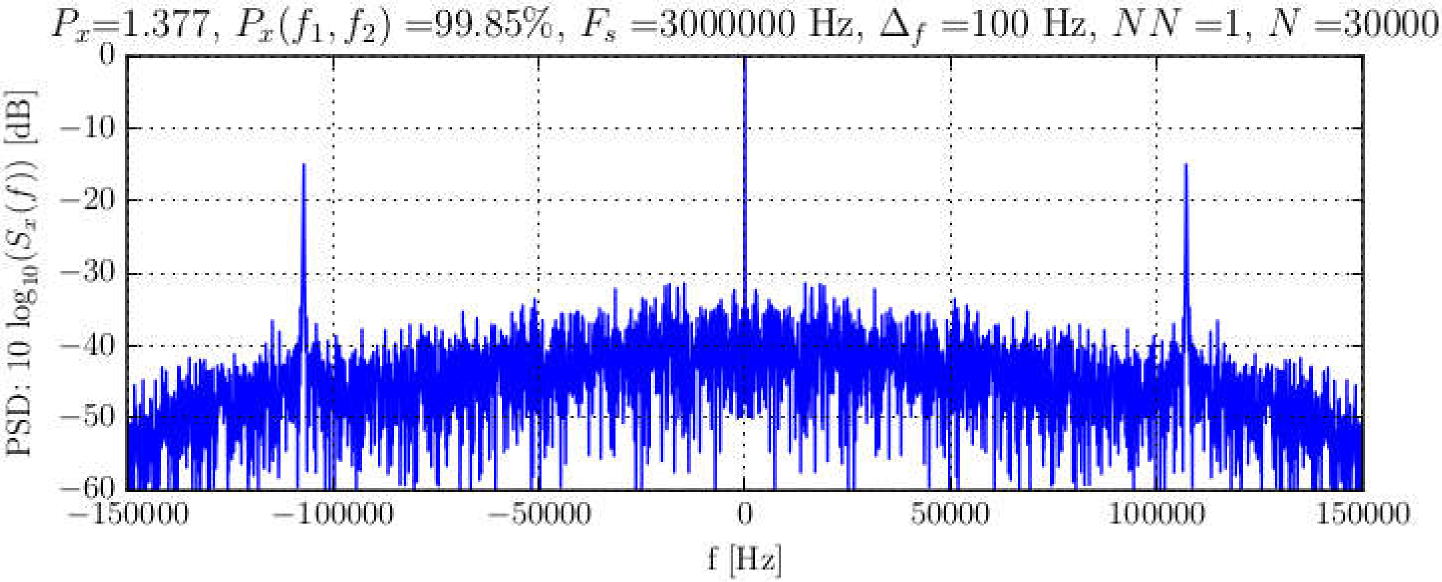
Band Occupancy and Symbol Rates



X_0, X_2 probably analog FM (carrier term)

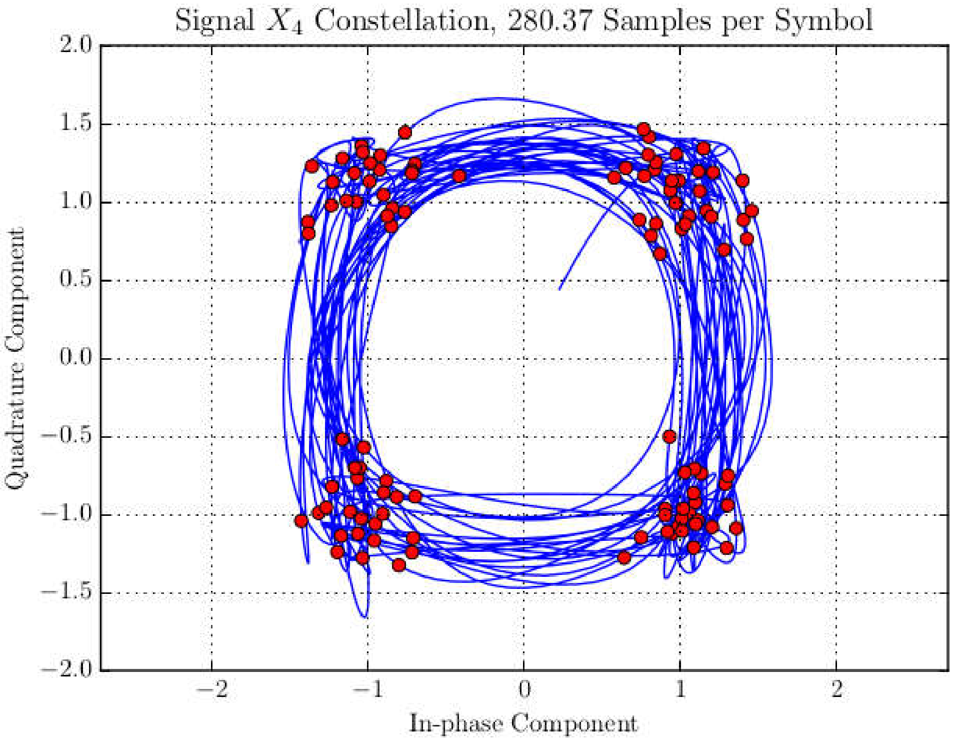
X_4 needs more examination

Convert X_4 to Time Domain Baseband: $s_4(t)$



Look at $[Re\{s_4(t)\}]^2$ to find symbol rate (107 kBaud)

IQ Plot Confirms X_4 as GMSK



Sample Files and Jupyter Notebook

- See https://github.com/mathys2000/BandOccupancyAndModulationDetection

Questions?