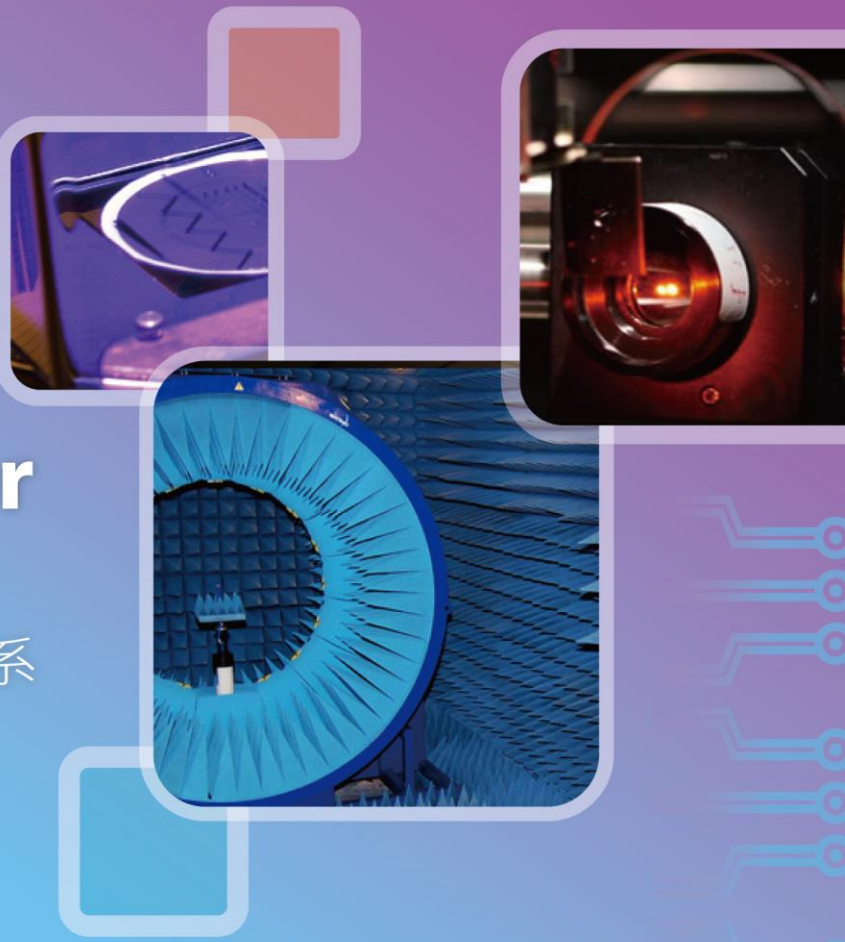
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Department of Electronic & Computer Engineering

電 子 及 計 算 機 工 程 學 系



Noise: Measurement and Estimation

21 June 2017

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Prof. Murch's group

MPhil student since Sept 2016
Acoustic Signal Acquisition and Analysis

Background

- Noise is the smallest signal in the system we can measure and therefore care needs to be taken in its measurement and analysis
- Need to:
  - Setup Hardware and Software for robust noise measurement.
  - Determine the noise floor of the measurement systems.
  - Estimate Power Spectral Density accurately.
  - Identify abnormalities in noise and determine their sources.
  - Analyze amplitude distribution: check if it is Gaussian.
  - Determine if noise is uncorrelated and random.
  - Analysis using advanced tools.

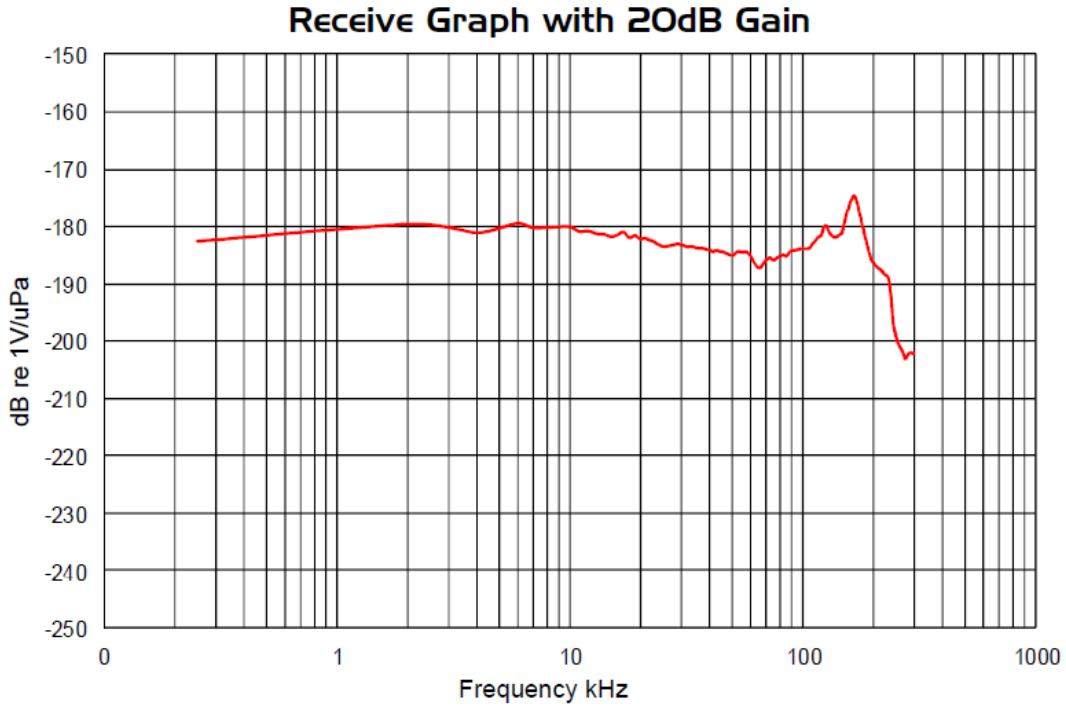
Hardware and Software Setup

Data Acquisition:

- NI USB 6356: 1M S/sec,16 bit ADC.
- LabVIEW and MATLAB

Transducer D/140/H

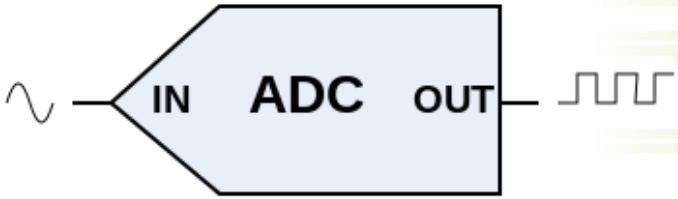
- Low self-noise.
- Pre-Amplifier: 20dB.
- Bandwidth: 200KHz.
- Receive Voltage sensitivity (RVS)
- Directionality : Omni directional.
- Transmit Voltage Sensitivity (TVS)



Noise Floor of the Measurement system

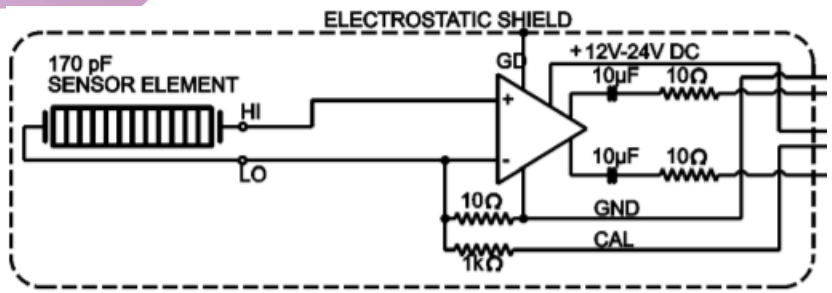
- Noise floor of system needs to be less than the noise we are trying to measure
- Main components of Measurement system which decides Noise Floor

Transducer with Pre-amplifier

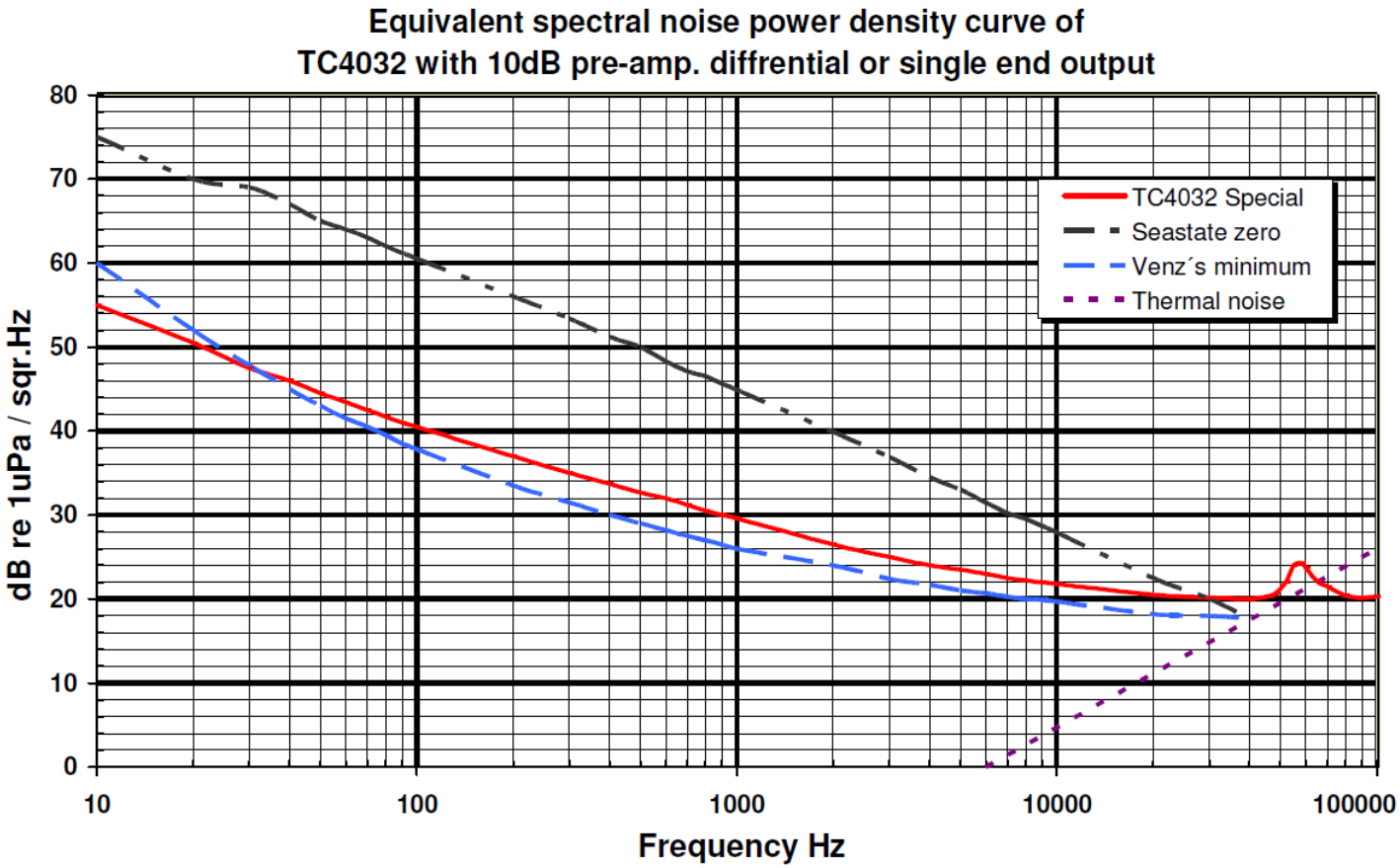


Inside Data Acquisition Device

Noise floor of the Transducer



- We use hydrophones TC 4032 or D/140/H which have been specially selected for their low self-noise
- Noise below the red curve cannot be measured!



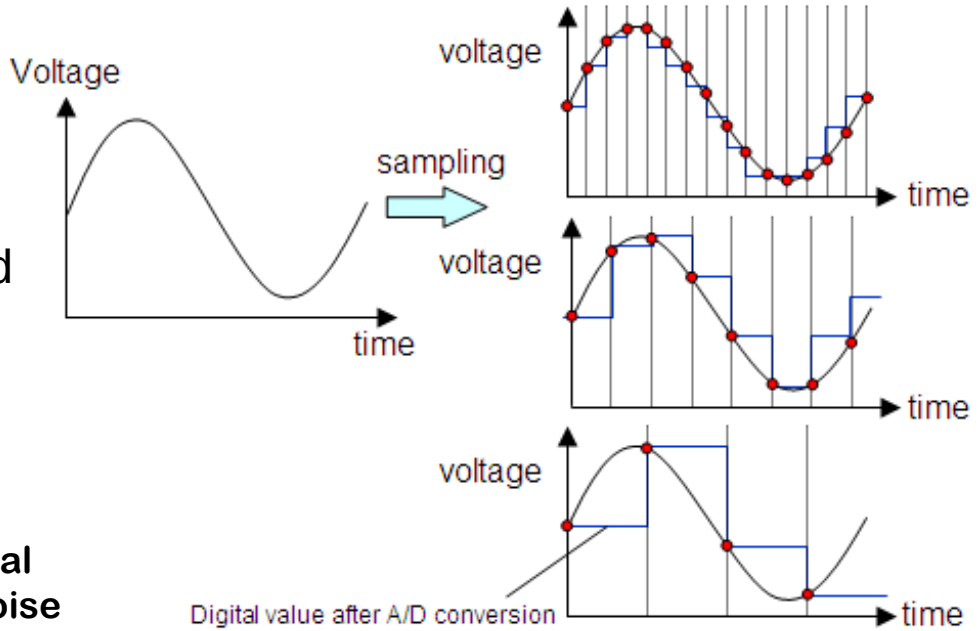
Noise Floor of the ADC

- **ADC resolution is one of the most important DAQ specification.**
- **Noise due to ADC: Quantization Noise (Variance = $\frac{(dV_{min})^2}{12}$).**
- **Our DAQ systems have 16 and 18 bits ADC with full scale input range of maximum** ±10V to minimum of ±0.1V .
- **Quantization noise and corresponding noise floor can be estimated theoretically (data sheet) as well as experimentally (short the input port).**

If we have 16 bits ADC with full scale input range = ± 1V
Then,
Minimum voltage which can be measured using this ADC is:

$$dV_{min} = \frac{1-(-1)}{2^{16}} = \frac{2}{2^{16}} = 30\mu V$$

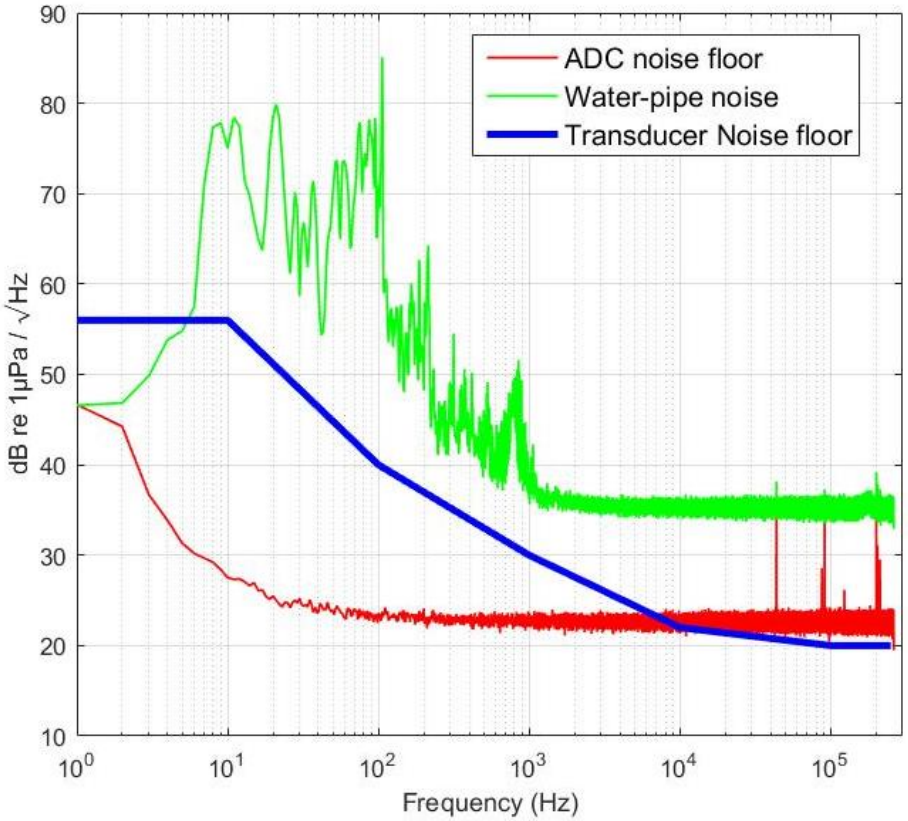
Max theoretical Quantization noise



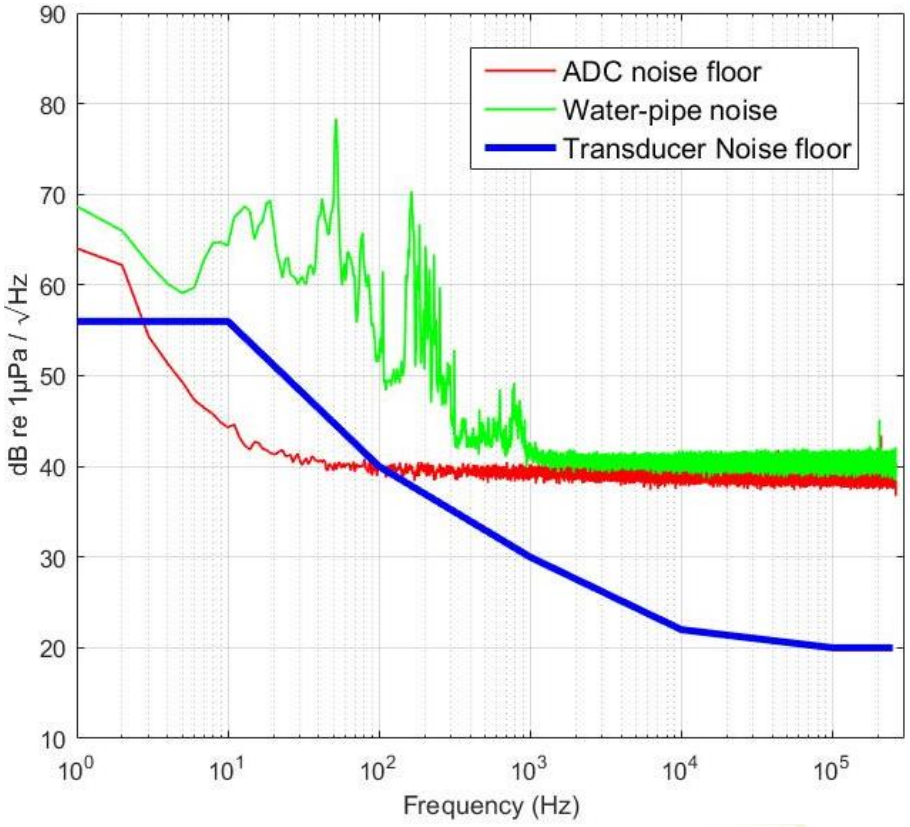
Theoretical noise floor is ideal and different from the experiments!

- For 16 bits ADC with 1V full scale input range, ADC accuracy is limited to $30\mu V$ (Theoretically).
- Taking environment effects (like temperature), offset errors, gain errors, noise uncertainty, etc into the account, the ADC accuracy is $300\mu V$. This is more accurate estimation.
- Experimentally (short the input ports of DAQ device), we can achieve best information about the ADC noise floor w.r.t frequency.

Noise floor of the measurement system



ADC = 16 bits, Full scale input range = ±1V,
Theoretical Quantization error ≈ 30μV
Transducer : TC 4032



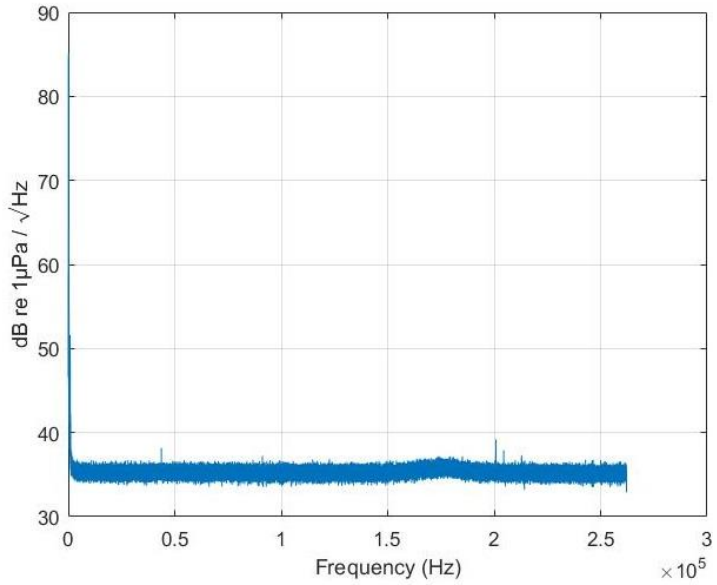
ADC = 16 bits, Full scale input range = ±10V
Theoretical Quantization error ≈ 300μV
Transducer : TC 4032

Power Spectral Density Estimation

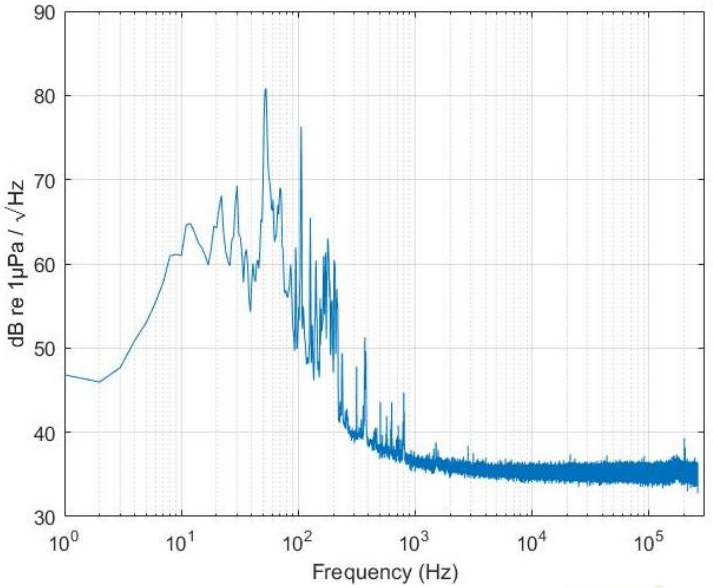
- Sampling rate: 500KS/s, Duration = 40 mins.
- Averaging Periodograms with 1 second window.
- Hamming window for reducing spectral leakage.
- Allow window overlapping of 0.2 seconds.
- Divide by the bandwidth of transducer.
- Add Receive Voltage sensitivity (RVS) of Transducer :

Also called Welch's method

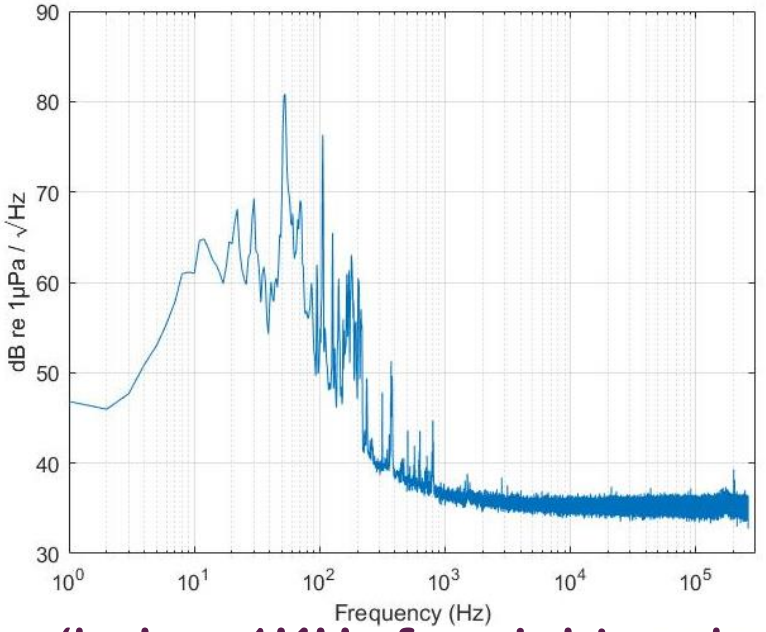
$$SPL(dB\ re\ 1\mu Pa\ /\ \sqrt{Hz}) = |RVS| + G\ (dB/Hz)$$



Log scale



Measurement results



Measurement Locations:

- Steel, Acrylic, HDPE pipe
- Water Tank and Bucket
- Swimming pool.

Measurement Time: Day and night

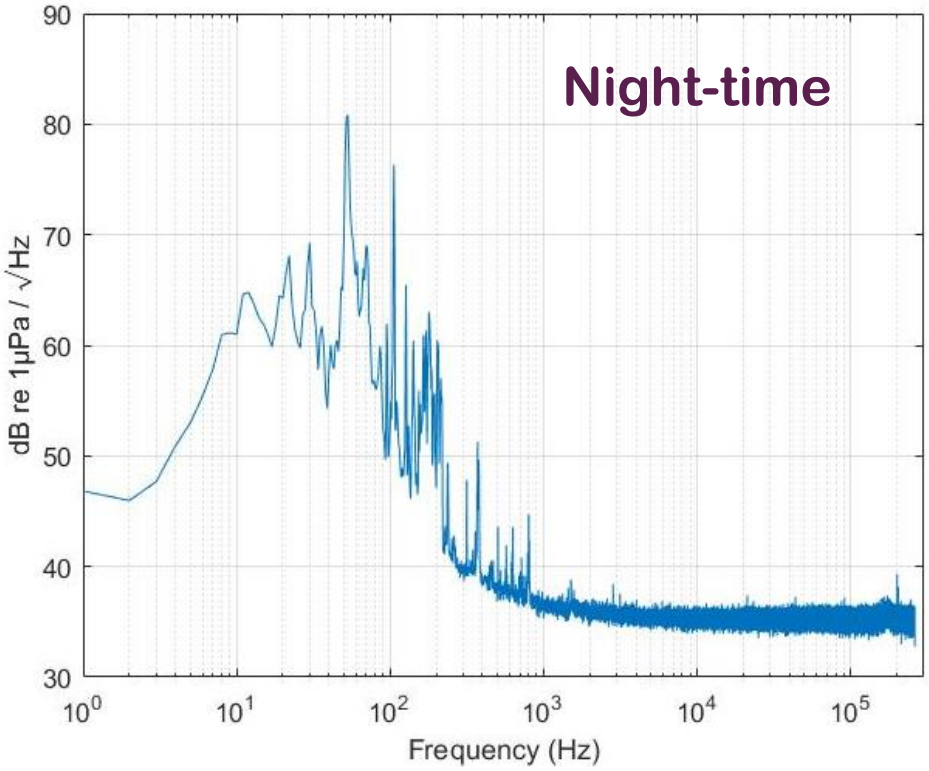
Preliminary Observations:

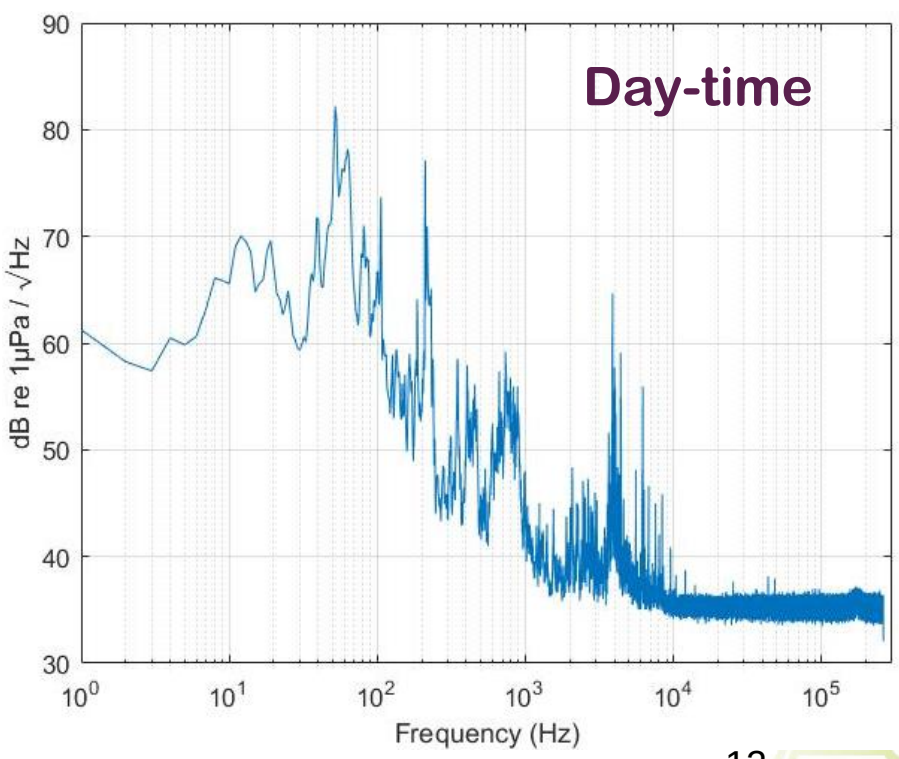
- High energy in low frequency region (below 1KHz for night and below 10KHz for daytime).
- Presence of 50Hz power line interference and its harmonics.
- Flat response after 1KHz with few abnormalities/peaks at 4KHz, 23KHz and 43KHz.
- Broad peak at 160Kz due to the resonant frequency of transducer.
- Choice of Ground source is critical.

Measurement results

- Night-time Vs Day-time: Effect of sound and vibrations from the environment.

Non-flat portion below 1KHz in night and below 10KHz in day.

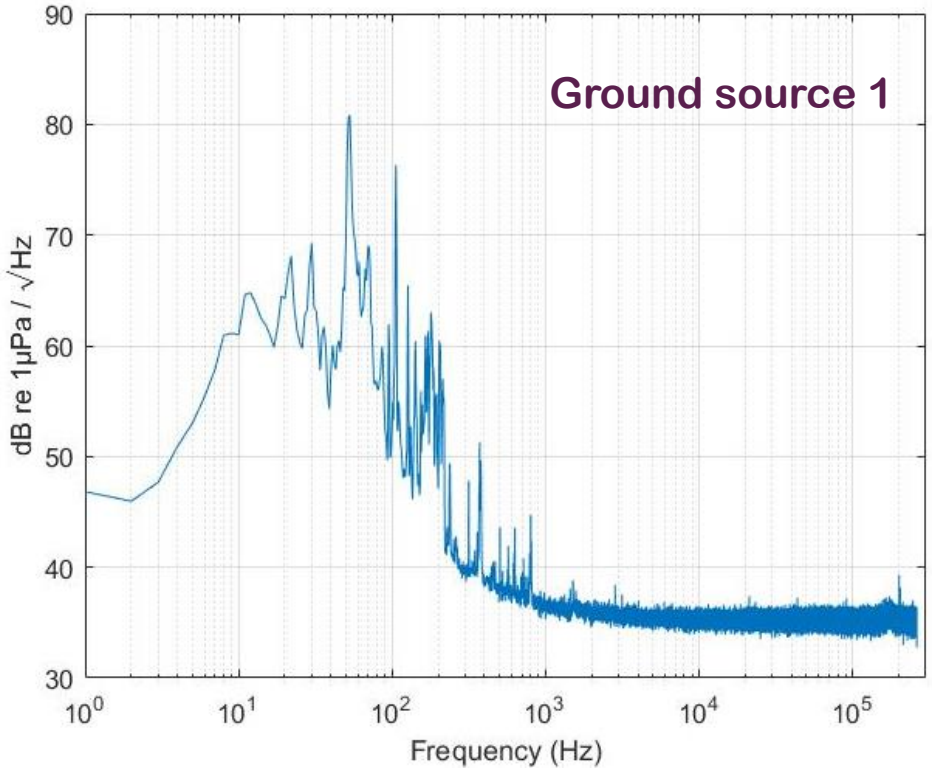


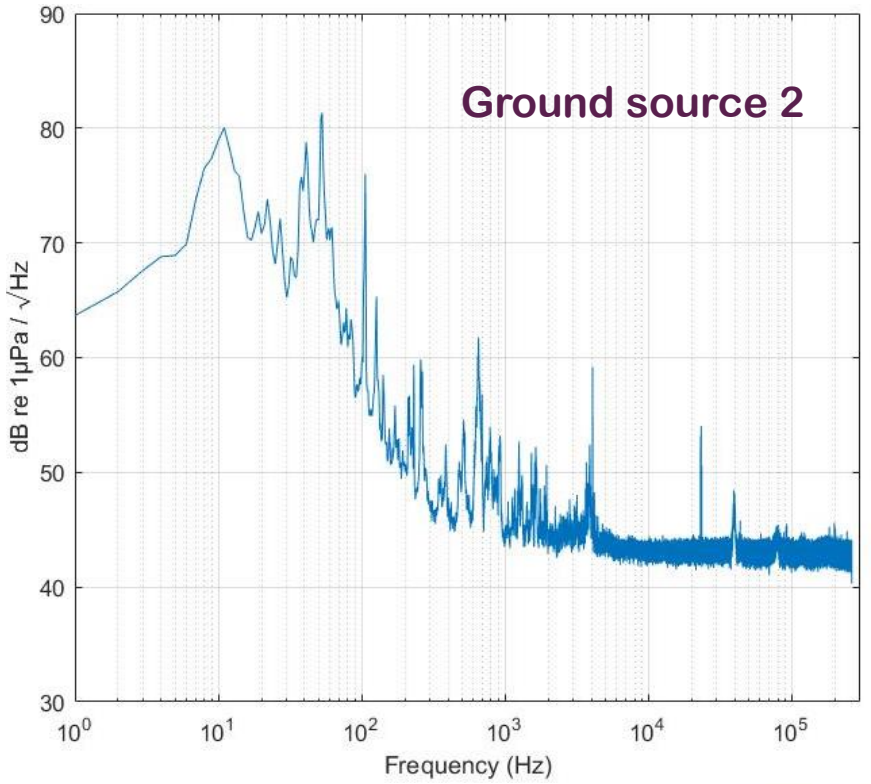


Measurement results

- **Effect of Grounding source:**

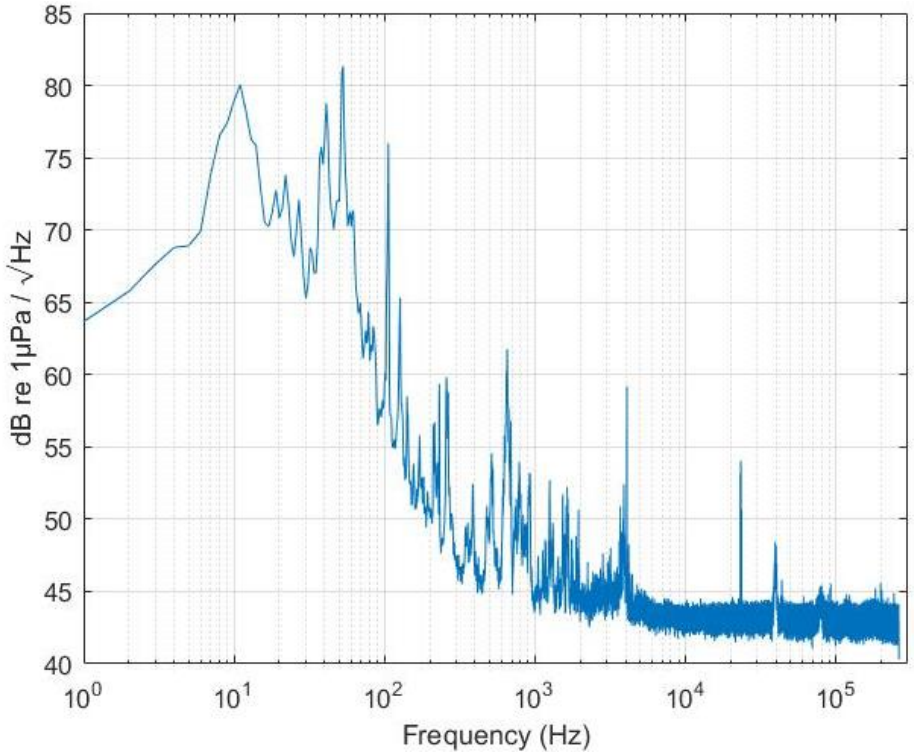
  Causes shift in the overall noise level and amplifies certain peaks.

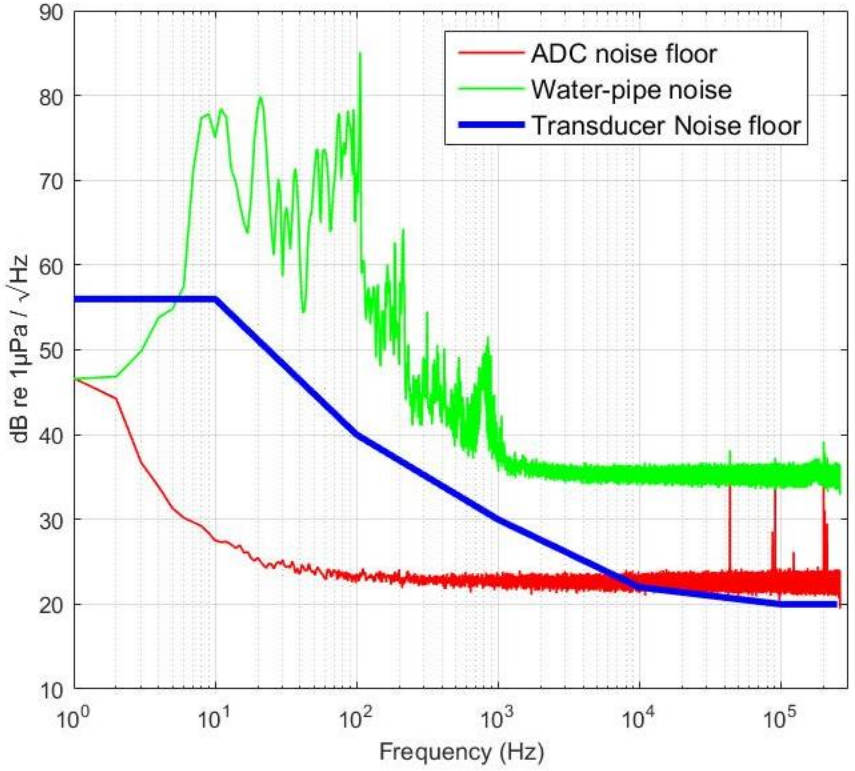




Measurement results

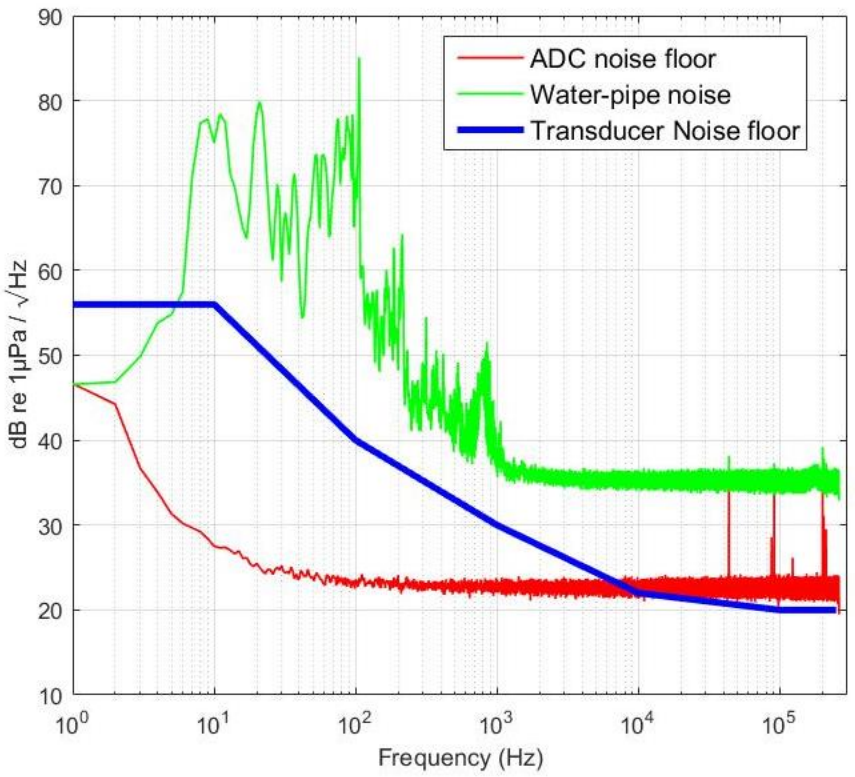
- Reasons for strong peaks in flat region: Due to the response of the ADC and grounding issues.





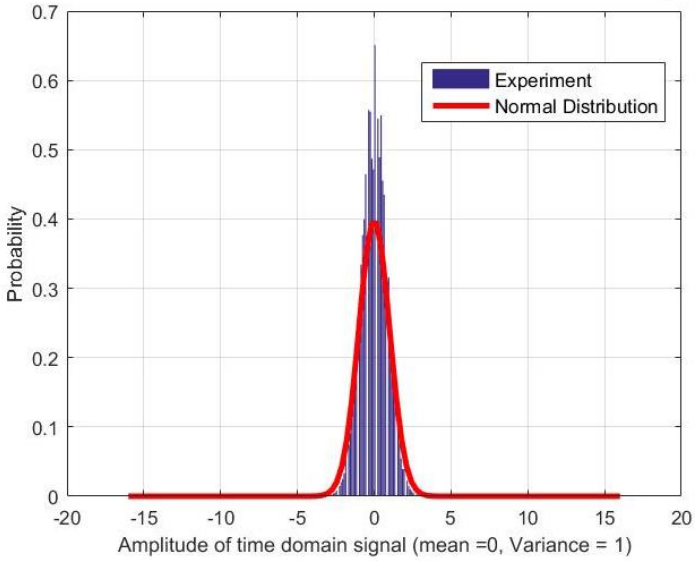
Amplitude distribution of water-pipe noise

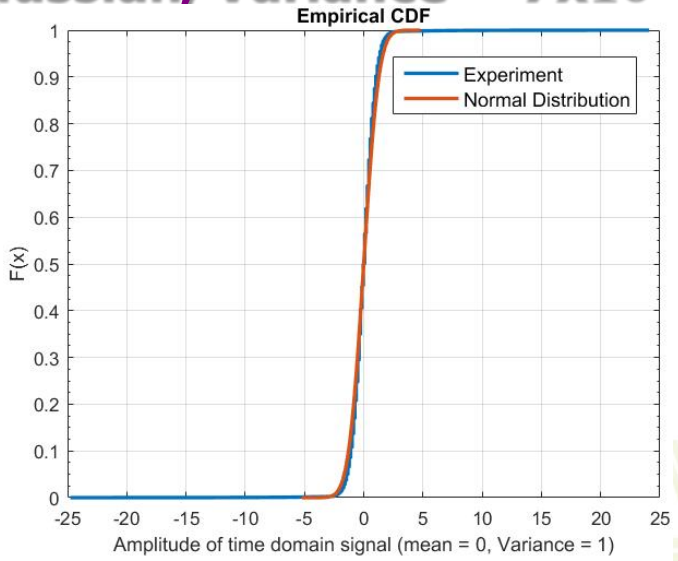
- Power spectral density describes the power present in the signal as a function of frequency (per unit frequency).
- It does not tell us about the statistics of the noise.
- Probability distribution function or cumulative distribution function are used for understanding the amplitude distribution of noise.
- Various statistical tests can be used to determine whether PDF/CDF of noise follows certain standard distributions (like Normal distribution) or not.



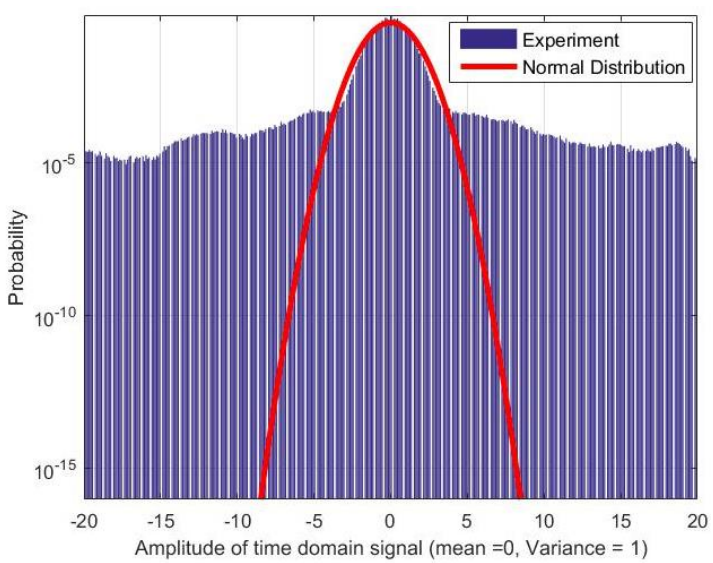
Amplitude distribution (not Gaussian, Variance = $7x10^{-8}$)

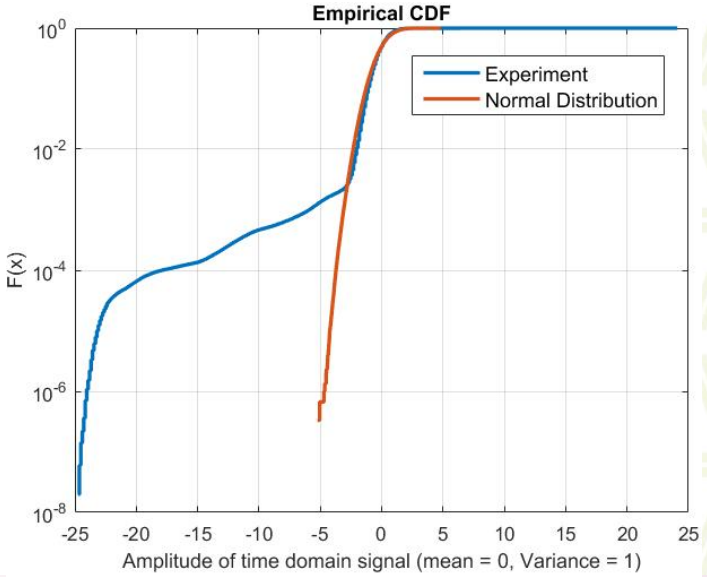
Linear scale



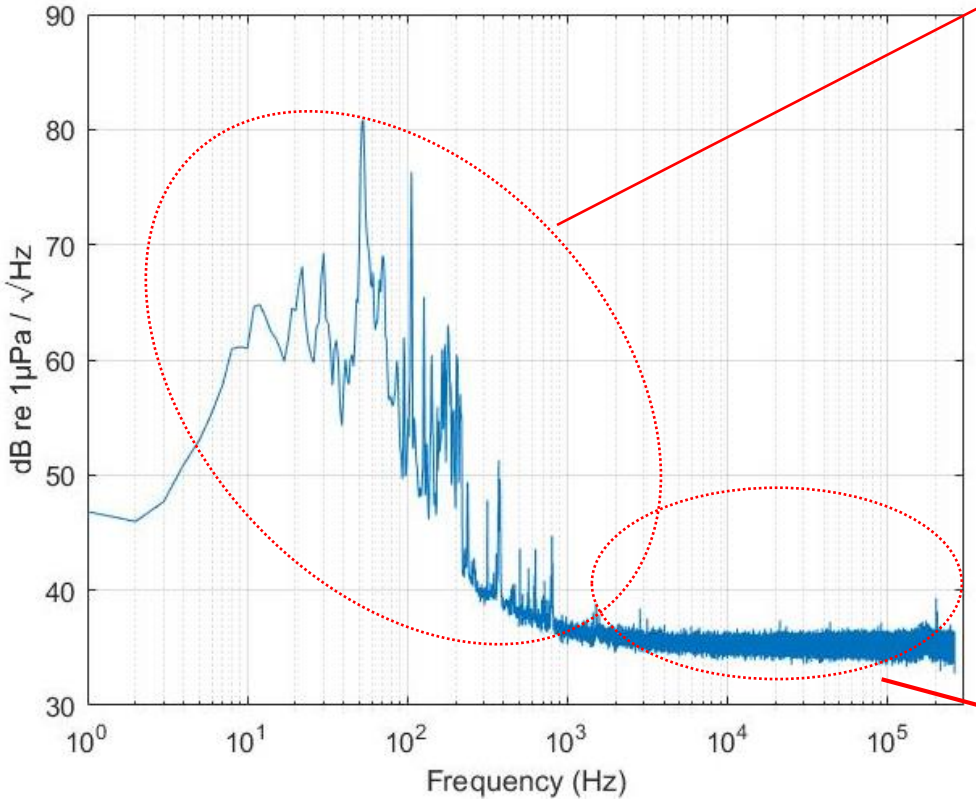


log scale





Why noise does not follow Gaussian Distribution?



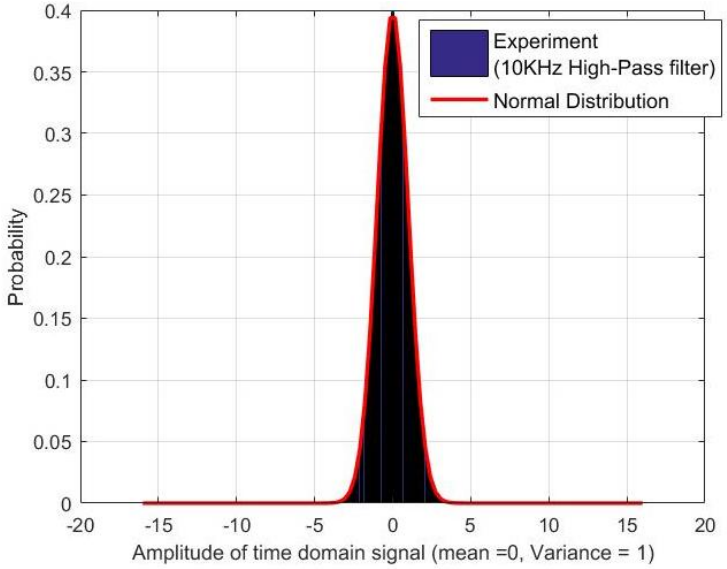
High power in low frequencies noise due to various sounds and vibrations from the environment and 50Hz power line interruption.

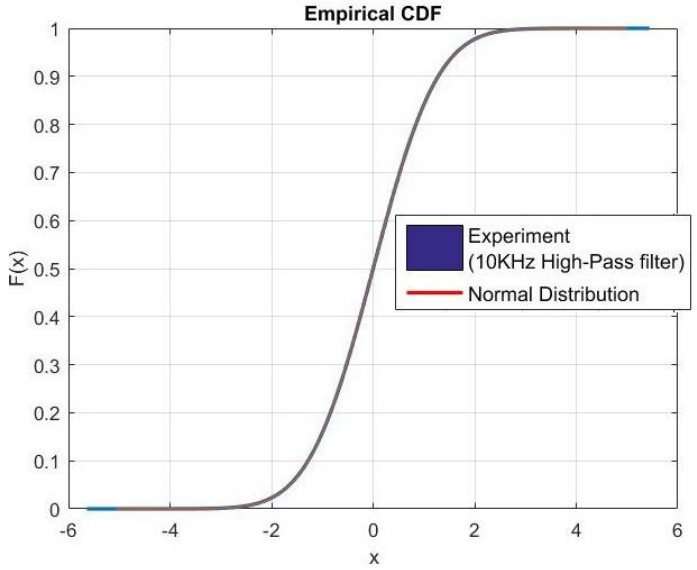
Is deviation from the normal distribution due to the low frequency noise?
Let's see..

High frequency noise spectrum is almost flat.

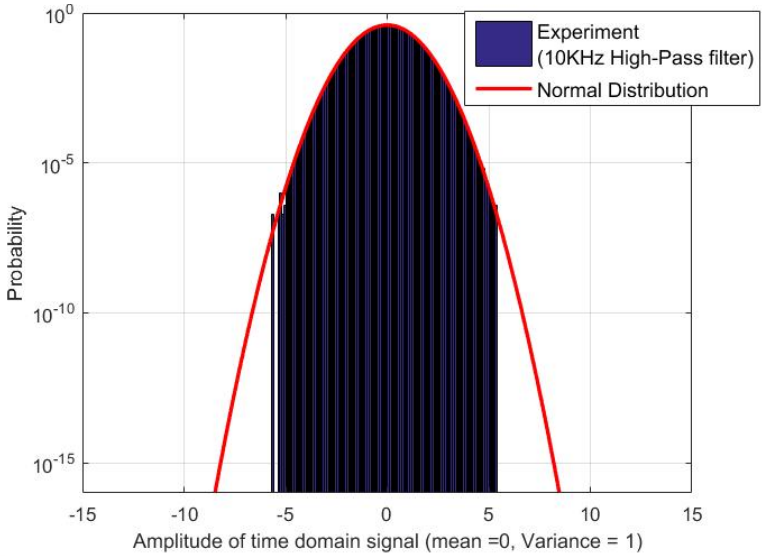
Amplitude distribution after 10KHz High Pass Filter

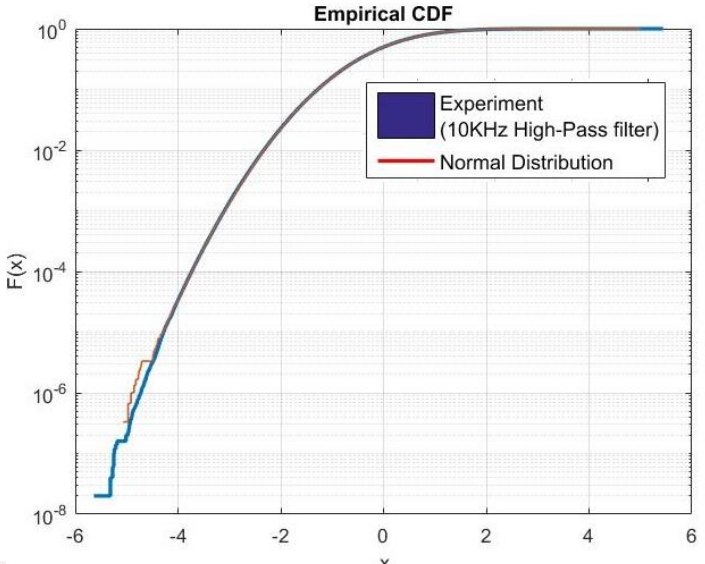
Linear scale





log scale





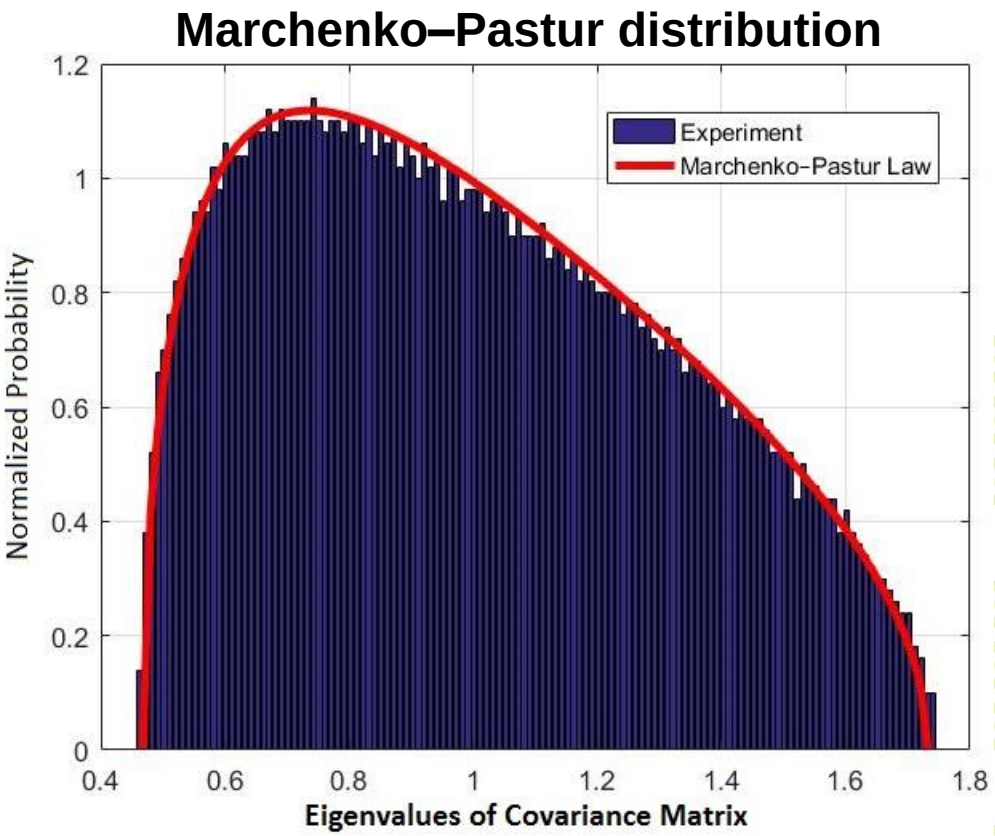
Conclusions on Amplitude distribution of water-pipe noise:

- Noise does not follows the normal distribution.
- The tails of PDF/CDF of noise significantly deviates from the normal distribution.
- This deviation is due to the low frequencies noise.
- The noise above 1KHz (in night time) and above 10KHz (in day-time) follows normal distribution.

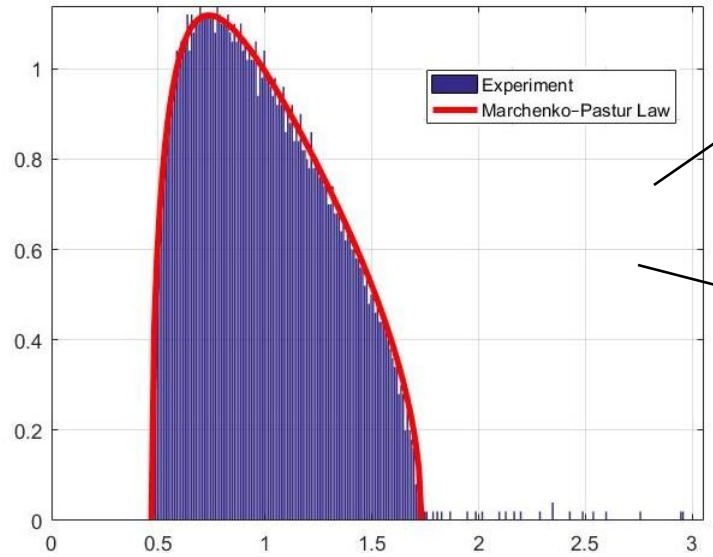
Some other statistical properties of noise:

- Are noise samples independent and identically distributed (i.i.d.) in time and space?
- Is noise stationary?

Can be analysed using eigenvalue distribution of Covariance matrix of the noise samples taken over different time slots and different spatial positions. Check if this distribution follows Marchenko–Pastur distribution for asymptotic limits.

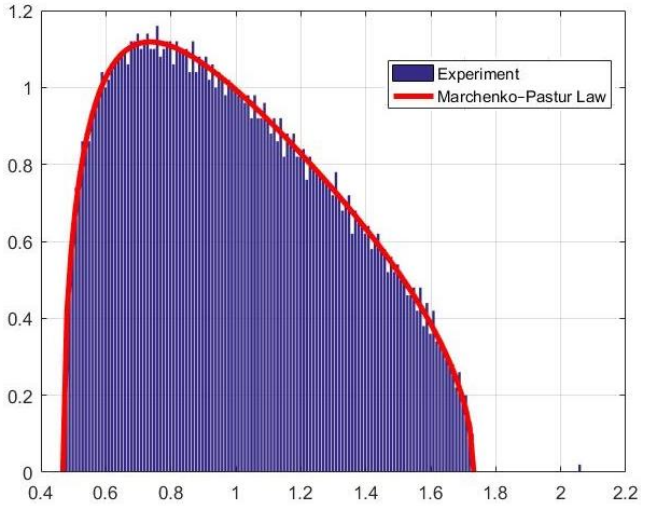


Noise samples are i.i.d. in time after applying 10KHz High Pass filter. This also means that noise is stationary over time (Finite mean iid sequences are stationary).



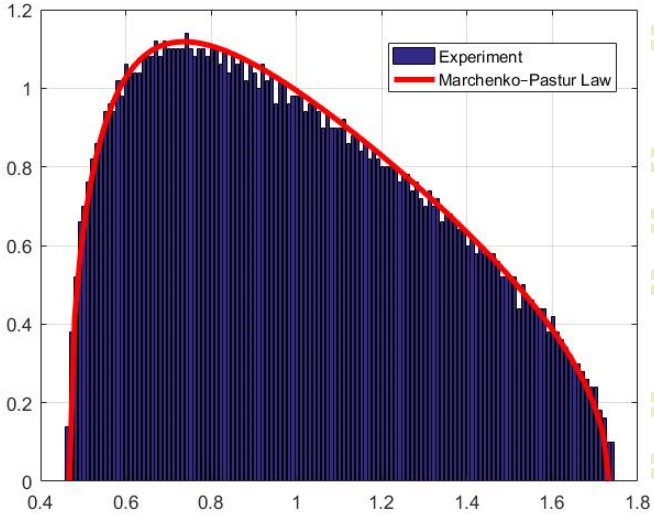
Eigenvalue distribution of Covariance matrix of the Noise samples collected over different time slots. Many eigenvalues are outside the MP Law support

1Khz High Pass Filter



Only one eigenvalues outside the MP Law support. This one eigenvalue corresponds to loud sound of the closing of the nearby door.

10Khz High Pass Filter



Eigenvalues perfectly follows the MP Law support

Conclusion and Future Plans

- Found noise floor of measurement systems.
- PSD analysis and identification of abnormalities in the PSD.
- Analyzed the amplitude distribution of the noise.
- Explored some other statistical properties .
- Future plans
  - Field tests need to be performed
  - Need help with transducer mounting and placement in field
  - Help in analysis of turbulence.

THANK YOU FOR
YOUR LİSTENİNG

DO YOU HAVE
ANY QUESTİONS?