Design Project 2 Report - Shreya Jampana

1. Summary information: Provide some basic overview information.

Secret Message - HMC

Maximum range at which we received the message (analytical and measured)

Analytical:

Maximum distance is 5855 meters, with calculations shown below:

Maximum distance reached when output signal = noise floor power (and signal no longer visible):

$$-75\text{ dBm} = P_{TX} + G_{TX} + G_{RX} + 20\log\left(\frac{3\times10^8}{(2.296\times10^9)\cdot 4\pi r}\right) + G_{amp1} - G_{mixer} - G_{filter} + G_{amp2}$$

power of noise floor, found using spreadsheet

find r = max distance

b/c actually losses

$$-115\text{ dBm} = 20\log\left(\frac{3\times10^8}{(2.296\times10^9)\cdot 4\pi r}\right)$$

$$r = 5855\text{ m}$$

Measured:

At 18.71 meters, we were able to see the signal clearly on the spectrum analyzer and visually see the message on the oscilloscope.

At 80.53 meters, we were able to see the signal clearly on the spectrum analyzer, as in, the signal was still above the noise floor. But we could not make out the message on the oscilloscope clearly. We could have kept going further, but were limited by hitting the wall in the physical department, not finding more plug points, and having limited cable lengths.

Receiver System Temperature (analytical and measured)

Analytical output referred system temperatures (calculation methods specified below):

- 0 bit: 745077407 K
- 1 bit: 648300034.2 K

measured noise floor power: -79.14 dBm

$$= 0.001\left(10^{-79.14/10}\right) = -1.219\times10^{-11}\text{ W}$$

$$T_n = \frac{P_n}{kB} = \frac{1.219\times10^{-11}}{(1.38\times10^{-23})(3000)} = 294441932.1\text{ K}$$

Measured: 294441932.1 K

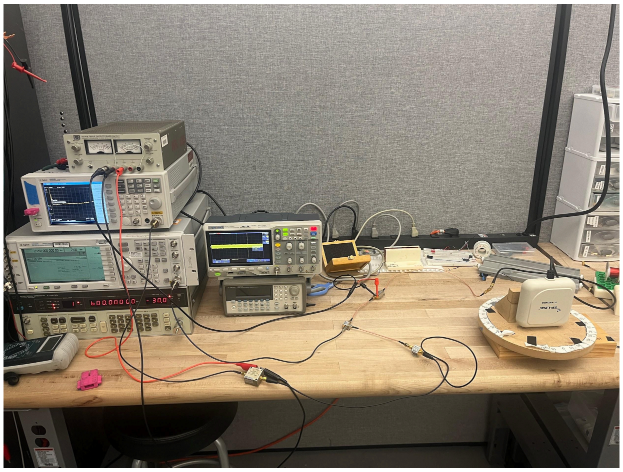
Receiver IIP3 (analytical and measured)

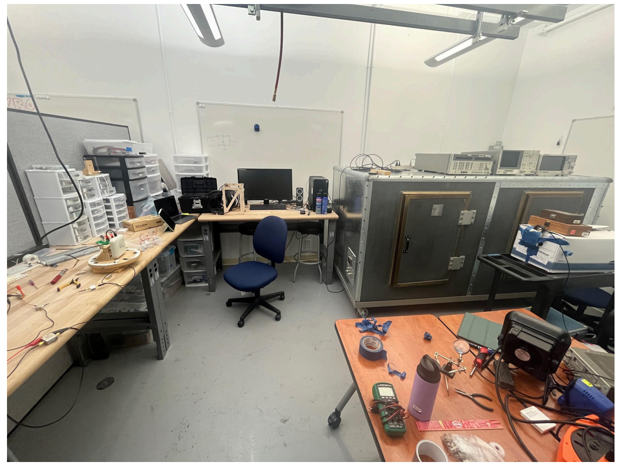
Analytical IIP3: -10.16 dBm (calculations shown in section 7 below)

Measured IIP3: -30.125 dBm

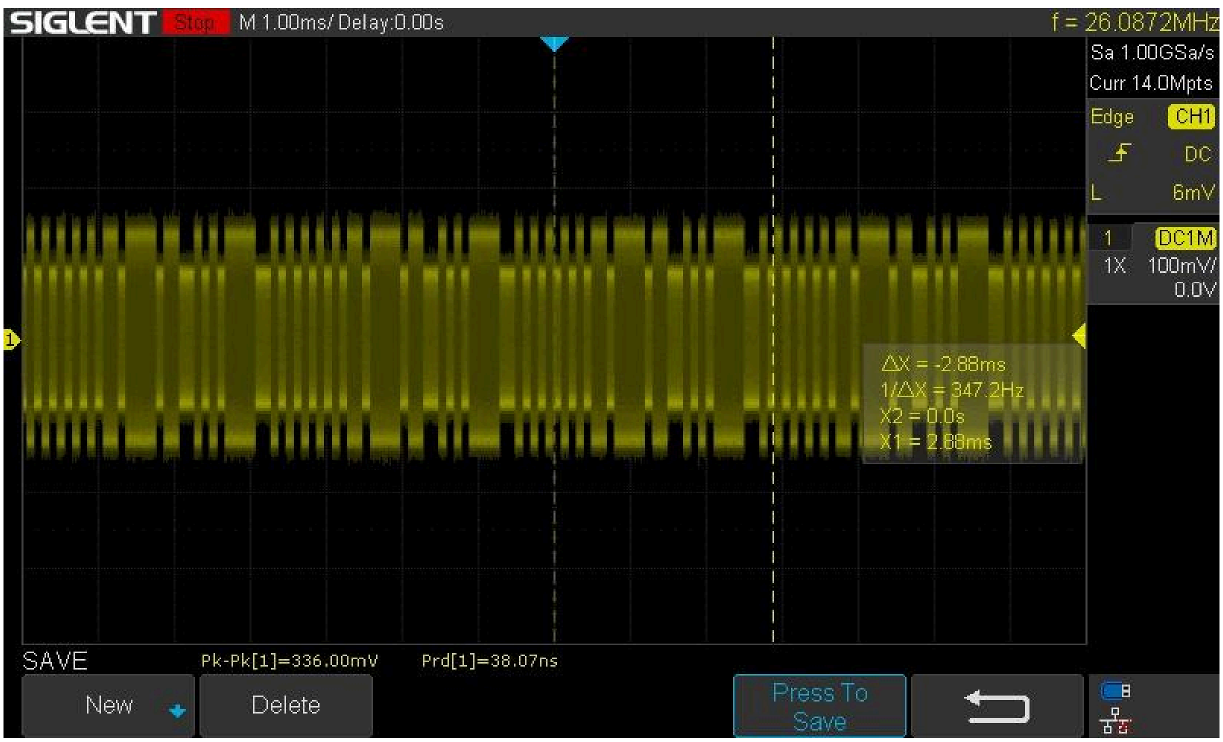
2. Pictures of received data

Picture of your setup at 3m range

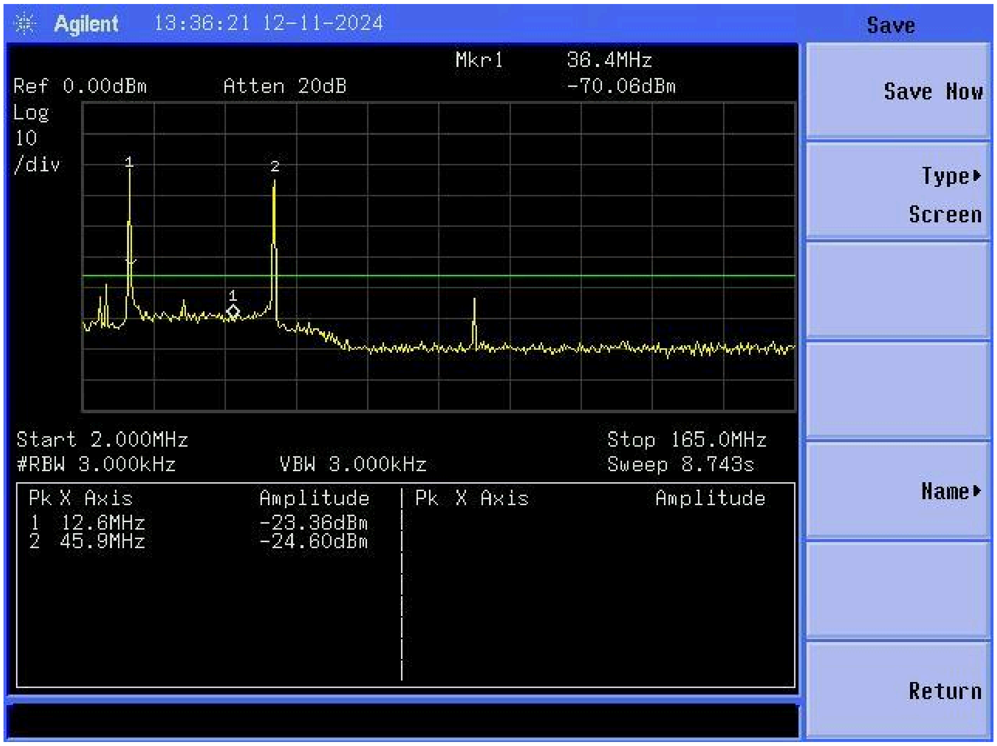




Oscilloscope trace of your receiver output at 3m range



Spectrum of your receiver output at 3m range.



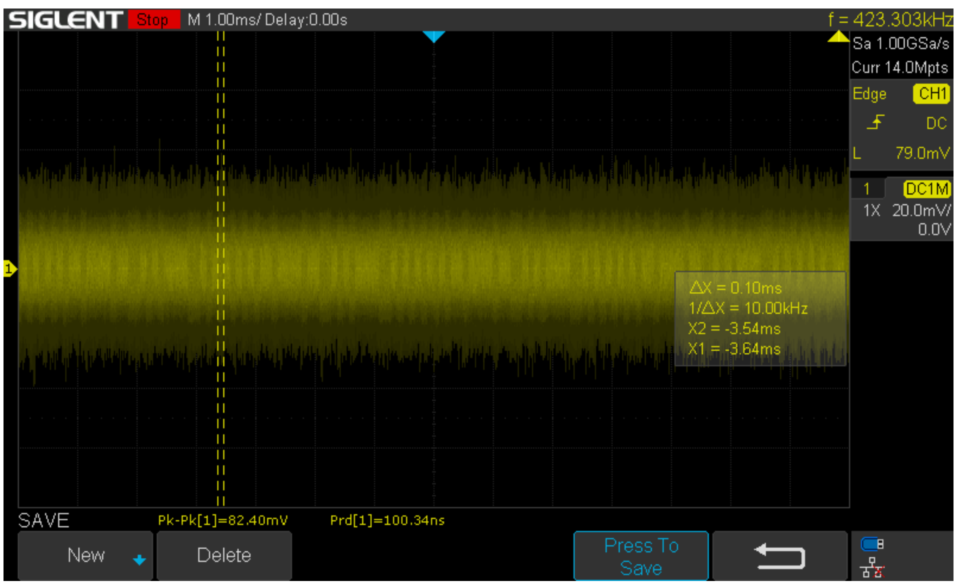
Picture of your setup at max range

18.71 meter setup:

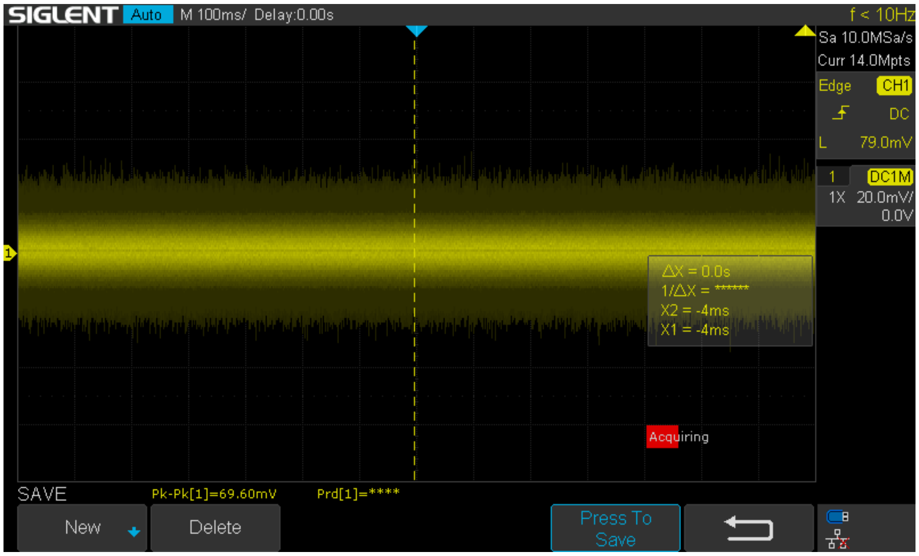
18.51 meter setup:

Oscilloscope trace of your receiver output at max range

At 18.71 meters (when we could still make out the signal on the oscilloscope):

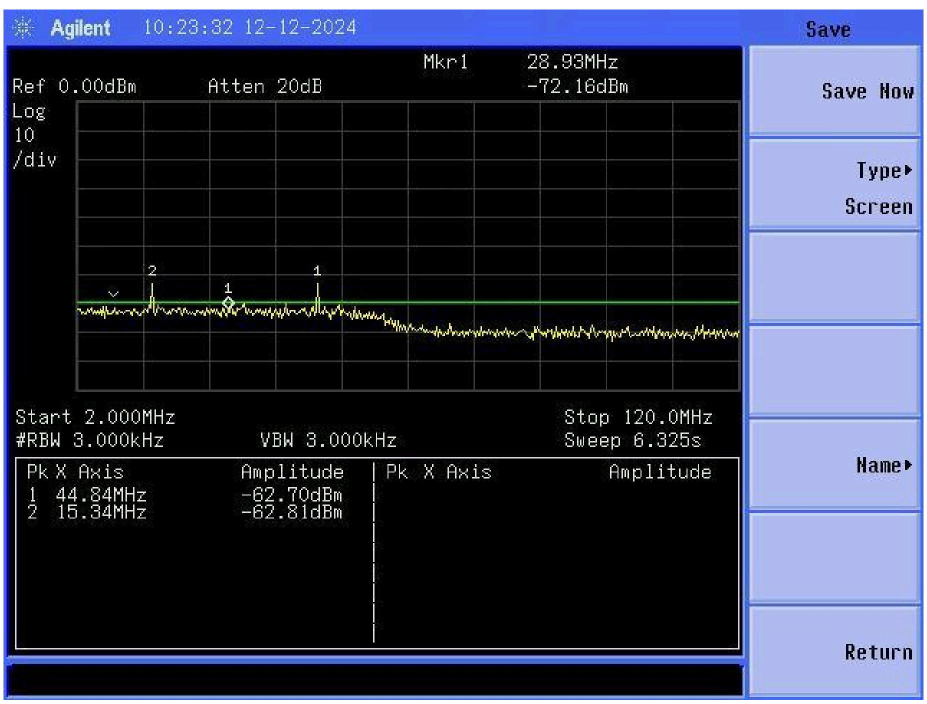


At 80.51 meters (when signal was just above noise floor):

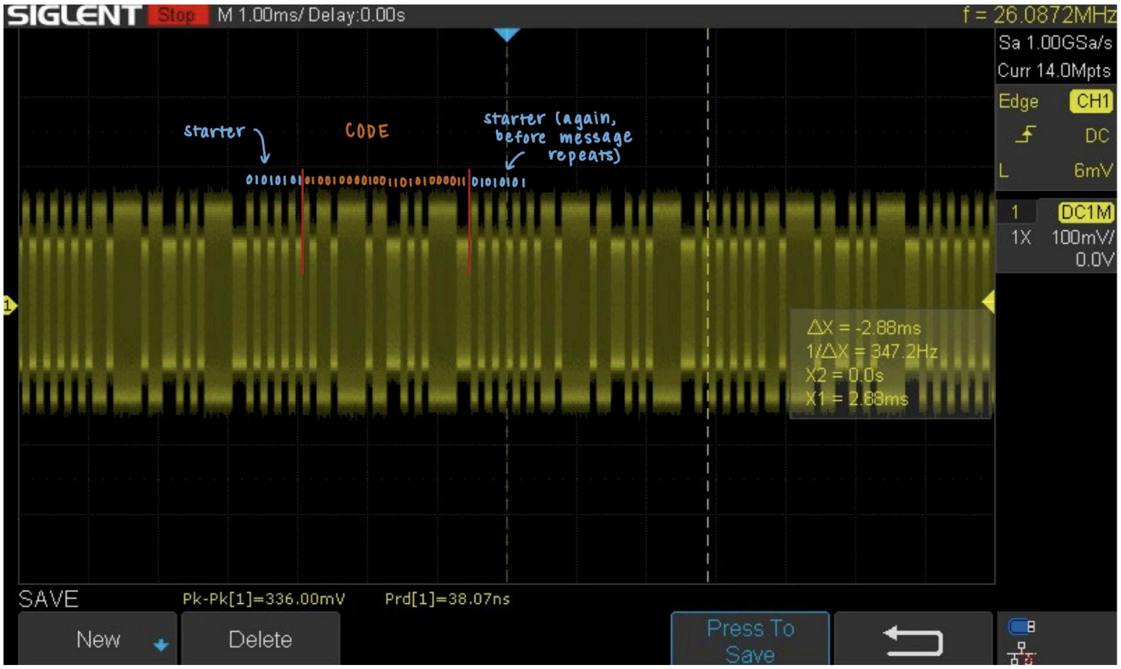


Spectrum of your receiver output at max range.

At 80.51 meters:



3. One page discussion of how to decode the oscilloscope trace to extract the secret message, possibly using an annotated copy of the oscilloscope trace to help explain your decoding scheme.

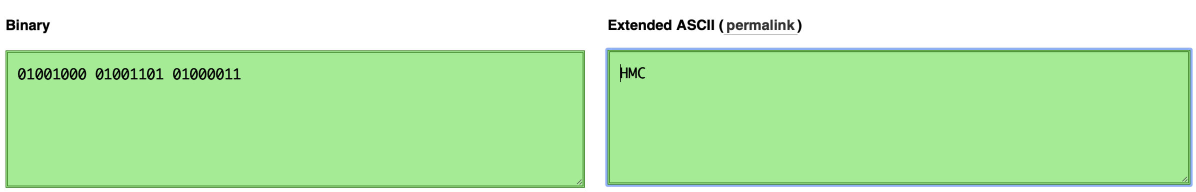


After getting the oscilloscope trace, we first identified which height corresponded to which bit. As given, the frequency for the 0 bit was 2.256 GHz, and that for the 1 bit was 2.296 GHz. The 1 bit corresponds to a higher frequency, but seeing as we were using a low pass filter in our receiver, and these filters attenuate higher frequencies more than lower ones, it was decided that the more attenuated signal (or height) corresponded to the 1 bit.

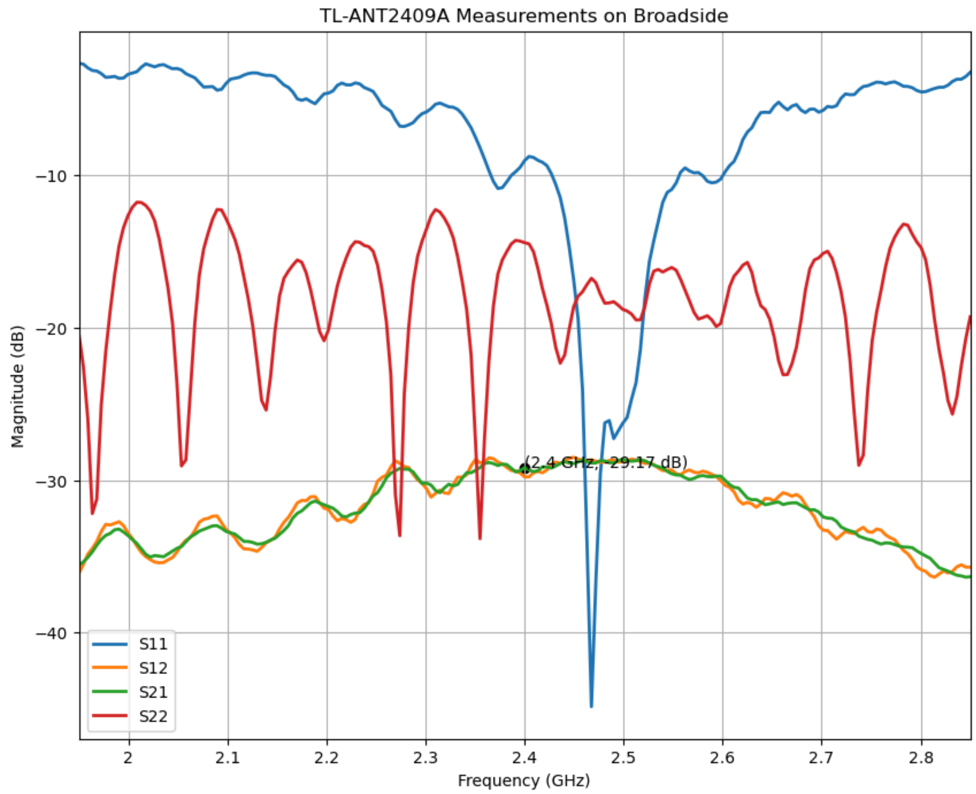
To decode the message, we first identified the pilot frame of “01010101.” Since the message bit rate was 10 kbps, 10,000 bits are outputted per second, meaning 1 bit is output every 0.01 millisecond. Therefore, to decode the message, we manually moved the cursor 1 ms at a time and noted down which bit it corresponded to. We repeated this process until we reached the pilot frame again.

This was the code we noted down: 010010000100110101000011

We plugged this code into a binary to ASCII text converter (https://mothereff.in/binary-ascii), and got the message HMC:



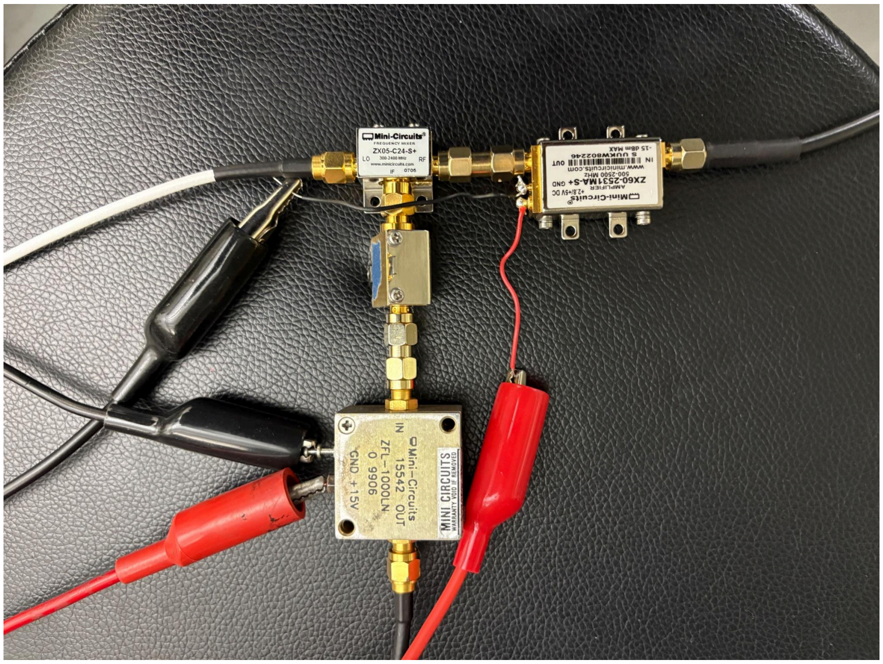
4. Antenna information



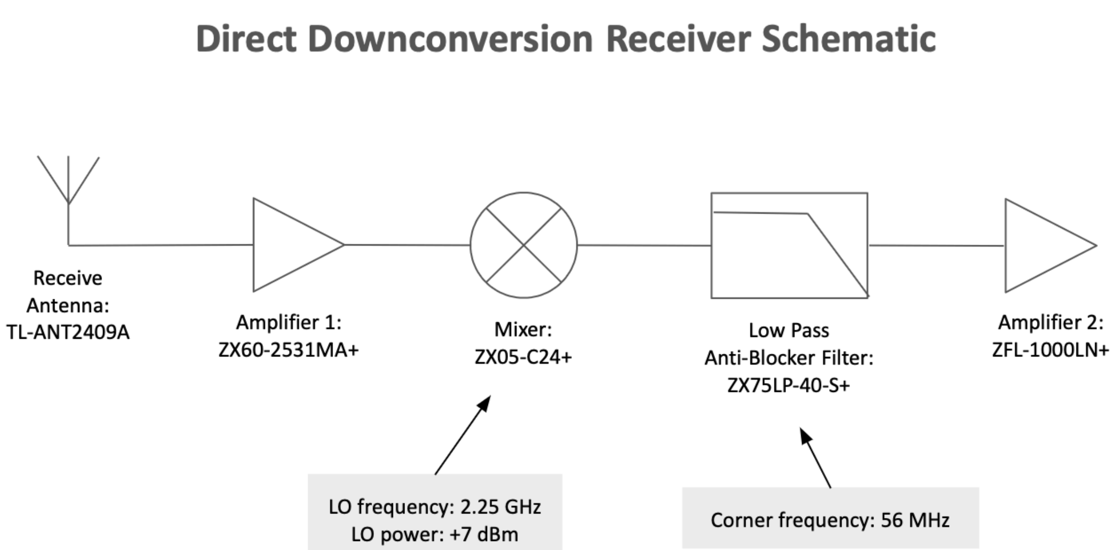
S11 of antenna, extracted from lab 5, because we used the same antenna

5. Receiver information

Picture of your receiver

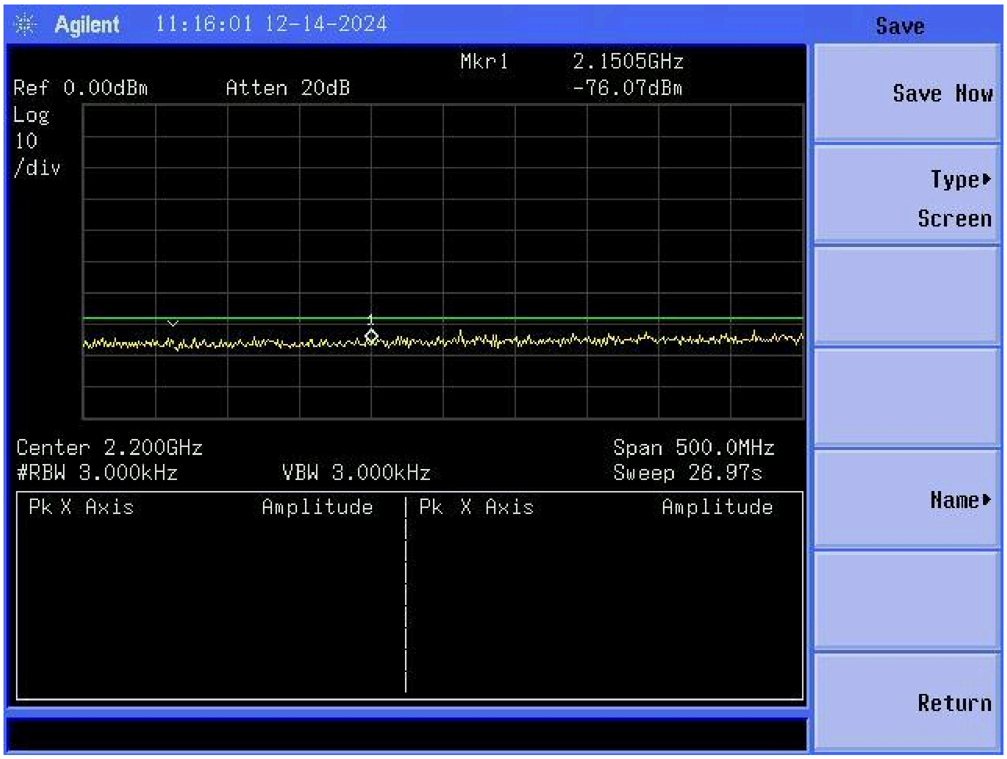


Schematic of your receiver drawn in Powerpoint or some other illustration program. Note the LO frequency, LO power, corner frequencies of filters and sampling rates of any samplers.

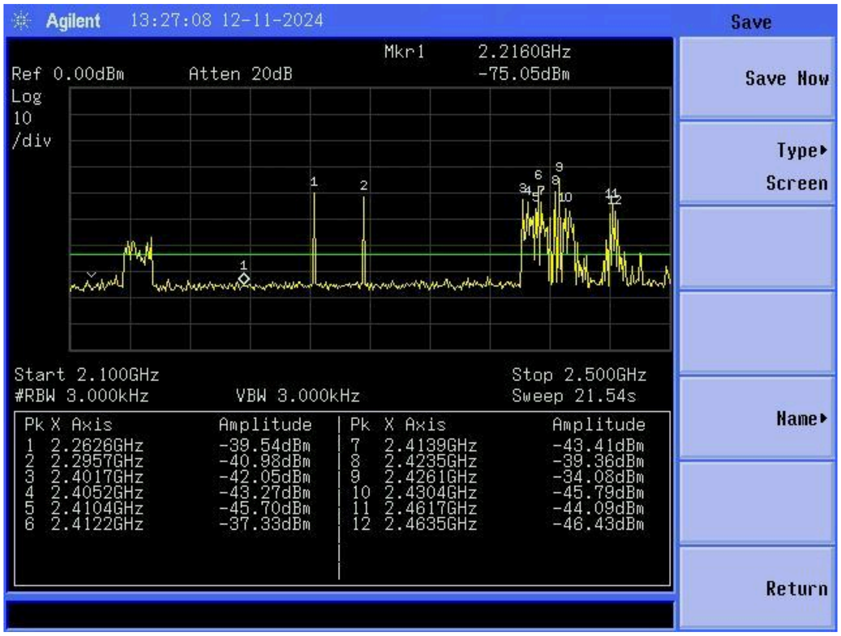


6. Spectra from each stage of your receiver in the 3m test condition, including one spectrum directly off the antenna. This test is to verify the intended operation of the receiver. For the spectrum directly off the antenna, use a frequency range of 2.0-2.4 GHz to capture nearby blockers. In each spectrum after that, select your frequency range to capture interesting behaviors of your signals and blockers, put a marker on the signal peaks (using peak table functionality in the Agilent VNA or multi-marker functionality in the Siglent VNA), and explain what causes the peak. Also put a marker on the DANL.

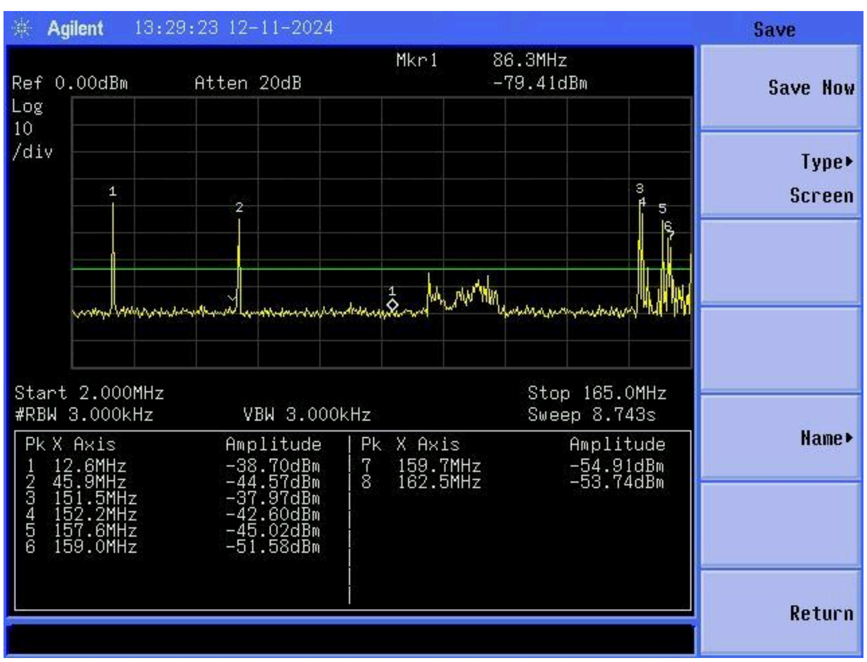
Spectrum directly after antenna: No signals observed on the spectrum analyzer due to them being unamplified and therefore, too small.



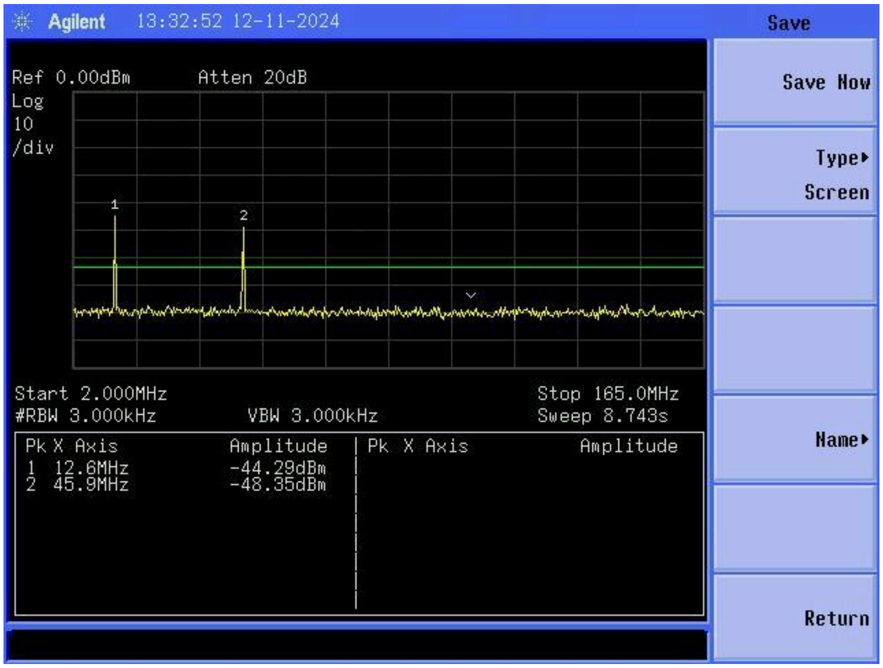
Spectrum after the first amplifier: There is a blocker signal present in the spectra at around 2.15 GHz. Peak 1 and 2, which are labeled, are found at 2.2626 GHz and 2.957 GHz, corresponding to the 0-bit and 1-bit signals respectively. The peaks 3-12 are found around 2.4 GHz and are therefore wifi signals.



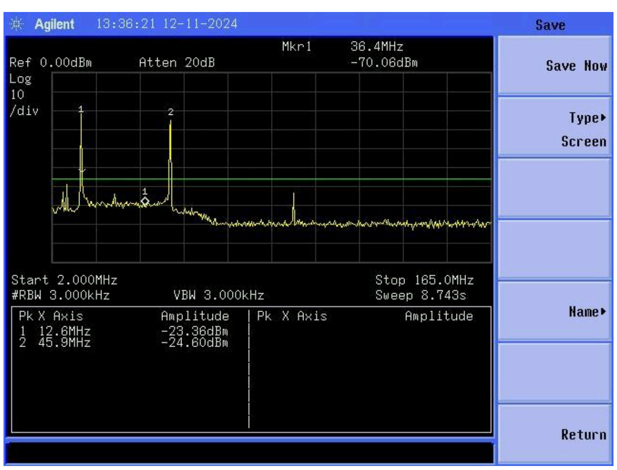
Spectrum after the mixer: Peak 1 corresponds to the 0 bit signal, which is found at 12.6 MHz, and peak 2 corresponds to the 1 bit signal, which is found at 45.9 MHz. This makes sense, given that our LO input was 2.25 GHz. The blocked and wifi are also shifted to around 100 MHz and 150 MHz, respectively.

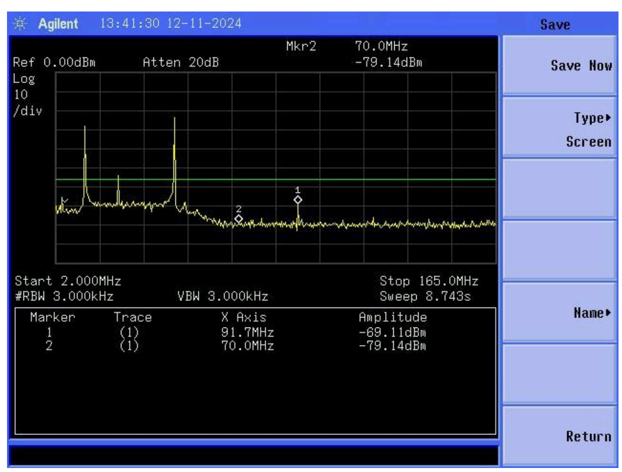


Spectrum after the low pass filter: The low pass filter had a cutoff at 40 MHz, so the 0 and 1 bit signals weren't affected. Peaks 1 and 2, which correspond to the 0 and 1 bit signals, are still found at 12.6 MHz and 45.9 MHz, respectively. Due to the filter, the blocker and WiFi signals are fully attenuated.

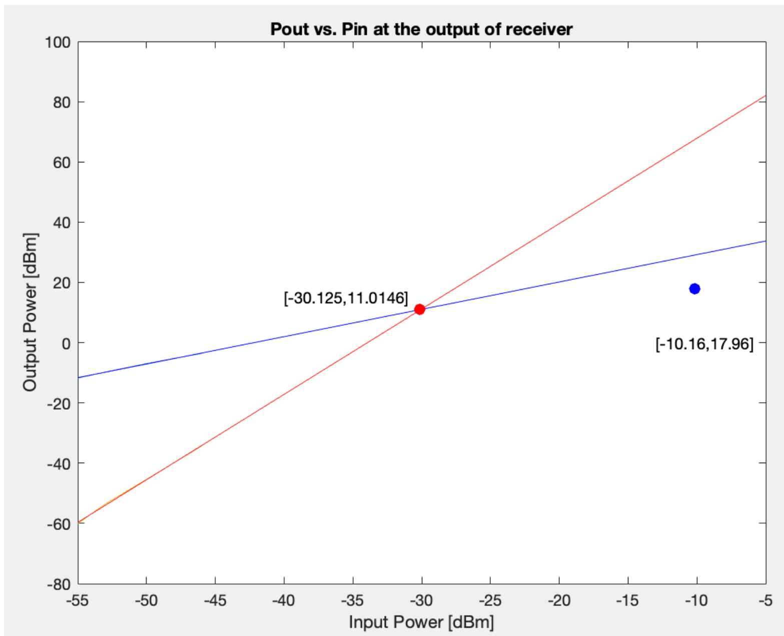


Spectrum after the second amplifier: The 0 bit and 1 bit signals still remain at 12.6 MHz and 45.9 MHz, respectively, as shown by peaks 1 and 2. The remaining peaks correspond to distortion products. A second order harmonic around 2*f1 is found at 24 MHz, and another second order harmonic around 2*f2 is found at 91.7 MHz.





7. Pout vs. Pin plot showing fundamental power and IM3 power at the output of your receiver in the receiver characterization test configuration. Extrapolate measured lines to indicate a measured IP3. Include a point showing your theoretical IP3. Include a calculation below (with references to datasheets where appropriate) to explain how you calculated your theoretical IP3.



Plot of Pout vs. Pin showing the fundamental power (blue line), the IM3 power (red line), measured IP3 point (in red), and theoretical IP3 point (in blue)

Calculations for theoretical IP3:

2nd amplifier: ZFL-1000LN:

from datasheet:

freq. (MHz)	$P_{out,-1dB}$	Gain (dB)
5.4	8.09	27.94
53.3	7.94	28.15
46	7.963	28.118

found using linear interpolation

known equation: $P_{out} = P_{in} + G$

to find input power to $P_{-1,dB}$: $7.963 - 28.118 = -20.16$ dBm

known relationship between IIP3 and input power to $P_{-1,dB}$: $IIP3 = P_{-1,dB} + 10$ dB

finding IIP3 using this: $IIP3 = -20.16$ dBm $+ 10$ dB $= -10.16$ dBm

using known equation to find $OIP3 = IIP3 + Gain$

$OIP3 = -10.16$ dBm $+ 28.12$ dB $= 17.96$ dBm

∴ theoretical IP3 point is (-10.16 dBm, 17.96 dBm)

8. Explanation of how you found the theoretical signal and noise levels for your receive chain. Also upload an Excel spreadsheet that includes these calculations for my review. Include both your analysis and your measured data in the spreadsheet.

Theoretical Signal Explanation

expected signal power calculation using friis equation:

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} + 20\log\left(\frac{\lambda}{4\pi r}\right)$$

transmit power after return loss

same receive and transmit gains

path loss

- transmitter output power (given): -29 dBm, but antenna has -10 dB return loss
  - → in linear space: $10^{-29/10}$
  - → 90% of that due to 10dB return loss: $0.9(10^{-29/10})$
  - → back to dB space: $10\log(0.9(10^{-29/10}))$
  - → ∴ $P_{TX} = 10\log(0.9(10^{-29/10})) = -29.458$ dBm
- $G_{TX} = G_{RX} = 6$ dBi
  - → given directionality info
- path loss: $20\log\left(\frac{c/f}{4\pi r}\right)$
  - → using $f = 2.256$ GHz for 0 bit and $f = 2.296$ GHz for 1 bit
  - → using $r = 3$ meters (target distance)

expected signal power after every stage:

To find the expected signal power after every stage, we added the gain of that stage to the P_{RX} calculated above, creating a chain. All of the gains were extracted using the components' datasheets, and we used interpolation to find the gains at the desired frequencies.

final output power:

$$P_{output} = P_{RX} + G_{amp1} - G_{mix} - G_{filter} + G_{amp2}$$

subtracting these values b/c they're actually losses

for 0 bit: $P_{out} = -8.22$ dB

for 1 bit: $P_{out} = -9.19$ dB

Theoretical Noise Calculation:

Expected noise temperature of receiver: 290 K

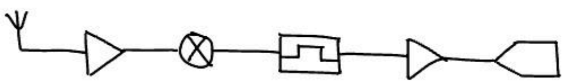
Expected noise temperature of amplifiers:

- using given noise figure NF in dB in datasheet, first found $nf = 10^{NF/10}$
- then found noise temperature using: $T_A = (nf-1)T_{ref} = (nf-1)(290)$
- used same process for amplifier 1 and 2

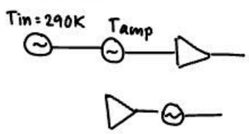
Expected noise temperature of mixer and filter:

- both mixer and filter can be modeled as lossy passives
- found their noise temperatures using $T_P = \left(\frac{1}{L}-1\right)(290)$, where L is the loss of the mixer or filter in dB, found in their respective datasheets

Expected noise temperature of overall receive chain, found by multiplying gain/attenuation to the sum of (noise coming into system + input referred noise temp. of the component:

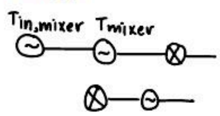


amplifier:



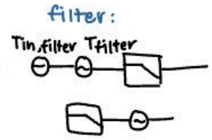
$T_{in,mix} = G_{amp}(T_{in} + T_{amp})$

mixer:



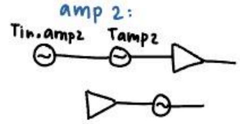
$T_{in,filter} = 2G_{mix}(T_{in,mix} + T_{mix})$

filter:



$T_{in,amp2} = G_{filter}(T_{in,filter} + T_{filter})$

amp 2:



$T_{in,osc} = G_{amp2}(T_{in,amp2} + T_{amp2})$

final equation

$$T_{n,output} = G_{amp2}(T_{amp2} + G_{filt}(T_{filt} + 2G_{mix}(T_{mix} + G_{amp1}(T_{amp1} + 290))))$$

to find the power from the temperature:

$P_{n,output} = KT_n BW$, where $K = 1.38 \times 10^{-23}$ J/K and BW = 3 kHz (what we used)

Link to spreadsheet:
https://docs.google.com/spreadsheets/d/11yKem4L0UgHhBkXeiHLw7Z2PGlb-EKyWdZLuiF3150I/edit?gid=1623652060#gid=1623652060

Datasheets used for all calculations:

First Amplifier: ZX60-2531-MA-S+

Mixer: ZX05-C24-X+

Low-Pass Filter: ZX75LP-40-S+

Second Amplifier: ZFL-1000LN