TECHNISCHE UNIVERSITÄT WIEN

INTERFERENCE IN BLUETOOTH LOW ENERGY

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HAMID KAVOUSI GHAFI
TU Wien
Institute of Electrodynamics, Microwave and Circuit Engineering

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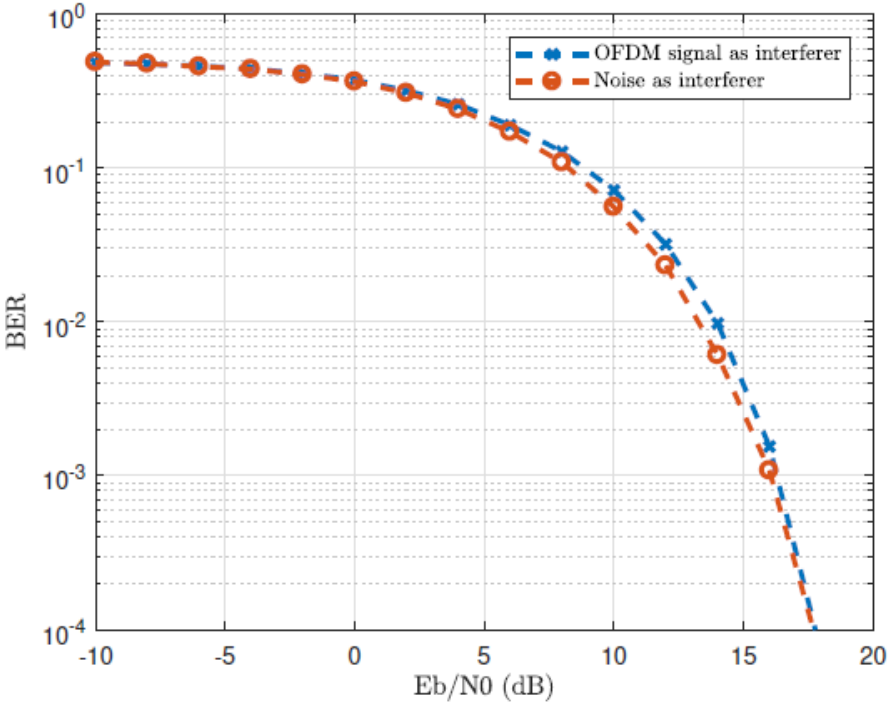
CONTENTS

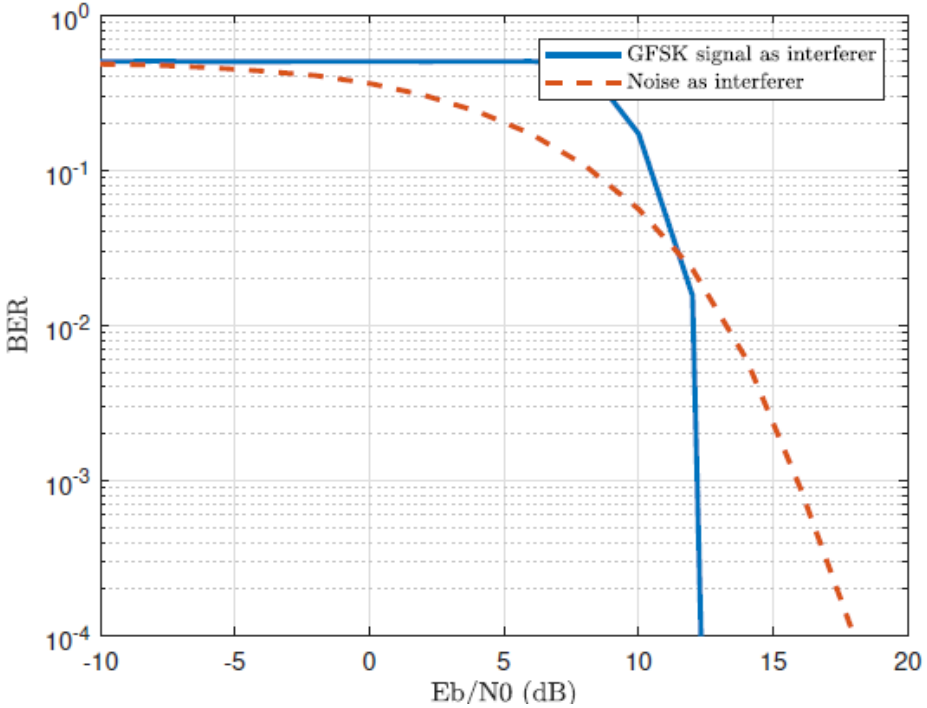
- BLE Performance against Different Interferences
- Statistical Models of Interference at ISM Bands
- Interference Modeling under Assumption of Uncorrelated Random Variables
- Interference Modeling under Assumption of Correlated Random Variables
- Interference Analysis in Spectrum Domain

BLE Performance against Different Interferences

OFDM Signal as interference



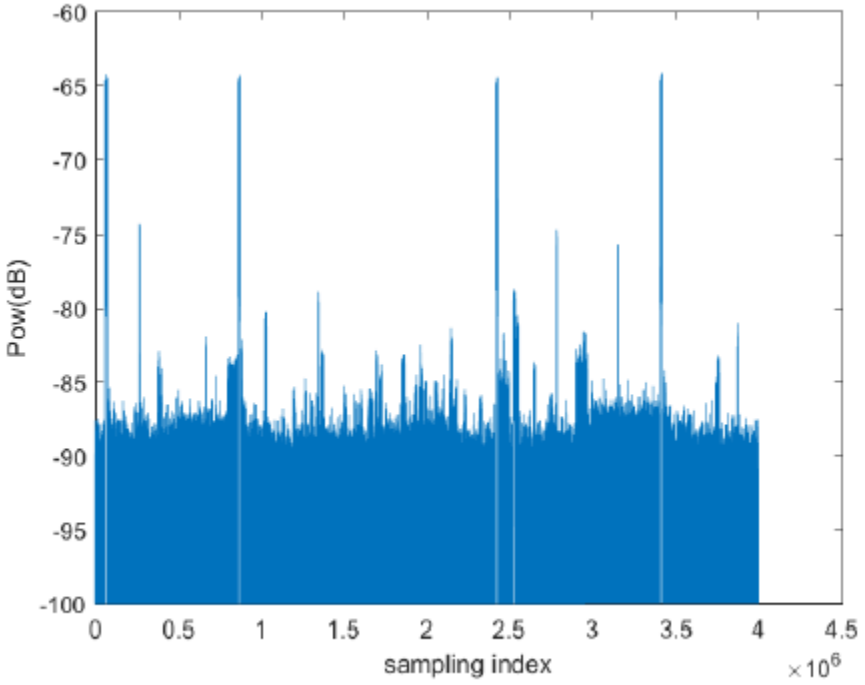
GFSK modulated Signal as interference

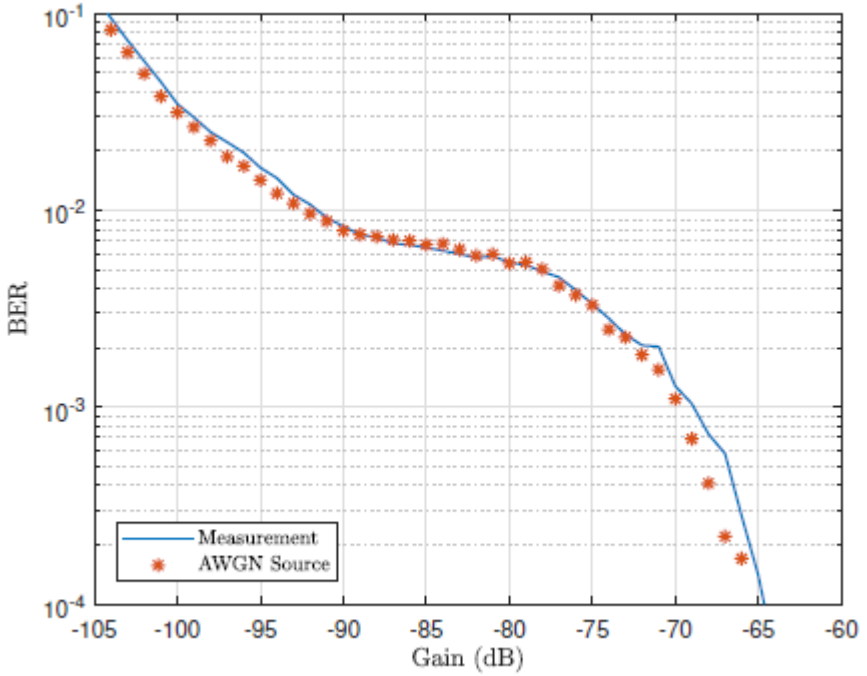


Interference Modeling at ISM Bands

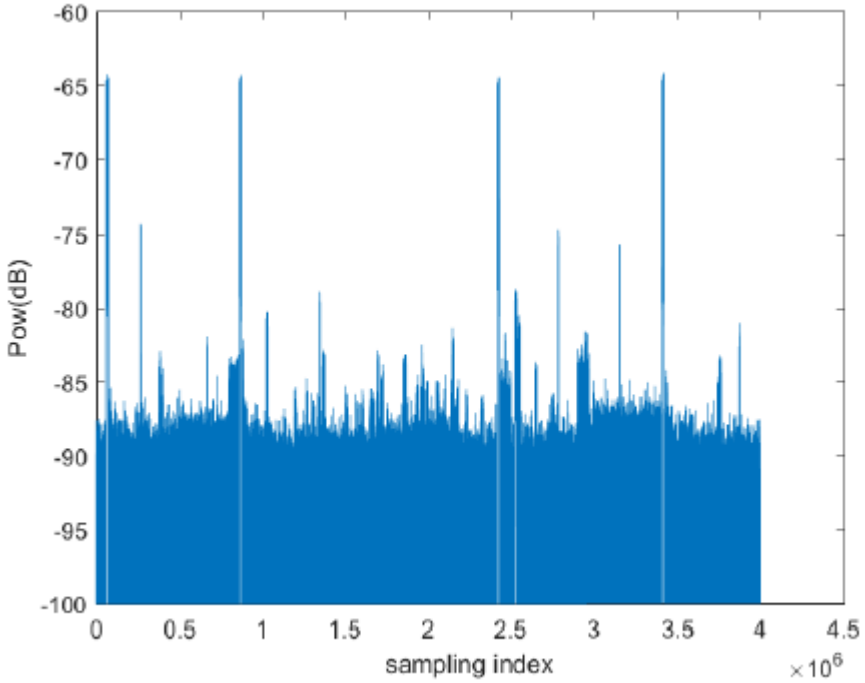
- Two Simplifying Facts
  - An AWGN source finely simulates the effects of various interferences.
  - Each interference is characterized by its power level, time duration (pulse width), and the time offset relative to the next interference

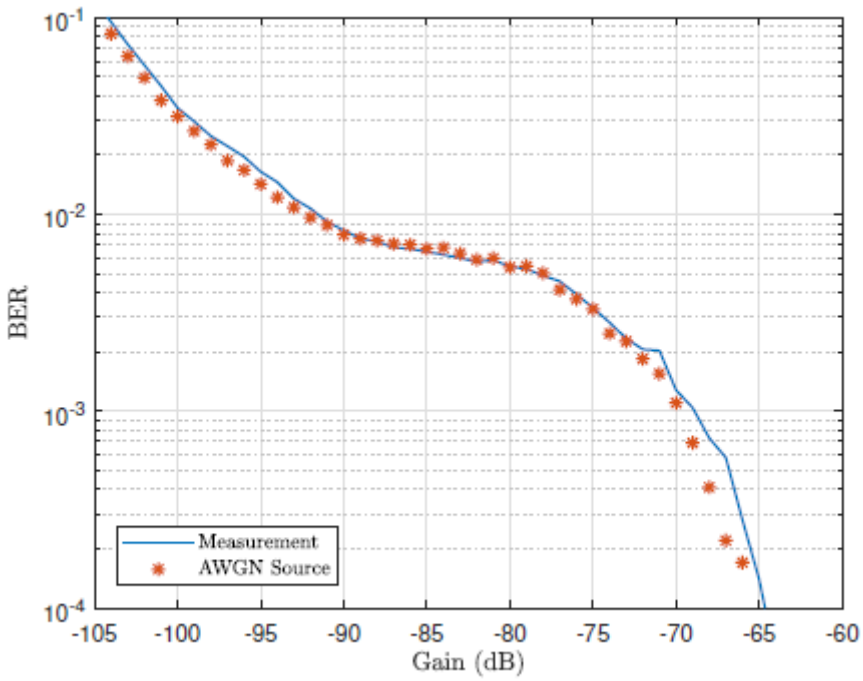
- Direct Modeling



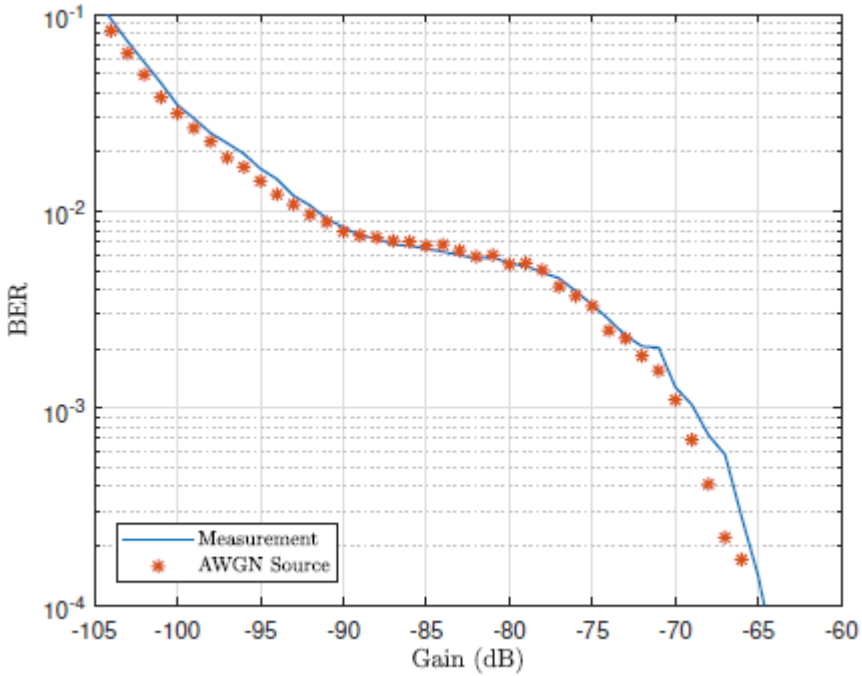


- Some Considerations
  - To detect the interferences in the measured data, the threshold value is set just a few dB above the noise level (for this example, it is 3 dB above the noise level).
  - The gain in the horizontal axis, represents the coefficient of the desired signal. Effects of different interferences are evaluated using this parameter. For example, in high gain region, interferences with greatest power levels are the main source of bit errors.

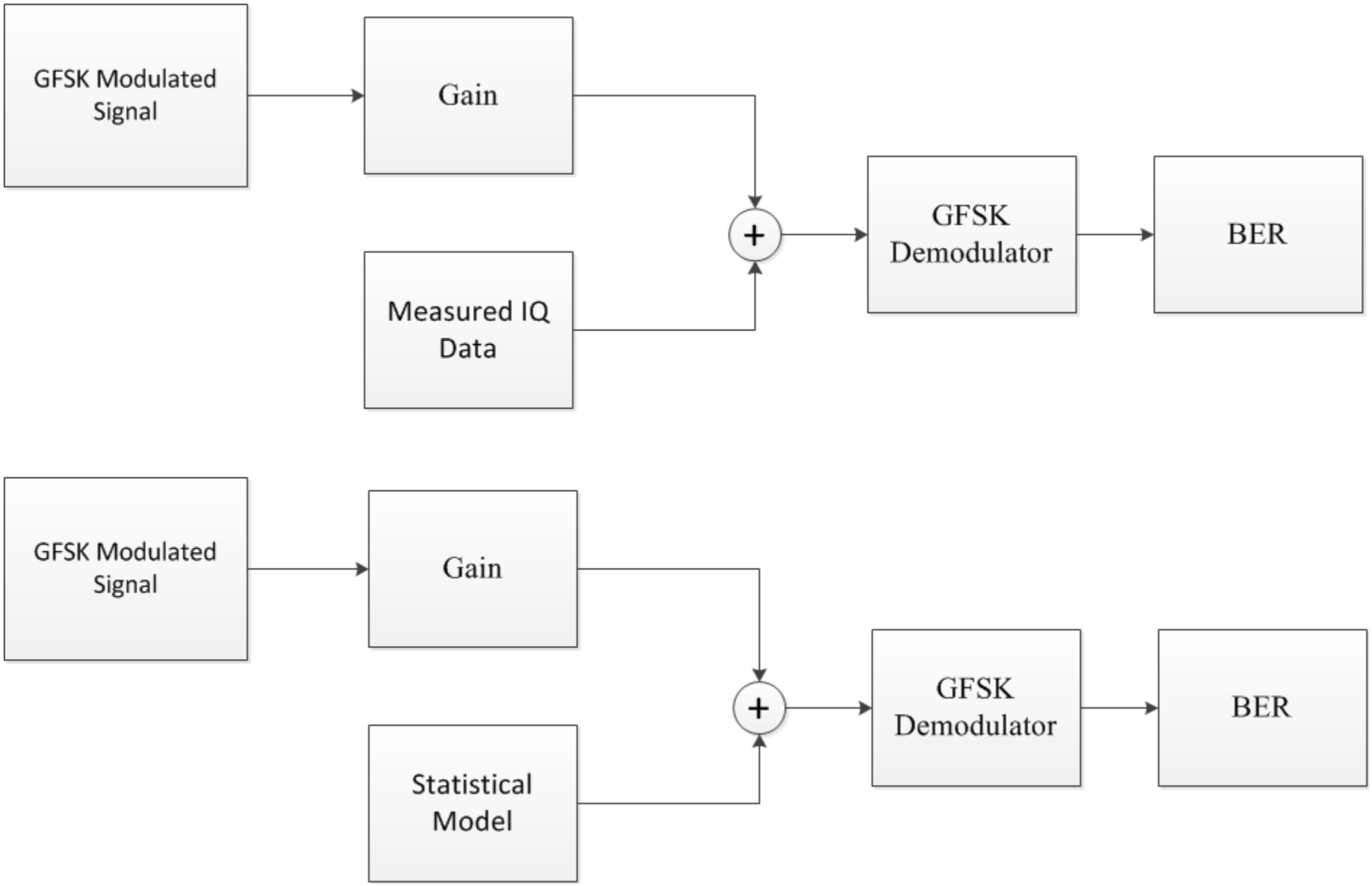




- Some Considerations
  - The effects of out of band signals are ignored. In other words, the measured signal, before any other processing, is passed through a low pass filter.
  - Doing this simulations for different times and different environments show that for the conditions that there are many narrow band interferences the modeling performance is slightly degraded.



Measurement Based Models of Interference



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Statistical Models

- Analytical Models

  - Find closed-form formulas for statistics of interference variables using distribution of interference sources.

- Measurement Based Models

  - Find statistics of interference variables using samples of interferences acquired from measurement data.

    - Find PDFs of interference random variables.

    - Find CDFs of interference random variables.

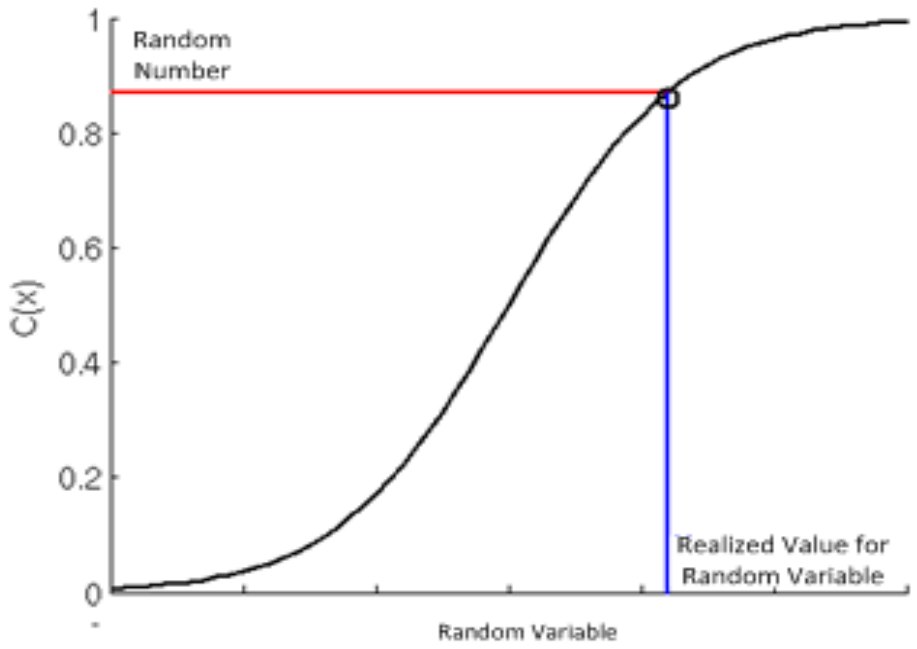
Inverse Transform Method

- Inverse Transform Method :

is a method to generate arbitrary number of realizations (variable samples) of a random variable using its cumulative distribution function.

- Generate a number from the uniform distribution in the interval [0,1]

- Map this number to a value by employing CDF of that random variable



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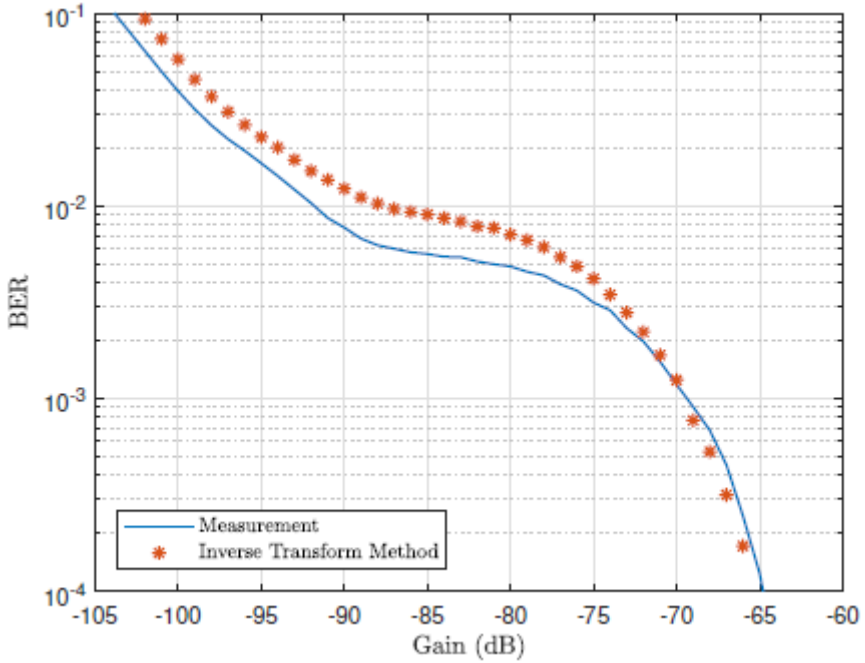
Uncorrelated Random Variables

- Interference Modeling under Assumption of Uncorrelated Random Variables

  - CDFs of three random variable are independently determined.

  - Use inverse transform method to realize arbitrary number of variable samples.



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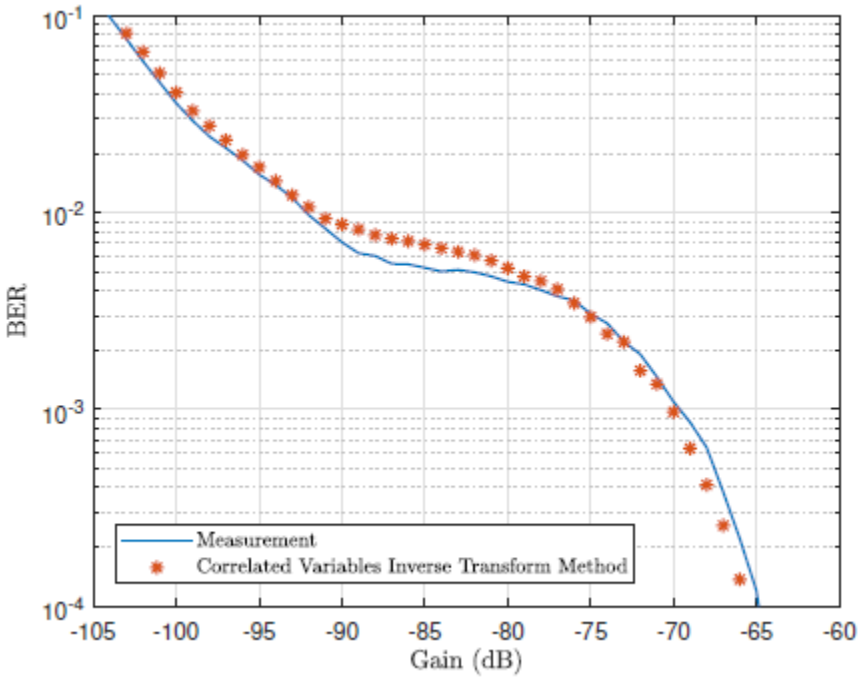
Correlated Random Variables

- Interference Modeling under Assumption of Correlated Random Variables

  - CDFs of three random variable are dependent. Use conditional CDFs of three random variables.

  - Use inverse transform method to realize arbitrary number of variable samples.



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Interference Analysis in Spectrum Domain

- Hypothesis

Measured IQ data (with a given bandwidth and sampling frequency at ISM band) acts as the interfering signal for a Bluetooth low energy system.

- Goal

To replace the big size IQ data with small size spectrum data

- Steps
  - Use measured IQ data to calculate spectrum
  - Use spectrum data to reconstruct an equivalent signal for interference
  - Calculate BER of a GFSK demodulator exposed to measured IQ data and reconstructed signal

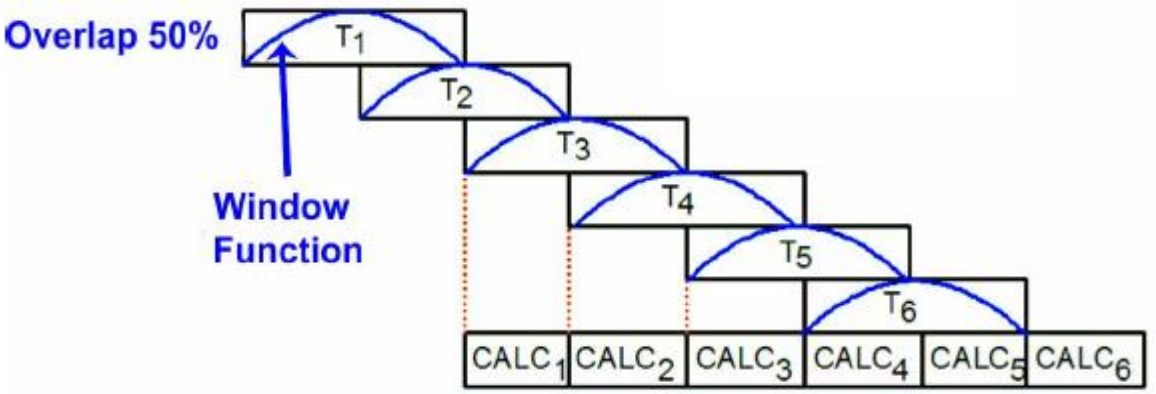
Interference Analysis in Spectrum Domain

FFT Length = 1024

Time Acquisition : 40µs , 100 µs , 200 µs, 500 µs

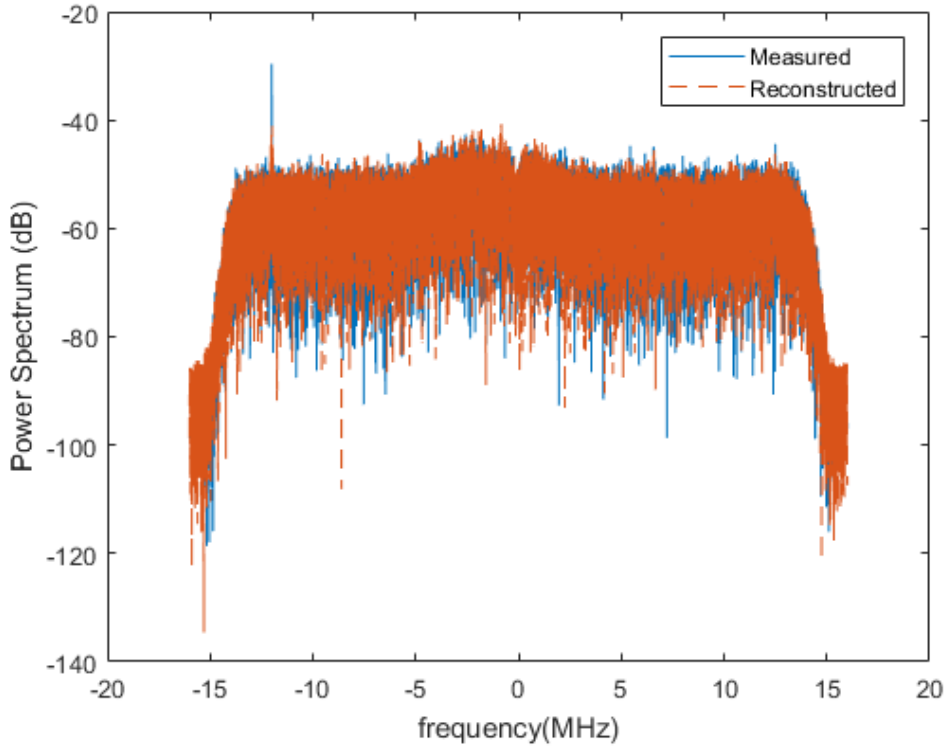
Overlapping = 50 %

Window Function : Keiser



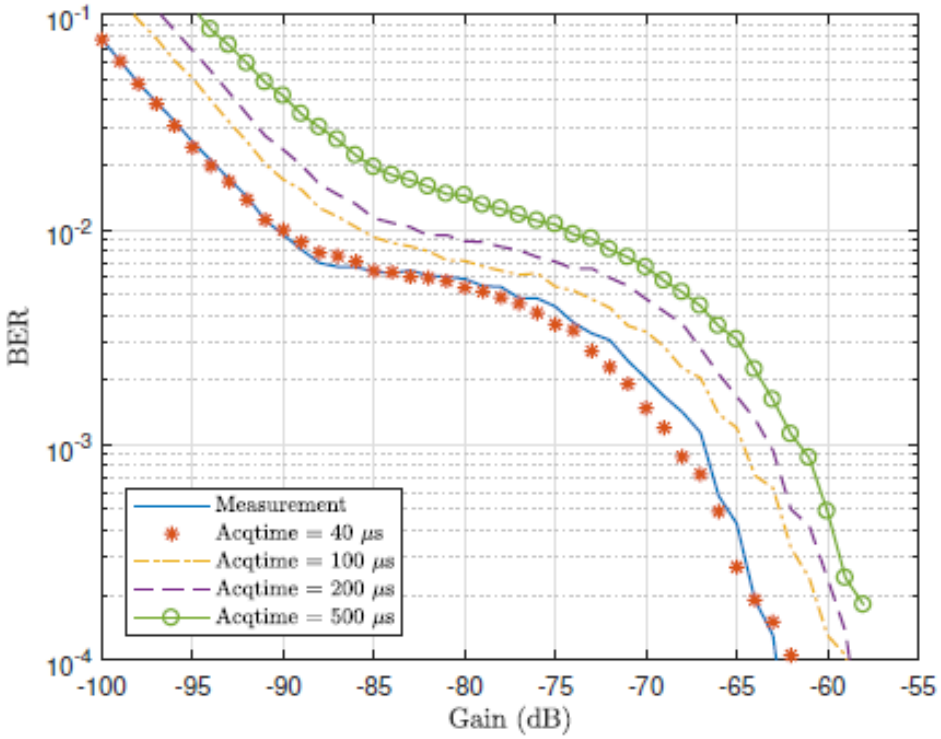
- Reconstruction Approach
  - Pass an AWGN signal through a filter
  - The calculated spectrum during the acquisition time is considered as filter frequency response

Example : compare spectrum of two signal through a certain acquisition time



Interference Analysis in Spectrum Domain

- Modeling Result
  - BER of a GFSK demodulator foe measured and modeled interference signals
  - Different acquisition time



Future Steps

- Enhance statistical models performance
- Test Models in different environments with different measurement scenarios
- Real time spectrum analyzer implementations
- Apply statistical models to spectrum data

Thank You For Your Attention!

TU Wien
Institute of Electrodynamics, Microwave and
Circuit Engineering
Microwave Engineering Group
Gusshausstrasse 25/354
1040 Vienna, Austria