Performance Characterization of USRPs

SDR WinnComm Presentation

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Outline

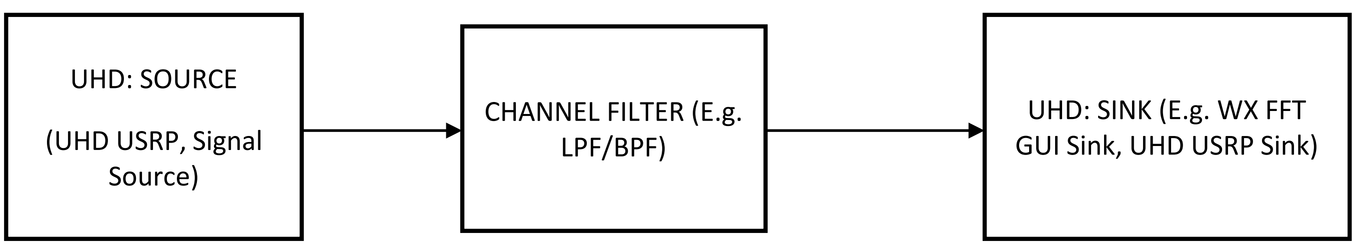
1. Introduction - Software Defined Radios (SDRs)
2. Hardware and Software Utilities
3. Calibration & its Necessity
4. Calibration Experiments and Implications
5. Practical Applications: Path Loss Modeling and Position Location estimation Results
6. Conclusions and Future Work

Software Defined Radio (SDR)

* Radio systems - Components typically implemented in Hardware are instead implemented in software [1]
* Example components: Mixers, Filters, Amplifiers, Modems, Detectors
* Signal processing performed in reconfigurable devices like General Purpose Processors (GPP) or Field Programmable Gate Arrays (FPGA)
* Flexibility of SDR systems - Improved interoperability, adaptation capability and more future-proof hardware

Hardware and Software Utilities

* SDR led to low cost hardware development - as functionality centered in GPP. E.g USRP – Universal Software Radio Peripheral, developed by Ettus Research [2]
* Universal Hardware Driver (UHD) – Open Source software driver and API for USRP devices
* Software utilities were also developed like GNU Radio: SDR application framework for USRP, others - LabView, Simulink [3]



Calibration & its Necessity

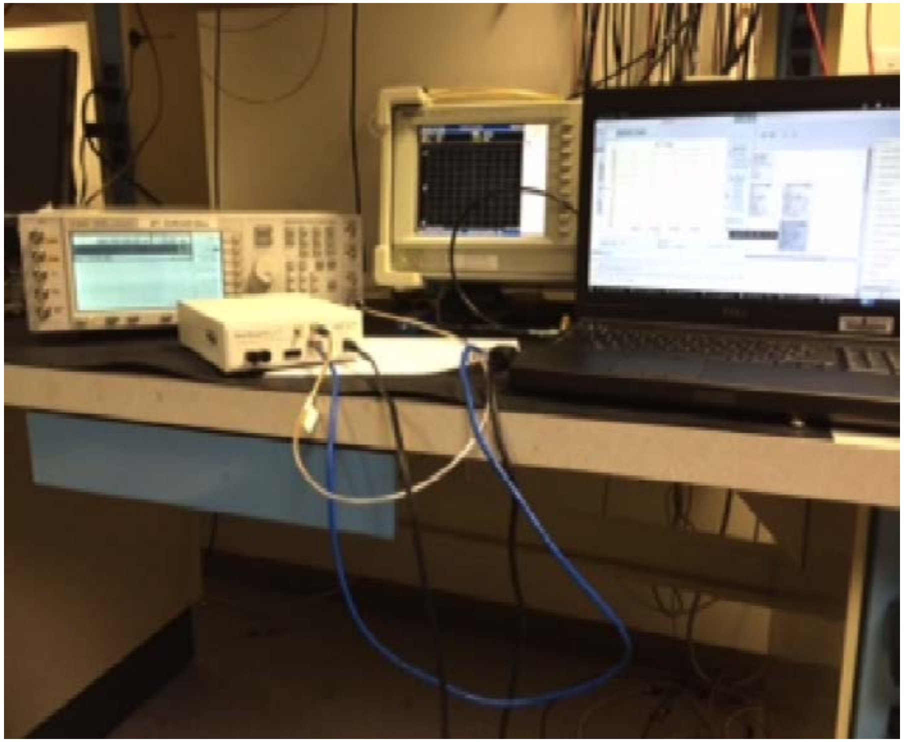
- Calibration - Comparison of measurements made from set of 2 devices - one of known correctness and other with measurement uncertainties [4]
- Provides inputs - variation in parameters like o/p power, gain, frequency in different scenarios
- Helps understand the limitations of the device
- USRPs, un-calibrated devices - need to be manually calibrated to understand their performance and set proper expectations
- For position estimation applications - calibration is mandatory to get good meaningful results/guarantee best performance

USRP Calibration Experiments

- Divided as RX and TX characterization
  - Ability to understand both operations
- DUT : USRPN210
  - RF Board: WBX , DC – 2.2 GHZ, 40 MHz Bandwidth
- Equipment: Standard Spectrum Analyzer and Signal generator

RX Side Characterization

- **1-dBCP Test :** Found the difference between the Pin (Std. Signal Gen) and Pout (UHD_FFT) for different Frequencies → Correction Factors
- **IIP3 Test :** Verified the correction factors & estimated the linear range
- **RX amplitude stability :** Validated Amplitude variation w.r.t to Frequency



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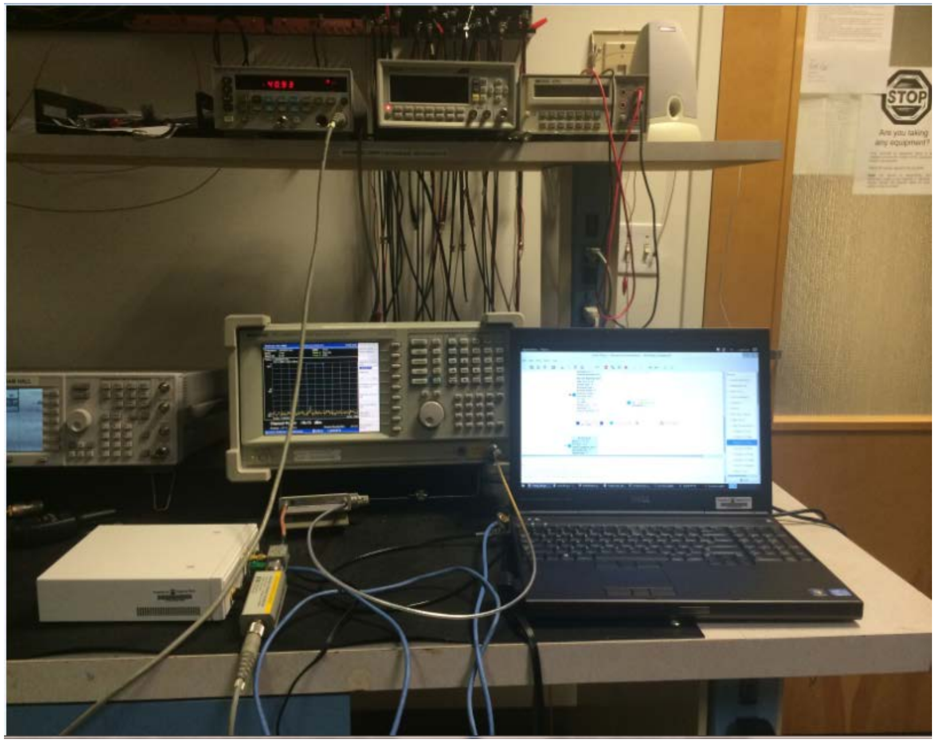
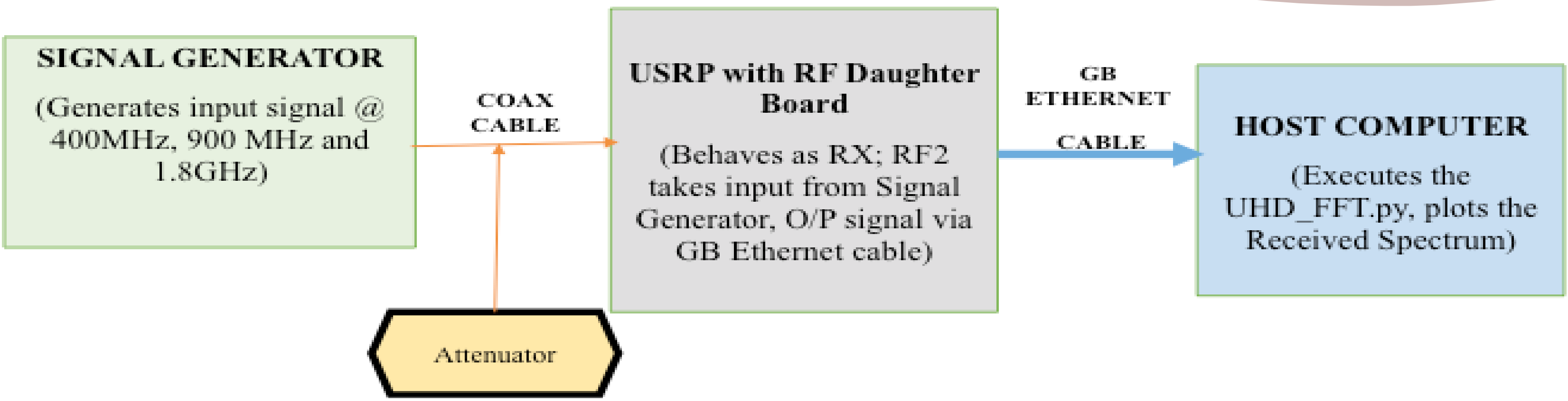
TX Side Characterization

- **Frequency Stability:** Frequency Variation w.r.t Time
- **Amplitude stability:** Amplitude Variation w.r.t Time
- **O/p power Vs Gain:**
  - 1 dB Compression Point
  - Power reference table

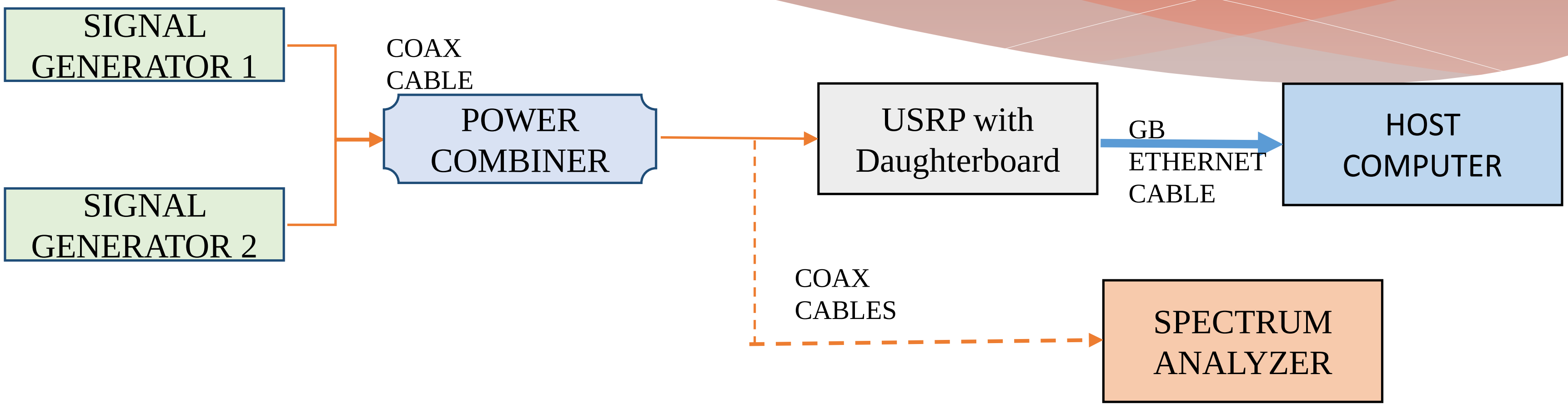


RX Side : 1-Db Compression Point Test



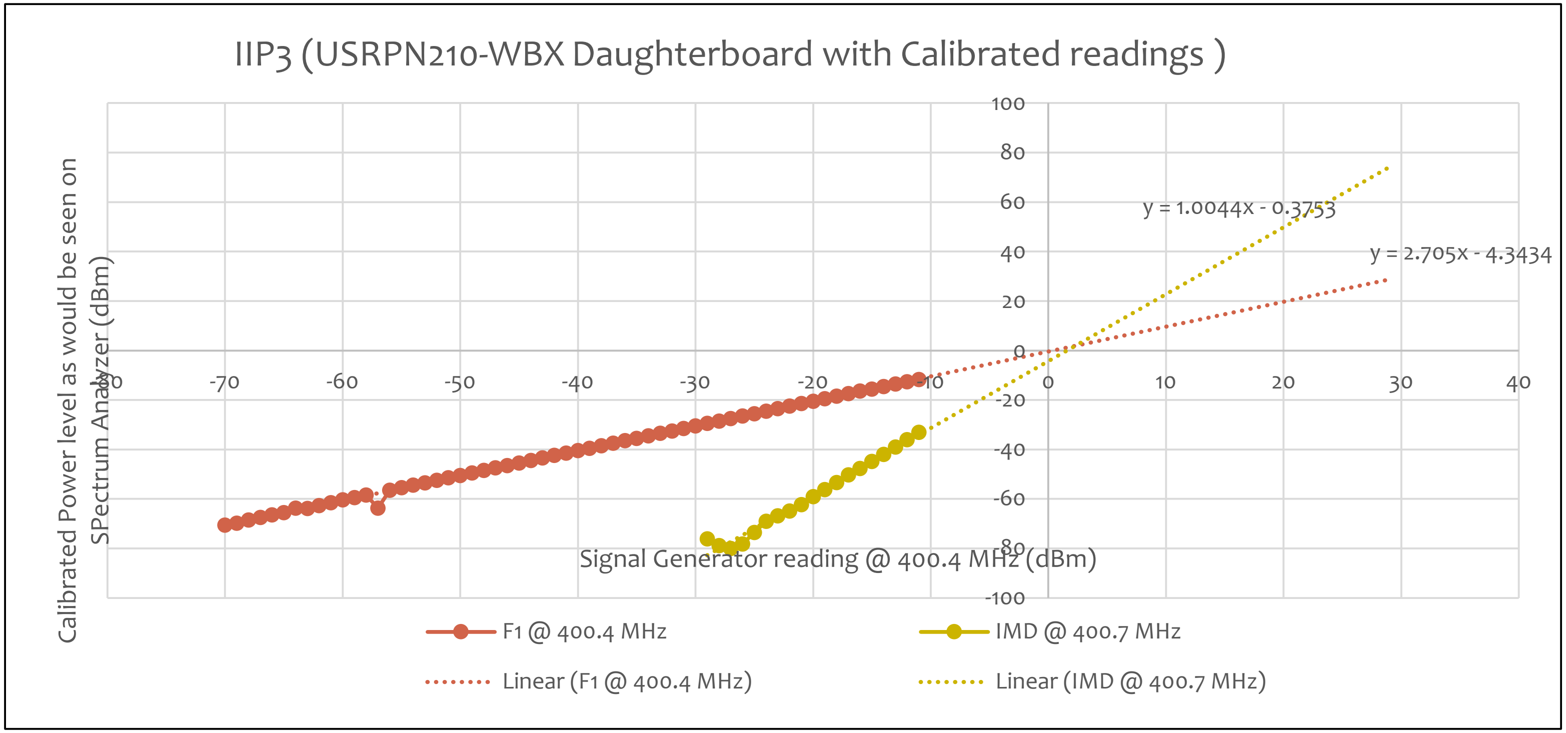
USRP Type	Average Received Power offset b/w UHD_FFT and Spectrum Analyzer		
	400 MHz	900 MHz	1800 MHz
USRPN210 + WBX board	35.54	31.24	23.57
USRPN210 + SBX board	32.19	24.43	20.54
USRP2 + WBX Board	32.90	32.04	26.67

RX Side: IIP3 Test

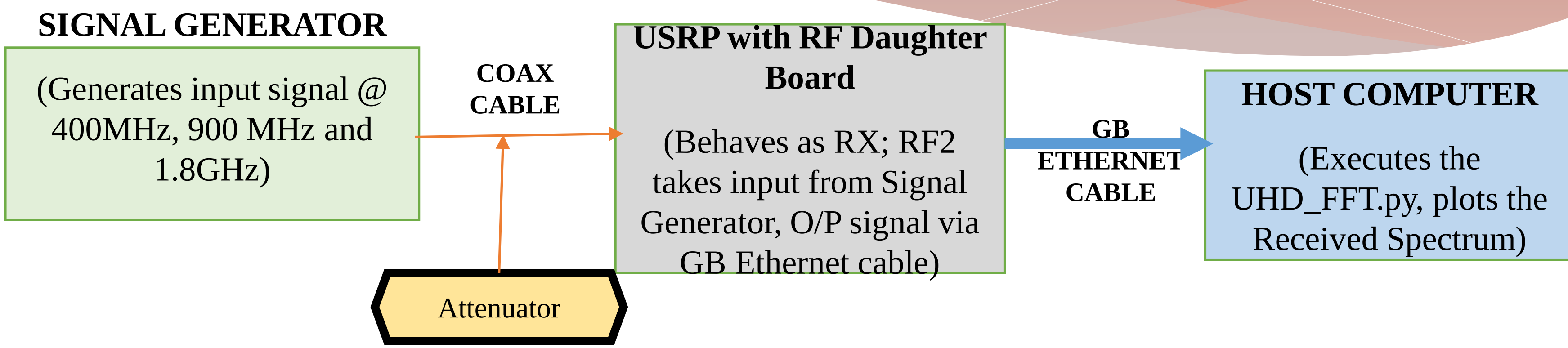


USRP Type	RX Gain Setting on UHD_FFT GUI (dB)	Center Frequency	Signal generator reading when the IMD reading is taken	O/p Reading on UHD_FFT GUI at the fundamental and IMD frequencies (dB)			IIP3 = (F2-IM1)/2+ (F1- Correction Factor+loss) (dBm)
				F1	F2	2F2-F1	
USRPN210 + WBX board (VT 361926)	0	400 MHz	-33	-1.984	-2.054	-68.81	-0.141
USRPN210 + WBX board (VT 361926)	0	900 MHz	-23.5	-8.736	-8.639	-84.934	2.29
USRPN210 + WBX board (VT 361926)	0	1800MHz	-10	2.689	3.013	-26.01	-2.46

RX Side: IIP3 Test Results

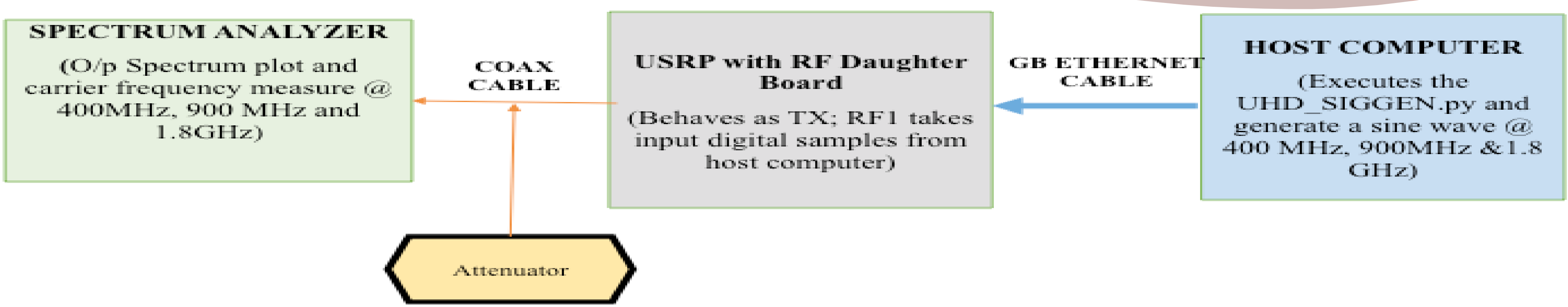


RX Side: Received Power Stability Test



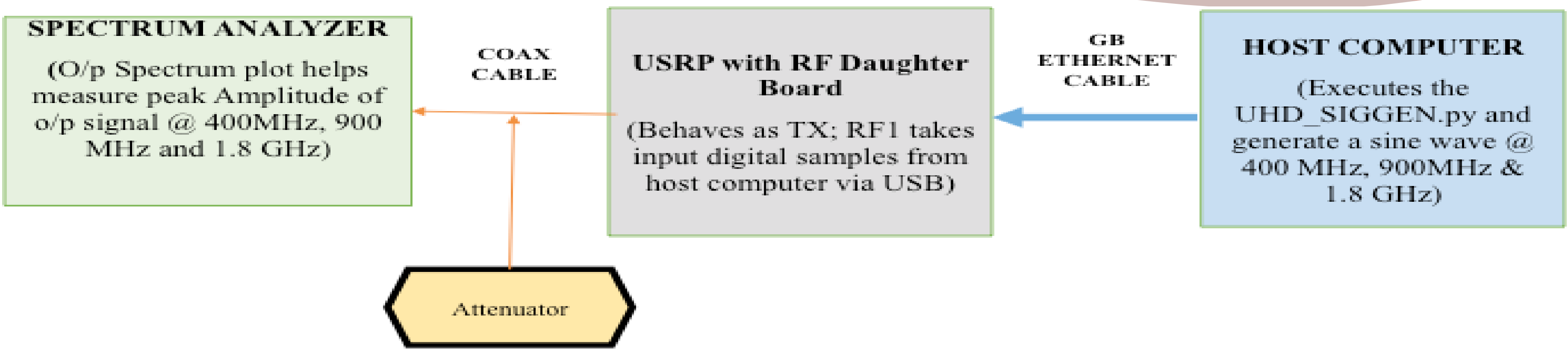
USRP Type	Input Power set (dBm)	Change in Pout on UHD_FFT across frequency in steps of 500 MHz (dB)				
		100 MHz to 500 MHz	500 MHz to 1000 MHz	1000 MHz to 1500 MHz	1500 MHz to 2000 MHz	2000 MHz to 2500 MHz
USRPN210 + WBX	-60	2.81	4.78	3.65	2.42	N/A
	-30	2.91	4.64	3.79	2.29	N/A
	-10	3.02	5.01	3.43	2.49	N/A
USRPN210 + SBX	-60	N/A	1.85	-3.43	2.00	1.40
	-30	N/A	1.79	3.15	2.90	4.58
	-10	N/A	1.69	-3.15	2.07	5.83

TX Side: Frequency Stability Test



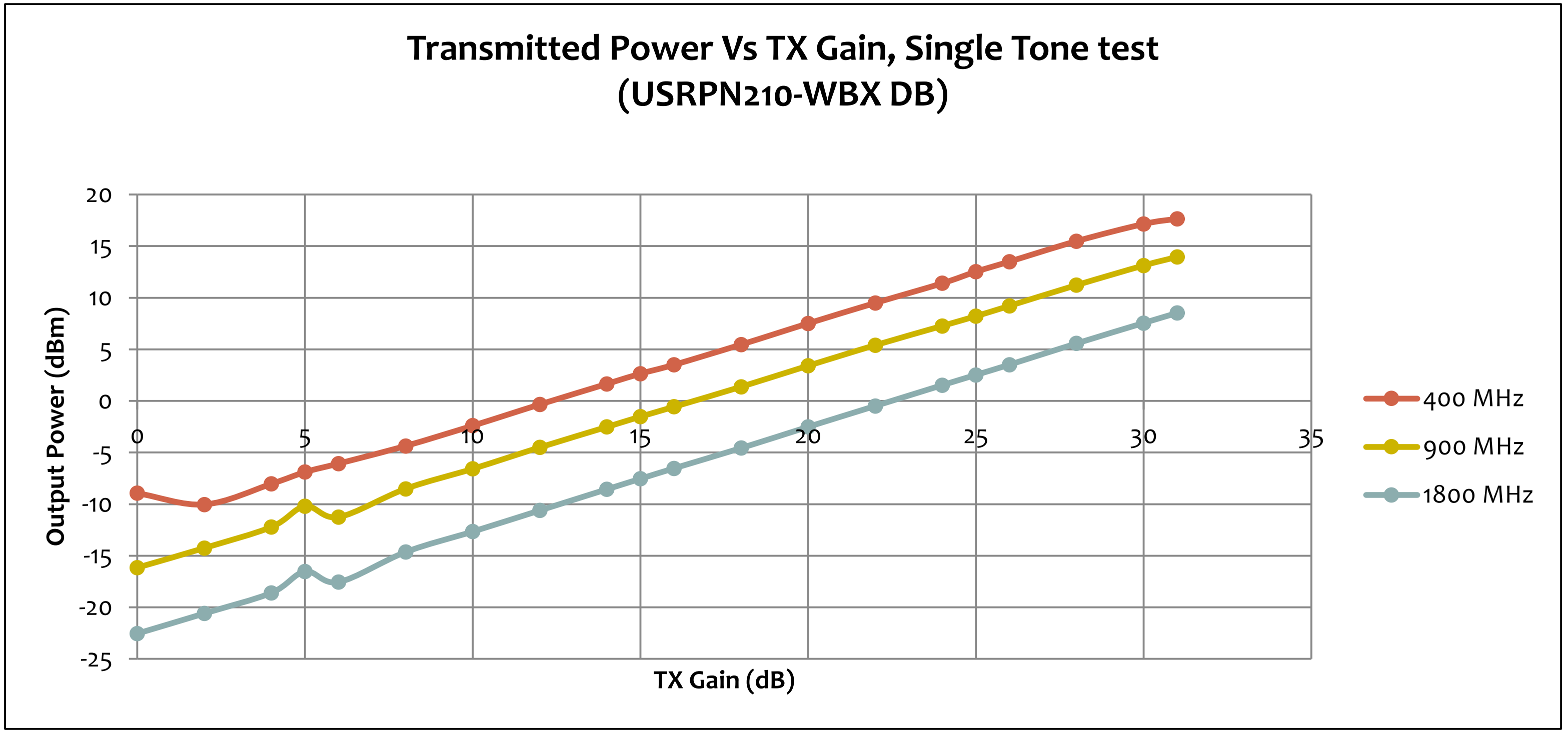
USRP Type	Average Frequency Deviation from the Expected Frequency i.e. Actual measured TX frequency – Expected TX frequency on spectrum analyzer (over a period of 1 hour) (MHz)			Average Frequency Deviation in ppm i.e. Average Freq. Dev. / Expected Frequency *10^6 (ppm)		
	400 MHz	900 MHz	1800 MHz	400 MHz	900 MHz	1800 MHz
USRPN210 + WBX board	-1.27E-04	1.81E-03	-4.83E-04	-0.32	-0.09	-0.27
USRPN210 + SBX board	2.12E-03	6.91E-04	-1.36E-03	5.31	0.77	-0.76
USRP2 + WBX Board	3.22E-03	8.53E-03	1.70E-02	8.05	9.47	0.01

TX Side: Variation with TX Gain Test

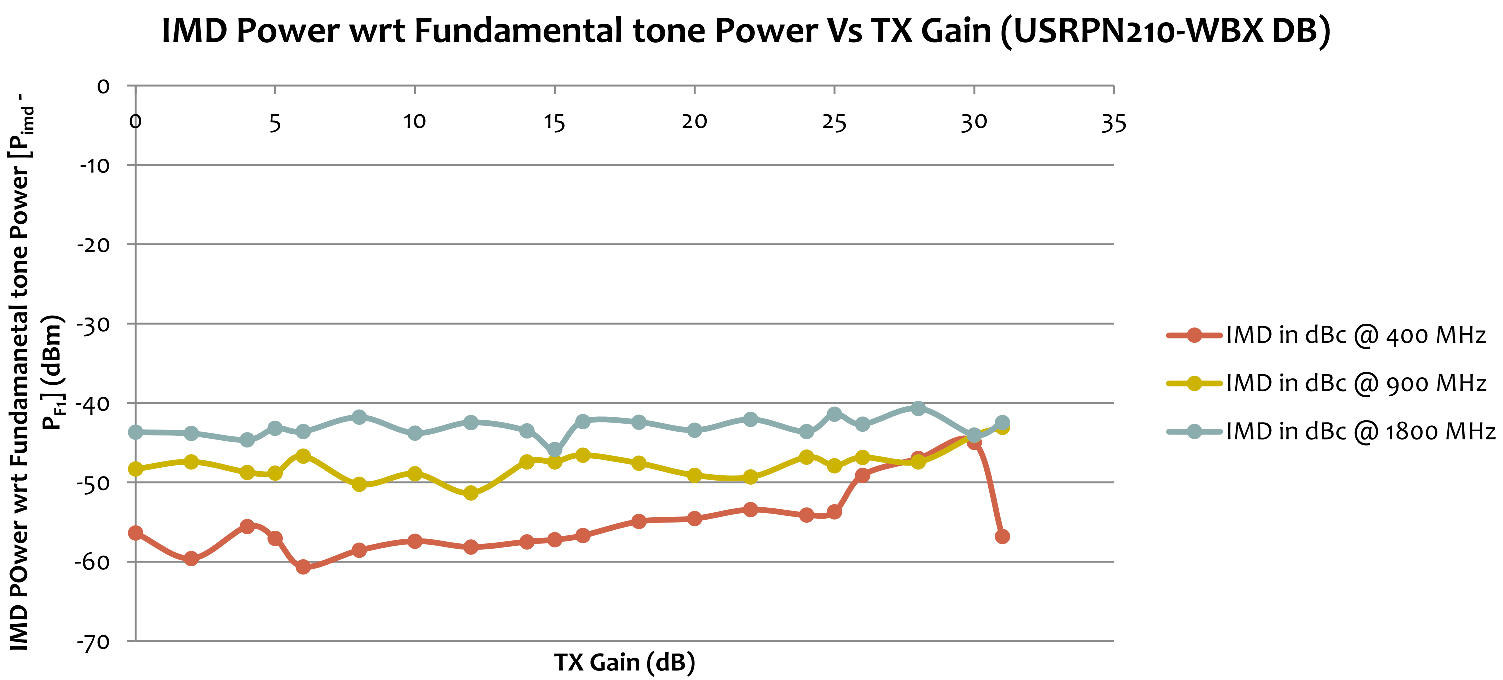


USRP #	Gain Value denoting the start of Compression Region for the Single Tone transmitted signal (Ampl =0.707) (dBm)			Gain Value denoting the start of IMD products near -30 dBc for the Two Tone transmitted signal (Ampl = 0.354) (dBm)		
	400 MHz	900 MHz	1800 MHz	400 MHz	900 MHz	1800 MHz
USRPN210 + WBX board	30	30	31	31	31	31
USRPN210 + SBX board	25	25	25	25	28	31
USRP2 + WBX board	4-25	5-25	5-25	2-10	8-10	5-10

TX Side: O/p Power Vs TX Gain Test Results



TX Side: O/p Power Vs TX Gain Results - 3



Power Reference table: Transmitted Power variation with TX Gain

Ampl Variation	0 to 1					Test	Single Tone Transmitter Power Vs Gain		
Frequency	400 MHz			900 MHz			1800 MHz		
TX GAIN	DUT :USRPN210 +SBX Spectrum Analyser Readings (dBm)	DUT :USRPN210 +WBX Spectrum Analyser Readings (dBm)	DUT :USRP2 +WBX Spectrum Analyser Readings (dBm)	DUT :USRPN210 +SBX Spectrum Ananlyser Readings (dBm)	DUT :USRPN210 +WBX Spectrum Ananlyser Readings (dBm)	DUT :USRP2 +WBX Spectrum Analyser Readings (dBm)	DUT :USRPN210 +SBX Spectrum Ananlyser Readings (dBm)	DUT :USRPN210 +WBX Spectrum Ananlyser Readings (dBm)	DUT :USRP2 +WBX Spectrum Analyser Readings (dBm)
AMPL : 1									
0	4.9	-9.16	-13.3	3.2	-13.2	-16.43	-3.13	-20.02	-12.2
5	8.8	-4.28	-11.52	8.15	-8.25	-16.43	1.9	-15.14	-12.2
10	13.5	0.4	-2.12	12.83	-3.54	-8.05	6.9	-10.2	-11.95
15	18.29	5.5	6.35	17.74	1.53	0.95	11.76	-6.02	-3.47
20	20.73	10.34	14.3	22.03	6.49	9.71	16.69	0	4.09
25	20.1	14.83	15.09	22.15	11.21	13.94	20.71	5.14	10.72
30	19.91	17.17	15.27	21.61	14.92	14.13	21.06	10.05	10.72
31	20.27	17.29	15.96	21.58	15.28	13.98	20.91	10.091	10.73
AMPL : 0.707									
0	1.8	-11.94	-16.5	0.64	-16.15	-13.87	-5.87	-22.54	-15.09
5	6.4	-6.89	-14.89	5.59	-11.25	-13.87	-0.88	-17.55	-15.09
10	11.15	-2.4	-5.3	10.21	-6.58	-5.43	4.12	-12.66	-15.09
15	16.09	2.64	3.14	15.17	-1.52	3.52	9	-7.54	-11.88
20	20.45	7.51	11.19	20.22	3.41	11.52	13.9	-2.51	-4.29
25	20.96	12.52	15.97	22.52	8.21	13.57	18.82	2.52	3.35
30	20.27	17.14	15.97	21.87	13.12	13.87	21.28	7.55	8
31	20.39	17.65	15.97	21.69	13.95	13.87	21.43	8.52	7.99
AMPL : 0.5									
0	-1.4	-15.14	-19.6	-2.56	-19.2	-10.87	-9.07	-26.14	-17.28
5	3.03	-10.26	-17.29	2.22	-14.25	-10.87	-4.25	-21.11	-17.1
10	7.97	-5.58	-7.65	7.03	-9.55	-2.43	0.94	-16.19	-11.13
15	12.88	-0.55	0.94	11.96	-4.46	6.52	5.79	-11.01	-3.56
20	17.34	4.41	10.91	17.11	0.5	14.52	10.79	-6.97	3.92
25	21.84	9.28	16.83	21.81	5.36	16.57	15.49	-0.91	5.22
30	20.97	14.07	16.33	21.35	10.38	16.87	20.95	4.3	5.22
31	20.4	14.97	16.09	20.98	11.32	16.87	20.48	5.3	5.22
AMPL : 0.354									
0	-4.4	-18.12	-22.7	-6.33	-22.2	-7.9	-11.87	-29.12	-30.24
5	0.54	-13.23	-20.4	-0.39	-17.24	-7.89	-6.88	-24.1	-30.04
10	5.19	-8.55	-10.75	4.24	-12.55	0.54	-1.86	-19.06	-11.17
15	10	-3.51	-2.18	9.13	-7.46	9.56	3.04	-13.99	-3.64
20	15.13	1.39	7.92	14.26	-2.5	17.48	8.05	-8.94	2.14
25	19.84	6.35	13.78	18.97	2.39	17.12	13	-3.89	2.3
30	21.1	11.41	13.23	22.35	7.46	13.39	17.19	1.23	2.3
31	21.03	12.23	12.99	22.43	8.45	13.13	18.06	2.36	2.4
AMPL : 0									
0	-45.46	-61.54	-37.25	-43.93	-60.15	-35.46	-47.93	-63.15	-39.19
5	-40.93	-46.51	-24.5	-38.98	-45.25	-22.15	-43.06	-48.22	-26.25
10	-36.24	-41.81	-24.15	-34.97	-40.55	-22.99	-38.05	-43.25	-26.11
15	-31.46	-36.81	-24.05	-29.52	-35.48	-22.4	-33.33	-38.08	-26.06
20	-26.48	-31.92	-24.19	-24.47	-30.51	-25.18	-28.43	-33.03	-26.02
25	-21.46	-27.05	-23.56	-19.72	-25.65	-21.34	-23.47	-28.01	-26.1
30	-16.61	-21.89	-23.93	-14.68	-20.53	-21.76	-19.24	-22.82	-25.95
31	-15.53	-20.93	-22.67	-13.71	-19.52	-20.55	-18.34	-21.8	-25.07

Path loss modeling at CORNET

* Use received power with and without calibration factors - helps check if exponent adhered to any particular model
* Log normal distribution helped get value close to expected results [5][6]
* Helps understand characteristics of the environment

Path loss modeling Results

Txd Node	Rx node	Power Transmitted (dBm)	Power Received on UHD_FTT (dB)	RX Gain (dB)	Power Received-Correction Factor-Gain (dBm)	Calculated PL (dB)	20log10(f) (dB)	10nlog(d) (dB)	K value for the ITU Model (dB)	Theoretical PL (dB)	Path Loss exponent using ITU Model	Path Loss exponent using log-Distance Model
Floor1	Floor 1											
7001	7002	15.5	-7.79	15	-54.99	70.49	53.06	45.25	-28.00	70.31	5.37	5.37
	7004	15.5	-35.16	15	-82.36	97.86	53.26	72.06	-28.00	97.31	5.75	5.80
	7005	15.5	-28.00	15	-75.20	90.70	53.26	65.02	-28.00	90.27	4.80	4.83
	7006	15.5	-37.72	15	-84.92	100.42	53.26	75.02	-28.00	100.28	5.10	5.11
	7007	15.5	-30.56	15	-77.76	93.26	53.26	67.58	-28.00	92.83	4.25	4.28
	7011	15.5	-45.51	15	-92.71	108.21	53.26	82.78	-28.00	108.03	4.60	4.61
		Average n (same floor)									4.98	5.00
Floor1	Floor 2											
7001	7013	15.5	-18.74	15	-65.94	81.44	53.26	55.61	-28.00	80.87	6.60	6.67
	7014	15.5	-28.84	15	-76.04	91.54	53.26	65.55	-28.00	90.80	6.60	6.68
	7024	15.5	-65.59	15	-112.79	128.29	53.26	102.38	-28.00	127.64	5.55	5.59
		Average n (1 floor above)									6.25	6.31
Floor1	Floor 3											
7001	7035	15.5	-73.05	15	-120.25	135.75	53.26	110.25	-28.00	135.50	6.10	6.12
	7036	15.5	-66.74	15	-113.94	129.44	53.26	103.46	-28.00	128.71	5.60	5.64
		Average n (2 floors above)									5.85	5.88

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Position Location Estimation

- Important and recently generated lot of interest
- Helped analyze effect of calibration factors in our case
- Algorithms Considered:
  - Simple RSS based [7]
  - CDRSS based [8]
- Flow graphs Used:
  - UHD_FFT.py (predefined; calibration factors : -35.5 @400 MHz)
  - power_measure_QT sink (custom developed; calibration factors : -62.8 @400 MHz)

Results of position location

* Simple RSS and UHD_FFT

	Root Mean Square Error	
Number of nodes/ Power	Calibrated Received Power (dBm)	Un-Calibrated Received Power (dB)
3 Receiver Nodes	0.55	0.53
5 Receiver Nodes	0.26	0.27

Results of position location - 2

* Simple RSS and QT sink

Using power_measure_QT_Sink.grc and n = 3.5	Simple RSS Based Algorithm		CDRSS Based Algorithm	
Number of Nodes	RMSE (m)		RMSE (m)	
	Calibrated	Un-Calibrated	Calibrated	Un-Calibrated
3.00	0.26	0.46	0.68	0.68
3.00	0.56	0.62	0.39	0.39
3.00	0.72	0.78	0.51	0.51
3.00	0.70	0.70	1.50	1.50
3.00	1.06	1.12	1.02	1.02
Average	0.66	0.73	0.82	0.82
Standard Deviation	0.29	0.25	0.45	0.45
95 % Confidence Interval	0.26	0.22	0.51	0.51

Using power_measure_QT_Sink.grc and n=3.5	Simple RSS Based Algorithm		CDRSS Based Algorithm	
Number of Nodes	RMSE (m)		RMSE (m)	
	Calibrated	Un-Calibrated	Calibrated	Un-Calibrated
5.00	0.54	0.57	0.23	0.23
5.00	0.19	0.22	0.48	0.48
5.00	0.52	0.57	0.68	0.68
Average	0.42	0.45	0.46	0.46
Standard Deviation	0.20	0.20	0.23	0.23
95 % Confidence Interval	0.17	0.18	0.26	0.26

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Summary & Future work

* Characterization - helped understand the performance capabilities of USRP devices and importance of Calibration
* Path loss modeling in CORNET useful for research purposes
* Position location further extendable to CORNET
* QT_Sink flow graph methodology - good substitute to find power measure
* Possibility of automation using programmable signal generators

Bibliography

1. Software Defined Radio: Architectures, Systems and Functions (Markus Dillinger, Kambiz Madani, Nancy Alonistioti) Page xxxiii (Wiley & Sons, 2003, ISBN 0-470-85164-3)
2. https://github.com/EttusResearch/uhd
3. http://code.ettus.com/redmine/ettus/projects/uhd/wiki/GNU_Radio_UHD
4. http://en.wikipedia.org/wiki/Calibration
5. T. R. Sontakke B. R. Jadhavar, "2.4 GHz Propagation Prediction Models for Indoor Wireless Communications Within Building," *International Journal of Soft Computing and Engineering (IJSCE)*, vol. 2, no. 3, July 2012.
6. John S. Seybold, *Introduction to RF Propagation*. Hoboken, NJ, USA: John Wiley & Sons Inc., 2005.
7. Ayad M. H. Khalel, "Position Location Techniques in Wireless Communication Systems," Department of Electrical Engineering, Blekinge Institute of Technology, Karlskrona, SWEDEN, M.S Thesis 2010.
8. Islam Alyafawi, Desislava Dimitrova, and Torsten Ingo Braun, "SDR-based Passive Indoor Localization System for GSM," in *SIGCOMM Software Radio Implementation Forum (SRIF)*, Chicago IL, 2014.

Questions

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