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Collection Methods for Wi-Fi and Bluetooth I/Q Recordings in the 2.4 GHz and 5 GHz Bands with Low-Cost Software Defined Radios

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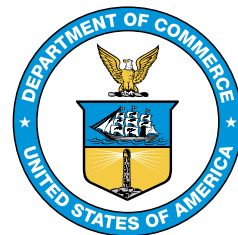
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Abstract

This report documents collection methods for radio frequency in-phase/quadrature (I/Q) recordings of Wi-Fi and Bluetooth emissions in the 2.4 GHz and 5 GHz unlicensed bands using low-cost software defined radios. The aim of this effort was to acquire datasets that could be used to aid the development of computational models for emissions from real-world communication hardware. The complete datasets are publicly available at https://doi.org/10.18434/mds2-2731.

Keywords

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Acronyms

ADC	analog-to-digital converter	**MCS**	modulation and coding scheme
AP	access point	**NTP**	network time protocol
API	application programming interface	**PSD**	power spectral density
CSV	comma-separated values	**RF**	radio frequency
COTS	commercial off-the-shelf	**SDR**	software-defined radio
DLC	Discovery and Learning Center	**UDP**	user datagram protocol
FFT	fast Fourier transform	**USB**	universal serial bus
HDF5	Hierarchical Data Format 5	**USRP**	universal software radio peripheral
I/Q	in-phase and quadrature	**VSA**	vector signal analyzer
LO	local oscillator	**VST**	vector signal transceiver

Acknowledgments

Author Contributions

Stefan Tschimben: Investigation, Software, Data Curation, Writing - Original Draft;
Siddhartha Subray: Investigation, Software, Data Curation, Writing - Original Draft;
Aric Sanders: Conceptualization, Data Curation, Visualization, Writing - Original Draft;
Adam Wunderlich: Conceptualization, Supervision, Writing - Review & Editing.

1. Introduction

The development and assessment of spectrum sharing technologies requires high-quality datasets of radio frequency (RF) emissions from commercial off-the-shelf (COTS) wireless communication systems for modeling and testing. In particular, data-driven computational models that capture realistic aspects of RF emissions require relatively large datasets for model fitting.

Although calibrated, measurement-grade equipment such as a spectrum analyzer can be used to collect high-quality RF data, the expense of such equipment can be prohibitive in many cases. For this reason, there is a need to employ low-cost alternatives to facilitate data collection. One inexpensive, flexible option for the acquisition of RF in-phase and quadrature (I/Q) data are software-defined radios (SDRs) [1]. Despite their lack of calibration, the low cost and easy configuration of SDRs makes them attractive for RF data collection.

In this technical note, we document SDR data collection methods for two over-the-air experimental configurations:

1. Simultaneous indoor/outdoor captures of Wi-Fi (802.11 protocol [2]) signals in the unlicensed 2.4 GHz and 5 GHz bands.

2. Co-channel Bluetooth [3] and Wi-Fi emissions in the 2.4 GHz band.

The first configuration aims to provide data to model differences in received signals due to indoor and outdoor RF propagation paths. The second configuration yields a dataset consisting of RF emissions from two different types of commonly used COTS communication systems, which can be used to develop computational models for multiple coincident emission types. Further details are given in the following sections.

2. Datasets

The published data resulting from this measurement effort is publicly available at https://doi.org/10.18434/mds2-2731. All I/Q captures were 1 s in duration, collected every 60 s, with a sampling rate of 30 mega samples per second (MS/s), i.e., a bandwidth of 30 MHz, with a center frequency of 2437 MHz for the 2.4 GHz band captures and 5825 MHz for the 5 GHz band captures.

In total, the data consist of 900 one second captures, organized into five files in the Hierarchical Data Format 5 (HDF5) format, where each HDF5 file has a size of 20.1 GB and consists of 180 one second captures. In addition, there is a metadata file in comma-separated values (CSV) format associated with each data file that contains relevant parameters such as center frequency, bandwidth, sampling rate, bit depth, receive gain, and antenna and hardware information.

The data is split up into the following 5 archives, where the first four files resulted from configuration #1 and the last file resulted from configuration #2.

1. 2_4GHz_indoor.h5

2. 2_4GHz_outdoor.h5

3. 5GHz_indoor.h5

4. 5GHz_outdoor.h5

5. 2_4GHz_bluetooth.h5

Within each archive, each I/Q capture is stored as interleaved 16-bit signed integers. The individual captures are stored with timestamps as their recording keys. The data can be loaded with the following Python code (version 3.7 or greater):

```python
import h5py
import numpy as np

with h5py.File("path_to_hdf5", "r") as hf:
    # to see a list of all keys
    keys = hf.keys()
    print(keys)
    # example of loading a single recording
    dset = hf.get(keys[0])
    data = np.array(dset)

# convert the 16-bit interleaved I/Q data to a complex-valued array
data = data / 32768 # normalize data to range between -1 and 1
# rearrange the data to complex numbers
dataset = data[0::2] + 1j*data[1::2]
```

Fig. 1. Data collection location inside building on campus of University of Colorado - Boulder.

3. Data Collection Methods

3.1. Location

Over the air data collection was conducted on the B1 level of the Discovery and Learning Center (DLC) building on the main campus of the University of Colorado - Boulder [4]. Because the data collections were conducted in a busy university building and not a controlled laboratory environment, RF conditions were uncontrolled and included emissions from other nearby emitters.

The location of the data collection inside the DLC is indicated in Fig. 1. The geodetic coordinates of the measurement location are $(\text{Latitude, Longitude}) = (40.007704°, -105.261644°)$.

3.2. Configuration #1: Simultaneous Indoor/Outdoor Wi-Fi

The data collection setup for Configuration #1 is depicted in Fig. 2. Two laptops, denoted #2 and #3 on Fig. 2, served as an iPerf [5] client and as an iPerf server, respectively. To record Wi-Fi signals, one SDR, denoted #4, was placed indoors equidistant between client and server and another SDR, denoted #5, was placed outdoors. For additional pictures of the location and positioning of transmitter, receiver, and SDR, see Appendix A. The specific hardware and software used for the simultaneous indoor/outdoor Wi-Fi data collection are listed in Table 1 and Table 2, respectively.[1]

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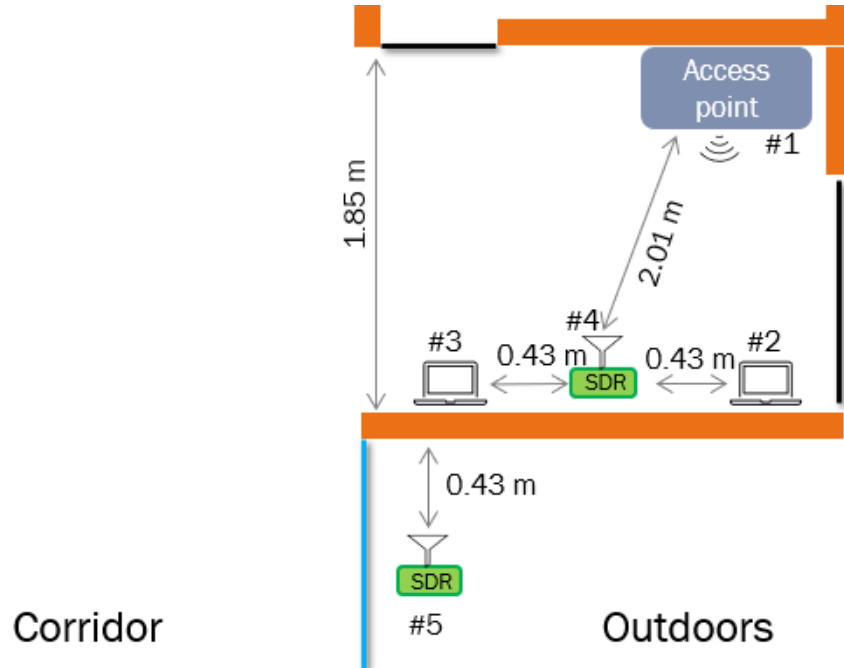
Fig. 2. Data Collection Setup for Configuration #1.

Table 1. Hardware used for Data Collection in Configuration #1.

#	Name	Description
1	Extreme Networks access point (AP) 650 [6]	Access Point
2	Dell Latitude 7480 [7]	iPerf client
2	Intel Wireless 8265 (rev 78) [8]	client Wi-Fi chipset
3	Dell Latitude E7450 [9]	iPerf server
3	Intel Wireless 7265 (rev 59) [10]	server Wi-Fi chipset
4	universal software radio peripheral (USRP) B205mini-i [11]	Software Defined Radio
4+5	Raspberry Pi 4 8 GB [12]	Single board host computer connected to the SDR
4+5	SDSQUAR-400G-GN6MA [13]	SanDisk 400 GB SD card
4+5	VERT2450 [14]	3 dBi omni-directional antenna
5	USRP B200mini-i [11]	Software Defined Radio

Table 2. Software used for the Data Collection in Configurations #1 and #2.

#	Name	Description
1	iPerf [5]	Network test software
2	UHD Python application programming interface (API) [15]	Exposes UHD API to Python
3	WiFiman application [16]	Wi-Fi channel characterization

For the 2.4 GHz Wi-Fi recordings, the Wi-Fi AP was set to Channel 6 centered at 2437 MHz; see Table 3 for a list of Wi-Fi channels overlapping with Channel 6 [2, Sec. 19.3.15]. For the 5 GHz Wi-Fi recordings, the AP was set to Channel 165 centered at 5825 MHz; see Table 4 for overlapping channels [2, Sec. 19.3.15].[2]. These channels were chosen since they were relatively unused by nearby APs, as verified using Ubiquiti's WiFiman Android application, version: 1.12.8 [16]; see Fig. 3.

Table 3. 2.4 GHz Wi-Fi Channels overlapping with Channel 6.

Channel	Center Frequency (MHz)	Frequency Range (MHz)
2	2417	2406-2428
3	2422	2411-2433
4	2427	2416-2438
5	2432	2421-2443
6	2437	2426-2448
7	2442	2431-2453
8	2447	2436-2458
9	2452	2441-2463
10	2457	2446-2468

Table 4. 5 GHz Wi-Fi Channels overlapping with Channel 165.

Channel	Center Frequency (MHz)	Frequency Range (MHz)	20 MHz	40 MHz	80 MHz	160 MHz
161	5805	5795-5815	20			
163	5815	5735-5895				160
165	5825	5815-5835	20			
167	5835	5815-5855		40		
169	5845	5835-5855	20			
171	5855	5815-5895			80	

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[2]The FCC rule allowing the use of the bands upwards of 5825 MHz, which would then allow the formation of up to 160 MHz bandwidth channels, is recent (November 2020) and has not been widely adopted yet [17]. As a result, channel 165 is generally free of energy.
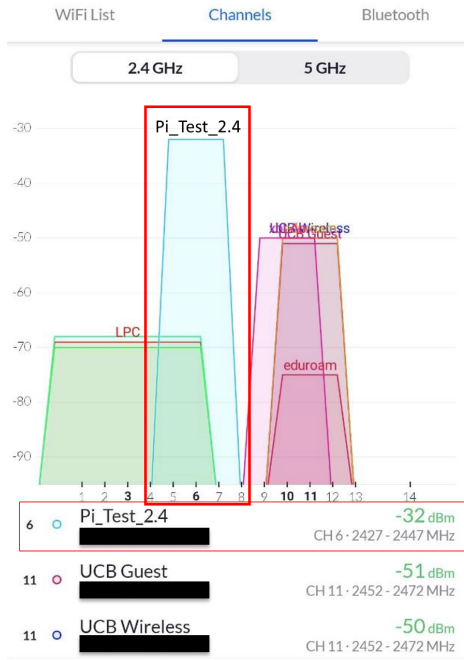
(a) Wi-Fi 2.4 GHz, indoor channel
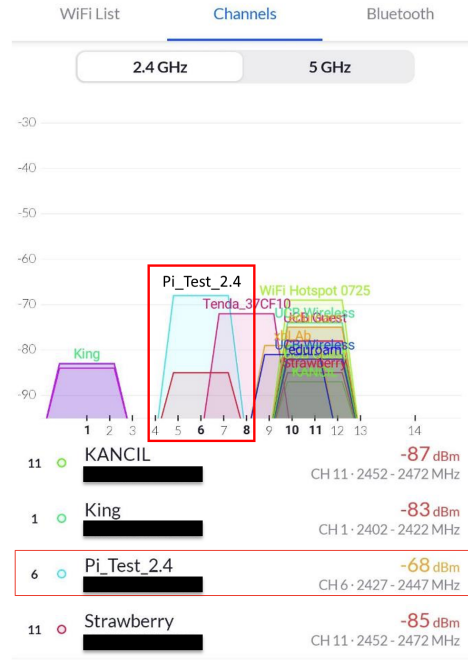
(b) Wi-Fi 2.4 GHz, outdoor channel
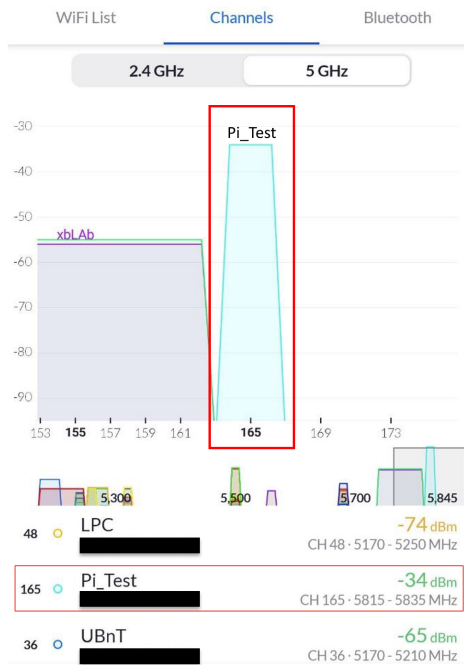
(c) Wi-Fi 5 GHz, indoor channel
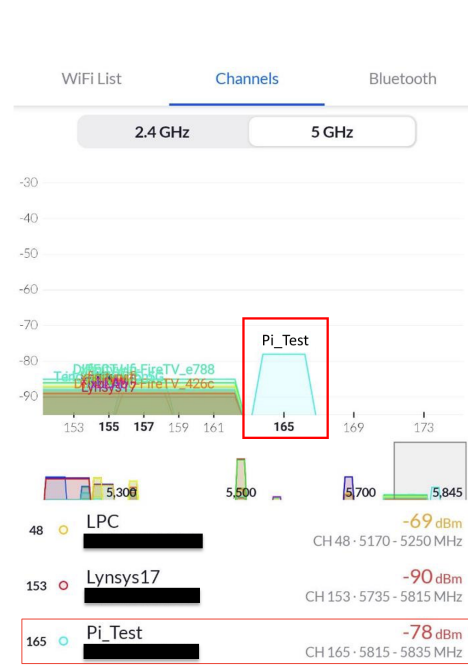
(d) Wi-Fi 5 GHz, outdoor channel

Fig. 3. Adjacent Wi-Fi channel occupancy for Configuration #1 data collections, as reported by the WiFiman Android application [16]. The service set identifier (SSID) for the AP in the 2.4 GHz and 5 GHz bands was set to 'Pi_Test_2.4' and 'Pi_Test', respectively. The vertical axis indicates estimated signal strength, in dBm.

3.3. Configuration #2: Co-channel Wi-Fi & Bluetooth

The data collection setup for Configuration #2 is depicted in Fig. 4. Two laptops, denoted #2 and #3 on Fig. 4, again served as an iPerf client and as an iPerf server, respectively. A single SDR, denoted #5, was placed outdoors next to a window with Bluetooth headphones and a smartphone co-located at #4 behind the window. For additional pictures of the location and positioning of transmitter, receiver, and SDR, see Appendix A. The specific hardware and software used for the co-channel Wi-Fi & Bluetooth data collection are listed in Table 5 and Table 2, respectively.

As in Configuration #1, the Wi-Fi AP was set to channel 6, which spans 2426 MHz to 2448 MHz. A list of Bluetooth channels that overlap with this band is given in Table 6.
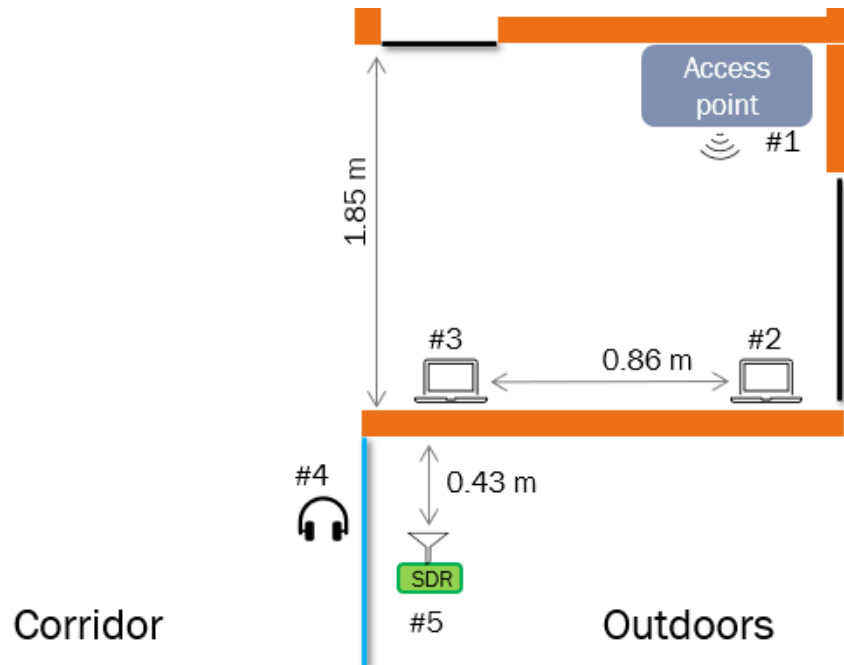
Fig. 4. Data Collection Setup for Configuration #2.

Table 5. Hardware used in Data Collection for Configuration #2.

#	Name	Description
1	Extreme Networks AP [6]	Access Point
2	Dell Latitude 7480 [7]	iPerf client
2	Intel Wireless 8265 (rev 78) [8]	client Wi-Fi chipset
3	Dell Latitude E7450 [9]	iPerf server
3	Intel Wireless 7265 (rev 59) [10]	server Wi-Fi chipset
4	JLAB GO Air POP [18]	Bluetooth headphones
4	OnePlus 5 [19]	Smartphone
5	USRP B200mini-i [11]	Software Defined Radio
5	Raspberry Pi 4 8 GB [12]	Single board host computer connected to the SDR
5	SDSQUA4-400G-AN6MA [13]	SanDisk 400 GB SD card
5	VERT2450 [14]	3 dBi omni-directional antenna

Table 6. Bluetooth Channels overlapping with Wi-Fi Channel 6.

Channel	Center Frequency (MHz)	Type
9	2422	Data
10	2424	Data
38	2426	Advertising
11	2428	Data
12	2430	Data
13	2432	Data
14	2434	Data
15	2436	Data
16	2438	Data
17	2440	Data
18	2442	Data
19	2444	Data
20	2446	Data
21	2448	Data
22	2450	Data
23	2452	Data

3.4. Collection Procedure

Each I/Q capture was 1 s in duration, collected every 60 s at a sampling rate of 30 mega samples per second (MS/s), i.e., a bandwidth of 30 MHz, with a center frequency of 2437 MHz for the 2.4 GHz band captures and 5825 MHz for the 5 GHz band captures. Each recording was limited to a 1 s duration to keep file sizes manageable since a 1 s capture of I/Q data at a 30 MS/s sampling rate results in a 120 MB file. A 30 MHz bandwidth was selected to record the entirety of the 20 MHz wide Wi-Fi channel as well as adjacent-band activity. The 60 s interval between captures was motivated by hard disk write speed limitations and inherent variability in write-speed.

Equipment locations were marked with black tape to ensure consistent positioning of all equipment. After all equipment was positioned, the iPerf server and client were started, creating Wi-Fi traffic between the two laptops and the AP. Also, in Configuration #2, Bluetooth data streaming was started from the smartphone to the headphones by streaming music. The requested (target) iPerf data rate was selected to be 50 Mbps for the simultaneous indoor/outdoor Wi-Fi data collections in Configuration #1 and 30 Mbps for the co-channel Wi-Fi & Bluetooth data collection in Configuration #2. The received data rate was verified on the iPerf server's terminal output. A lower iPerf data rate was used in Configuration #2 to better accommodate both Wi-Fi and the approximately 1-3 Mbps data rate transmitted by the co-channel Bluetooth signals. user datagram protocol (UDP) was selected as the transport protocol to avoid transmissions from the iPerf server.

The SDR models used for the data collection have a 12-bit analog-to-digital converter (ADC) resolution [11]. However, all of the I/Q samples from the SDRs were sent over the universal serial bus (USB) interface as complex 16-bit signed integers (16-bits for I and Q components, respectively) [20], corresponding to a maximum possible value of $\pm 2^{15}$.

The gain setting of each SDR was selected to ensure that I/Q samples were unlikely to be clipped by the ADC or distorted by the SDR front-end amplifier, and to ensure that quantization noise of the ADC did not exceed thermal noise. To select the SDR gain, a 1 s capture was acquired for each possible gain setting, which ranged from 0 dB to 76 dB in 1 dB steps. For each gain setting, the maximum value of the I/Q components was determined, along with the number of times that value was recorded; see Figs. 5 and 6 for example plots. In these plots, the interval indicated in by the vertical lines in green corresponds to gain settings where the maximum absolute value of the I/Q components was at least $2^{13} = 8192$ and was unlikely to be clipped, i.e., nearly zero counts at 2^{15}. The gain setting was selected as the mid-point of this interval. After data collection was completed, time-series and spectrogram plots were used to verify that the captured data were not clipped and had a good utilization of the available dynamic range.

A bash script was run during the data capture on the iPerf client to characterize changes, if any, in the Wi-Fi modulation and coding scheme (MCS) index. Once every second, the script would check the Wi-Fi link using `iw dev wlan0 link`, grab the output's MCS information, and store it in a text file. The observed MCS index value was very consistently

at MCS-8 in the 5 GHz band (IEEE 802.11ac, 256 QAM, 3/4 coding)[21] and MCS-15 in the 2.4 GHz band (IEEE 802.11n, 64 QAM, 5/6 coding)[21] and did not fluctuate over the duration of the collection.

With the receiver gain setting determined, and iPerf and bash scripts running on the laptops, a python script was started to capture the I/Q data at the specified center frequencies and sampling rate. The laptops were synchronized to an network time protocol (NTP) server for synchronous indoor and outdoor capture and the python script recorded data for 1 second at the beginning of every minute.
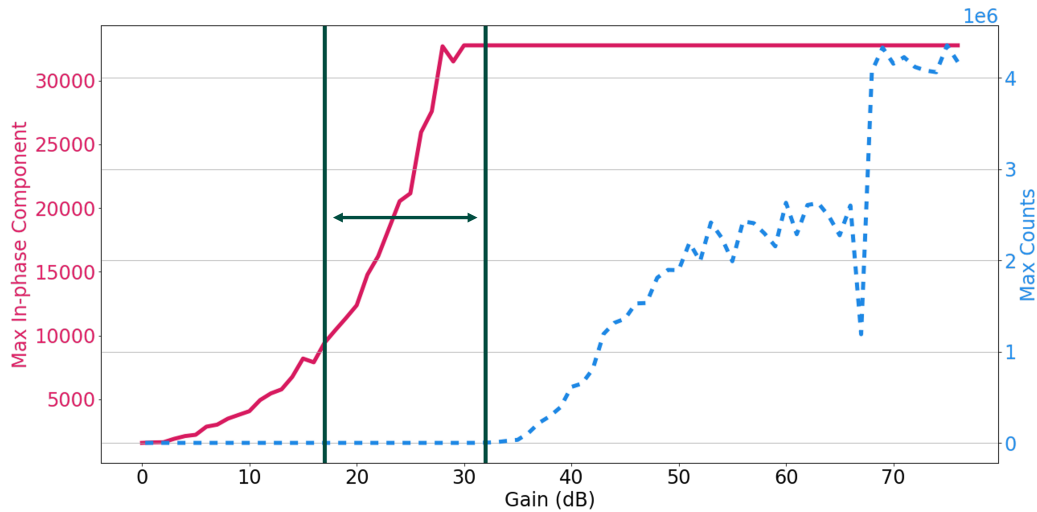
Fig. 5. Example of gain selection, Indoor 2.4 GHz. The gain value was selected as the midpoint of the interval indicated by the vertical lines.
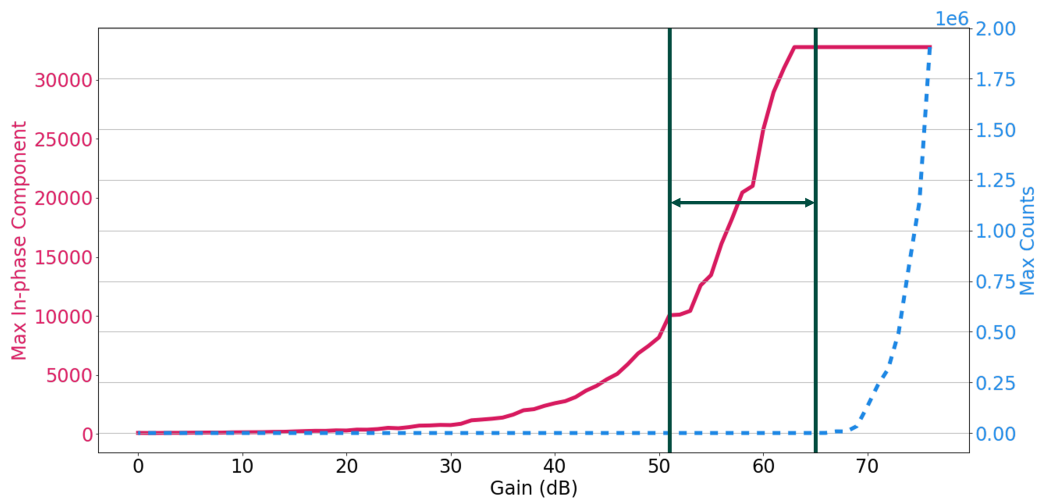
Fig. 6. Example of gain selection, Outdoor 2.4 GHz. The gain value was selected as the midpoint of the interval indicated by the vertical lines.
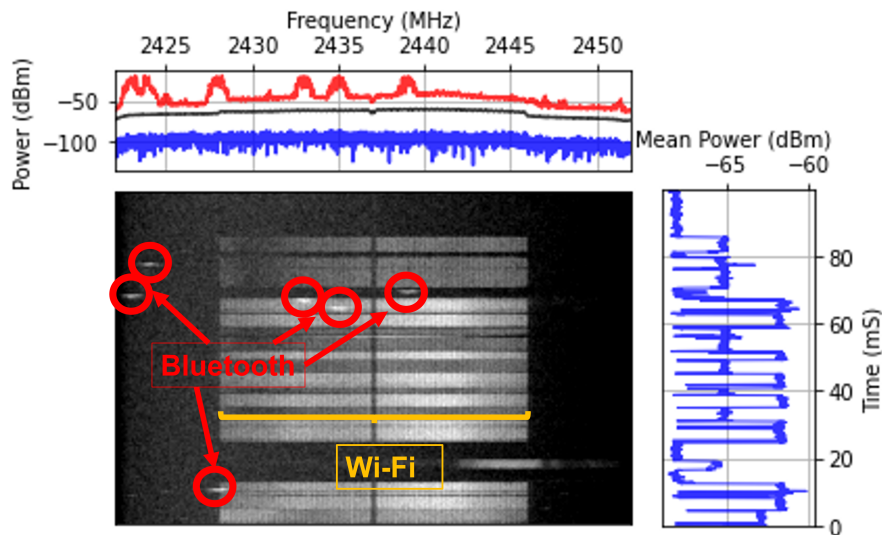
4.   Example Captures

In this section, visualizations of example I/Q data captures from each measurement config-uration are presented. In addition, we discuss notable anomalous captures.

4.1.   Data Visualization

Below, spectrograms, which are visual representations of signal power in time and fre-quency, are utilized to summarize notable signal characteristics. Each spectrogram is cal-culated by computing the magnitude squared of the fast Fourier transform (FFT) of suc-cessive non-overlapping segments from the complex-valued I/Q time series, where each time segment is first multiplied by a Hann window prior to the FFT operation. Each of the spectrograms shown here has a 15 kHz frequency bin size. So given a 30 MHz capture bandwidth, the corresponding FFT window length is 2000 samples.

An anotated example spectrogram for a 100 ms segment from a capture in Configuration #2 is shown in Fig. 7. The spectrogram image is displayed in grayscale, with the grayscale range indicated in the caption. Above the spectrogram, the power spectral density versus frequency is plotted, with the black (middle), red (top) and blue (bottom) lines correspond-ing to the mean, maximum, and minimum values of each frequency bin. To the right of the spectrogram, the mean power versus time is plotted, where the mean is taken over each 2000 sample time window. The annotations indicate Wi-Fi channel 6, as well as Bluetooth emissions.

Fig. 7. Annotated example spectrogram for a 100 ms segment from a capture of co-Channel Wi-Fi and Bluetooth. The spectrogram is displayed with a grayscale range of [-80, -50] dBm.

A dark vertical line is visible at the center frequency of each spectrogram, which corre-

sponds to the local oscillator (LO) frequency of the SDR receiver. Energy from the LO is likely suppressed by internal SDR post-processing of the acquired signal. Furthermore, because the center frequency of each Wi-Fi channel corresponds to the unoccupied DC subcarrier [2, Sec. 17.3.5.10], the energy transmitted by the Wi-Fi transmitter is expected to be low at the channel center frequency.

4.2. Configuration #1: Simultaneous Indoor/Outdoor Wi-Fi - 2.4 and 5 GHz

Visualizations of 100 ms segments for simultaneous captures from Configuration #1 are shown in Fig. 8 and Fig. 9 for the 2.4 GHz band, and Fig. 10 and Fig. 11 for the 5 GHz band. In Fig. 11, which shows an example 5 GHz outdoor capture, in addition to the aforementioned LO artifact at the channel center frequency, four vertical lines, evidently corresponding to the subcarriers used for Wi-Fi pilot signals [2, Sec. 17.3.5.9], are visible in the Wi-Fi channel.
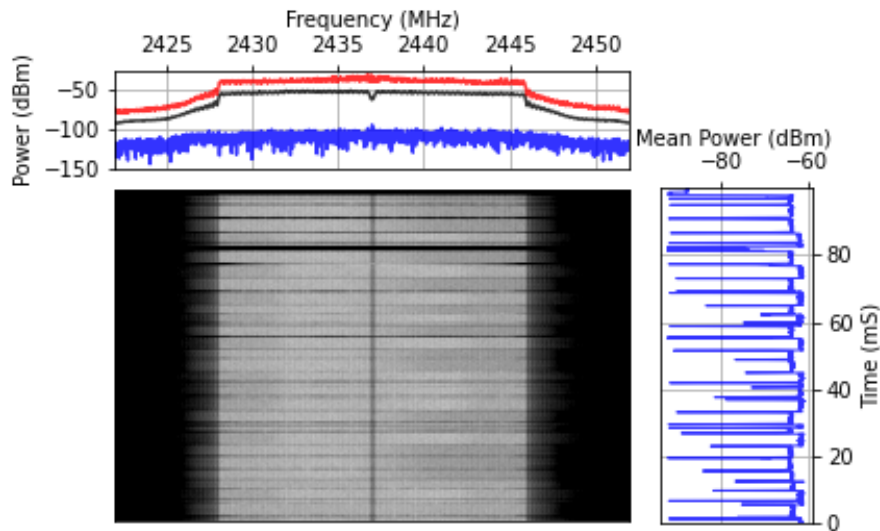
Fig. 8. Example indoor capture at 2.4 GHz in Configuration #1. The spectrogram is displayed with a grayscale range of [-80, -35] dBm.
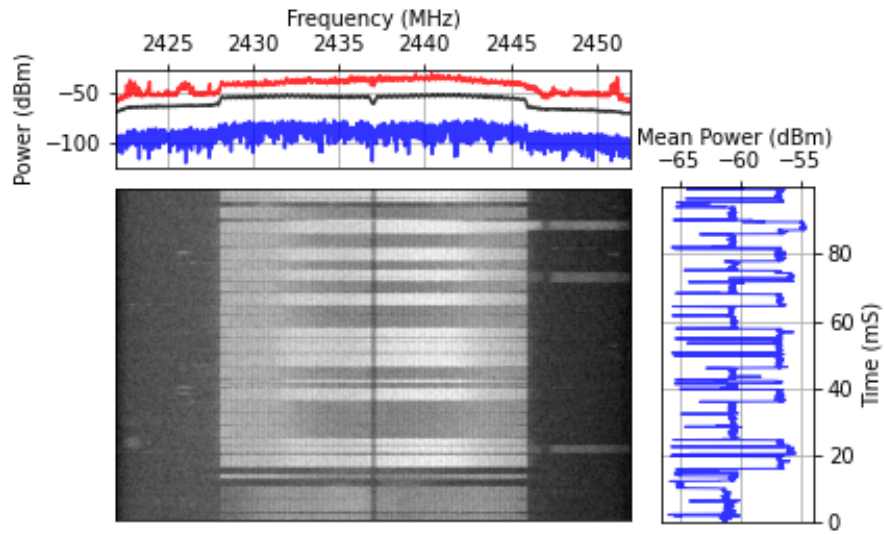
Fig. 9. Example outdoor capture at 2.4 GHz in Configuration #1. The spectrogram is displayed with a grayscale range of [-74, -44] dBm.
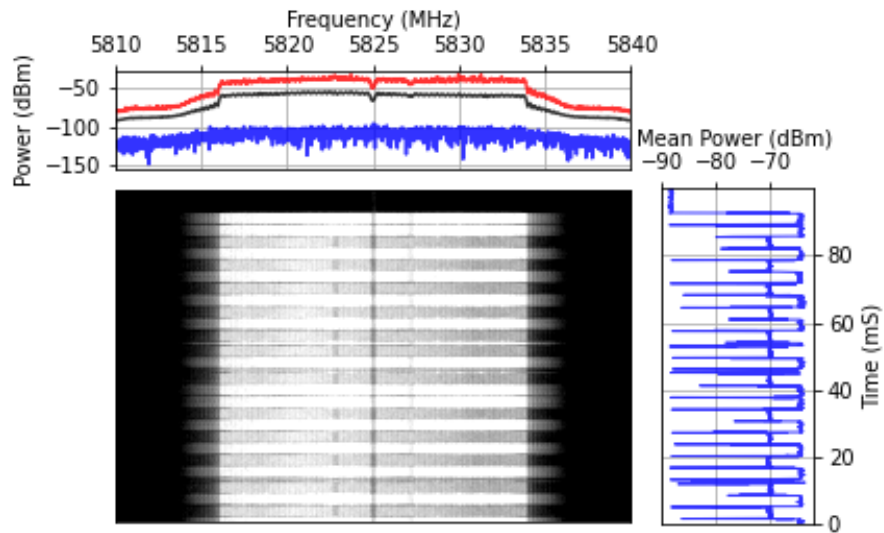
Fig. 10. Example indoor capture at 5 GHz in Configuration #1. The spectrogram is displayed with a grayscale range of [-84, -54] dBm.

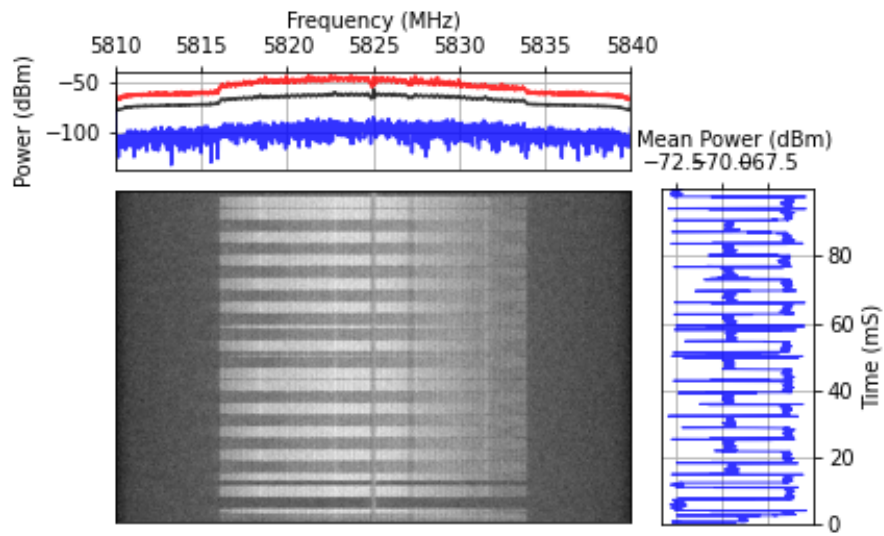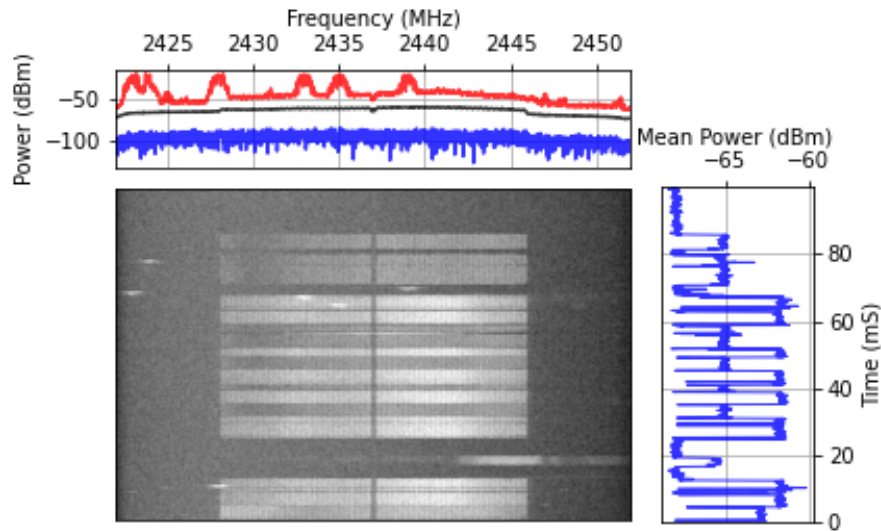**Fig. 11.** Example outdoor capture at 5 GHz in Configuration #1.The spectrogram is displayed with a grayscale range of [-83, -53] dBm.

## 4.3. Configuration #2: Co-Channel Wi-Fi & Bluetooth

An example spectrogram for a 100 ms segment of a capture from Configuration #2 is shown in Fig. 12. An annotated version of this spectrogram was previously shown in Fig. 7.

Fig. 12. Example co-Channel Wi-Fi and Bluetooth capture in Configuration #2. The spectrogram is displayed with a grayscale range of [-80, -50] dBm.

4.4. Anomalous Captures

Spectrograms for all data captures were visually inspected for data quality and anomalous features. In the Configuration #2 data set (Co-Channel Wi-Fi & Bluetooth), three anomalous captures were observed (out of a total of 180 captures). Namely, two consecutive captures with time stamps 19:23:00 and 19:24:00 recorded an unexpected signal. Fig. 13 and Fig. 14 show 1 s spectrograms for these captures. In these spectrograms, a strong narrowband signal is visible on the right side at approximately 2.45 GHz. Since these captures were collected 1 minute apart, the duration of the anomalous signal is approximately 60 seconds. It is likely that the anomalous emission is from a microwave oven that was turned on for 60 seconds, since microwave ovens operate at 2.45 GHz.
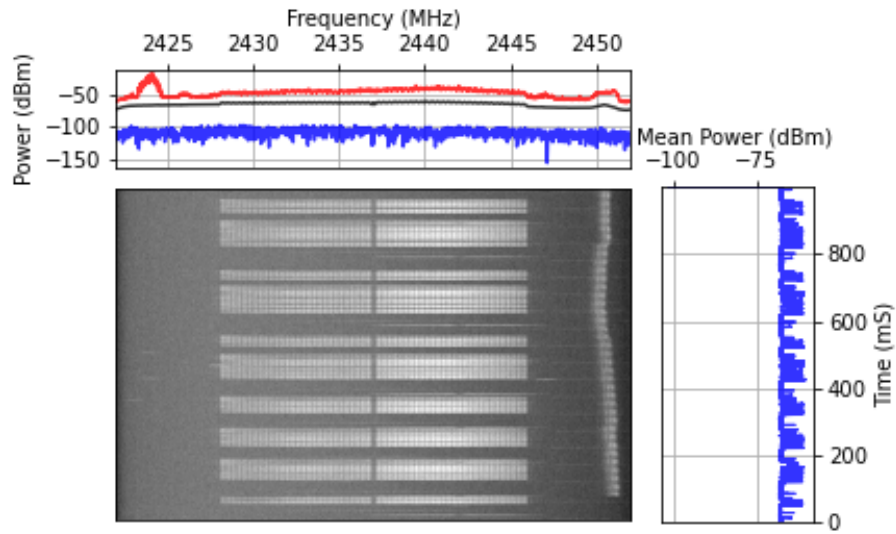
Fig. 13. Anomalous I/Q data recording showing Wi-Fi, Bluetooth, and emissions likely from a microwave oven at 2.45 GHz. The spectrogram is displayed with a grayscale range of [-80, -50] dBm.
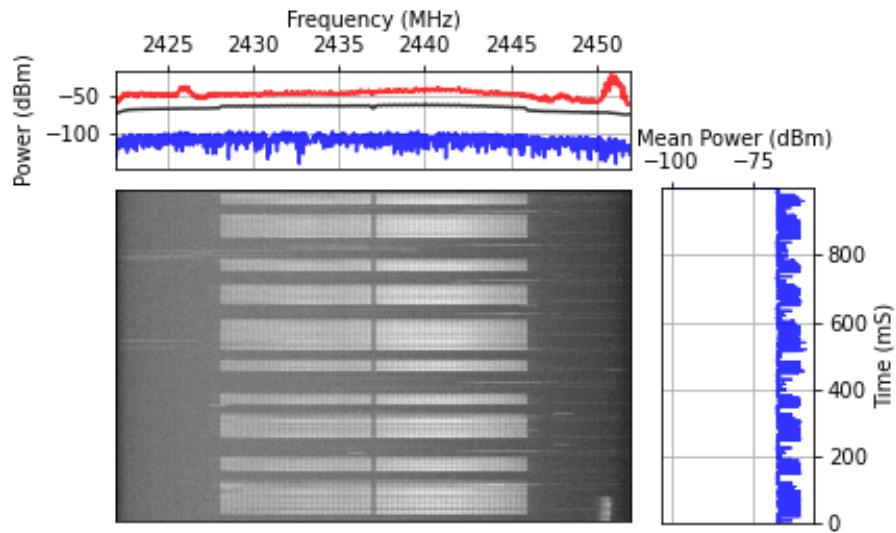
Fig. 14. Anomalous I/Q data recording showing Wi-Fi, Bluetooth, and emissions likely from a microwave oven at 2.45 GHz finishing its cycle. The spectrogram is displayed with a grayscale range of [-80, -50] dBm.

Another anomalous capture was observed in the Configuration #2 dataset at timestamp 19:34:00; Fig. 15 shows a 1 s spectrogram. In this spectrogram, heavy Wi-Fi traffic can be observed in channel 6 due to increased activity from another AP transmitting in the same channel. As a result, the usual gaps between Wi-Fi transmissions are not present because the channel is saturated by the other transmitter.
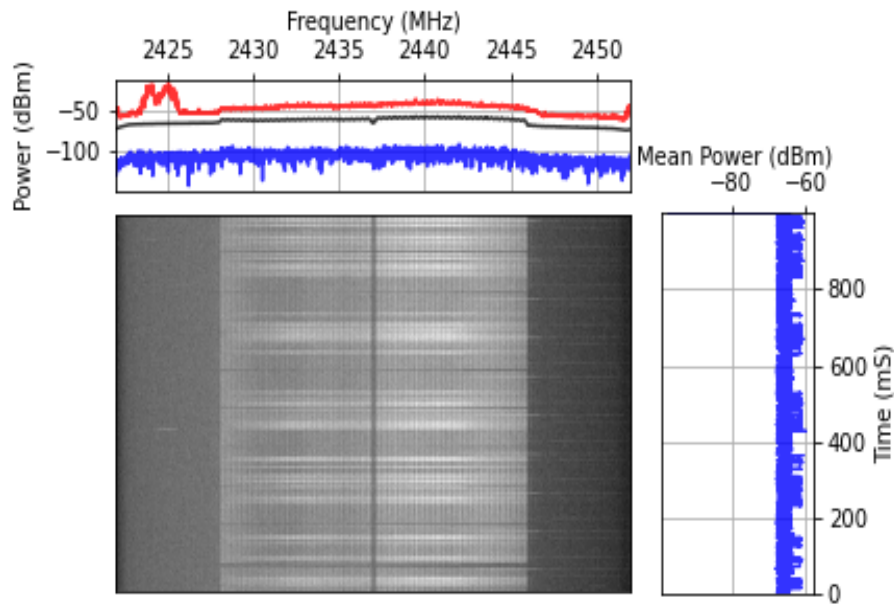
Fig. 15. I/Q data recording showing a saturated 2.4 GHz Wi-Fi channel. The spectrogram is displayed with a grayscale range of [-79, -49] dBm.

5.   Summary

This report presented I/Q data collection methods using SDRs for two configurations: 1) simultaneous indoor/outdoor Wi-Fi (802.11 protocol) in the unlicensed 2.4 and 5 GHz bands and 2) Co-channel Bluetooth and Wi-Fi in the 2.4 GHz band. Section 2 outlined the format in which the data was stored and how to load it for further use with Python. Section 3 described the specific data collection methods for each configuration. Section 4 provided example results for each dataset and also highlighted notable anomalous captures. Two appendices contain additional information pertaining to the data collection. Namely, Appendix A presented pictures of the data collection setup. Appendix B documented measurements to estimate effective gain and noise floor levels that can be used to scale the recorded data to obtain absolute power levels.

The data collection methods documented here can inform similar acquisitions of RF data with low-cost SDRs. In addition, the datasets resulting from our over-the-air collections can be used to develop and fit data-driven models for RF emissions from real-world COTS communication systems.

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Appendix A. Setup Environment Photos

Fig. 16. Data Collection Setup with Outdoor SDR in red Circle.

(a) Outdoor View

(b) Outdoor SDR

(c) iPerf Client, SDR, and iPerf server


(d) Access Point

Fig. 17. Outdoor and indoor setup.

Fig. 18. Indoor, west side of the access point.

Appendix B. Gain and Noise Floor Estimation

A received signal undergoes filtering and amplification in the SDR before entering the ADC stage. The actual gain level is determined by the (uncalibrated) gain setting of the SDR.[3] To determine the actual power gain at a given frequency and SDR gain setting, we applied a single frequency tone with a known amplitude. For this purpose, we used a vector signal transceiver (VST) to generate a signal, a vector signal analyzer (VSA) to detect that signal (as a reference value) and recorded I/Q data using the SDR; see Fig. 19.
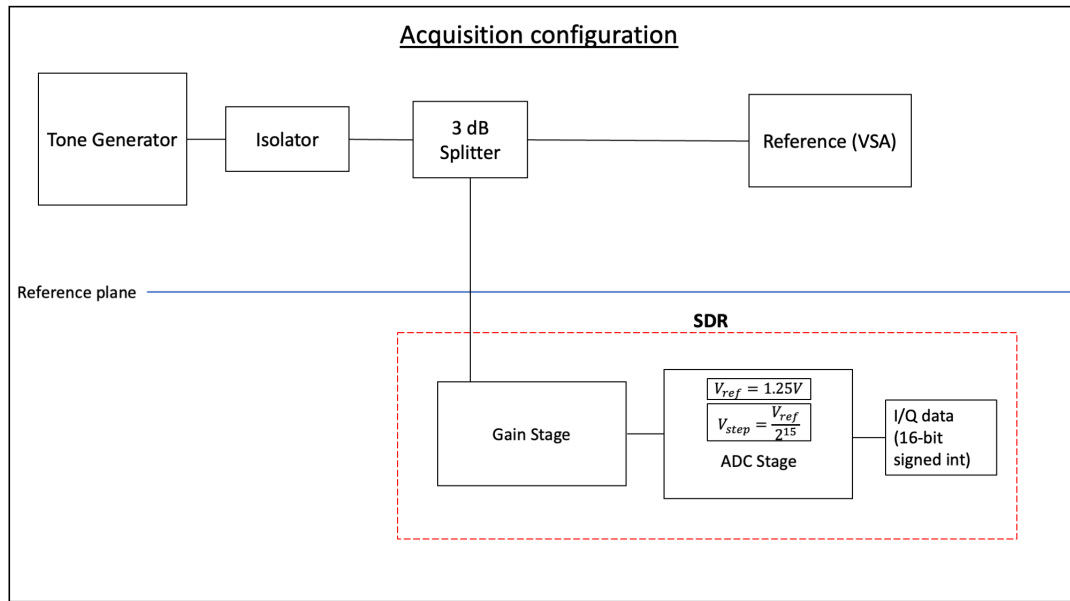

Fig. 19. Gain Estimation Setup.

For each data acquisition configuration outlined in Section 3, the SDR gain was assessed with two tone amplitudes and three tone frequencies. To account for variations in the frequency response of the SDR front-end, the test frequencies included the acquisition center frequency and frequencies near the edges of the acquisition bandwidth. Any signals that the reference detector (VSA) did not detect were excluded. Each of the frequency and amplitude combinations was tested for 1 s four times to aid uncertainty estimation.

To determine the received power at a single tone, a power spectral density (PSD) was estimated using Welch's method [22] with zero overlap, a Hann window, and a frequency bin size of 15 kHz. The detected power was taken to be the PSD value where the mean as a function of frequency was maximized. To ensure that the tone was significantly above the background noise level, we required that the maximum mean value was within 1 dB of the global maximum value of the PSD. An example 100 ms spectrogram over the full 30 MHz capture bandwidth of a test tone is shown in Fig. 20 and a spectrogram localized around the

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[3]Because the SDR gain setting is not calibrated, we do not attribute units to it.

tone is shown in Fig. 21. In Fig. 20, energy from the local oscillator of the SDR is visible at 2437 MHz as well as an image at 2450 MHz that is likely due to I/Q imbalance [23]. Note that energy from these spurious components was excluded by the gain estimation method.
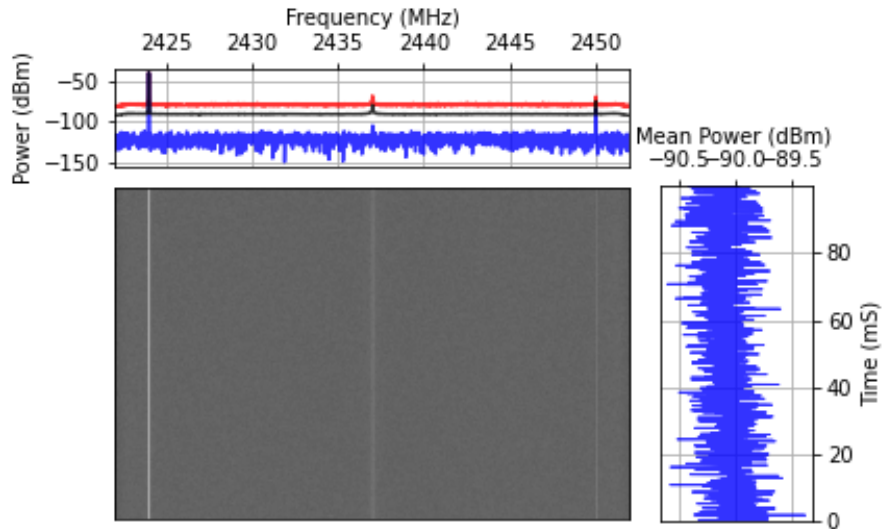
Fig. 20. Example spectrogram of gain measurement data with a tone at 2424 MHz. The spectrogram is displayed with a grayscale range of [-125, -36] dBm.
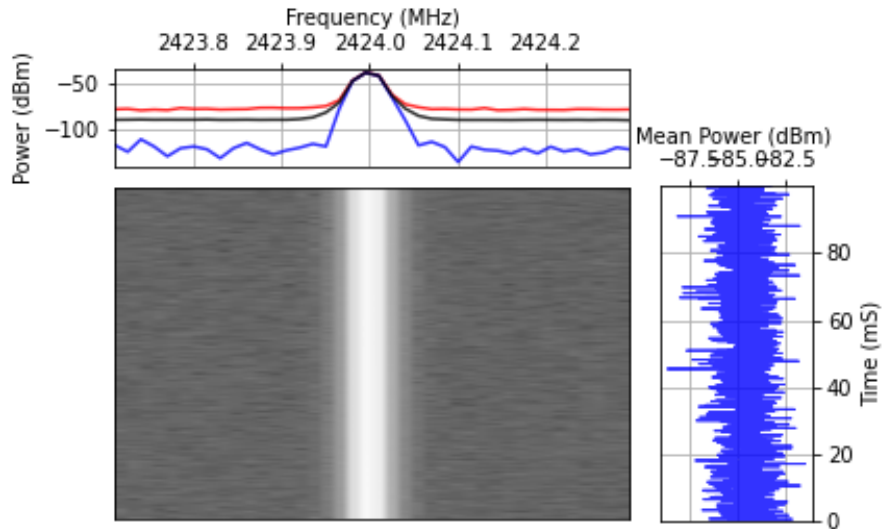
Fig. 21. Spectrogram over narrow frequency band around a tone at 2424 MHz. The spectrogram is displayed with a grayscale range of [-125, -36] dBm.
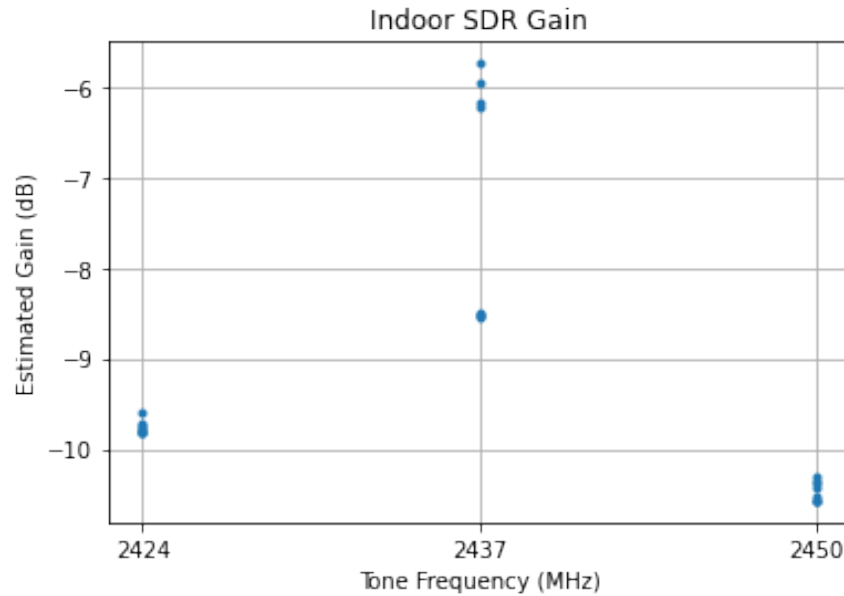
Fig. 22. Example gain estimate at an SDR gain setting of 13 for a 2437 MHz center frequency over a 30 MHz acquisition bandwidth. In this example, the mean gain over the acquisition bandwidth was estimated to be -9.16 ± 1.55 dB, i.e., in this case, the SDR front-end decreased the signal power entering the ADC.

This procedure led to at most 24 gain estimates (3 frequencies × 2 amplitudes × 4 repeats) that then were averaged to give the mean gain for each condition. Fig. 22 illustrates the result of the process for one SDR at a given center frequency. The full set of gain estimates is reported in Table 7. The uncertainties in this gain estimation procedure were dominated by the frequency response of the instrument, i.e., the gain is much smaller for frequencies offset from the center frequency; see Fig. 22.

In addition to measuring the effective gain of the SDR, the effective noise floor of the SDR was determined. The effective noise floor of the received signal for each combination of data collection settings was measured by first terminating the SDR receiver input with a 50 ohm load and then measuring the mean noise floor level. Each measurement had a duration of 1 s and was repeated four times to aid uncertainty estimation. The observed noise floor values were not corrected for the gain, and represent the effective noise level at the input to the ADC. The mean noise floor of the four repeats is reported along with the expanded uncertainty (k=2) in Table 8.

Table 7. Measured Power Gain for Acquisition Conditions.

SDR	Center Frequency (MHz)	Gain Setting (dB)	Actual Gain (dB)	Expanded Uncertainty (k=2) (dB)
B200	2437	13	-9.16	3.10
B200	2437	55	33.82	2.29
B200	5825	30	8.67	1.75
B200	5825	65	42.17	2.57
B205	2437	13	4.24	1.51
B205	2437	55	44.56	1.83
B205	5825	30	12.49	1.95
B205	5825	65	41.05	3.36

Table 8. Approximate Noise Floor for Acquisition Conditions, resolution bandwidth 15 KHz.

SDR	Center Frequency (MHz)	Gain Setting (dB)	Noise Floor (dBm)	Expanded Uncertainty (k=2) (dB)
B200	2437	13	-90.29	0.08
B200	2437	55	-76.79	0.06
B200	5825	30	-86.32	0.04
B200	5825	65	-70.37	0.07
B205	2437	13	-90.08	0.07
B205	2437	55	-77.43	0.31
B205	5825	30	-86.22	0.22
B205	5825	65	-70.36	0.03