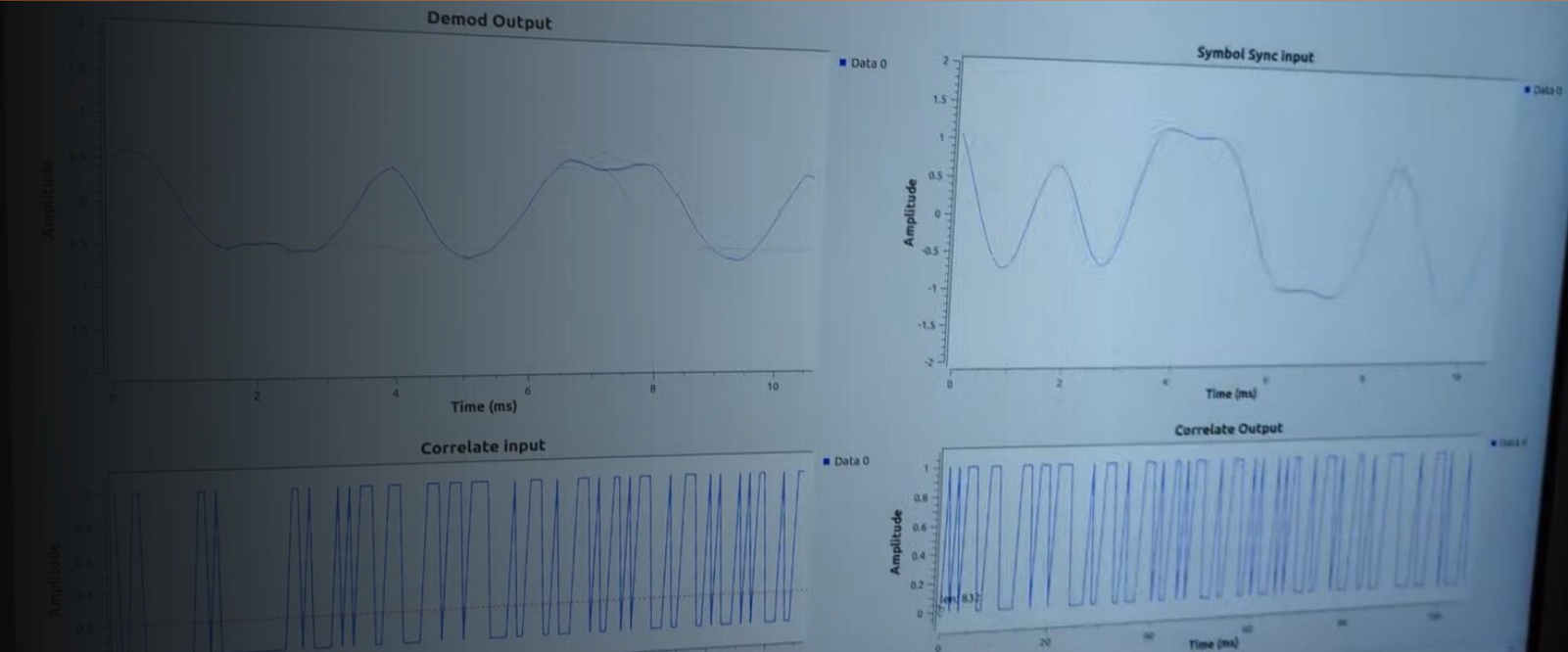


# Using GNU Radio in a Multipath Environment



GRCon 24 Presentation  
PHD candidate @ UTS  
TMP Analyst @Sydney Trains  
20<sup>th</sup> September 2024



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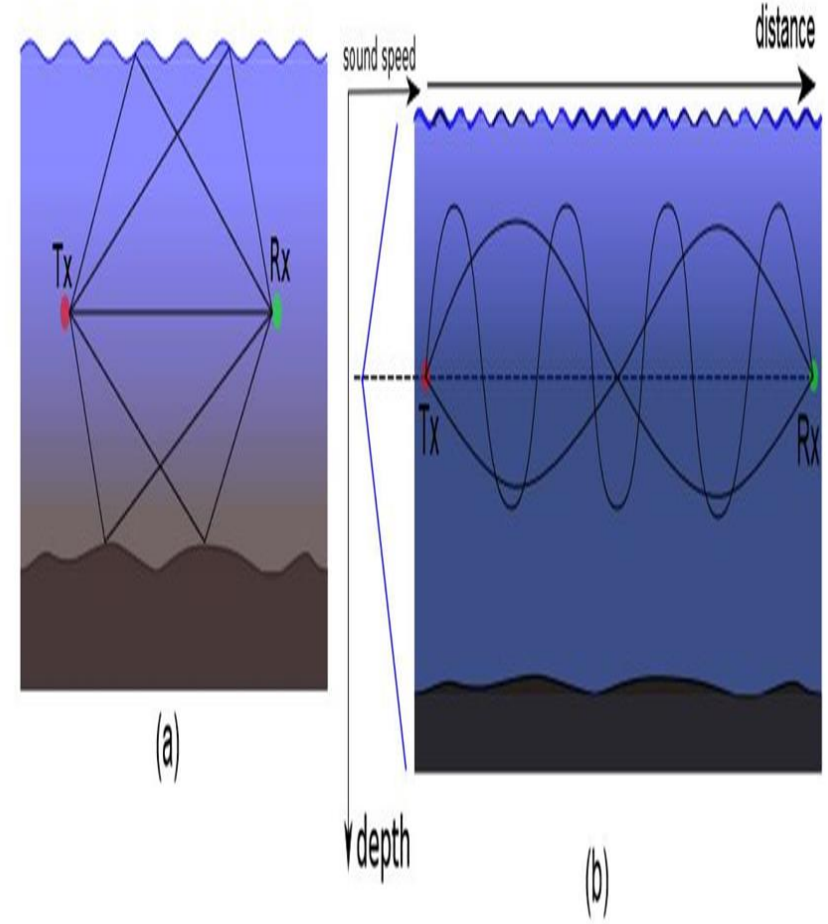
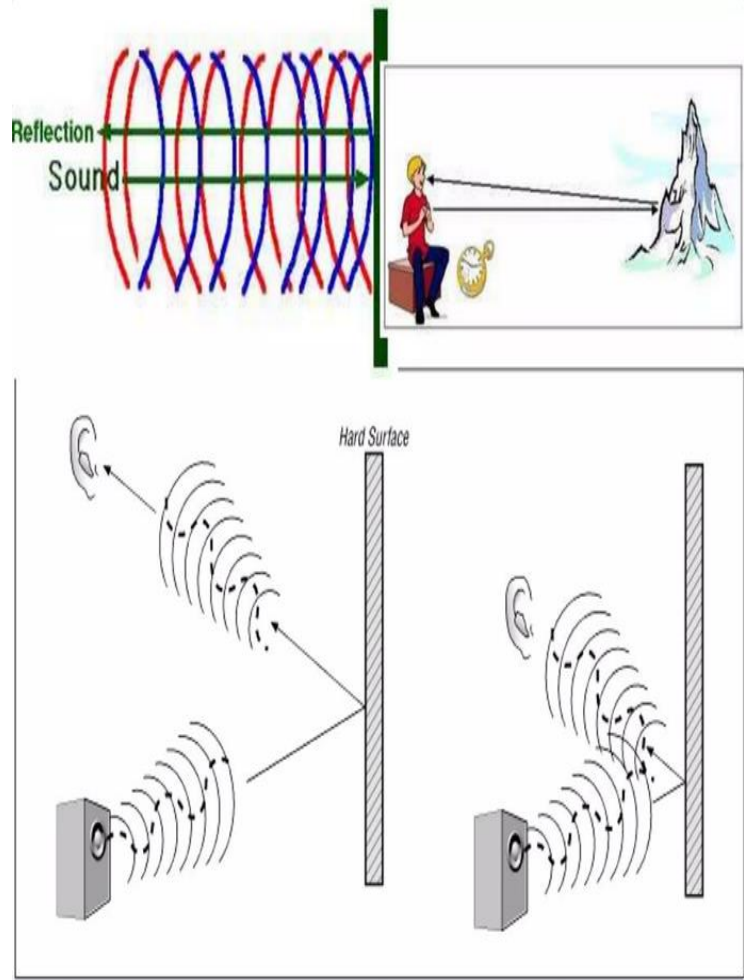


## Introduction

One of the projects original objective was to allow Hi-Rail vehicles to communicate with each other through the rail wheels (when they were travelling in a group), the track and the wayside

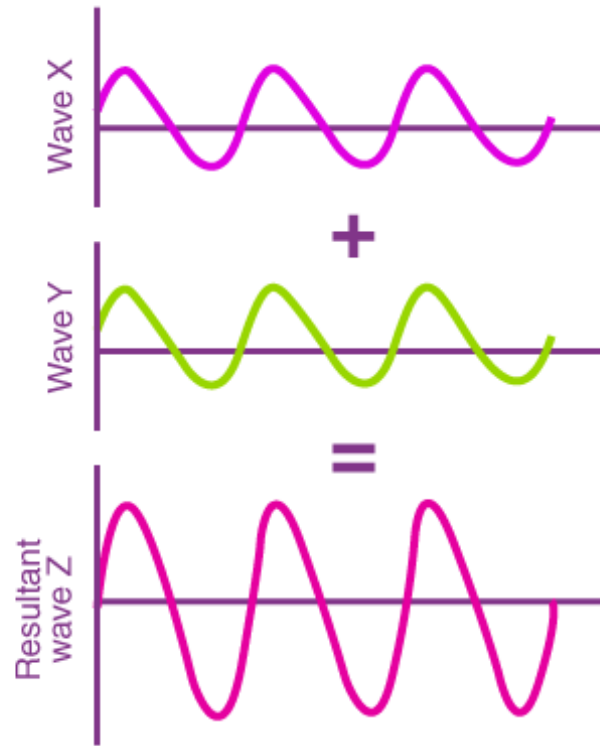


# What is Multipath and Echo

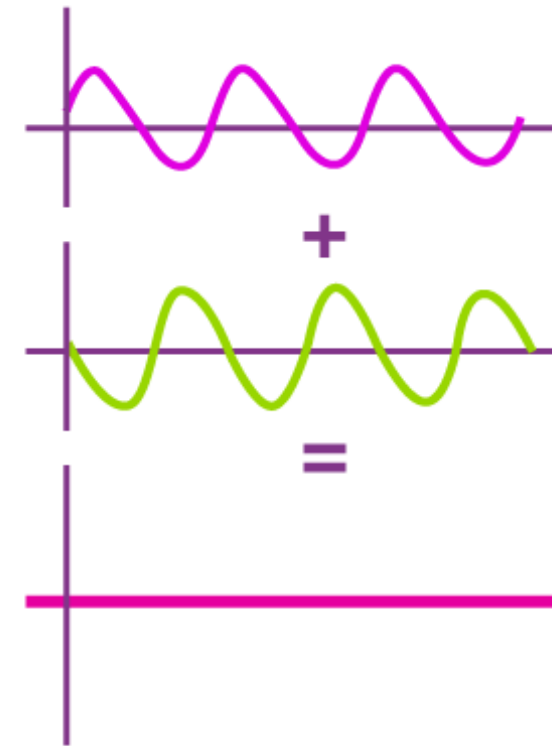


## WAVE INTERFERENCE

Interference caused by audio signals arriving a different times



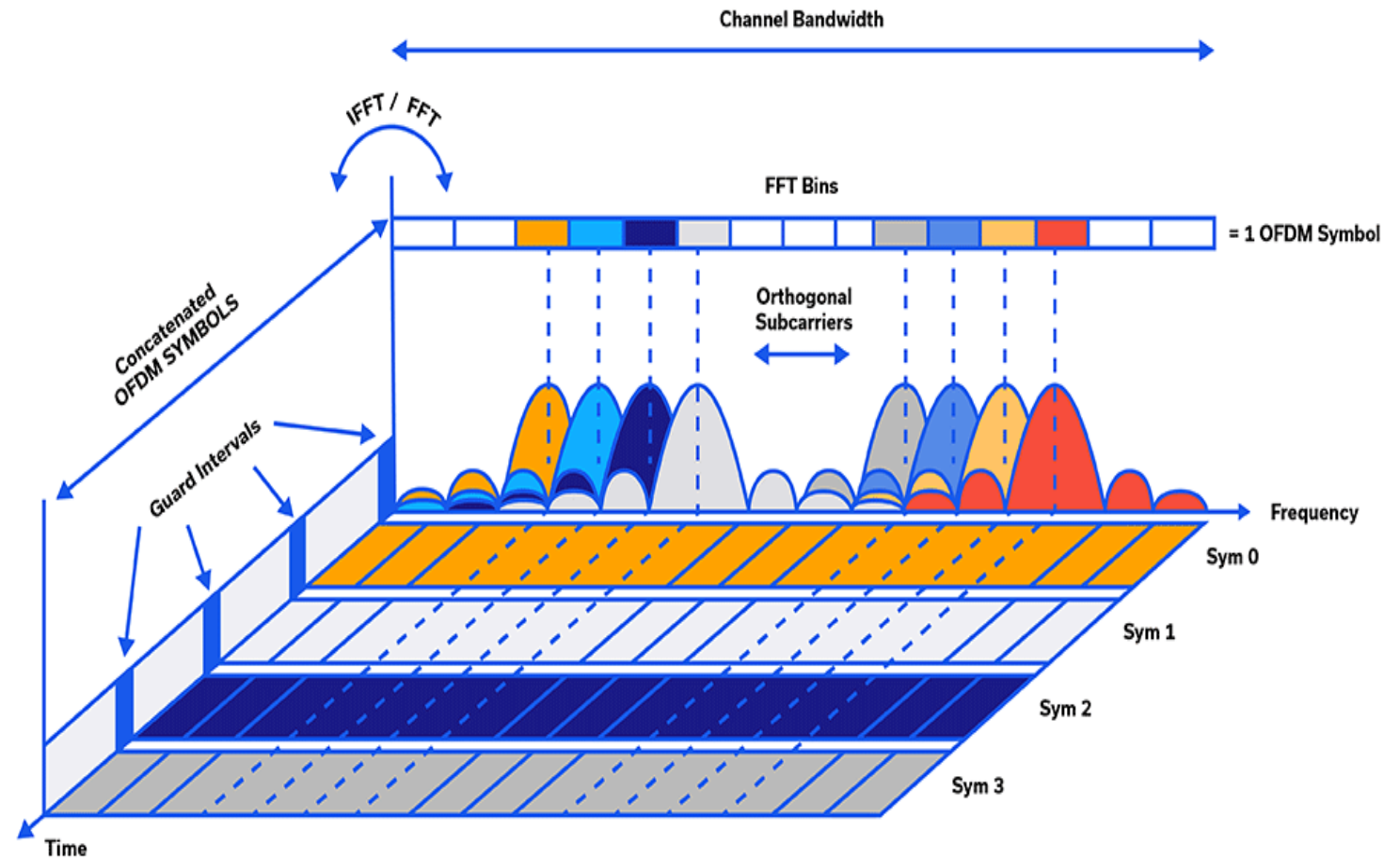
Constructive interference



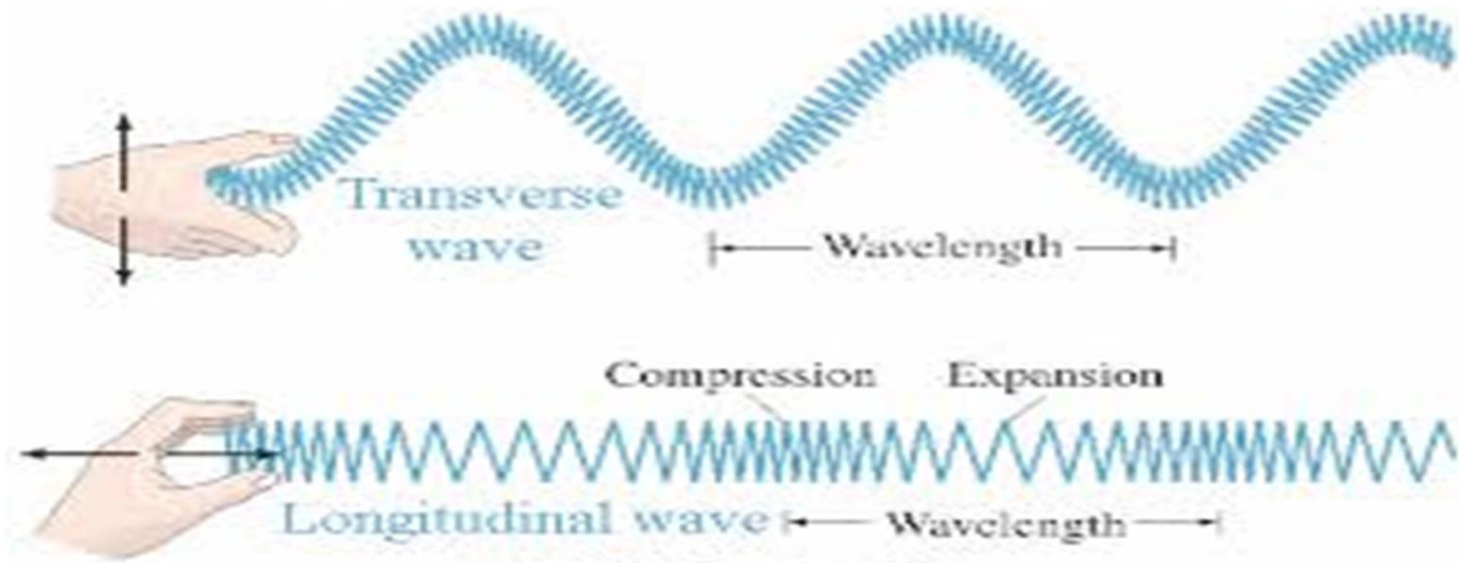
Destructive interference



OFDM is a great solution but requires bandwidth to get good results



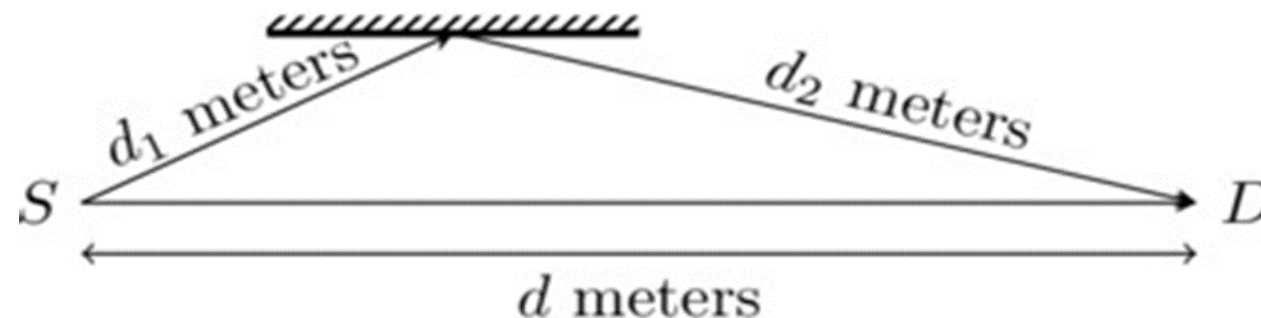
What is a  
Transverse and  
Longitudinal  
waves



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Can morse code be used to overcome multipath in narrow band systems using discrete channels

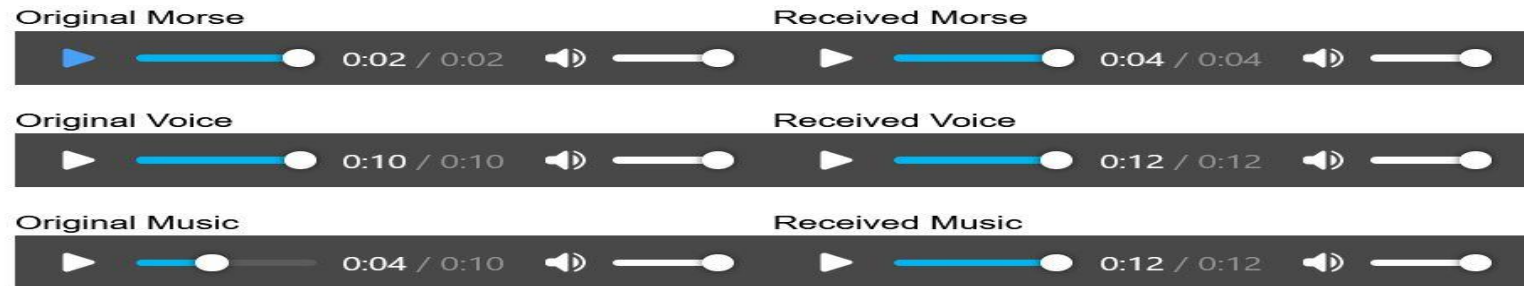
- Consider the following when an audio signal is sent in air from a source to a destination a short distance away along with a reflected signal.
- As an observations the morse code and voice are distorted. They are harder to understand and decipher, however the classical music uses different tones and the echo for each tone does not distort the audio as much. OFDM is a bit like the received music, can tolerate some interference before it fails
- [Example located at the following location:](https://dspillustrations.com/pages/posts/misc/multipath-propagation-and-its-effect-on-audio.html)  
<https://dspillustrations.com/pages/posts/misc/multipath-propagation-and-its-effect-on-audio.html>





- Morse code audio and voice are difficult to hear but the music has less distortion because the different frequencies don't overlap each other

Examples of  
morse code ,  
voice and music  
reflected back to  
the listener at  
different times



Tests with  
morse code  
using hardware  
solutions

- Test conducted using FSK hardware solution designed in 2019 propagating modulated audio through a metal plate
- The word length tested was 10 and 20 words a minutes
- A 1khz tone modulated onto a 40Khz carrier
- The tones that are sent and received can be compared
- There are many app available to read the morse and output the ASCII text
- I used GGMorse App which converted the audio and gave a text output
- Morse code is well understood and supported; many people in this room are familiar with this coding technique and can tell when the signal is degraded

Hardware test  
using SCR  
Version 4 and  
FSK

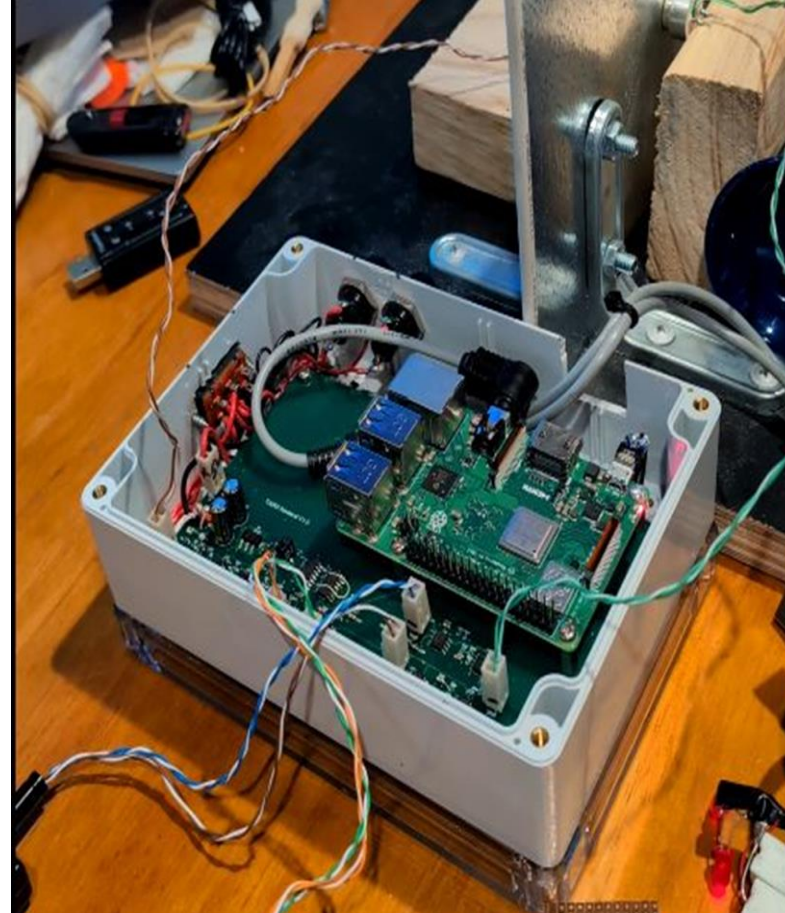


Image of SCR 4 and steel plate showing main board and Raspberry Pi 3 used in this configuration

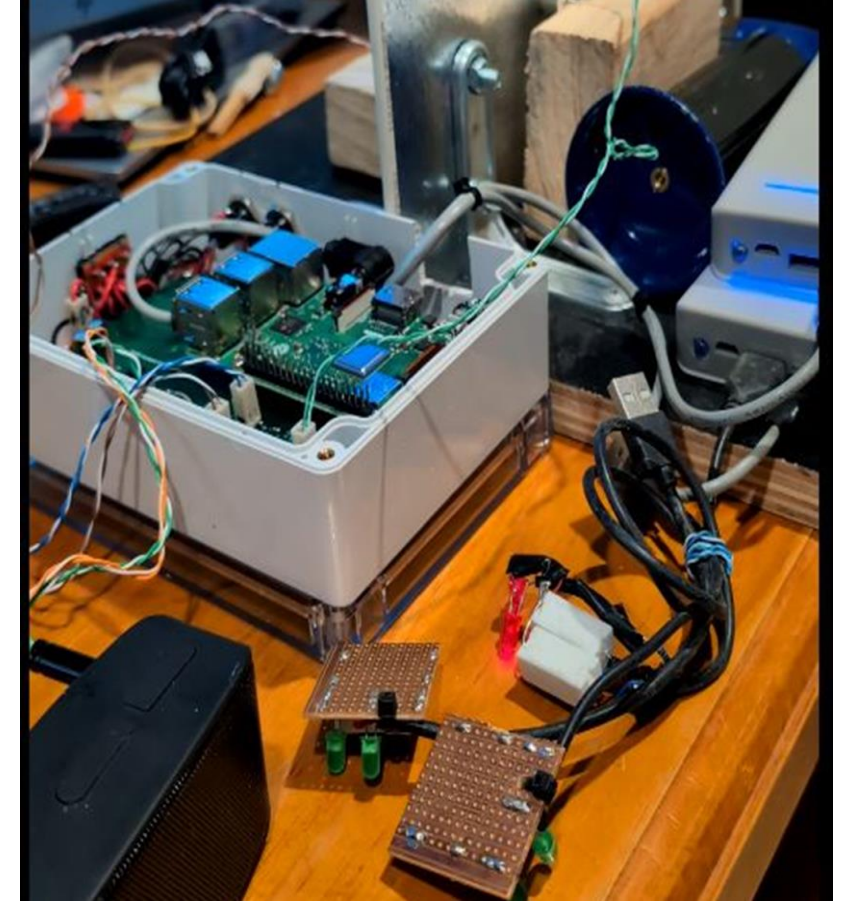
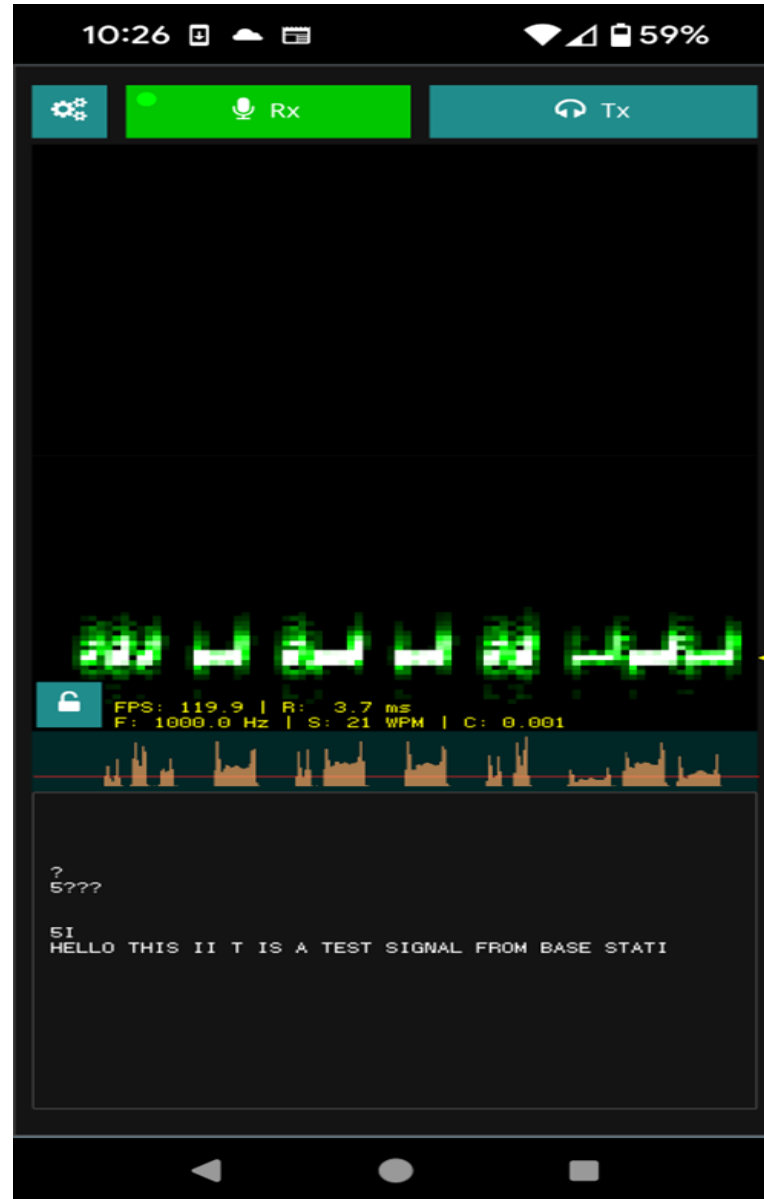


Image of SCR 4 and steel plate. Showing battery packs and load resistors to keep the power pack from a no load switch off

Good Results  
from this test





## Tests using BFSK flowgraph and Sound card

- A number of tests were preformed on different substances previously
- An image was modulated on to a bit's streams and modulated using BFSK into ultrasonic transducers and transmitted though the substance
- A baud rate of 1200 was used allowing file to be sent in reasonable time
- The RX transducer picked up the received sound wave which was demodulated in the software
- Good results were obtained, text, images, audio files sent and received
- The tank used created a lot of reflected sound wave and a cover was placed around the RX transducer to limit the interference (multipath waves)
- Some material failed with BFSK and are shown in red in the following slide

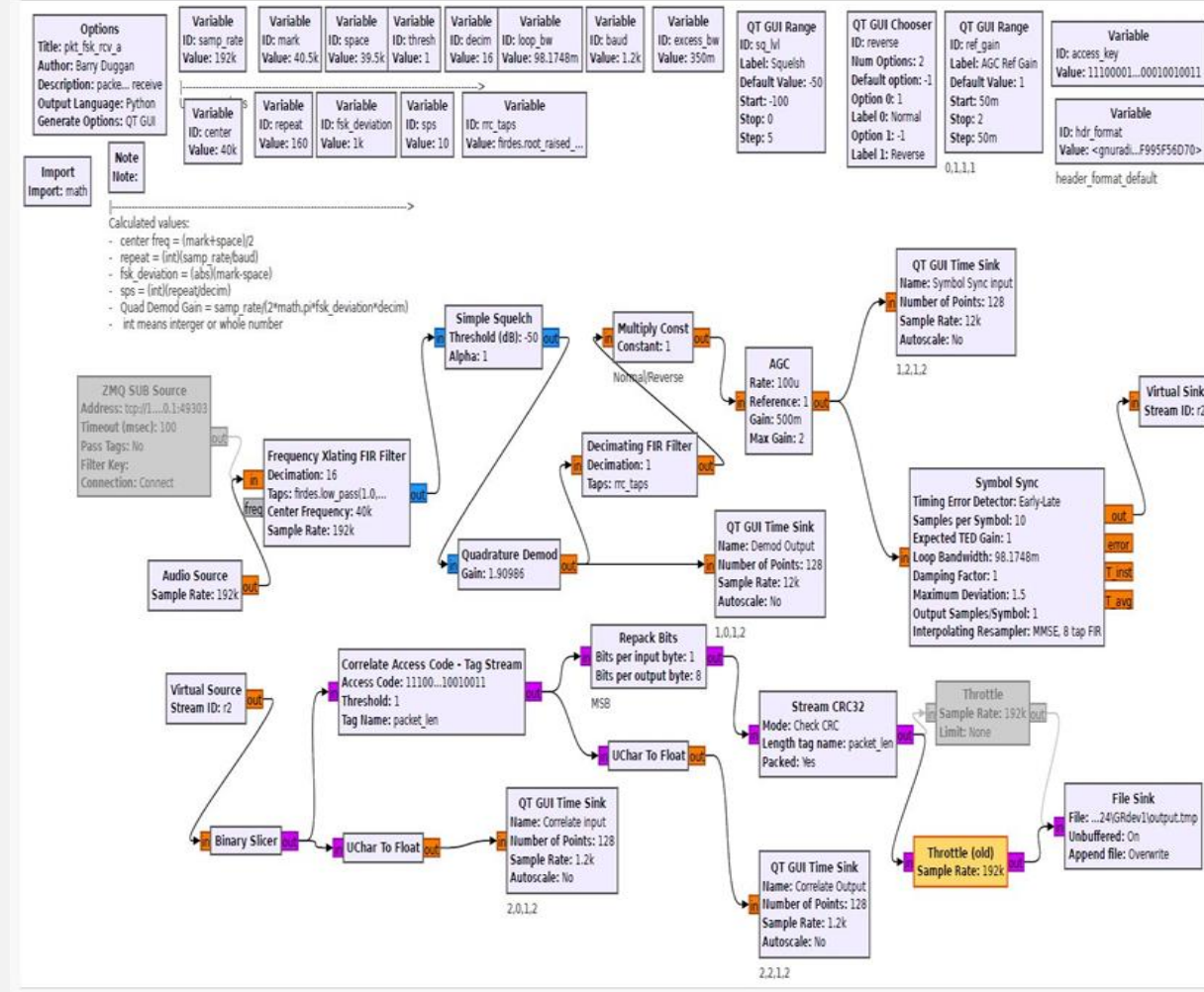
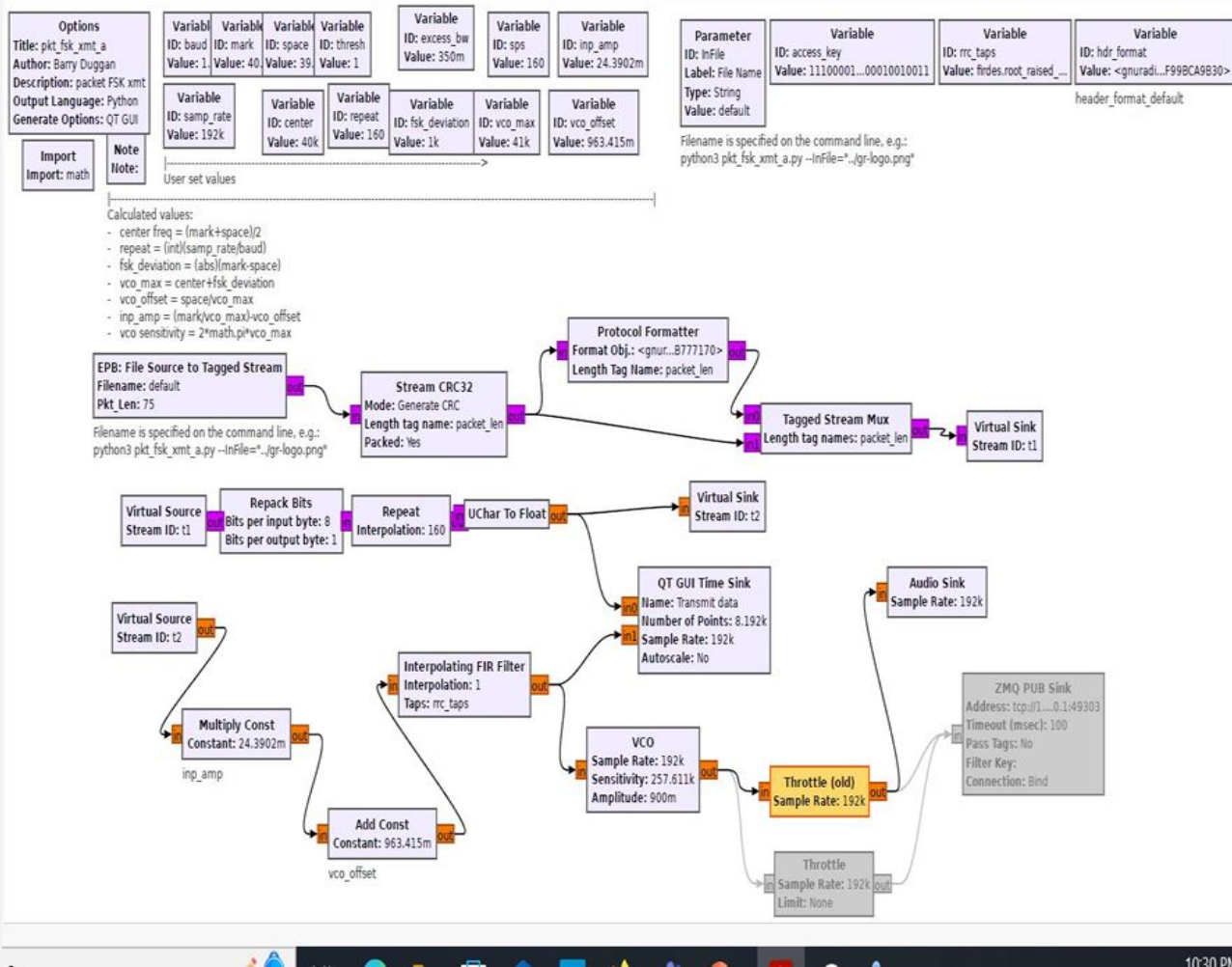
# Equipment and Test tank

Blue laundry detergent used in this test

Image of blue laundry detergent along with the tank and mounted transducer

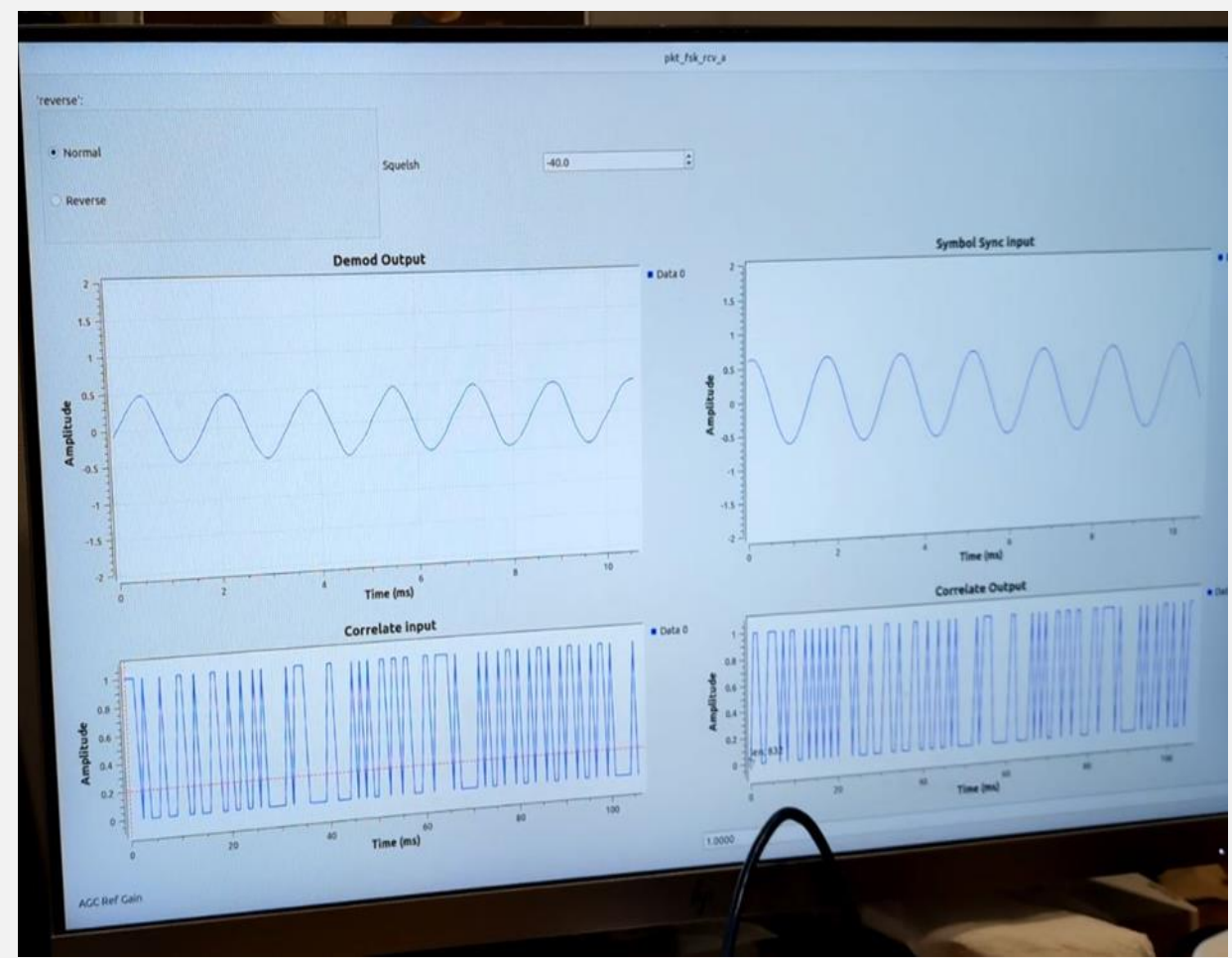
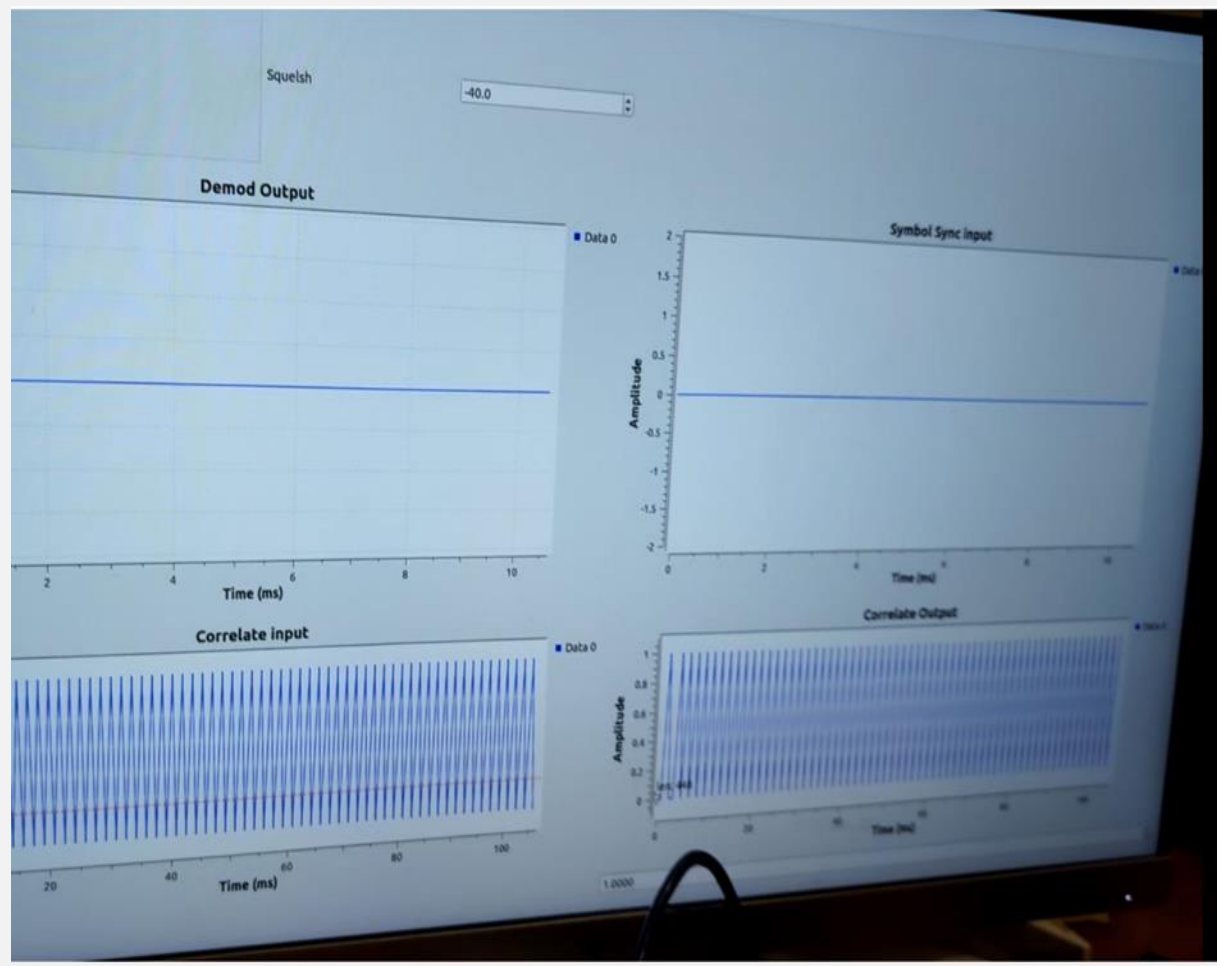


# BFSK Flowgraph used TX and RX





# Graphs showing input & output along with post and preamble







# Using FSK modulation in Air and Liquids. A good solution until the material becomes dense/hard

The following has been tested using BFSK modulation getting good results  
(example and result shown in following slides)

- Air
- Water
- Petrol (Gas)
- Diesel
- Milk
- Orange Juice
- Coke
- Ice
- Laundry liquid
- Washing up liquid
- Wood (pine)
- Steel Rail and plate (failed)
- Rock and hard material (failed)


Can OFDM be used when you have limited bandwidth.

- We have confirmed that FSK is a great solution until we get dense substances such as steel, rock, aluminum, plastics, glass, etc
- We know that tones can be heard in metals like rail for long distances
- Ultrasound is above what people can hear in the normal audio range
- There is less general noise at 40Khz than in the normal range we can hear at up to about 15khz.
- OFDM is normally used in broadband solutions requiring a bandwidth range in Mhz, not Khz
- Transducer have a +/- range of 1khz above and below 40Khz
- The solution is to get transducer with a bigger range, 4khz or 8khz if possible
- Reduce the flow graph to the lowest value without breaking it.

Can OFDM  
resolve this  
issue

- In normal RF transmission, OFDM has been a great benefit to resolve the issues with signal ghosting from multipath.
- Radio and TV reception has improved exponentially as a result, especially in location where there are many structures that can block or reflect the signal
- The sub carriers used are very resilient and are not corrupted easily as opposed to the more tradition transmission protocols
- There are many application using OFDM, Wifi, LTE, TV, etc; xDSL, including ADSL/VDSL use the same structure with Discrete Multi-Tone (DMT) so it can work on telephone twisted pair.
- The OFDM structure reduces the impact that multipath and cross talk have on the transmitted data

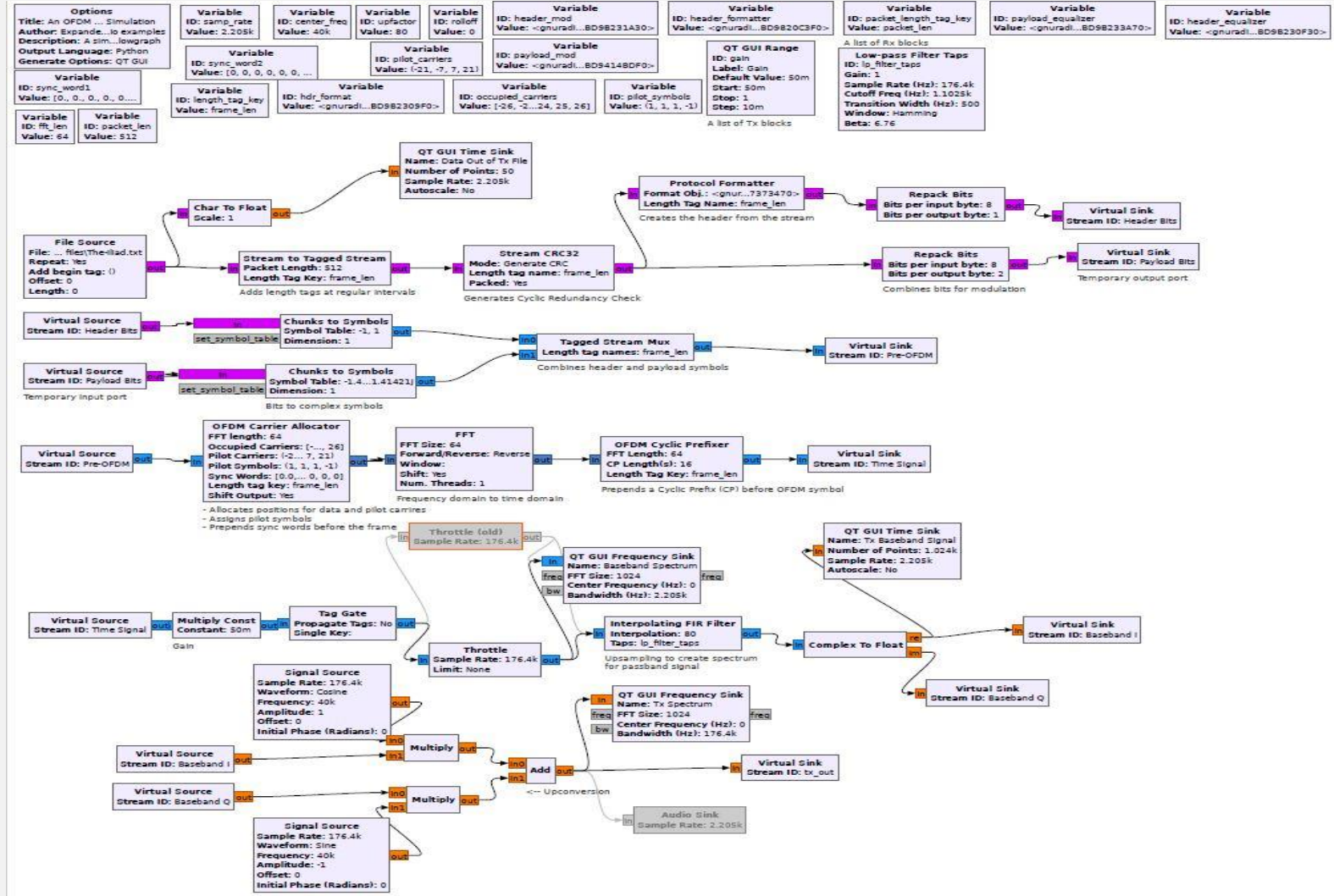




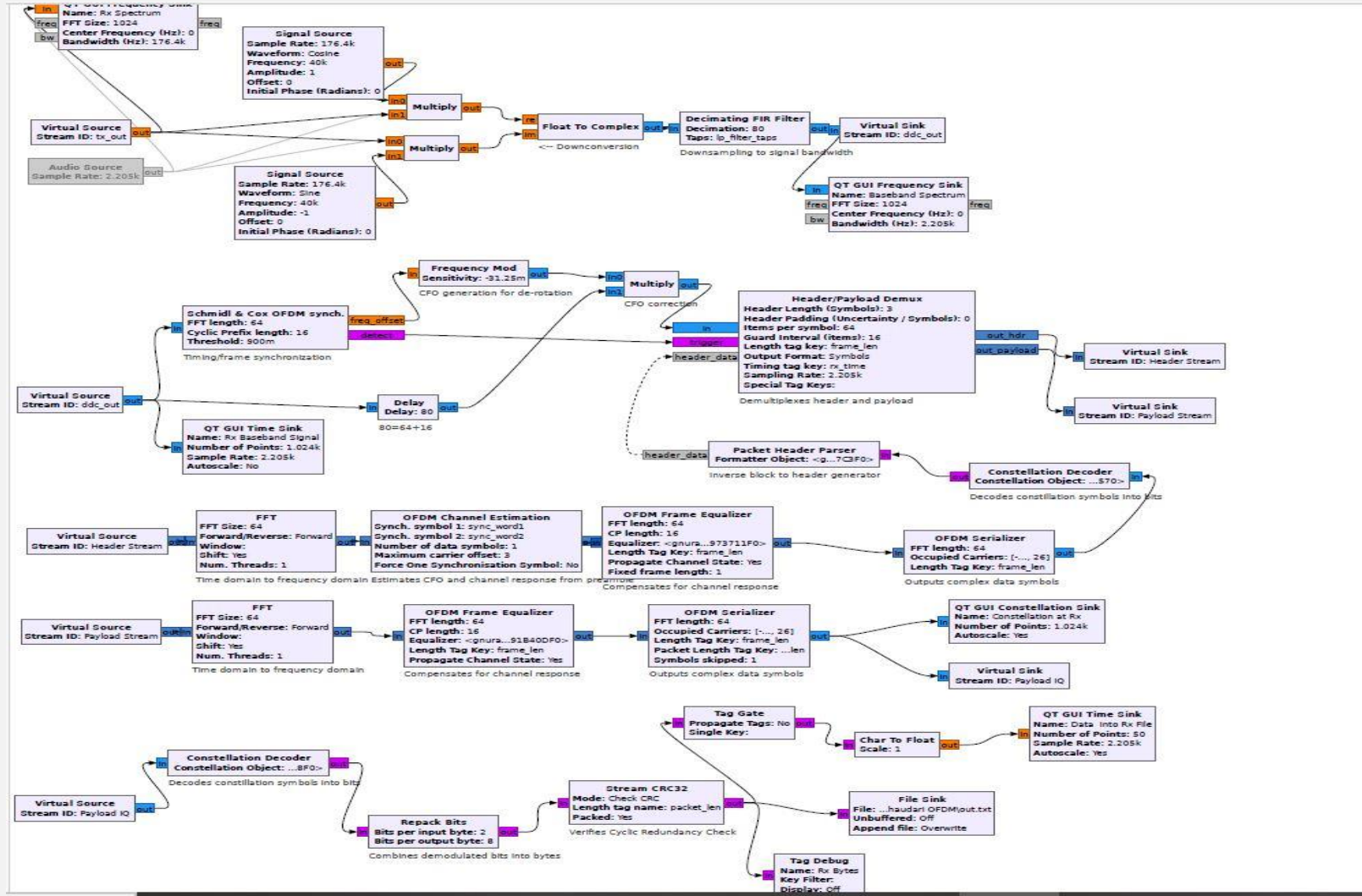
OFDM test  
methodology  
requirements

- Ubuntu Laptop with GNU radio software and sample rate set to 192KHz in pulse audio/root directory
- USB Sound card with sampling rate of at least 192KHz
- Transducer with a bandwidth of 3KHz and center frequency of 40KHz
- Steel rail track with attached transducers and audio plugs
- Text test file to compare the output with the original
- OFDM flowgraph that has been tested using a simulation config.
- The flow graph I used was created by Qasim Chaudari, modified to work with my hardware and is shown on the following slide

# OFDM flow graph showing TX

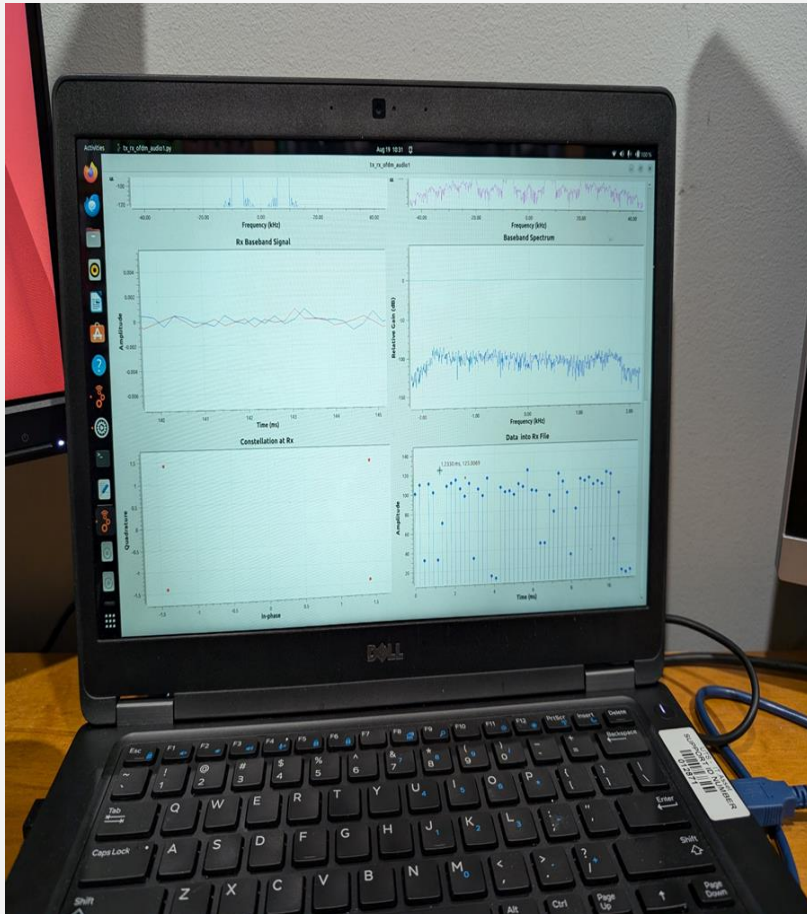


# OFDM flow graph showing RX



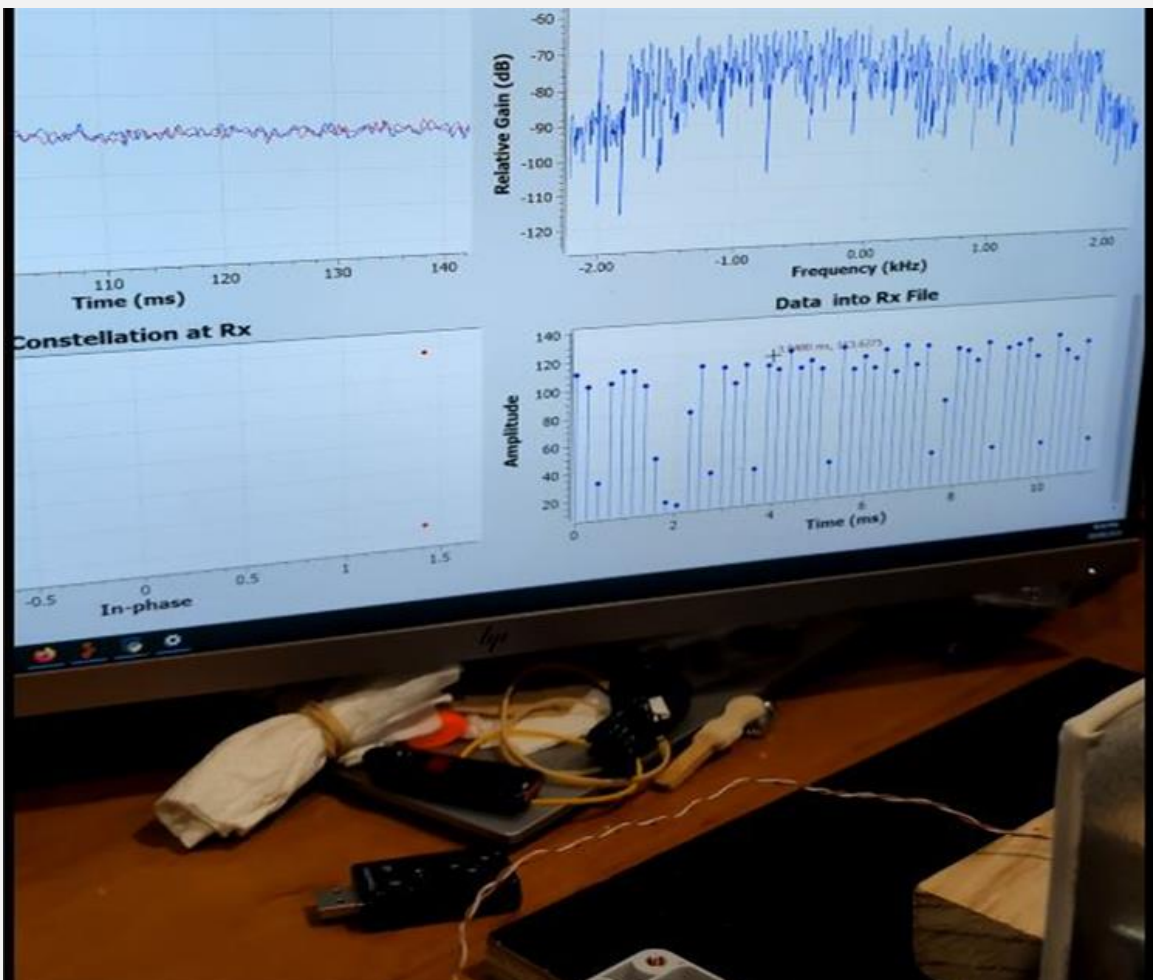
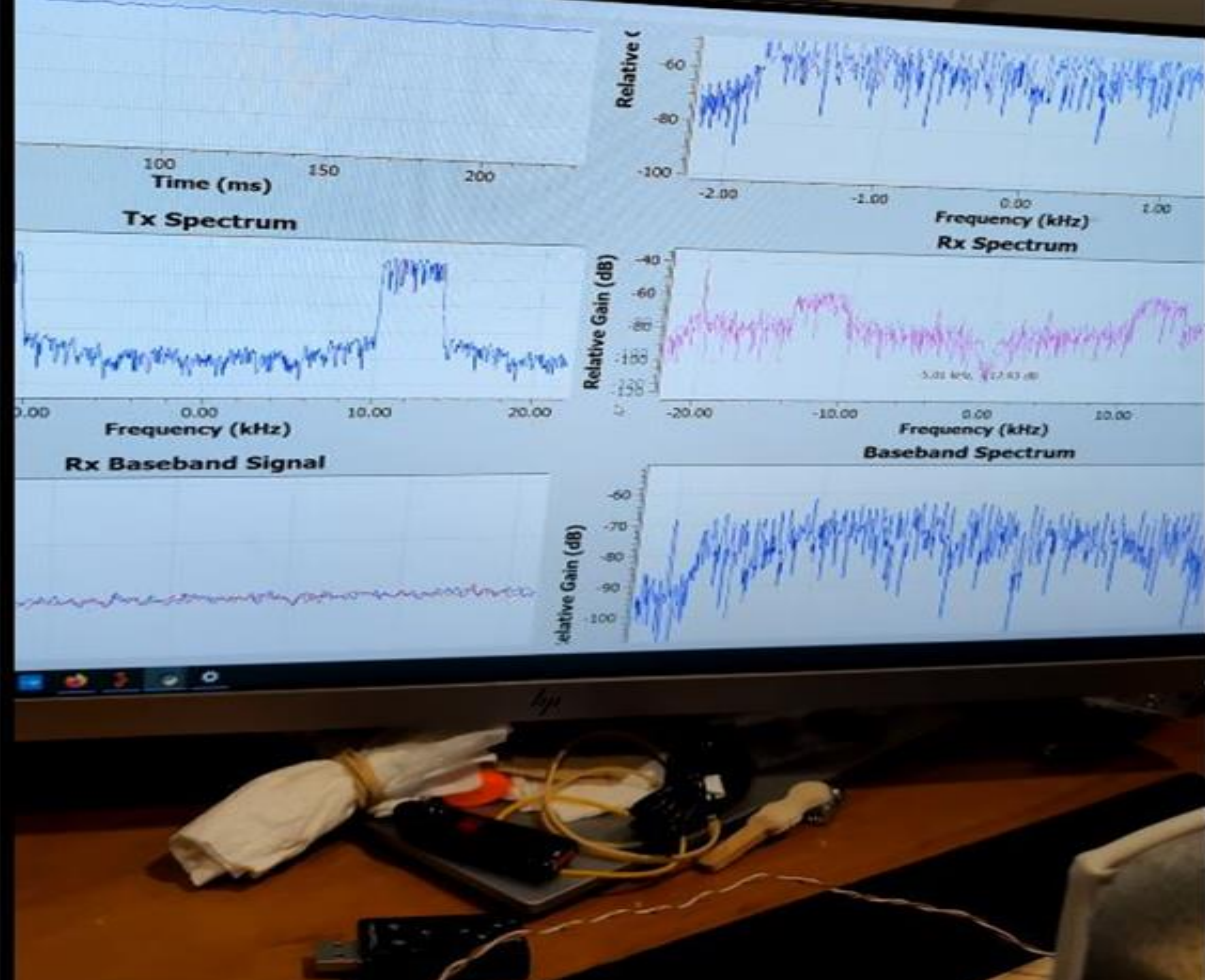


# OFDM test equipment

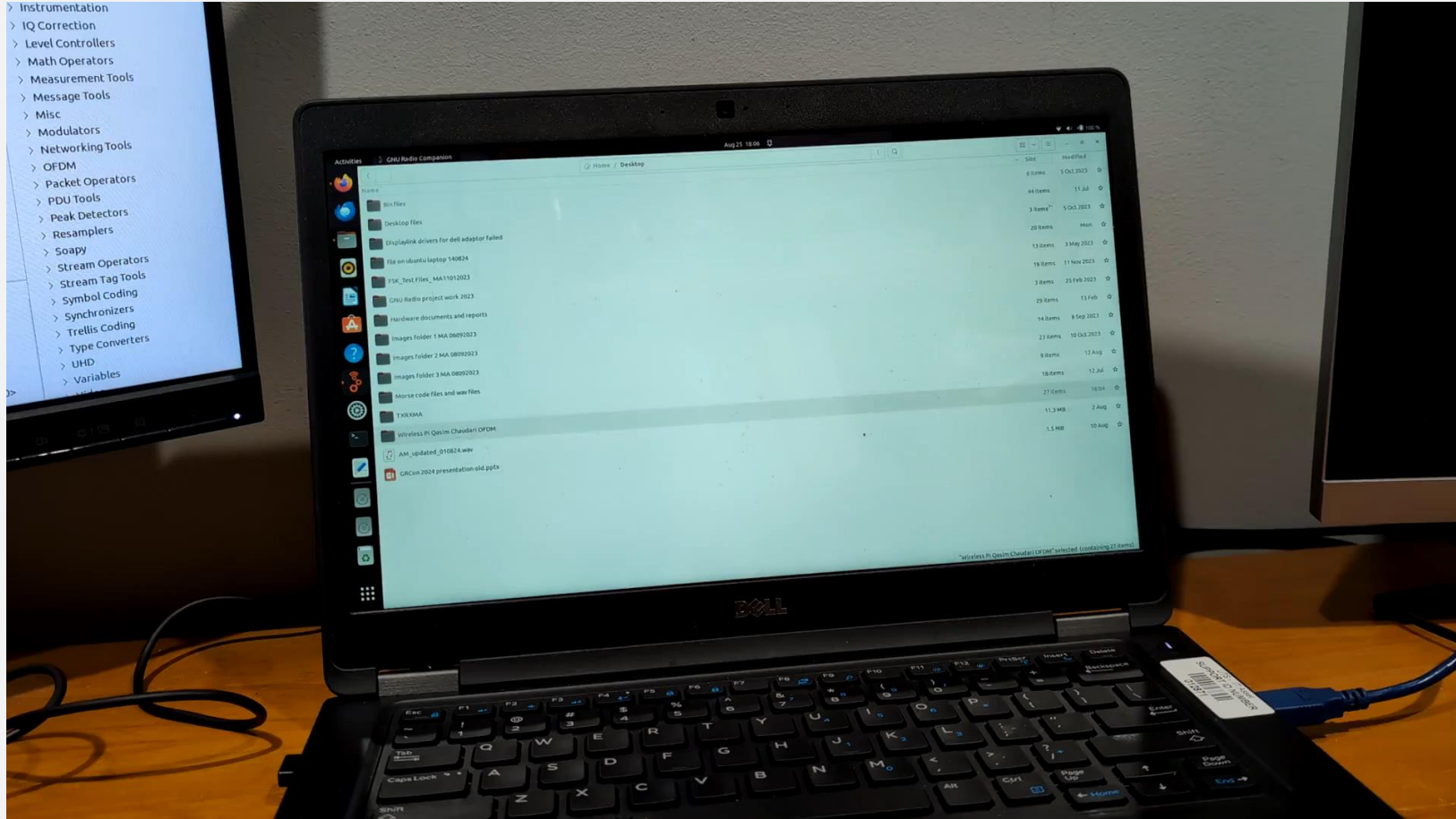




# Graphs showing data transmission including RX stem graph and band width



# OFDM video demonstration using Steel rail





# Text file original and received

## Gettysburg Address

Fourscore and seven years ago our fathers brought forth on this continent a new nation, conceived in liberty and dedicated to the proposition that all men are created equal.

Now we are engaged in a great civil war, testing whether that nation or any nation so conceived and so dedicated can long endure. We are met on a great battlefield of that war. We have come to dedicate a portion of that field as a final resting-place for those who here gave their lives that that nation might live. It is altogether fitting and proper that we should do this.

But in a larger sense, we cannot dedicate, we cannot consecrate, we cannot hallow this ground. The brave men, living and dead who struggled here have consecrated it far above our poor power to add or detract. The world will little note nor long remember what we say here, but it can never forget what they did here. It is for us the living rather to be dedicated here to the unfinished work which they who fought here have thus far so nobly advanced.

It is rather for us to be here dedicated to the great task remaining before us—that from these honored dead we take increased devotion to that cause for which they gave the last full measure of devotion—that we here highly resolve that these dead shall not have died in vain, that this nation under God shall have a new birth of freedom, and that government of the people, by the people, for the people shall not perish from the earth.

Line Break 1

Line Break 2

Line Break 3

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Line Break 1

Line Break 2




Improvements  
that are  
planned

- The FSK flowgraph had a pre and postamble which I am hoping to add
- Tweak of the flow graph to reduce the bandwidth to about 2KHz if possible, without breaking it
- Testing with images and audio files when flow graph is improved
- Testing in other dense materials
- Tabulating the results from this work to find improvement
- Replacing transducer cable leads so it is shielded
- Finding better transducers that have improved characteristic and performance



Thank you to  
the following

- Professor Robin Braun & Dr Zenon Chaczko for their support in achieving these results
- Barry Duggan for help with the software, especially the preamble
- GNU Radio Organizing committee for their invitation to GRCon24
- UTS and friends who work there
- Support from Sydney Trains/TfNSW for time off to attend 
- Family, colleagues and friends

## Conclusion

- Thank you for attending
- I hope you enjoyed the presentation
- My contact details are listed below
  - Question or comments
    - Michael Alldritt
      - Michael.Alldritt@transport.nsw.gov.au
      - Michael.Alldritt@student.uts.edu.au