Digital Communication Systems Engineering with Software-Defined Radio

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Lecture 21

Knowledge of Signal Structures

- Often we know some of the details behind the signal structure of an intercepted transmission
  - Data rates
  - Modulation scheme
  - Carrier frequency
  - Guard band locations
- Digitally modulated signals possess periodic features that may be implicit or explicit
  - Carrier frequencies and symbol rates can be obtained using square-law devices
  - Cyclic extensions can reveal periodic nature of signal structure

Definition of Cyclostationary Processes

- A *cyclostationary signal* is a signal whose statistics vary periodically with time
- A signal $x(t)$ is wide-sense cyclostationary if its mean and autocorrelation are periodic:

$$R_x(t, \tau) = R_x(t + T_0, \tau), \ \forall t, \tau \quad \text{and} \quad \mu_x(t) = \mu_x(t + T_0)$$

- We can express the periodic signal as a Fourier series:

$$R_x\left(t - \frac{\tau}{2}, t + \frac{\tau}{2}\right) = \sum_{\alpha} R_x^{\alpha}(\tau) e^{-j2\pi\alpha t} \qquad (1)$$

where the cyclic frequency α is equal to $\alpha = m/T_0$

  - The Fourier series is the decomposition of a signal into a summation of contributing frequencies

Spectral Correlation Function Implementation

- The *cyclic autocorrelation function* (CAC) is equal to:

$$R_x^\alpha(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_T x\left(t + \frac{\tau}{2}\right) x^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi\alpha t} dt \qquad (2)$$

  - For $\alpha = 0$, this equation is equal to the traditional autocorrelation of the signal
- Using the CAC, we can derive the *spectral correlation function* (SCF) to be equal to:

$$S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha(\tau) e^{-j2\pi f\tau} d\tau \qquad (3)$$

  - The SCF is a cross correlation between frequency components of the signal separated by $f - \alpha/2$ and $f + \alpha/2$

Formulating a Cyclostationary Detector

- We are interested in computing the correlation coefficients of the SCF, called the *spectral coherence function* (SOF)
- The magnitude of the SOF varies from 0 to 1 and represents strength of second order periodicity within the signal
- The SOF is computed using:

$$C_x^{\alpha}(f) = \frac{S_x^{\alpha}(f)}{\sqrt{S_x^{\alpha}(f-\frac{\alpha}{2})S_x^{\alpha}(f+\frac{\alpha}{2})}} \tag{4}$$

- The SOF contains the spectral features of interest
  - Non-zero frequency components of the signal at various cyclic frequencies
  - Different modulation schemes contain spectral components at different cyclic frequencies

QPSK Spectral Correlation Function

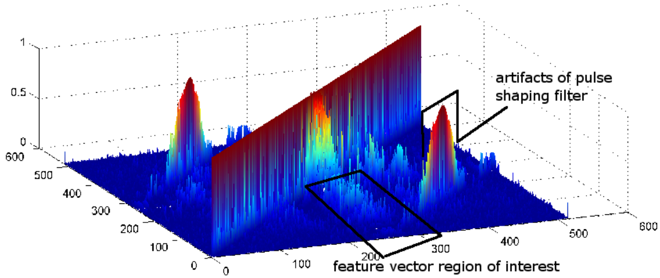

Figure : Spectral Correlation Function of QPSK Modulation with Raised Cosine Filter of $\beta = 0.5$.

M. Calabro. *A Cooperative Spectrum Sensing Network with Signal Classification Capabilities.* Major Qualifying Project Report, Worcester Polytechnic Institute, 2010.

QPSK Spectral Correlation Function

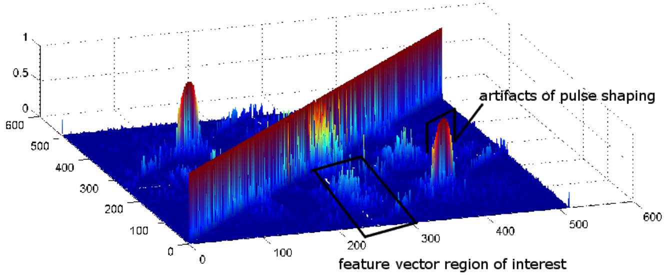

Figure : Spectral Correlation Function of QPSK Modulation with Raised Cosine Filter of $\beta = 0.3$.

M. Calabro. *A Cooperative Spectrum Sensing Network with Signal Classification Capabilities*. Major Qualifying Project Report, Worcester Polytechnic Institute, 2010.

QPSK Spectral Correlation Function

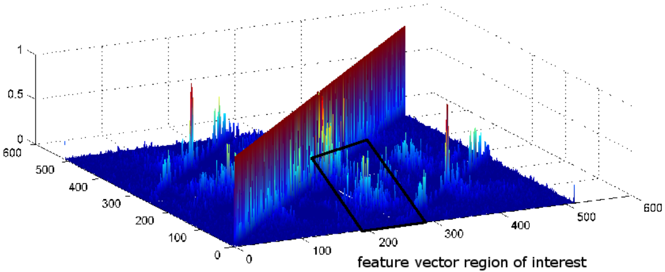

Figure : Spectral Correlation Function of QPSK Modulation with Raised Cosine Filter of $\beta = 0.0$.

M. Calabro. *A Cooperative Spectrum Sensing Network with Signal Classification Capabilities*. Major Qualifying Project Report, Worcester Polytechnic Institute, 2010.

AWGN Spectral Correlation Function

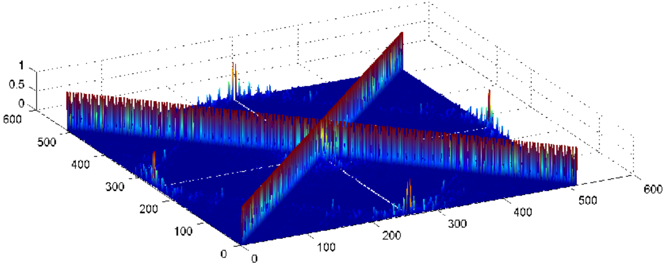

Figure : Spectral Correlation Function of an Additive White Gaussian Noise Signal.

M. Calabro. *A Cooperative Spectrum Sensing Network with Signal Classification Capabilities*. Major Qualifying Project Report, Worcester Polytechnic Institute, 2010.

FSK Spectral Correlation Function

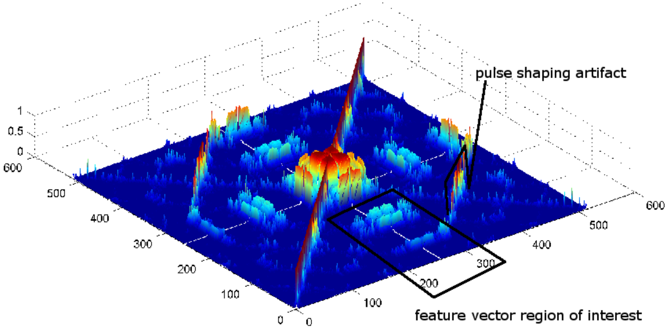

Figure : Spectral Correlation Function of FSK Modulation with Raised Cosine Filter of $\beta = 0.3$.

M. Calabro. *A Cooperative Spectrum Sensing Network with Signal Classification Capabilities*. Major Qualifying Project Report, Worcester Polytechnic Institute, 2010.

Bi-Frequency Spectral Correlation Functions

- Cyclostationary detectors draw their conclusions from the periodic statistics of a signal
  - Major advantage over other detection schemes
  - These statistics are calculated at the receiver and assume no prior knowledge of the transmission
- Examining bi-frequency plane of each kind of digital modulation has distinct features
  - These features can be extracted to create a profile
  - Note that modulation schemes belonging to the same family exhibit cyclic frequency components on the same cyclic frequencies $\rightarrow$ second order statistics appear similar
- Roll-off factor β of pulse shaping filter introduces redundancy into the signal
  - More excess bandwidth introduced by the pulse-shaping filter $\rightarrow$ more signal redundancy $\rightarrow$ clearer spectral features

Advantages of Cyclostationary Detectors

- The capability to accomplish this signal classification as a natural extension of the cyclic detector is a major advantage of cyclostationary signal analysis
- Cyclic detectors are robust to multipath, white noise, and can practically function with little to no prior information about the signal of interest