Expanding Versatility with Wireless Instrumentation System

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OUTLINE

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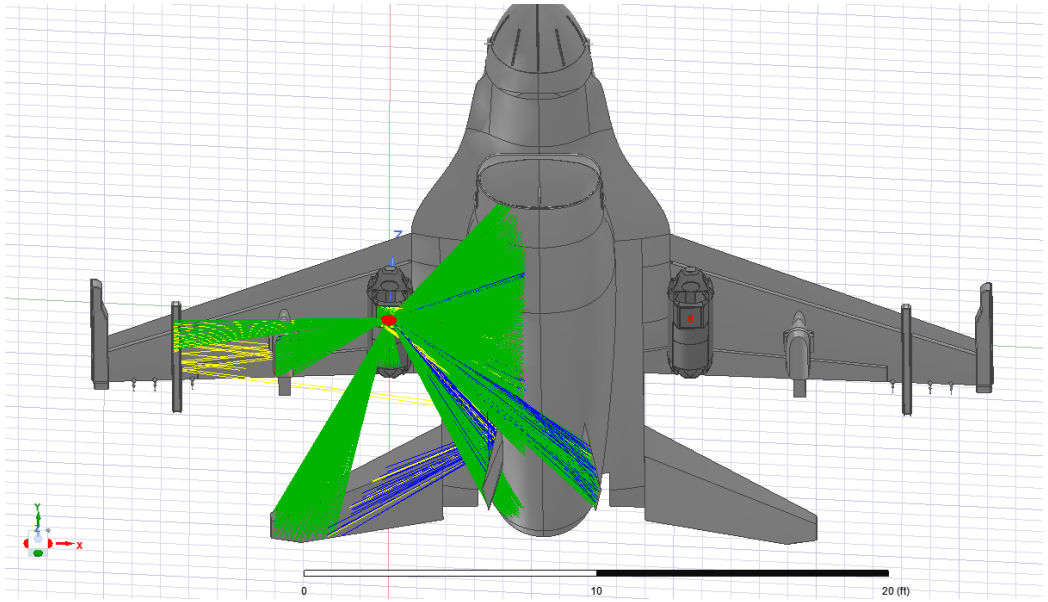
- Validation in the lab
  - Bluetooth bit error rates (BER)
  - PCM over Bluetooth frame drop rates



WIRELESS DEVELOPMENT TEAM

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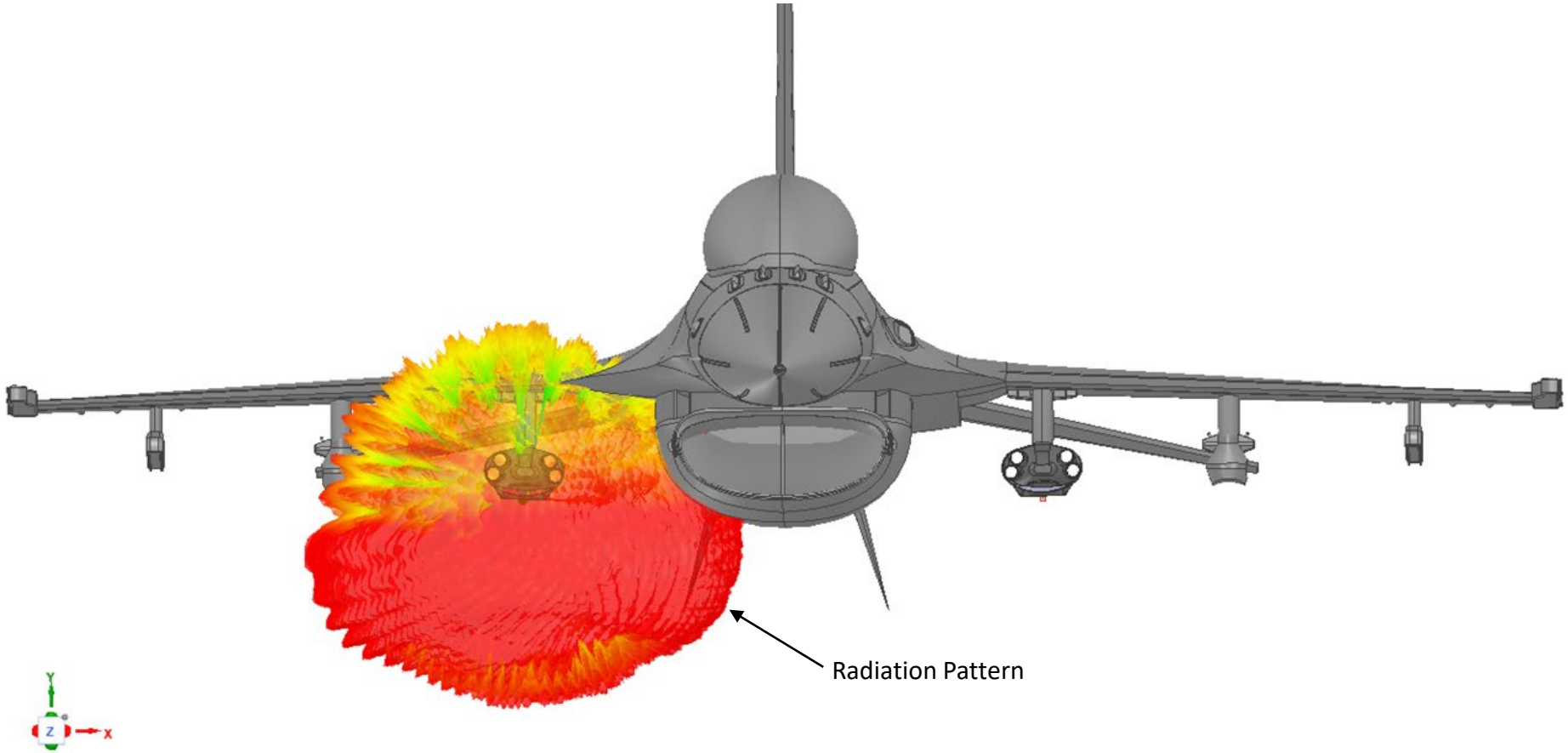
TEAM WIRELESS



WIRELESS INSTRUMENTATION SYSTEM OVERVIEW

Purpose

To test the effectiveness of using wireless communication in an intra-plane instrumentation system.

Motivations:

- Provide capability to overcome the limitations of wired connections.
- Reduce the amount of orange wire in aircraft.
- Reduce aircraft down time, material cost and weight.
- Support networked based instrumentation systems, such as CANIS.

Test Objectives:

- Characterize timing over wireless links.
- Prove RF link performance and reliability.
- Demonstrate functionality in an operationally relevant environment.
- Gain expertise and experience in overcoming wireless system challenges.

Potential Practical Application Ideas

B-52 engine upgrade

- Utilize small, modular data acquisition units to collect sensor data around each engine cell and create an RF mesh network for the instrumentation system to transport that data back to centralized recording

F-16 weapon's station PCM data source

- A good candidate for utilizing a Bluetooth connection back to the main instrumentation system cluster

Command & control in the cockpit

- Already done and demonstrated by Eglin, saves a bunch of mod work in and around the cockpit

Multi-pallet communications on larger aircraft like KC-46 and C-17

- Demonstrated at Edwards

Multi-Aircraft synchronized instrumentation during mid-air refueling operations

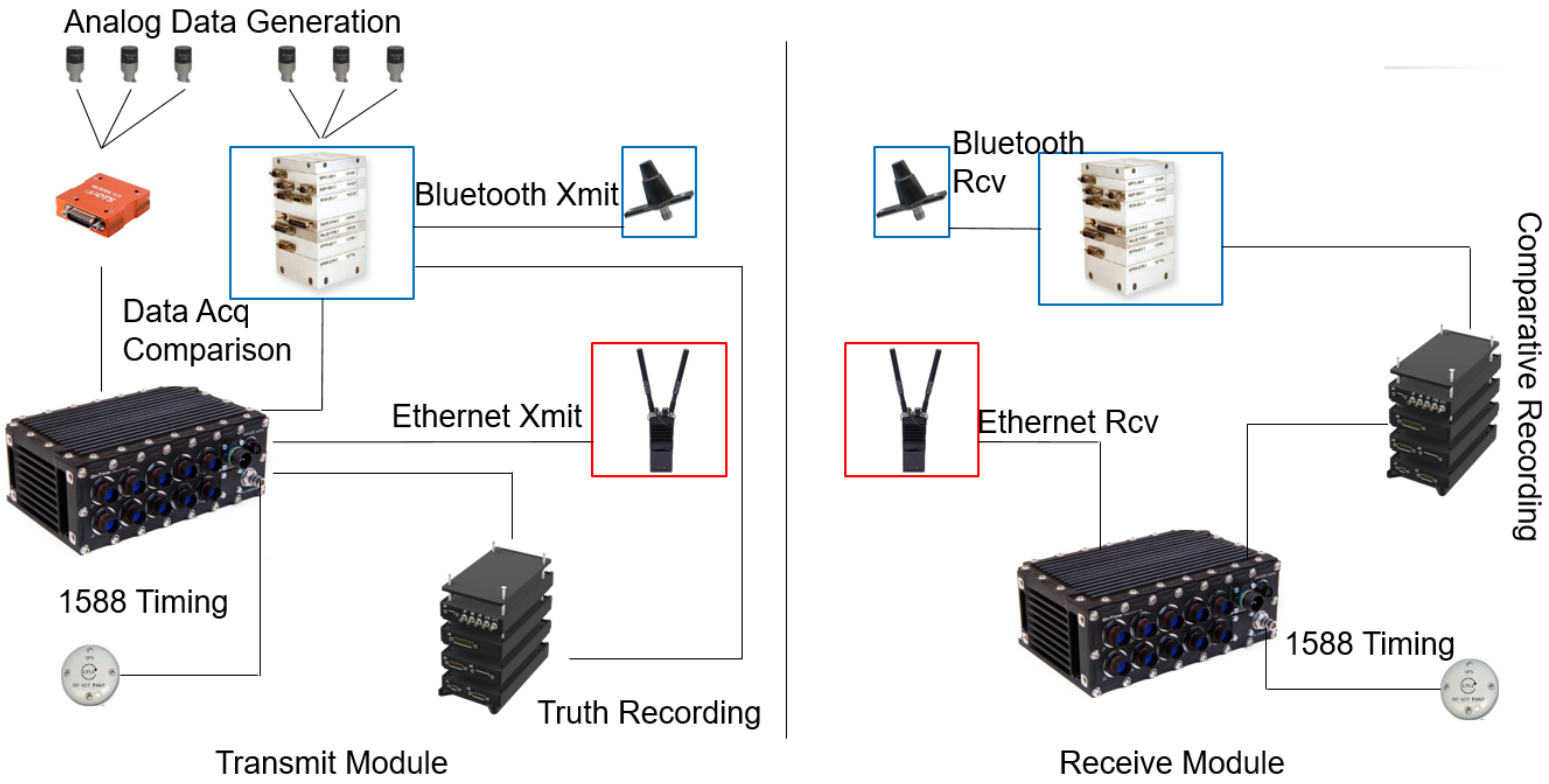
Project Overview

The wireless instrumentation project intends to test **two wireless communication systems**. One is **wireless Ethernet** radio and the other is **PCM over Bluetooth**. The goal is to capture the behavior of wireless instrumentation systems in an operational environment.

This will be achieved by:

- Housing the transmit module in RASCAL Pod.
- Receiver module will be housed in some other part of the same aircraft.
- Data will be captured before transmission and on receiver end.

Equipment Overview



Transmit Module

- TTC Stack (DAU and Bluetooth)
- Slice 6 DAU
- Ethernet Radio
- Network Switch
- GPS splitter
- Transducers
- Recorder

Receiver Module

- TTC Stack
- Radio
- Network Switch
- Recorder

Equipment

DAU 1 - TTC MNACQ-2600

- Contains PCM over Bluetooth cards

DAU 2 - Slice6 Air

- New Network DAU under test
- 6-channel DAU
- Outputs Ethernet packets
- 1588 V2

Equipment

OnTime 12-port Network Switch

- 1588 Grandmaster timing from GPS

Silvus Ethernet Radio

- Wireless mesh network
- 100 Mbps

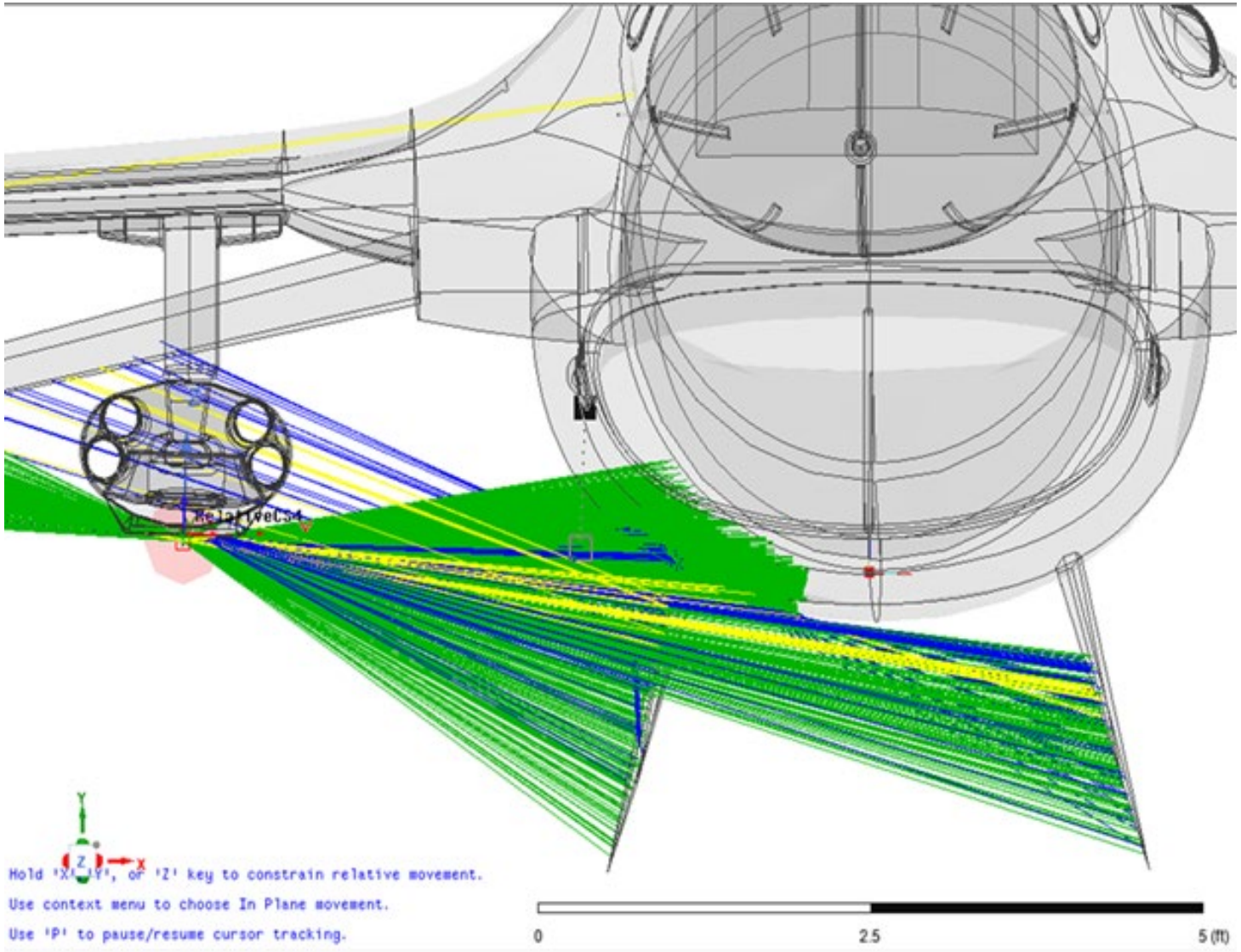
Equipment

Calculex 1401 Ch 10 Recorder

- PCM and Ethernet.

Data Generation - Sensors

- 2 x Pressure transducers
- 2 x Temperature sensors
- 2 x Strain gauges
- 2 x Tri-axial accelerometers
- Two sensors for each measurement type, one for each DAU



Challenges

- Cybersecurity
  - Secure TM
- EMI/C
- RF line of sight & timing system (dependent on configuration of Receiver module)

Cybersecurity

Currently working with the Cybersecurity Engineering Support Team

- Security Mitigations established for Wireless Ethernet Radio and Bluetooth.
- Perform Security Impact Analysis (SIA) to determine if there is a need for additional cybersecurity sign-off.

EMI/C

Emitters we are adding to aircraft (no tail number currently assigned):

Wireless Radio

- 900 MHz
- 1W maximum transmit power

Bluetooth

- 2.4GHz
- 1mW transmit power

Lab Validation

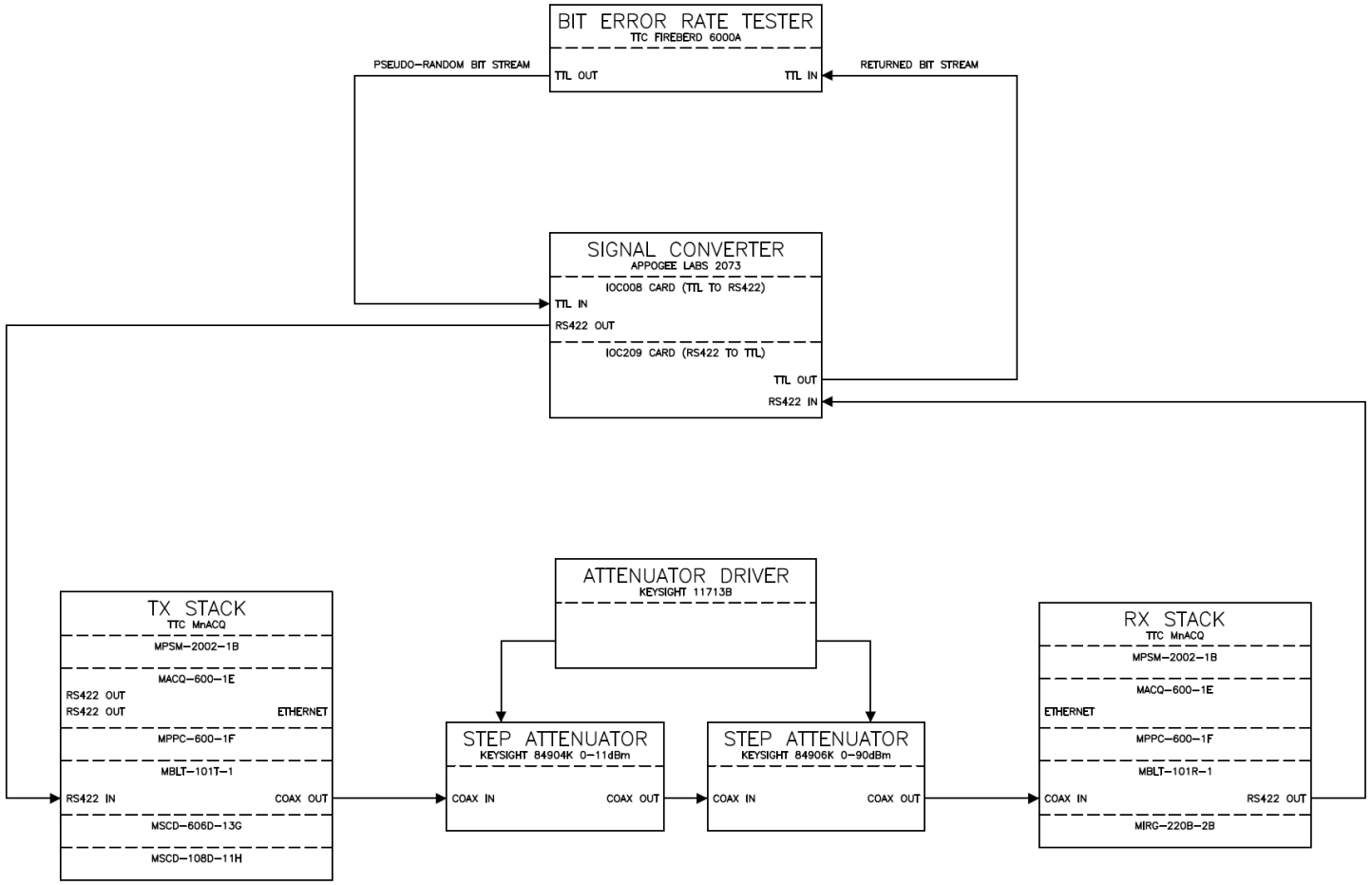
Completed Lab Validation

Characterization of Bluetooth link reliability.

- Bit error rate tests at various attenuation levels and data rates.

PCM over Bluetooth (wired):

- Established a baseline hardware performance using direct coaxial connection.



Bluetooth Bit Error Rate Tests

Purpose:

- Characterize Bluetooth link reliability at various attenuation levels and data rates.

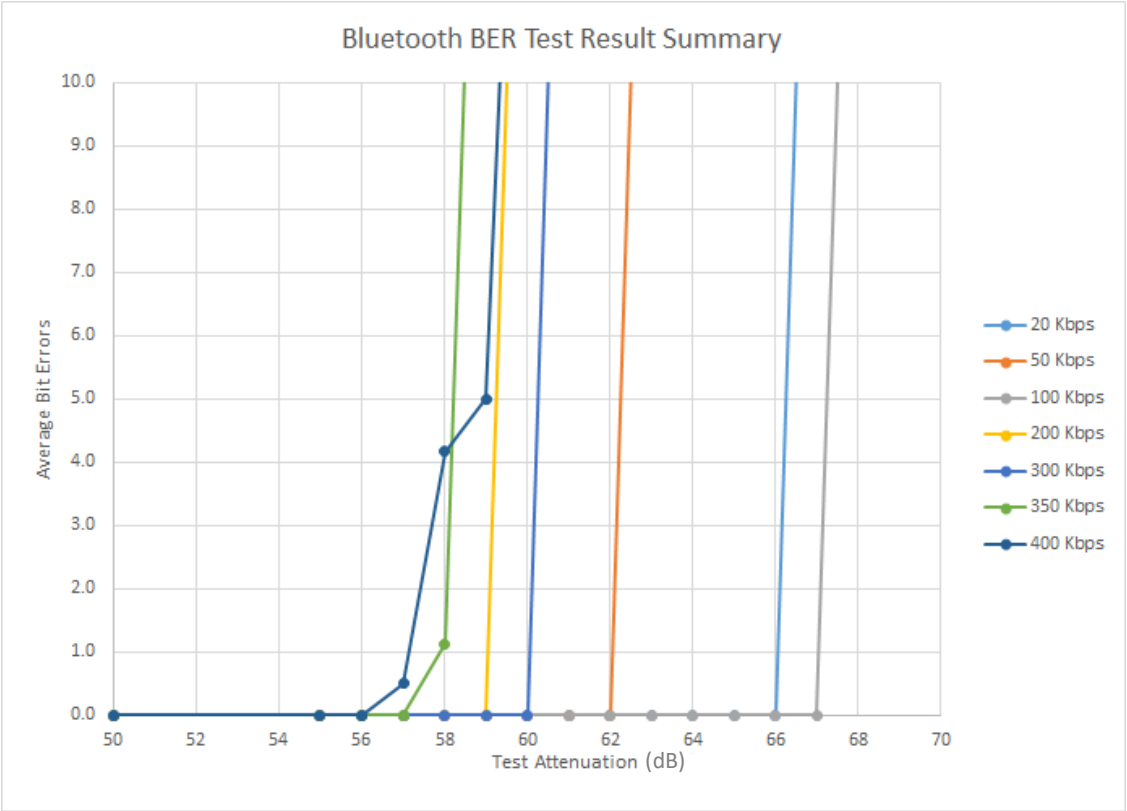
Test Setup:

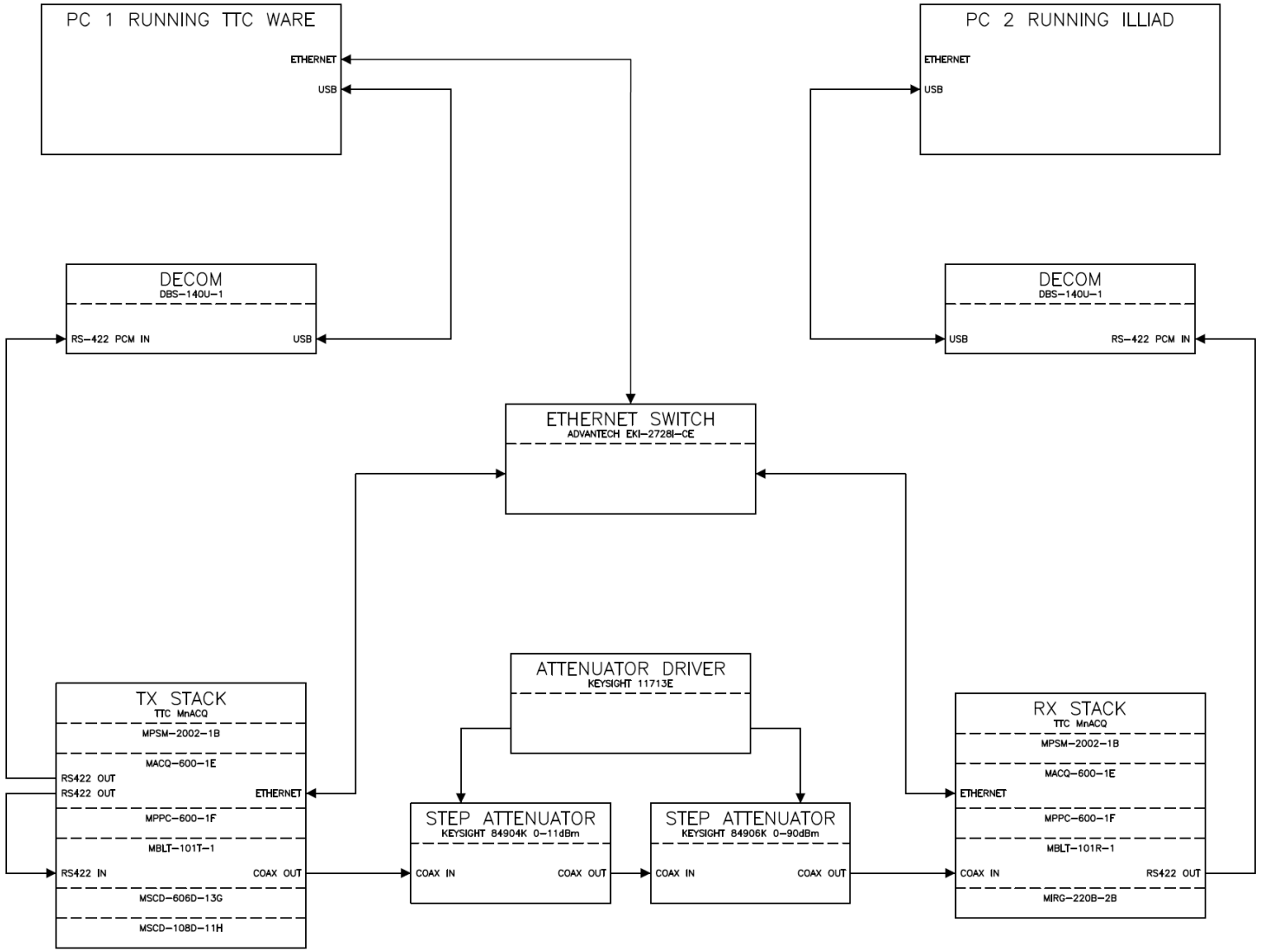
- Transmit and receive stacks were connected via a direct RF (coax) connection through step attenuators.
- A Fireberd Bit Error Rate tester was used to generate a pseudo-random bit stream for transmission by the Bluetooth card on the TX side.
- The RX side would then return the bit stream that it received back to the Fireberd for comparison with the true stream where it would count the number of bits that came back wrong.
- Sent 10^8 bits per step in attenuation.
- Attenuation was raised until we reached a point where we could not get a link at all.
- This test was repeated at 20, 50, 100, 200, 300, 350, and 400kbps.

Bluetooth Bit Error Rate Test Results

Conclusions:

- Bluetooth link performance is nearly binary. It either works fully and we get good data, or it doesn't.
- We were able to show that Bluetooth links are good up into the -65dB to -70dB range (including –9dB cable loss).





PCM over Bluetooth Test (Wired)

Purpose:

- Characterize behavior of Bluetooth when streaming Ch4 PCM.
- Used a direct RF connection to establish a baseline for hardware performance before introducing factors that come along with over-the-air transmission.
- Quantify the number of minor frame drops at various PCM frame geometries and data rates for comparison.

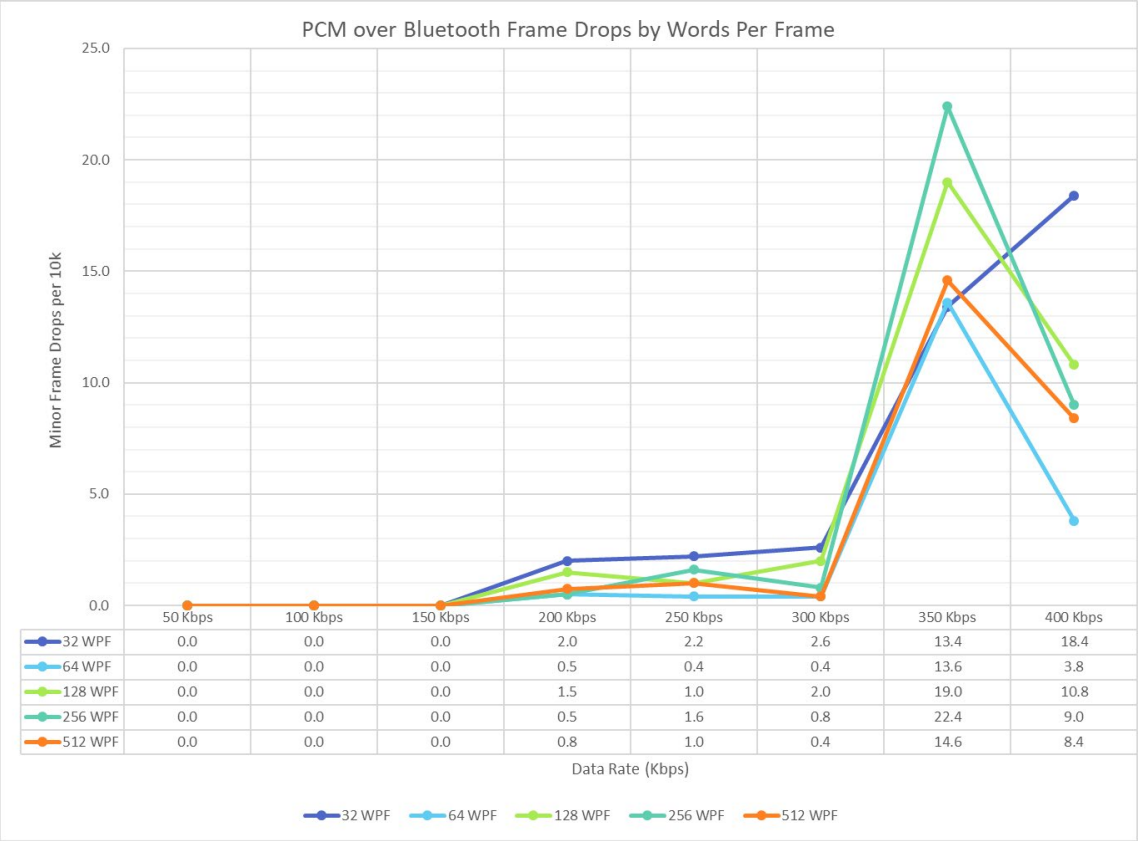
Test Setup:

- Transmit and receive stacks were connected via a direct RF (coax) connection through step attenuators.
- Attenuation was set constant at -30dB for all test runs.
- Cable losses within this test setup added only –0.001dB (upgrade!).
- Each test run involved sending 10k minor frames 5 times for every set of settings (50k minor frames total).
- Total minor frame drops were recorded at the end of each test run.

PCM over Bluetooth

Preliminary Conclusions (tests were short):

- Data rate affects minor frame drop rates. 350kbps did not perform well so some unknown reason.
- Words per frame setting may have an impact. We would like to run longer tests so we can have a clearer picture.



	50 Kbps	100 Kbps	150 Kbps	200 Kbps	250 Kbps	300 Kbps	350 Kbps	400 Kbps
32 WPF	0.0	0.0	0.0	2.0	2.2	2.6	13.4	18.4
64 WPF	0.0	0.0	0.0	0.5	0.4	0.4	13.6	3.8
128 WPF	0.0	0.0	0.0	1.5	1.0	2.0	19.0	10.8
256 WPF	0.0	0.0	0.0	0.5	1.6	0.8	22.4	9.0
512 WPF	0.0	0.0	0.0	0.8	1.0	0.4	14.6	8.4

PCM over Bluetooth

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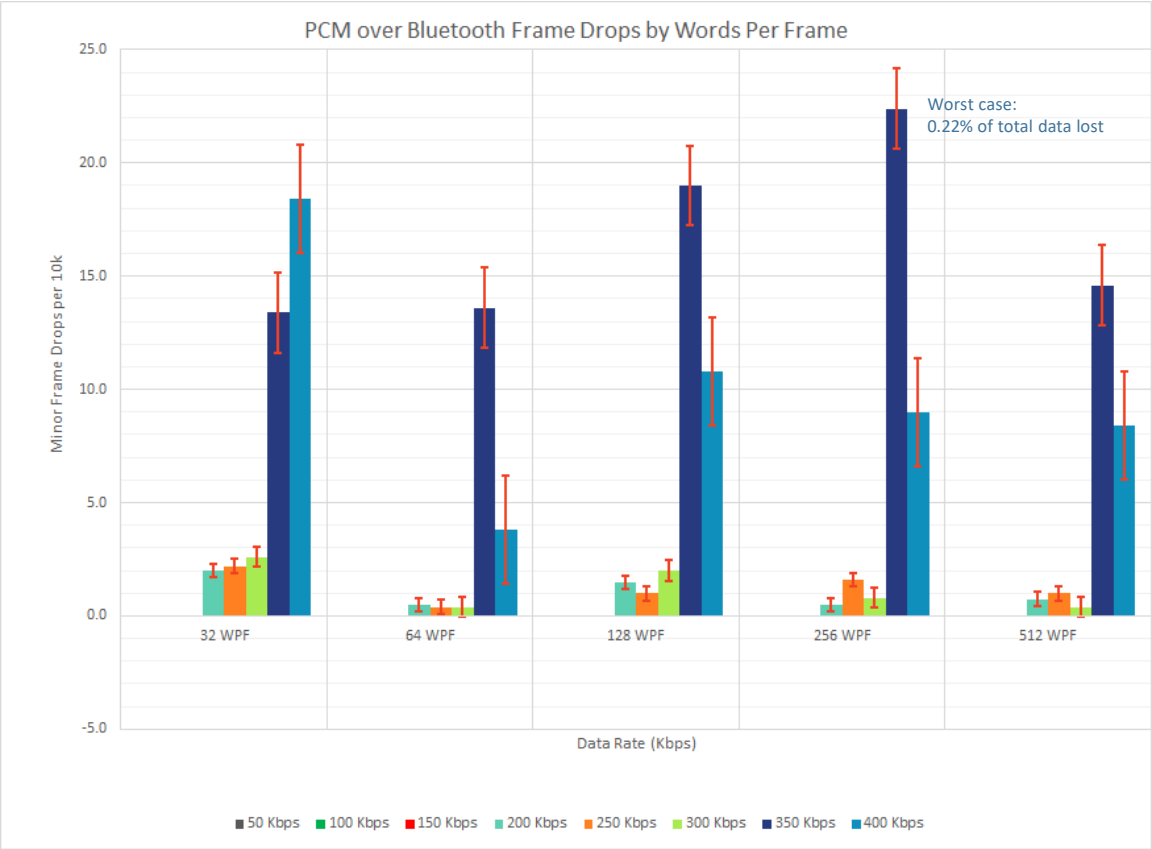


Minor Frame Drops

Most words in each frame were configured to be "0x5555".

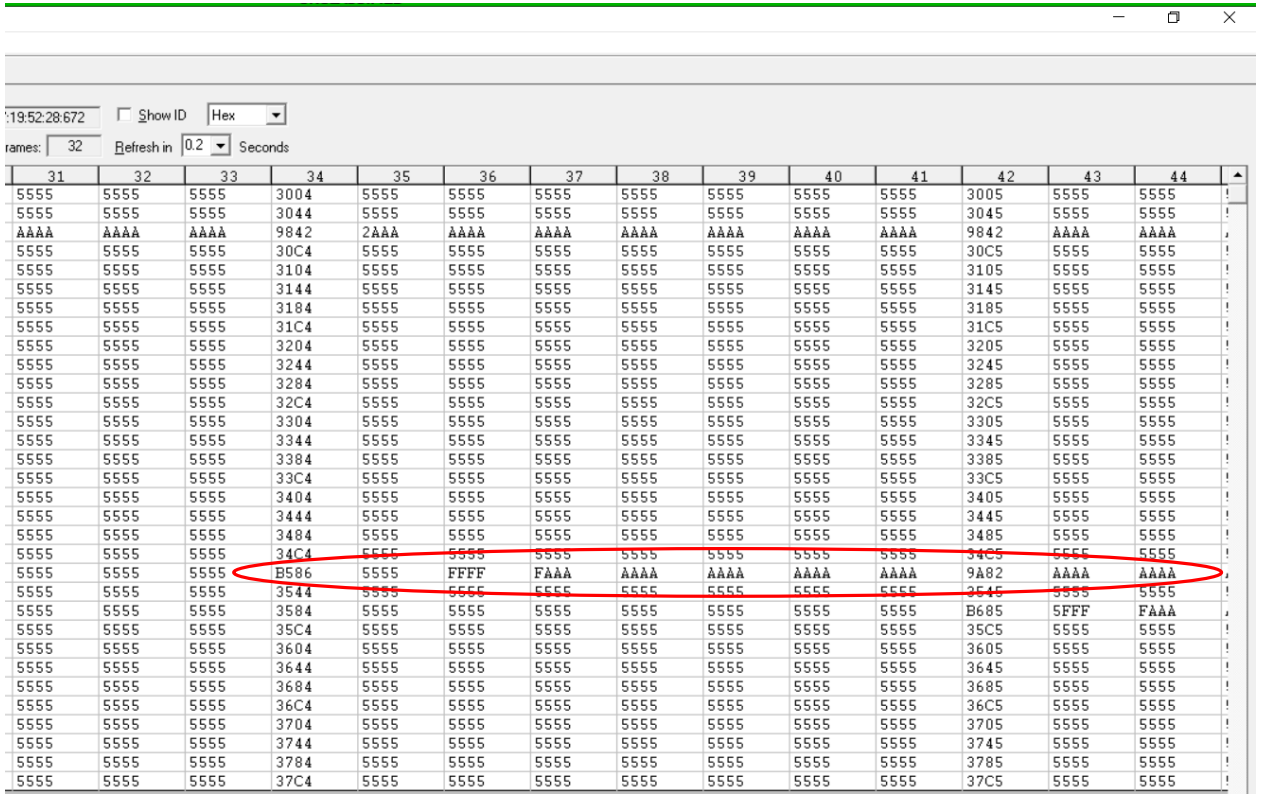
In Hex:

- 5555 = 0101 0101 0101 0101
- AAAA = 1010 1010 1010 1010
- FFFF = 1111 1111 1111 1111

Looks like the Bluetooth transmit card is getting "stuck" while transmitting a bit.

- We didn't see this in the BER tests, so it is likely a compatibility issue between the overhead card and the Bluetooth TX card.

We have recently written a Python library to help us examine Ch4 PCM recordings more closely.

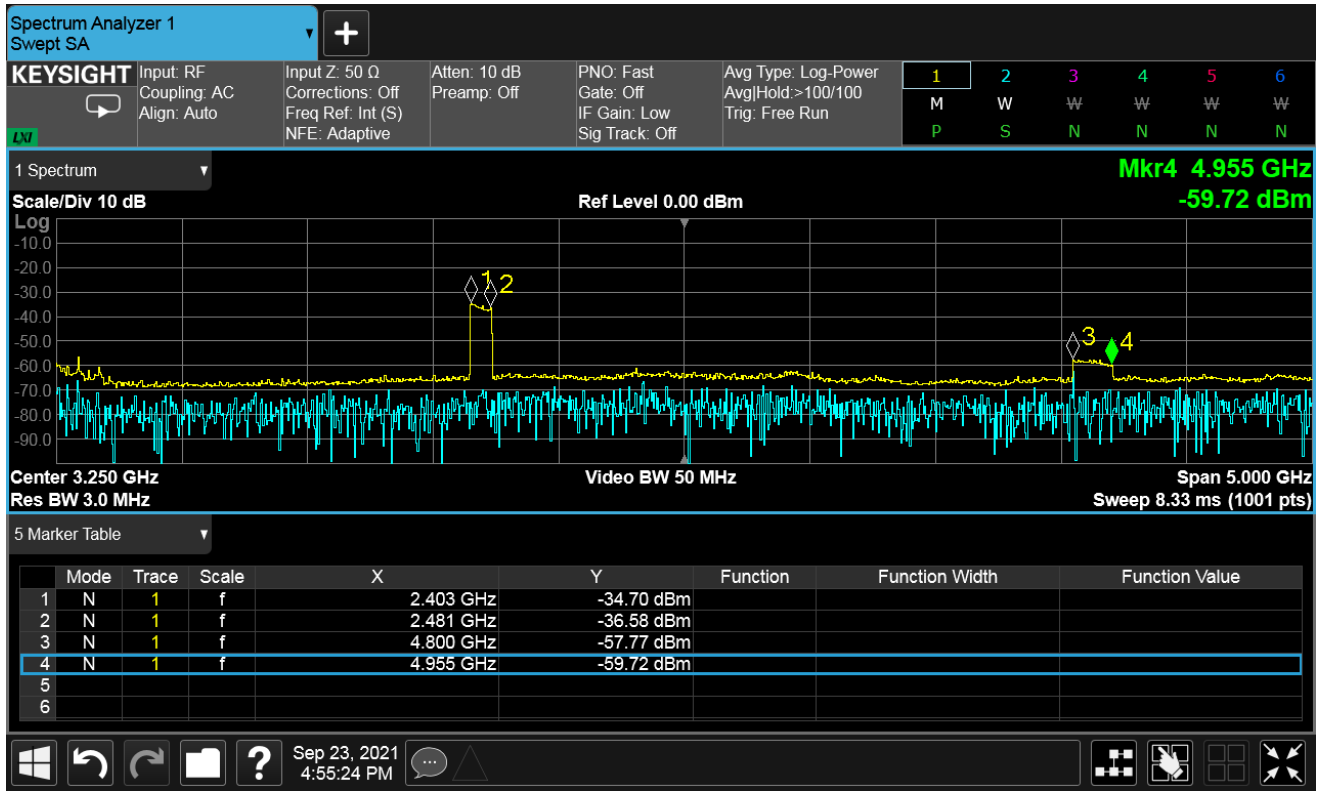


31	32	33	34	35	36	37	38	39	40	41	42	43	44
5555	5555	5555	3004	5555	5555	5555	5555	5555	5555	5555	3005	5555	5555
5555	5555	5555	3044	5555	5555	5555	5555	5555	5555	5555	3045	5555	5555
AAAA	AAAA	AAAA	9842	2AAA	AAAA	AAAA	AAAA	AAAA	AAAA	AAAA	9842	AAAA	AAAA
5555	5555	5555	30C4	5555	5555	5555	5555	5555	5555	5555	30C5	5555	5555
5555	5555	5555	3104	5555	5555	5555	5555	5555	5555	5555	3105	5555	5555
5555	5555	5555	3144	5555	5555	5555	5555	5555	5555	5555	3145	5555	5555
5555	5555	5555	3184	5555	5555	5555	5555	5555	5555	5555	3185	5555	5555
5555	5555	5555	31C4	5555	5555	5555	5555	5555	5555	5555	31C5	5555	5555
5555	5555	5555	3204	5555	5555	5555	5555	5555	5555	5555	3205	5555	5555
5555	5555	5555	3244	5555	5555	5555	5555	5555	5555	5555	3245	5555	5555
5555	5555	5555	3284	5555	5555	5555	5555	5555	5555	5555	3285	5555	5555
5555	5555	5555	32C4	5555	5555	5555	5555	5555	5555	5555	32C5	5555	5555
5555	5555	5555	3304	5555	5555	5555	5555	5555	5555	5555	3305	5555	5555
5555	5555	5555	3344	5555	5555	5555	5555	5555	5555	5555	3345	5555	5555
5555	5555	5555	3384	5555	5555	5555	5555	5555	5555	5555	3385	5555	5555
5555	5555	5555	33C4	5555	5555	5555	5555	5555	5555	5555	33C5	5555	5555
5555	5555	5555	3404	5555	5555	5555	5555	5555	5555	5555	3405	5555	5555
5555	5555	5555	3444	5555	5555	5555	5555	5555	5555	5555	3445	5555	5555
5555	5555	5555	3484	5555	5555	5555	5555	5555	5555	5555	3485	5555	5555
5555	5555	5555	34C4	5555	5555	5555	5555	5555	5555	5555	34C5	5555	5555
5555	5555	5555	B586	5555	FFFF	FAAA	AAAA	AAAA	AAAA	AAAA	9A82	AAAA	AAAA
5555	5555	5555	3544	5555	5555	5555	5555	5555	5555	5555	3545	5555	5555
5555	5555	5555	3584	5555	5555	5555	5555	5555	5555	5555	B685	5FFF	FAAA
5555	5555	5555	35C4	5555	5555	5555	5555	5555	5555	5555	35C5	5555	5555
5555	5555	5555	3604	5555	5555	5555	5555	5555	5555	5555	3605	5555	5555
5555	5555	5555	3644	5555	5555	5555	5555	5555	5555	5555	3645	5555	5555
5555	5555	5555	3684	5555	5555	5555	5555	5555	5555	5555	3685	5555	5555
5555	5555	5555	36C4	5555	5555	5555	5555	5555	5555	5555	36C5	5555	5555
5555	5555	5555	3704	5555	5555	5555	5555	5555	5555	5555	3705	5555	5555
5555	5555	5555	3744	5555	5555	5555	5555	5555	5555	5555	3745	5555	5555
5555	5555	5555	3784	5555	5555	5555	5555	5555	5555	5555	3785	5555	5555
5555	5555	5555	37C4	5555	5555	5555	5555	5555	5555	5555	37C5	5555	5555

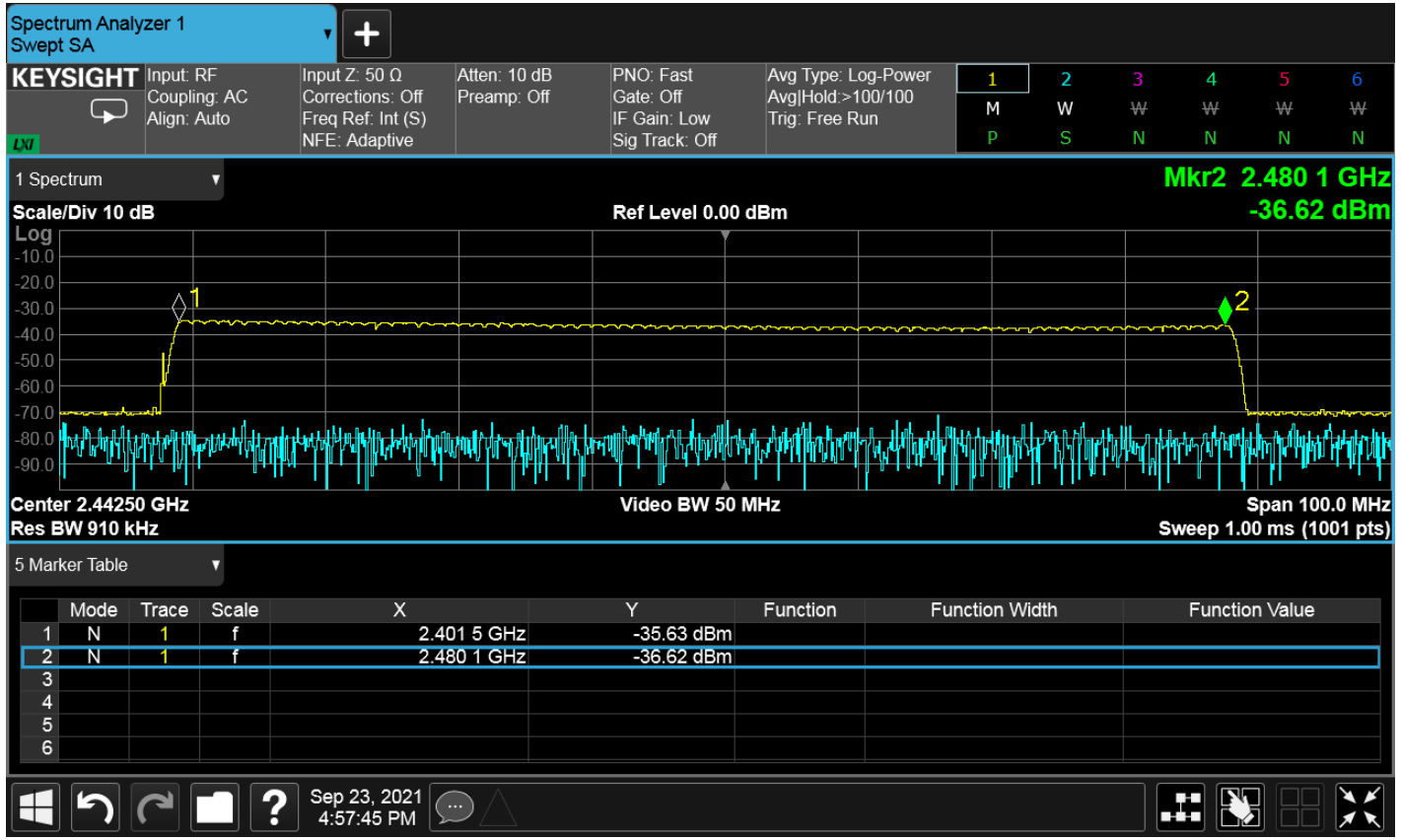
Bluetooth on a Spectrum Analyzer

Our test setup was connected to a spectrum analyzer via a direct connection (coax).

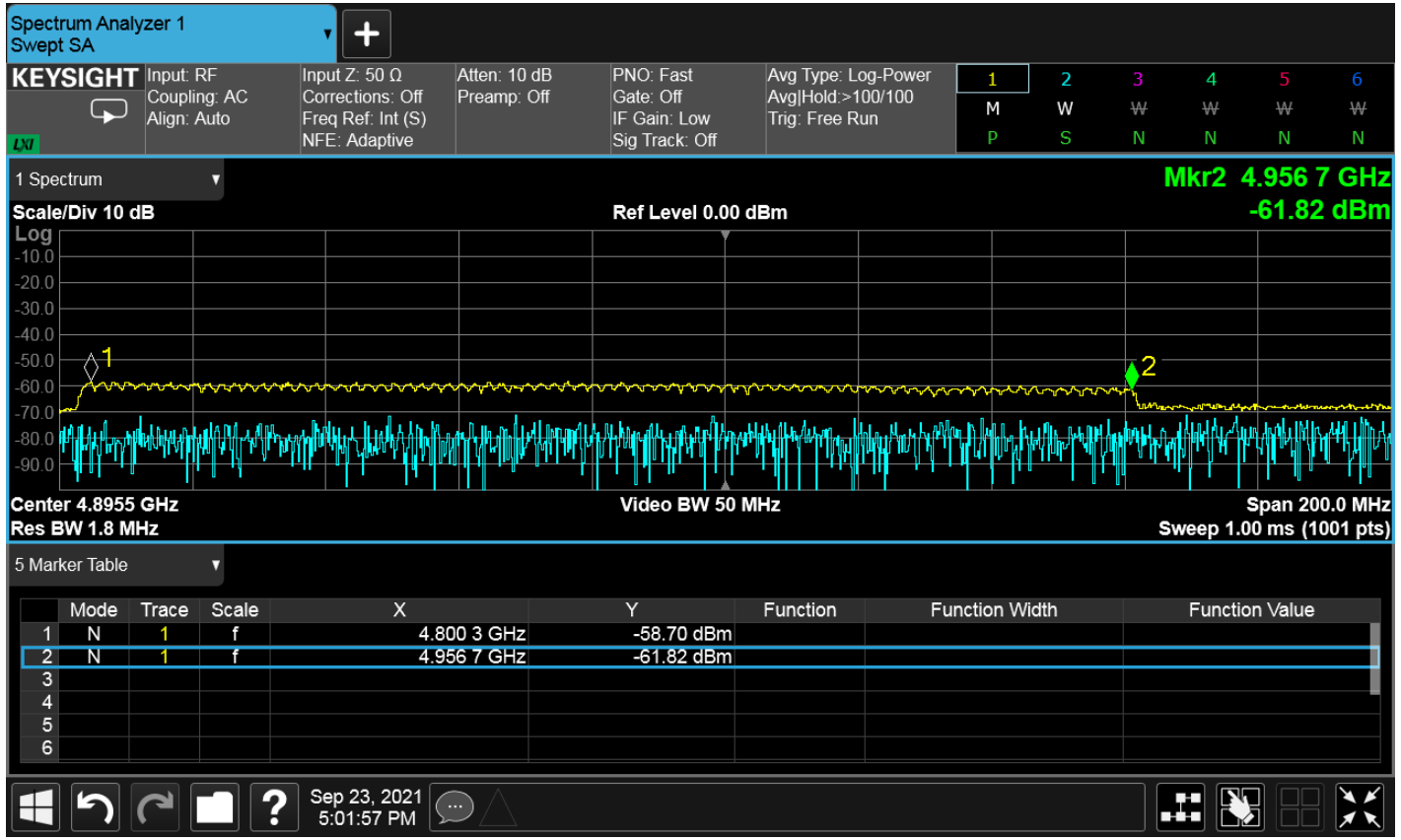
- Bluetooth's fundamental signal can be seen in the 2.4 - 2.48 GHz range.
- 1st harmonic can clearly be seen in on the right in the 4.8 - 4.96 GHz range.
  - Likely a byproduct of an internal amplifier.
  - This harmonic is within the C-band, so a filter will need to be added to eliminate it.



Bluetooth on a Spectrum Analyzer



Bluetooth on a Spectrum Analyzer



Lab Validation Overview

- ✓ Characterize Bluetooth link reliability.
  - ✓ Bit error rate tests at various attenuation levels.
- ✓ PCM over Bluetooth:
  - ✓ Establish a baseline using direct coaxial connection.
  - ❑ Characterize behavior in an anechoic chamber and around the body of an aircraft.
- ❑ Wireless ethernet:
  - ❑ Speed benchmarks.
  - ❑ Ethernet traffic tests.
  - ❑ Characterize behavior in an anechoic chamber and around the body of an aircraft.
  - ❑ Identify optimal power and bandwidth parameters.
- ❑ Determine if there are EMI/C issues between Bluetooth and the Silvus radios.
- ❑ Build and test full system in the lab.

What's Next for the Project?

- Finish validation of critical components in laboratory environment.
- Validate full system in the lab.
- Demonstrate full system in a relevant environment.
  - May involve outside ground testing around the body of an aircraft.
- Demonstrate system in an operational environment.
  - Test flights.

Questions / Comments?