PERFORMANCE ANALYSIS OF A HARDWARE IMPLEMENTED COMPLEX SIGNAL KURTOSIS RADIO-FREQUENCY INTERFERENCE DETECTOR

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUC</td>
<td>Area Under Curve</td>
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<tr>
<td>CSK</td>
<td>Complex Signal Kurtosis</td>
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<tr>
<td>CW</td>
<td>Continuous Wave</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
</tr>
<tr>
<td>DVB-S2</td>
<td>Digital Video Broadcasting - Satellite - Second Generation</td>
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<tr>
<td>FB</td>
<td>Full Band</td>
</tr>
<tr>
<td>Gbps</td>
<td>Billions of Bits per Second</td>
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<tr>
<td>INR</td>
<td>Interference to Noise Ratio</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>RFI</td>
<td>Radio Frequency Interference</td>
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<td>ROC</td>
<td>Receiver Operating Characteristic</td>
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<td>RSK</td>
<td>Real Signal Kurtosis</td>
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<td>SB</td>
<td>Sub Band</td>
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Motivation

RFI compromises quality of science products.

Spectrum is becoming crowded and shared.

Hardware capabilities allow for digital radiometry.

Need more sensitive detectors for wide-band interference.
Real Signal Kurtosis

Given a complex baseband signal $z(n) = I(n) + jQ(n)$, the fourth standardized moment is computed independently for both the real and imaginary vectors, I and Q, as was used in SMAP[3].

$$RSK\downarrow I = \frac{\mathbb{E}[(I-\mathbb{E}[I])^4]}{(\mathbb{E}[(I-\mathbb{E}[I])]^2 - 3}, \quad RSK\downarrow Q = \frac{\mathbb{E}[(Q-\mathbb{E}[Q])^4]}{(\mathbb{E}[(Q-\mathbb{E}[Q])]^2 - 3}

The test statistic, RSK (Real Signal Kurtosis), is then defined as

$$RSK = |RSK\downarrow I| + |RSK\downarrow Q|/2$$
Complex Signal Kurtosis

Given a complex baseband signal \( z(n) = I(n) + jQ(n) \), moments \( \alpha_{\ell,m} \) of \( z(n) \) are defined as

\[
\alpha_{\ell,m} = \mathbb{E}[(z - \mathbb{E}[z])^{\ell} (z - \mathbb{E}[z])^{m*}] , \ell, m \in \mathbb{R}_{\geq 0}
\]

With \( \sigma^2 = \alpha_{1,1} \), Standardized moments \( \varphi_{\ell,m} \) can then be found as

\[
\varphi_{\ell,m} = \alpha_{\ell,m} / \sigma^{\ell+m}
\]

Leading to the CSK (Complex Signal Kurtosis) RFI test statistic used [1,2].

\[
C_{\ell} = \varphi_{2,2} - 2 - |\varphi_{2,0}|^2 / 1 + 1/2 |\varphi_{2,0}|^2
\]
Moment Calculation

Using the nomenclature for raw moments of the rth power, \( m_I^{r} = \mathbb{E}[I^r] \), \( m_Q^{r} = \mathbb{E}[Q^r] \), full band moments produced to compute kurtosis include

\[ \{ m_I^r , m_Q^r \} , \quad r \in \{1,2,3,4\} \]

Additionally, the following cross complex moments are generated

\[ \{ mIQ, mIQQ, mIIQ, mIIQQ \} \]

In the case of sub-banding, all 12 moments for each polarization are produced for every sub-band.
Methodology

Simulation
- Noise + RFI Test Signals
- Python Algorithms
- Performance Evaluation

Hardware Verification
- COMPUTER
  - Matlab
  - Python
- AWG
- FPGA Firmware
- ROACH2
  - ADC
  - Ethernet (10 Gbps)

Performance Evaluation
- Matlab Simulink Xilinx
- Python
Simulation Results

![Simulation - ROC Curves](image1)

- CW RFI, N = 20000

![Simulated Pulsed Narrow Band at INR = -20dB](image2)

- Full Band RSK
- Full Band CSK
- Sub Band RSK
- Sub Band CSK

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Simulation Results

Simulated Performance, RSK and CSK, N = 20000

Area Under ROC Curve

INR

Narrow Band d=0.01 SB CSK | INR = -27
Narrow Band d=0.01 SB RSK | INR = -26.4
Narrow Band d=0.01 FB CSK | INR = -19
Narrow Band d=0.01 FB RSK | INR = -18.4
Narrow Band d=1 SB CSK | INR = -15.4
Narrow Band d=1 SB RSK | INR = -13.3
Narrow Band d=1 FB CSK | INR = -8.47
DVB-S2 d=1 SB CSK | INR = -8.15
DVB-S2 d=1 FB CSK | INR = -7.89
Narrow Band d=1 FB RSK | INR = -7.65
DVB-S2 d=1 FB RSK | INR = -6.93
DVB-S2 d=1 SB RSK | INR = -4.84
Hardware Results

Hardware ROC, Wideband RFI, N = 20000

Hardware ROC, Narrowband RFI, N = 20000
Hardware Results

Hardware Performance, RSK and CSK, N = 20000

Area Under ROC Curve vs INR for Narrow and Wide Band CSK and RSK.
Conclusions

CSK (*Complex Signal Kurtosis*) provides a better detection rate than real signal kurtosis.

Interference becomes detectable at an INR (*Interference to Noise Ratio*) of 2dB lower than what can be detected using RSK (*Real Signal Kurtosis*).

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References

