PERFORMANCE TRADE-OFFS AND DESIGN LIMITATIONS OF ANALOG-TO-INFORMATION CONVERTER FRONT-ENDS

OMID ABDI, FRED CHEN, FABIAN LIM, VLADIMIR STOJANOVIC

Department of EECS, Massachusetts Institute of Technology, Cambridge, MA

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**MOTIVATION**

- High-speed sampling resolution limiter:
  - Jitter (sampling uncertainty)
  - Aperture (circuit bandwidth)

- High-speed ADCs:
  - High Power
  - Limited Resolution

- Analog-to-Information Converters (AIC):
  - Relax the frequency requirements of ADC

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**ADC Performance**

- **FOM** (J/conv-step):
  - 6 bits: $10^{-15}$
  - 5 bits: $10^{-14}$
  - 10 bits: $10^{-13}$

- **Sampling Rate** (samp/sec):
  - $10^6$ to $10^{10}$

**AIC Performance**

- **FOM** (J/conv-step):
  - $10^{-12}$

- **Sampling Rate** (samp/sec):
  - $10^6$ to $10^{10}$
AIC: COMPRESSED SENSING

\[
\Phi(t) \quad f(t) \quad CS \quad \text{Sampling} \quad y_1 \quad y_M \quad f_1 \quad f_N \quad M < N
\]

\[
\text{ADC} \quad f_s/N \quad y_1 \quad f_1 \quad \cdots \quad \hat{f}_N
\]

\[
A\text{ ADC} \quad f_s/N \quad \hat{y}_1 \quad \hat{y}_2 \quad \cdots \quad \hat{y}_M
\]

\[
f(t) \quad A\text{ ADC} \quad f_s/N \quad \hat{f}_1 \quad \hat{f}_N
\]

\[
\text{High-Speed ADC} \quad \Phi_1(t) \quad \Phi_2(t) \quad \cdots \quad \Phi_M(t)
\]

\[
f(t) \quad \Phi(t) \quad \text{CS Sampling} \quad y_{1:}\end{bmatrix} \quad \text{reconstruct signal} \quad \hat{f}_{1:}\end{bmatrix}
\]

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Jitter Noise:
- Jitter width: $\varepsilon \sim N(0,\sigma)$, $\sigma$ is jitter RMS.
- Spatial correlation: same PLL is used across all measurements

$$n_i(t) = f(t) \cdot N_i(t)$$
Mixer Jitter affects AIC Measurements

Each measurement, $y_i$, is computed by:

$$y_i = \Phi_i \Psi x + n^o$$

Where:

$$\Phi_{ij} = \Phi_i(t) \big|_{t = jT_s}$$

$$n_i(t) = f(t) \cdot N_i(t)$$
APERTURE MODEL

Effects of ADC’s bandwidth and clock rise time

Sampler Transfer Function

-3dB

F_\text{M}(t)

-1/dt

dt

Time

Freq

-1/dt

1/dt

BW

Effects of mixer delay and PN sequence rise time

Real

Ideal

Error

-1

1

-1

1

-1

1

-1

1

-1

0

-Tr

Tp

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Cognitive radio environment:
- Observe the entire frequency spectrum: 500MHz-20GHz
- Determine the location of used channels: N=1000 channels
- Only S << N users are “active” at any one time

Signal Model:
\[ f(t) = \sum_{j=1}^{N} x_j \sin(\omega_j t) \text{ where } x \text{ is sparse} \]
As sparsity level S increases:
- ADC performance improves
- AIC performance worsens
- AIC marginally better for small number of components (S)
Aperture affects ENOB of AIC and ADC.

- Aperture and mixer delay worsen ENOB in high-speed ADC and AIC, respectively.

\[ \Phi(t): \]

\[ T_r, T_p \]

High-Speed ADC

\[ T'_r \]

\[ N=1000, M=100, S=2 \]

- ADC
  - \( T'_r=5\) ps
  - BW=128 GHz

- ADC
  - \( T'_r=10\) ps
  - BW=64 GHz

- AIC, \( T_r=5\) ps
  - BW=128 GHz

- AIC, \( T_r=10\) ps
  - BW=64 GHz
Aperture and mixer delay worsen ENOB in high-speed ADC and AIC, respectively.

- **Ideal ADC**
- **AIC, $T_r=5\text{ps}$**
- **AIC, $T_r=10\text{ps}$**
- **ADC, $T_r'=5\text{ps}$**
- **ADC, $T_r'=10\text{ps}$**

### Jitter (rms) vs. ENOB

- N=1000, M=100, S=10

![Graph](image.png)
**AIC & High-Speed ADC Power Model**

\[ P_{ADC} = \]

**Tunable Parameters:**
- ENOB
- \( G_A \)

\[ P_{AIC} = \]

**Tunable Parameters:**
- ENOB
- \( G_A \)
- M
- N
**Power Consumption-M**

- Dominated by the integrator power, not a function of ENOB

- Increasing number of measurements, $M$:
  - Allows reconstruction of more components ($S$)
  - Increases the AIC power
System Gain ($G_A$) varies for different applications:

- To accommodate the input range of the ADC

Increasing $G_A$:
- High-speed ADC power changes very little: Single amplifier is not dominant
- AIC power increases: Amplifiers power is dominant
CONCLUSIONS

- Compared the energy cost and performance limitations of AIC and Nyquist ADC systems in the context of cognitive radio applications.

- Jitter and Aperture in the mixer stage limit the performance of the AIC system.

- No significant performance benefits over High-Speed ADC, even at low sparsities.

- AICs enable roughly a 2x reduction in power when no pre-amplification is required.