# Accurate Full Spectrum Test Robust to Simultaneous Non-coherent sampling and Amplitude clipping

Siva Sudani[1], Li Xu, Degang Chen[1]

Iowa State University, Ames, IA, USA

# Acknowledgments


- Semiconductor Research Corporation
- Texas Instruments Inc.
- National Science Foundation

# Purpose of the Method

# Purpose of the Method

- To perform accurate spectral testing
  - WITHOUT requiring Coherent sampling
  - WITHOUT requiring precise amplitude control
  - At LOW TEST COST

# Purpose of the Method

- To perform accurate spectral testing
  - WITHOUT requiring Coherent sampling
  - WITHOUT requiring precise amplitude control
  - At LOW TEST COST
- Compared to state-of the-art
  - Efficient test method with simultaneous non-coherent sampling and amplitude clipping

# Purpose of the Method

- To perform accurate spectral testing
  - WITHOUT requiring Coherent sampling
  - WITHOUT requiring precise amplitude control
  - At LOW TEST COST
- Compared to state-of the-art
  - Efficient test method with simultaneous non-coherent sampling and amplitude clipping
- Applications
  - Analog Mixed Signal Built-in Self Test (AMS-BIST)
  - Low cost spectral testing

# Outline

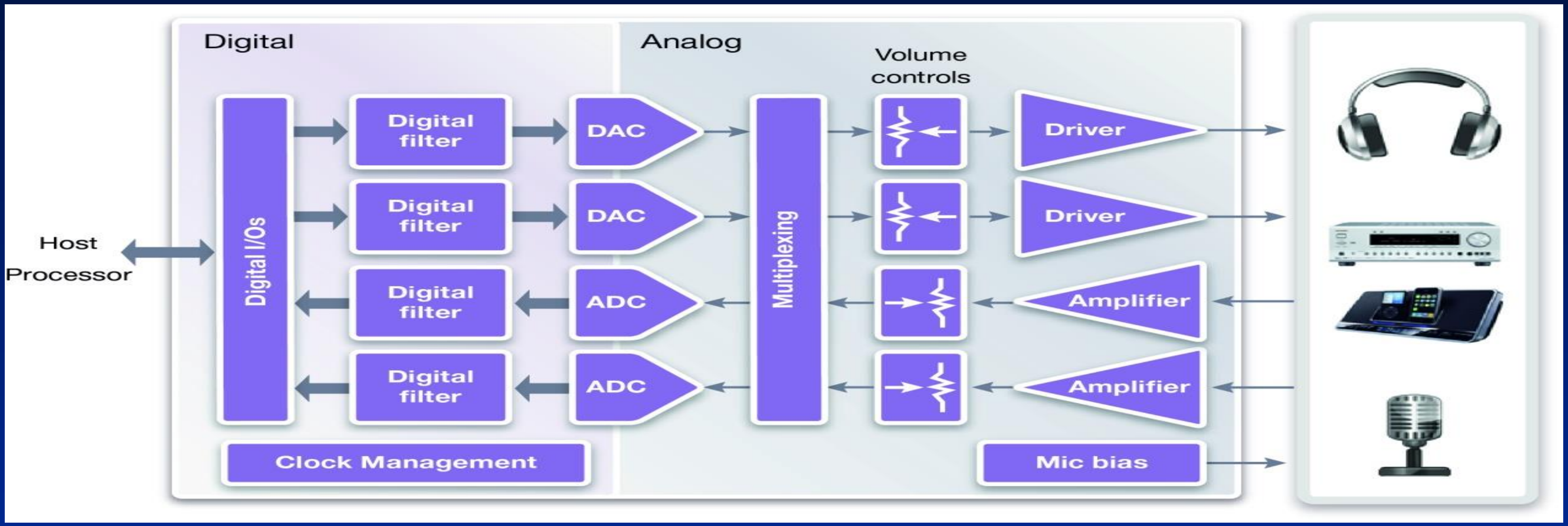
- Motivation and Spectral testing Background
- Proposed spectral testing method
  - Fundamental Estimation, Removal And Residue Interpolation (FERARI)
  - Spectral Testing Algorithm
- Simulation Results
- Measurement Results
- Conclusion

# Outline

- Motivation and Spectral testing Background
- Proposed spectral testing method
  - Fundamental Estimation, Removal And Residue Interpolation (FERARI)
  - Spectral Testing Algorithm
- Simulation Results
- Measurement Results
- Conclusion

# Motivation

Emerging products have embedded data converters

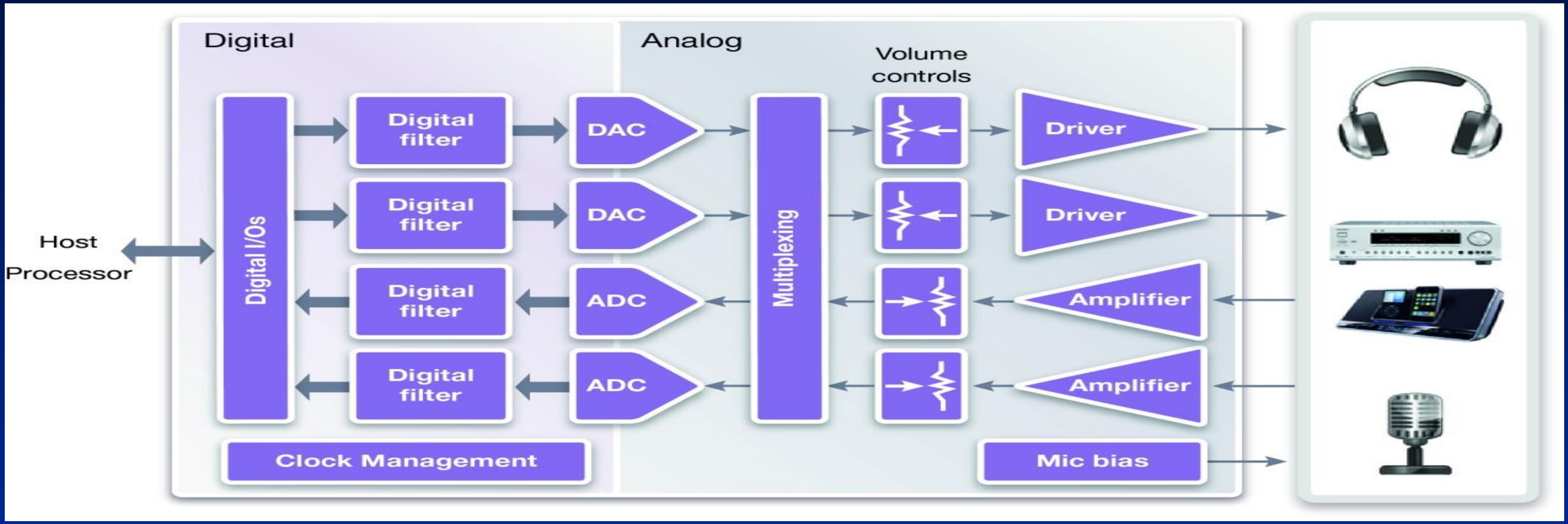





http://m.eet.com/media/1181967/digital_audio_hub_for_multimedia_fig1.jpg

# Motivation

Emerging products have embedded data converters



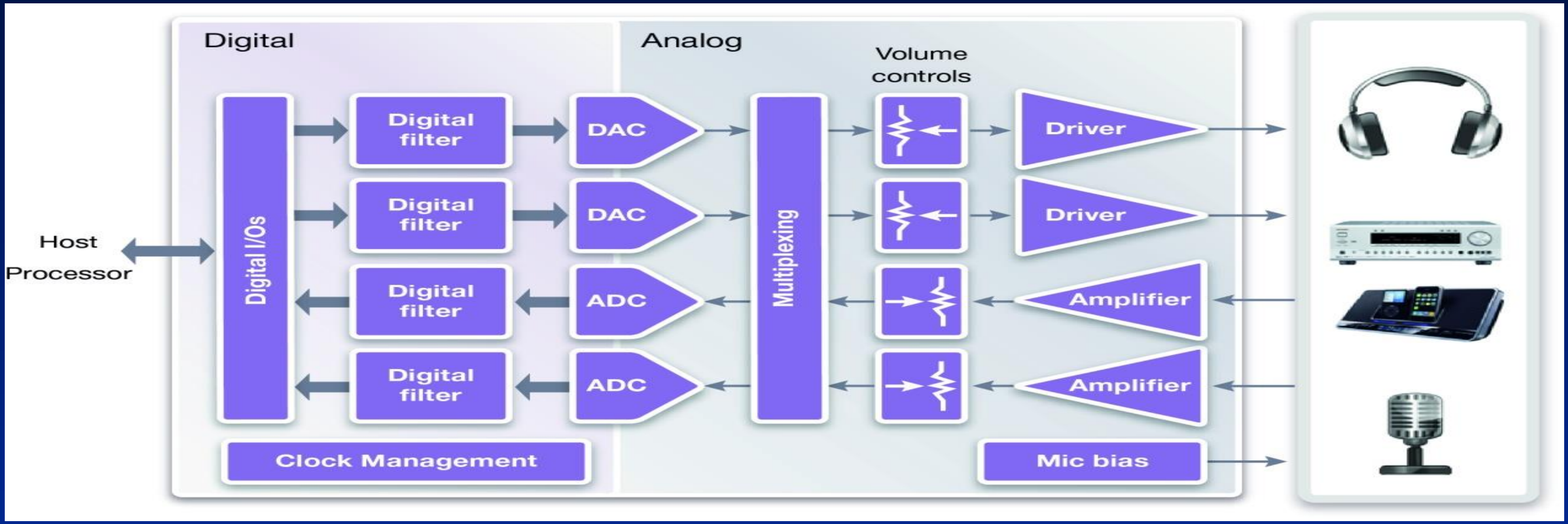

Challenging to de-embed and test block cost effectively



http://m.eet.com/media/1181967/digital_audio_hub_for_multimedia_fig1.jpg

# Motivation

Emerging products have embedded data converters




Challenging to de-embed and test block cost effectively

AMS Built In Self Test (AMS-BIST) is one of the solutions

-- Conventional testing → precise amplitude and frequency control

-- Designing high end test circuitry on-chip is challenging

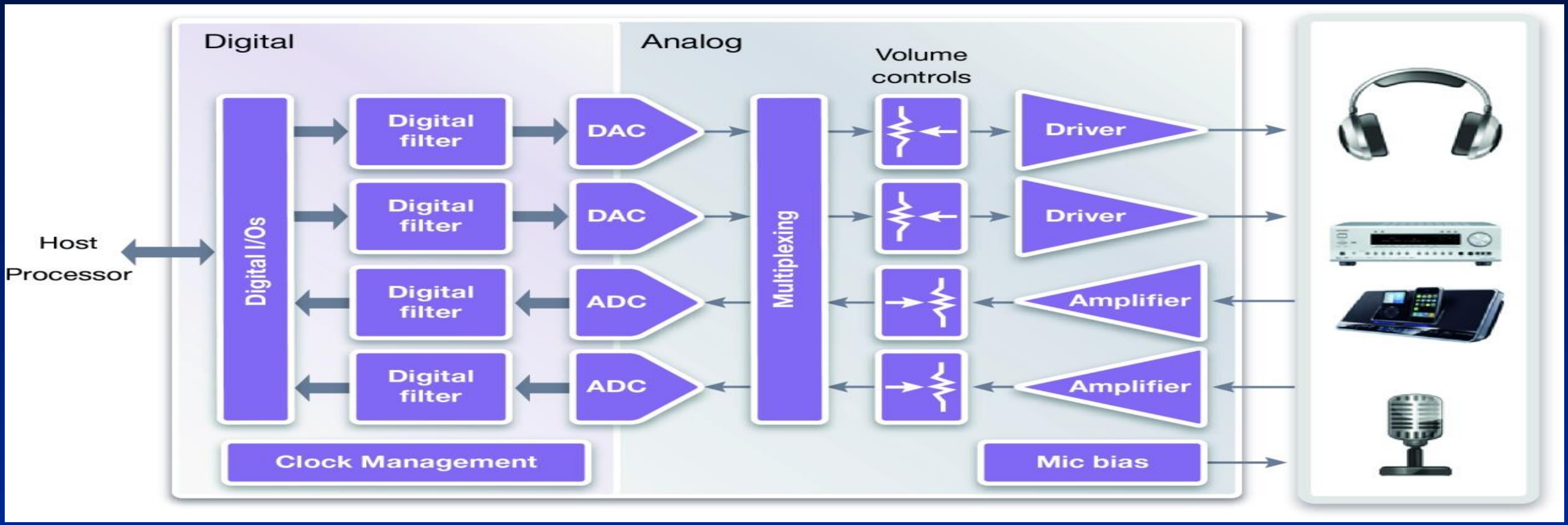
-- Large area



http://m.eet.com/media/1181967/digital_audio_hub_for_multimedia_fig1.jpg

# Motivation

Emerging products have embedded data converters




Challenging to de-embed and test block cost effectively

AMS Built In Self Test (AMS-BIST) is one of the solutions

-- Conventional testing → precise amplitude and frequency control

-- Designing high end test circuitry on-chip is challenging

-- Large area

Require new test methods that relax stringent conditions



http://m.eet.com/media/1181967/digital_audio_hub_for_multimedia_fig1.jpg

# Spectral Testing

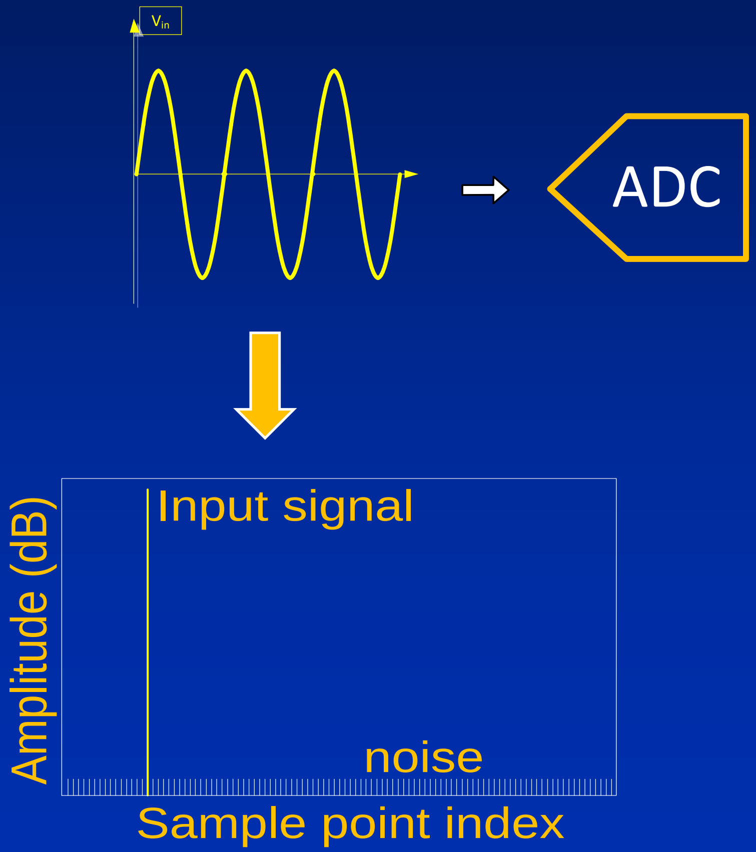
Used to test the frequency characteristics of a device under test (DUT)

# Spectral Testing

Used to test the frequency characteristics of a device under test (DUT)

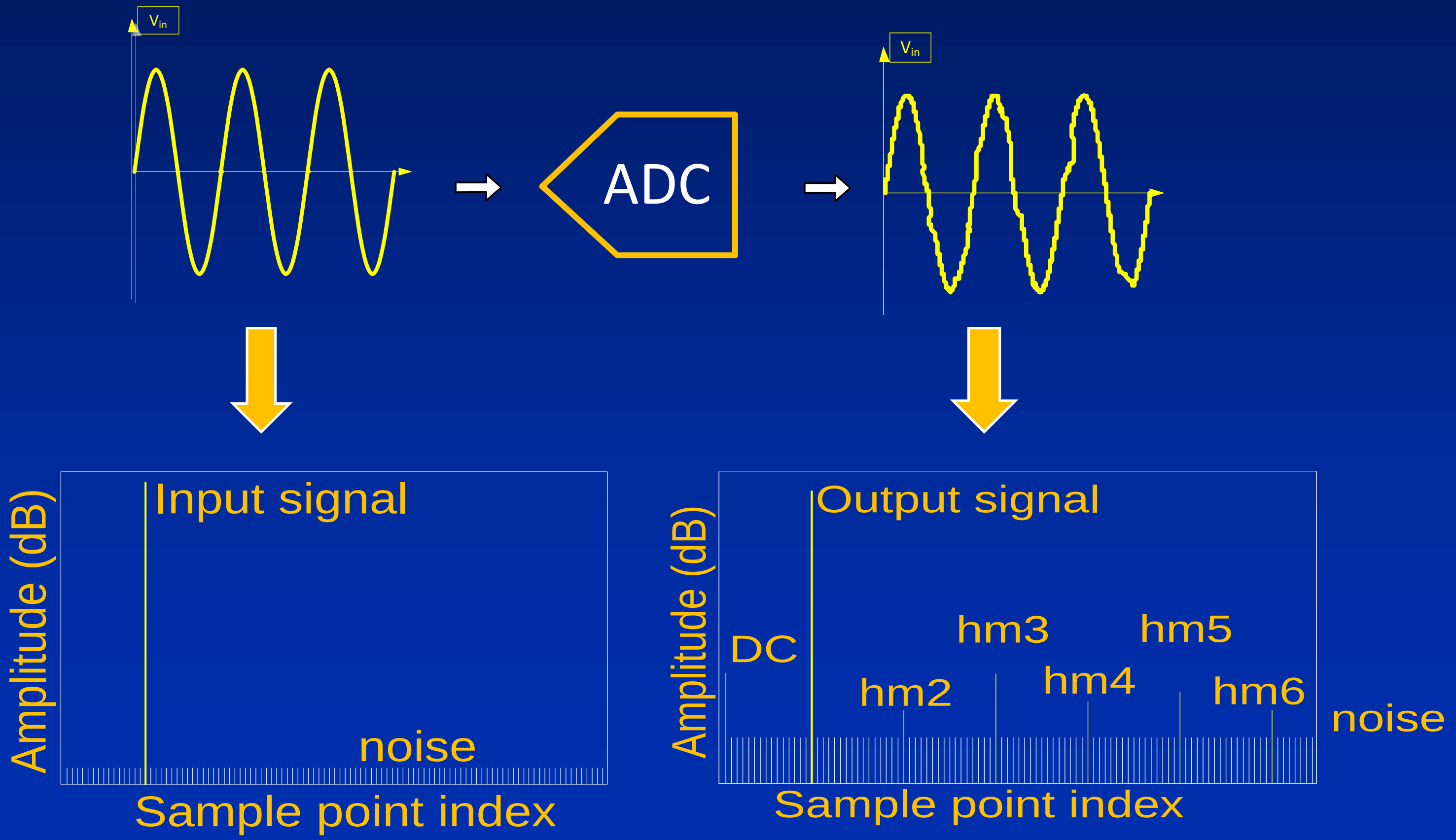
# Spectral Testing

Used to test the frequency characteristics of a device under test (DUT)



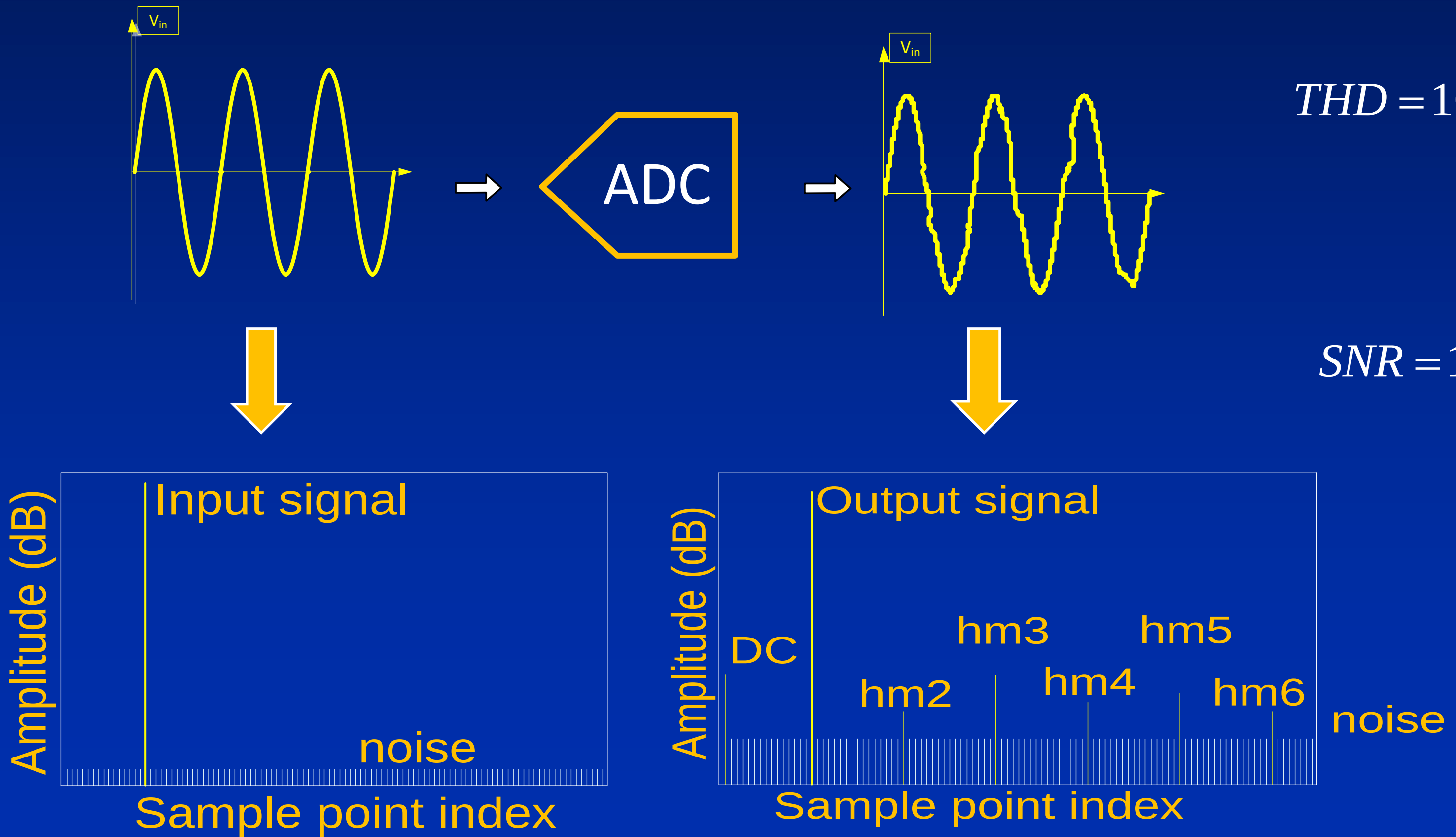
# Spectral Testing

Used to test the frequency characteristics of a device under test (DUT)



# Spectral Testing

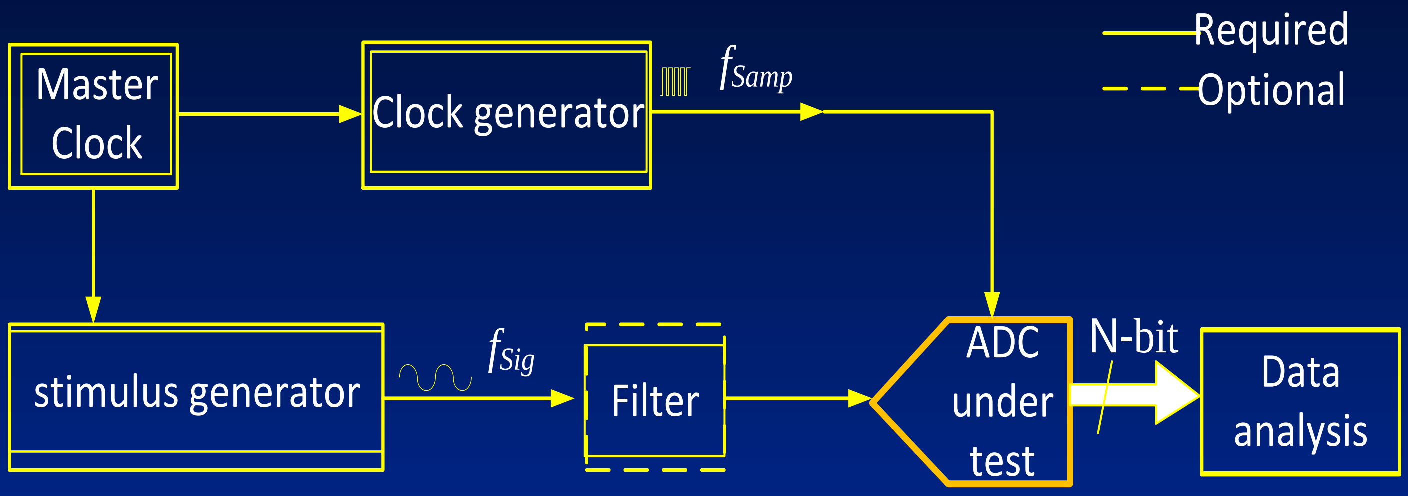
Used to test the frequency characteristics of a device under test (DUT)



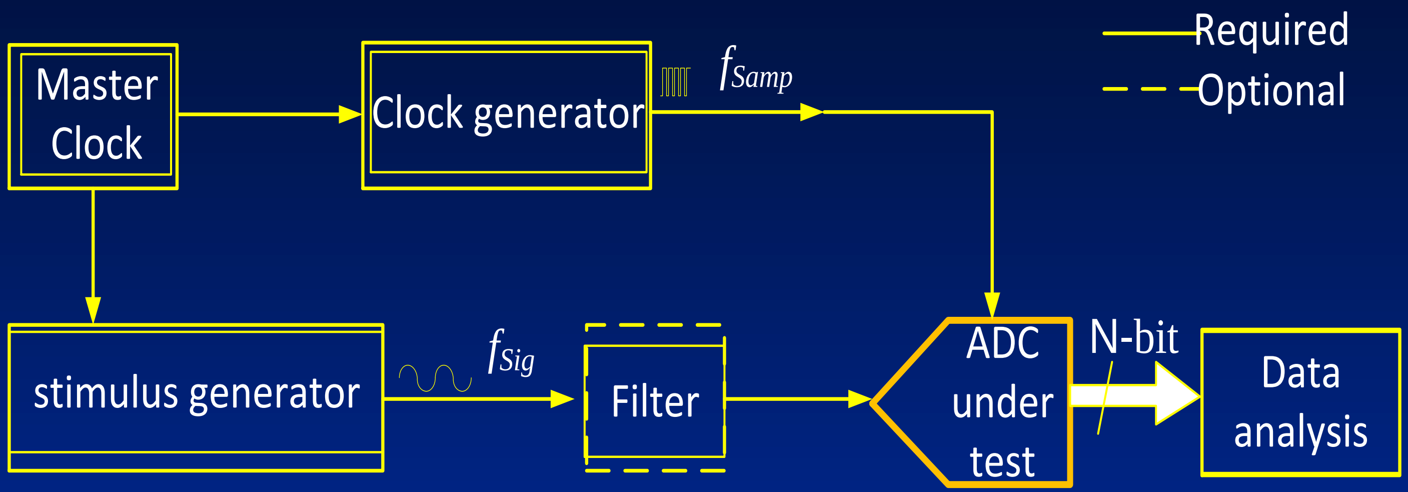

$$THD = 10 * \log_{10}\left(\frac{\sum_{i=2}^{H} P_{hmi}}{P_{Sig}}\right)$$

$$SNR = 10 * \log_{10}\left(\frac{P_{Sig}}{P_{noise}}\right)$$

# IEEE Standard method



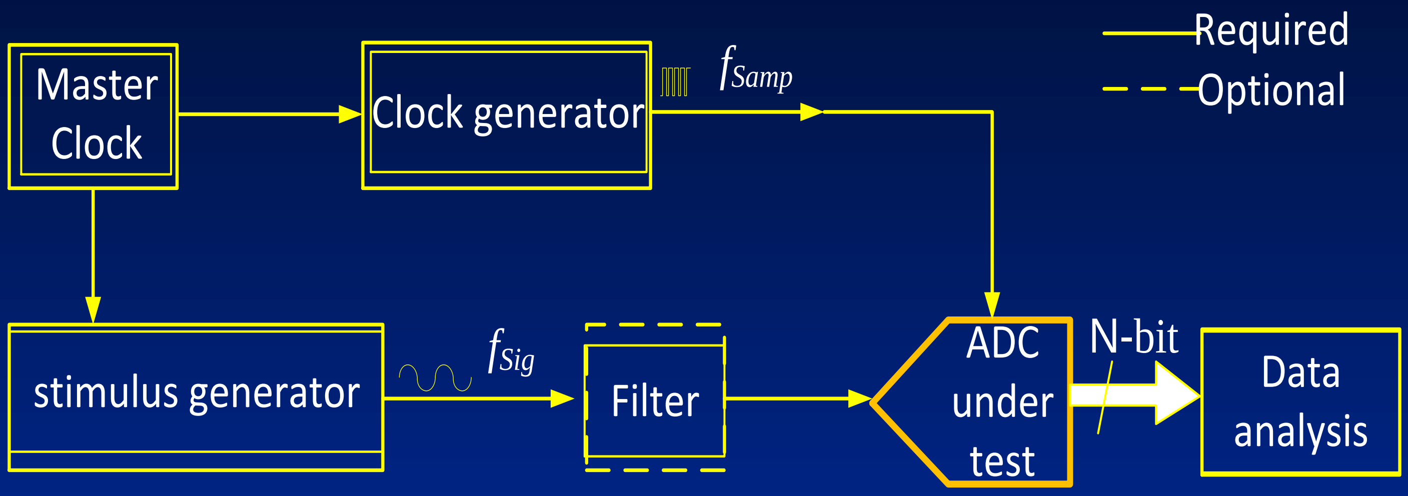
# IEEE Standard method




## Challenging Requirements

- Input signal about 3-4 bits more pure than ADC

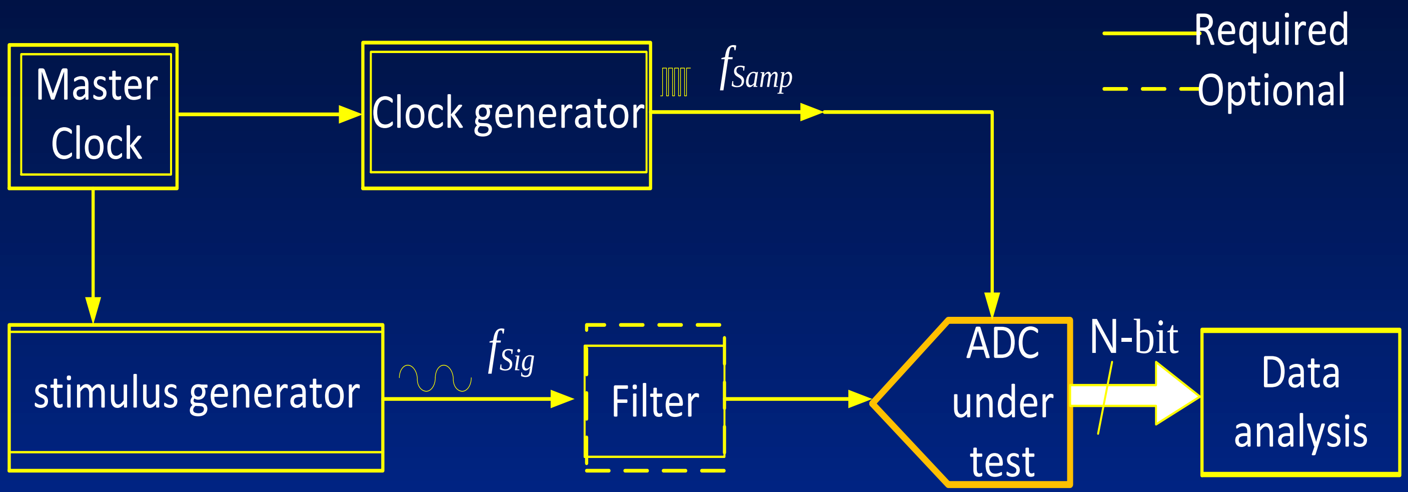
# IEEE Standard method




## Challenging Requirements

- Input signal about 3-4 bits more pure than ADC
- Peak-peak voltage slightly less than ADC input range

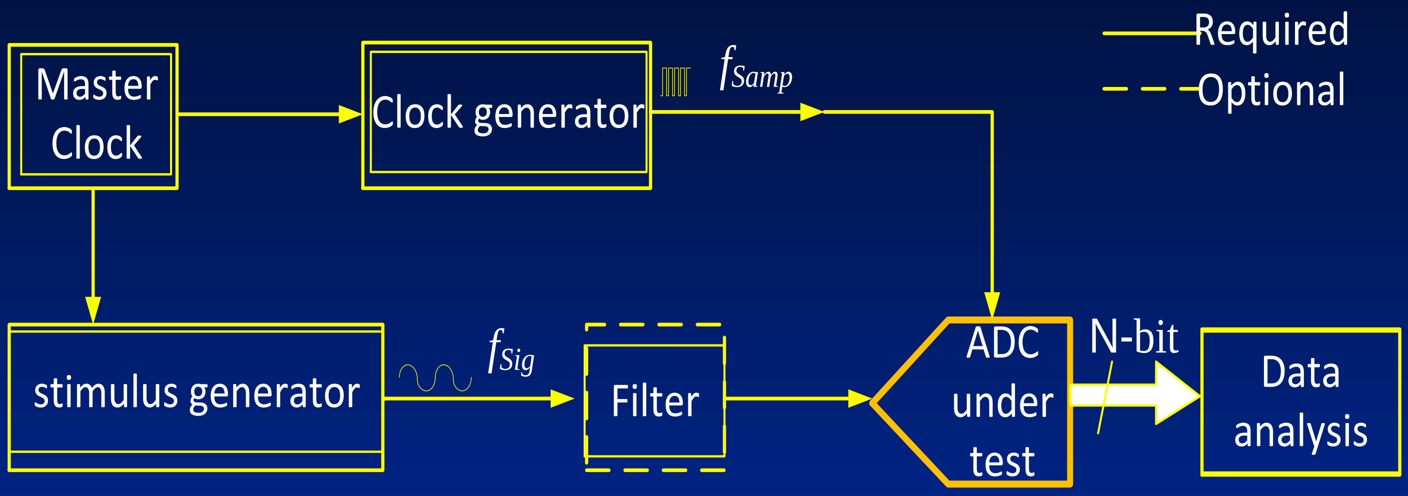
# IEEE Standard method




## Challenging Requirements

- Input signal about 3-4 bits more pure than ADC
- Peak-peak voltage slightly less than ADC input range
- Coherent sampling

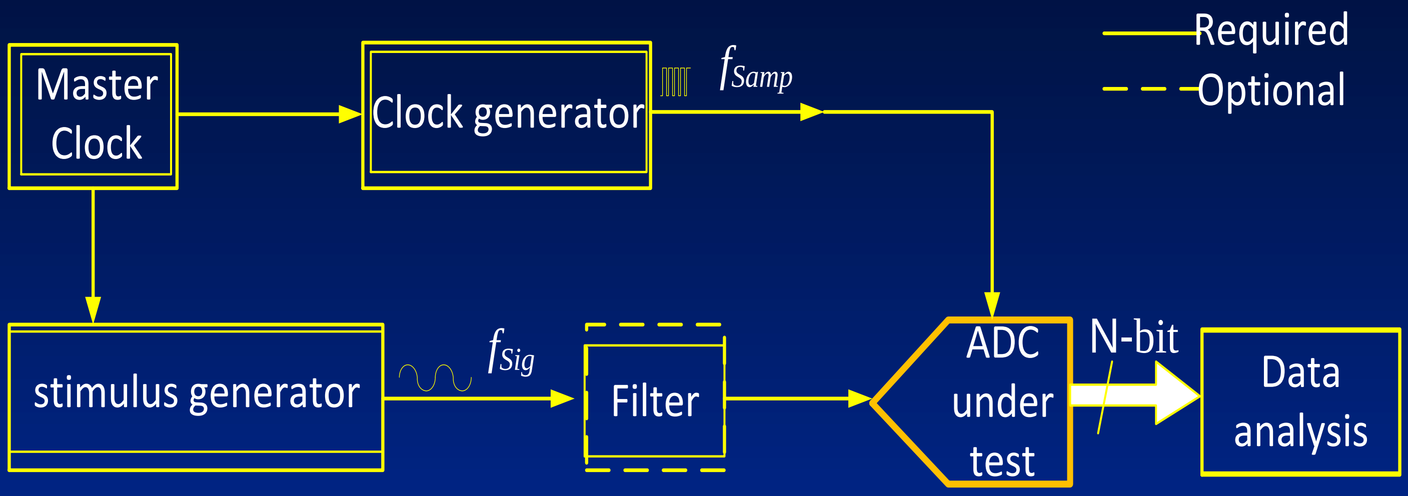
# IEEE Standard method




## Challenging Requirements

- Input signal about 3-4 bits more pure than ADC
- Peak-peak voltage slightly less than ADC input range
- Coherent sampling ⇒ Sample integer periods of input signal

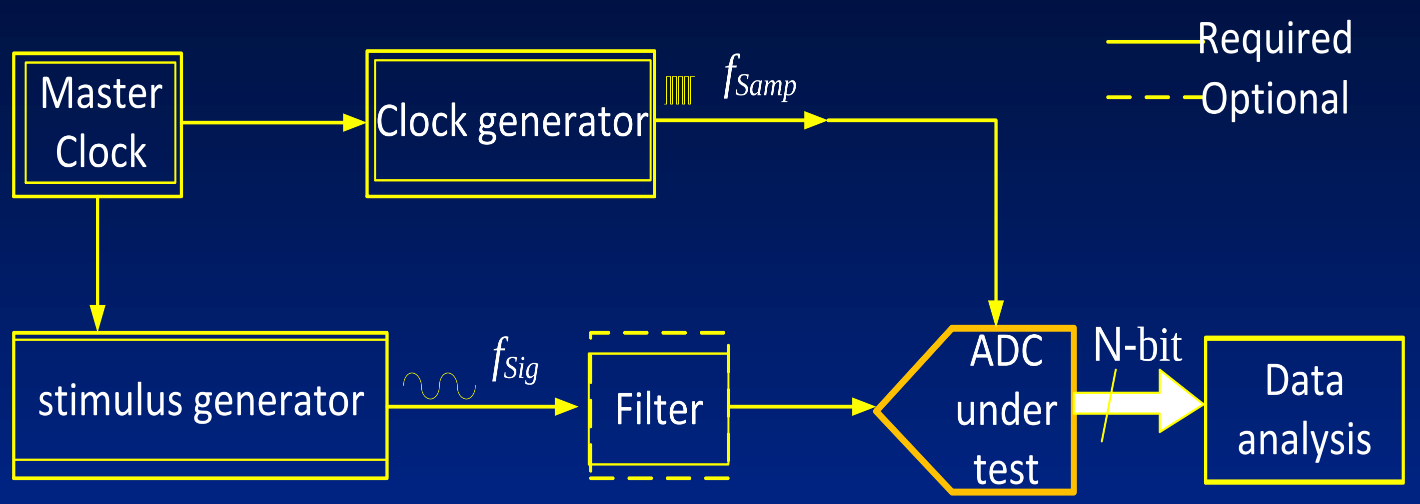
# IEEE Standard method




## Challenging Requirements

- Input signal about 3-4 bits more pure than ADC
- Peak-peak voltage slightly less than ADC input range
- Coherent sampling ➡ Sample integer periods of input signal
- Low clock jitter

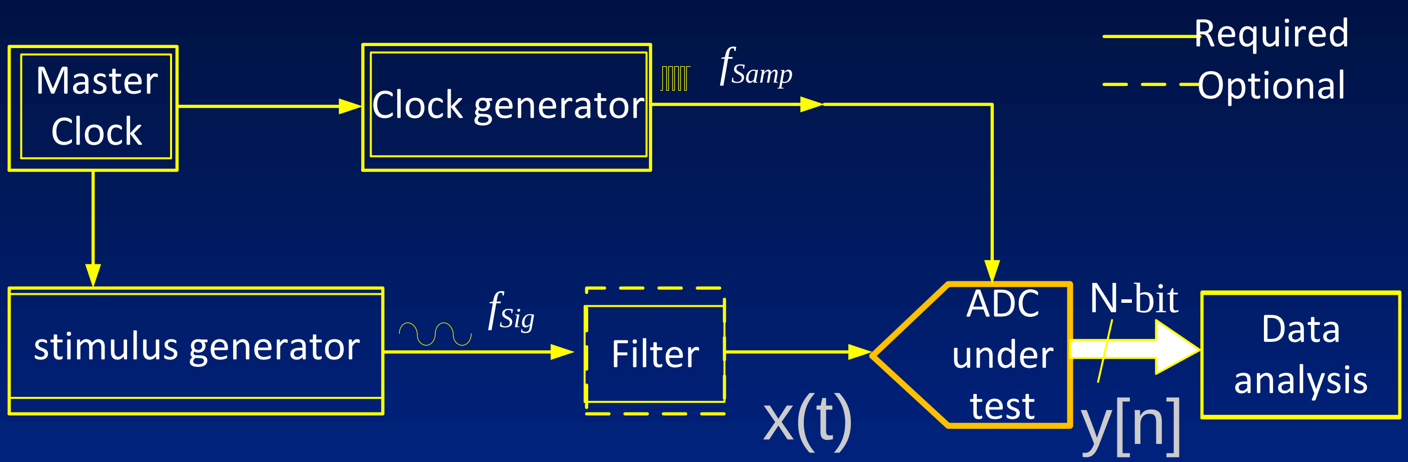
# IEEE Standard method



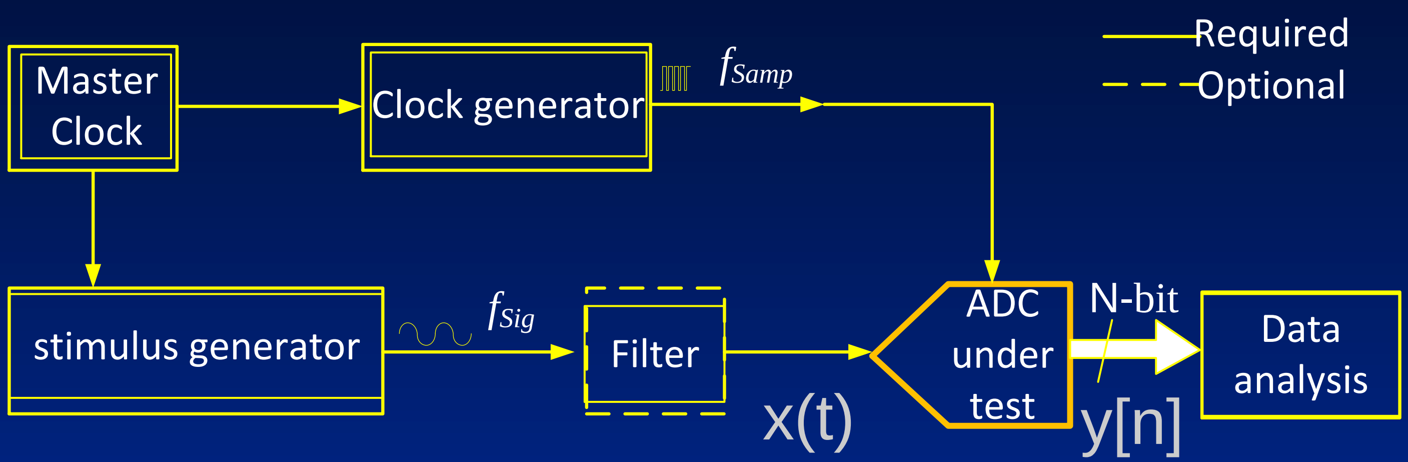

## Challenging Requirements

- Input signal about 3-4 bits more pure than ADC
- Peak-peak voltage slightly less than ADC input range
- Coherent sampling → Sample integer periods of input signal
- Low clock jitter

# IEEE Standard test method



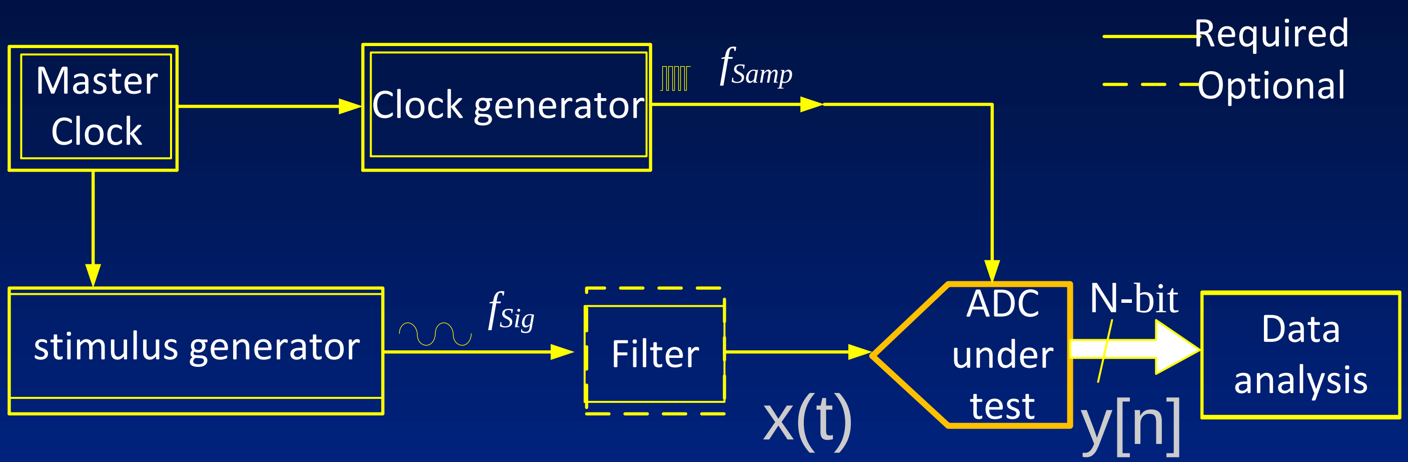
# IEEE Standard test method




## Notations

- *x(t)* : Analog input signal
    - $x(t) = A*\sin(2\pi f_{Sig} t)$
- *y[n]*: Analog interpretation of digital output of ADC, n = 0,1,2,..,M-1.
- $f_{Sig}$: Input signal frequency
- $f_{Samp}$: Clock frequency
- M: the data record length
- J: Number of input periods

# IEEE Standard test method




## Notations

- *x(t)* : Analog input signal
  - $x(t) = A*\sin(2\pi f_{Sig} t)$
- *y[n]*: Analog interpretation of digital output of ADC, n = 0,1,2,..,M-1.
- $f_{Sig}$: Input signal frequency
- $f_{Samp}$: Clock frequency
- M: the data record length
- J: Number of input periods

$$J = M*f_{Sig}/f_{Samp}$$

# Issue 1

Sampling (Coherent vs Non-coherent)

# Issue 1

## Sampling (Coherent vs Non-coherent)

M sampled points

# Issue 1

## Sampling (Coherent vs Non-coherent)

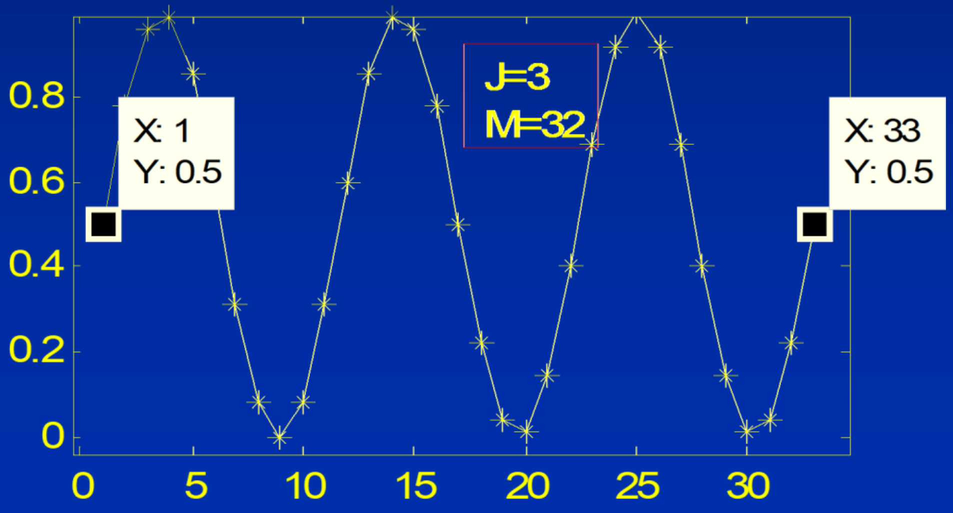
M sampled points

Time domain

Coherent

Integer # of input cycles (J) sampled

Y[1] = Y[M+1]



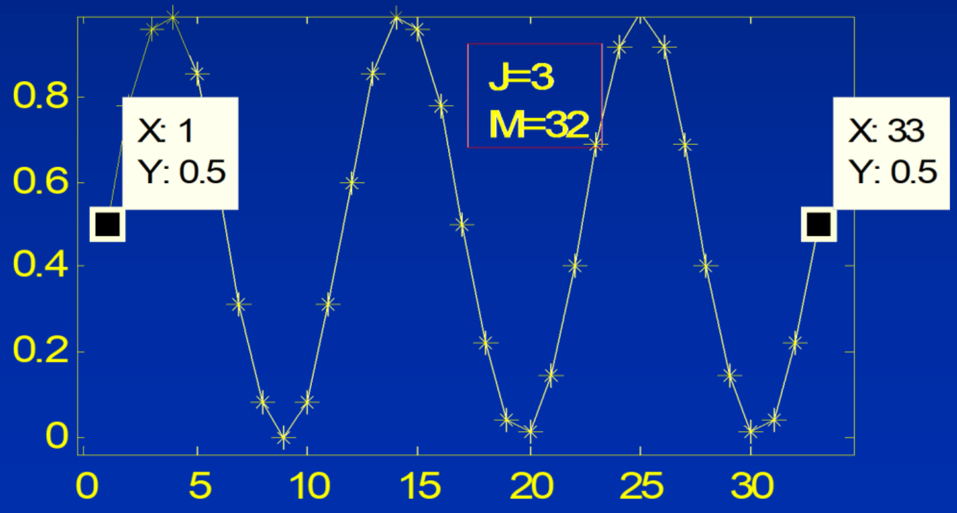
# Issue 1

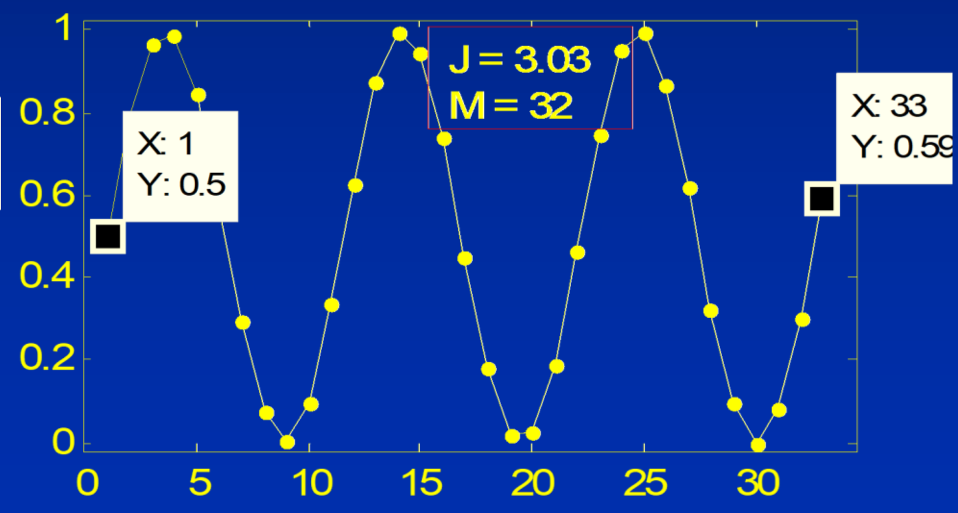
## Sampling (Coherent vs Non-coherent)

M sampled points

Time domain

| Coherent | Non-coherent |
|---|---|
| Integer # of input cycles (J) sampled | Non-integer # of input cycles (J) |
| Y[1] = Y[M+1] | Y[1] ≠ Y[M+1] |



# Issue 1

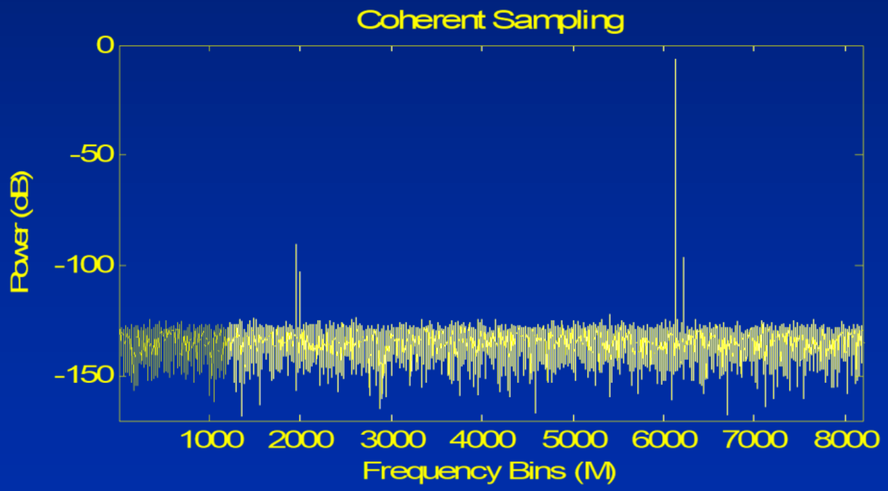
## Sampling (Coherent vs Non-coherent)

M sampled points

Frequency domain

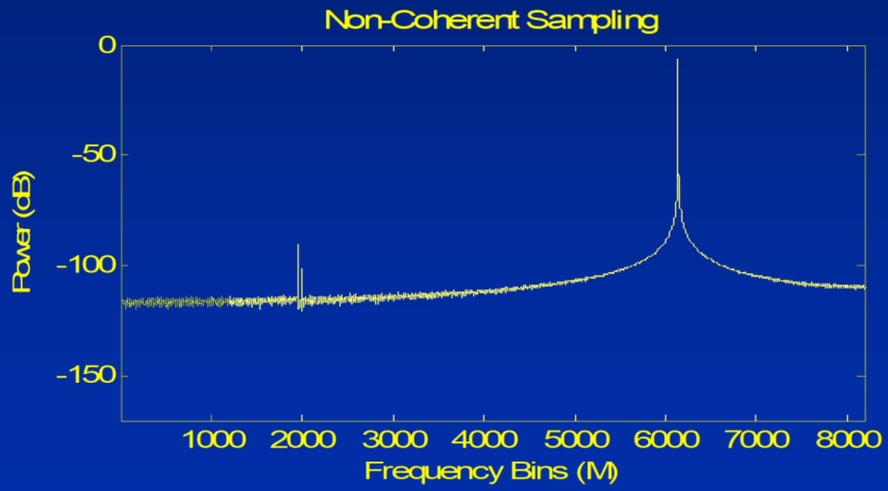
Coherent

Integer # of input cycles (J) sampled




Non-coherent

Non-integer # of input cycles (J)



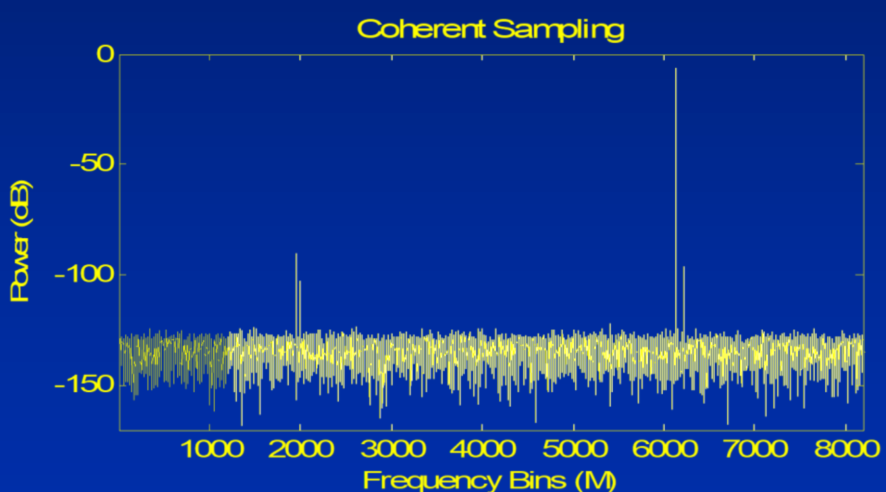
# Issue 1

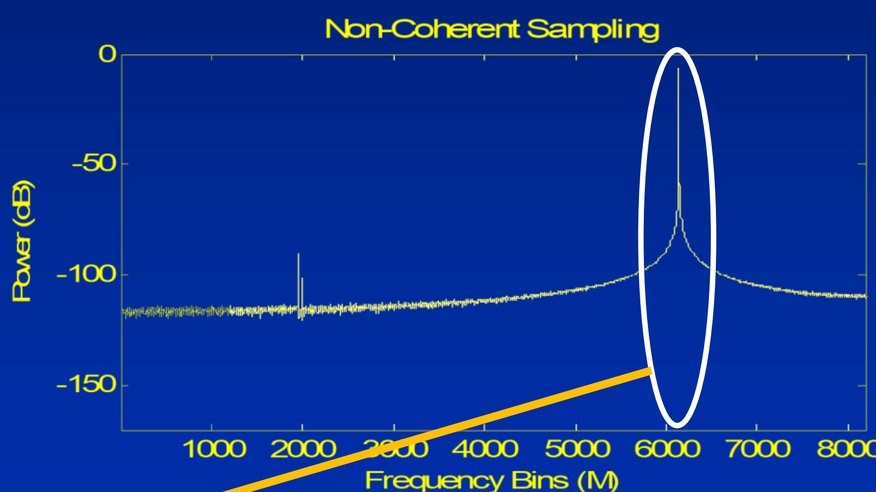
## Sampling (Coherent vs Non-coherent)

M sampled points

Frequency domain

| Coherent | Non-coherent |
| --- | --- |
| Integer # of input cycles (J) sampled | Non-integer # of input cycles (J) |




Severe leakage in the spectrum → Inaccurate results

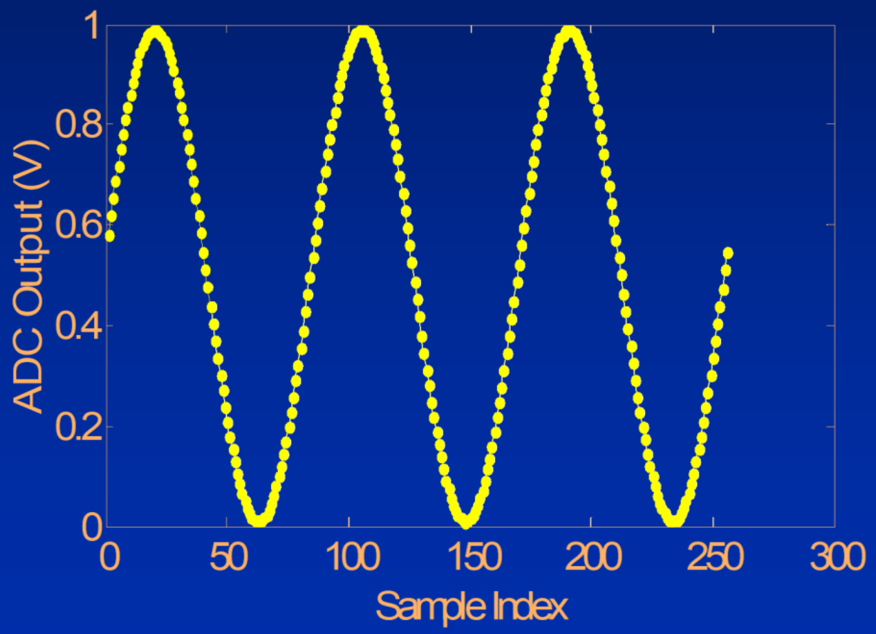
# Issue 2

Input Amplitude

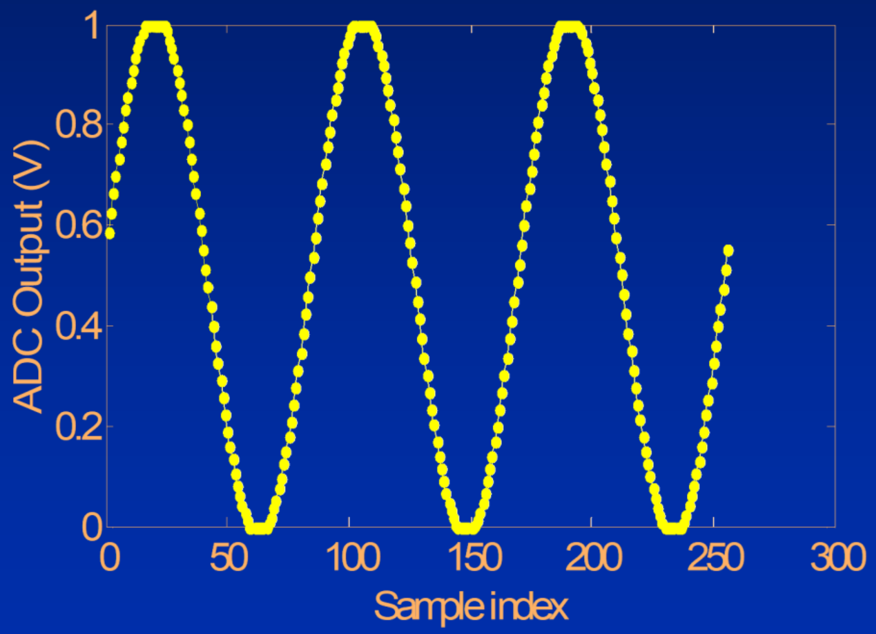
M sampled points

Time domain

In-range




Over-range



# Issue 2

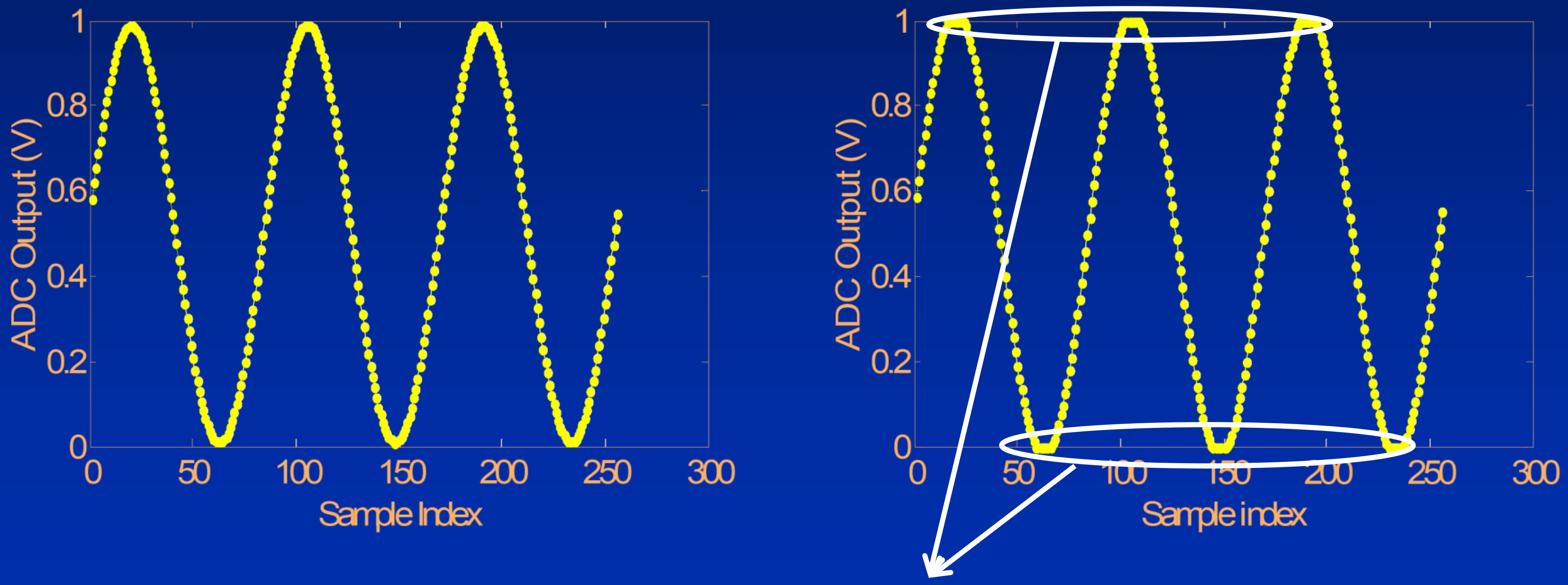
## Input Amplitude

M sampled points

Time domain

In-range

Over-range




Over-range input → Clipped ADC output

# Issue 2

Input Amplitude M sampled points

Frequency domain

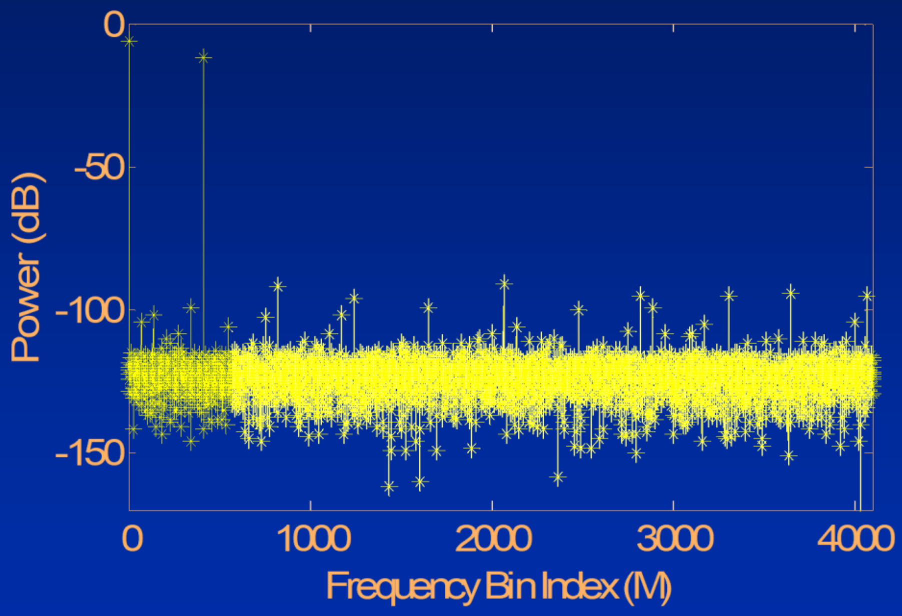
# Issue 2

## Input Amplitude

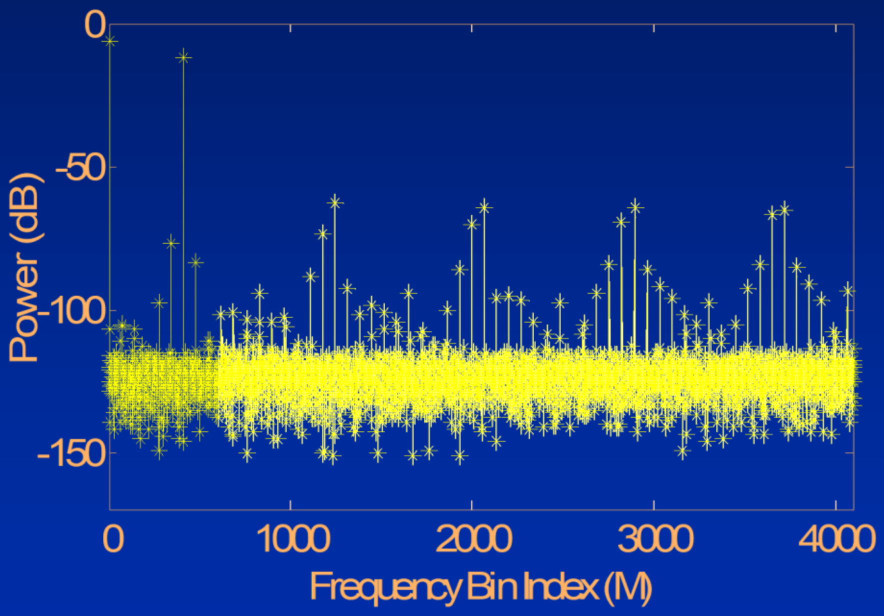
M sampled points

### Frequency domain

In-range




Over-range

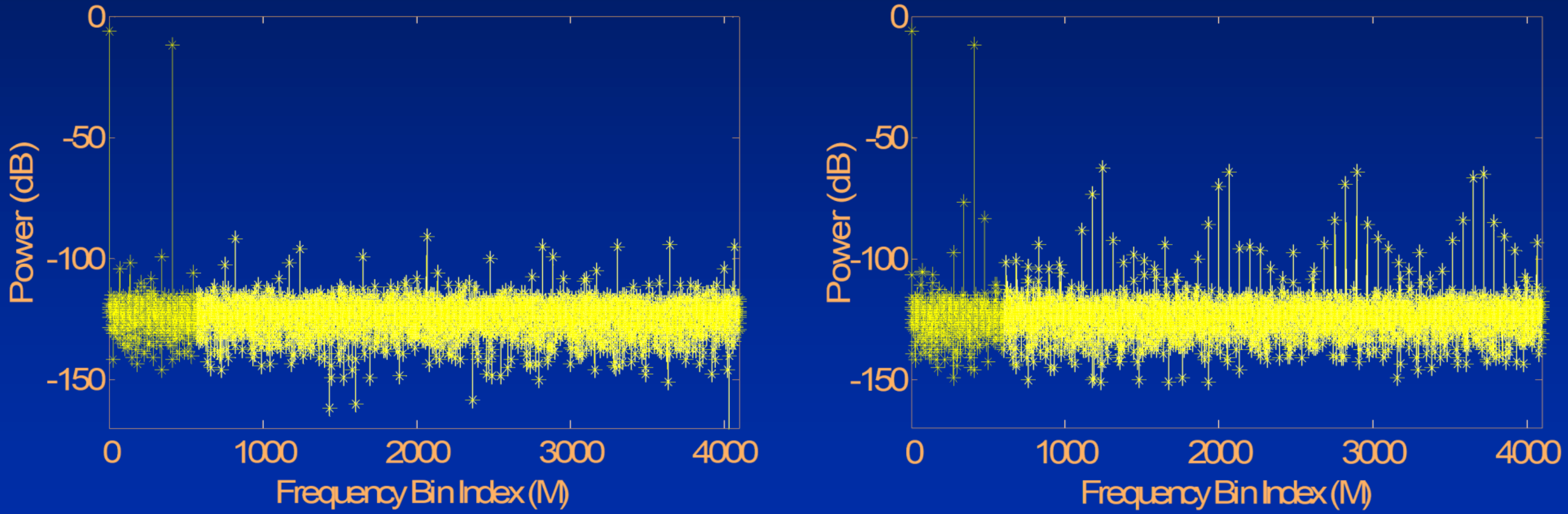


# Issue 2

Input Amplitude M sampled points

Frequency domain

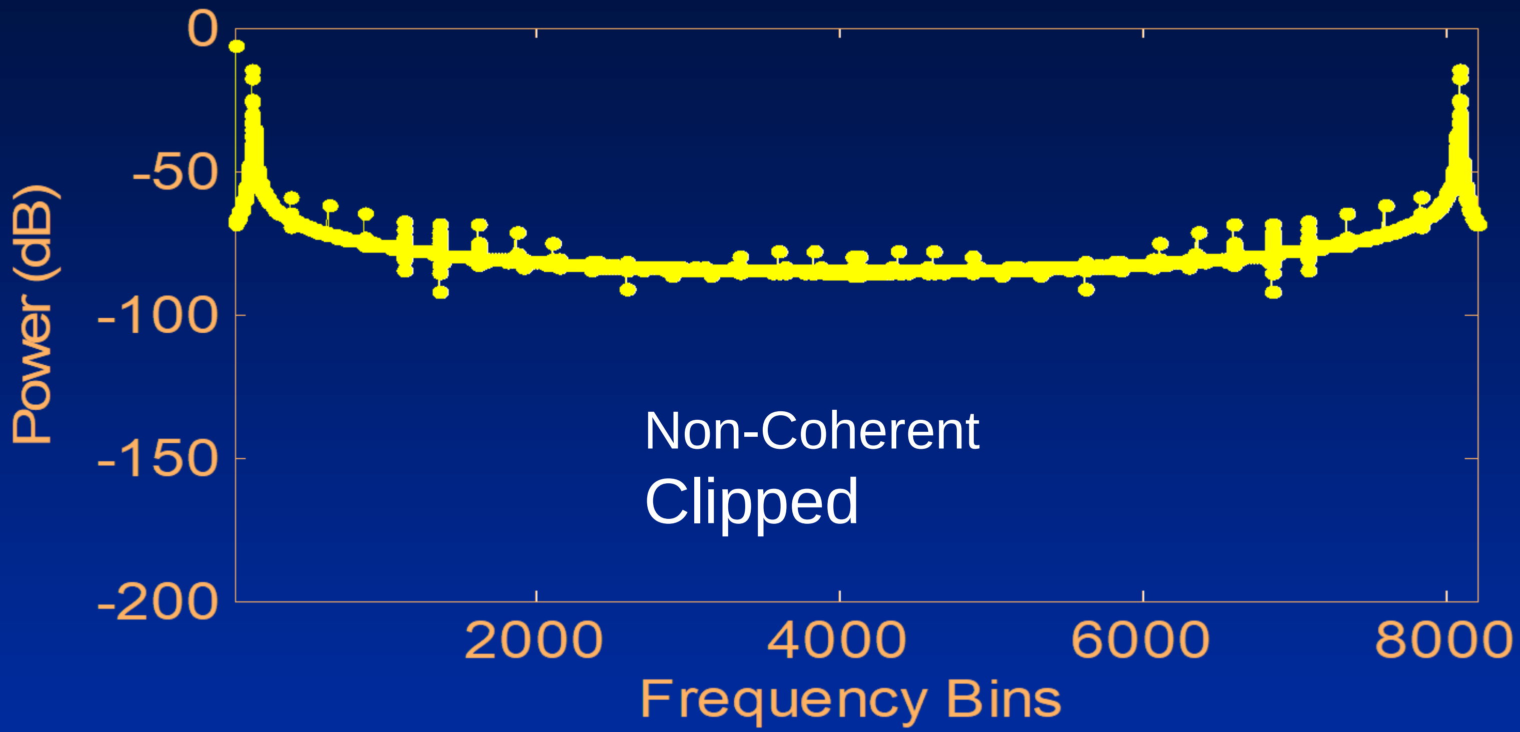
In-range Over-range



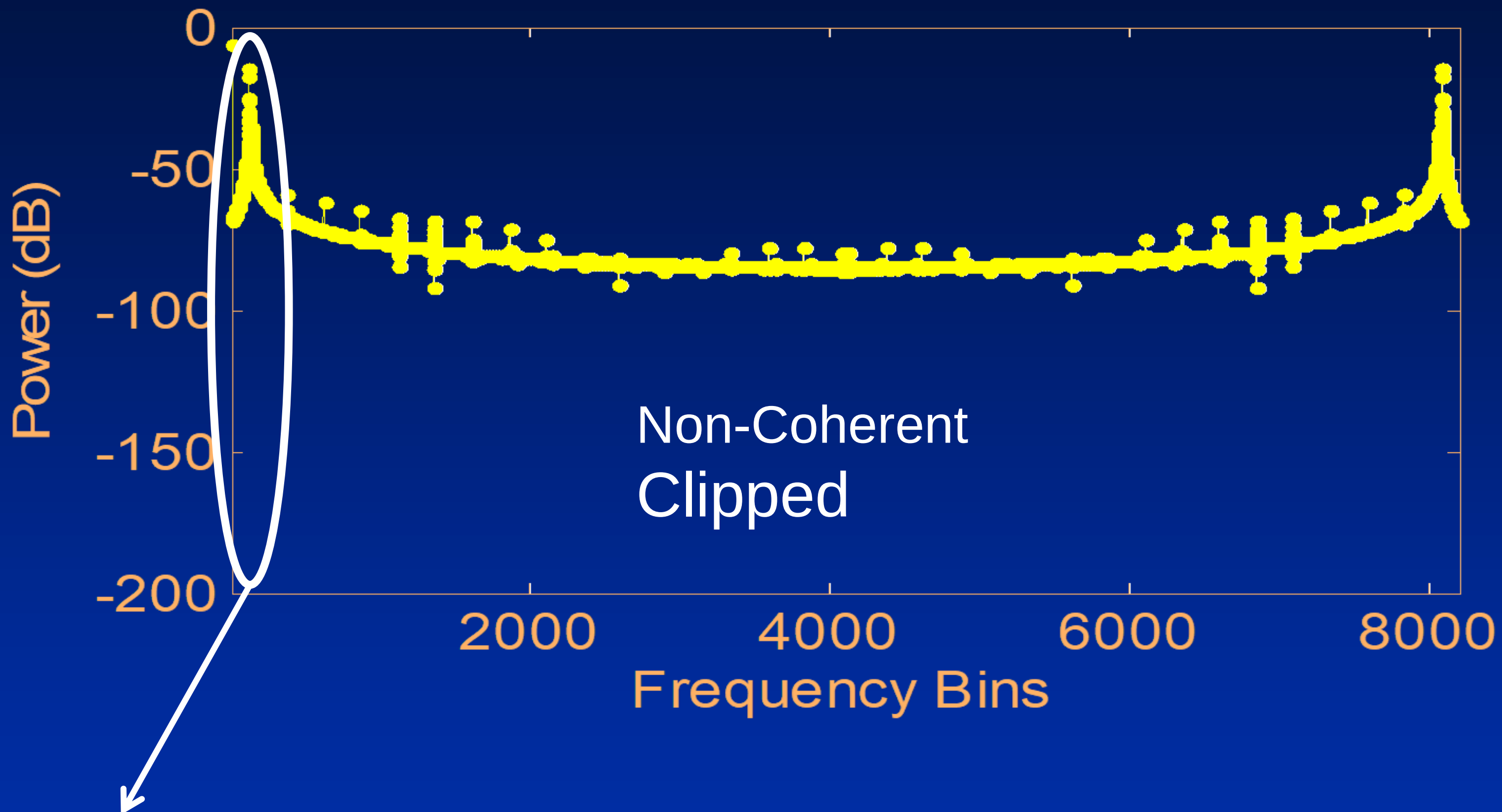

Increase in distortion power → Inaccurate results

# Effect of clipping & non-coherency

# Effect of clipping & non-coherency

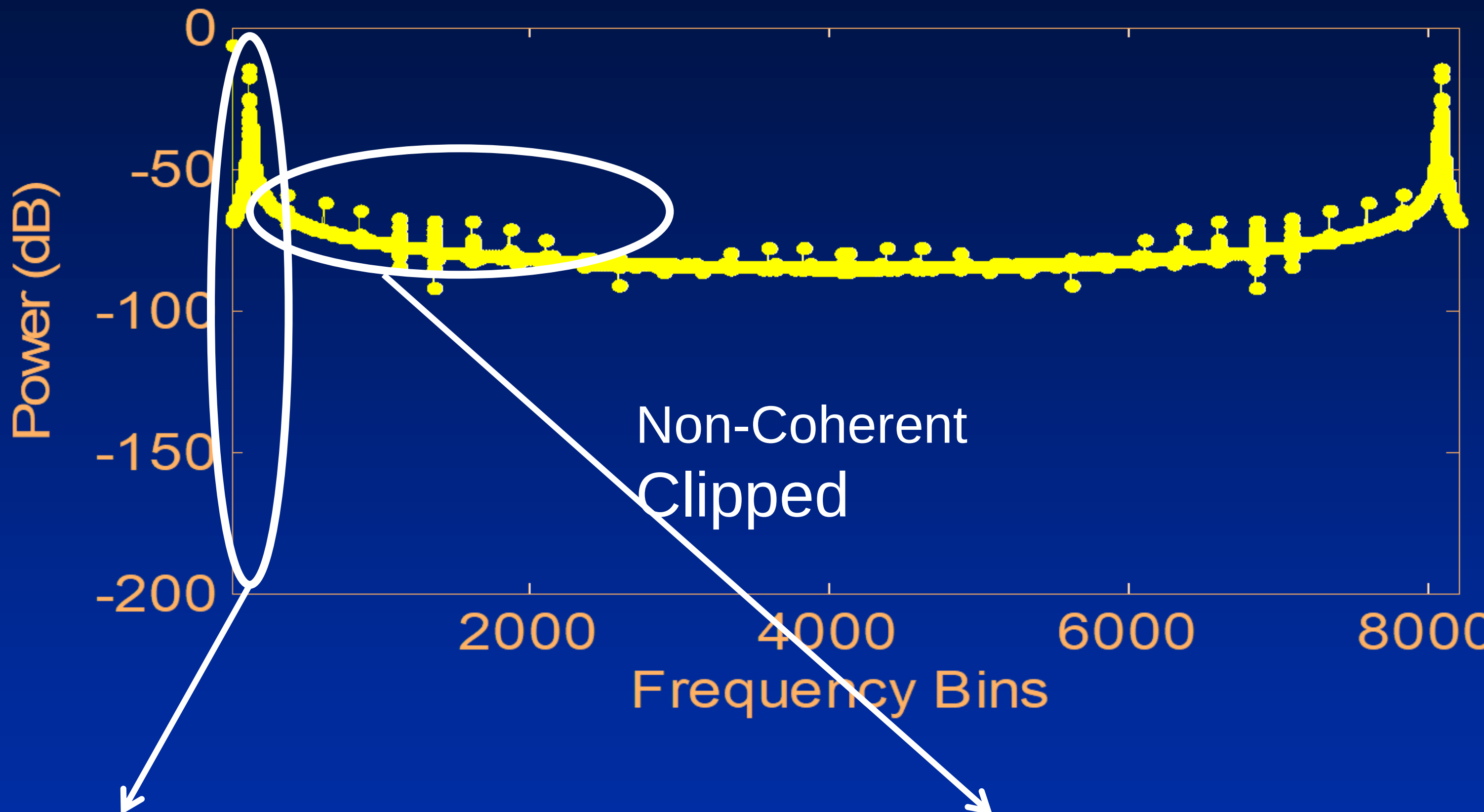


# Effect of clipping & non-coherency




Leakage ← Non-coherent sampling

# Effect of clipping & non-coherency




Leakage ← Non-coherent sampling

Higher Harmonics ← Clipping

# State-of the-art methods

# State-of the-art methods

- Non-coherent sampling
  - Windowing technique
  - Four parameter sine fitting
  - Filter bank
  - Interpolating DFT
  - FIRE

# State-of the-art methods

- Non-coherent sampling
  - Windowing technique
  - Four parameter sine fitting
  - Filter bank
  - Interpolating DFT
  - FIRE

Cannot work with clipping

# State-of the-art methods

- Non-coherent sampling
  - Windowing technique
  - Four parameter sine fitting
  - Filter bank
  - Interpolating DFT
  - FIRE

  } Cannot work with clipping

- Clipped Amplitude
  - [N. Giaquinto, 1997]
  - FER [Li Xu, (Under 2nd revision)]

# State-of the-art methods

- Non-coherent sampling
  - Windowing technique
  - Four parameter sine fitting
  - Filter bank
  - Interpolating DFT
  - FIRE

  } Cannot work with clipping

- Clipped Amplitude
  - [N. Giaquinto, 1997]
  - FER [Li Xu, (Under 2nd revision)]

  } Limited clipping allowance
  Limited accuracy
  Only ENOB test

# State-of the-art methods

- Non-coherent sampling
  - Windowing technique
  - Four parameter sine fitting
  - Filter bank
  - Interpolating DFT
  - FIRE

  } Cannot work with clipping

- Clipped Amplitude
  - [N. Giaquinto, 1997]
  - FER [Li Xu, (Under 2nd revision)]

  } Limited clipping allowance
  Limited accuracy
  Only ENOB test

- Proposed method (FERARI)
  → Both non-coherent and clipped data

# Outline

- Motivation and Spectral testing Background
- Proposed spectral testing method
  - Fundamental Estimation, Removal And Residue Interpolation (FERARI)
  - Spectral Testing Algorithm
- Simulation Results
- Measurement Results
- Conclusion

# Proposed Test Setup

Can accommodate

-- over-range input to ADC

-- non-coherent sampling

# Proposed Test Setup

Can accommodate

-- over-range input to ADC

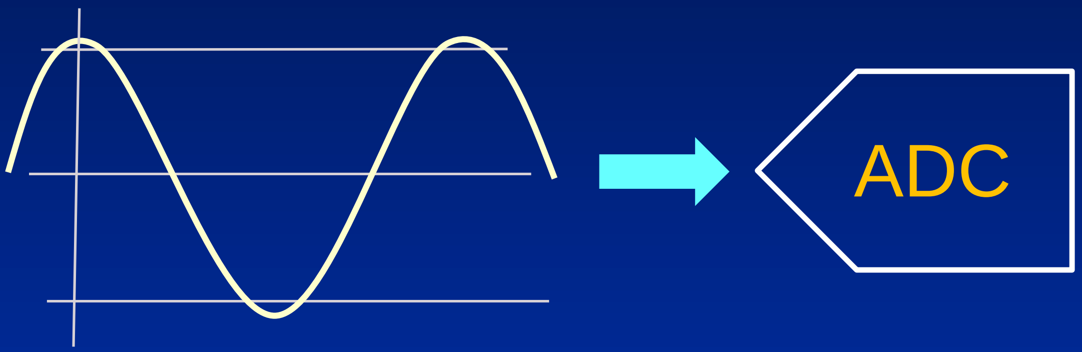
-- non-coherent sampling

# Proposed Test Setup

Can accommodate

-- over-range input to ADC

-- non-coherent sampling



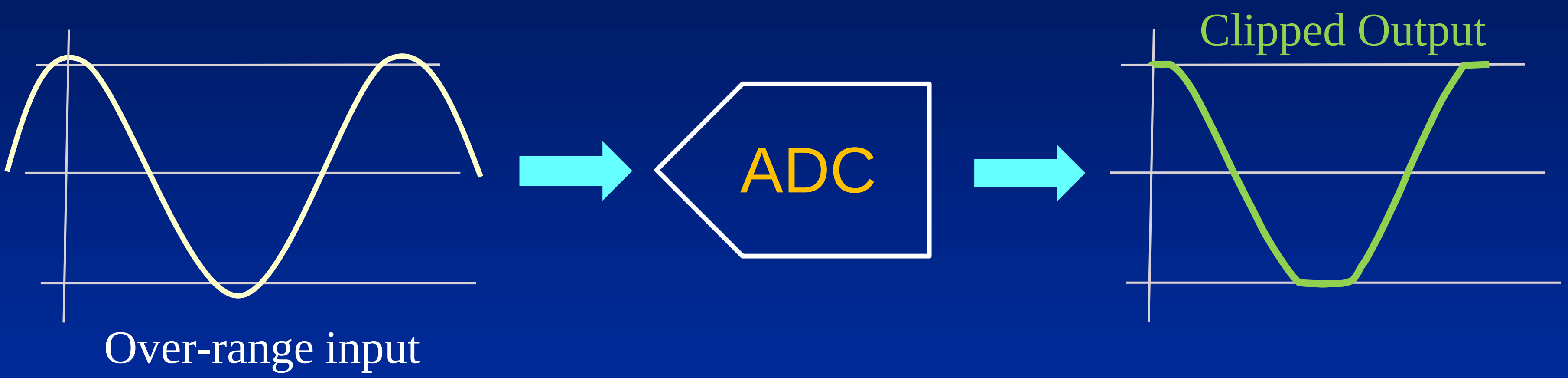

Over-range input

# Proposed Test Setup

Can accommodate

-- over-range input to ADC

-- non-coherent sampling

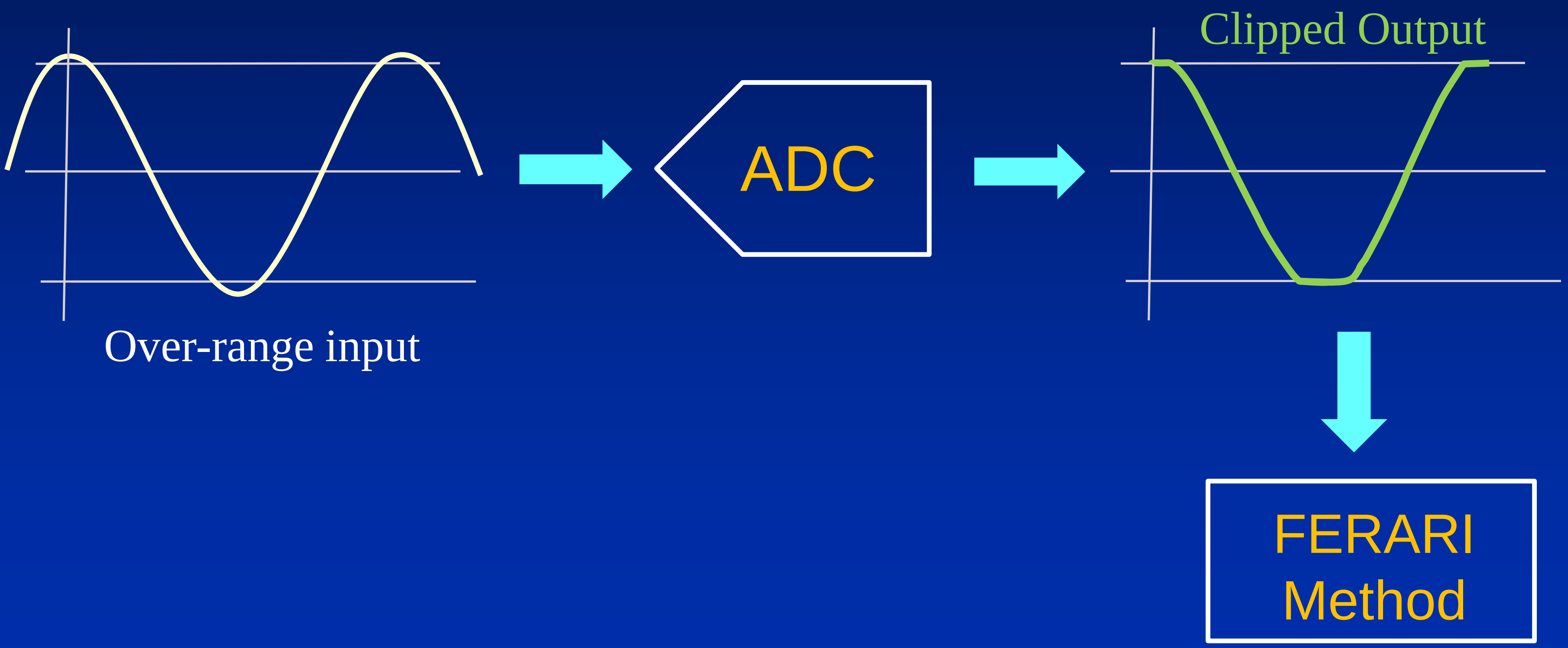


# Proposed Test Setup

Can accommodate

-- over-range input to ADC

-- non-coherent sampling

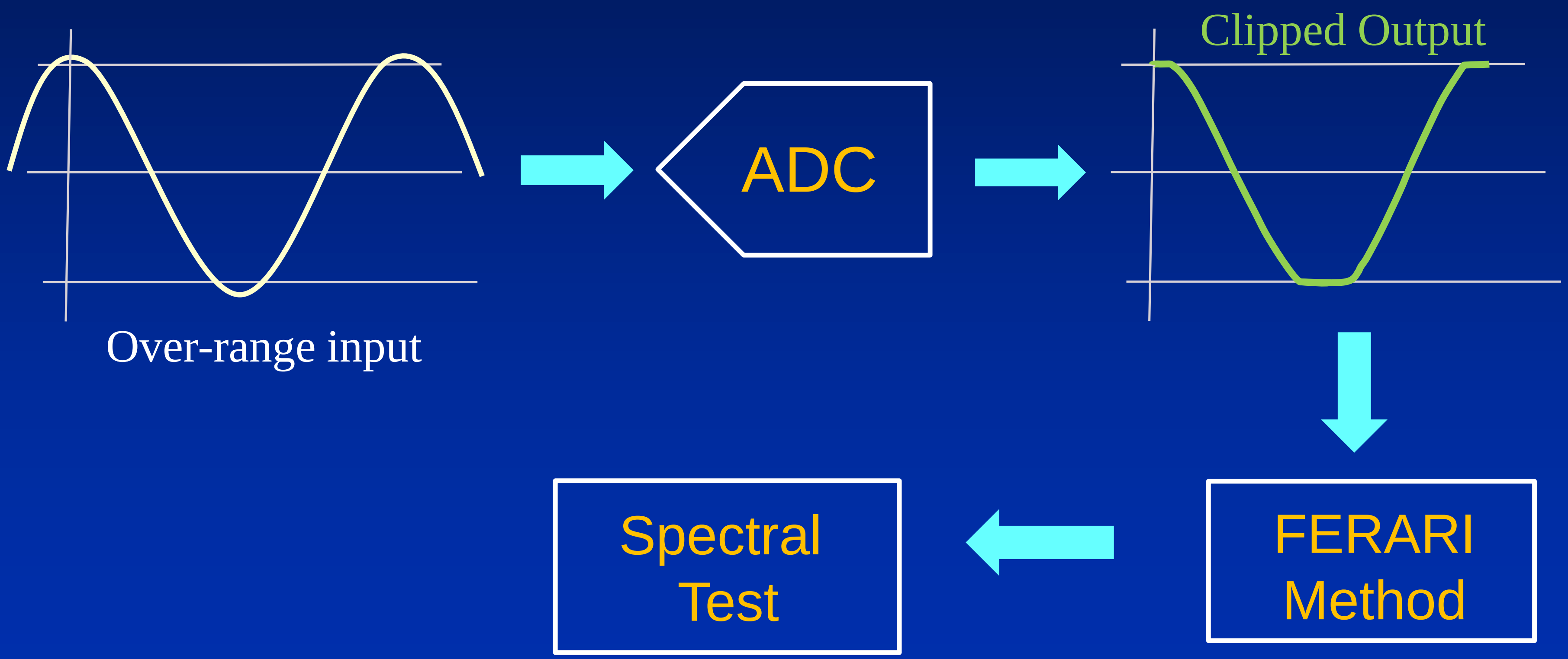


# Proposed Test Setup

Can accommodate

-- over-range input to ADC

-- non-coherent sampling



# FERARI method for NC-AC data

# FERARI method for NC-AC data

## Fundamental Estimation

- Use both time domain and frequency domain data

# FERARI method for NC-AC data

## Fundamental Estimation

- Use both time domain and frequency domain data

## Fundamental Removal

- Remove estimated fundamental from the clipped data to obtain residue

# FERARI method for NC-AC data

## Fundamental Estimation

- Use both time domain and frequency domain data

## Fundamental Removal

- Remove estimated fundamental from the clipped data to obtain residue

## Residue Interpolation

- Generate a coherent, unclipped fundamental
- For each point on the coherent signal, interpolate the residue to obtain the information of harmonics accurately

# FERARI method for NC-AC data

## Fundamental Estimation

- Use both time domain and frequency domain data

## Fundamental Removal

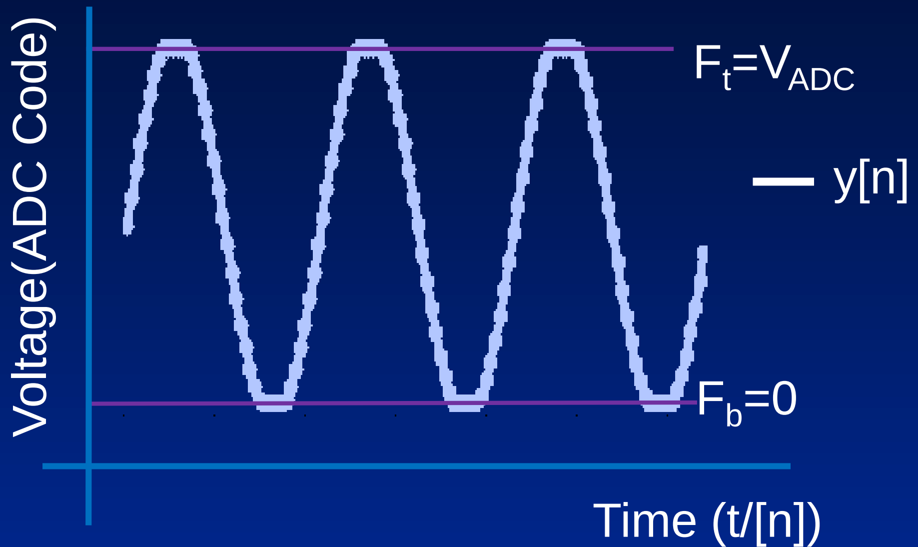
- Remove estimated fundamental from the clipped data to obtain residue

## Residue Interpolation

- Generate a coherent, unclipped fundamental
- For each point on the coherent signal, interpolate the residue to obtain the information of harmonics accurately

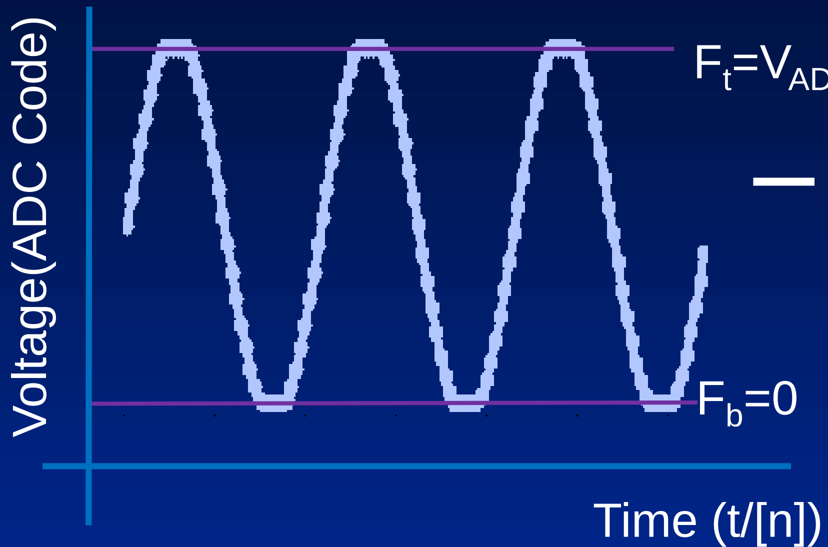
→ New fundamental estimation method is proposed

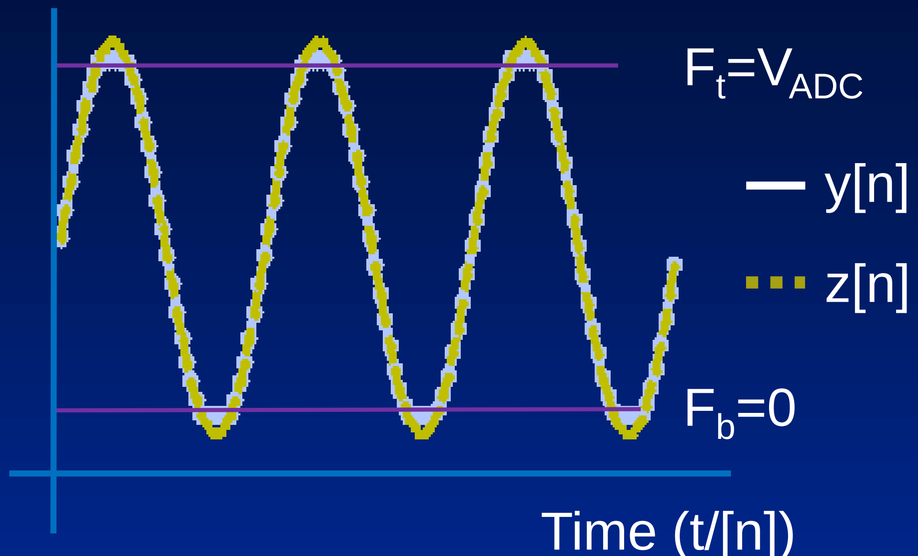
# FERARI (Fundamental Estimation)




y[n] (Unclipped) = Fundamental
+ Harmonics
+ Noise

# FERARI (Fundamental Estimation)

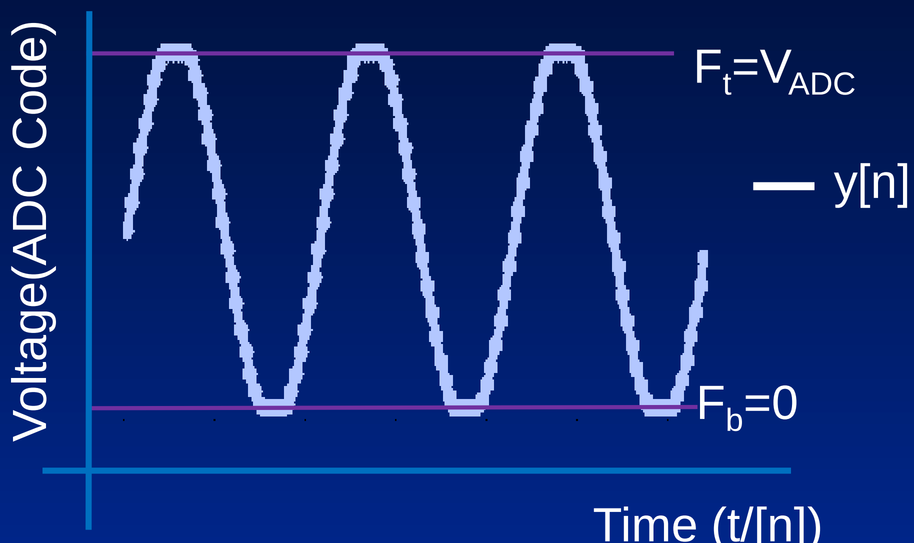


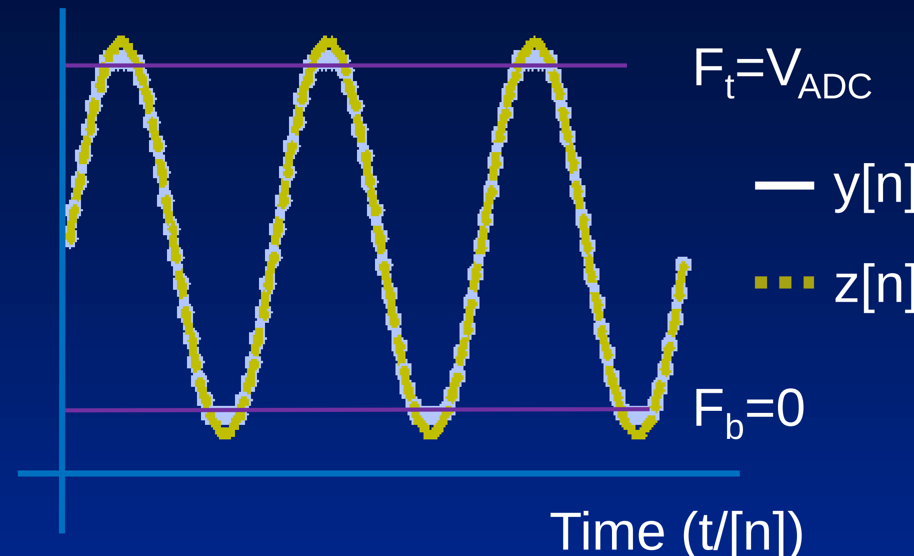




y[n] (Unclipped) = Fundamental
+ Harmonics
+ Noise

z[n] = Fundamental (Estimated)

# FERARI (Fundamental Estimation)

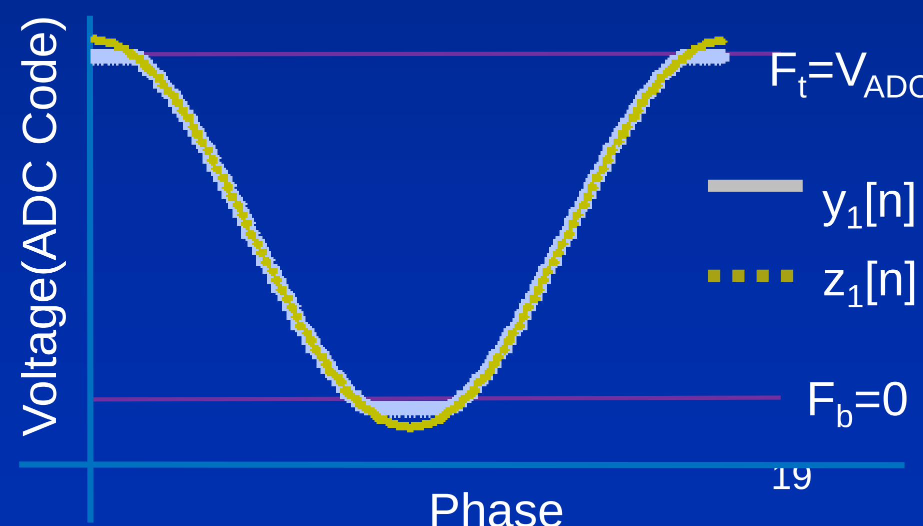


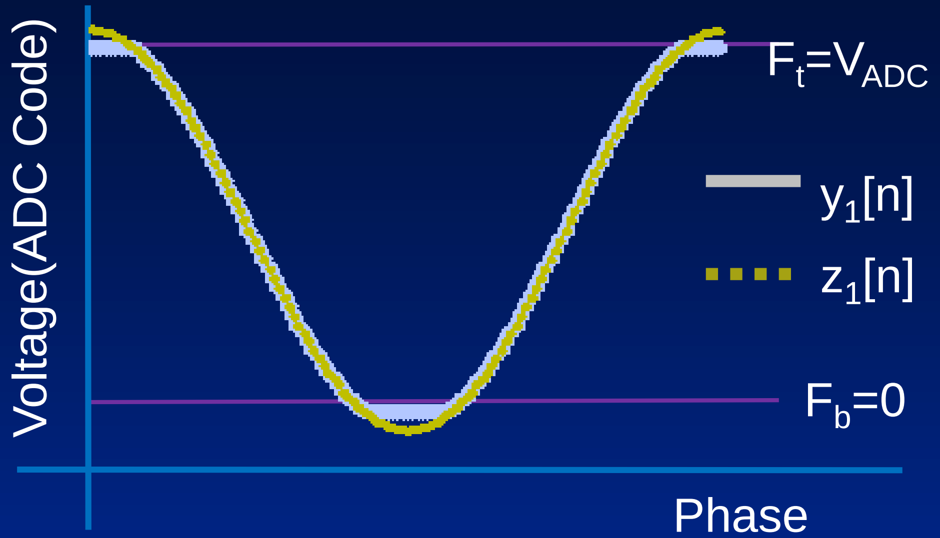

z[n] = Fundamental (Estimated)

y[n] (Unclipped) = Fundamental
+ Harmonics
+ Noise

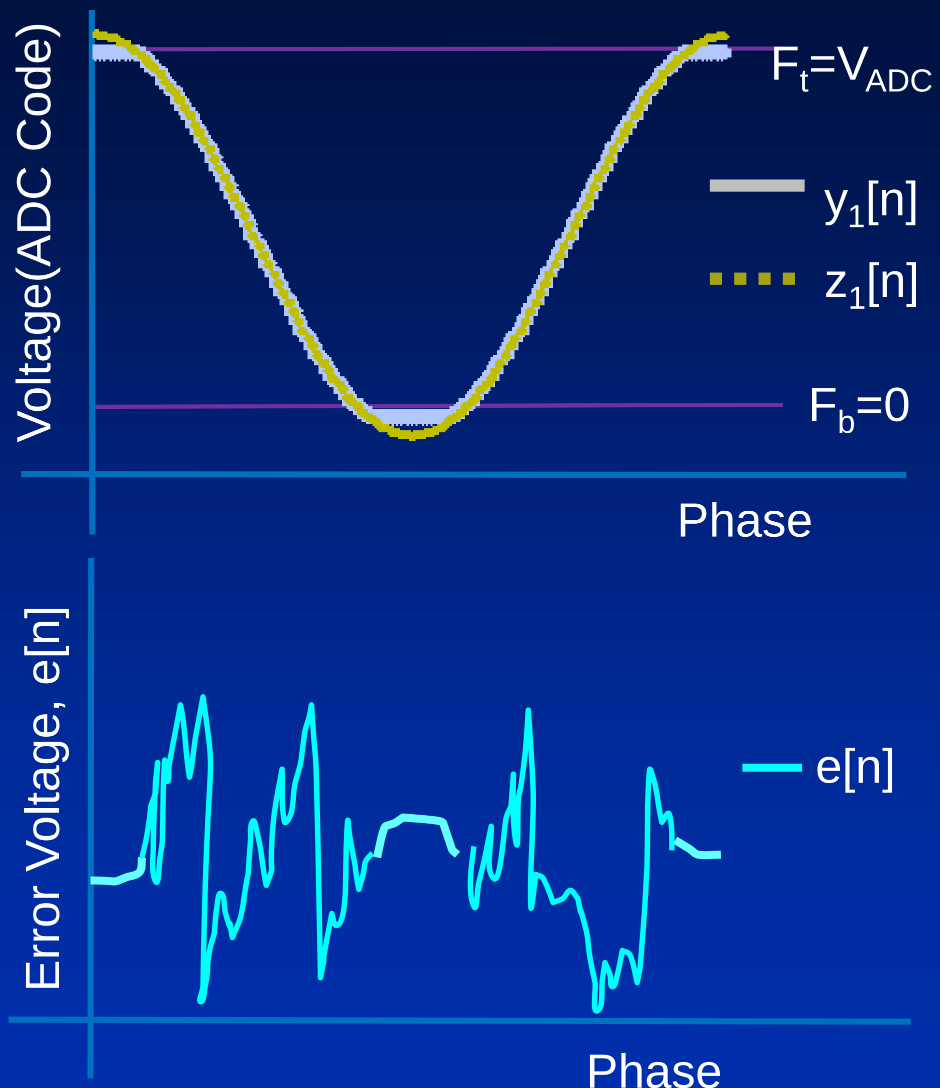
Fold y[n] and z[n] to one cycle



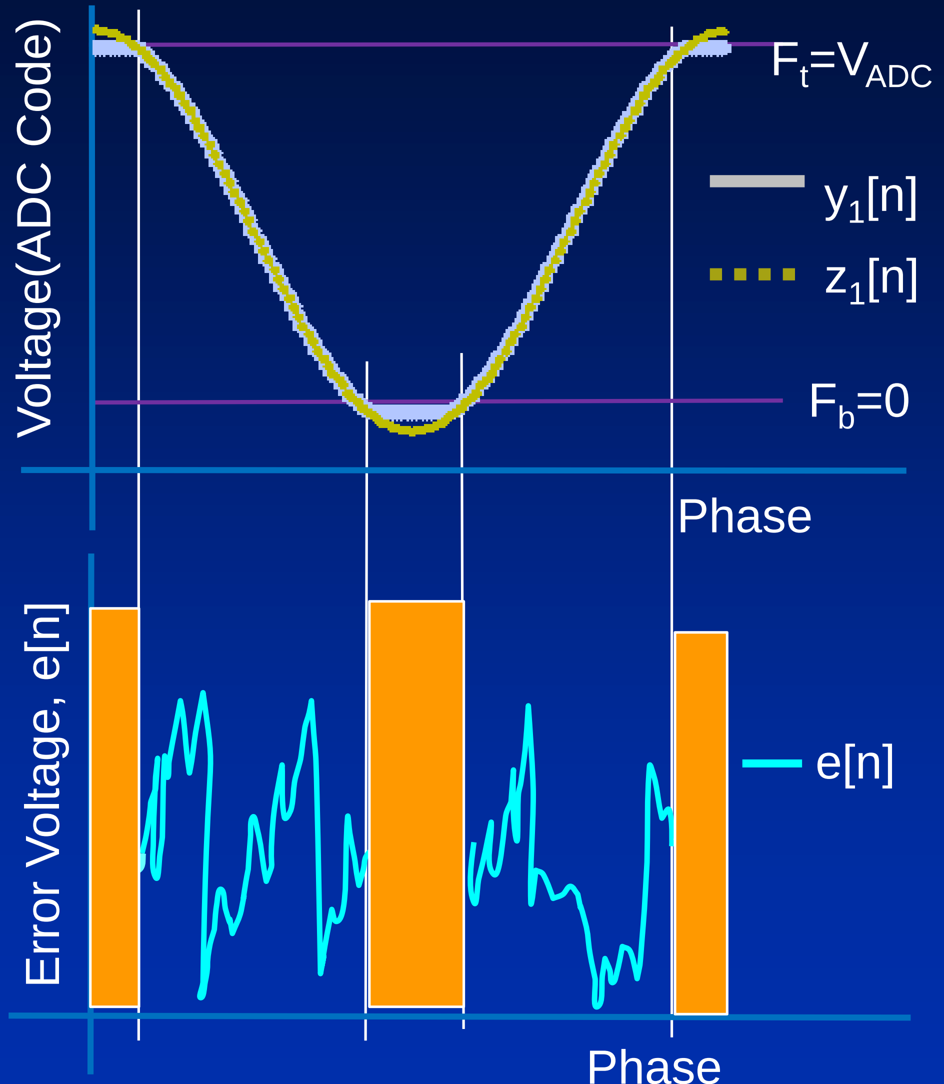
# FERARI (Fundamental Removal)



# FERARI (Fundamental Removal)

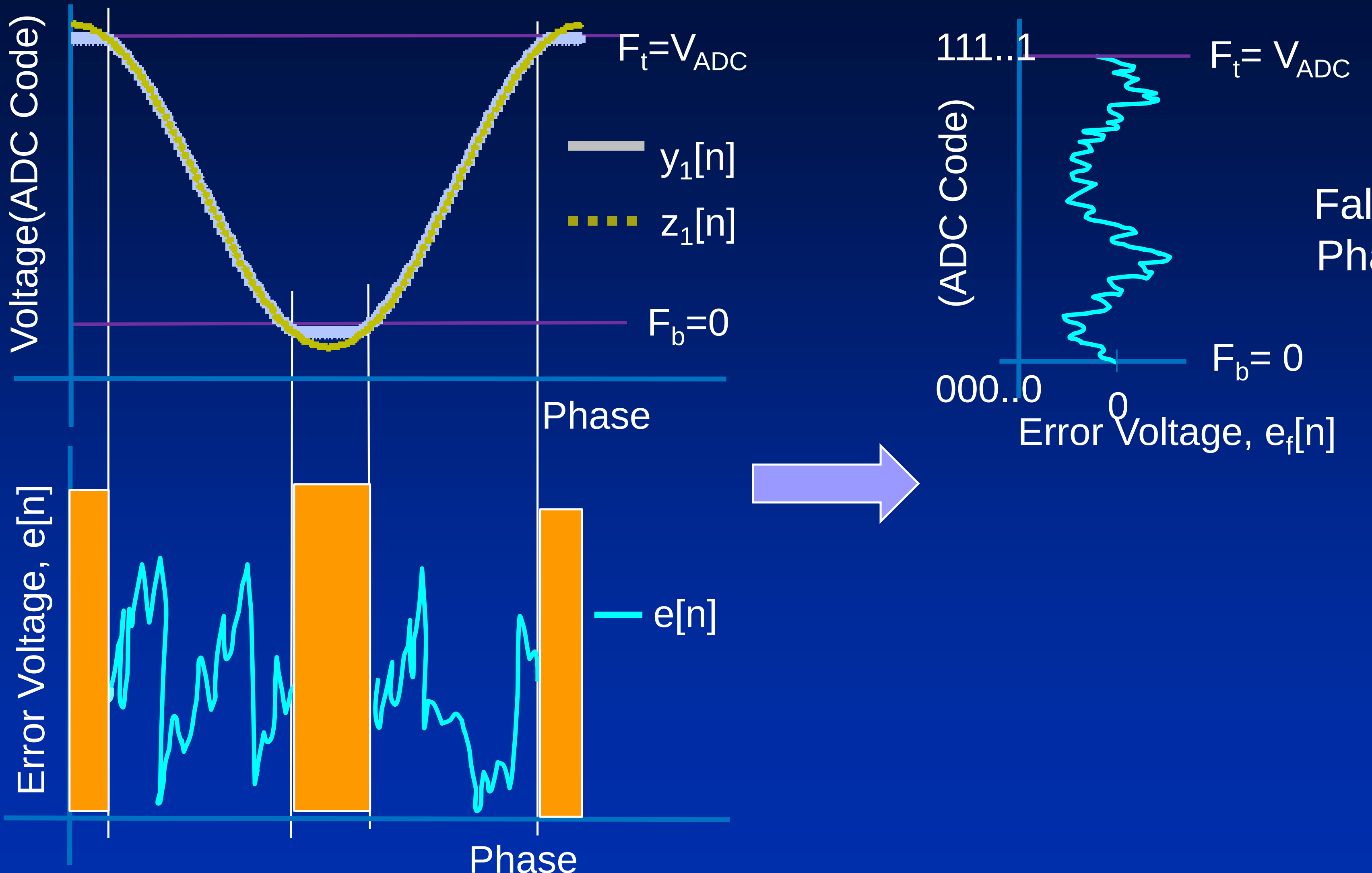


# FERARI (Fundamental Removal)



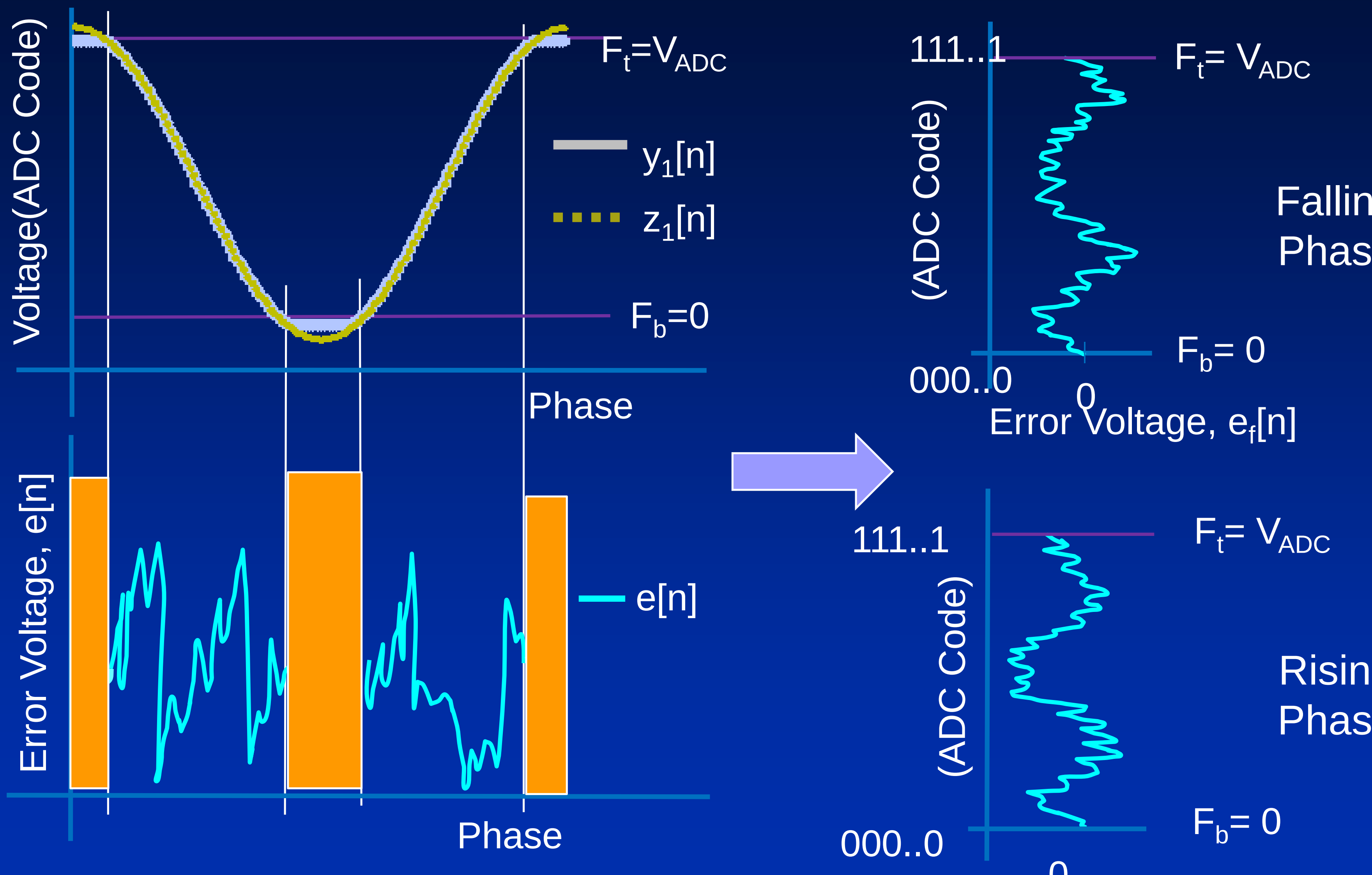

$e[n] = y_1[n] - z_1[n]$ = Harmonics + Noise

# FERARI (Fundamental Removal)




$e[n] = y_1[n]-z_1[n]$=Harmonics + Noise

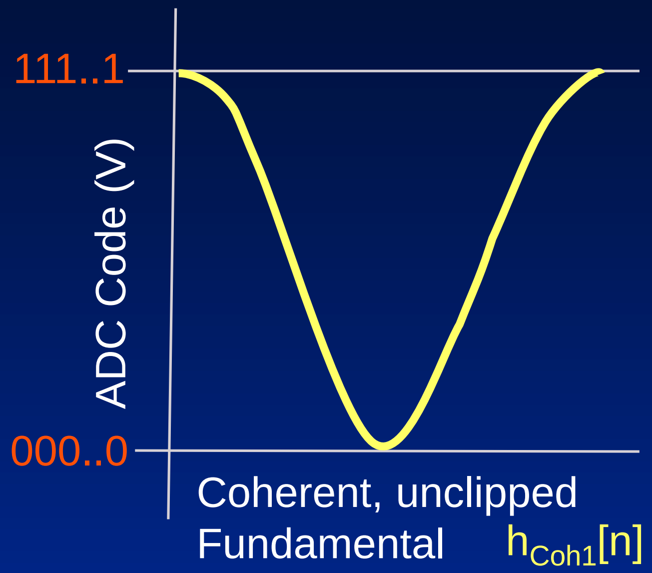
# FERARI (Fundamental Removal)



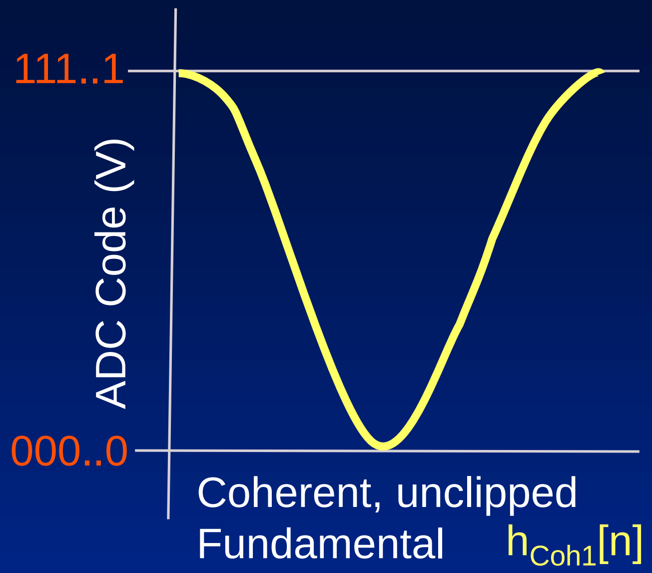

$e[n] = y_1[n]-z_1[n]$=Harmonics + Noise

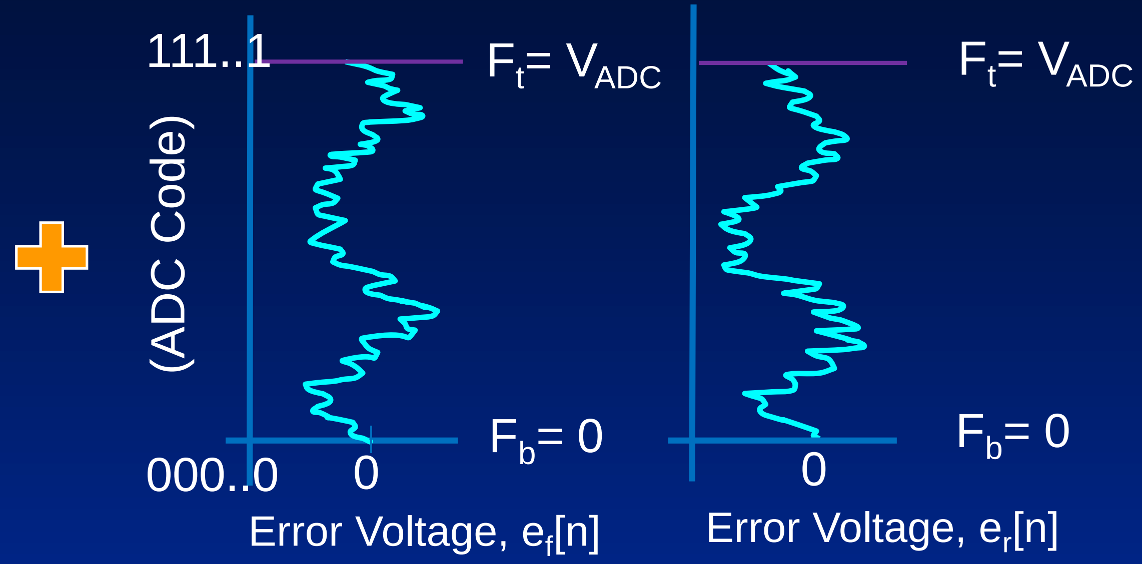
# FERARI (Residue Interpolation)

# FERARI (Residue Interpolation)

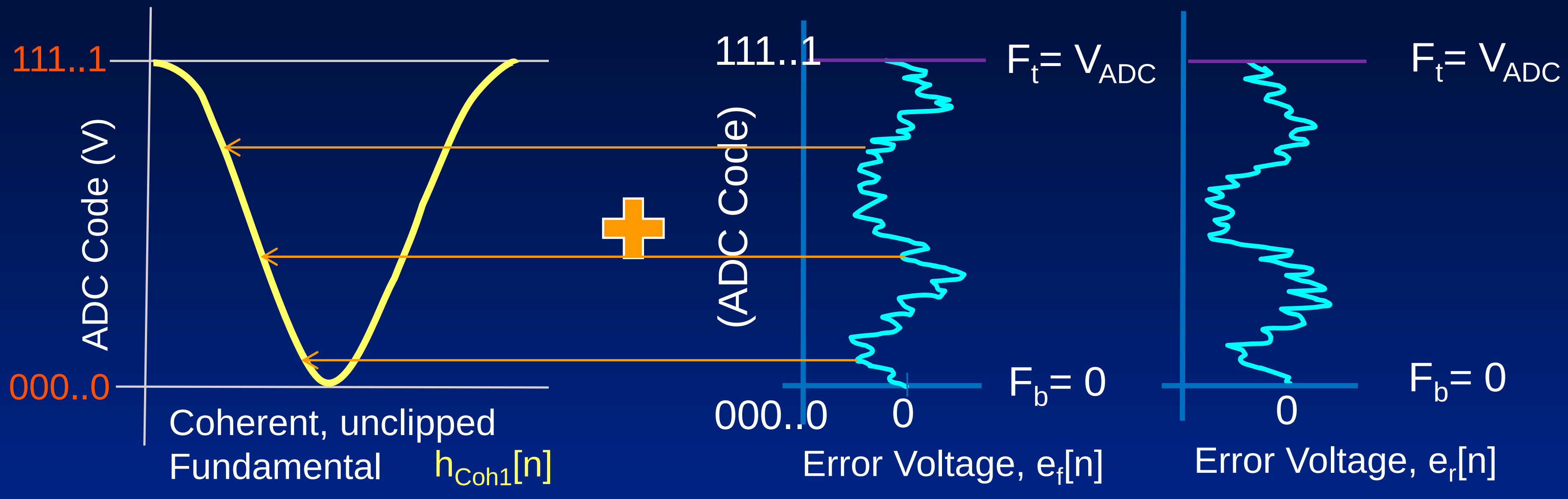


# FERARI (Residue Interpolation)

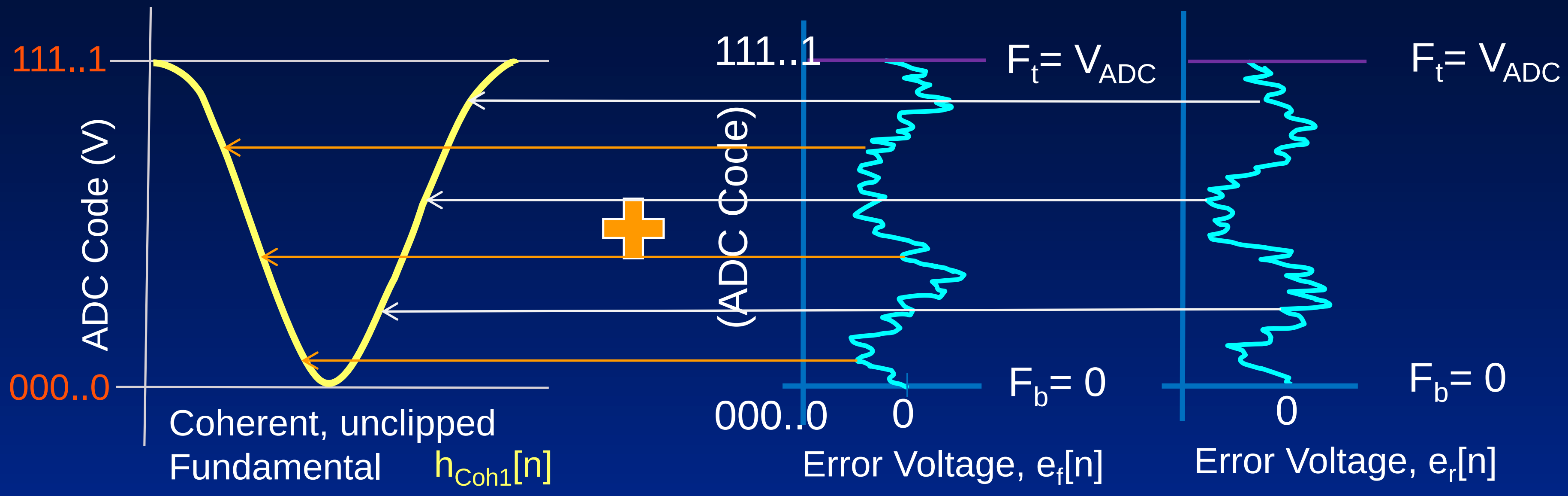


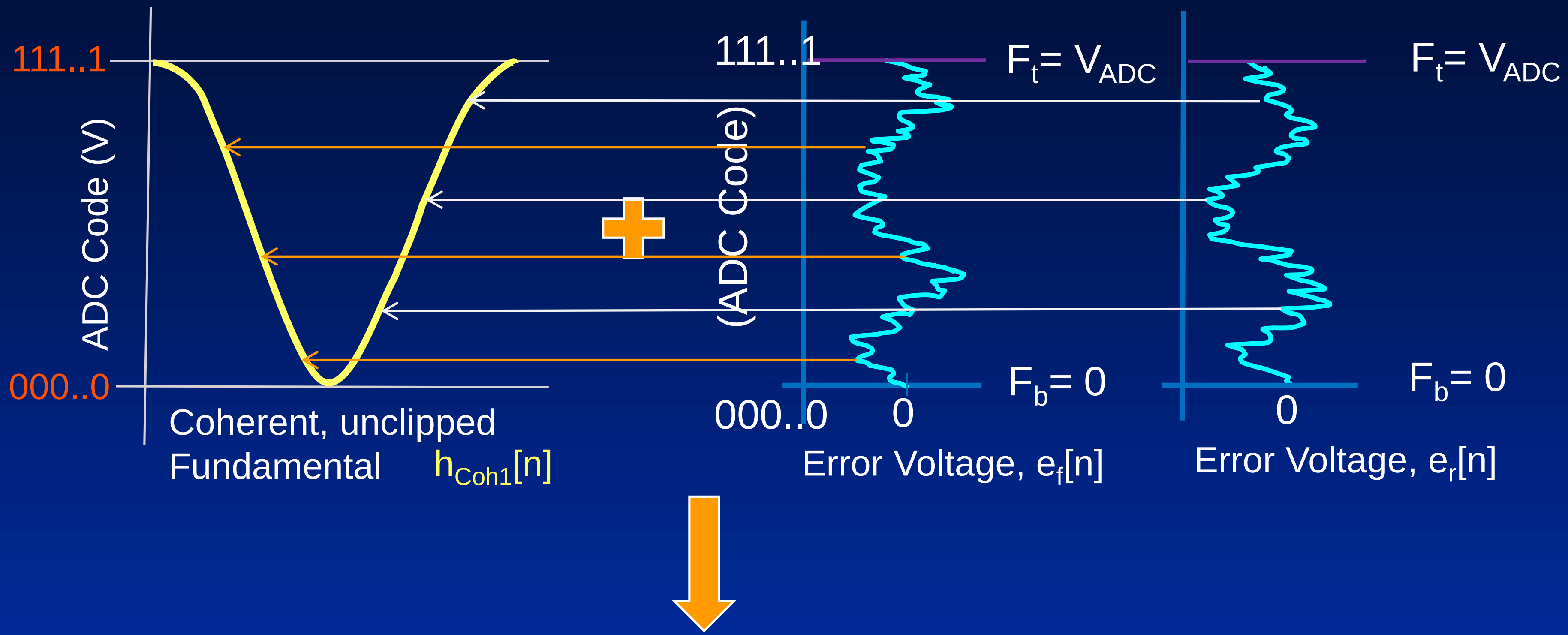
# FERARI (Residue Interpolation)



# FERARI (Residue Interpolation)

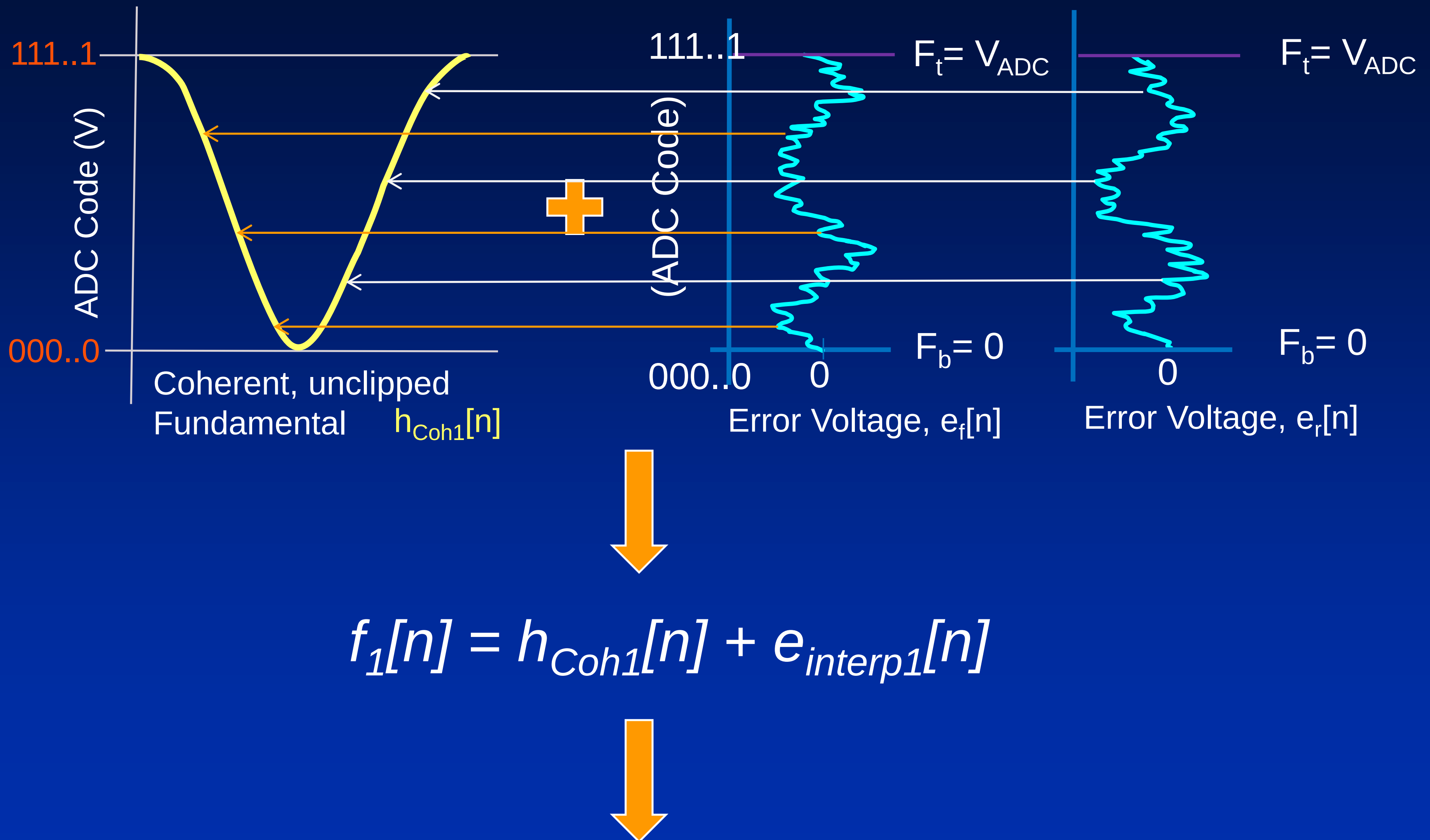


# FERARI (Residue Interpolation)




$$f_1[n] = h_{Coh1}[n] + e_{interp1}[n]$$

# FERARI (Residue Interpolation)




$$f_1[n] = h_{Coh1}[n] + e_{interp1}[n]$$

Unfold $f_1$ and perform DFT for spectral test

# Fundamental Estimation (A, $V_{OS}$)

$$y[n] = V_{OS} + A\cos\left(\frac{2\pi J}{M}n + \phi\right) + \sum_{h=2}^{H} A_h \cos\left(\frac{2\pi hJ}{M}n + \phi_h\right) + w[n] \qquad if\ \ 0 < x[n] < V_{ADC}$$

$J = J_{int} + \delta$

# Fundamental Estimation (A, $V_{OS}$)

$$y[n] = V_{OS} + A\cos\left(\frac{2\pi J}{M}n + \phi\right) + \sum_{h=2}^{H} A_h \cos\left(\frac{2\pi hJ}{M}n + \phi_h\right) + w[n] \qquad if\ \ 0 < x[n] < V_{ADC}$$

$J = J_{int} + \delta$

Estimate Fundamental → $V_{OS}$, A, $J_{int}$, δ and ϕ

# Fundamental Estimation (A, $V_{OS}$)

$$y[n] = V_{OS} + A\cos\left(\frac{2\pi J}{M}n + \phi\right) + \sum_{h=2}^{H} A_h \cos\left(\frac{2\pi hJ}{M}n + \phi_h\right) + w[n] \qquad if \;\; 0 < x[n] < V_{ADC}$$

$J = J_{int} + \delta$

Estimate Fundamental → $V_{OS}$, A, $J_{int}$, δ and ϕ

Estimate $V_{OS}$ & A (from time domain data)

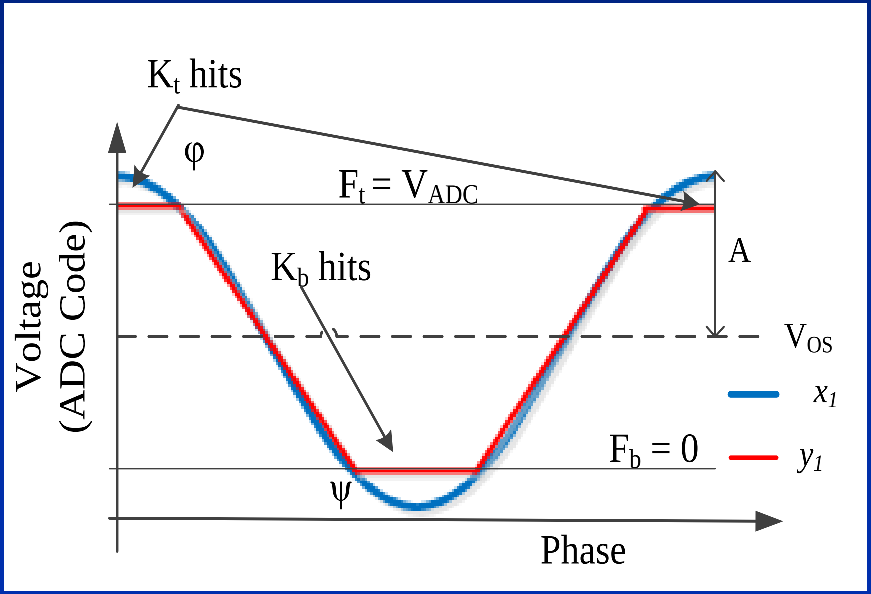
# Fundamental Estimation (A, $V_{OS}$)

$$y[n] = V_{OS} + A\cos\left(\frac{2\pi J}{M}n + \phi\right) + \sum_{h=2}^{H} A_h \cos\left(\frac{2\pi hJ}{M}n + \phi_h\right) + w[n] \qquad if\ \ 0 < x[n] < V_{ADC}$$

$J = J_{int} + \delta$

Estimate Fundamental → $V_{OS}$, A, $J_{int}$, δ and ϕ

Estimate $V_{OS}$ & A (from time domain data)



# Fundamental Estimation (A, $V_{OS}$)

$$y[n] = V_{OS} + A\cos\left(\frac{2\pi J}{M}n + \phi\right) + \sum_{h=2}^{H} A_h \cos\left(\frac{2\pi hJ}{M}n + \phi_h\right) + w[n] \qquad if\ \ 0 < x[n] < V_{ADC}$$

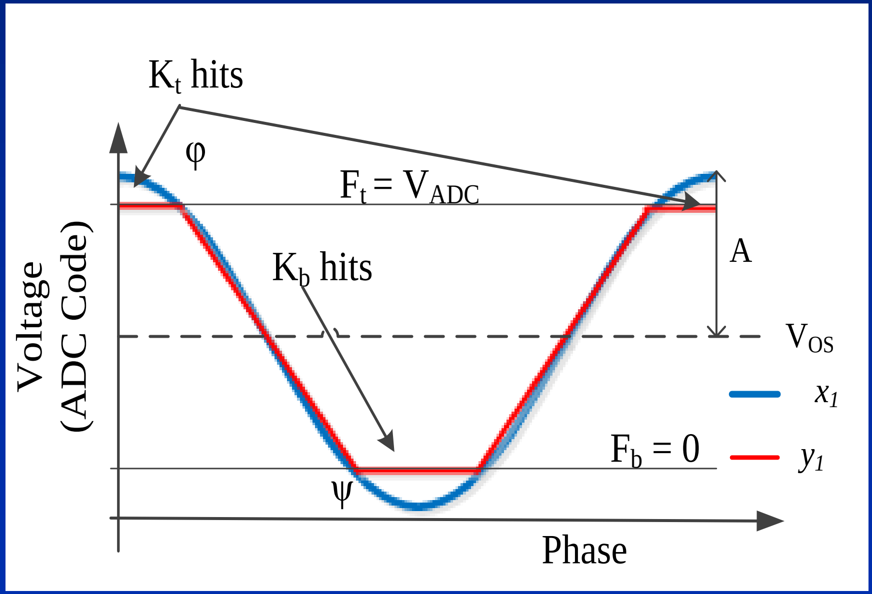
$J = J_{int} + \delta$

Estimate Fundamental → $V_{OS}$, A, $J_{int}$, δ and ϕ

Estimate $V_{OS}$ & A (from time domain data)

$$A = \frac{F_t - F_b}{\cos\left(\frac{K_t - 1}{M}\pi\right) + \cos\left(\frac{K_b - 1}{M}\pi\right)}$$

$$V_{OS} = \frac{F_t + F_b + A\left\{\cos\left(\frac{K_b - 1}{M}\pi\right) - \cos\left(\frac{K_t - 1}{M}\pi\right)\right\}}{2}$$



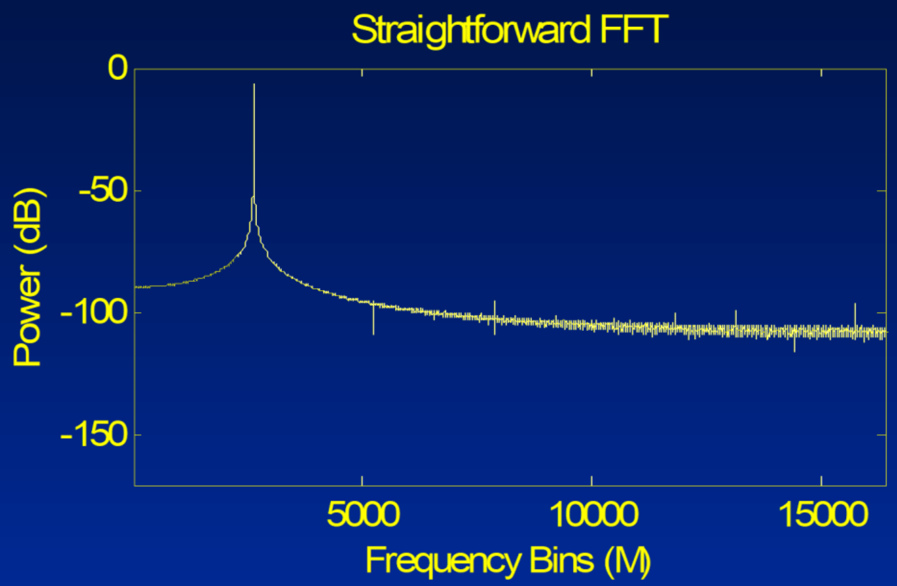
# Fundamental Estimation ($J_{int}$, $\delta$, $\phi$)

Using y[n] and frequency domain data, $Y_k$

# Fundamental Estimation ($J_{int}$, δ, ϕ)

## Using y[n] and frequency domain data, $Y_k$

$Y_k$ → $k^{th}$ DFT coefficient of y[n]

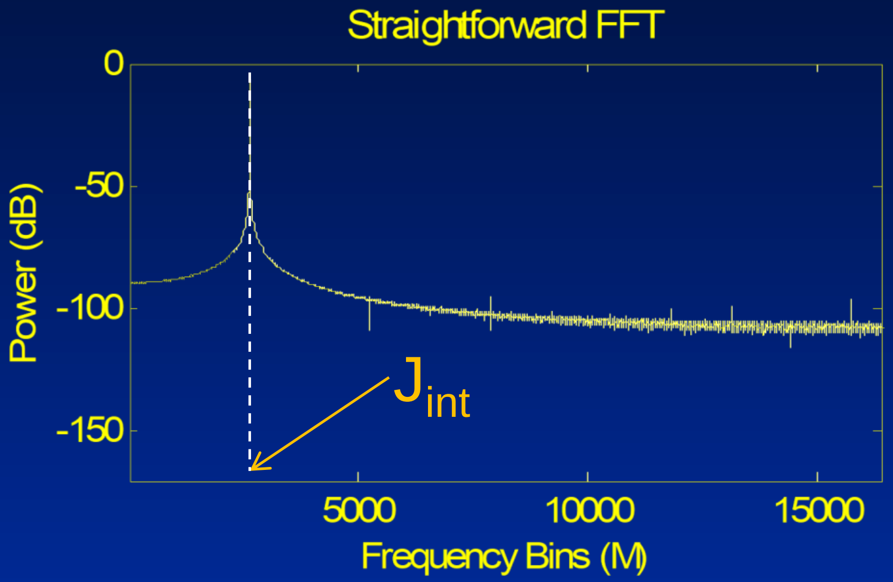


# Fundamental Estimation ($J_{int}$, δ, ϕ)

## Using y[n] and frequency domain data, $Y_k$

$Y_k \rightarrow k^{th}$ DFT coefficient of y[n]

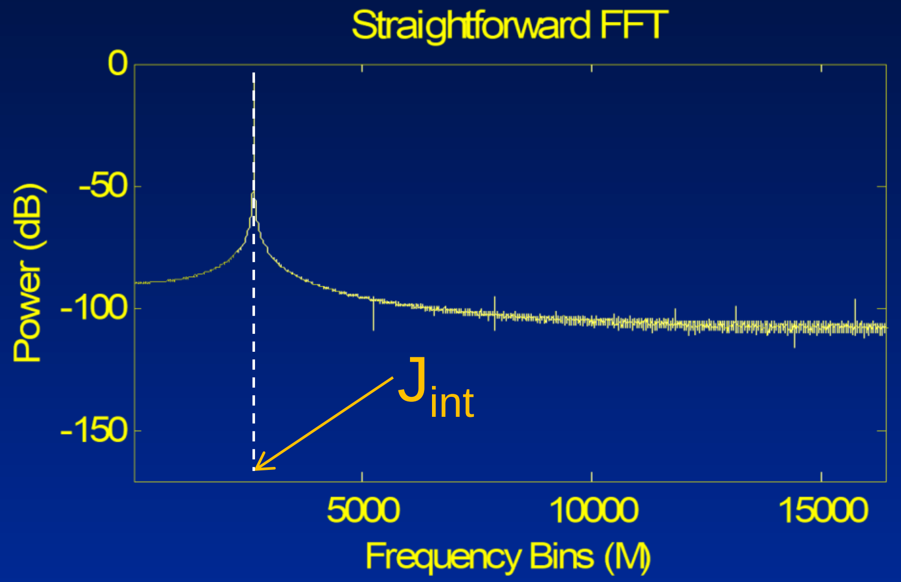
$$J_{\text{int}} = \arg\max_{1 \le k \le M/2} |Y_k|$$



# Fundamental Estimation ($J_{int}$, δ, ϕ)

## Using y[n] and frequency domain data, $Y_k$

$Y_k$ → $k^{th}$ DFT coefficient of y[n]




$$J_{\text{int}} = \underset{1 \le k \le M/2}{\arg\max} |Y_k|$$

## Initial estimates of δ and ϕ

$$\delta_0 = -\frac{M}{2\pi} imag\left( \ln\left( \frac{\frac{Y_{J_{\text{int}}}}{Y_{J_{\text{int}}+1}} - \frac{Y_{J_{\text{int}}}}{Y_{J_{\text{int}}-1}}}{\frac{Y_{J_{\text{int}}}}{Y_{J_{\text{int}}+1}} - \frac{Y_{J_{\text{int}}}}{Y_{J_{\text{int}}-1}} + e^{j\frac{2\pi}{M}} - e^{-j\frac{2\pi}{M}}} \right) \right)$$

$$\phi_0 = -imag\left( \ln\left( \frac{2MY_{J_{\text{int}}}}{\widehat{A}} \frac{1 - e^{j\frac{2\pi\delta_0}{M}}}{1 - e^{j2\pi\delta_0}} \right) \right)$$

# Fundamental Estimation

$$y[n]=V_{os}+A*\sin\left(\frac{2\pi J}{M}n+\phi\right)+HD+w[n]$$

# Fundamental Estimation

$$y[n]=V_{os}+A*\sin\left(\frac{2\pi J}{M}n+\phi\right)+HD+w[n]$$

To improve accuracy in δ and ϕ

$\Delta\delta = \delta - \delta_0$ $\Delta\phi = \phi - \phi_0$

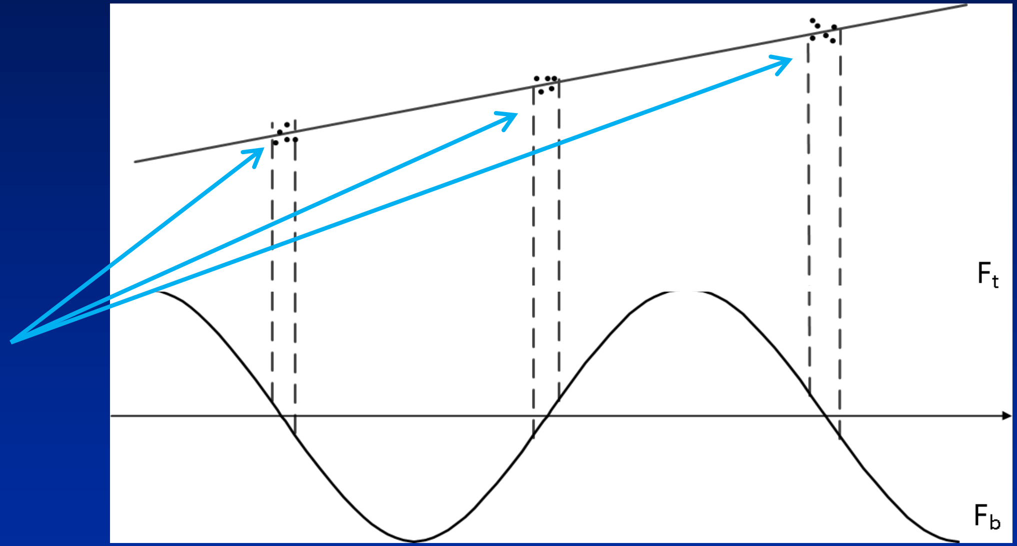
# Fundamental Estimation

$$y[n]=V_{os}+A*\sin\left(\frac{2\pi J}{M}n+\phi\right)+HD+w[n]$$

To improve accuracy in δ and ϕ

$\Delta\delta = \delta - \delta_0$ $\Delta\phi = \phi - \phi_0$

Estimate Δδ and Δϕ using Least squares on points close to mid-range codes



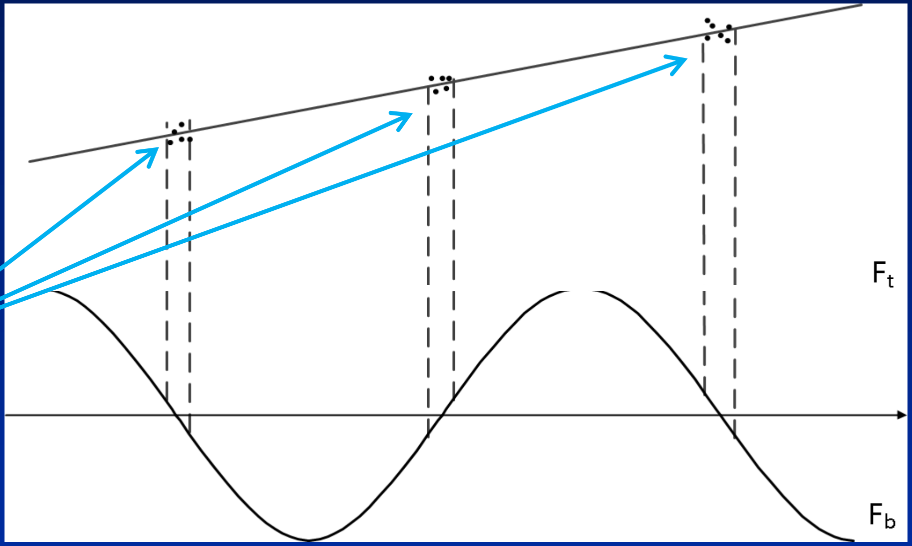
# Fundamental Estimation

$$y[n]=V_{os}+A*\sin\left(\frac{2\pi J}{M}n+\phi\right)+HD+w[n]$$

To improve accuracy in δ and ϕ

$\Delta\delta = \delta - \delta_0$ $\Delta\phi = \phi - \phi_0$

Estimate Δδ and Δϕ using Least squares on points close to mid-range codes




$$\frac{2\pi n}{M}\Delta\delta+\Delta\phi=\cos^{-1}\left(\frac{y[n]-V_{OS}}{A}\right)-\phi_0-\frac{2\pi\left(J_{int}+\delta_0\right)n}{M}$$

→ n corresponds to mid-code points

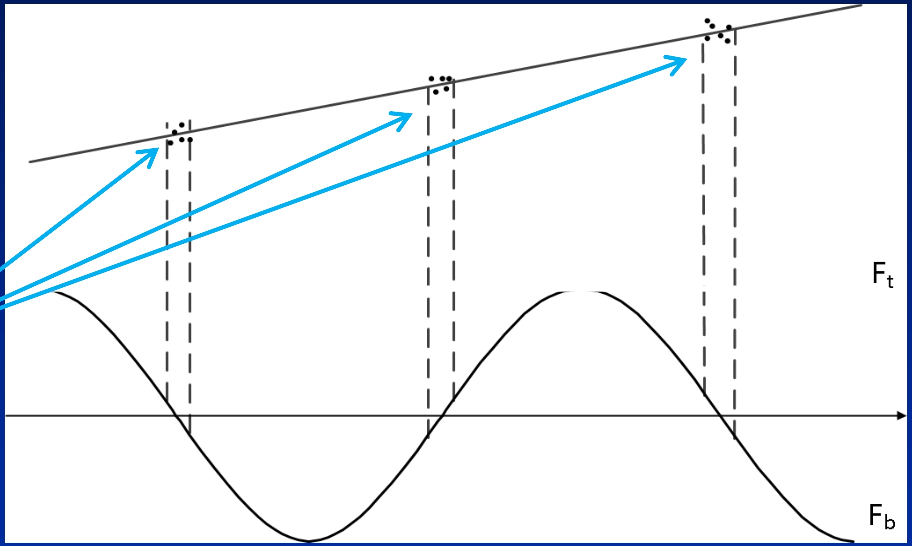
# Fundamental Estimation

$$y[n]=V_{os}+A*\sin\left(\frac{2\pi J}{M}n+\phi\right)+HD+w[n]$$

To improve accuracy in δ and ϕ

$\Delta\delta = \delta - \delta_0$ $\Delta\phi = \phi - \phi_0$

Estimate Δδ and Δϕ using Least squares on points close to mid-range codes

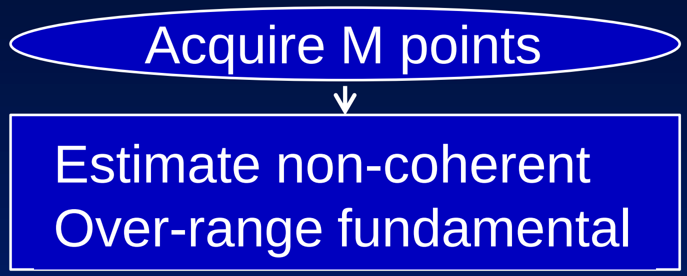



$$\frac{2\pi n}{M}\Delta\delta+\Delta\phi=\cos^{-1}\left(\frac{y[n]-V_{OS}}{A}\right)-\phi_0-\frac{2\pi\left(J_{\text{int}}+\delta_0\right)n}{M}$$

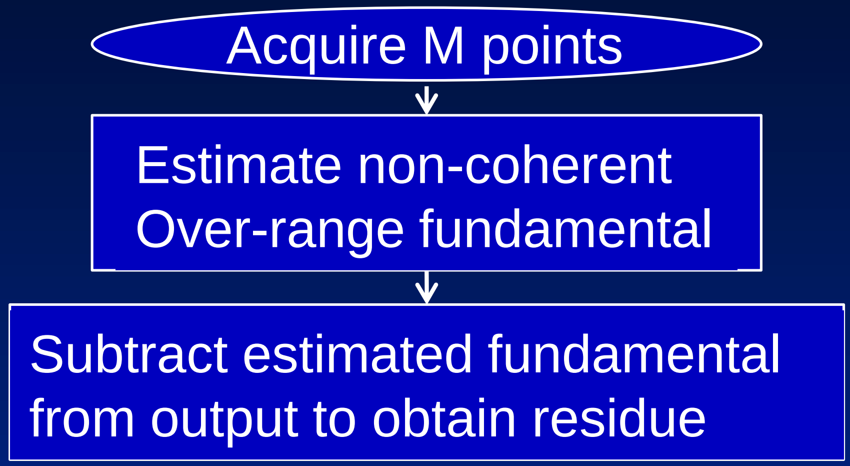
→ n corresponds to mid-code points

Fundamental Estimated

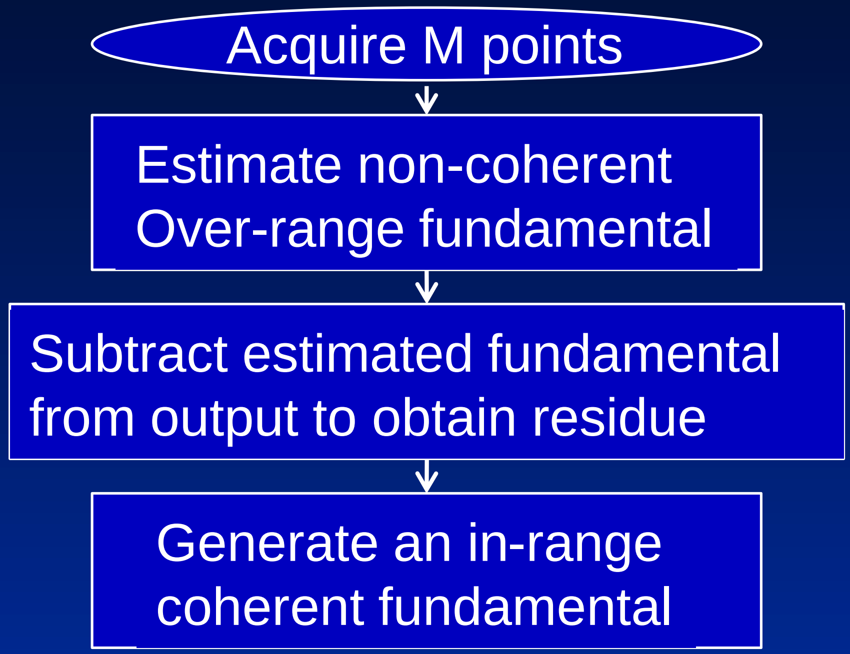
# Flow Chart of FERARI



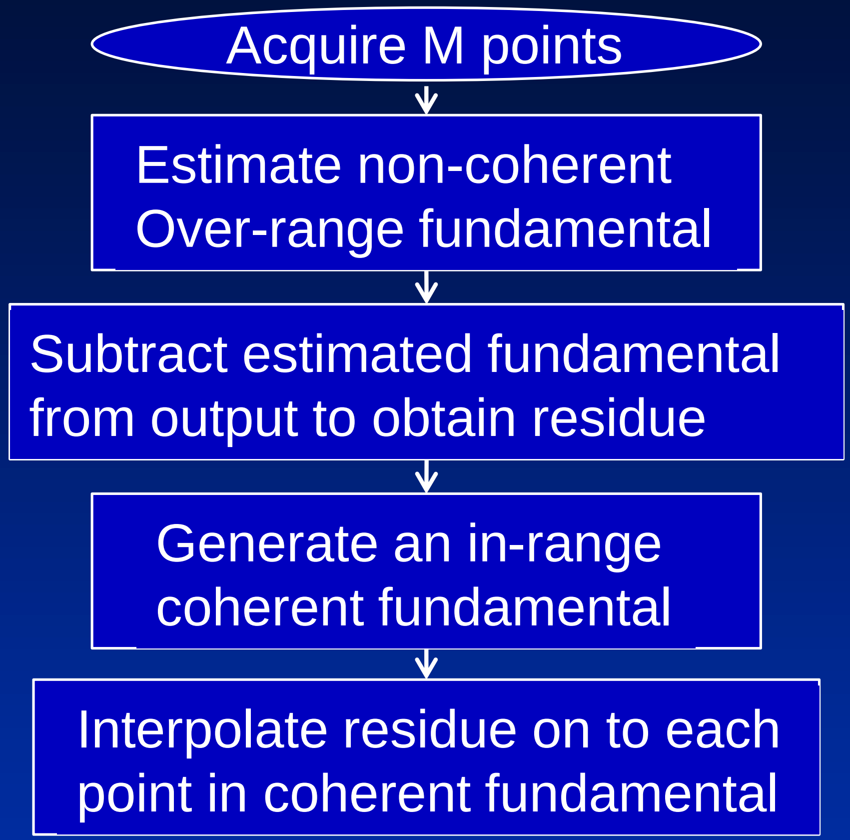
# Flow Chart of FERARI



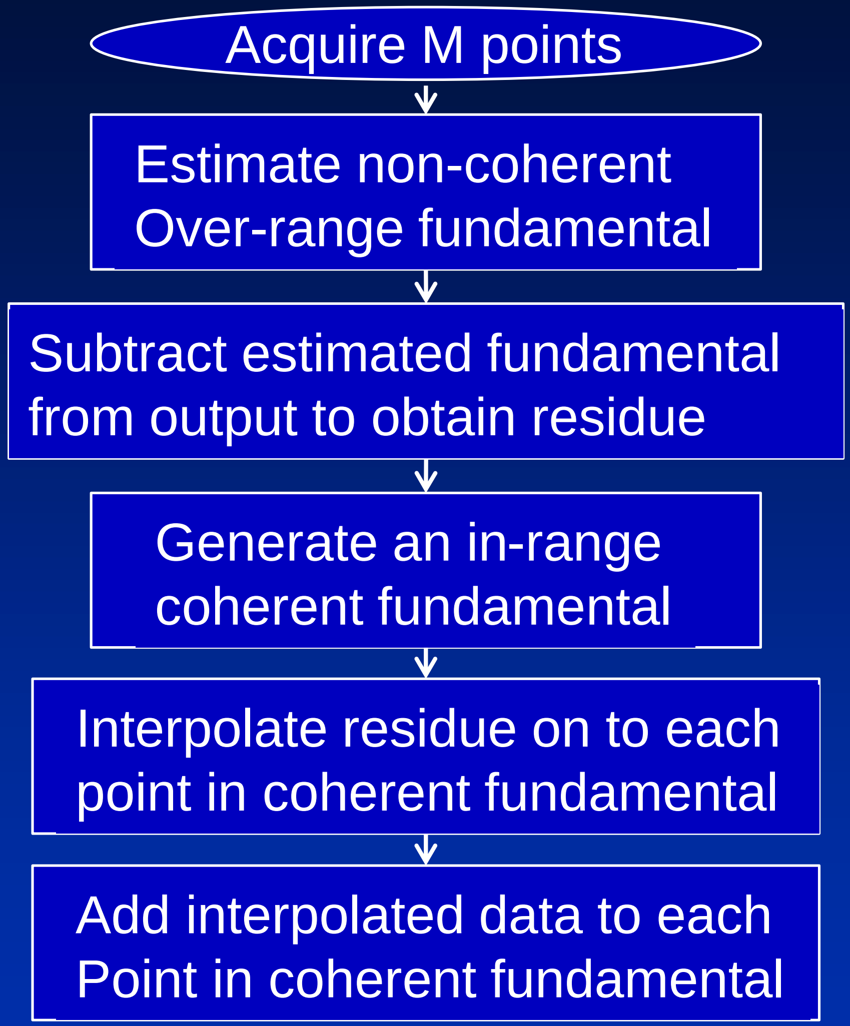
# Flow Chart of FERARI



# Flow Chart of FERARI



# Flow Chart of FERARI



# Flow Chart of FERARI

- Acquire M points
- ↓
- Estimate non-coherent Over-range fundamental
- ↓
- Subtract estimated fundamental from output to obtain residue
- ↓
- Generate an in-range coherent fundamental
- ↓
- Interpolate residue on to each point in coherent fundamental
- ↓
- Add interpolated data to each Point in coherent fundamental
- ↓
- Take DFT and perform spectral testing

# Outline

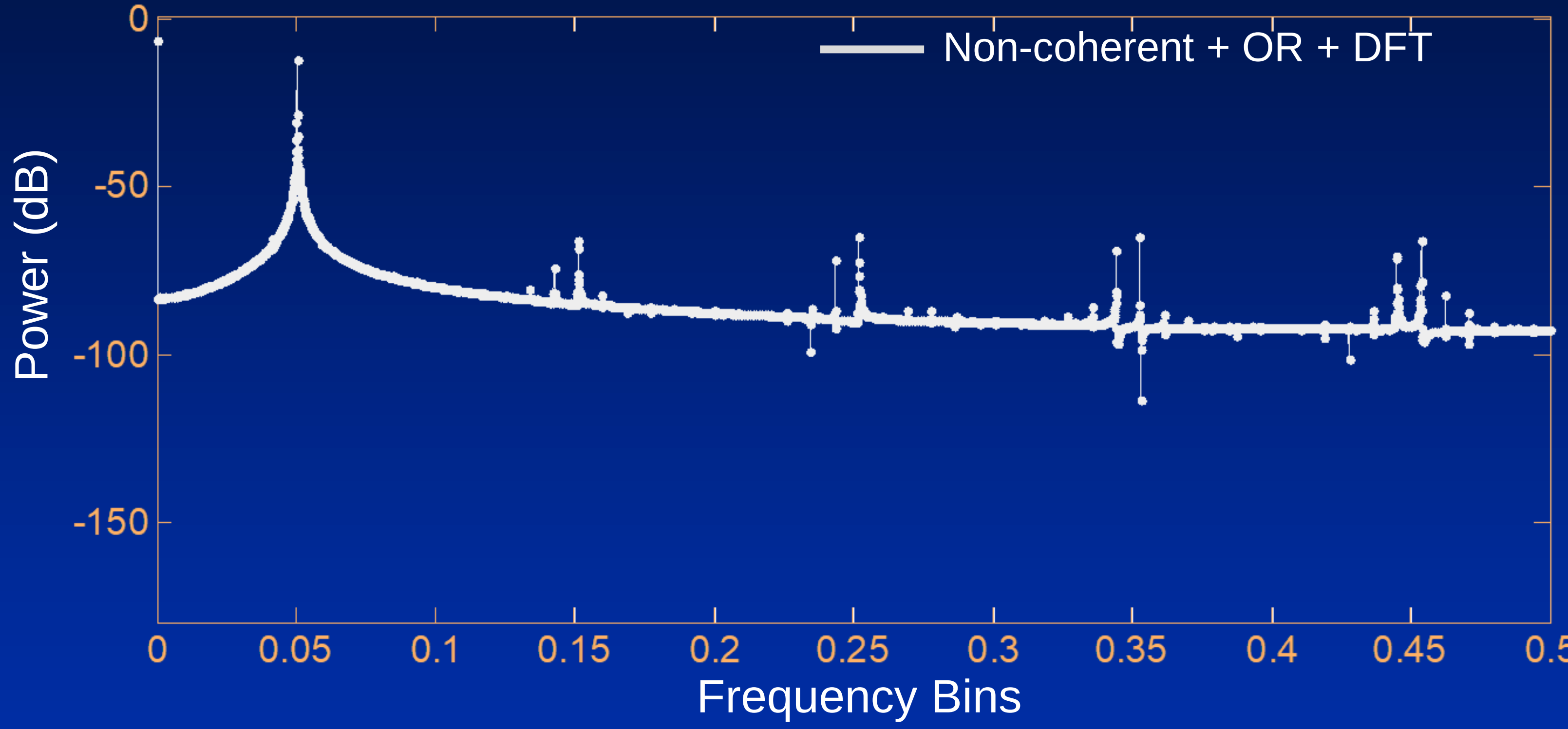
- Motivation and Spectral testing Background
- Proposed spectral testing method
  - Fundamental Estimation, Removal And Residue Interpolation (FERARI)
  - Spectral Testing Algorithm
- Simulation Results
- Measurement Results
- Conclusion

# Simulation Results

Functionality : 16-bit ADC, INL = 0.6 LSB, M = 8192

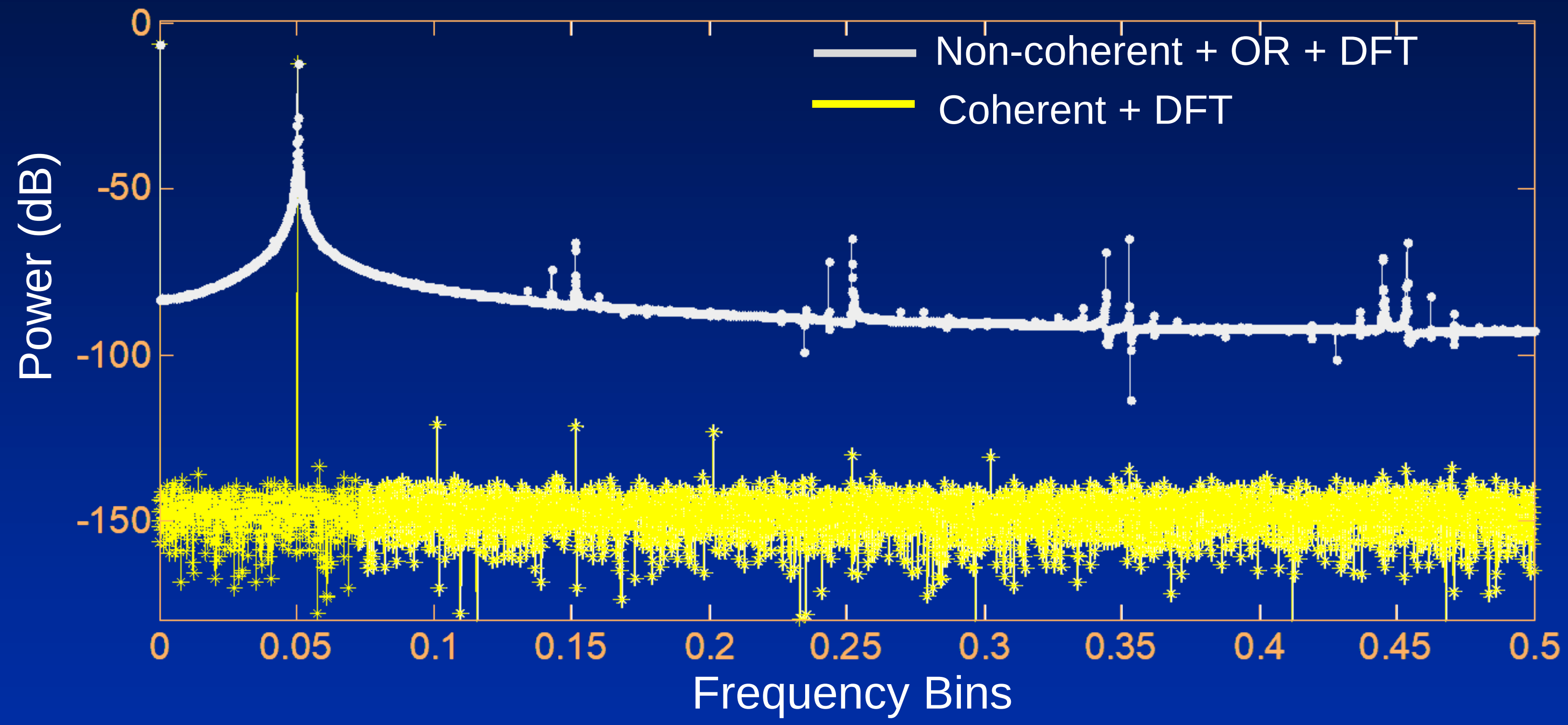
# Simulation Results

Functionality : 16-bit ADC, INL = 0.6 LSB, M = 8192



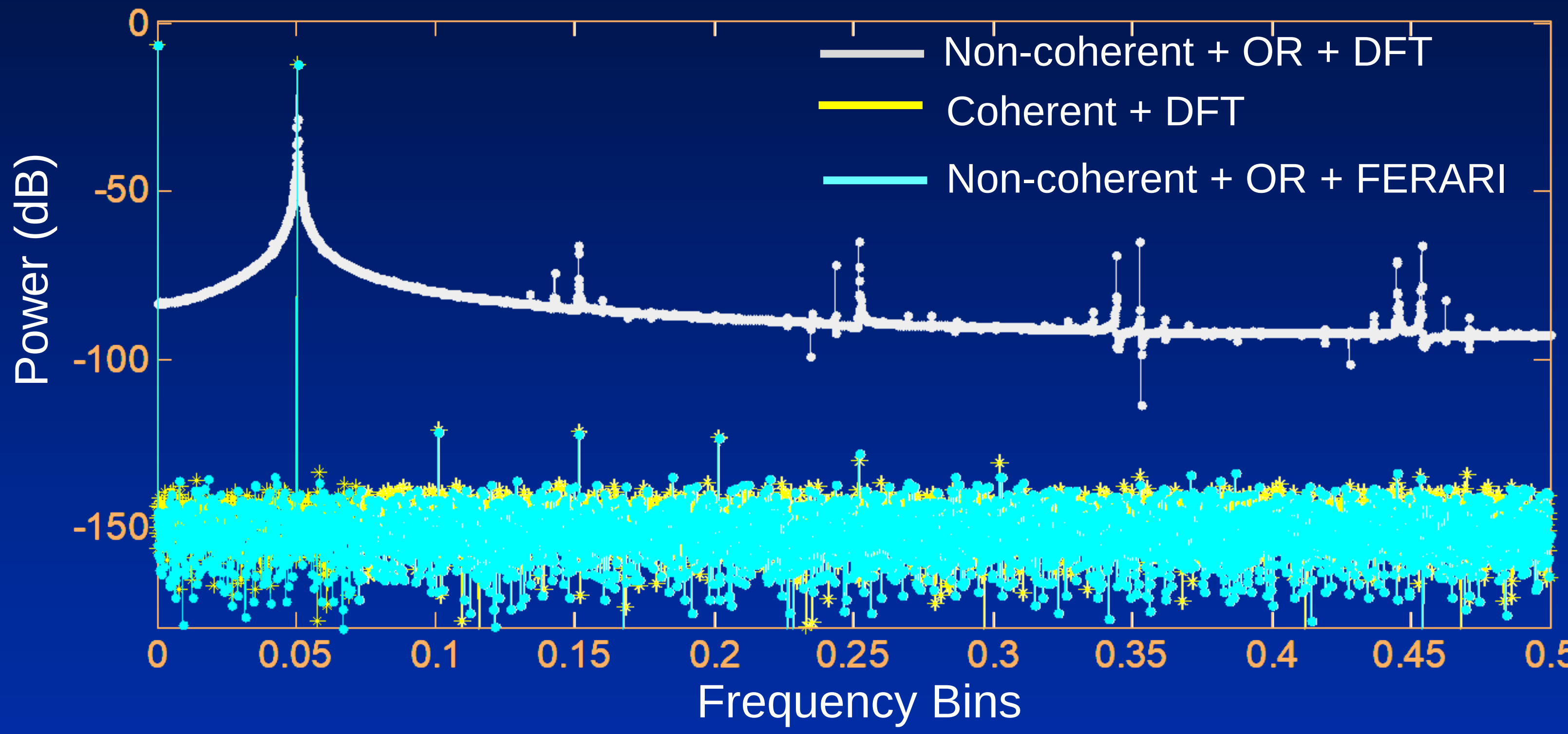
# Simulation Results

Functionality : 16-bit ADC, INL = 0.6 LSB, M = 8192



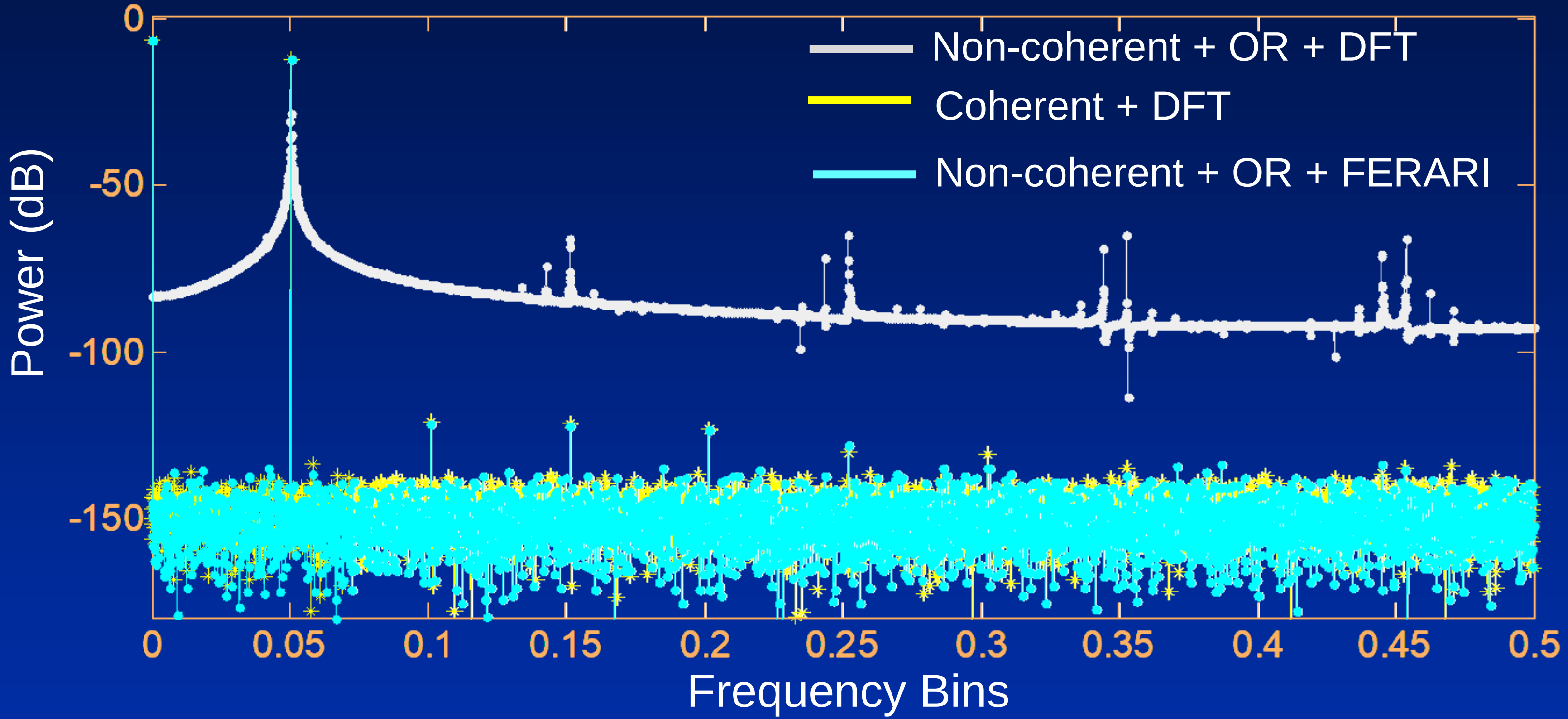
# Simulation Results

Functionality : 16-bit ADC, INL = 0.6 LSB, M = 8192



# Simulation Results

Functionality : 16-bit ADC, INL = 0.6 LSB, M = 8192




| Method | % Clip | δ | THD (dB) | SFDR (dB) |
|---|---|---|---|---|
| Coherent + DFT | 0 | 0 | -104.2 | 108.6 |
| Non-coherent + Clipping + FERARI | 1.7 | 0.14 | -104.7 | 109.4 |

# Simulation Results

## Robustness (w.r.t non-coherency and clipping)

16-bit ADC, INL = 1.8LSB, M = 8192

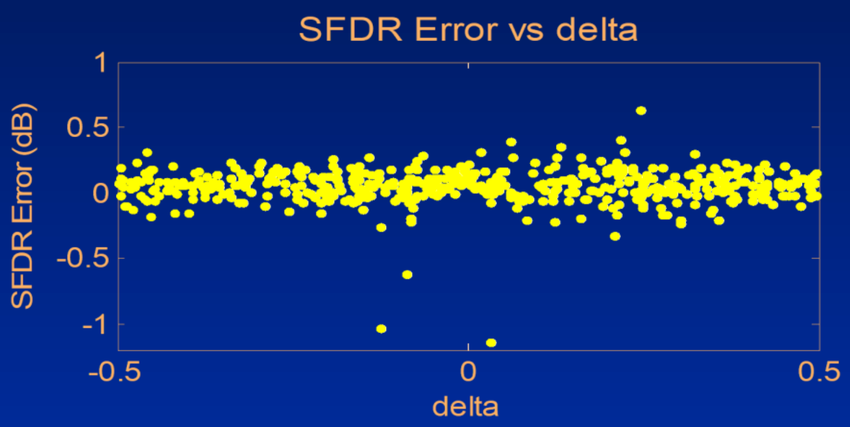
$\delta$ range = -0.5 to 0.5; % amplitude over-range = 0 to 2

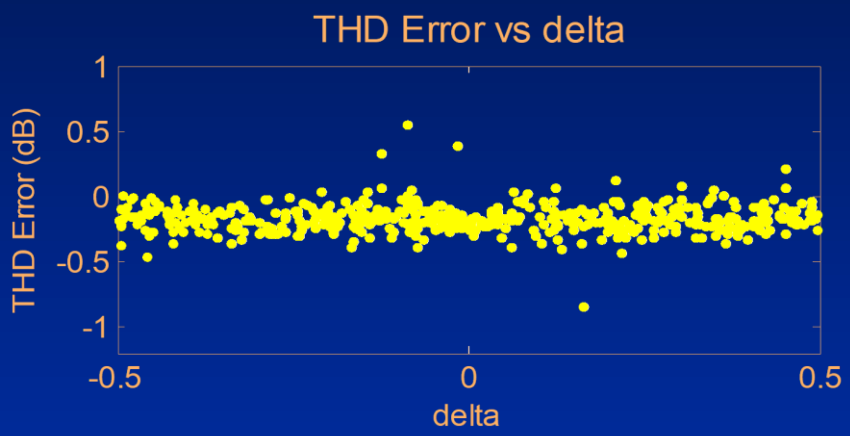
# Simulation Results

## Robustness (w.r.t non-coherency and clipping)

16-bit ADC, INL = 1.8LSB, M = 8192

δ range = -0.5 to 0.5; % amplitude over-range = 0 to 2



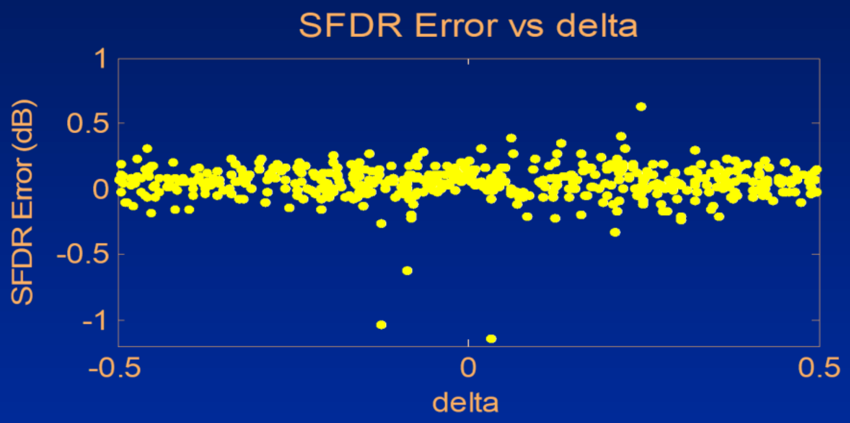



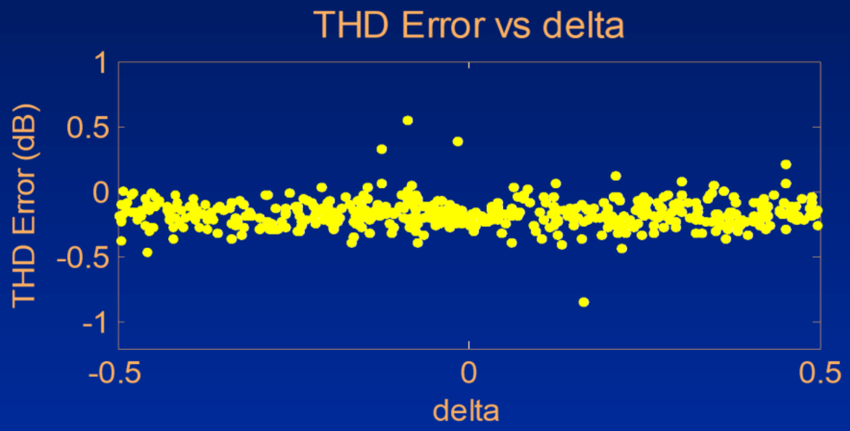
# Simulation Results

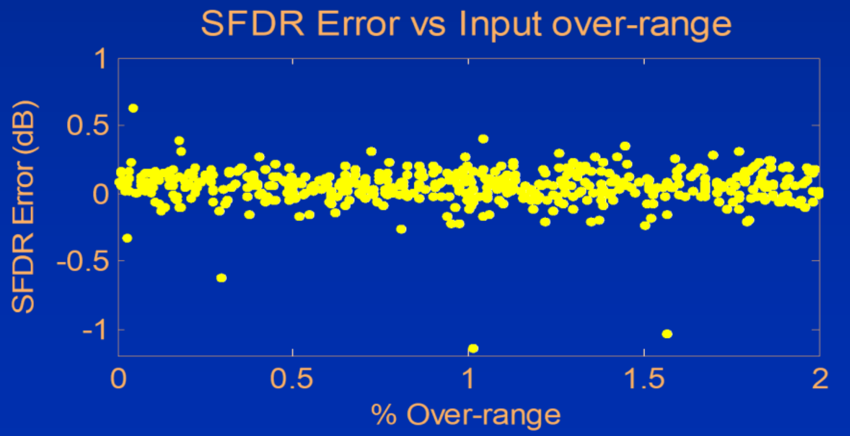
## Robustness (w.r.t non-coherency and clipping)

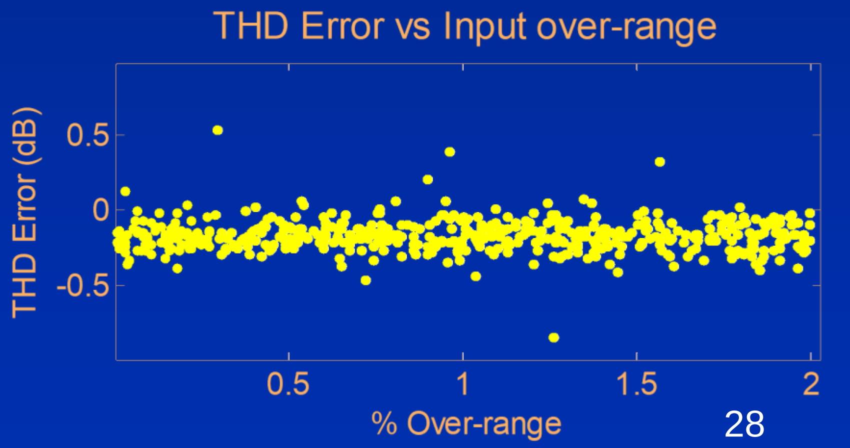
16-bit ADC, INL = 1.8LSB, M = 8192

δ range = -0.5 to 0.5; % amplitude over-range = 0 to 2



# **Use of interpolation** (Varying over-range)

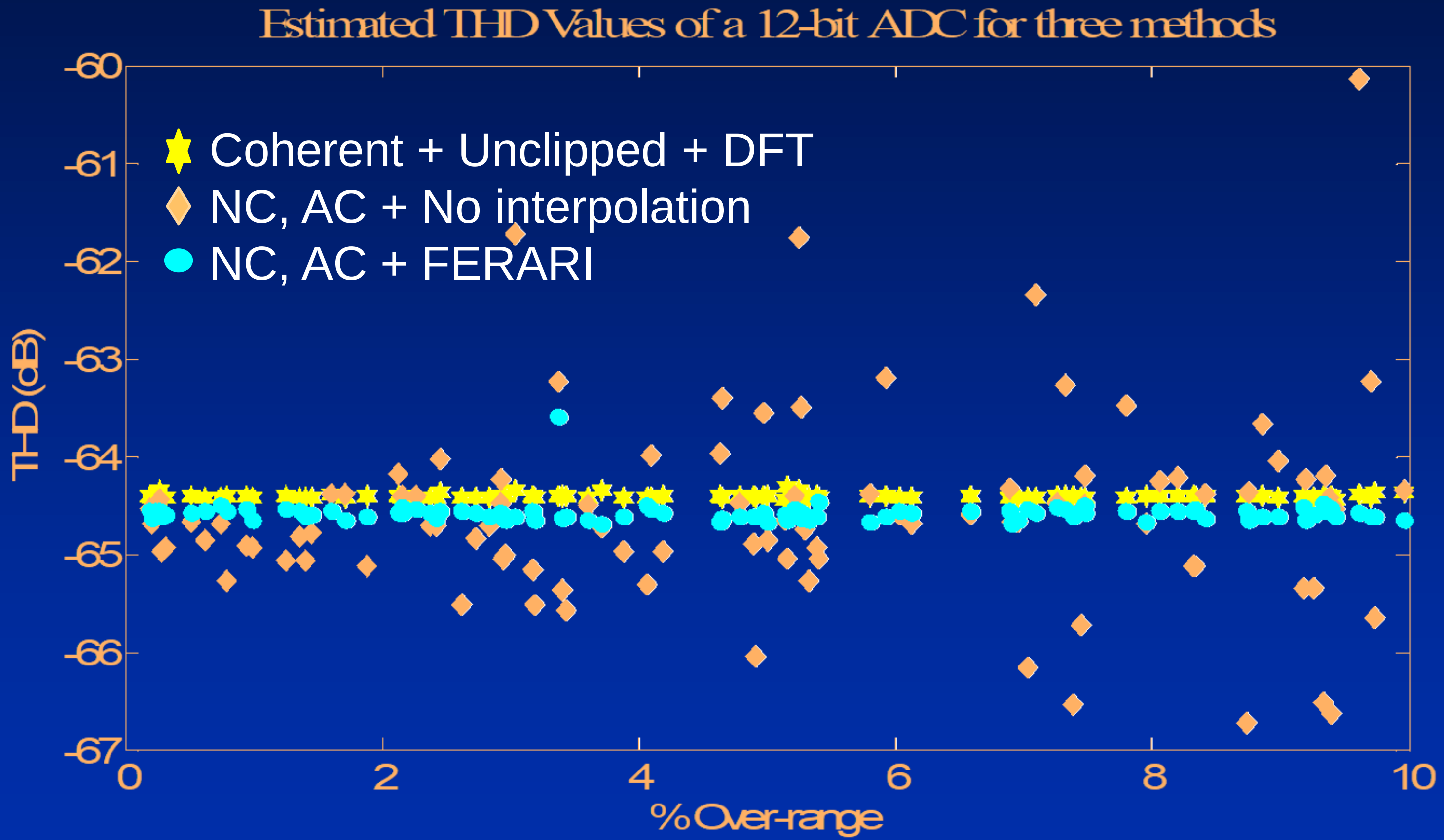
ADC resolution = 12

Input over-range : From 0 to 10%

# **Use of interpolation** (Varying over-range)

ADC resolution = 12

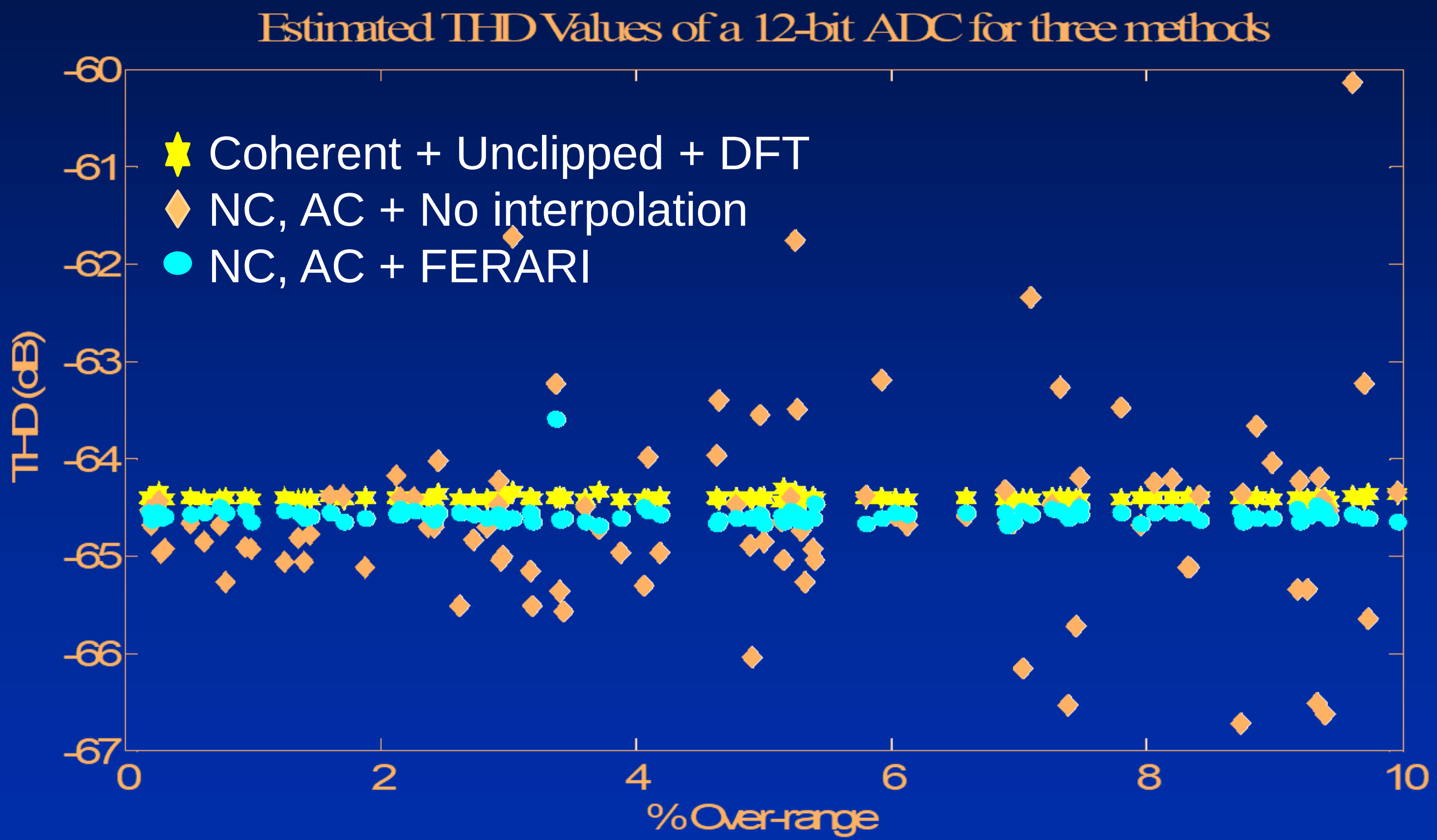
Input over-range : From 0 to 10%



# Use of interpolation (Varying over-range)

ADC resolution = 12

Input over-range : From 0 to 10%



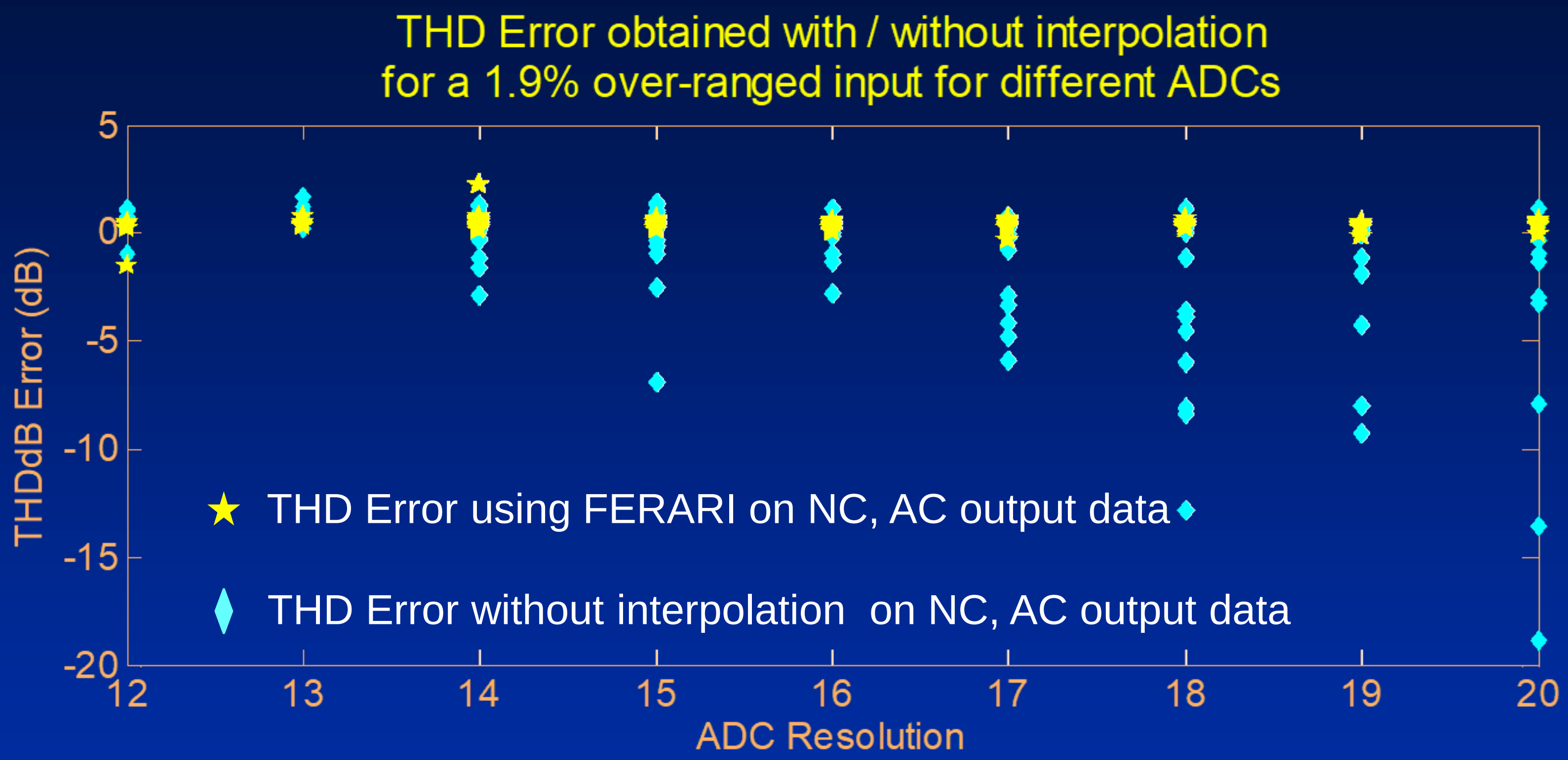

Interpolation required for accurate results

# **Use of interpolation** (Varying resolution)

ADC resolution = From 12 to 20 bits;    Input over-range = 1.9%

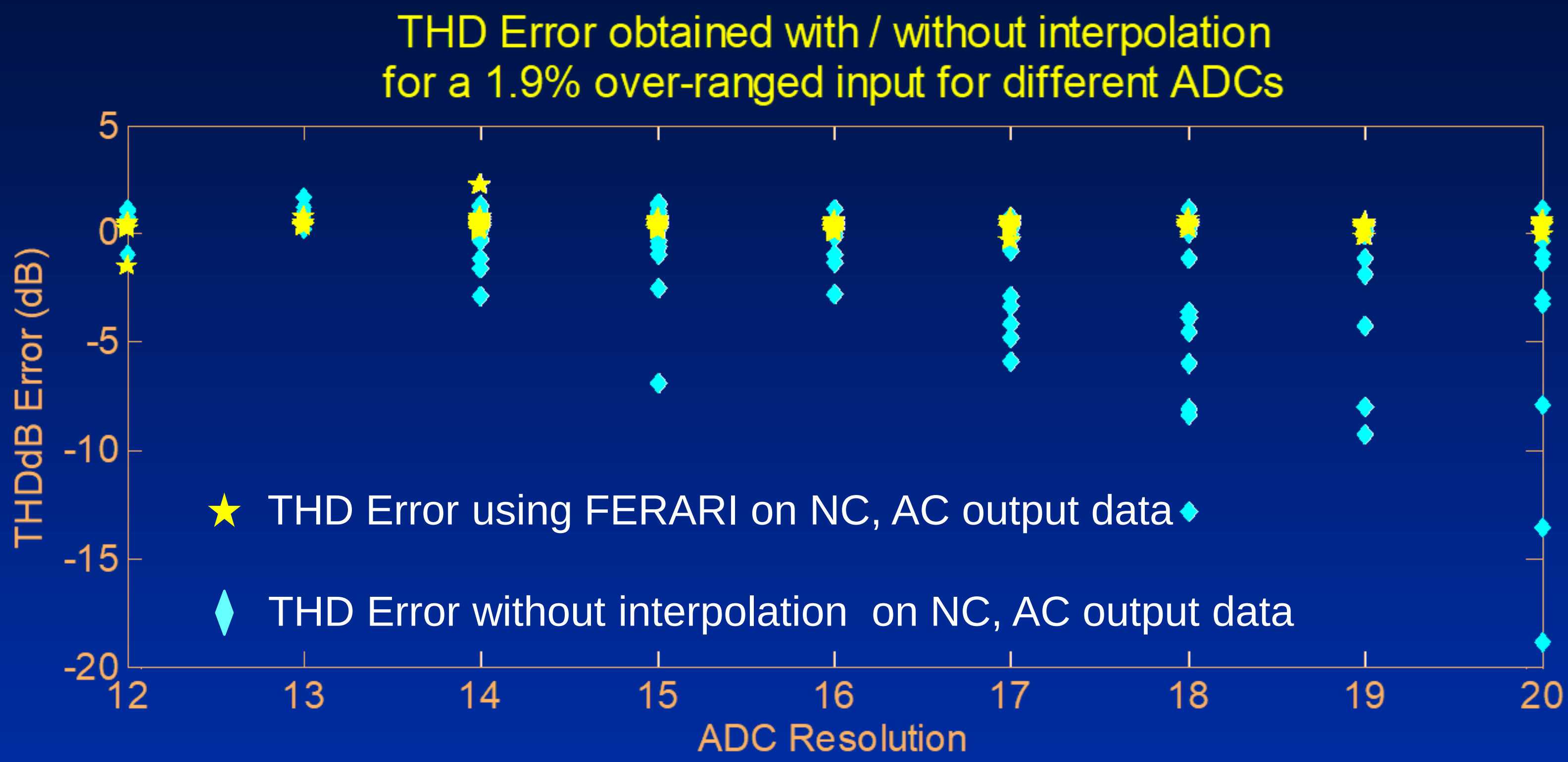
# Use of interpolation (Varying resolution)

ADC resolution = From 12 to 20 bits;    Input over-range = 1.9%



# Use of interpolation (Varying resolution)

ADC resolution = From 12 to 20 bits;   Input over-range = 1.9%




Low resolution, 12-bit (1.7% over-range)

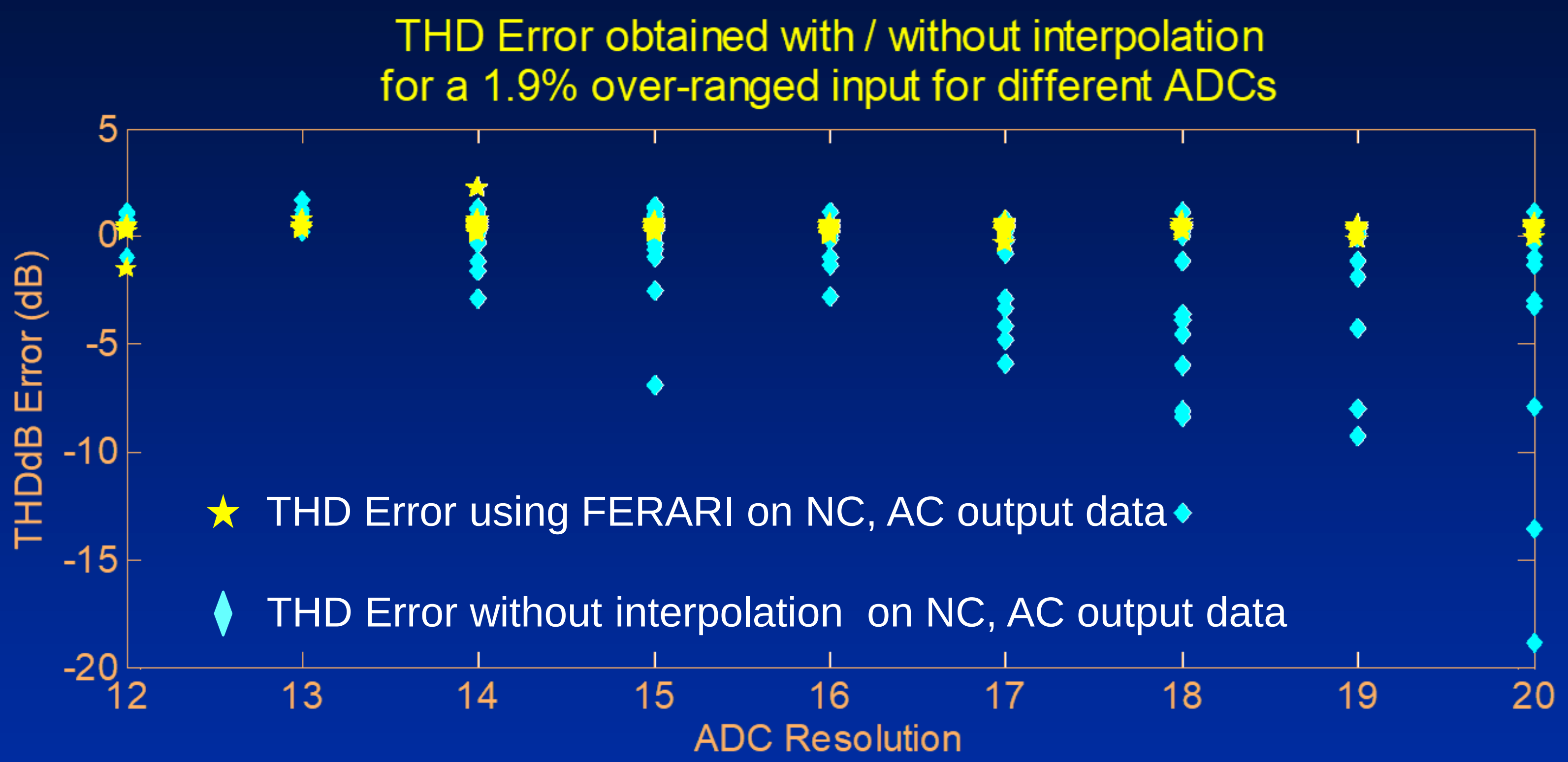
| Method | THD (dB) | SFDR (dB) |
|---|---|---|
| Coherent Unclipped (Reference) | -70.3 | 73.9 |
| NC, AC + No residue interpolation | -70.5 | 74.7 |
| NC, AC + FERARI | -70.8 | 74.3 |

High resolution, 18-bit (1.7% over-range)

| Method | THD (dB) | SFDR (dB) |
|---|---|---|
| Coherent Unclipped (Reference) | -93.1 | 97.7 |
| NC, AC + No residue interpolation | -79.7 | 84.2 |
| NC, AC + FERARI | -93.3 | 97.7 |

# Use of interpolation (Varying resolution)

ADC resolution = From 12 to 20 bits; Input over-range = 1.9%




Low resolution, 12-bit (1.7% over-range)

| Method | THD (dB) | SFDR (dB) |
|---|---|---|
| Coherent Unclipped (Reference) | -70.3 | 73.9 |
| NC, AC + No residue interpolation | -70.5 | 74.7 |
| NC, AC + FERARI | -70.8 | 74.3 |

High resolution, 18-bit (1.7% over-range)

| Method | THD (dB) | SFDR (dB) |
|---|---|---|
| Coherent Unclipped (Reference) | -93.1 | 97.7 |
| NC, AC + No residue interpolation | -79.7 | 84.2 |
| NC, AC + FERARI | -93.3 | 97.7 |

# Outline

- Motivation and Spectral testing Background
- Proposed spectral testing method
  - Fundamental Estimation, Removal And Residue Interpolation (FERARI)
  - Spectral Testing Algorithm
- Simulation Results
- Measurement Results
- Conclusion

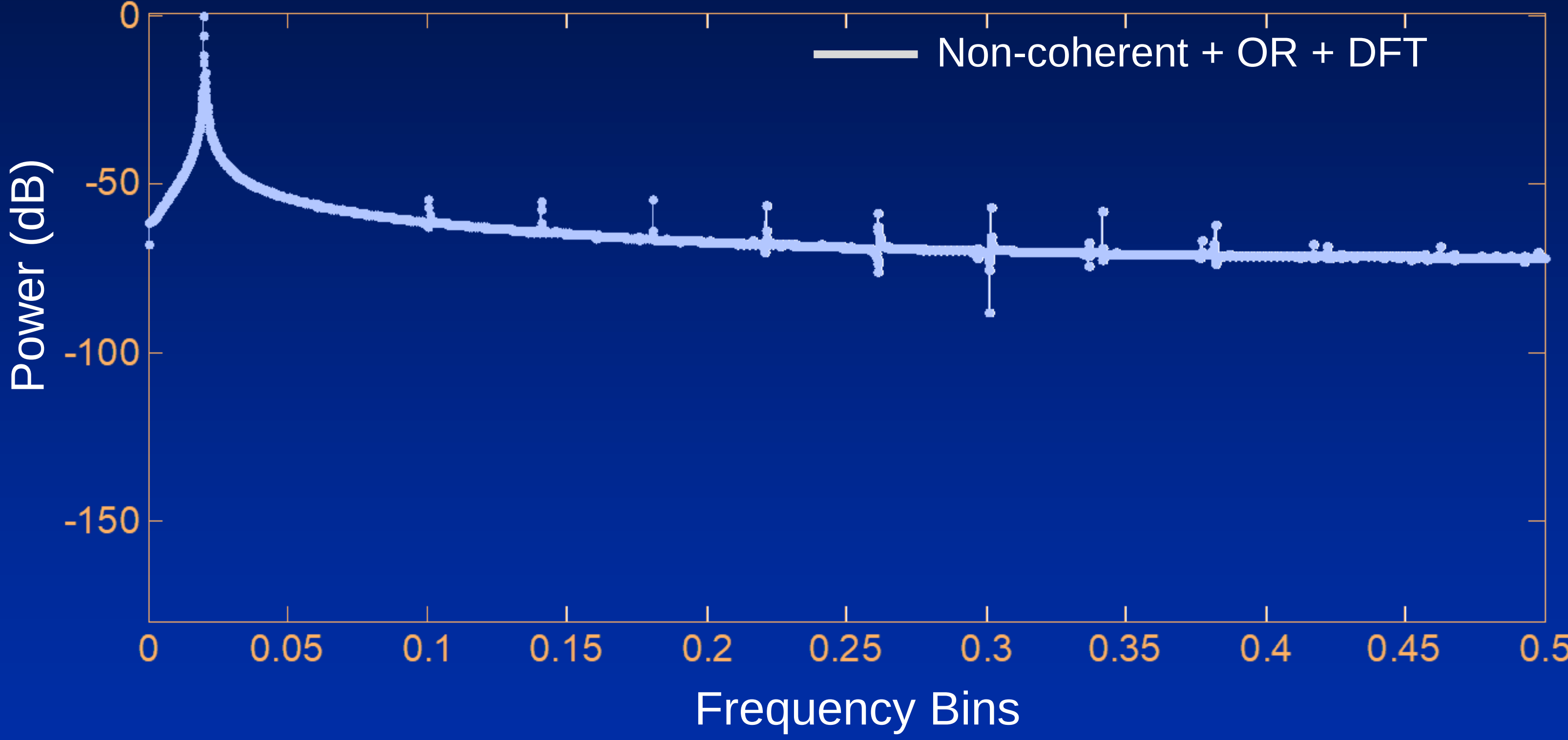
# Measurement Results

Functionality : 16-bit SAR ADC, ADS8318

$\delta$=-0.35, %OR = 1.5

# Measurement Results

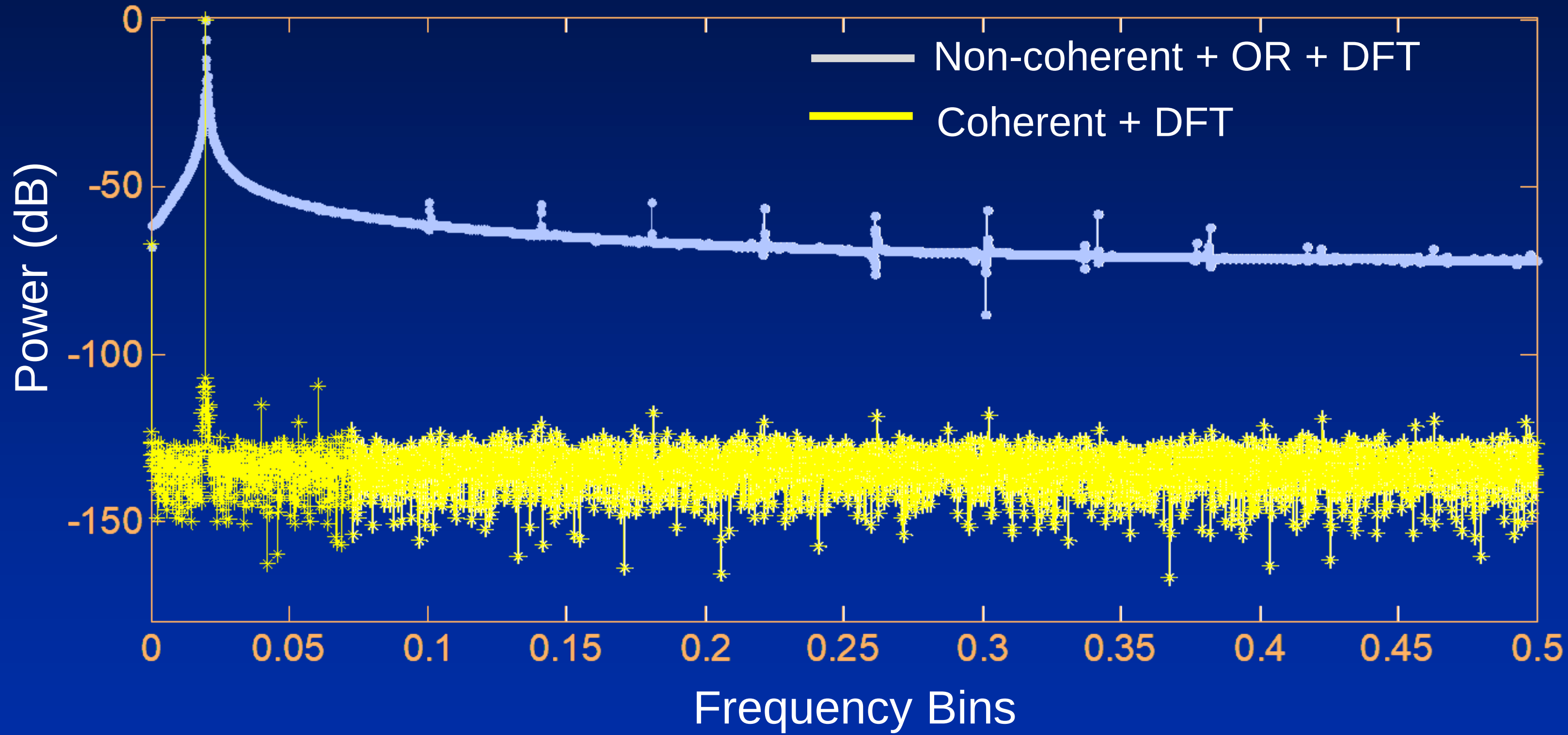
Functionality : 16-bit SAR ADC, ADS8318 δ=-0.35, %OR = 1.5



# Measurement Results

Functionality : 16-bit SAR ADC, ADS8318

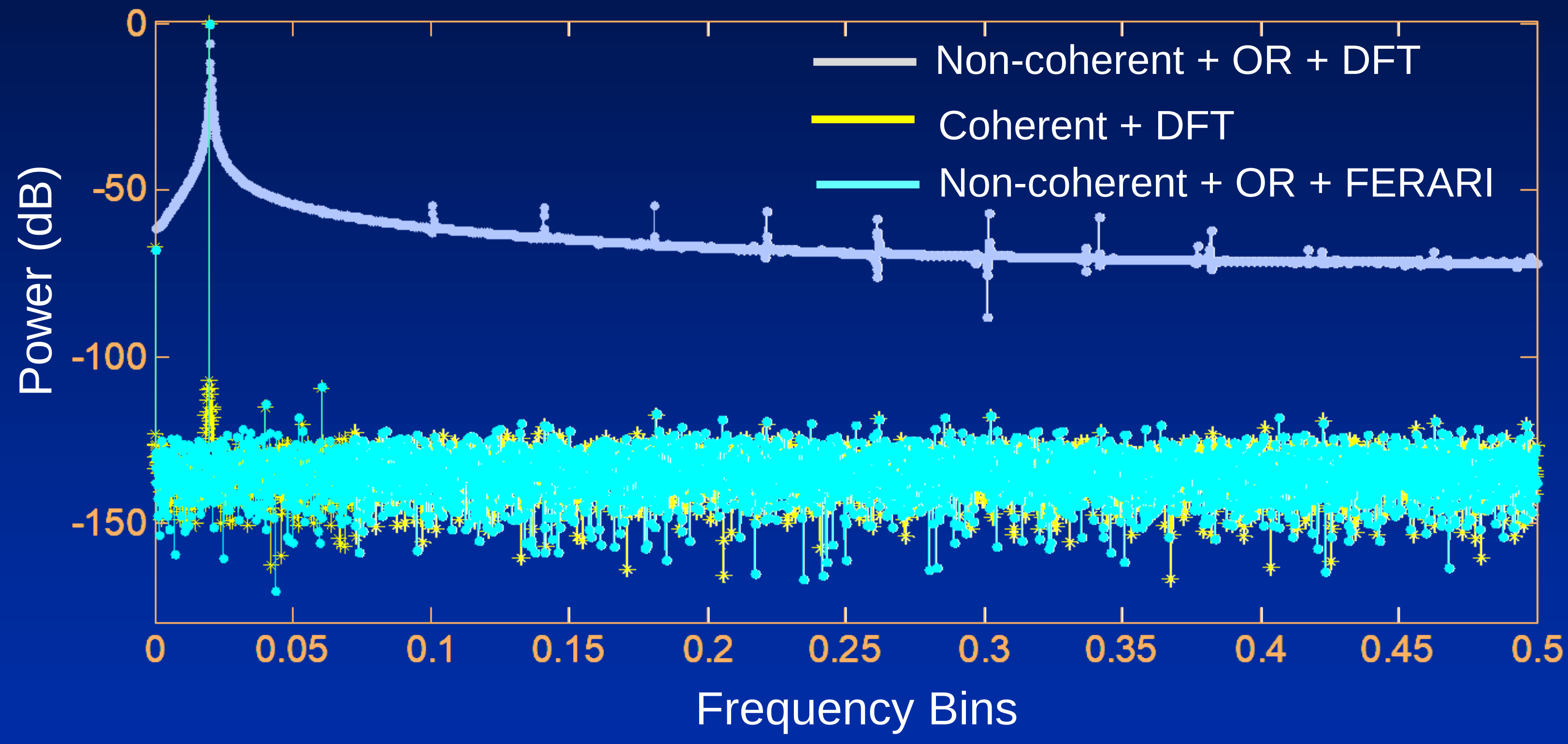
δ=-0.35, %OR = 1.5



# Measurement Results

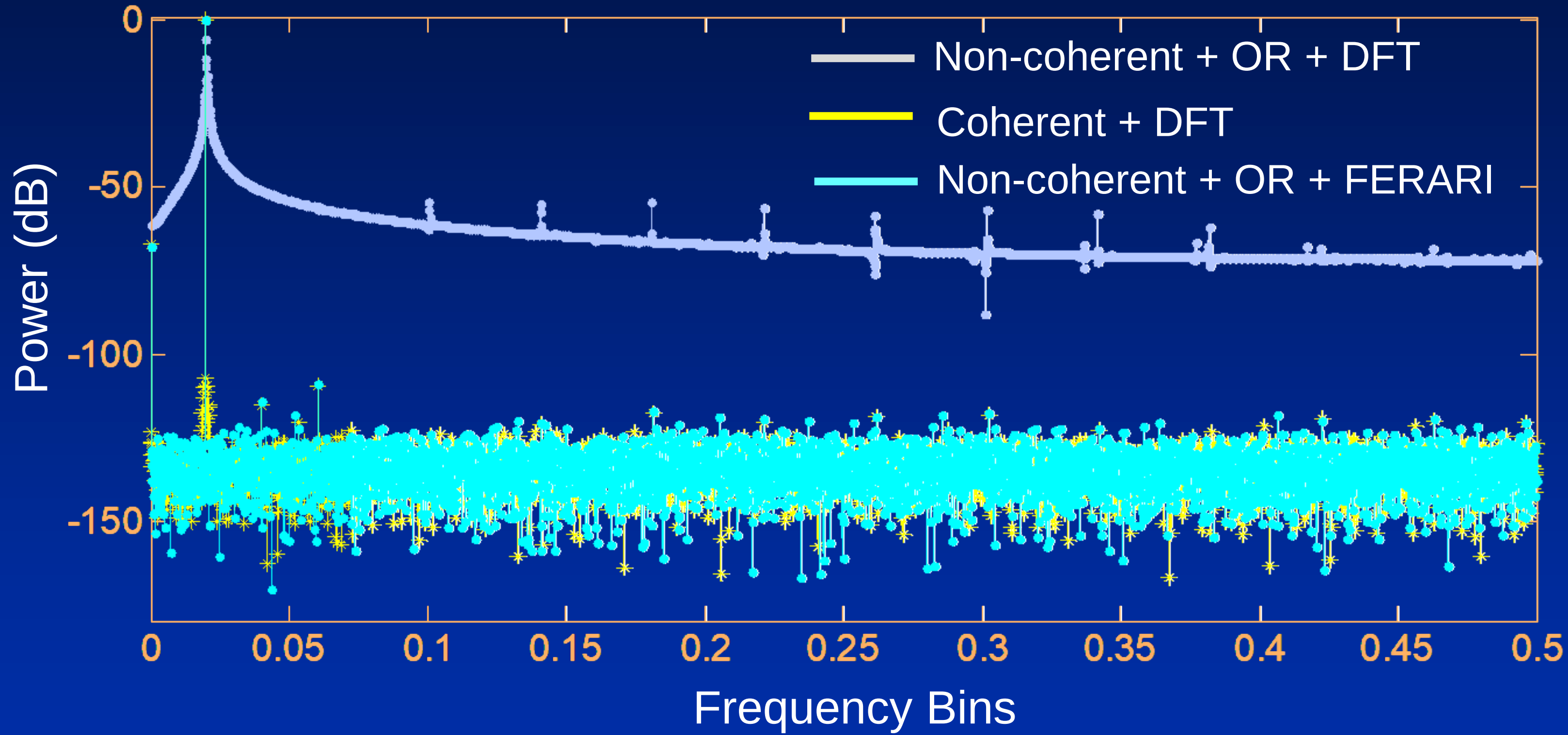
Functionality : 16-bit SAR ADC, ADS8318

δ=-0.35, %OR = 1.5



# Measurement Results

Functionality : 16-bit SAR ADC, ADS8318 δ=-0.35, %OR = 1.5

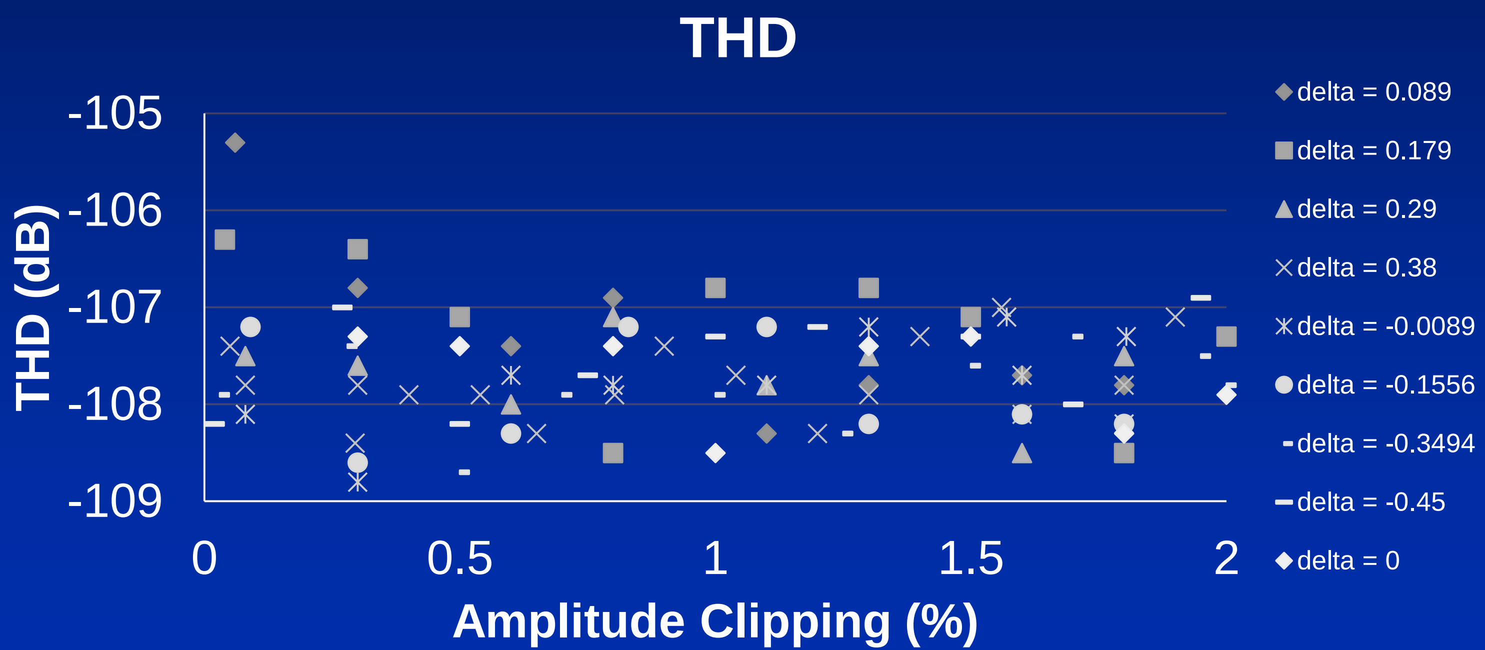



| Method | % Clip | THD (dB) | SFDR (dB) | SNR (dB) |
|---|---|---|---|---|
| Coherent | 0 | -107.5 | 108.5 | 95.8 |
| Non-coherent +Clipping | 1.5 | -108.1 | 109.2 | 95.8 |

# ADS8318

16-bit SAR
Signal frequency in the range of 10kHz (Varies with value of δ)
$f_{Samp}$ = 500kSPS, M = 8192
Amplitude Clipping : 0-2% linear range
Non-coherency: -0.5 to 0.5

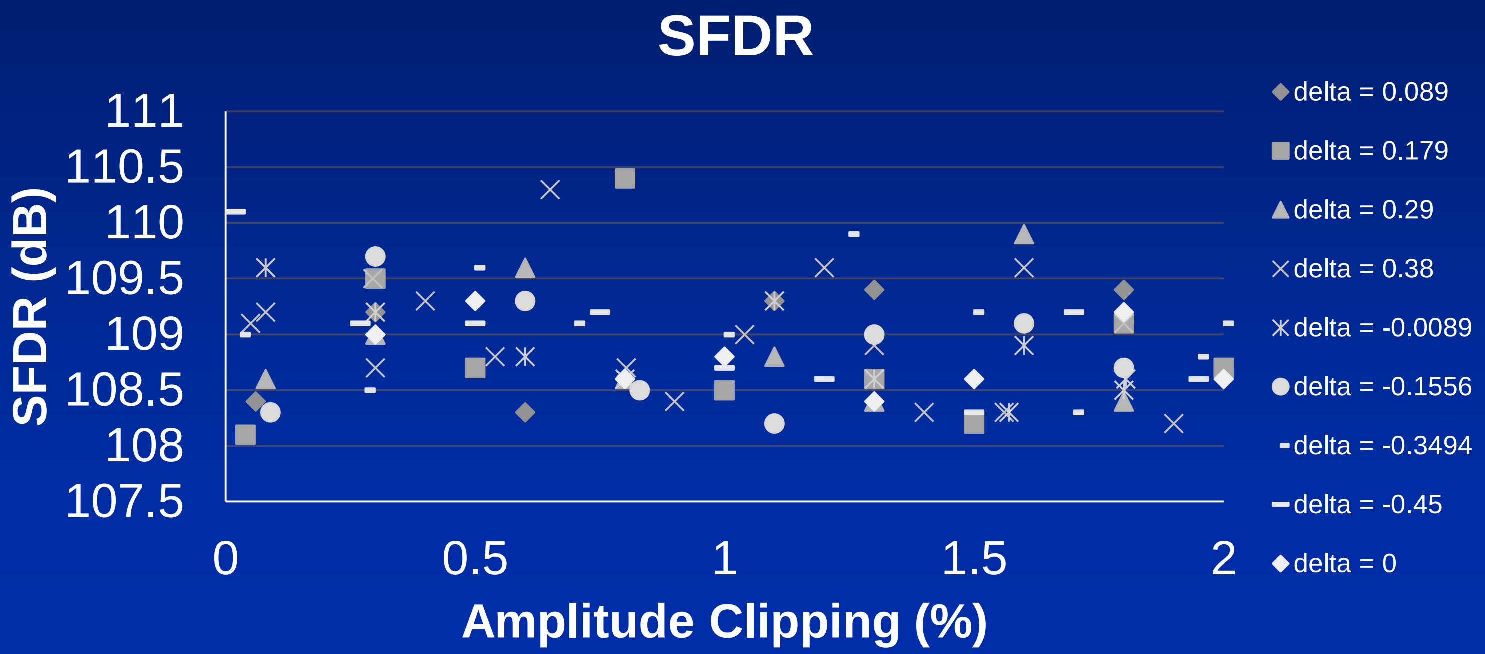
**THD coherent = -107.5dB**



# ADS8318

16-bit SAR
Signal frequency in the range of 10kHz (Varies with value of δ)
$f_{Samp}$ = 500kSPS, M = 8192
Amplitude Clipping : 0-2% linear range
Non-coherency: -0.5 to 0.5

**SFDR coherent = 108.5dB**



# ADS8318

16-bit SAR

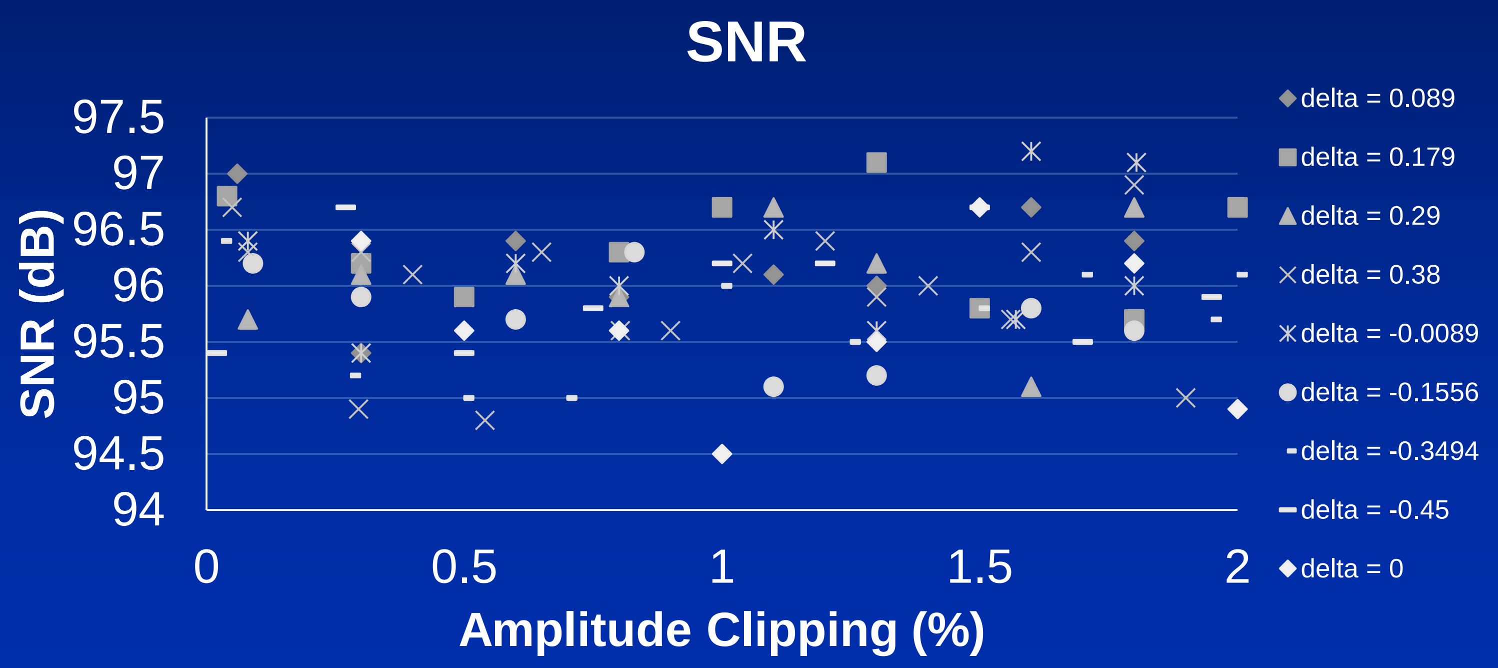
Signal frequency in the range of 10kHz (Varies with value of δ)

$f_{Samp}$ = 500kSPS, M = 8192

Amplitude Clipping : 0-2% linear range

Non-coherency: -0.5 to 0.5

**SNR coherent = 95.8dB**



# Outline

- Motivation and Spectral testing Background
- Proposed spectral testing method
  - Fundamental Estimation, Removal And Residue Interpolation (FERARI)
  - Spectral Testing Algorithm
- Simulation Results
- Measurement Results
- Conclusion

# Conclusion

- Proposed new test method
  - Non-coherent sampling and amplitude clipping
- Fundamental identification
  - Using both time and frequency domain data
- Accurate functionality and robustness verified
  - Simulation and measurement data
- Applicable for BIST ADCs where precise amplitude and frequency control is challenging

# Thank You