Interference Mitigation Techniques

Steve Ellingson

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Sydney, Australia

http://est.eng.ohio-state.edu/steve
ellingson.19g@osu.edu

1320 Kinnear Rd, Columbus, OH 43212
The Ohio State University Electronic Science Laboratory
- Combined techniques — the future (think system...)  
- Post-processing, off-line techniques — also important  
- Pre-processing, potentially real-time, techniques — the focus of this talk  
- RFI suppression approaches:  
  - Self-generated RFI (e.g., spurious signals, digital harmonics)  
  - Terrestrial systems (e.g., broadcast: mobile radio)  
  - Satellites  

Interference-to-noise ratio (INR) < SNR, due to: it is becoming important to be able to make measurements when  

- Often, observations are done in multiple domains simultaneously  
- Space domain (power/angle): surveying, interferometry  
- Time domain (power/time): pulsars, GRB's, etc.  
- Frequency domain (power/bandwidth): continuum, spectroscopy  

At very low signal-to-noise ratio (SNR) in: radio astronomy seeks to measure power spectral density (PSD)  

Introduction
Interference Mitigation Strategies

- Windowed BF – Tradeoff beamwidth for sidelobe reduction
- FFT beamforming – multiple beams

Arrays: Convolutional beamforming (CBF) – single beam

- A large dish is itself a spatial filter
  
  Space Domain *

- Bandpass filters implemented in receivers (analog, digital)
  
  Frequency Domain *

- Time gating (e.g., radar evasion)
  
  Time Domain *

Implementations

- Simple: Not adaptive, no RFI information required to implement
- Define region of interest, and suppress everything outside that region
- Assumes sources and RFI exist in separate freq-time-space regions

- Fixed Filtering
All domains: parametric methods, eigenspace methods

- Constrained power minimization (CPM) – e.g., MV
- Deterministic Nulling – Force pattern nulls (NFRA)

Space domain *

- Notch filtering, including analog and FFT methods

Frequency domain *

- Blanking (similar to gating, but requires detection)

Time domain *

- Implementations:

  Non-overlapping source PSD may be distorted ("toxic")
- Overlapping source PSD is obliteratable;
- Moderate complexity: Adaptive, location of RF in freq-time-space required
- Selectively discards affected portions inside region-of-interest
- Assumes sources and RF in the same freq-time-space region, but do not overlap

Interference Mitigation Strategies
parametric methods, eigenstructure methods
* Space: Minimum mean-square-error (MSE), RLS/LMS,
parametric methods, eigenstructure methods
* Time: Minimum mean-square-error (MSE), RLS/LMS,

Implementations:
- Considerations: Increased potential for backfire – Noise injection, etc.
- High complexity: Adaptive, high-quality RF waveform information required
- RF is estimated and subtracted from original data
- Assumes sources and RF are overlapped

3 Cancelling

Interference Mitigation Strategies
- Increasing degrees of freedom without increasing number of antennas
- Bandwidth expansion for phased arrays (required for wideband nulls)

Some applications:

Example: Joint space-time filter:

Multiple domains can be processed jointly, with synergistic effect.

For each time (frequency) domain RF suppression algorithm:

Space-Time Duality
Filter response can be further tailored by using constraints at various frequencies/directions.

In which only the desired signal is present, the response $x$ for the special case

$$\|\phi \| v$$

Solution is $I (C B F)$

- Simplest beamformer maximizes $S$ in direction with constraint $\phi$
- Simplest bandpass filter maximizes $S$ at frequency $\phi$ with constraint $I = \| \phi \|$
- Examples:

$$N \times N \{ x x \} = H \text{ Temporal/spatial covariance matrix}$$

$$m H m = \{ \phi \phi \} = S \text{ Output power}$$

- $m$ is the "weight vector" (defines filter response)
- Given filter $\phi$

Single-Domain Non-Adaptive Filters
and the number of taps and delays (tapped-delay line case).

Resolvability depends on the number of antennas and geometry (array case).

- In theory, can null up to \( N - 1 \) resolvable interferers.

- E.g., RFI in main beam when array has calibration errors.
  - Tends to null desired signal under certain conditions.

- Sidelobes tend to change from update to update.

- "Pattern Rumble" property: Only one point on pattern is constrained.
  - "Power Inversion" property: Depth of null \( \propto \text{INR} \)

- In this application, \( \mathbf{v} \) is sometimes referred to as the "quiescent weight vector".

\[
\mathbf{v}_1^H \mathbf{H} \propto \frac{\mathbf{v}_1^H \mathbf{H} \mathbf{v}}{\mathbf{v}_1^H \mathbf{H} \mathbf{v}} = \mathbf{m}
\]

Solution is known as "Minimum Variance" (MV).

This form also known as "Minimum Variance" (MV).

Minimizes \( S(\phi) \) with a constraint on the response that \( \mathbf{m} \) has

Constrained Power Minimization (CPM)
As \( d(t) \) becomes less correlated, problems emerge.

However, one must know enough about the interference to generate a reasonable

- Array calibration not required!

- MSE identities signals by their temporal - not spatial - structure.

- and subtract the output from the input.

- Simply select \( d(t) \) to be correlated with the interference.

- For radio astronomy use, this algorithm is easily refreshed as a canceler:

\[
\{ \frac{d(t)}{x(t)} \} = \mathbf{F}^{-1} \mathbf{H} \mathbf{x}(t-\tau) \]

- Solution is \( \mathbf{m} \), the "reference correlation vector."

- and hopefully uncorrelated with any interference.

- where \( d(t) \) is a "reference signal" which is highly correlated with the desired signal.

\[
\{ \frac{\mathbf{x}(t)}{x(t)} \} \}

- Find \( \mathbf{m} \) that minimizes the MSE (MSE)

\[
\begin{align*}
\text{Minimum Mean Square Error (MSE)}
\end{align*}
\]
Other Pitfalls of CPM/MSME
A typical procedure using parametric techniques:

1. Assume a model for the RFI in terms of a small number of variables.
2. Acquire a block of data.
3. Use the data block to calculate the value of each variable (‘parameter estimation’).
4. Synthesize a copy of the RFI based on the model and the estimated parameters.
5. Subtract synthesized RFI from original data.

A. MUltiple SIgnal Classification (USIC); ESPRIT, Maximum Likelihood (ML), many other possible techniques.

Motivation: Potential for better resolution and dynamic range.

Improve Reference Signal InR

Potential, model dependence, potential for outliers (may not be robust).

Pitfalls:

Applicable to any single- or multidomain strategy

Parametric Techniques
- Sensitivity to INR > 1
- Complete lack of signal waveform information
  (unlike INR, INR vs
- Large bandwidth (rarely may need to be "time" as opposed to "phasel"

Unique problems for radio astronomy are

<table>
<thead>
<tr>
<th>Interferer</th>
<th>SIR</th>
<th>SNR</th>
<th>Waveform</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not a concern</td>
<td>1</td>
<td>1</td>
<td>Usually &lt;</td>
<td>10^3 Hz</td>
</tr>
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</tbody>
</table>

Yes, with caveats:

**IS Research From Other Fields Aplicable?**
There are certainly others...

- Sinusoidal estimation & subtraction (pillking) (OSU)
- Any wideband digital output:
  - Axi. beam-forming techniques to improve ref. signal INR (SI'Osu)
  - Time-domain MSE cancelling at beamformer output (SI)
- Large arrays of narrowbeam elements (e.g., INT):
  - Subspace-tracking spatial projections (OSU/NERA)
- Large arrays of broadbeam elements (e.g., LOFAR, Argus):
  - Time-frequency excision (blanking) (Westerbork/Dept)
- Interferometry:
  - Consider parametric reference signal generation to improve ref. signal INR?
  - Time-domain MSE cancelling at IF (NRAC)

Some Promising Techniques
RFI suppression cannot be simply an "add-on"

For SKA-class instruments, system integration will be critical.

RFI work in other fields is relevant, but not directly applicable to radio astronomy

and difficult with low INR

In radio astronomy, accurate estimation of interference will be important,
locally estimated

- If given a choice, fight RFI in the domains in which it can be most easily
measurement domains and the nature of the RFI should be taken into account

- However, some guiding principles seem clear:

Neither has this task touched on all the possibilities

There is no single best RFI suppression technique

Closing Remarks