Digital Programmable Gaussian Noise Generator

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Project Proposal Presentation

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LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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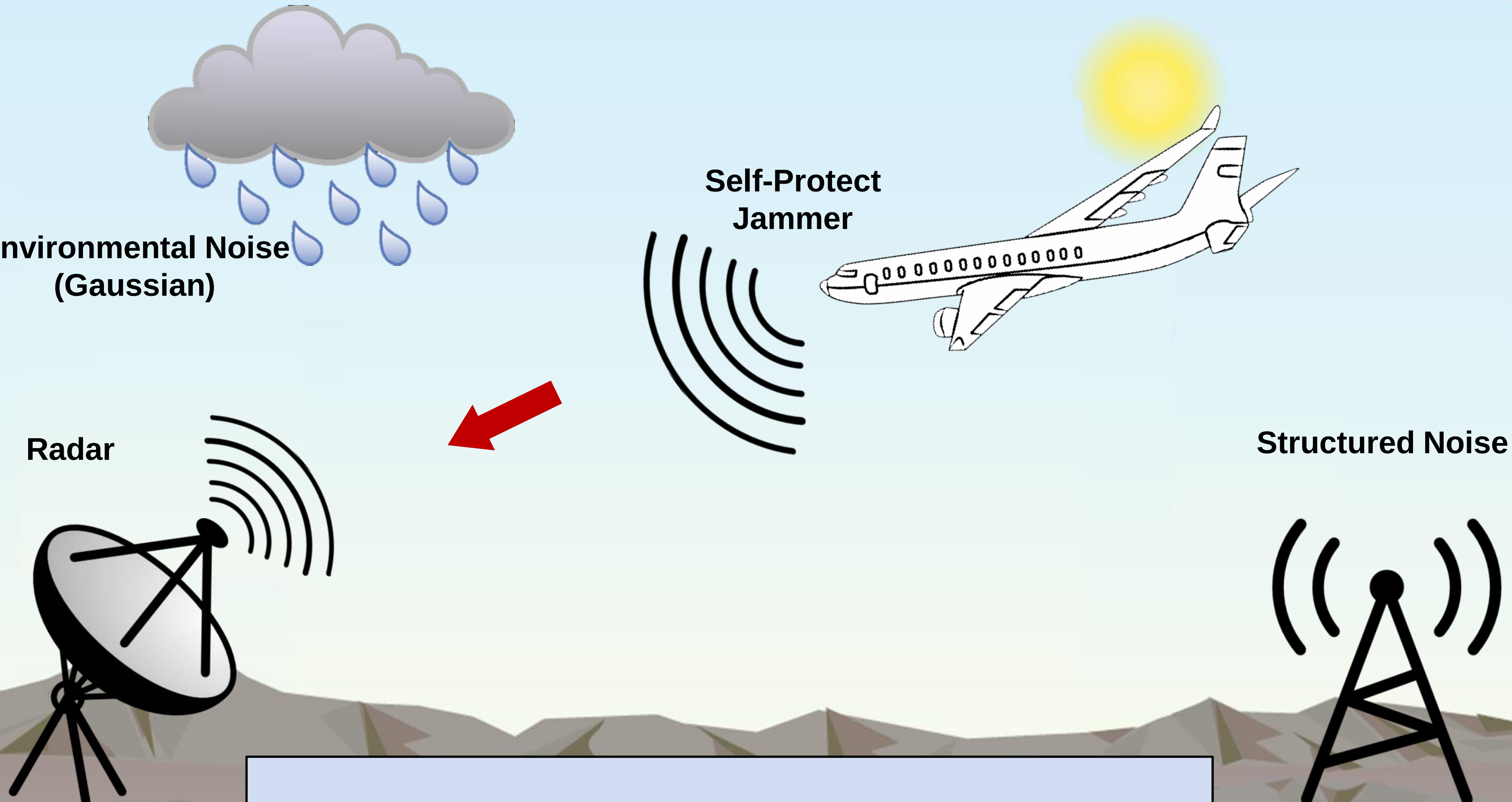
Outline

- **Introduction**
- **Background**
- **Methods**
- **Results**
- **Conclusion**

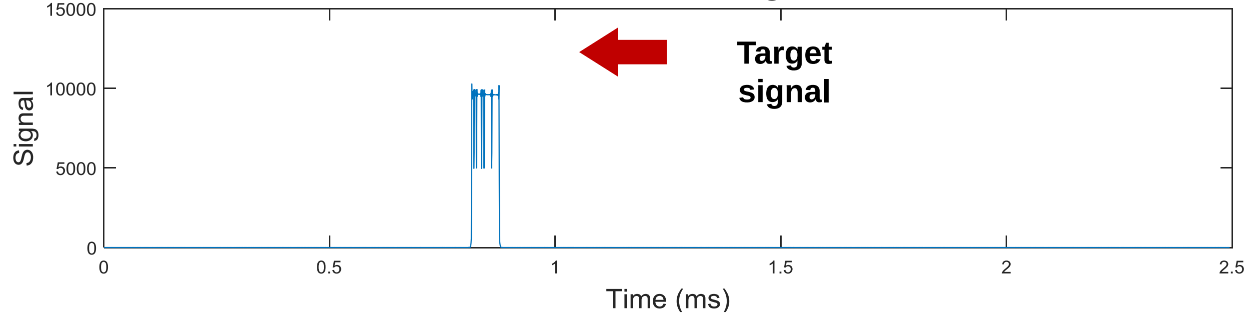
Motivation



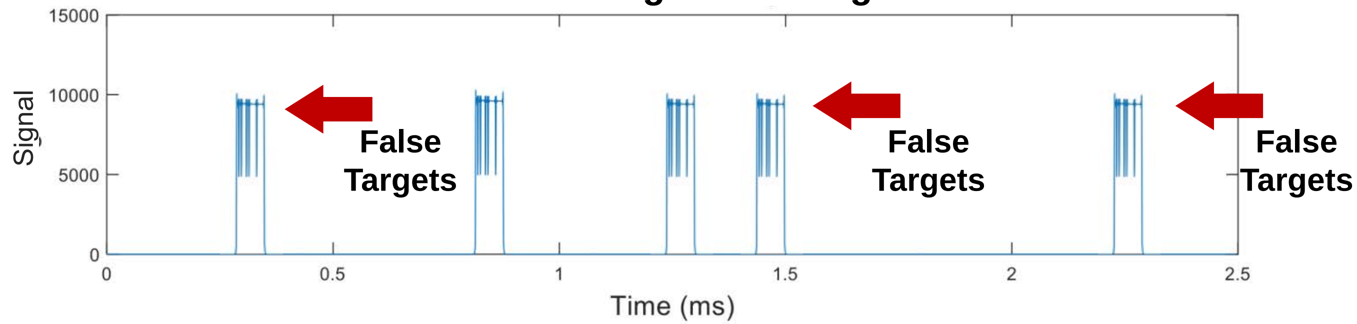
Group 108 is interested in studying Gaussian vs. structured noise and its effect on various threat radar systems.

Jamming Overview

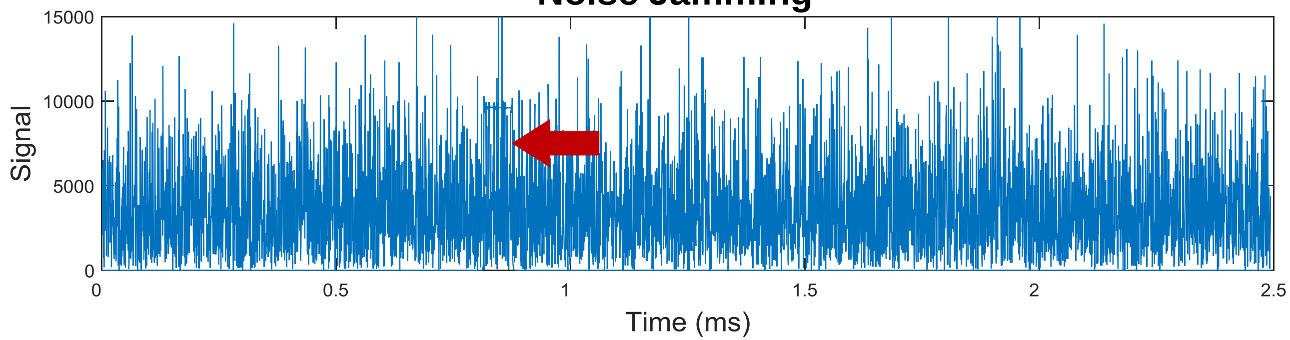
No Jamming



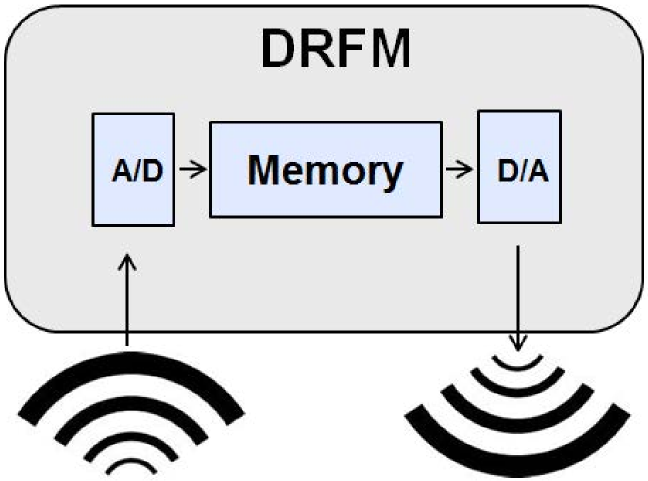
False Target Jamming

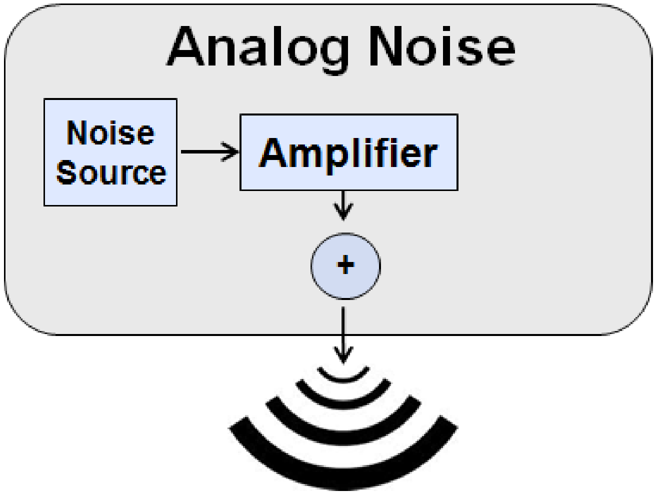


Noise Jamming



DRFM vs Analog Noise



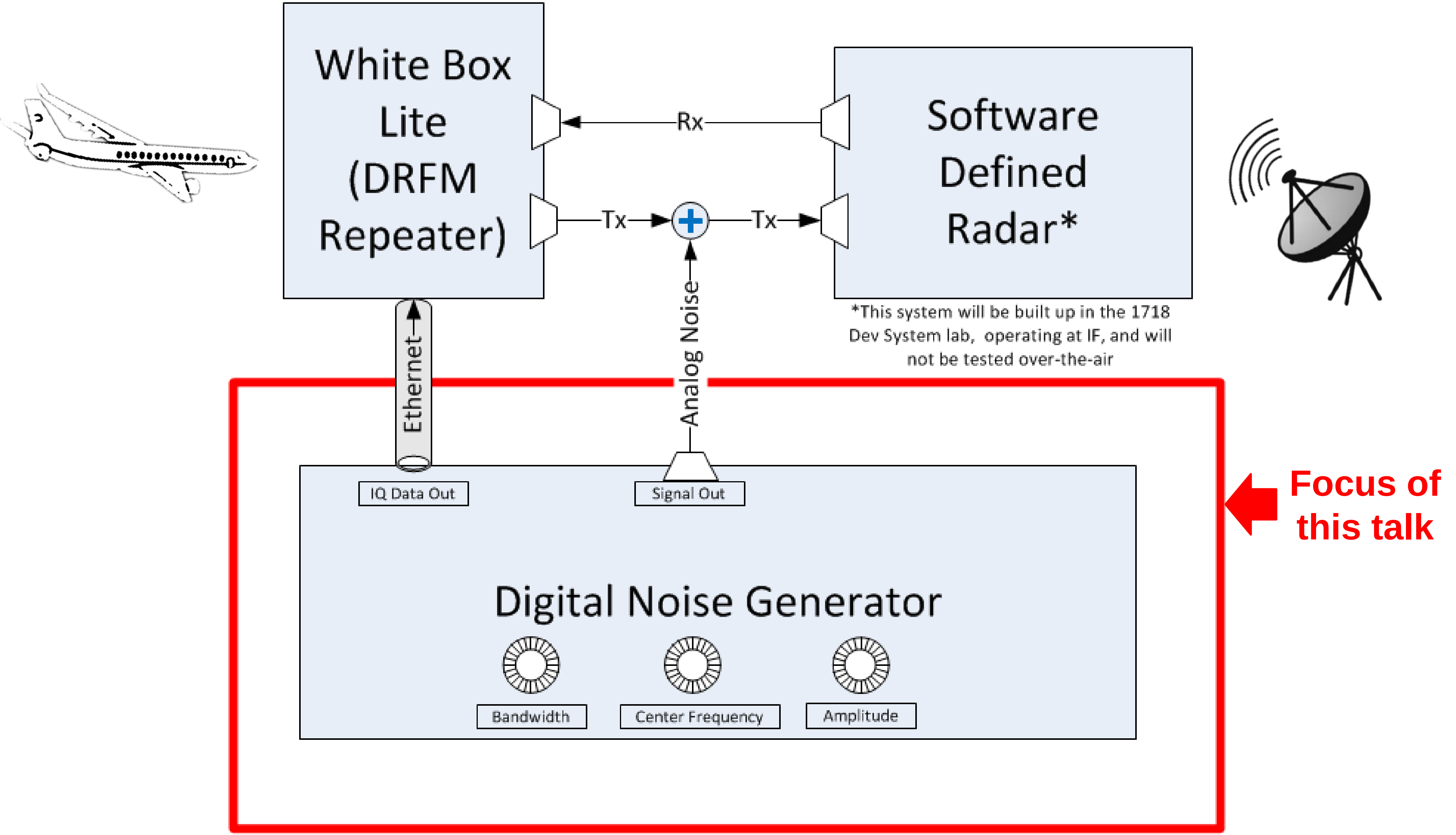


•High Configurability
•Plays back recorded radar waveform
  •Power concentrated into narrower frequency band
  •Radar matched filter gives additional power gain
  •Gaussian noise is possible but requires work

•Limited Configurability
•Always wideband Gaussian noise
  •Power level dependent on external amplification

Digital Gaussian noise generator is a desirable expansion to existing DRFM capabilities

Project Overview



Digital Noise Generator Requirements

- Standalone hardware
- User programmable center frequency, bandwidth, and amplitude
- Analog output
- Digital in-phase and quadrature output through Ethernet
- Pass test suite for Gaussian distribution

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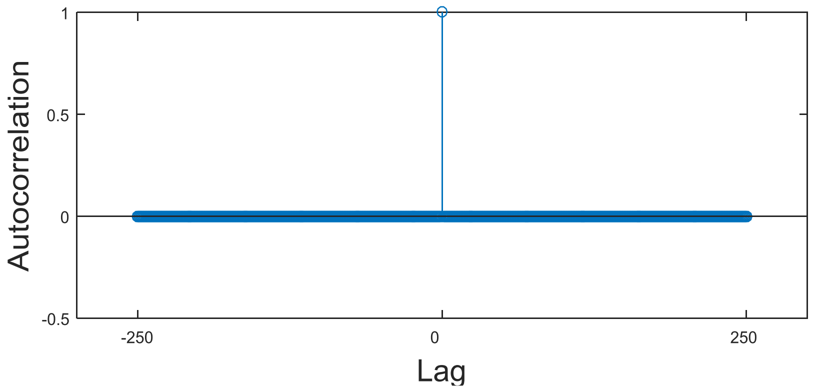
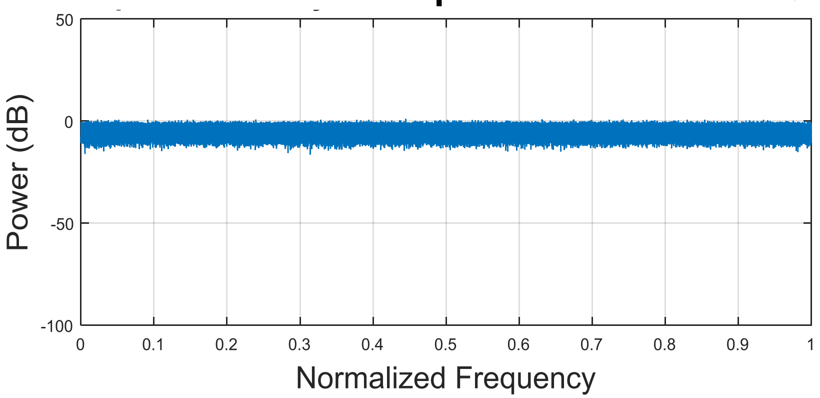
Noise Characteristics

White Noise

Autocorrelation*

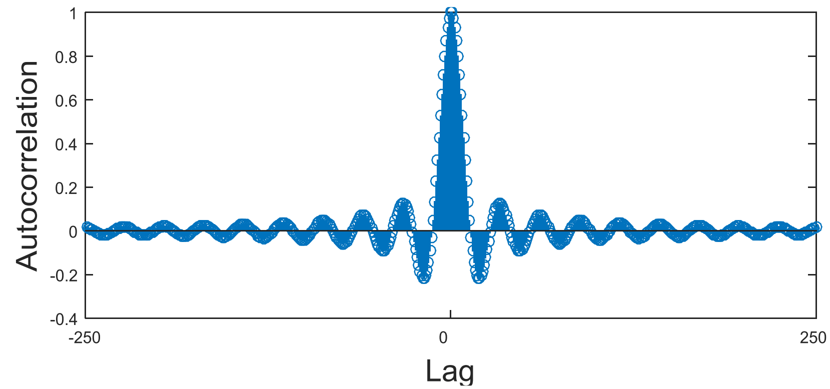


Power Spectrum*

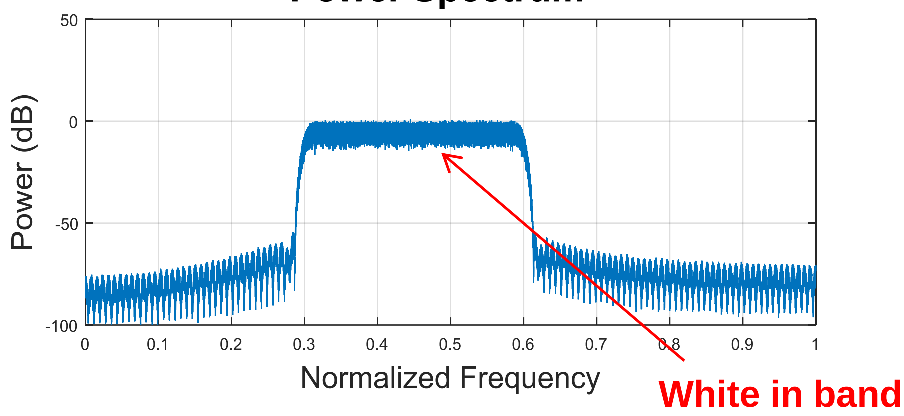


Band-Limited White Noise

Autocorrelation*

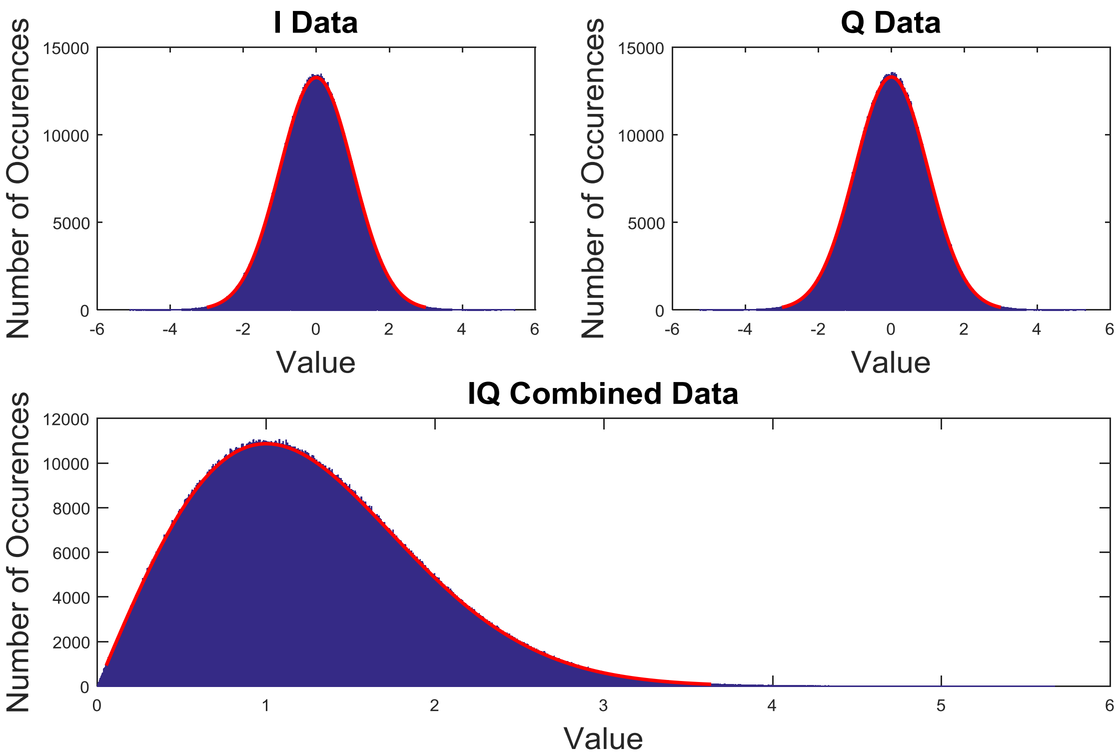


Power Spectrum*

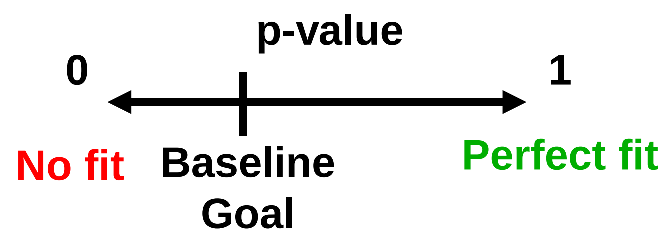


***Simulated in MATLAB**

Gaussian Characteristics



MATLAB Samples		
Test	IQ Average	Rayleigh
Chi-Squared	0.54	0.42
Anderson-Darling	0.20	N/A



*Normally distributed 10e6 samples from simulation

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Considered Hardware Platforms

Score Value	Category (Platform)		Ettus USRP	Xilinx Kintex-7 DSP Dev Kit	Per Vices Crimson	Beecube Nano Bee	Nutaq uSDR 420	Nutaq PicoSDR	Epic Maveriq	Nuand BladeRF
	Price	Weight	Score							
0	Over 10k	1	1	2	0	0	-	0	0	2
1	5-10k									
2	Under 5k									
	Bandwidth	Weight	Score							
0	< 200 MHz	3	1	-	1	1	1	0	0	0
1	> 200 MHz									
	RF Range	Weight	Score							
0	Does not contain 20 MHz	3	1	1	1	0	0	0	0	0
1	Contains 20 MHz									
	DAC Width	Weight	Score							
0	<=12 bits	4	1	1	1	-	-	-	0	-
1	>12 bits									
	DAC Rate	Weight	Score							
0	< 100 MS/s	4	2	2	1	-	-	-	0	0
1	100-500 MS/s									
2	> 500 MS/s									
	Lead Time	Weight	Score							
0	Over 2 weeks	4	1	2	2	0	-	-	0	-
1	1-2 weeks									
2	less than a week									
	Digital Interface?	Weight	Score							
0	No Ethernet	3	1	1	1	1	1	1	1	1
1	Ethernet									
	FPGA	Weight	Score							
0	Not Xilinx	3	1	1	0	1	1	1	1	0
1	Xilinx									
	# Logic Cells	Weight	Score							
0	<250	3	2	1	1	2	2	2	0	0
1	250-400									
2	400+									
	Weighted Total		36	34	28	15	15	12	6	5

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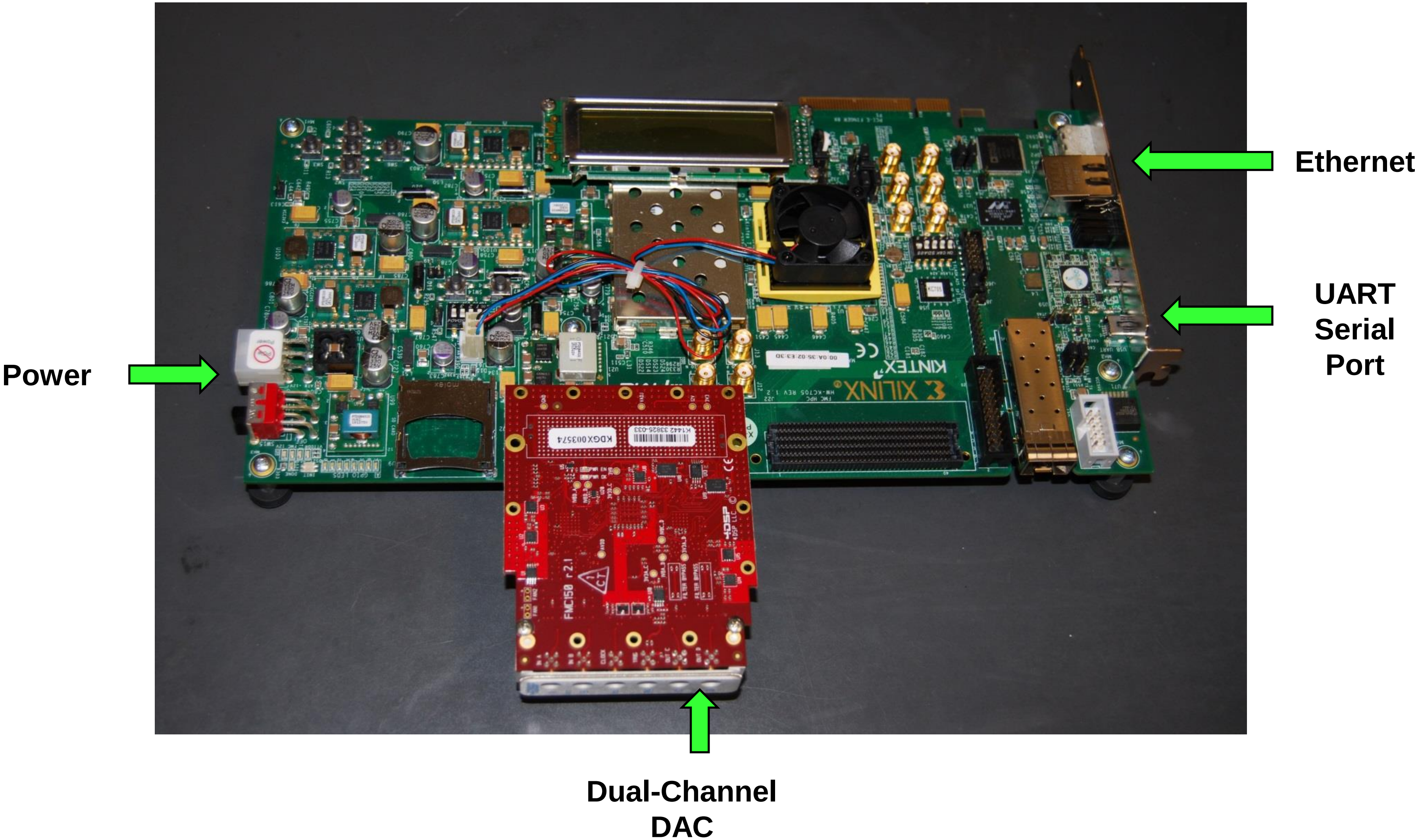
Selected Hardware Platform: KC705



Methods for Digitally Generating Gaussian Noise

Inversion	**Box Muller Transform**	Central Limit Theorem
Recursion	Analog Sampling	Rejection

$$n_1 = \sqrt{-2ln(u_1)} * sin(u_2)$$

$$n_2 = \sqrt{-2ln(u_1)} * cos(u_2)$$

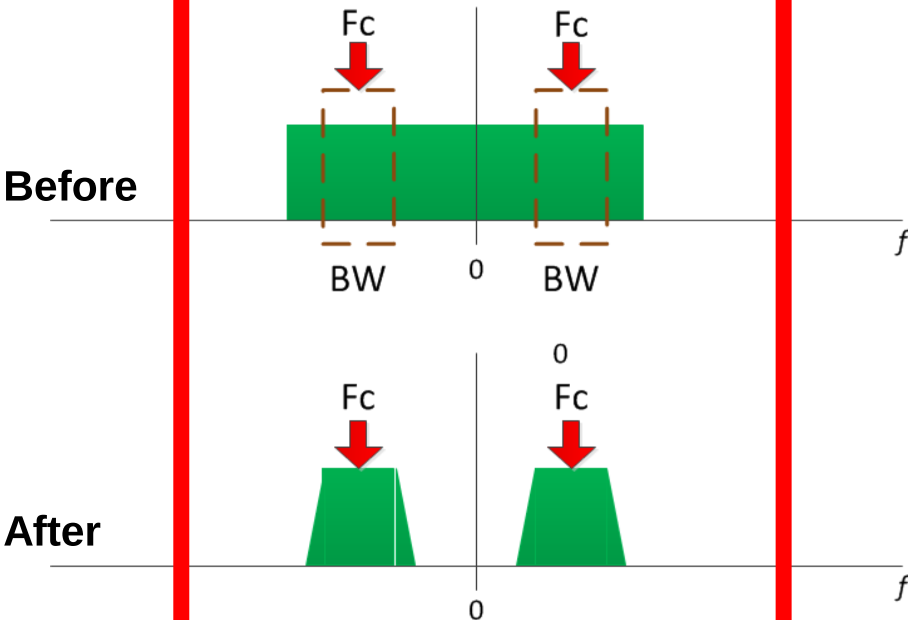
u_1, u_2 Uniform
n_1, n_2 Normal

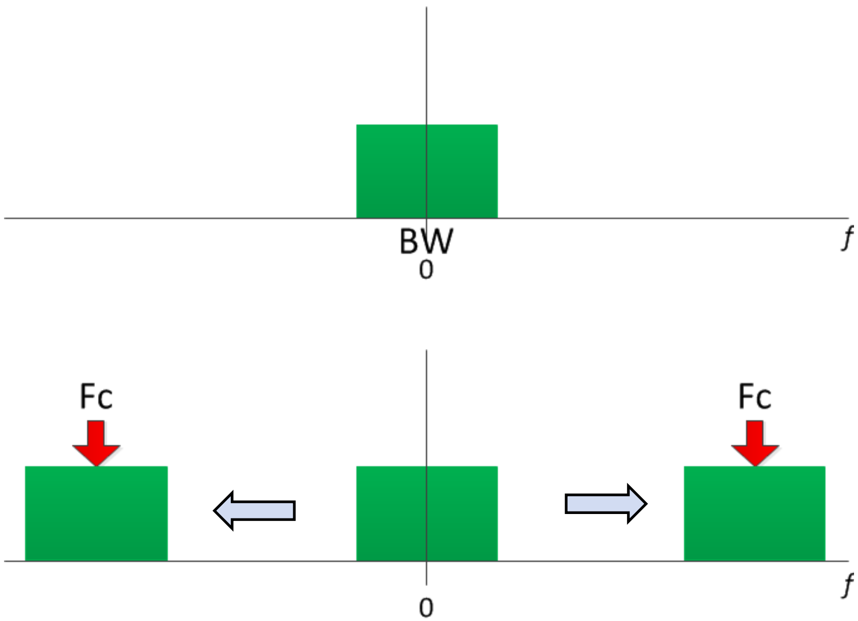
Defining Bandwidth and Center Frequency

Filter broadband noise

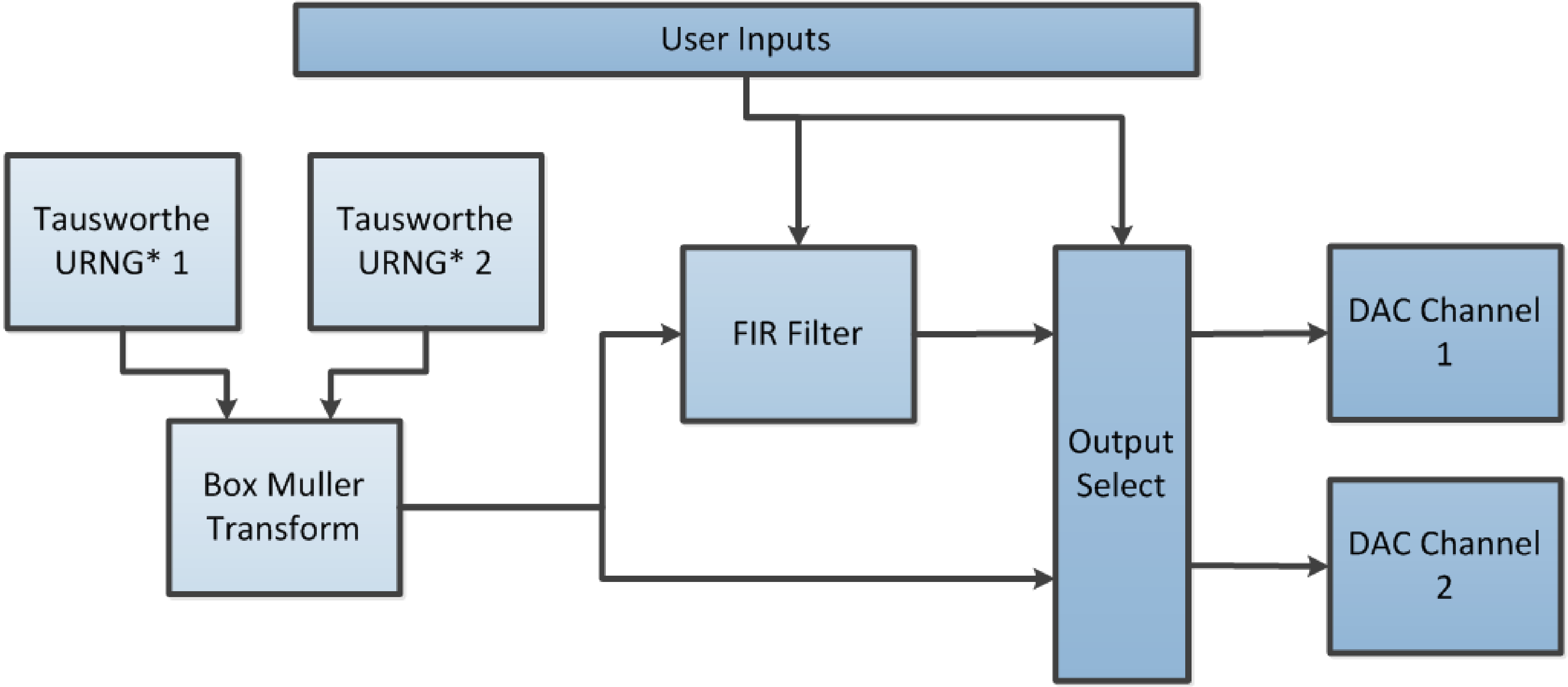
VS

Generate at baseband and mix to higher frequencies



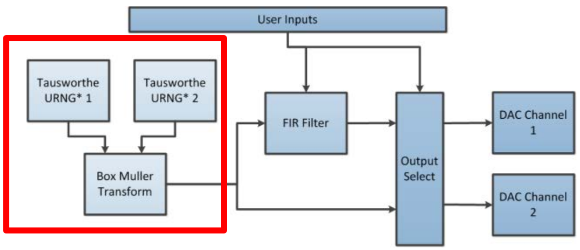


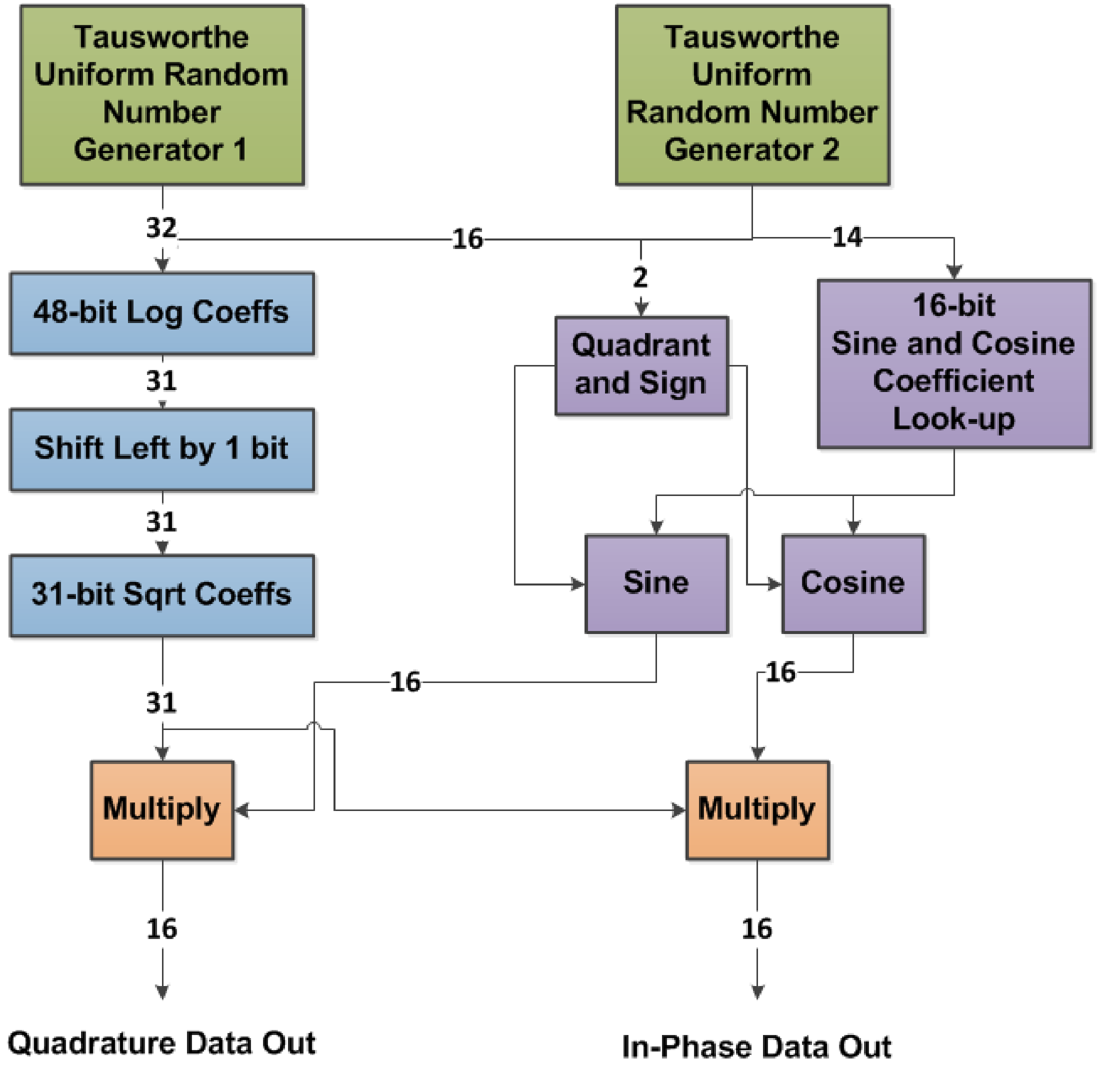
Generator Flowchart



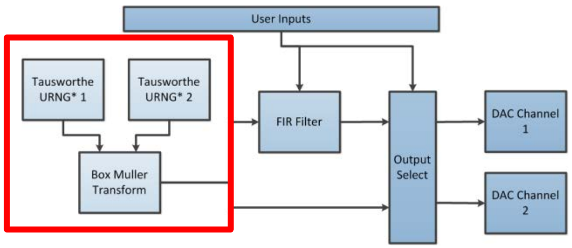
***Uniform Random Number Generator**

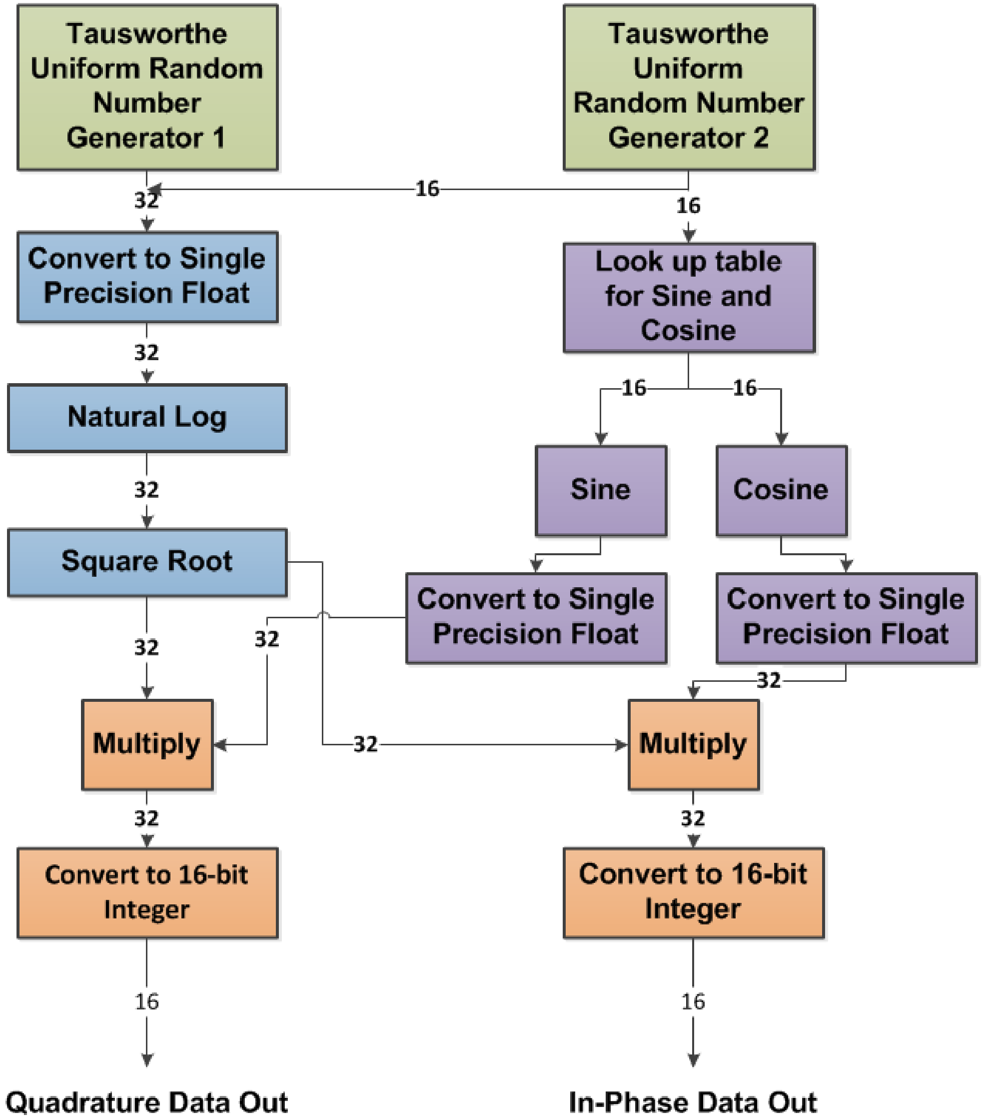
Box-Muller Algorithm and Implementation Fixed Point Operations



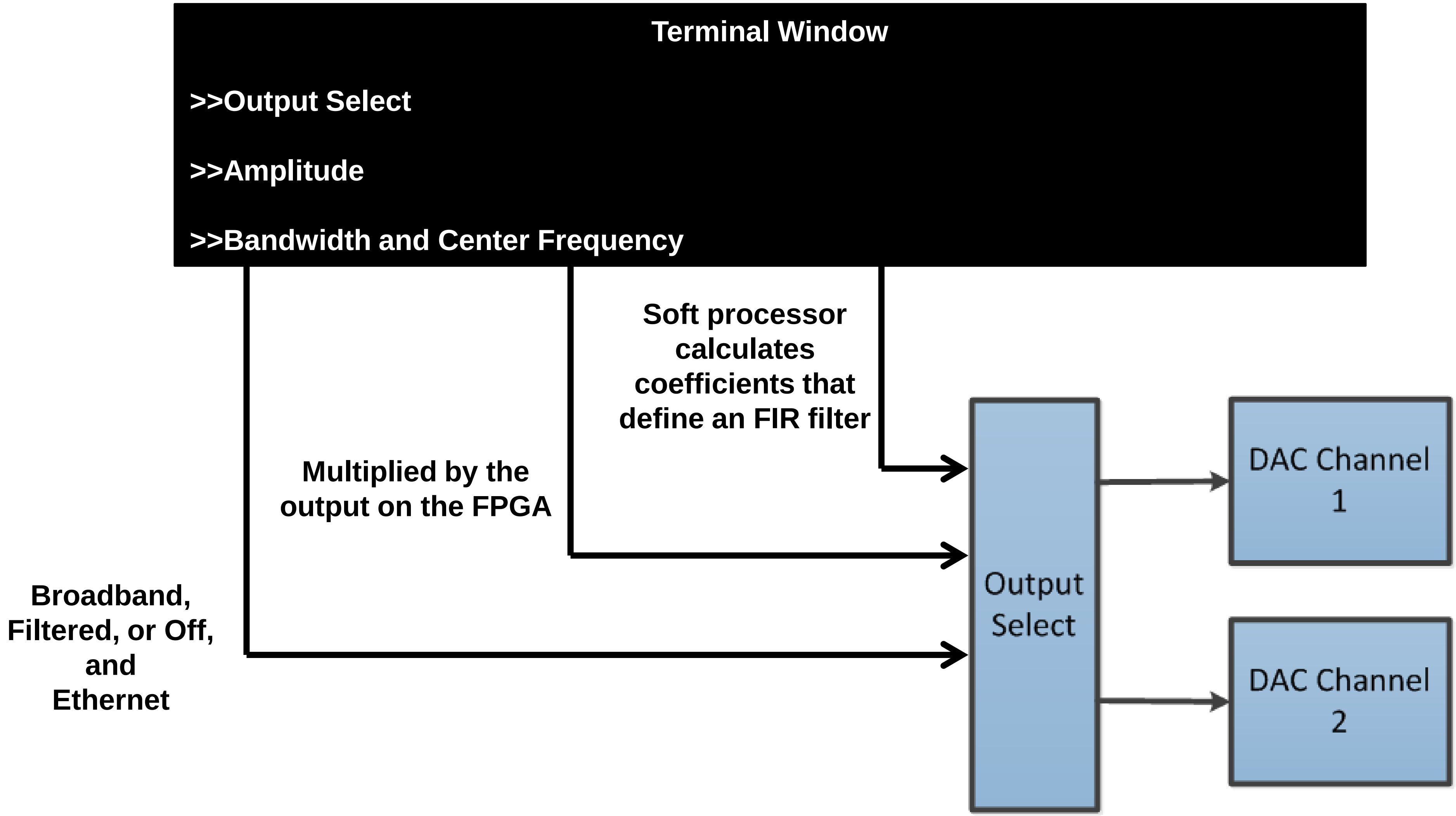


Box-Muller Algorithm and Implementation Floating Point Operations

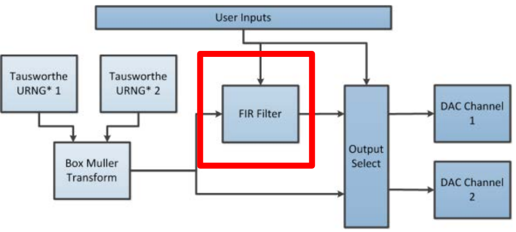




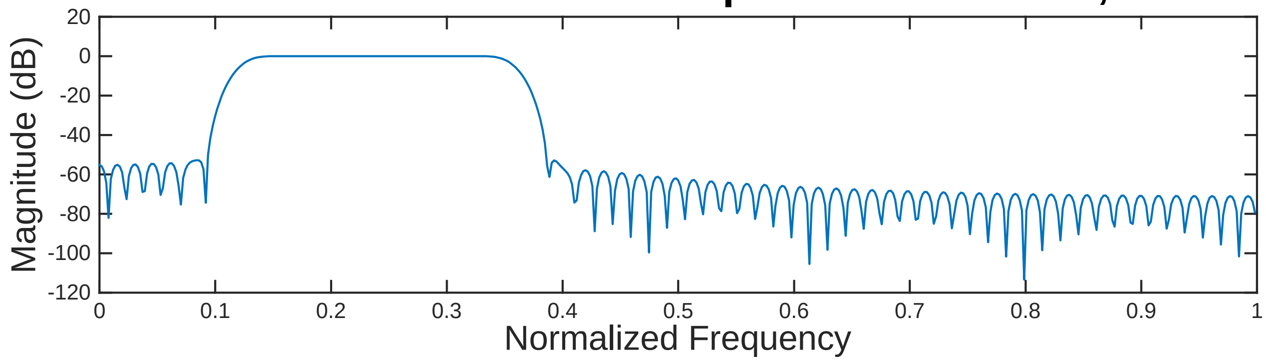
Programmability



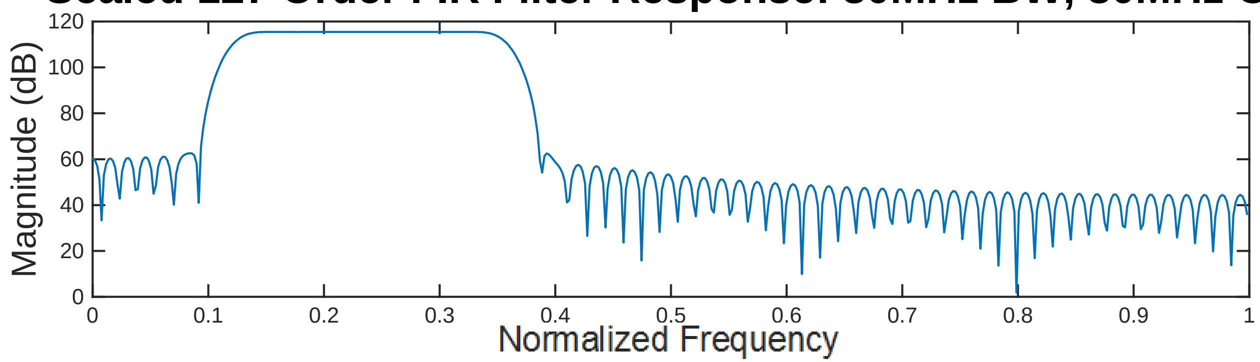
Filter Implementation



Unscaled 127 Order FIR Filter Response: 30MHz BW, 30MHz CF



Scaled 127 Order FIR Filter Response: 30MHz BW, 30MHz CF



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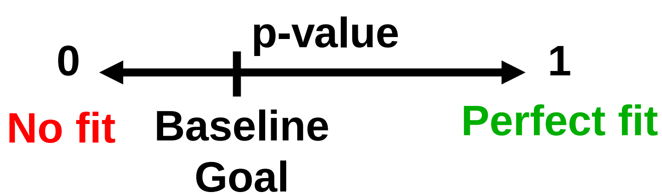
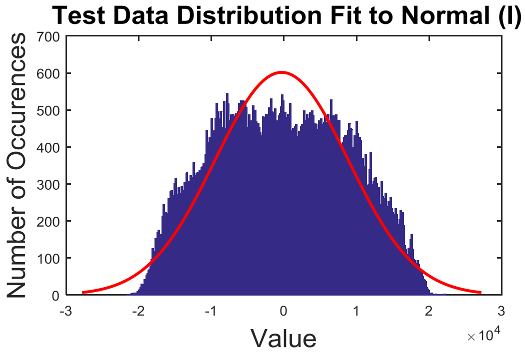
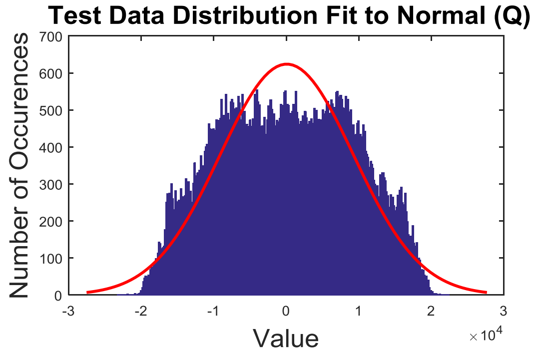
Noise Comparison

Result Comparison			
Platform	Data	Test	
		Chi-Squared	Anderson-Darling
MATLAB	I&Q Average	0.54	0.42
	Rayleigh	0.2	N/A
White Box Lite	I&Q Average		
	Rayleigh		
Analog Generator	I&Q Average		
	Rayleigh		
KC705 Fixed Point Xilinx Simulation	I&Q Average		
	Rayleigh		
KC705 Floating Point Xilinx Simulation	I&Q Average		
	Rayleigh		

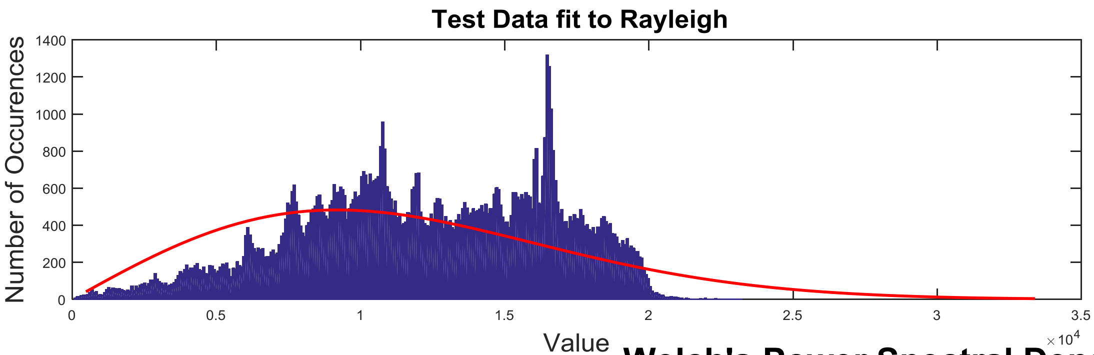


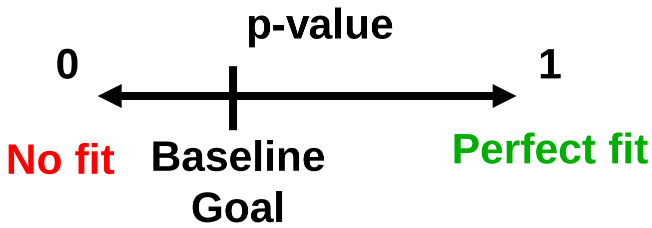
Characterizing Existing Noise Sources
White Box Lite Frequency Sweep*

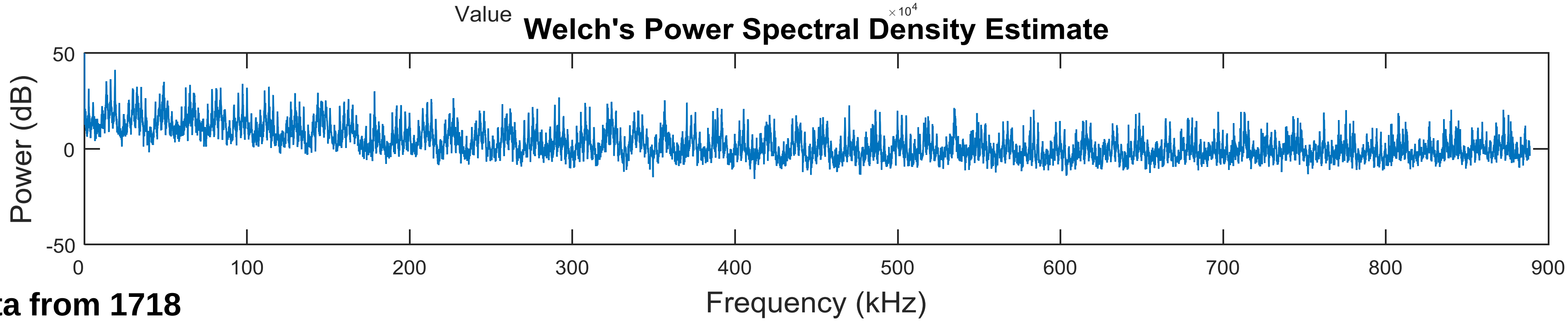




WBL Freq Sweep		
Test	I and Q Average	Rayleigh
Chi-Squared	0	0
Anderson-Darling	0	N/A

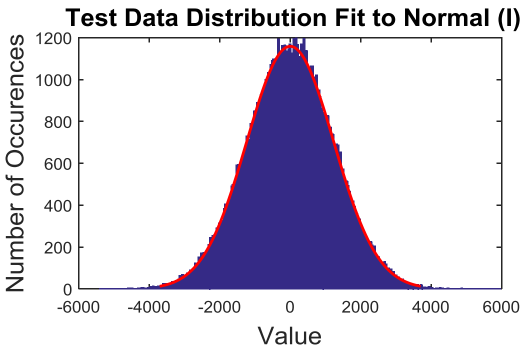


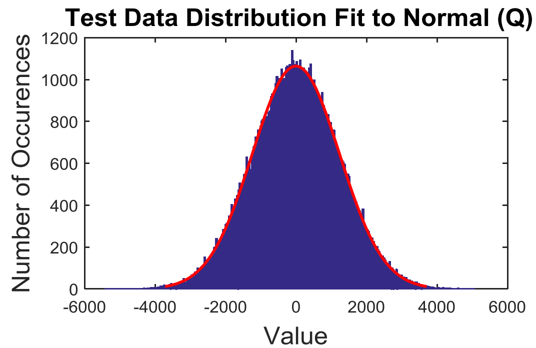


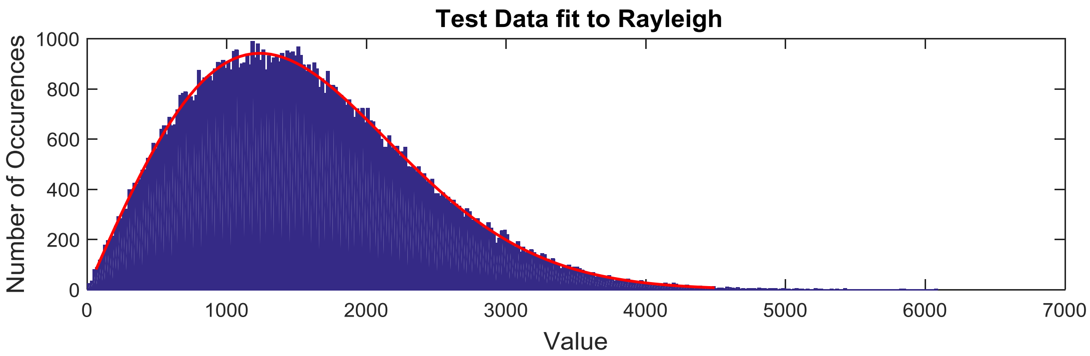


*Data from 1718

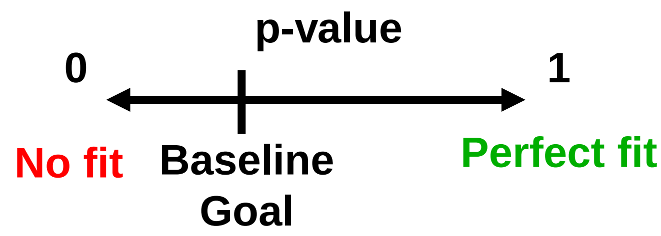
Characterizing Existing Noise Sources
Analog Noise Generator*

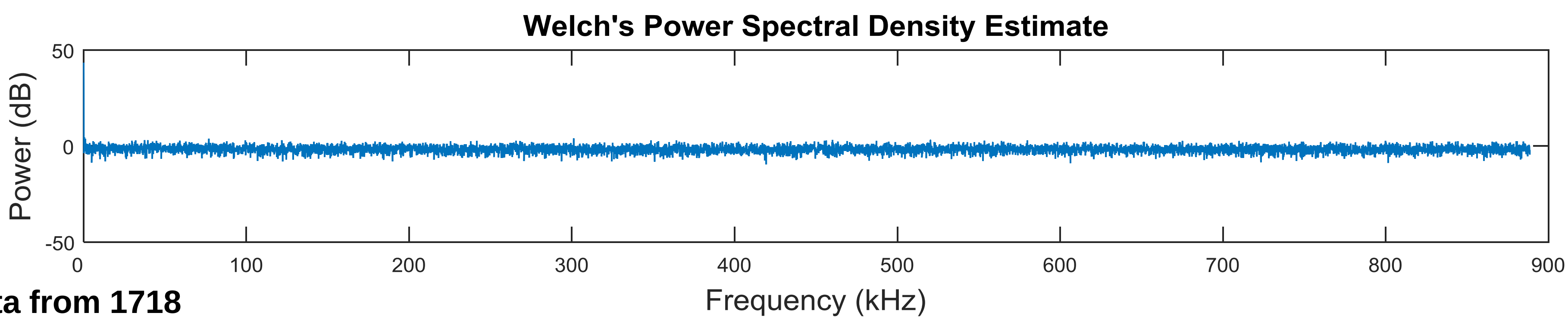






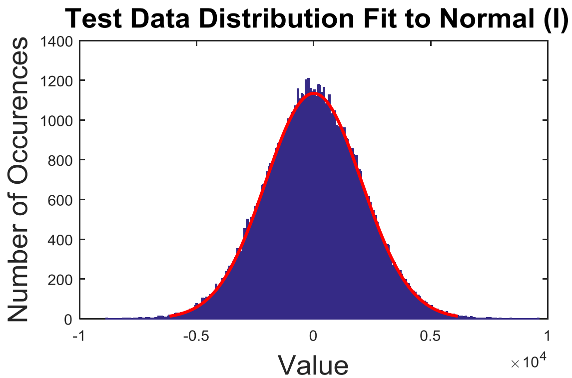
Analog 0dB		
Test	I and Q Average	Rayleigh
Chi-Squared	0.46	0.64
Anderson-Darling	0.47	N/A

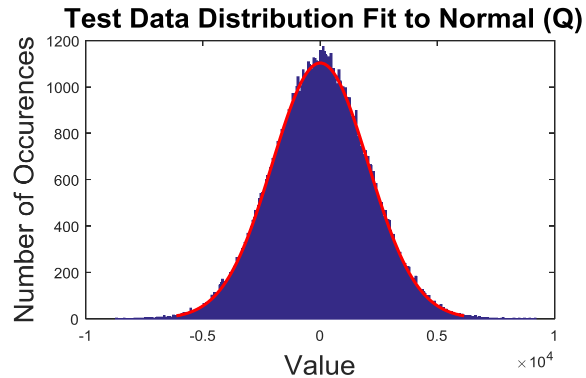


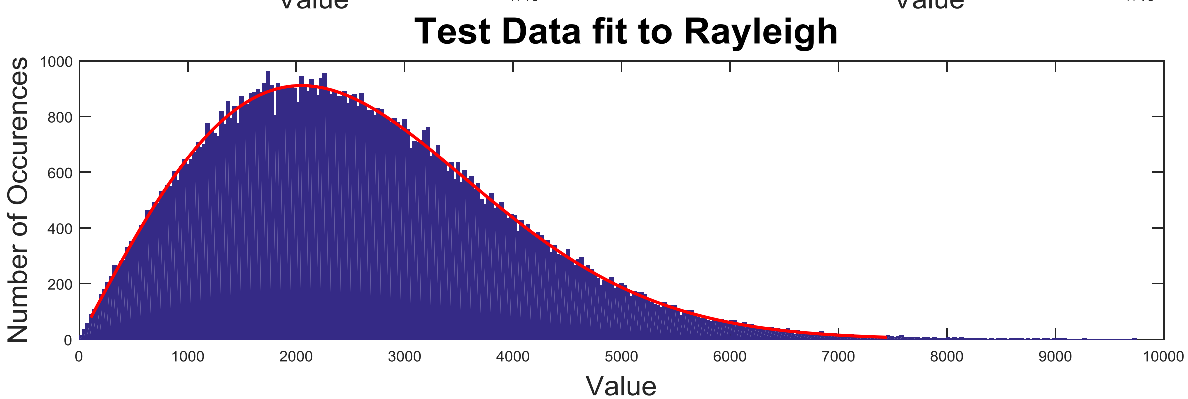


***Data from 1718**

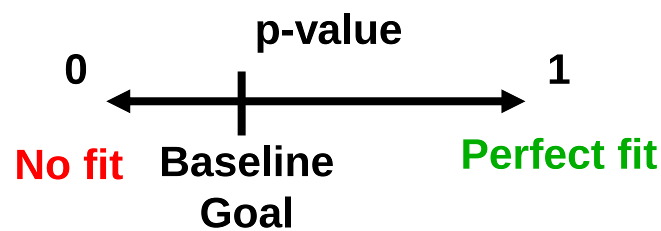
KC705 Results*





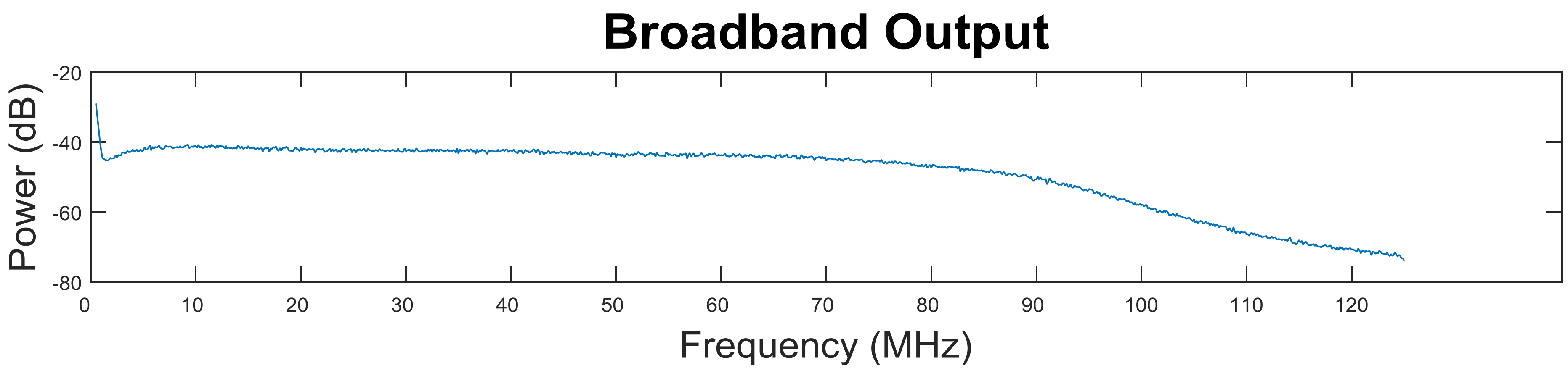


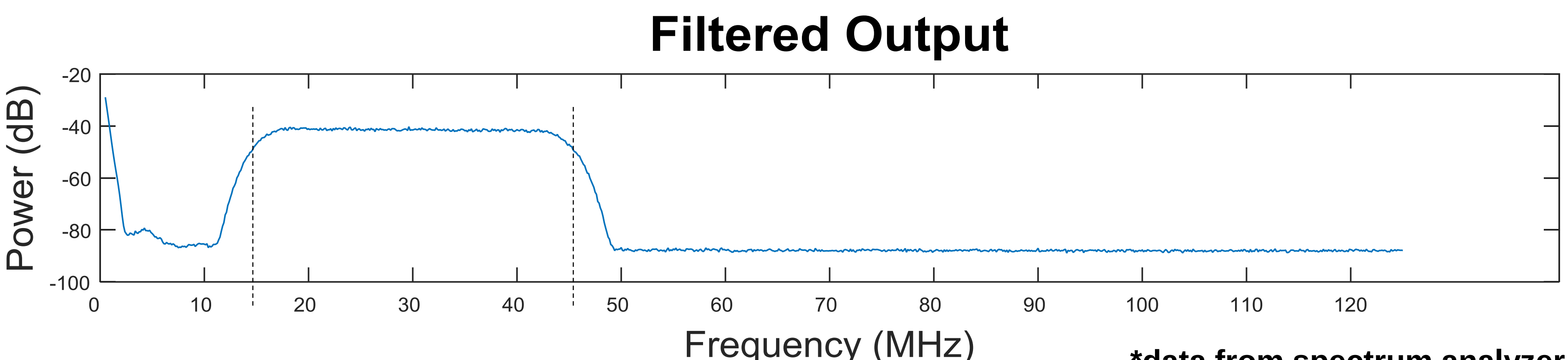
KC705 Full Amplitude		
Test	I and Q Average	Rayleigh
Chi-Squared	.44	.55
Anderson-Darling	.42	N/A



*data from Xilinx Test Bench

KC705 Results*
Power Spectrum

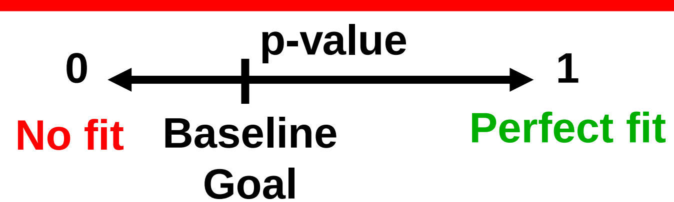




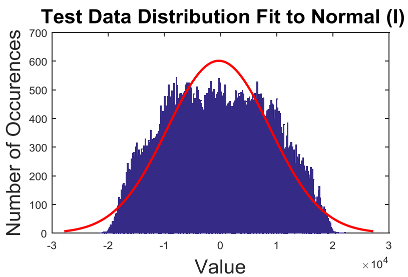
***data from spectrum analyzer**

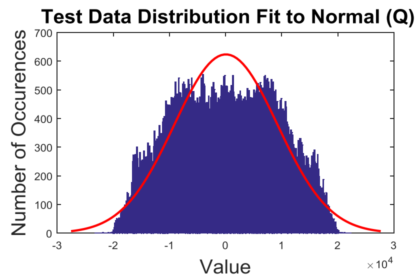
Full Noise Comparison

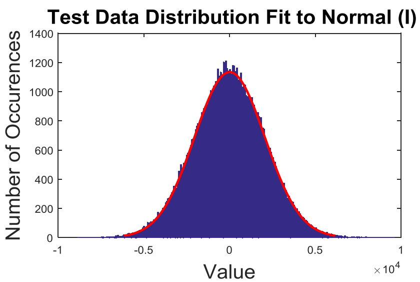
Result Comparison			
		Test	
Platform	Data	Chi-Squared	Anderson-Darling
MATLAB	I&Q Average	0.54	0.42
	Rayleigh	0.2	N/A
White Box Lite	I&Q Average	0	0
	Rayleigh	0	N/A
Analog Generator	I&Q Average	0.46	0.47
	Rayleigh	0.64	N/A
KC705 Fixed Point Xilinx Simulation	I&Q Average	0	0
	Rayleigh	0	N/A
KC705 Floating Point Xilinx Simulation	I&Q Average	0.44	.55
	Rayleigh	0.42	N/A

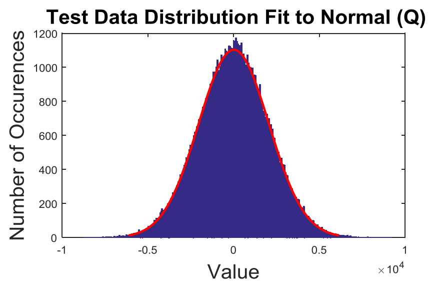


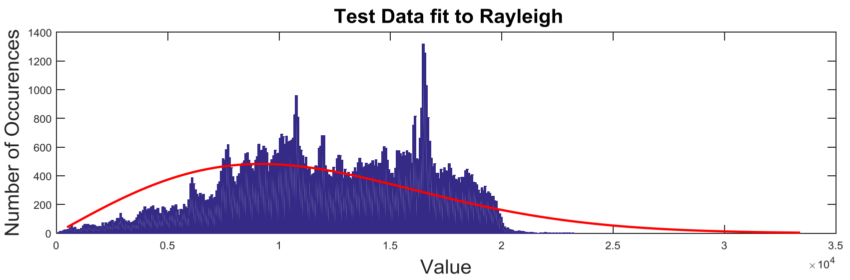
WBL vs Final Implementation

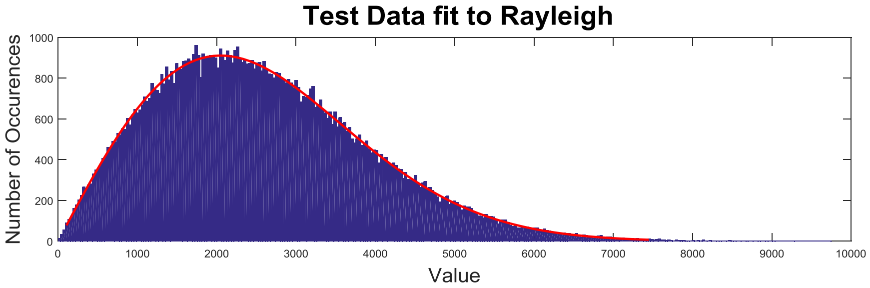












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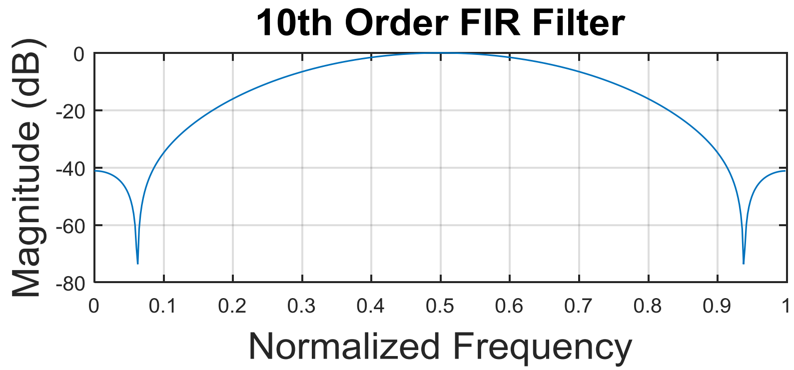
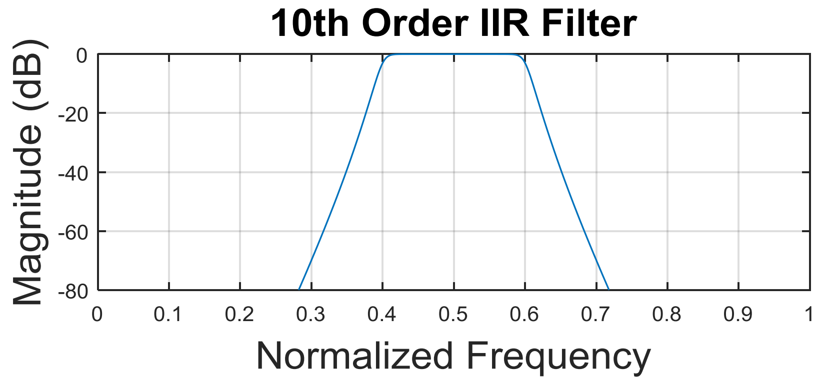
Future Work

- **Filter Improvements**
- **Change Platforms**
  - **Double Bandwidth**
  - **Analog Mixing**
  - **Enclosed Platform**





Conclusion

- **Characterized Gaussian noise**
- **Evaluated techniques for generating noise**
- **Benchmarked existing technology**
- **Successfully designed and implemented a digital, programmable, Gaussian noise generator**
  - **Improvement over existing technology**
  - **Immediately available for Group 108 testing**

Acknowledgements

Mentors

- **Lisa Basile**
- **Ted Clancy**
- **Sarah Curry**
- **Emily Fenn**
- **Chris Massa**

MVPs

- **Dave Baur**
- **Brent Dennis**
- **Dave McQueen**

And the rest of group 108!

Thank You

Questions?

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Simulation vs 1718 Data Collection