U.S. DOT LTE-V2X Testing:
Lab Characterization

August 2022

U.S. Department of Transportation

ITS / V2X Communications Summit

ITS / V2X
COMMUNICATIONS
FOR DEPLOYMENT

Summary of Lab Characterization Results

Device problems:

- GPS drift
- Radios not syncing the system time with the GPS time
- Potential for loss synchronization during GPS outages. Though mitigations have been implemented, they are proprietary, and therefore may not be interoperable with other chipset vendors
- Leakage of energy out of ports that was unknown by vendors
- Significant length of time to get devices up and running
- Inability to hold a constant MAC or IPv6 address through power cycles
- Inability to transmit BSMs
- Significant power variation among devices
- Some devices barely met spectrum mask

Test feature problems:

- Duplicate sequence numbers
- Bad UDP checksum when receiving packets
- No IP addresses
- Problem logging BSMs

Summary of Preliminary Field Observations

- **Device Problems/Issues included:**
  - Overheating of devices; melting components in 90-degree weather
  - Ignition circuit problem
  - Devices unable to connect to the test system despite connecting when in the lab
  - Devices stop transmitting randomly after 20 -30 seconds
  - BSM misreporting

OBU Device Performance Characterization: List of Tests

Number	Name
1	Turn On/Off
2	Log into devices
3	Support for Draft SAE J3161/1 LTE-V2X Parameter Settings
4	Tx/Rx Channel
5	Tx Power
6	Tx Packet Length
7	Tx Packet Rate
8	Tx Emission Mask
9	Tx Adj Channel Leakage/Rejection
10	Tx/Rx Position Information
11	Rx Packet Number
12	Rx sensitivity
13	Tx/Rx Resource Pool
14	Tx Data Rate or MCS
15	Tx EVM
16	Rx Power
17	Interference susceptibility
18	Noise figure
19	Tx Resource Block and sub-frame selection
20	Tx dynamic BSMs
21	Technology Readiness Level (TRL)

Basic Functionality Checks

- ✓ Turn On/Off
- ✓ Log in
- ✓ Support for SAE J3161/1
- ✓ Select Tx/Rx Channel
- ✓ Select Tx Packet Length and Rate
- ✓ Position Information
- ✓ Change Data Rate / MCS
- ✓ Change Resource Block and Subframe Selection

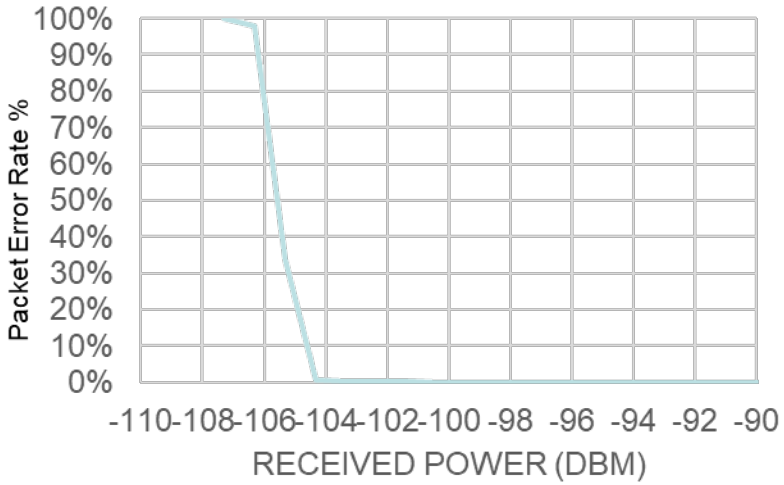
RF Characterization

- Receiver Characterization
  - Cabled Setup
  - Rx Sensitivity
  - AWGN Interference
  - Noise Figure Extraction

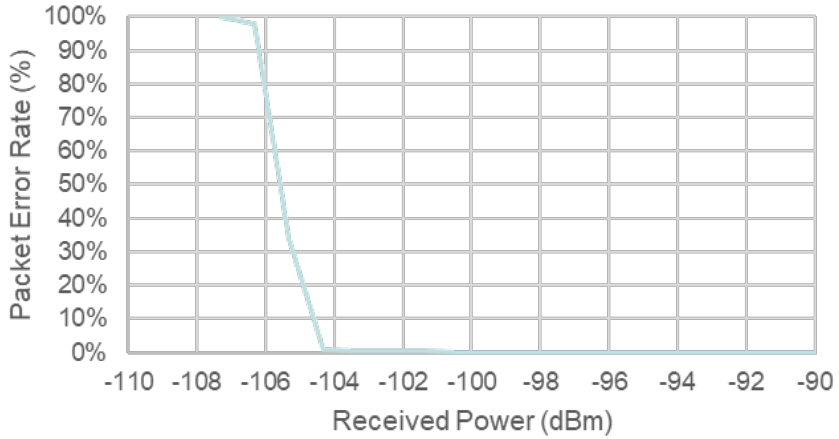
- Transmitter Characterization
  - Cabled Setup
  - Transmit Power
    - Leakage Analysis
  - Radio Configuration for SEM/ACLR
  - Spectral Emission Mask
  - Adjacent Channel Leakage
  - EVM

Rx Sensitivity Findings

Vendor 1



Vendor 2



Receive Sensitivity Findings

Vendor 1

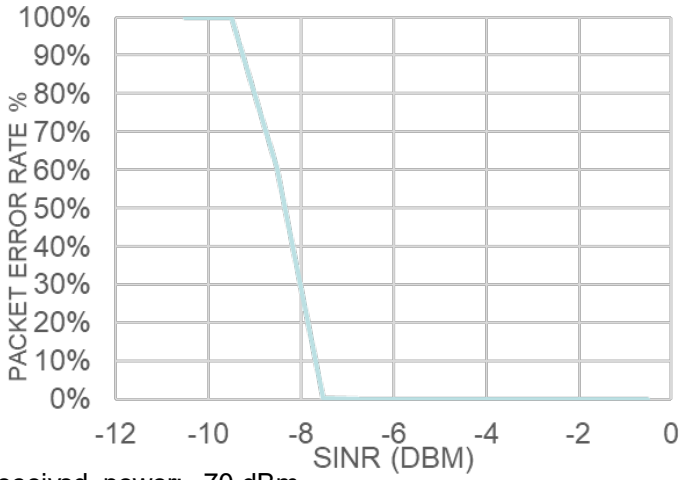
ID	Receive Sensitivity [dBm]
1044	-104.6
1045	-104.4
1046	
1189	
1195	-104.5
1196	-104.6
1308	-105.2
1309	
1310	-104.2

Vendor 2

ID	Receive Sensitivity [dBm]
1104	-105.9
1211	-103.9
1220	-103.9

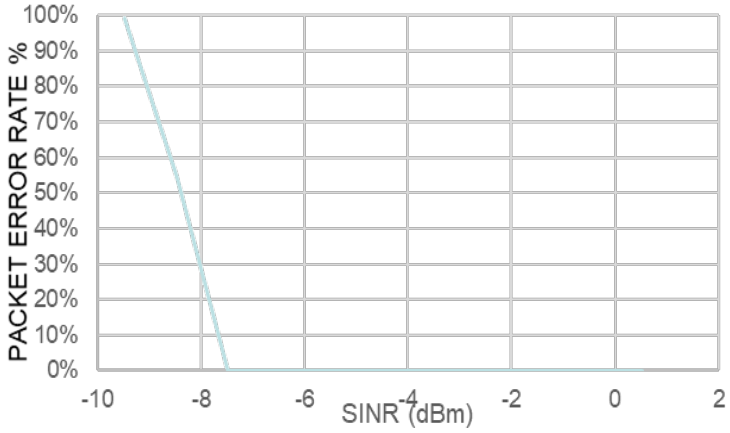
AWGN Interference Findings

Vendor 1



Received power: -70 dBm

Vendor 2



*SINR calculated over entire 20MHz CH183

Estimated Noise Figure Findings

Vendor 1

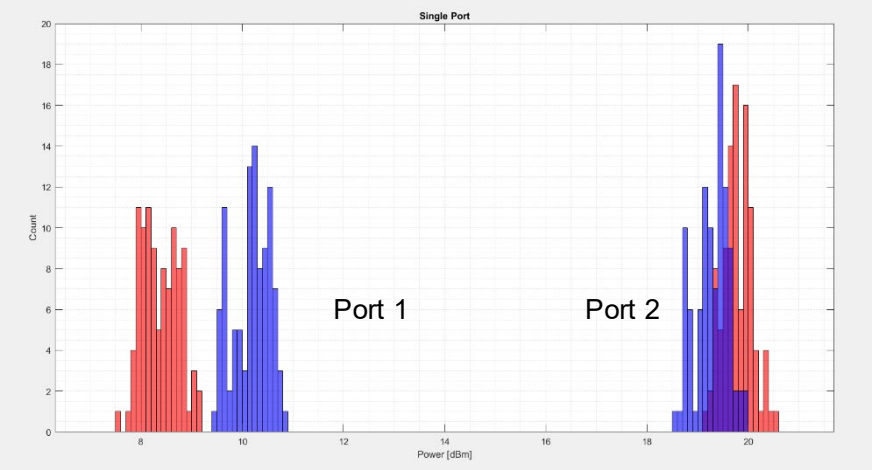
ID	Estimated Noise Figure
1044	3.8
1045	4.3
1046	
1189	
1195	4.1
1196	4
1308	3.5
1309	
1310	4.9

Vendor 2

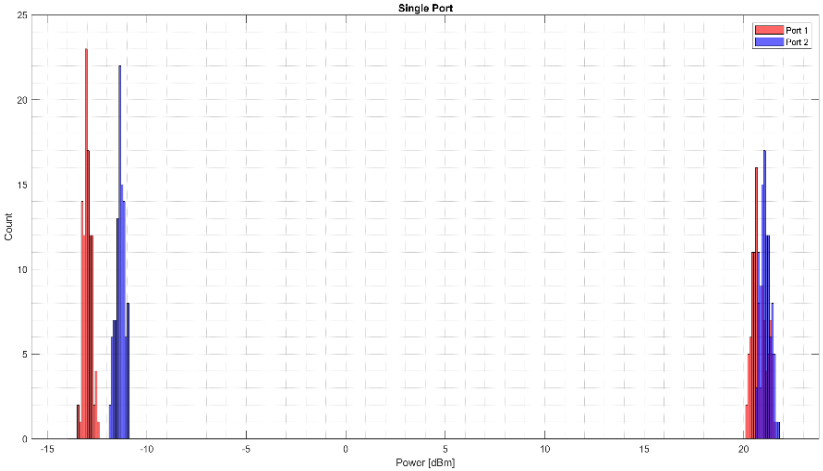
ID	Estimated Noise Figure
1104	3.1
1211	5.9
1220	5.4

Transmit Power – Single Port Findings

Vendor 1

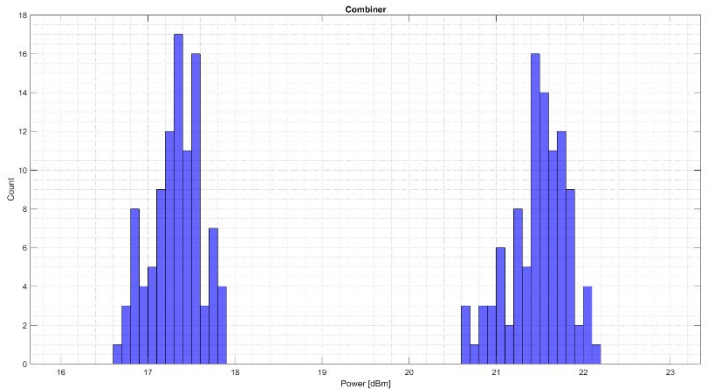


Vendor 2

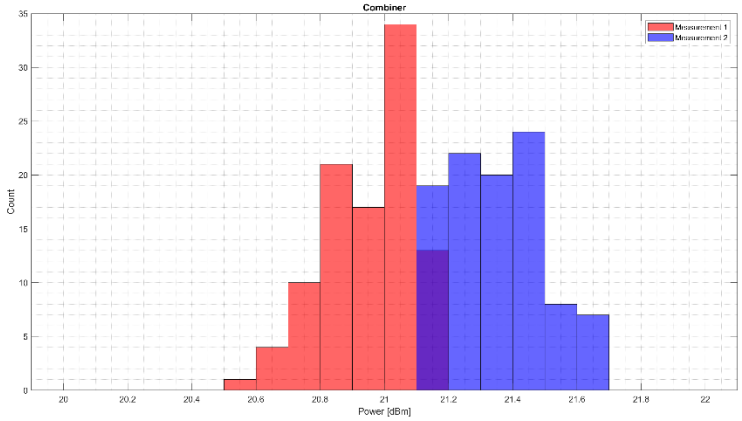


Transmit Power – Combiner Findings

Vendor 1



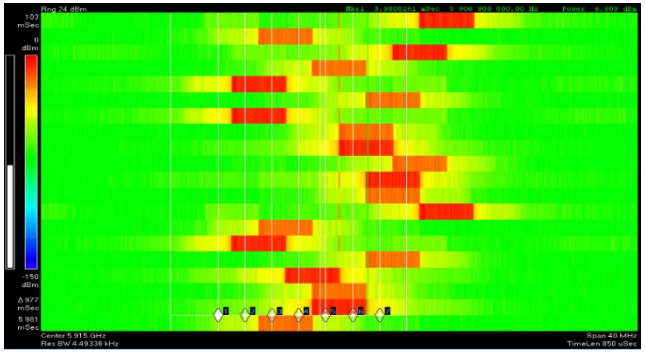
Vendor 2



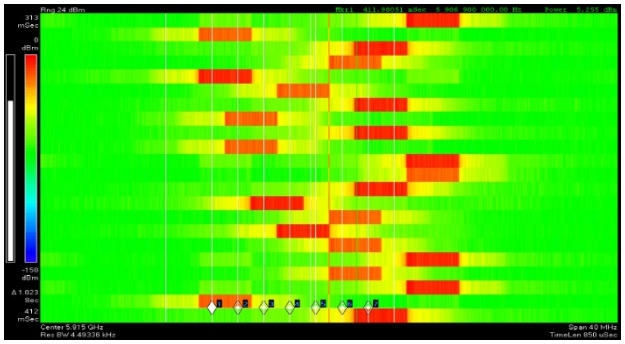
One Vendor's Port to Port Cross Talk Issue

Tx Diversity - Enabled

Port 1

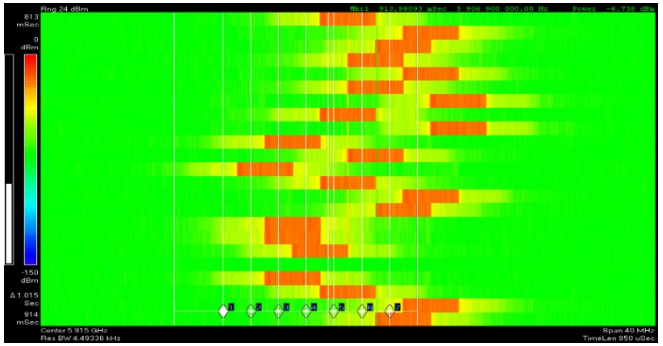


Port 2

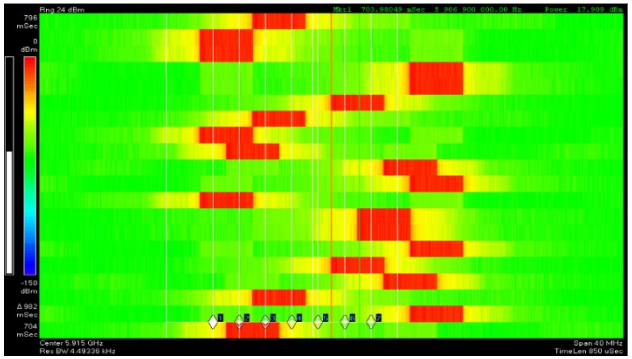


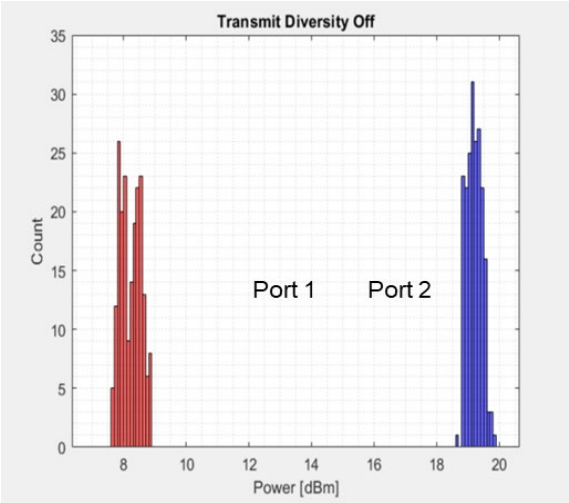
Tx Diversity - Disabled

Port 1



Port 2





Transmit Power Findings

Vendor 1

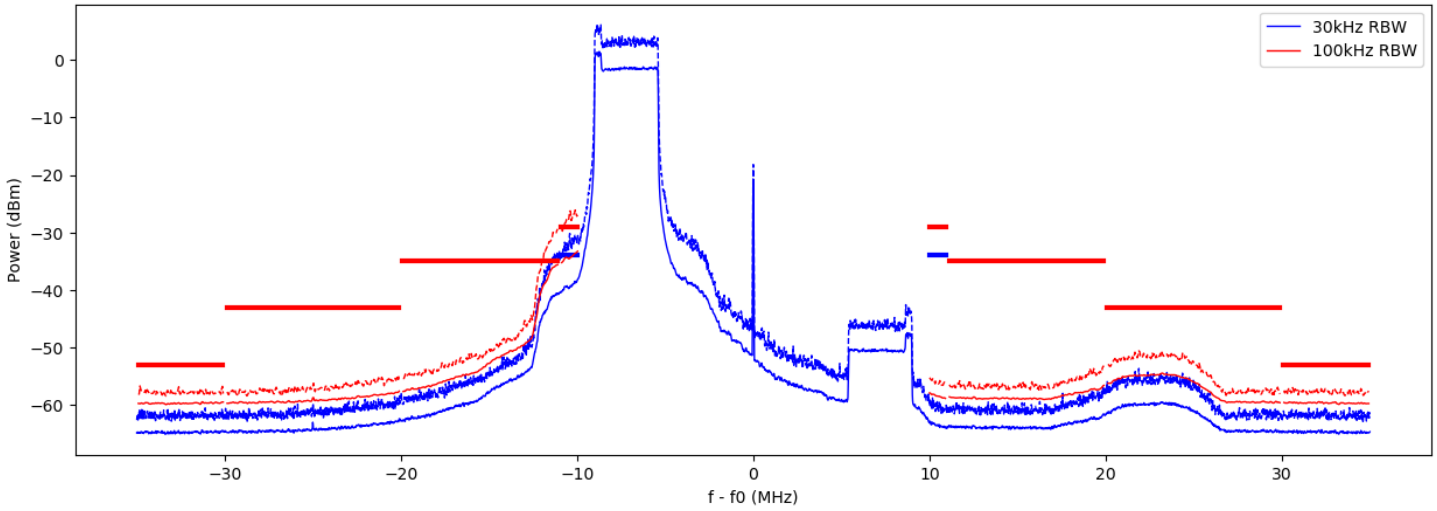
ID	TxPower: Mean of 100 [dBm]	TxPower: Min of 100 [dBm]	TxPower: Max of 100 [dBm]
1044	19.89	16.65	22.14
1045	20.41	18.78	22.27
1046			
1189			
1195	19.68	17.27	21.6
1196	20.19	18.03	22.02
1308	19.6	17.36	12.43
1309			
1310	19.96	17.23	21.84

Vendor 2

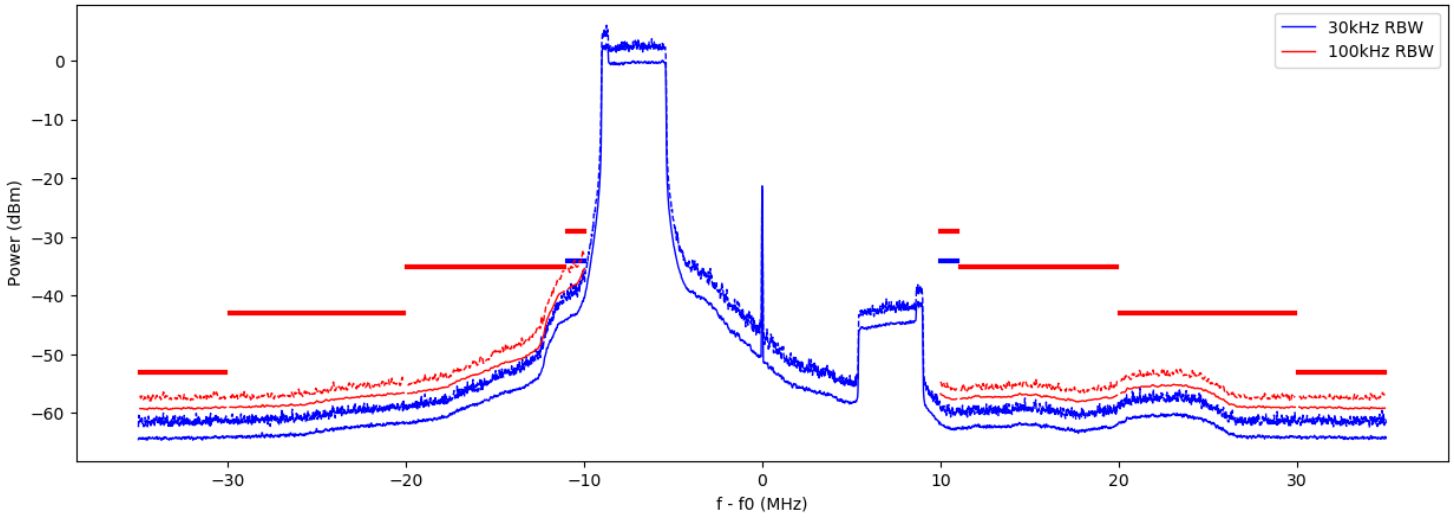
ID	TxPower: Mean of 100 [dBm]	TxPower: Min of 100 [dBm]	TxPower: Max of 100 [dBm]
1104	20.98	20.29	21.8
1211	21.16	20.59	21.69
1220	20.23	19.17	21.07

SEM – First 20 RBs Findings

Vendor 1

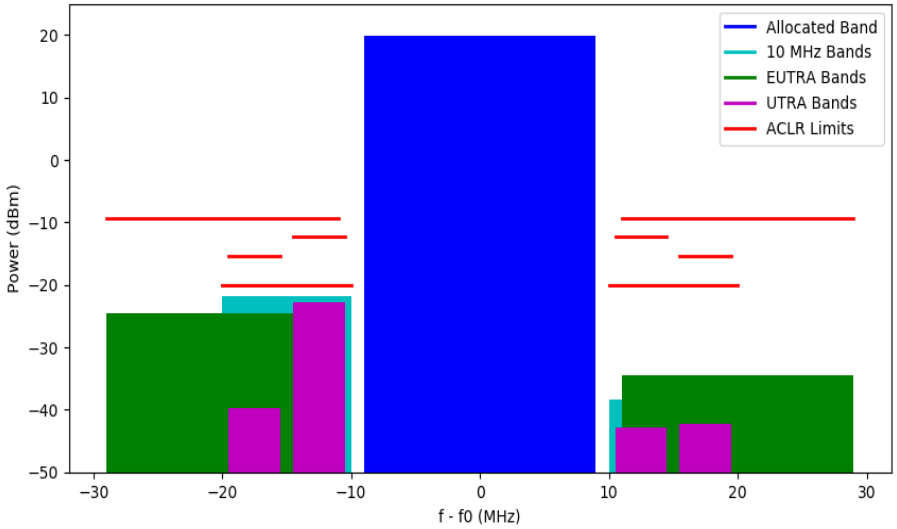


Vendor 2

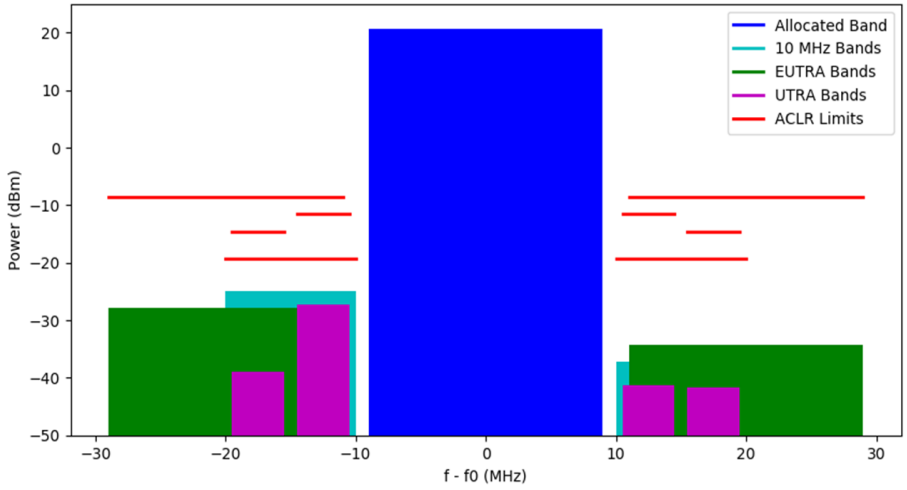


ACLR – First 20 RBs Findings

Vendor 1

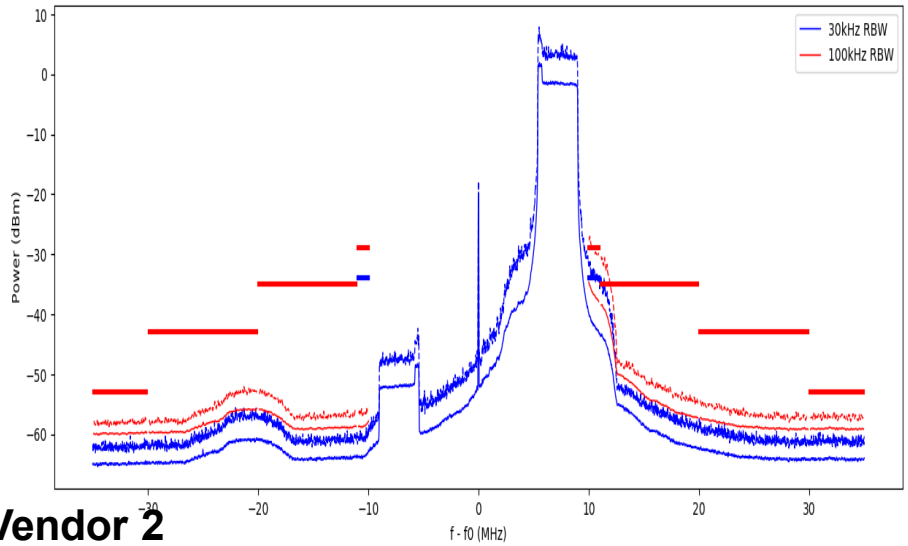


Vendor 2

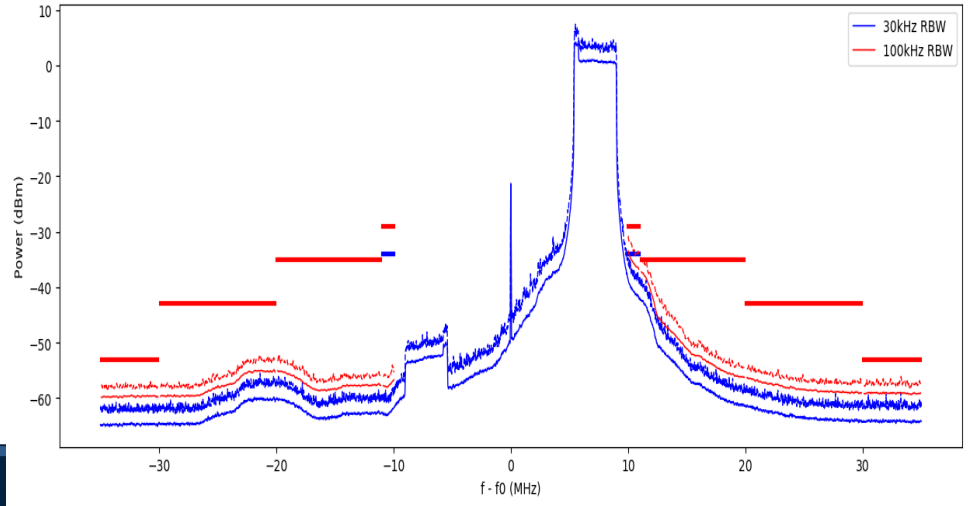


SEM – Last 20 RBs Findings

Vendor 1

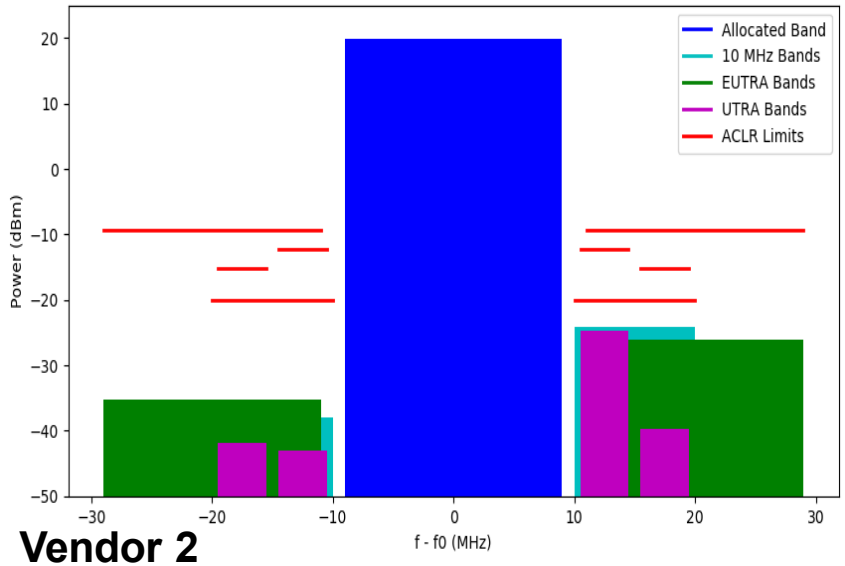


Vendor 2

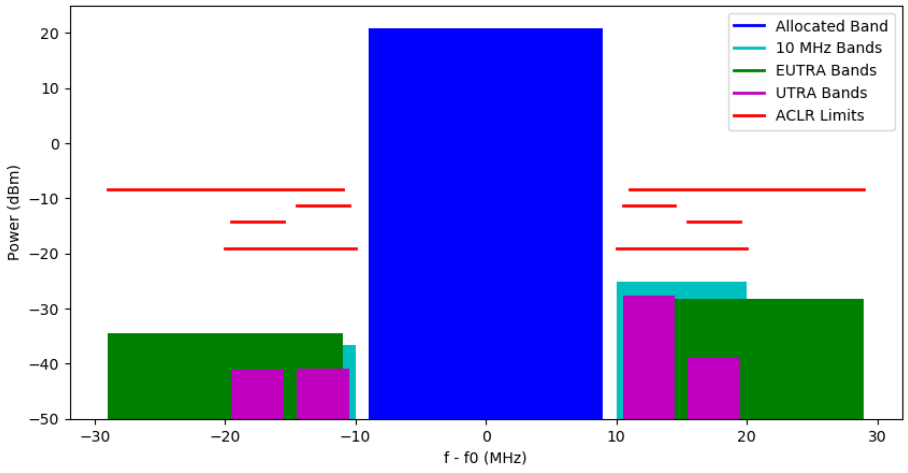


ACLR – Last 20 RBs Findings

Vendor 1

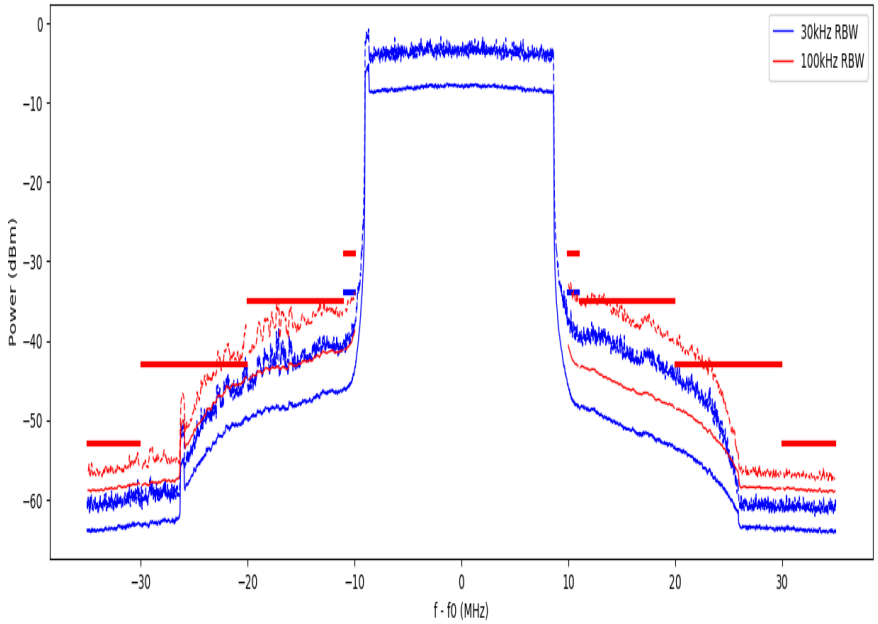


Vendor 2

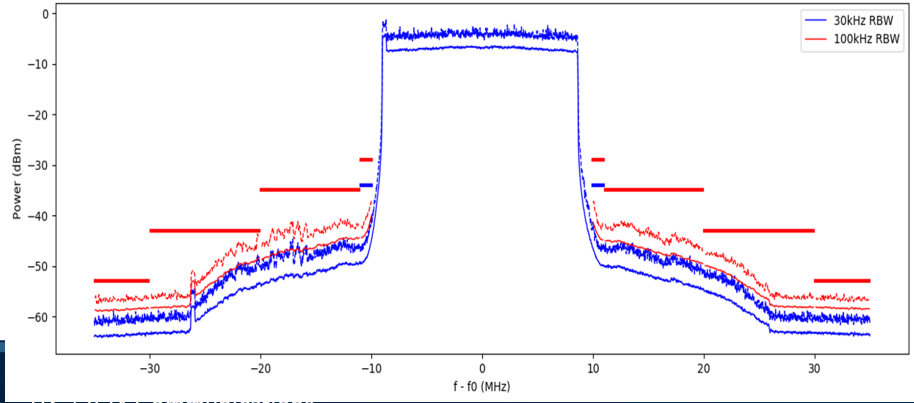


SEM - 100 RBs Findings

Vendor 1

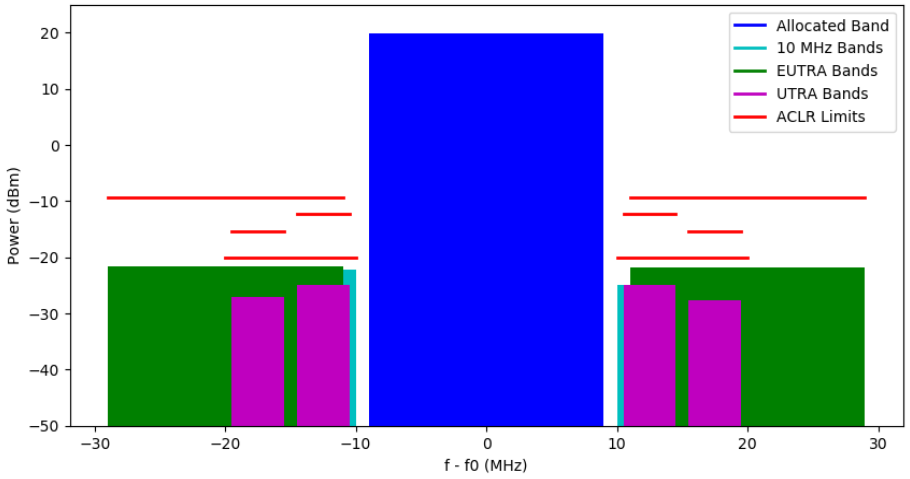


Vendor 2

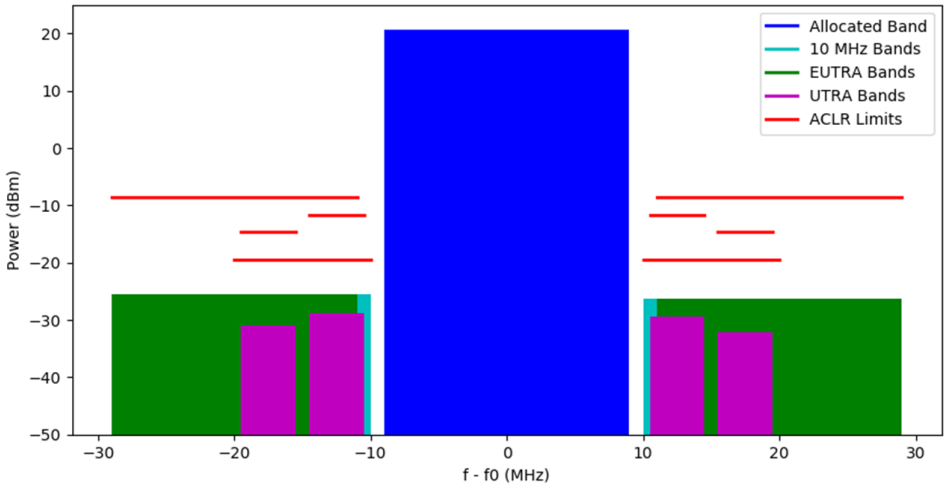


ACLR – 100 RBs Findings

Vendor 1

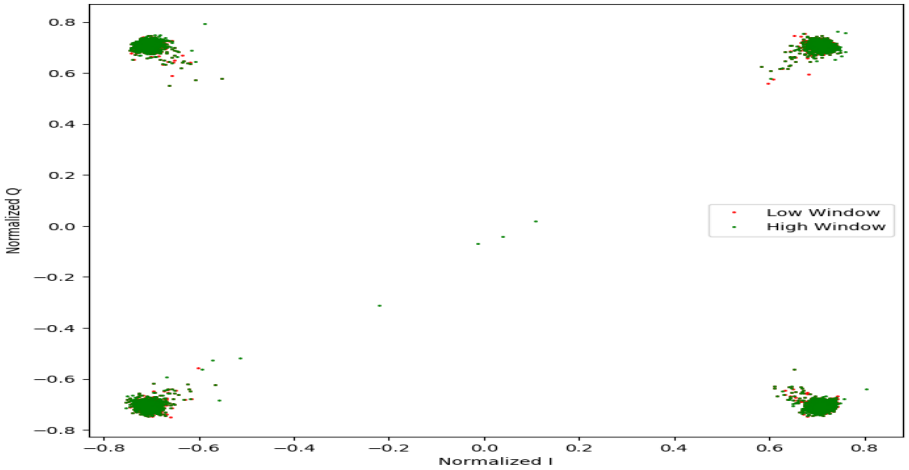


Vendor 2

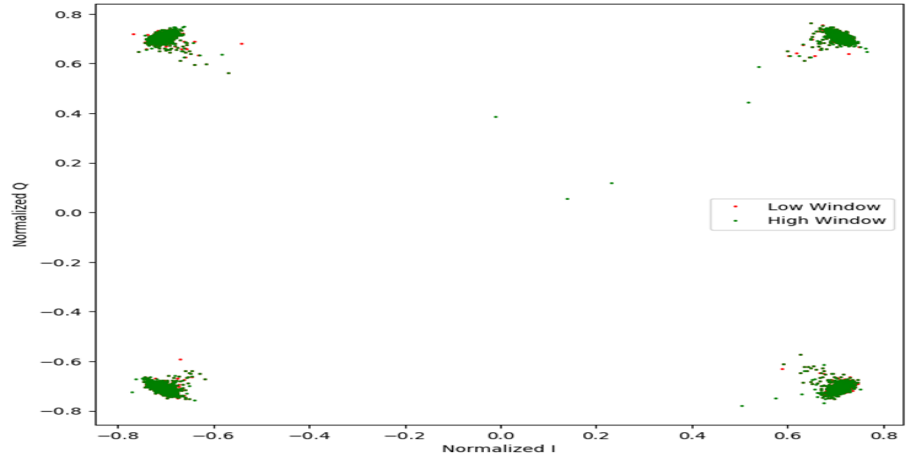


EVM – QPSK Findings

Vendor 1 RMS EVM (low): 2.34 %,
RMS EVM (high): 3.00 %

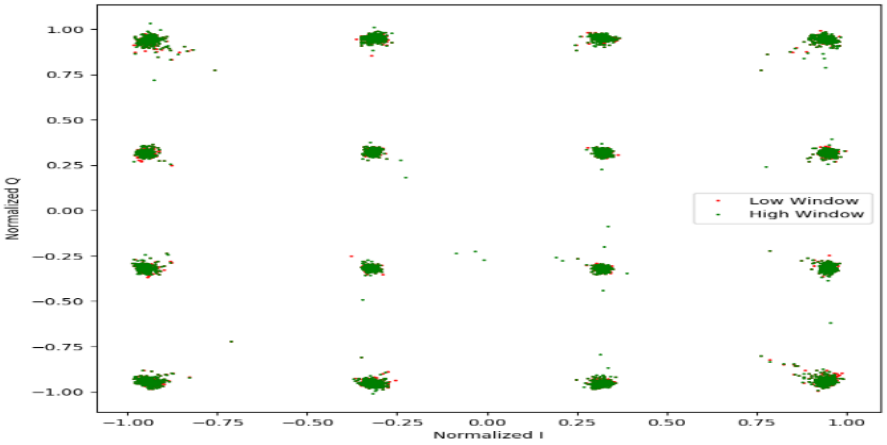


Vendor 2 RMS EVM (low): 5.31 %,
RMS EVM (high): 5.68 %

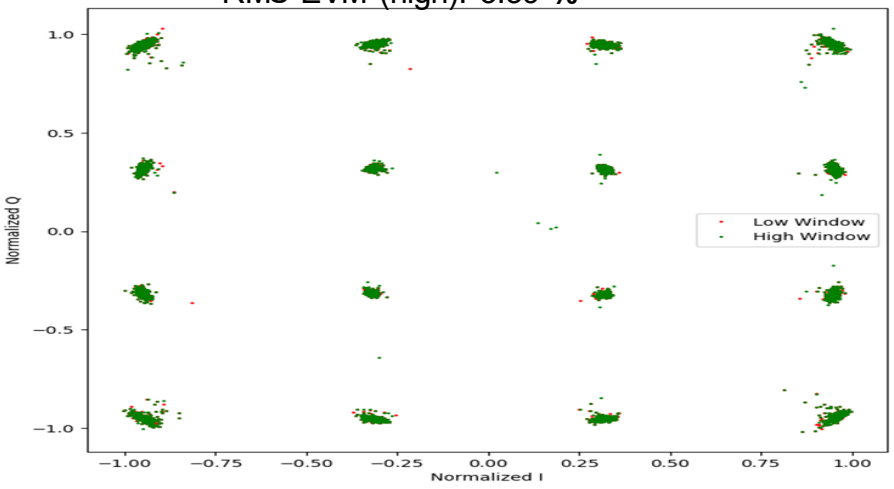


EVM – 16QAM Findings

Vendor 1 RMS EVM (low): 2.38 %,
RMS EVM (high): 3.01 **%**

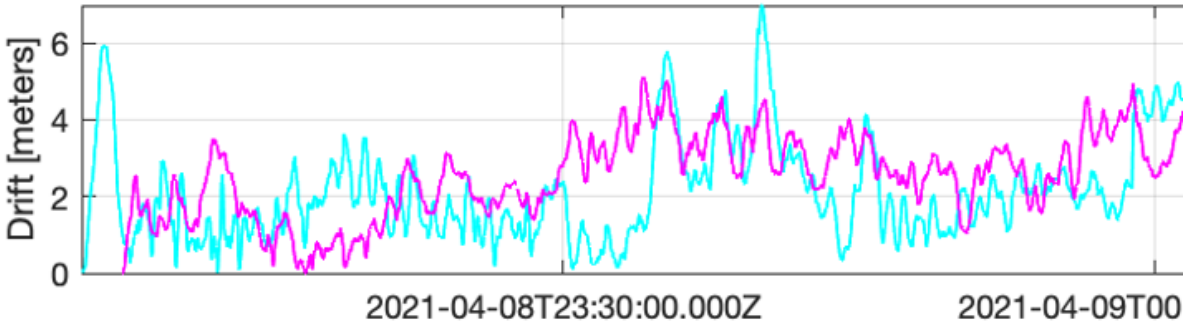


Vendor 2 RMS EVM (low): 3.06 %,
RMS EVM (high): 3.39 **%**



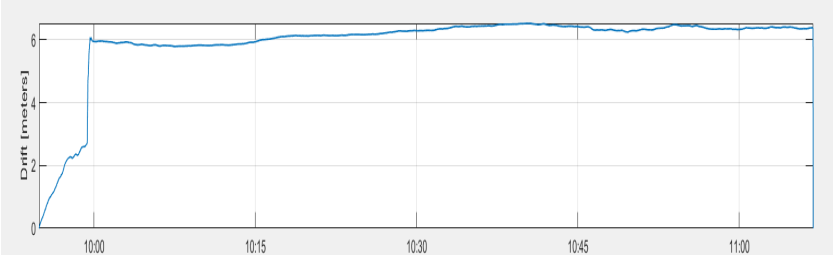
Position Drift

Vendor 1

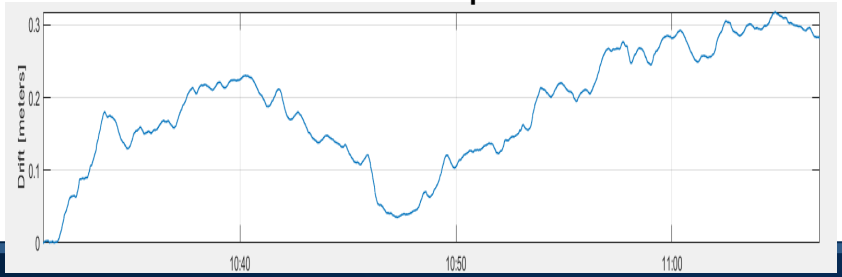


Vendor 2

No Warm-Up Time



After 30 Minute Warm-Up



RSU Device Performance Characterization: List of Tests

Number	Name
1	Turn On/Off
2	Log into devices
3	Support for Draft SAE J3161/1 LTE-V2X Parameter Settings
4	Tx/Rx Channel
5	Tx Power
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10	Tx/Rx Position Information
11	Rx Packet Number
12	Rx sensitivity
13	Tx/Rx Resource Pool
14	Tx Data Rate or MCS
15	Tx EVM
16	Rx Power
17	Interference susceptibility
18	Noise figure
19	Tx Resource Block and sub-frame selection
20	Tx dynamic BSMs
21	Technology Readiness Level (TRL)

Basic Functionality Checks

- ✓Turn On/Off
- ✓Log In
- ✓Support for SAE J3161/1
- ✓Select Tx/Rx Channel
- ✓Select Tx Packet Length and Rate
- ✓Position Information
- ✓Change Data Rate / MCS
- ✓Change Resource Block and Subframe Selection

Notes:

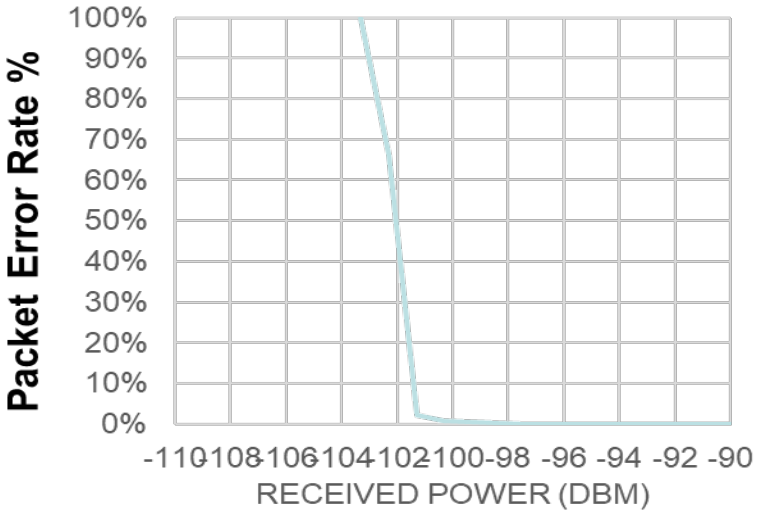
- Packet logs sometimes malformed if logged immediately after printing a summary log line.

RF Characterization

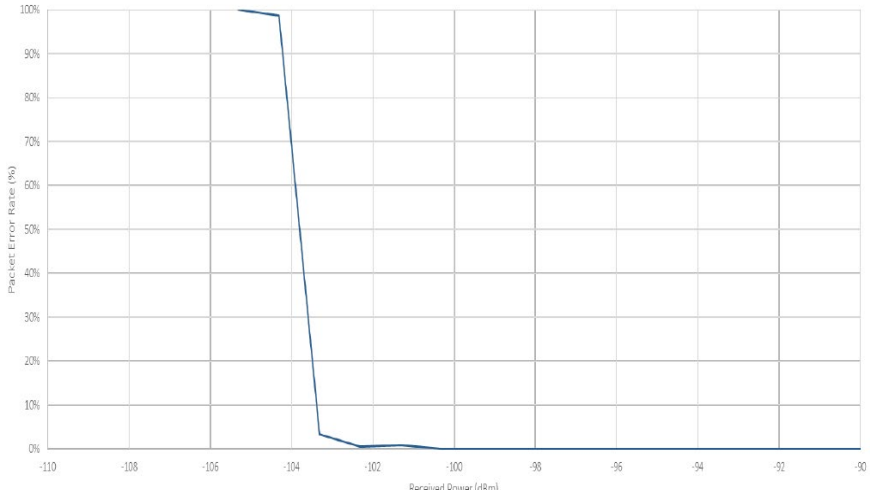
- Receiver Characterization
  - Cabled Setup
  - Rx Sensitivity
  - AWGN Interference
  - Noise Figure Extraction
- Transmitter Characterization
  - Cabled Setup
  - Transmit Power
    - Leakage Analysis
  - Radio configuration for SEM/ACLR
  - Spectral Emission Mask
  - Adjacent Channel Leakage
  - EVM

Rx Sensitivity Findings

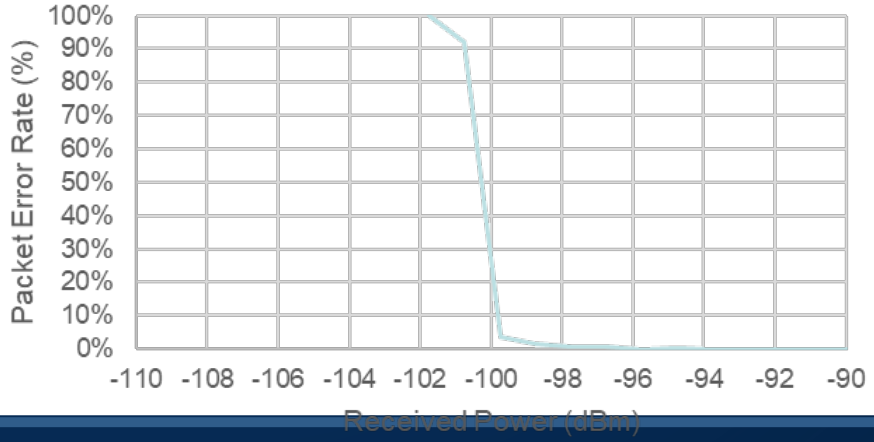
Vendor 1



Vendor 2



Vendor 3



Receive Sensitivity Findings

Vendor 1

ID	Receive Sensitivity [dBm]
1041	-101.4
1042	-101.6
1043	
1206	-100.5
1208	
1210	-100.8

Vendor 2

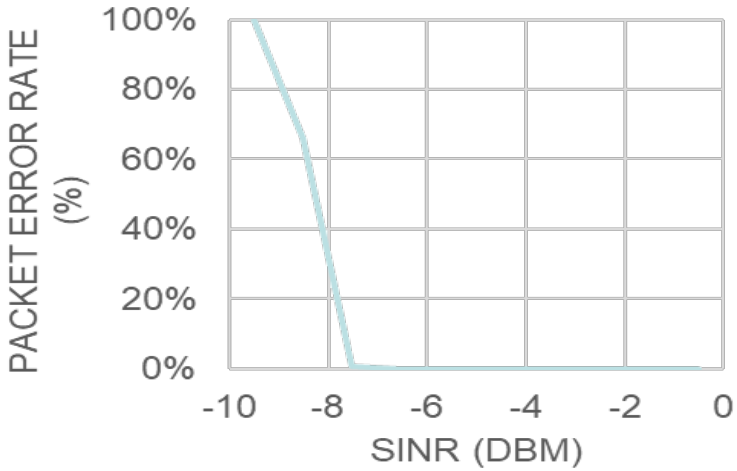
ID	Receive Sensitivity [dBm]
1013	-103.4
1014	
1015	-103.5
1023	-104.3
1024	
1029	-103.3

Vendor 3

ID	Receive Sensitivity [dBm]
1025	-99.8
1031	-100.9
1037	-100.0

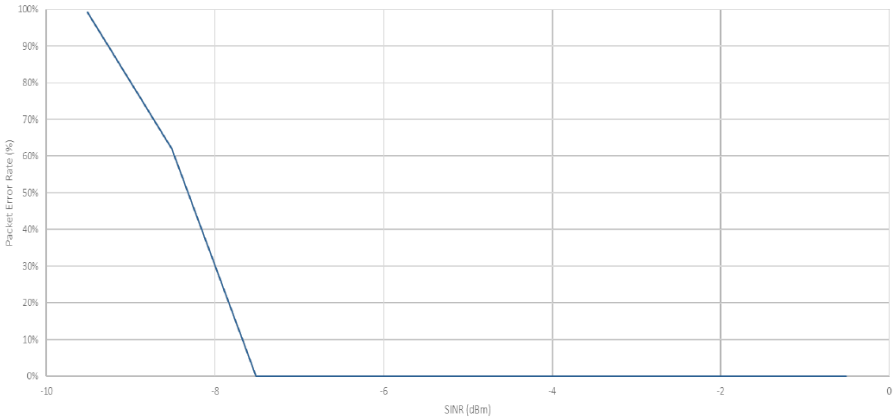
AWGN Interference Findings

Vendor 1



*Received power: -70 dBm; SINR calculated over entire 20MHz CH183

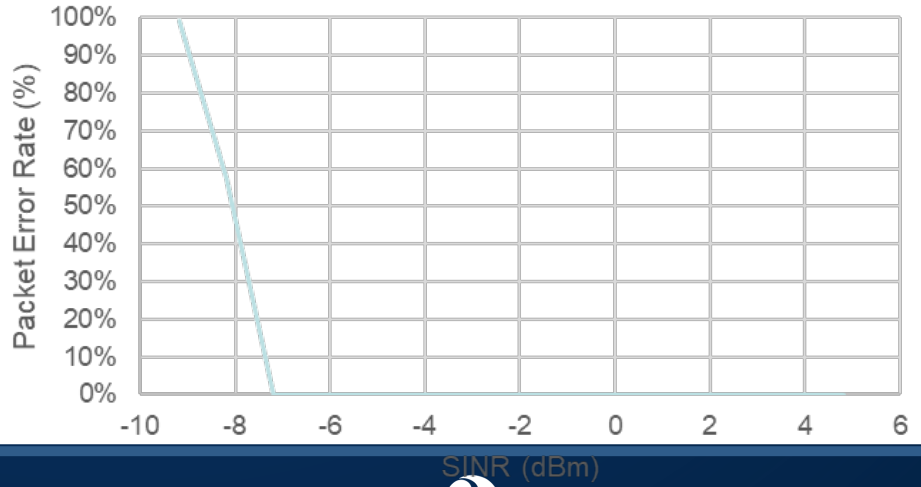
Vendor 2



Received power: -70 dBm

*SINR calculated over entire 20MHz CH183

Vendor 3



Estimated Noise Figure Findings

Vendor 1

DUT	Estimated Noise Figure
1041	7.27
1042	6.73
1043	
1206	8.1
1208	
1210	7.65

Vendor 2

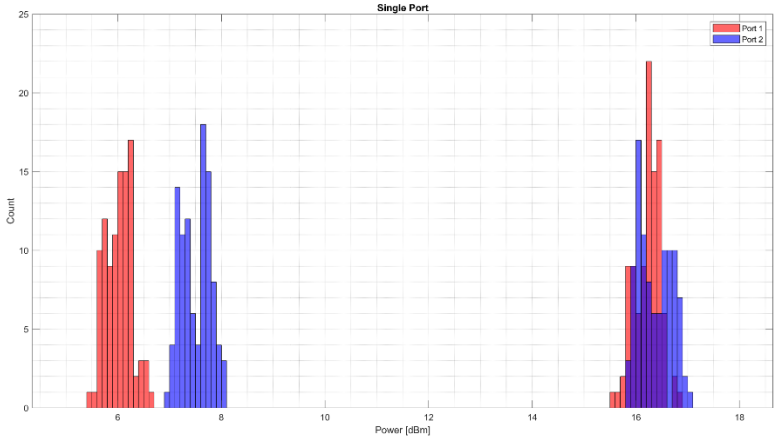
DUT	Method 1	Method 2
1013	5.5 dB	6.1 dB
1015	5.1 dB	5.9 dB
1023	4.4 dB	4.8 dB
1029	5.5 dB	6.0 dB

Vendor 3

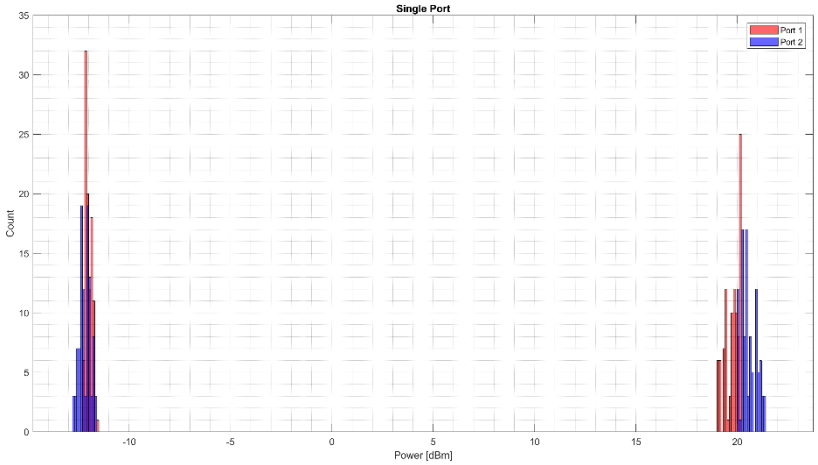
DUT	Estimated Noise Figure
1025	9.3
1031	7.9
1037	8.5

Transmit Power – Single Port Findings

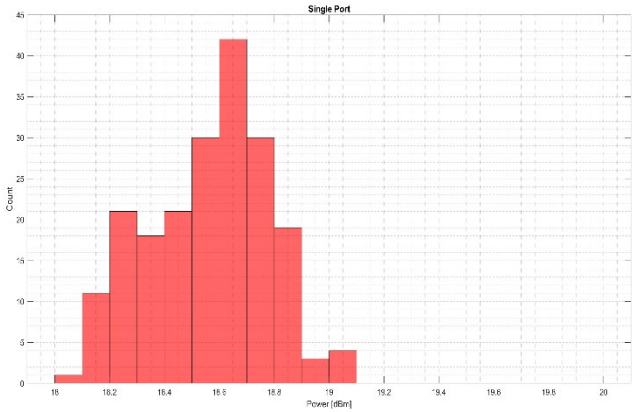
Vendor 1



Vendor 2

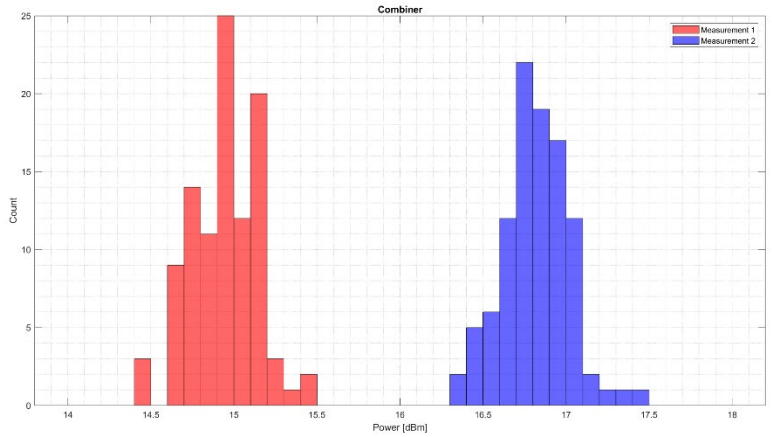


Vendor 3

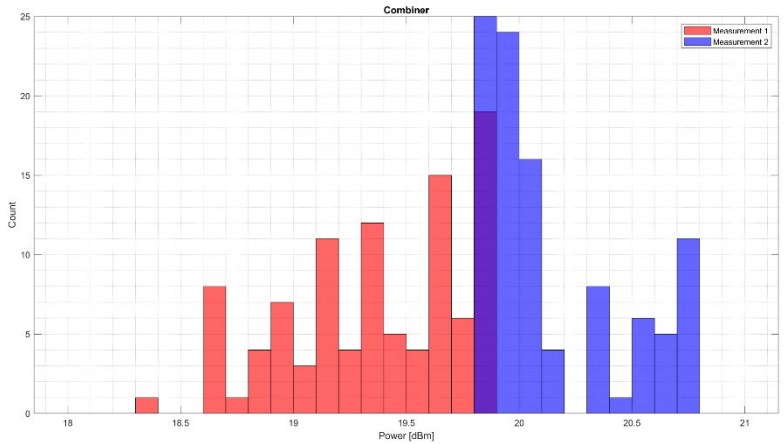


Transmit Power – Combiner Findings

Vendor 1



Vendor 2



Vendor 3: Not Applicable

Single Port Analysis of Vendor 2

	Port 1	Port 1 Leakage	Port 2	Port 2 Leakage
Power (dBm)	20.78	-15.24	21.23	-16.43
V_{RMS} (mV)	1744.81	509.91	1824.82	600.84
Port 1 + Port 2 Leakage	**Port 2 + Port 1 Leakage**	**Port 1 – Port 2 Leakage**	**Port 2 – Port 1 Leakage**	**Port 1 + Port 2 Leakage**
20.90	21.36	20.66	21.10	20.90
2345.65	2334.74	1143.97	1314.91	2345.65

Transmit Power Findings

Vendor 1

ID	TxPower: Mean of 100 [dBm]	TxPower: Min of 100 [dBm]	TxPower: Max of 100 [dBm]
1041	15.99	14.47	17.41
1042	15.68	11.47	18.24
1043			
1206	15.74	13.44	17.68
1208			
1210	16.1	14.24	17.73

Vendor 2

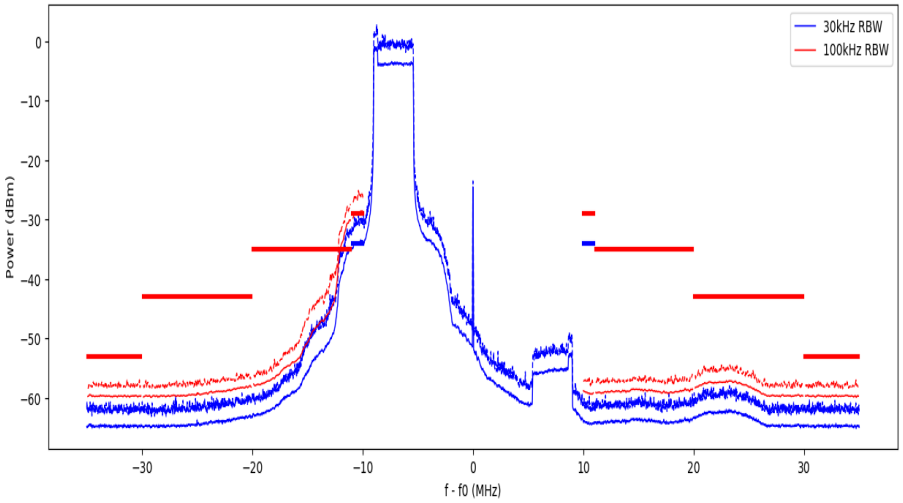
ID	TxPower: Mean of 100 [dBm]	TxPower: Min of 100 [dBm]	TxPower: Max of 100 [dBm]
1013	19.79	18.34	20.77
1014			
1015	20.73	19.79	21.54
1023	20.42	19.19	21.73
1024			
1029	20.72	19.27	21.88

Vendor 3

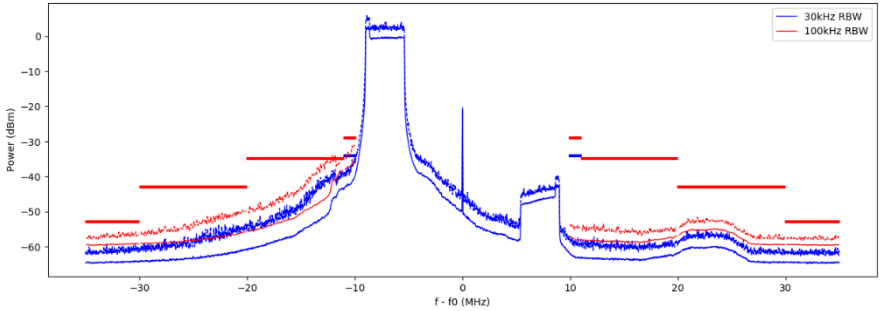
ID	TxPower: Mean of 100 [dBm]	TxPower: Min of 100 [dBm]	TxPower: Max of 100 [dBm]
1025	18.57	18.07	19.08
1031	18.79	18.33	19.34
1037	18.73	18.18	19.29

SEM – First 20 RBs Findings

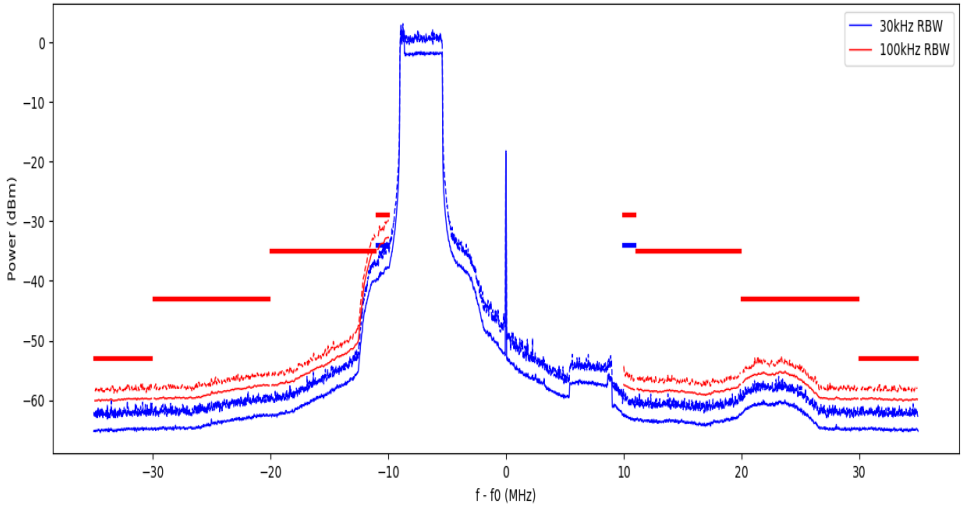
Vendor 1



Vendor 2

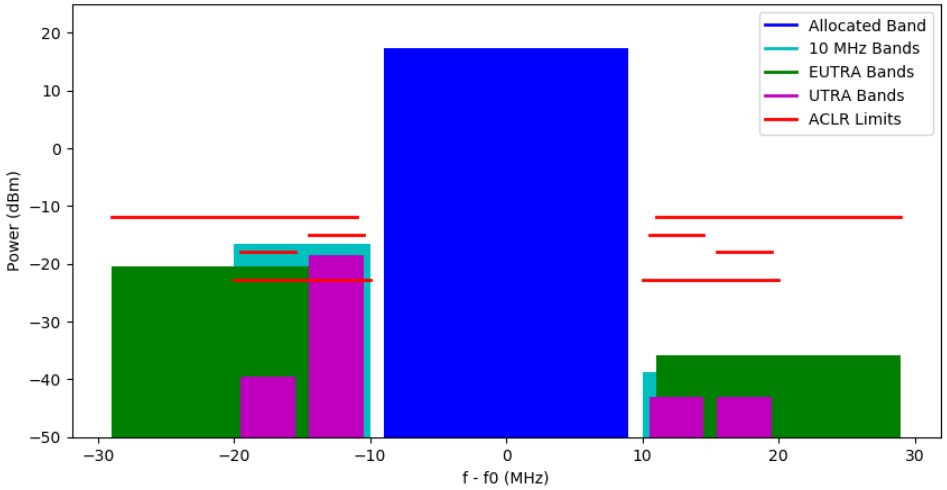


Vendor 3

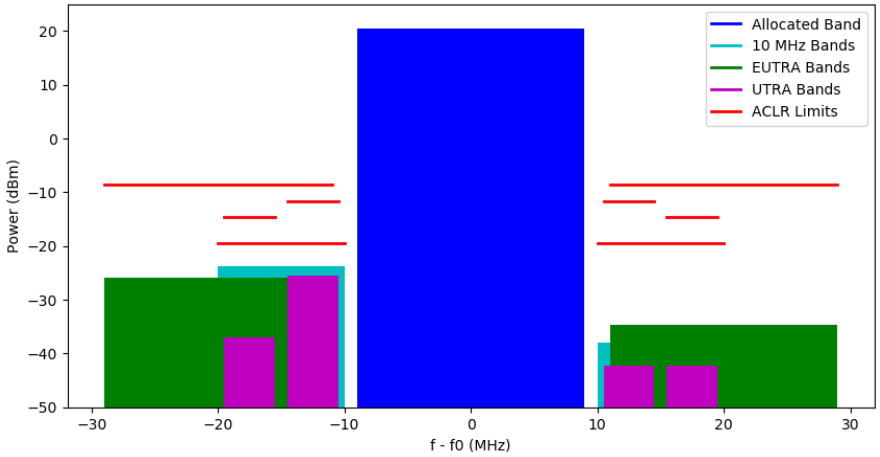


ACLR – First 20 RBs Findings

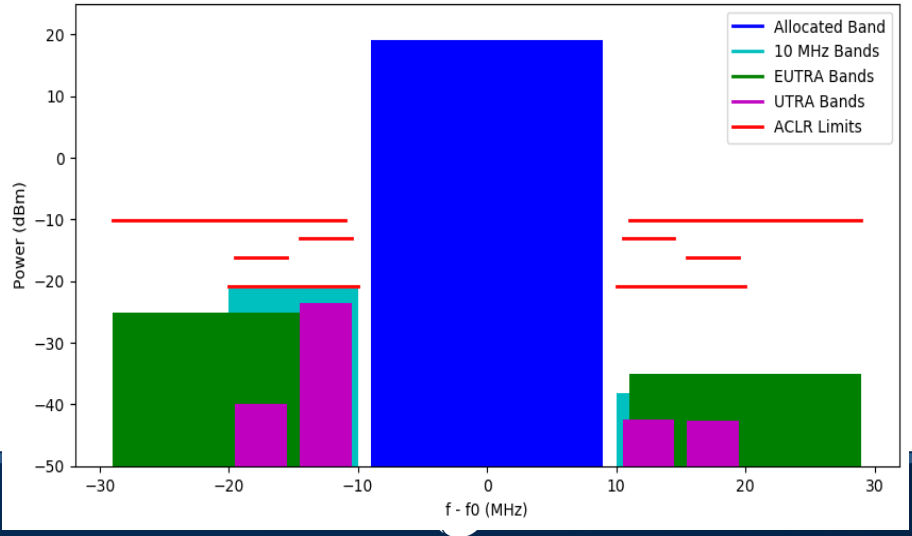
Vendor 1



Vendor 2

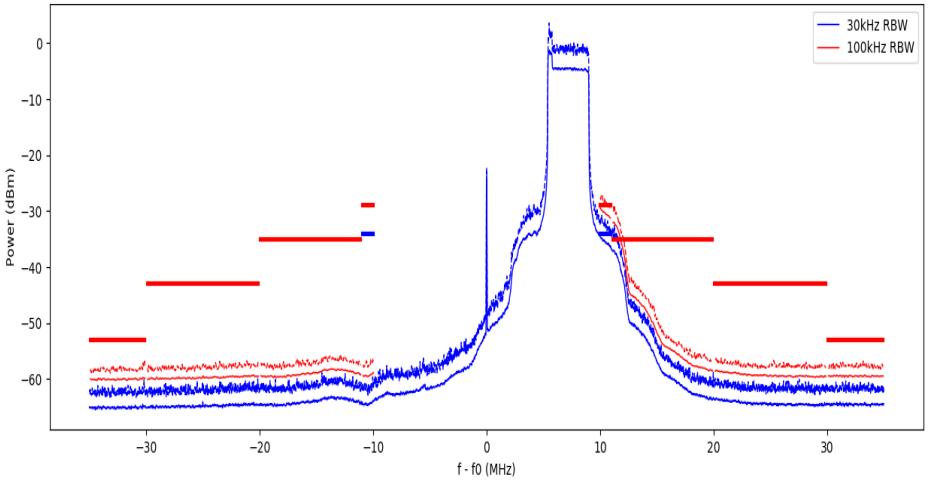


Vendor 3

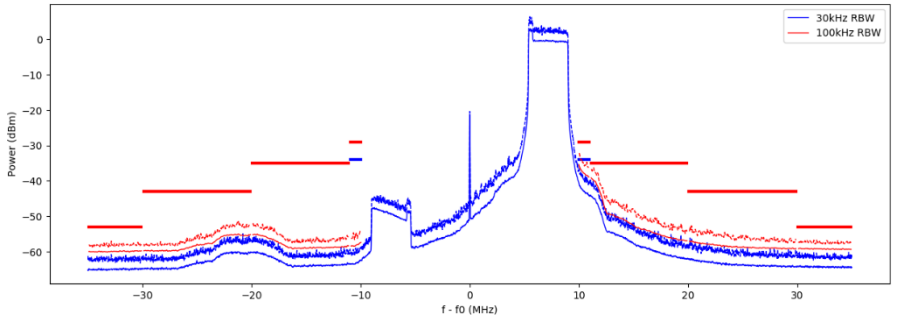


SEM – Last 20 RBs Findings

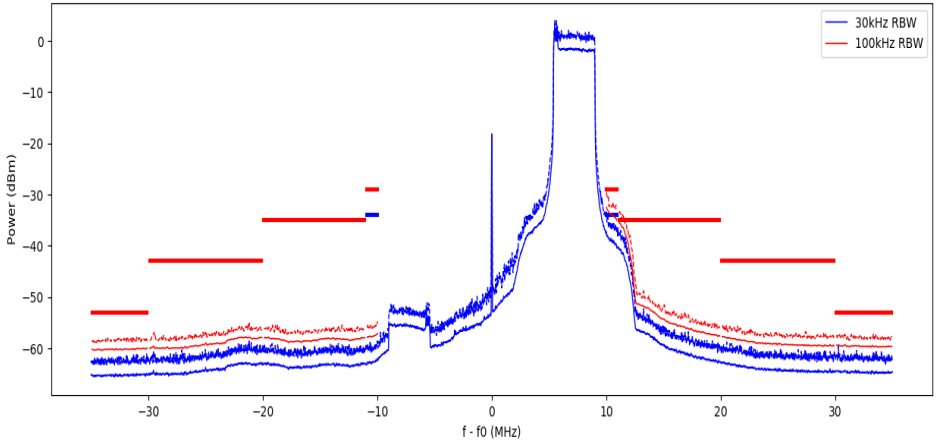
Vendor 1



Vendor 2

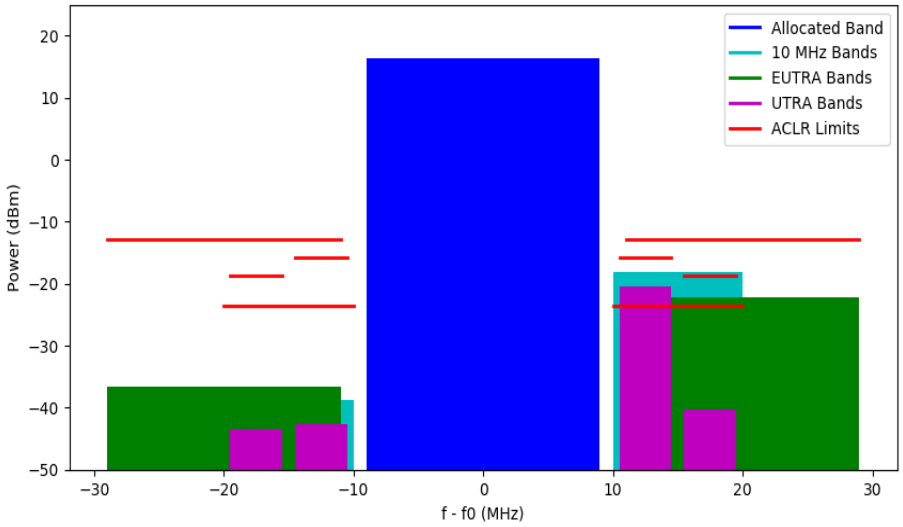


Vendor 3

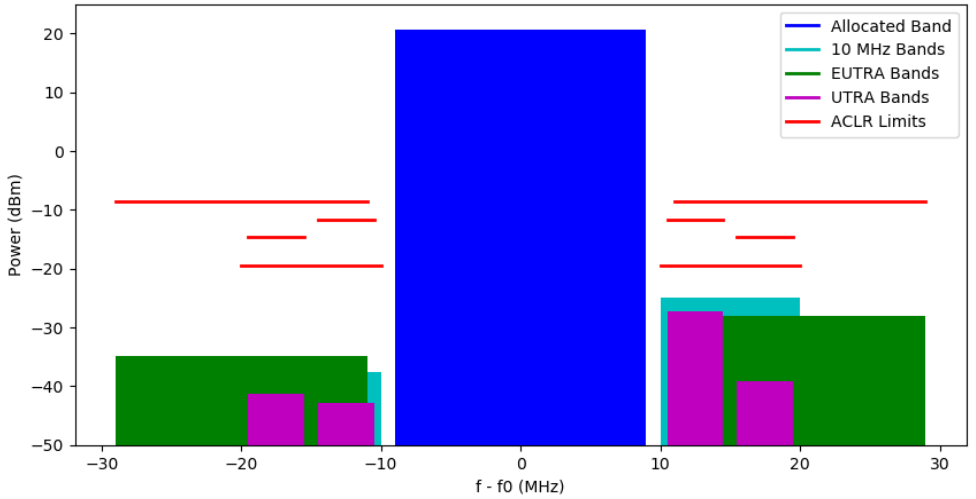


ACLR – Last 20 RBs Findings

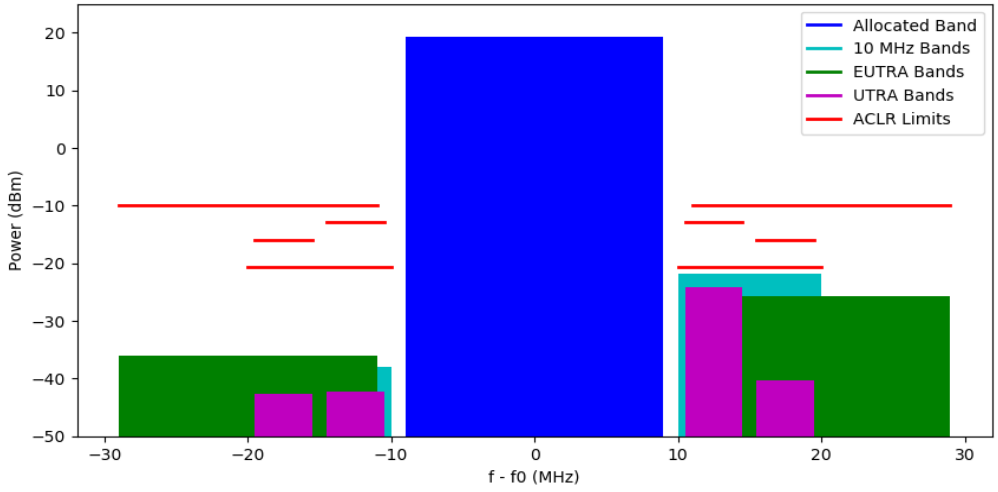
Vendor 1



Vendor 2

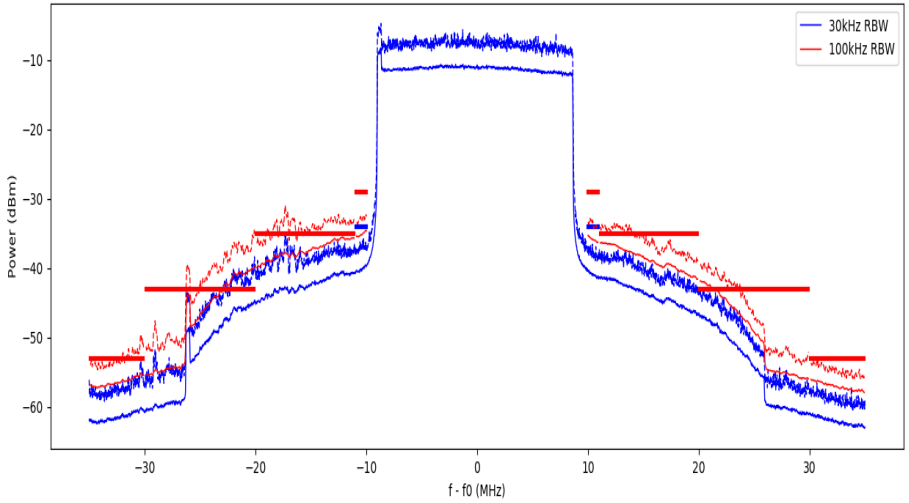


Vendor 3

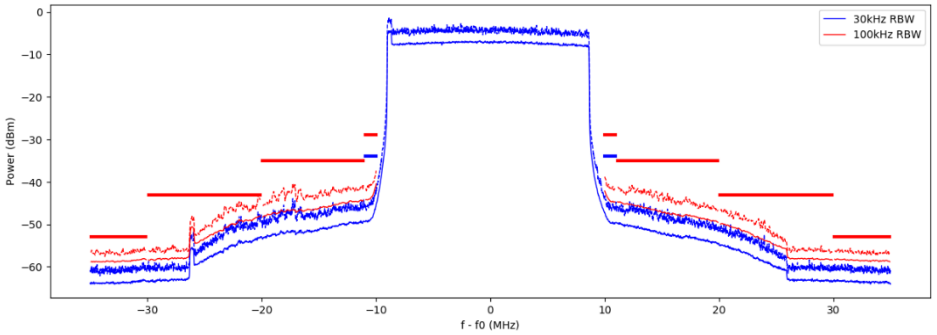


SEM - 100 RBs Findings

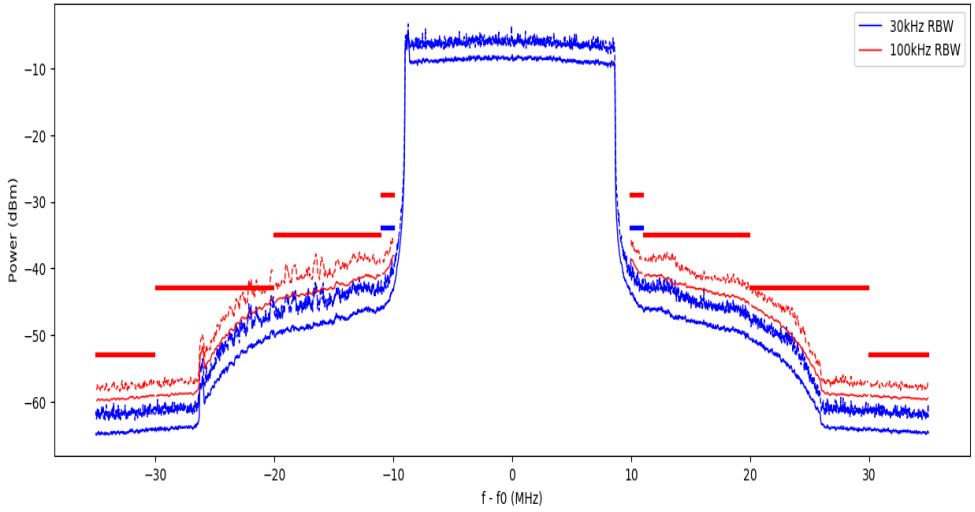
Vendor 1



Vendor 2

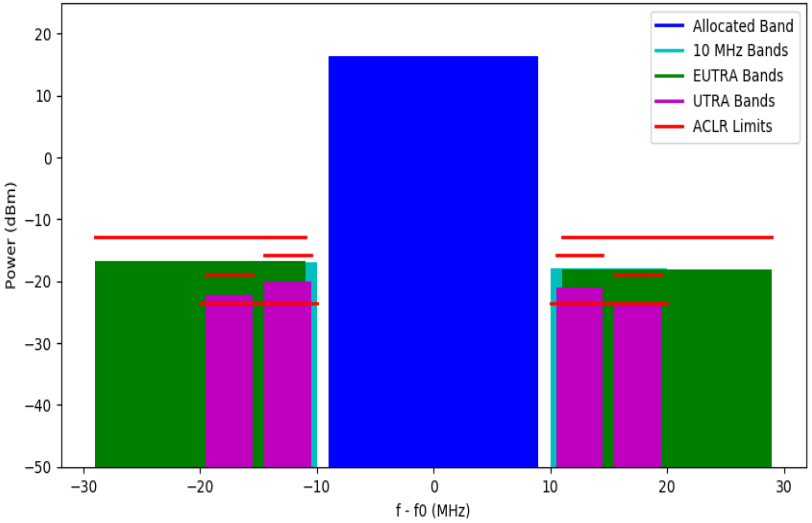


Vendor 3

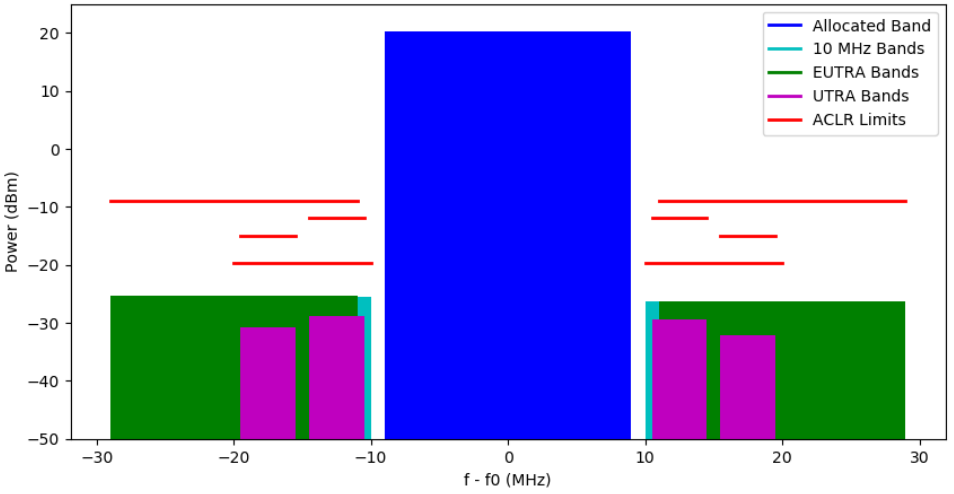


ACLR – 100 RBs Findings

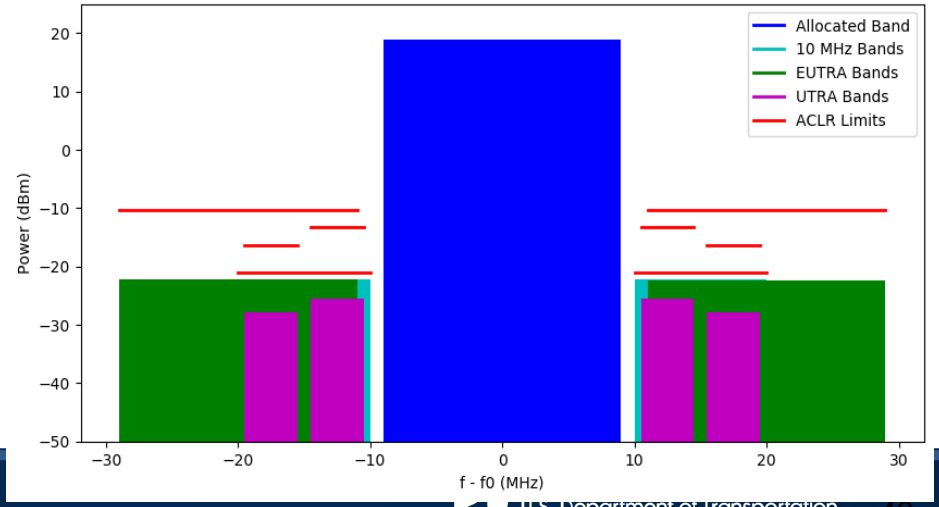
Vendor 1



Vendor 2

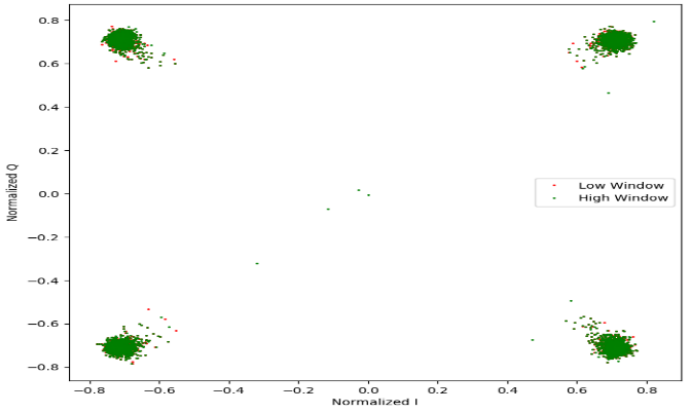


Vendor 3

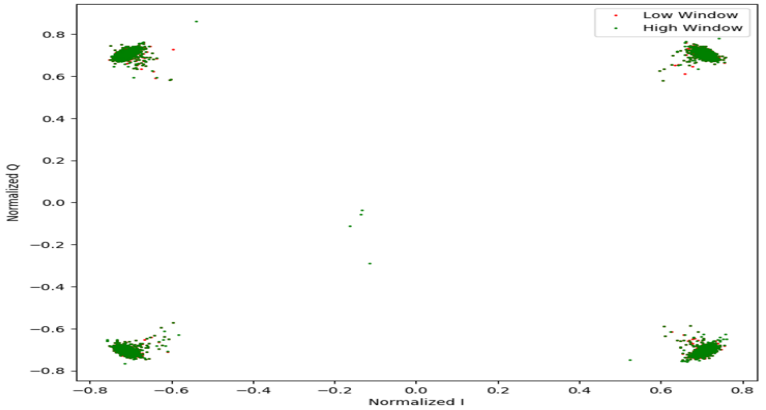


EVM – QPSK Findings

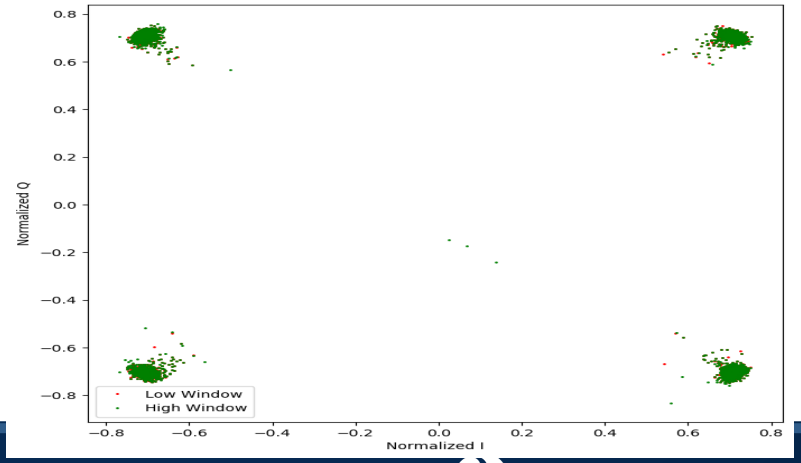
Vendor 1 RMS EVM (low): 3.60 %,
RMS EVM (high): 4.06 %



Vendor 2 RMS EVM (low): 9.78 %,
RMS EVM (high): 8.93 %

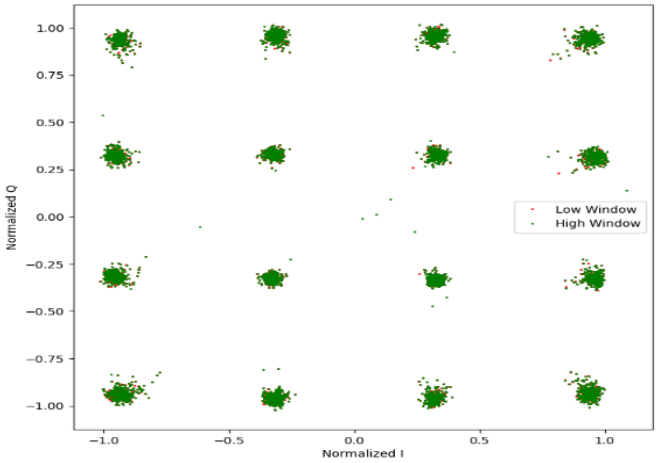


Vendor 3 RMS EVM (low): 2.51%,
RMS EVM (high): 3.09%

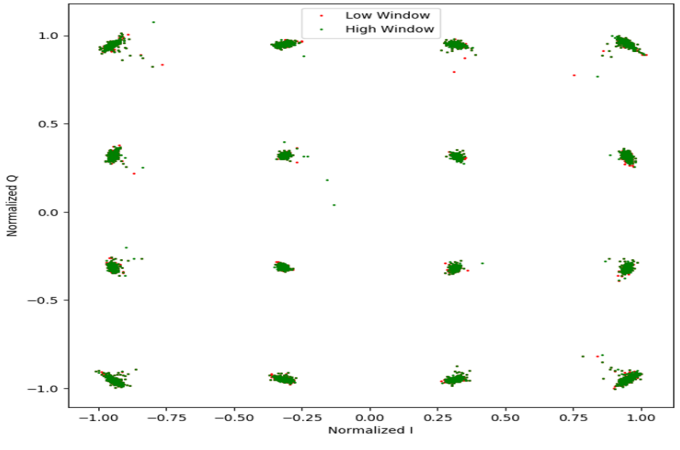


EVM – 16QAM Findings

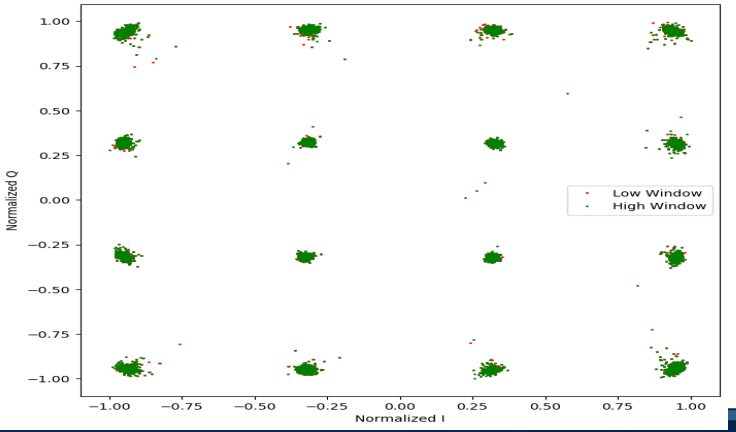
Vendor 1 RMS EVM (low): 4.33 %,
RMS EVM (high): 4.75 %



Vendor 2 RMS EVM (low): 8.12 %,
RMS EVM (high): 7.13 %



Vendor 3 RMS EVM (low): 2.53 %,
RMS EVM (high): 3.21%



Device Acceptance Characterization: List of Tests

- Test Procedures
  - Pre-configuration
  - Transmit Power
  - SEM
  - Rx Sensitivity

Device Acceptance Characterization: List of Tests

1. Copy the .xml config. file using scp to a permanent directory on the device. Power and SEM tests use all 100 resource blocks, Rx. sensitivity uses 20.
2. Kill the cv2x-daemon.
3. Update the configuration path.

   sudo cv2x-config --update-config-file <file path>
4. Start the cv2x-daemon.
5. Ensure GPS is getting a signal.
6. Check v2x status.

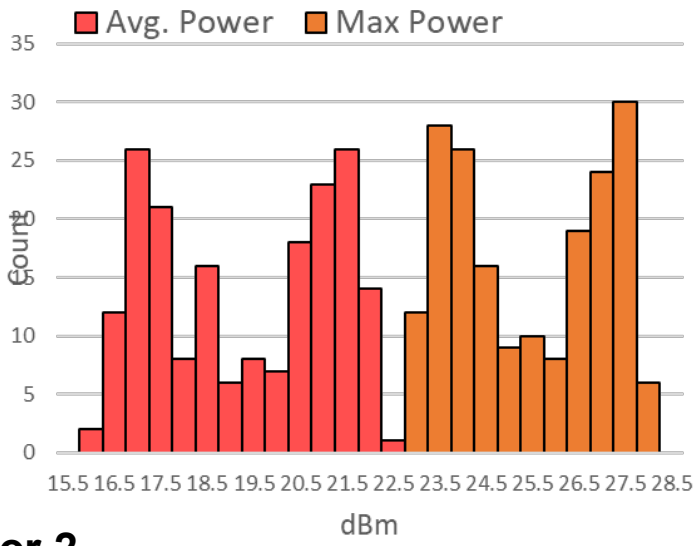
   sudo cv2x-config --get-v2x-status
7. Make sure acme runs.

Tx Power

1. Run pre-configuration.
2. Connect transmission antenna output to a power sensor which runs into the spectrum analyzer (SA). If transmitting from two ports, run them through a combiner then into the power sensor. Set external attenuation to 25-30 dB.
3. Recall the pulse measurements configuration file (frequency = 5.915 GHz).
4. Run *acme -E* (event mode).
5. Press Sweep-->Single on the SA to make one sweep measurement.
6. Run 5 sweeps for each device.
7. Record the AVG. and MAX power from each sweep.

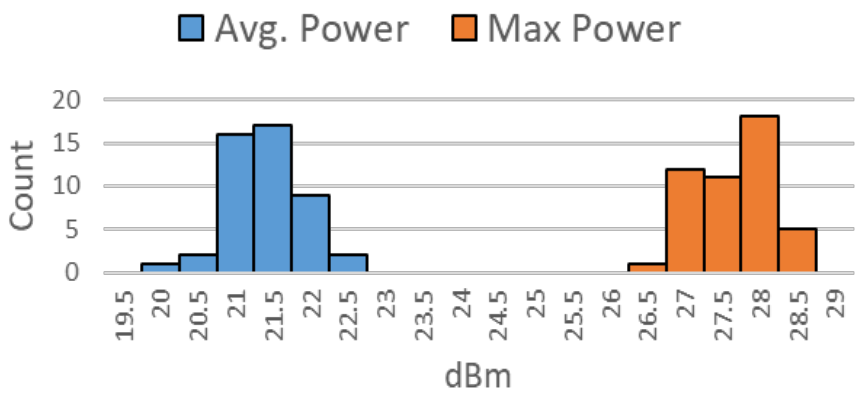
OBU Tx Power Findings

Vendor 1



Vendor 3: N/A

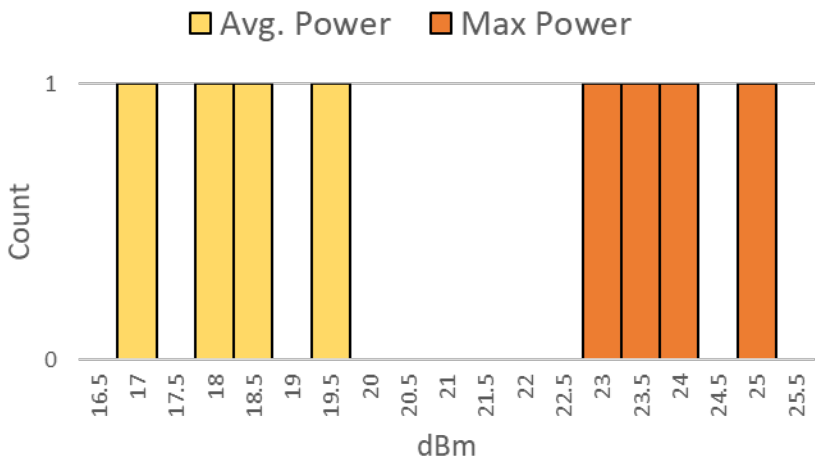
Vendor 2



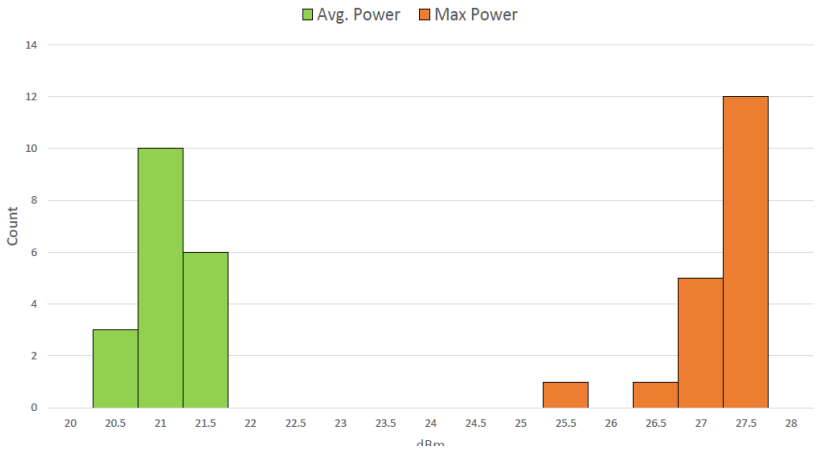
Vendor 4: N/A

RSU Tx Power Findings

Vendor 1

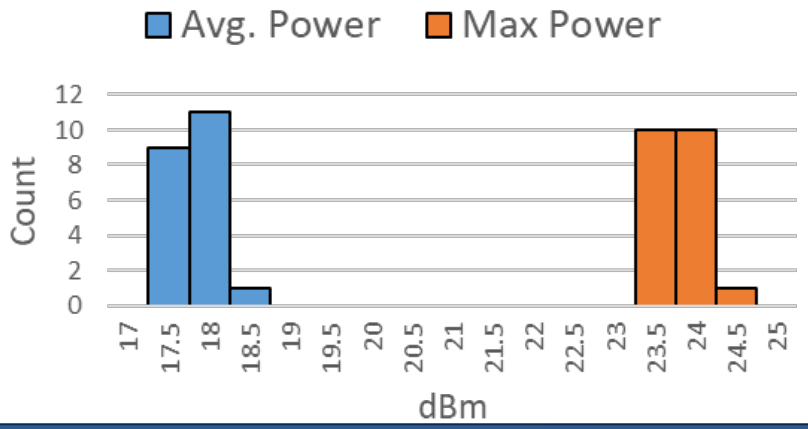


Vendor 3



Vendor 2: N/A

Vendor 4



Spectral Emission Mask

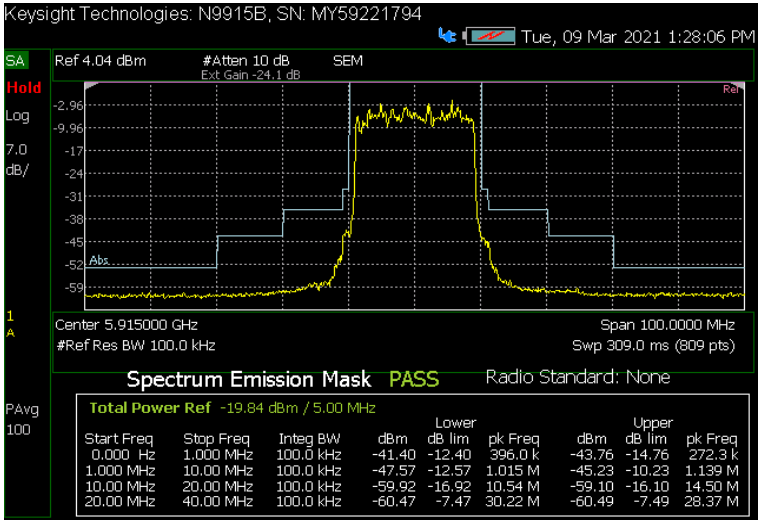
1. Run pre-configuration.
2. Connect transmission antenna output to a spectrum analyzer (SA). If transmitting from two ports, run them through a combiner then into the spectrum analyzer. Set external attenuation to 25-30 dB.
3. Center the view span of the SA to the 20 MHz C-V2X channel. This is done by recalling the signal analyzer configuration file with the mask from Boulder (Center = 5.915 GHz, freq. span = 100 MHz) Use averaging on SA.
4. run *acme -E* (event mode) *-l 1400* (packet length of 1400 bytes) *-l 5* (interpacket gap of 5 milliseconds).
5. Run for ~1 min.
6. Is the output fully within the mask provided by Boulder at channel 183?

Spectral Emission Mask

1. Run pre-configuration.
2. Connect transmission antenna output to a spectrum analyzer (SA). If transmitting from two ports, run them through a combiner then into the spectrum analyzer. Set external attenuation to 25-30 dB.
3. Center the view span of the SA to the 20 MHz C-V2X channel. This is done by recalling the signal analyzer configuration file with the mask from Boulder (Center = 5.915 GHz, freq. span = 100 MHz) Use averaging on SA.
4. run *acme -E* (event mode) *-l 1400* (packet length of 1400 bytes) *-l 5* (interpacket gap of 5 milliseconds).
5. Run for ~1 min.
6. Is the output fully within the mask provided by Boulder at channel 183?

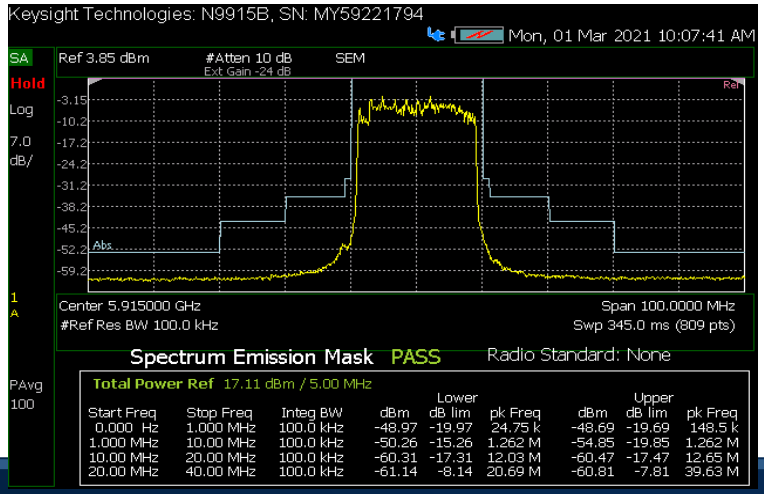
OBU SEM Findings

Vendor 1



Vendor 3: N/A

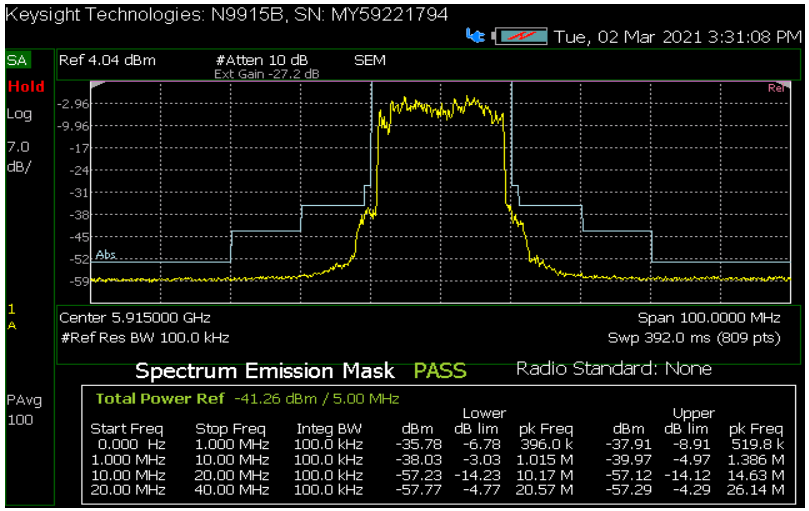
Vendor 2



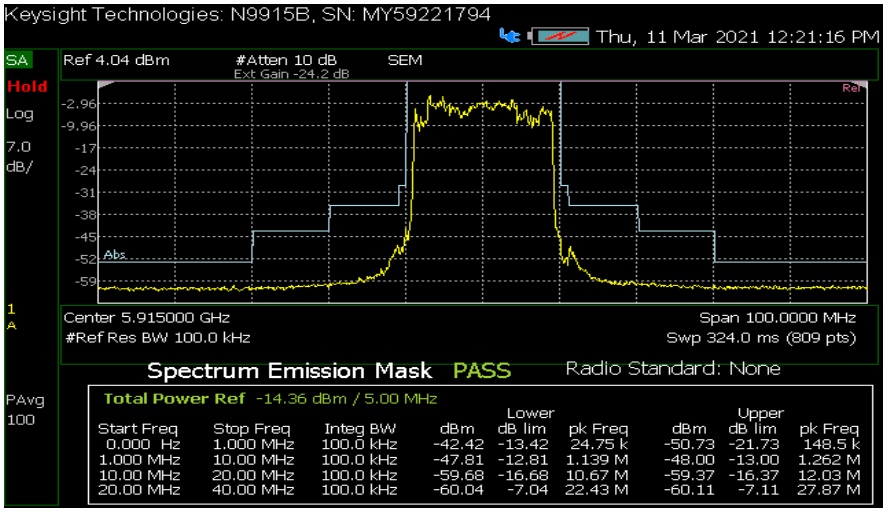
Vendor 4: N/A

RSU SEM Findings

Vendor 1

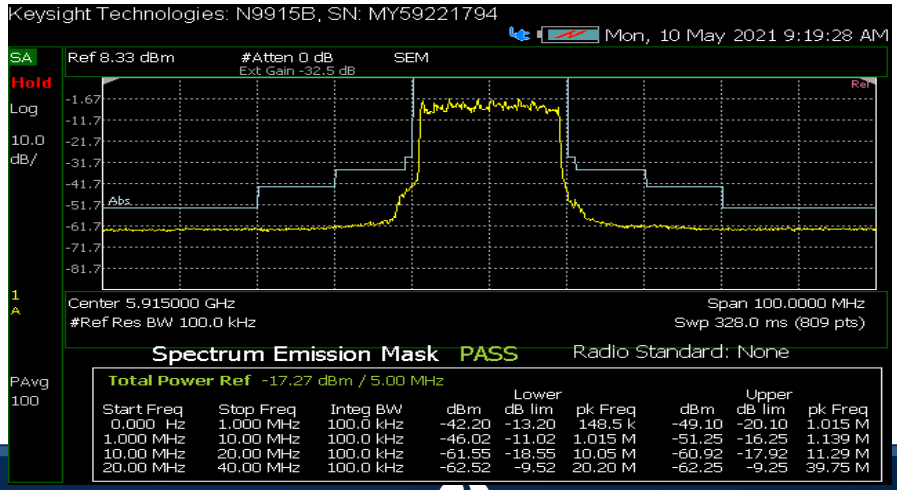


Vendor 3



Vendor 2: N/A

Vendor 4

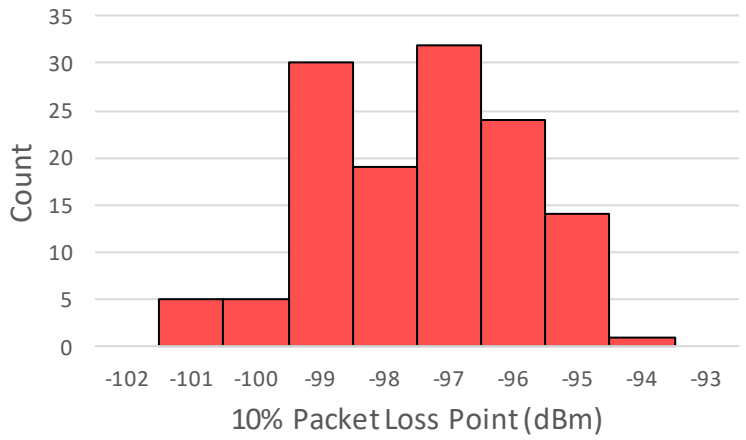


Rx Sensitivity

1. Set the Qualcomm device to transmit using 20 resource block at the 20 MHz C-V2X channel -- connected directly via coax cables to the Rx device.
2. Use external attenuators and variable attenuator to reach desired value.
3. Run pre-configuration on the DUT.
4. ssh into the DUT and run *acme –RVV*
5. Open another ssh window on the DUT and run *tcpdump –i rmnet_data1 –vv –w RxAT_0/U10/O10_attenuation.pcap*
6. Run *acme -k 1000 -l 193 -l 100* on the Qualcomm device.
7. At a lower attenuation value is the DUT successfully receiving all packets?
8. Record the attenuation values and packets lost for <10% packets loss and >10% packet loss.

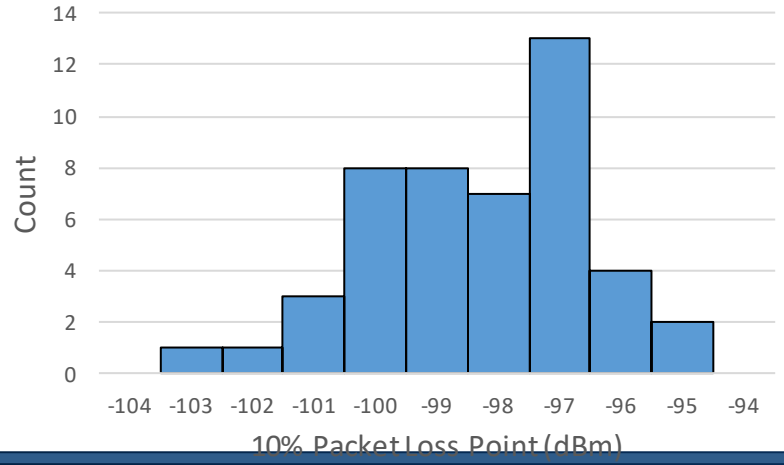
OBU Rx Sensitivity Findings

Vendor 1



Vendor 3: N/A

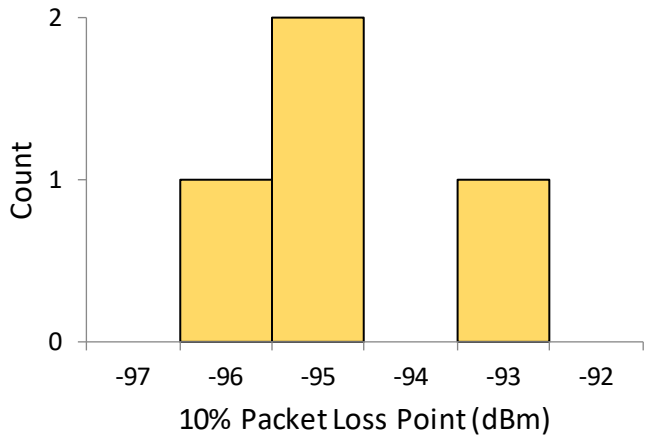
Vendor 2



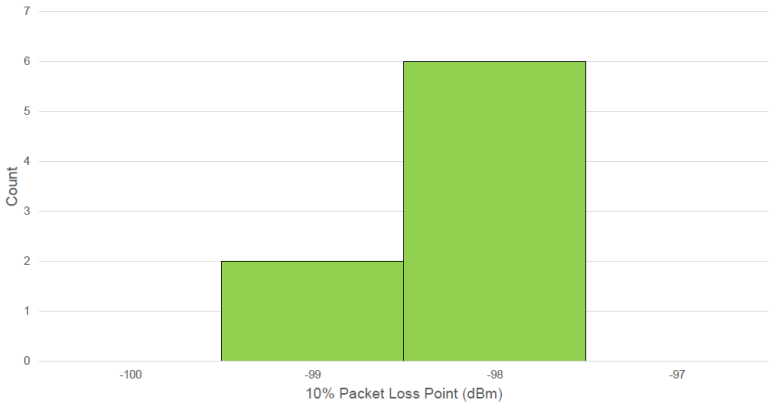
Vendor 4: N/A

RSU Rx Sensitivity Findings

Vendor 1



Vendor 3



Vendor 2: N/A

Vendor 4