Capabilities & Limitations of Adaptive Canceling for Microwave Radiometry

IGARSS 2002

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Introduction

• Much interest in expanding the bandwidth of passive microwave radiometers beyond the existing protected allocations

• Problem: Radio frequency interference (RFI) can be severe in the spectral regions bordering these bands

• To achieve 100 MHz bandwidth at L-Band, RFI mitigation techniques are required

• Such techniques could also be helpful in dealing with RFI in other bands
“Traditional” RFI Mitigation Techniques

• Regulation / Frequency coordination
  • Already not enough spectrum

• Avoidance of contaminated frequency bands & time periods
  • Not always possible

• Analog bandpass filtering / High dynamic range receivers
  • Not effective against interference in passband

• Data editing
  • In many situations, an unacceptable amount of data is lost
  • Time consuming for large data sets
  • Potential introduction of observer bias
Emerging RFI Mitigation Techniques

- Regulation / Frequency Coordination
- Avoidance of contaminated frequency bands and time periods
- Analog filtering / High dynamic range receivers

Predetection Signal Processing
- **Excision**: (“cutting out”) e.g., pulse blanking, FFT bin blanking
- **Canceling**: Subtracting the RFI from the predetection data → “Look through” capability

Postdetection Signal Processing (arrays)
- Post-correlation & Cross-spectral techniques

Data editing

Real-time signal processing

Topic of this talk
Adaptive Canceling Concept

Desired signal (noise)  
RFI  
Undesired noise

\[ x(t) = s(t) + z(t) + n_x(t) \]

Estimates and subtracts \( z(t) \)

Separate signal (possibly from another sensor) having:
(1) \( z(t) \) with high interference-to-noise ratio (INR), and
(2) \( s(t) \) with low (preferably zero) signal-to-noise ratio (SNR)

- Many, many signal processing algorithms fall in this category
A Simple - But Important - Special Case

• Let the RFI be a single sinusoid in AWGN:
  \[ z(t) = A \exp\{ j\omega t \} \quad (A \text{ is complex-valued}) \]

• Note that the parameters \( A \) and \( \omega \) completely describe the signal

• Given \( \omega \), \( A \) can be estimated from \( L \) samples of \( x(t) \) as follows:
  • Define: \( Z(\omega) = \sum_{k=1}^{L} [x(t_k) \exp\{ -j\omega t_k \}] \)
  • Then: Best estimate of \(|A|\) is \(|Z(\omega)|/ L\)
  • Best estimate of \( \angle A \) is \( \arctan[ \text{Im}\{Z(\omega)\} / \text{Re}\{Z(\omega)\} ] \)

• This is important because many man-made signals look like sinusoids, especially when observed over short time frames at high sample rates
Case 1: Ideal Canceler for Sinusoidal RFI

- Assuming (for the moment) that reference channel response is known and $\text{INR}_r \gg \text{INR}_p$

- Assumptions useful here because results will tend to correspond to upper bound of performance for other cases
Performance in Case 1

RFI Suppression

\[ = \text{INR}_r L \]

Assuming noise is statistically-independent between samples
Type 2: Canceler for Unknown Ref. Ch. Response

- Assuming (for the moment) that \( d(t) = H_{dz} x(t) \); i.e., Ref. ch. response is known to within a complex constant

- Now must estimate \( H_{dz} \) as well; possible by cross-correlation
Performance in Case 2, $\text{INR}_p = \infty$

RFI Suppression

$= \text{INR}_i \frac{L}{4}$
Performance in Case 2, $\text{INR}_p=30$ dB

RFI Suppression $\leq \text{INR}_p L$
Case 3: Canceler for Unknown RFI Waveform

- Note: This is a 1-tap adaptive filter

- Since the stimulus is a sinusoid, higher-order adaptive filtering does not improve RFI suppression (only effect is to reduce noise power)
Performance of Type 3 Canceler, $\text{INR}_p = \infty$

Canceler becomes ineffective as $\text{INR}_r \to 1$ regardless of $L$
Summary

- If the RFI waveform is unknown, significant suppression can only be achieved if $\text{INR}_r \gg 1$; i.e., if RFI is strong.

- If the RFI is unknown but can be simply parameterized, then significant suppression can be achieved regardless of $\text{INR}_r$.

- Many forms of man-made RFI can be parameterized in a suitable fashion:
  - Narrowband signals in short time frames
  - Phase-modulated signals of any bandwidth can often be modeled as sinusoids plus one additional parameter.
Example: GLONASS Canceler for Radio Astronomy

- **Note:** No external reference signal; that is, the parametric model itself serves this function.
- **Simple implementation:** less complex than a GPS receiver!
GLONASS C/A Canceling Example

About 25 dB canceling of GLONASS for $L = 1024$ at INR $\approx 0$ dB
(i.e., consistent with previous result)
Closing Remarks

• Adaptive canceling is feasible for microwave radiometry, but one requires:
  • Large $\min(\text{INR}_r L, \text{INR}_p L)$ and
  • Either high INR$_r$ or a solvable parametric model

• What about LMS, RLS, MMSE, etc?
  • These are in the same class as Case 3 (unknown waveform)
  • Performance is typically awful relative to the bound described here
  • Reason: When INR$_r < 1$, these algorithms suppress noise, not RFI.

• Estimating the RFI waveform is key. Model knowledge helps a lot.