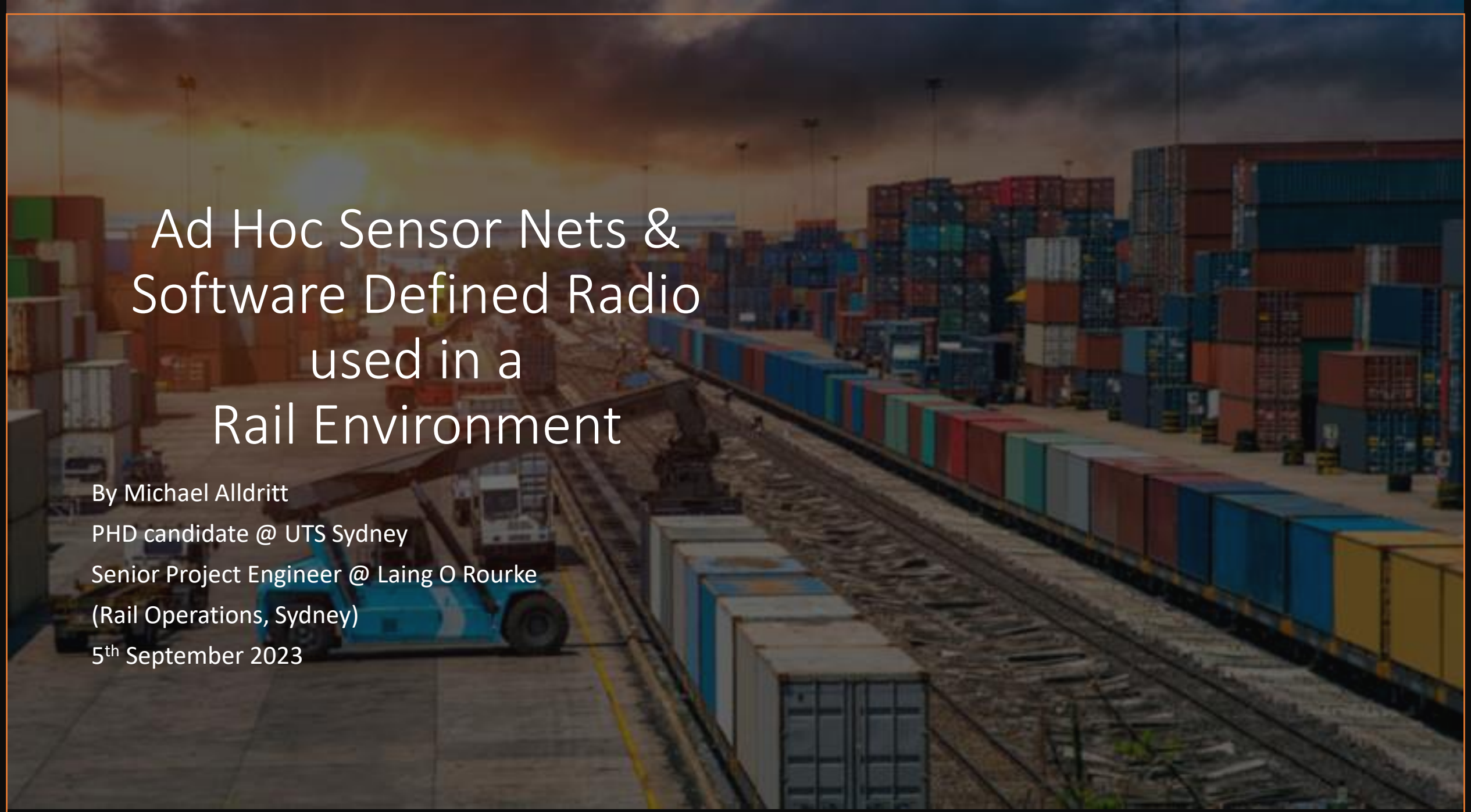

Ad Hoc Sensor Nets & Software Defined Radio used in a Rail Environment

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(Rail Operations, Sydney)

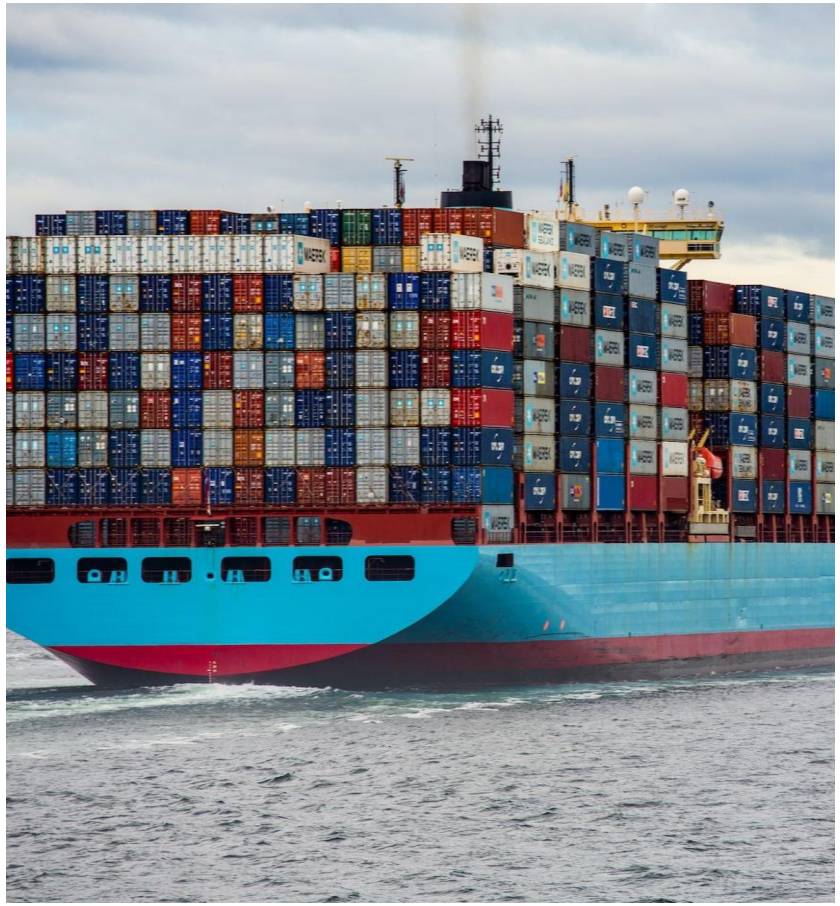
5th September 2023

Introduction (about me)

- Good Afternoon
- My work career
  - Has included communication utilities such as Telecom (Ireland), Telstra (Australia), technology companies including Siemens and Hitachi along with a Railway Operators (MTS/MTR who manage Sydney first driverless train network)
  - My current employer is an infrastructure company called Laing O Rourke who builds railways, power stations, roads, hospitals, etc in Europe and Australia
- My research at University Technology Sydney started in 2019 and extended from an idea using audio to transmit data using ultrasound
- The Ad Hoc shipping network project was initiated by my supervisor Professor Robin Braun, my objective is to create a working prototype using GNU radio (SDR) to modulate and demodulate data at 40Khz air, water and steel
- The original concept was theoretical in nature to create nets using modulated ultrasound, a software solution was novel and innovative with many benefits

Research Background

- Communications devices would connect to each other to form networks, nodes could be created when a certain number of connections had been made
- The application that was considered revolved around shipping container with sensitive and precious cargo, this freight normally had high monetary value
- The environment inside the container would be continuously monitored so it is not damaged. Sensors would capature, temperature, humidity, air quality, gases or venting, vibration, radiation (if required), location, elevation, inclination, etc.
- This logged information would be transmitted to the cargo owner providing regular updates on the status of the freight
- Conventional tracking uses a 4G modem attached to the outside of the container that would connect to the nearest cell network and transmit the data to the owner or shipping management
- When container are stacked, 4G modems on the inside cannot propagate RF (EM) through the stack, however audio frequencies (sound waves) can travel through each container to the outside where its data can be transmitted to the outside world though an node.




Freight Train travelling in outback Australia where mobile phone coverage does not exist
A freight train can be 2km long with more than a 100 cars. Using modulated sound waves, data from each containers can be shared between cars and the drivers cab without expensive hardware or network access.

How this works

- Every container is on a metal car or stacked on a container that is attached to the car
- Each car is connected to another car by a metal coupling
- Each car is on a bogie that is connect to the track
- Sound waves propagate between each car and the container on it
- A device called a **Shipping Container Radio (SCR)** has been developed that can modulate and demodulate data using ultrasound
- The sound waves propagate through the streel enclosure for a short distance and can be received by devices that are nearby
- If every freight metal enclosure on each railway car has an SCR device, each one could communicate with one closest to it
- This is the concept behind how an Ad hoc networks could be created using GNU radio (SDR) as a way to exchange data between the devices
- The communication link can extend to the locomotive where the driver can monitor the container data
- If a container generates an alarm, because the sensors detect heat, fire, water, etc, then the driver can take immediate action to resolve the failure before it spreads

How does sound propagate in different mediums

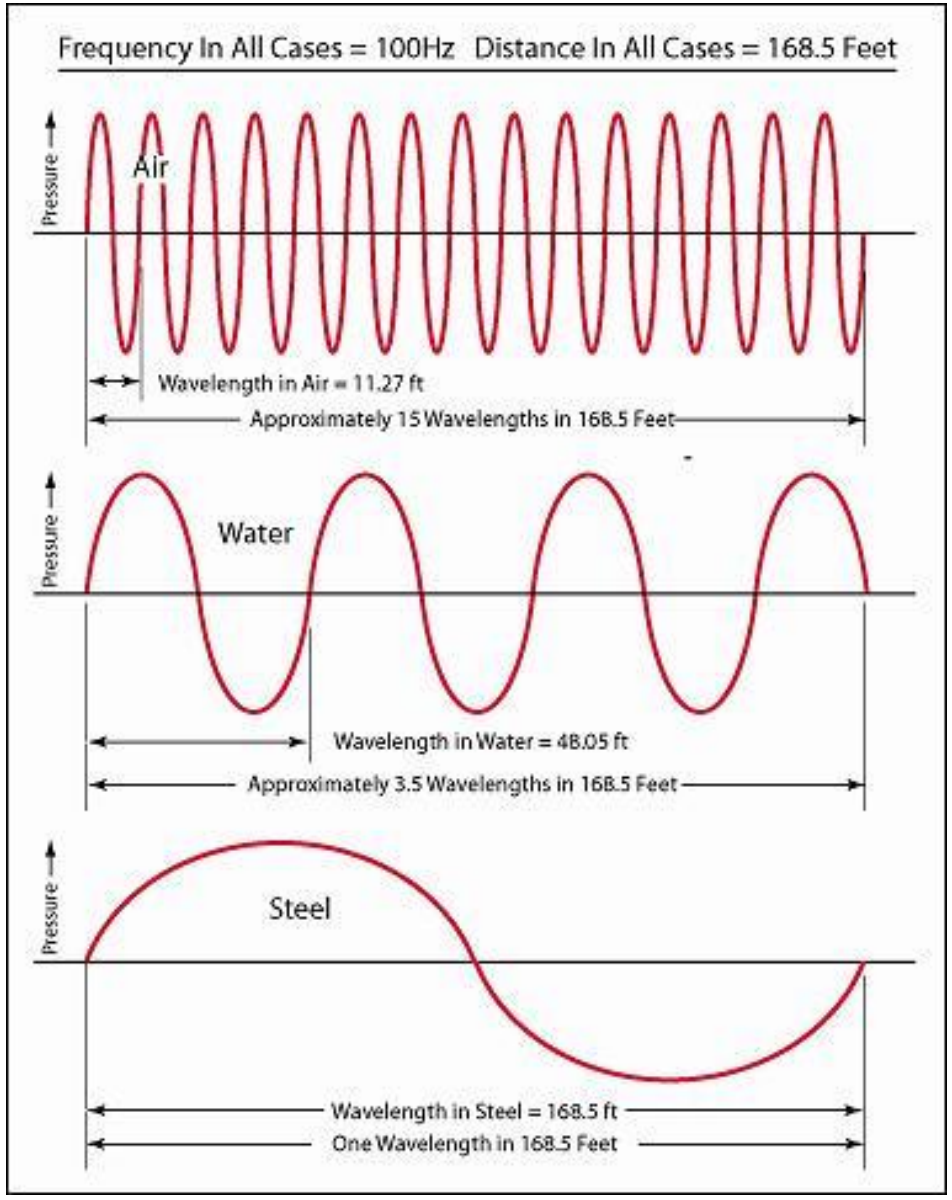
- If a receive transducer is in the sound wave audio path, the wave energy will cause it piezo carminic plate to vibrate in response to the received sound
- This vibration is converted back to an electrical signal by the transducer that is received by the sound card.
- The electrical signal is amplified and resampled to create a complex data stream
- The software blocks with in GNU radio filter out the unwanted component of the signal so the part that remain is the data stream
- This stream has to synchronise with the receiver, a preamble has been created to allow the signal to correlate and start the data read at the correct location
- If it all goes well, the data is captured and can be opened to read the message, see the image or hear the audio

Elongation of sound wave from air to steel

For the target speed of 40Khz the wavelength for each medium is as follows

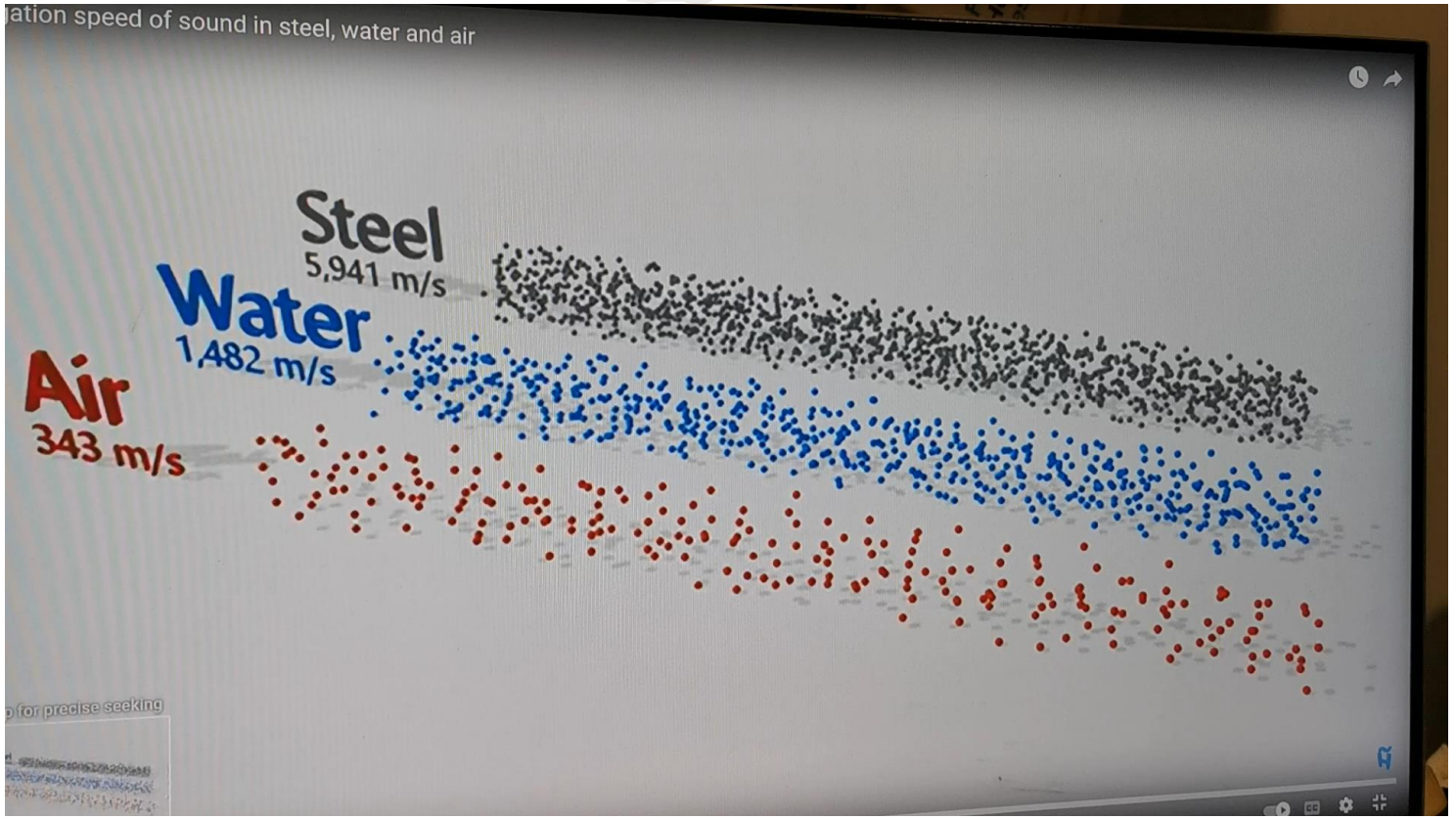
Air is 8.5mm at 343m/s
Water is 37.05mm at 1482m/s
Steel is 148.5mm at 5941m/s
Electro magnetic wave in a vacuum and all mediums is

7500m at 300000Km/sec
(actual result 7494.81)



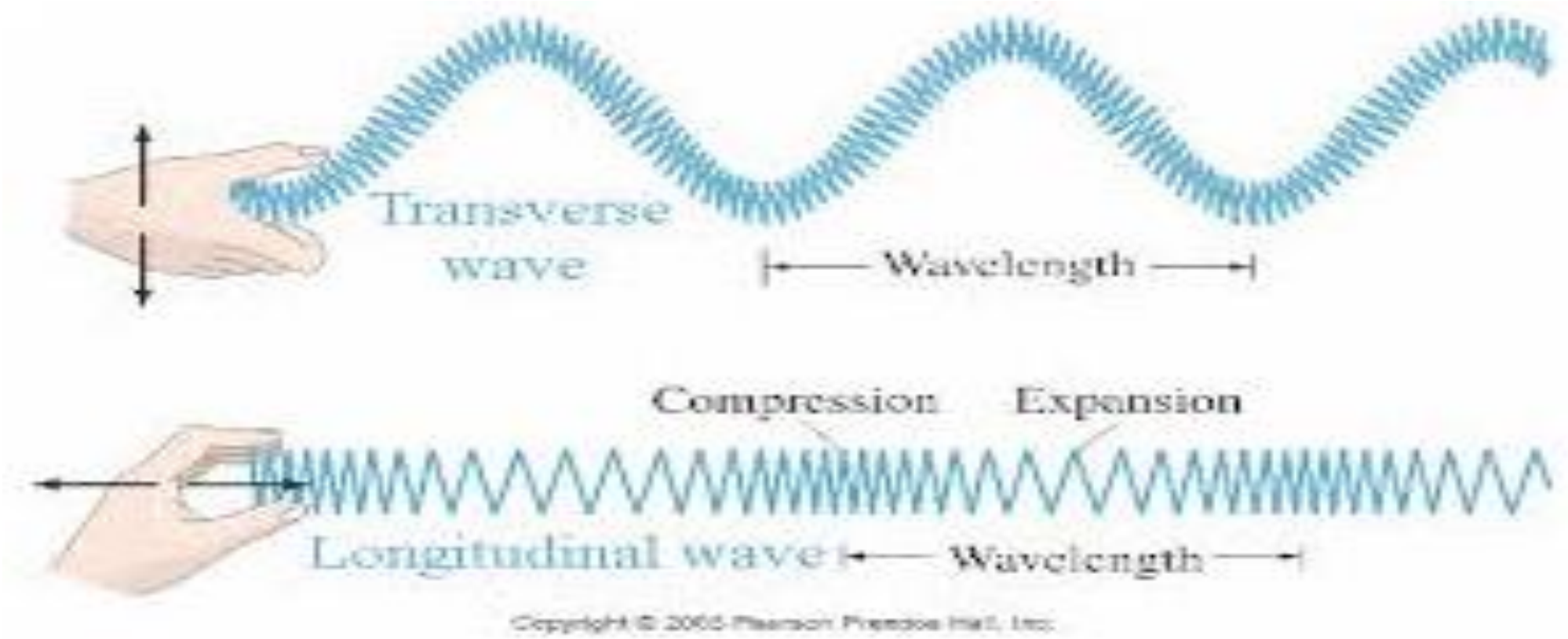
Sound wave video in different material

The waves travel very fast in the steel but take much longer in air. In water the speed is slower than steel but faster than air



Transverse and Longitudinal waves

The difference between a transverse wave and longitudinal wave. In a medium you can have both types, an EM wave will only be Transverse



Modulation Techniques

i. On Off keying (OOK)
   - This is where the signal is switched on and off to correspond to the binary output
   - The amplitude value is 1

ii. Amplitude Shift Keying (ASK)
   - In this test we are only looking at Binary Amplitude Shift Keying (BASK) using amplitude of 1
   - Proper ASK would use amplitude of 2 and 3 to represent all 4 values (00, 01, 10, 11)
   - BASK is the same as OOK

iii. Frequency Shift Keying (FSK)
   - In this test we are only using Binary Frequency Shift keying (BFSK) that is two frequencies
   - The frequencies used are 39.5KHz and 40.5KHz for Space and Mark
   - The ultrasonic transducers filter out all signal below 39khz and above 41khz
   - The bandwidth available is 2 KHz
   - Proper FSK requires more bandwidth, 4 frequencies to represent 4 values (00, 01, 10, 11)

iv. Phase Shift Keying
   - In this test we are only using Binary Phase Shift keying (BPSK) that is two quadrants 0 and 180 degrees
   - The ultrasonic transducers filter out all signal below 39khz and above 41khz
   - The bandwidth available is 2 KHz
   - Proper QPSK requires more bandwidth, 4 frequencies to represent 4 values (00, 01, 10, 11)

Signal to Noise Ratio

This test was conducted to get a usable signal base line

Transmit values table

Raspberry Pi 4 TX Sound Card (Board No 1) and TX Op-Amp					
Distance	Transmit (dB)	Frequency (Hz)	Noise level (dB)	SNR (dB) (TX-Noise)	Comments
10cm	3	40000	-120	123	Very good signal level

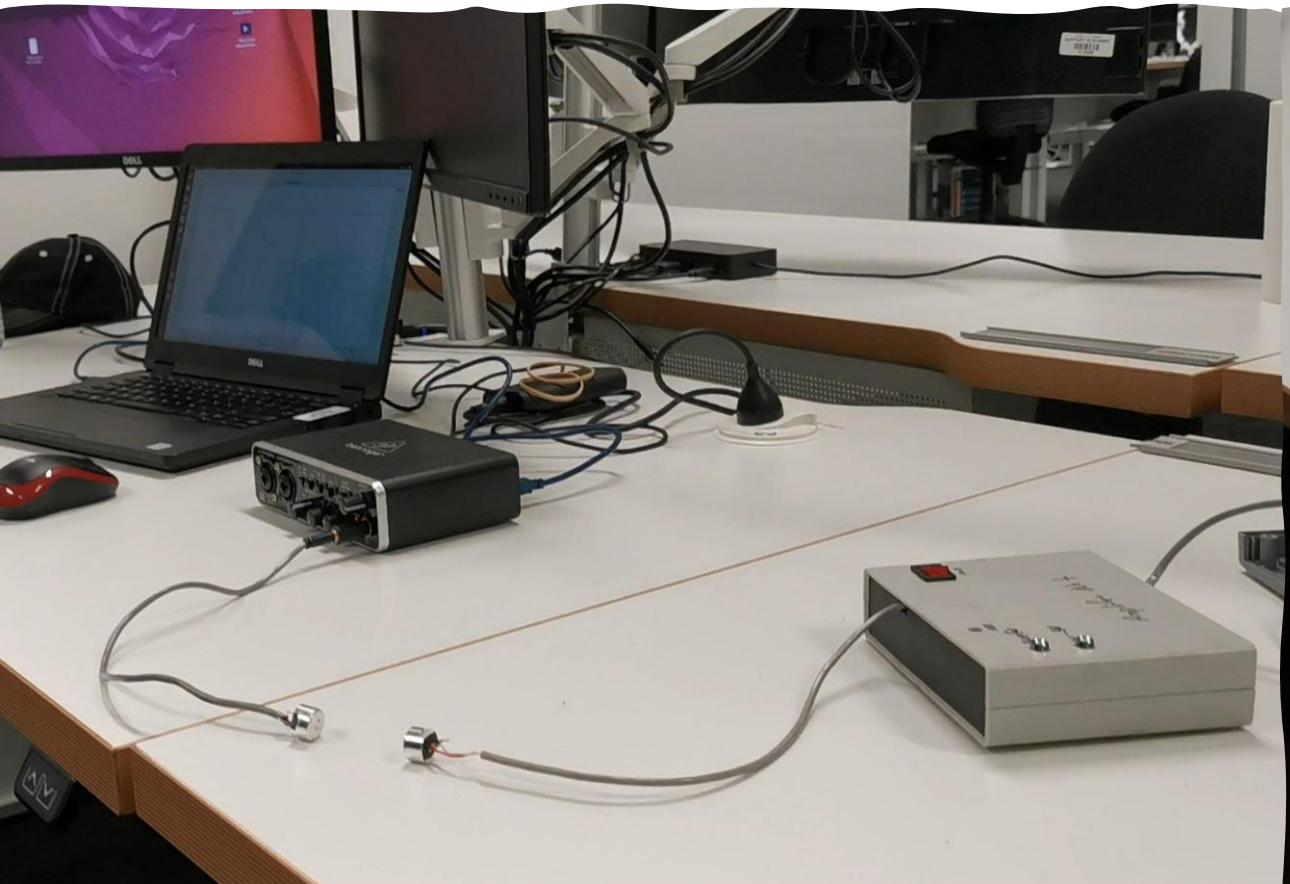
Receive value table

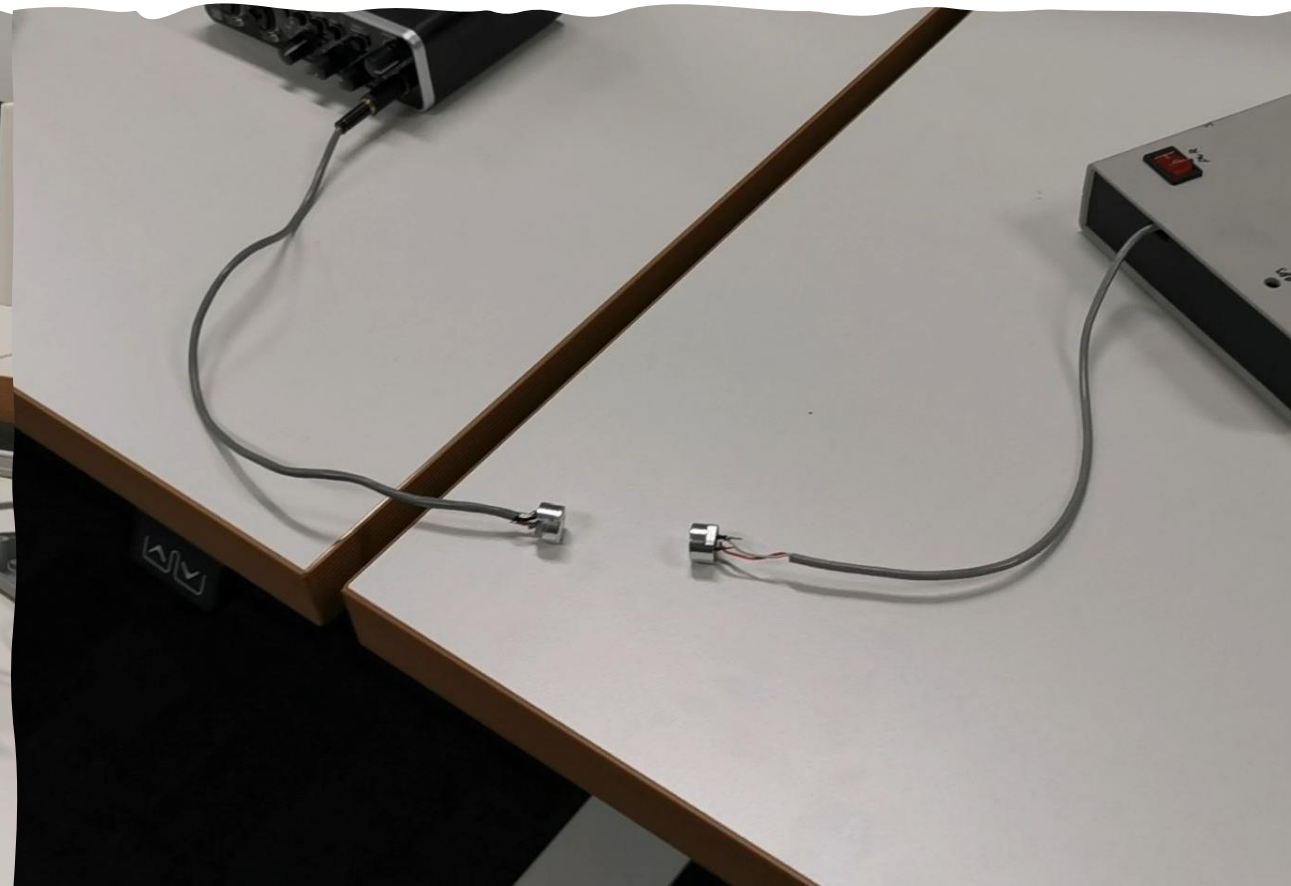
Raspberry Pi 4 RX Sound Card (Board No 2) and RX Op-Amp					
Distance (cm)	Receive (dB)	Frequency (Hz)	Noise level (dB)	SNR (dB) (RX- Noise)	Comments
10	-12.18	40000	-50	37.82	Very good signal level
20	-12.36	39960	-47	33.64	Very good signal level
30	-11.91	39950	-42	30.09	Very good signal level
40	-11.72	39960	-36	24.28	Very good signal level
50	-11.67	39950	-29	17.33	Good signal level
60	-11.93	39960	-28.34	16.41	Good signal level
70	-11.92	39950	-28.31	16.39	Good signal level

TX/RX testing on a section of Rail in 2023

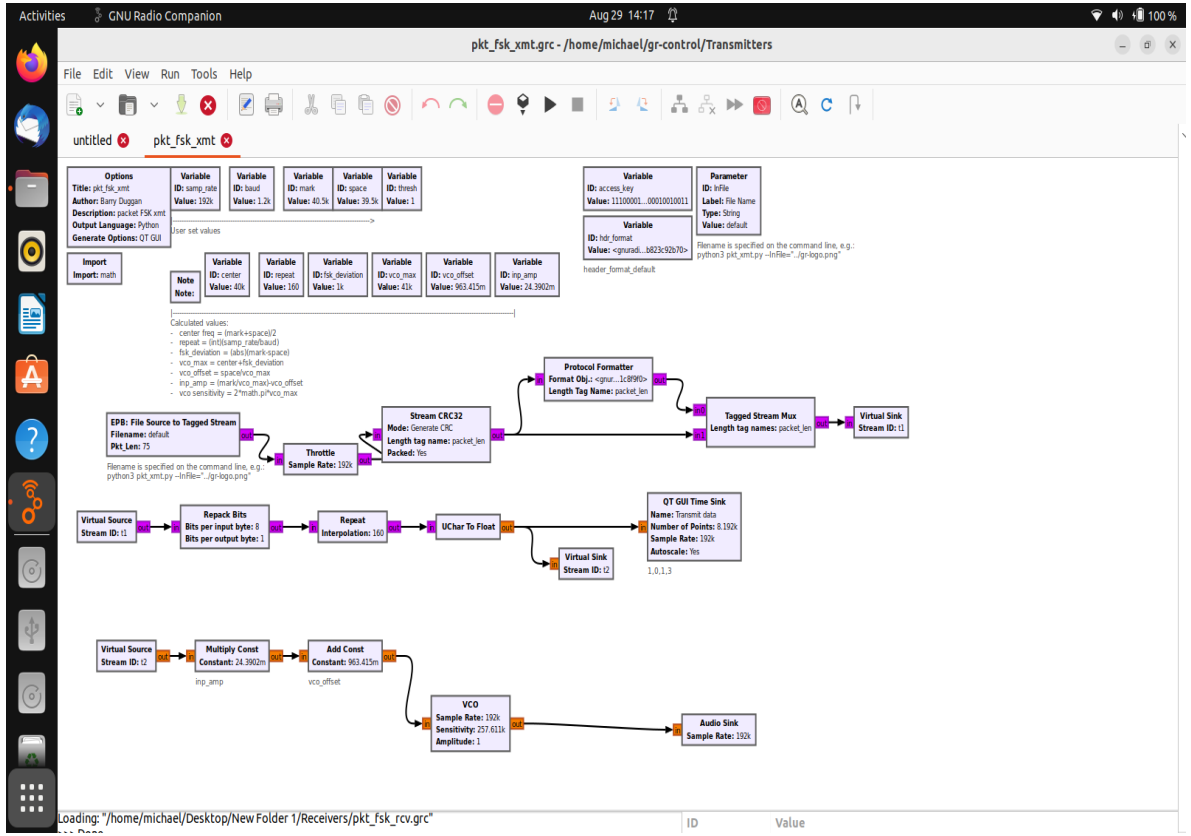
- Preformed tests on a 2m section of rail in February 2023 at my work place
- 2 RP4 were used, they were running Ubuntu (Linux), Gnu Radio and appropriate files for TX/RX
- The rail (weighting approx. 120kg) was mounted on wooden supports and the ultrasonic transducer attached.
- The rail webbing was cleaned to remove surface rust, this allowed good contact between the transducer and the rail track
- Repeating data was modulated on to the 40khz carrier, amplified and transmitted through a transducer where the acoustic signal could propagate into the rail
- The signal from the receive transducer was amplified, fed into the microphone port of the sound card where it was sampled at 192Khz
- The signal was demodulated and displayed on the monitor
- The transmit and receive waveform were compared and the results were very good
- 3 modulation techniques were uses ASK (OOK), FSK and PSK
- The ASK (OOK) protocol appeared to give the best results

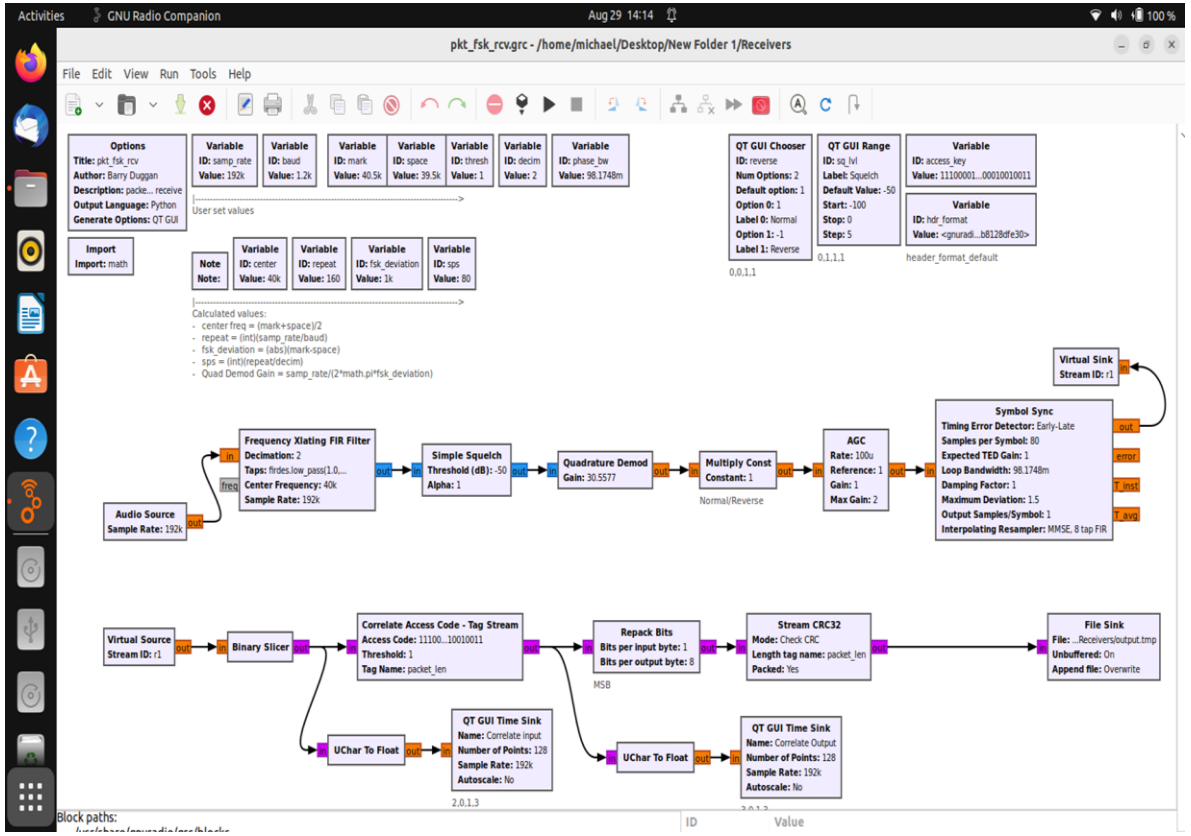
Ultrasonic transducer test in air





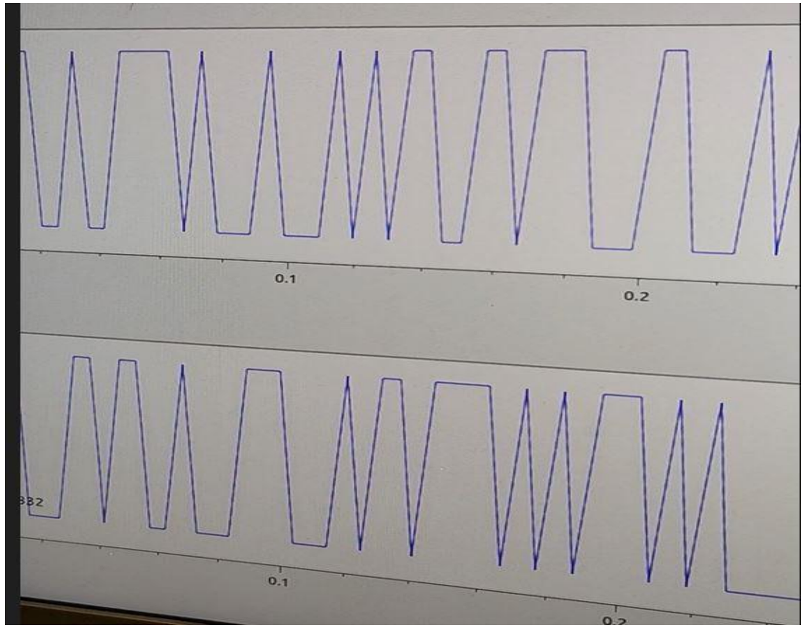
TX and RX GRC files

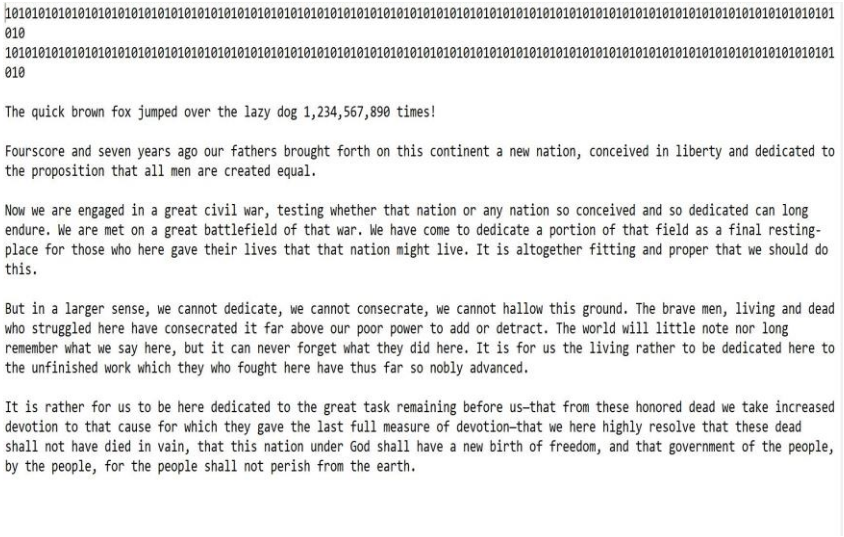




Using software with preamble for first text TX/RX

- The modified software that Barry Duggan created included a preamble was used to transfer a text file
- The preamble allowed the receiver to synchronize and it correlated straight away allowing the target file to build
- I transmitted the text (mostly Gettysburg address) from source to target in air
- The TX/RX rate was 120 baud
- The size of the source file was 2KB
- It took about 2 or 3 mins for the text to be transmitted
- The output.tmp file was a little bigger which included the preamble





1010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101
010
1010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101010101
010

The quick brown fox jumped over the lazy dog 1,234,567,890 times!

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.

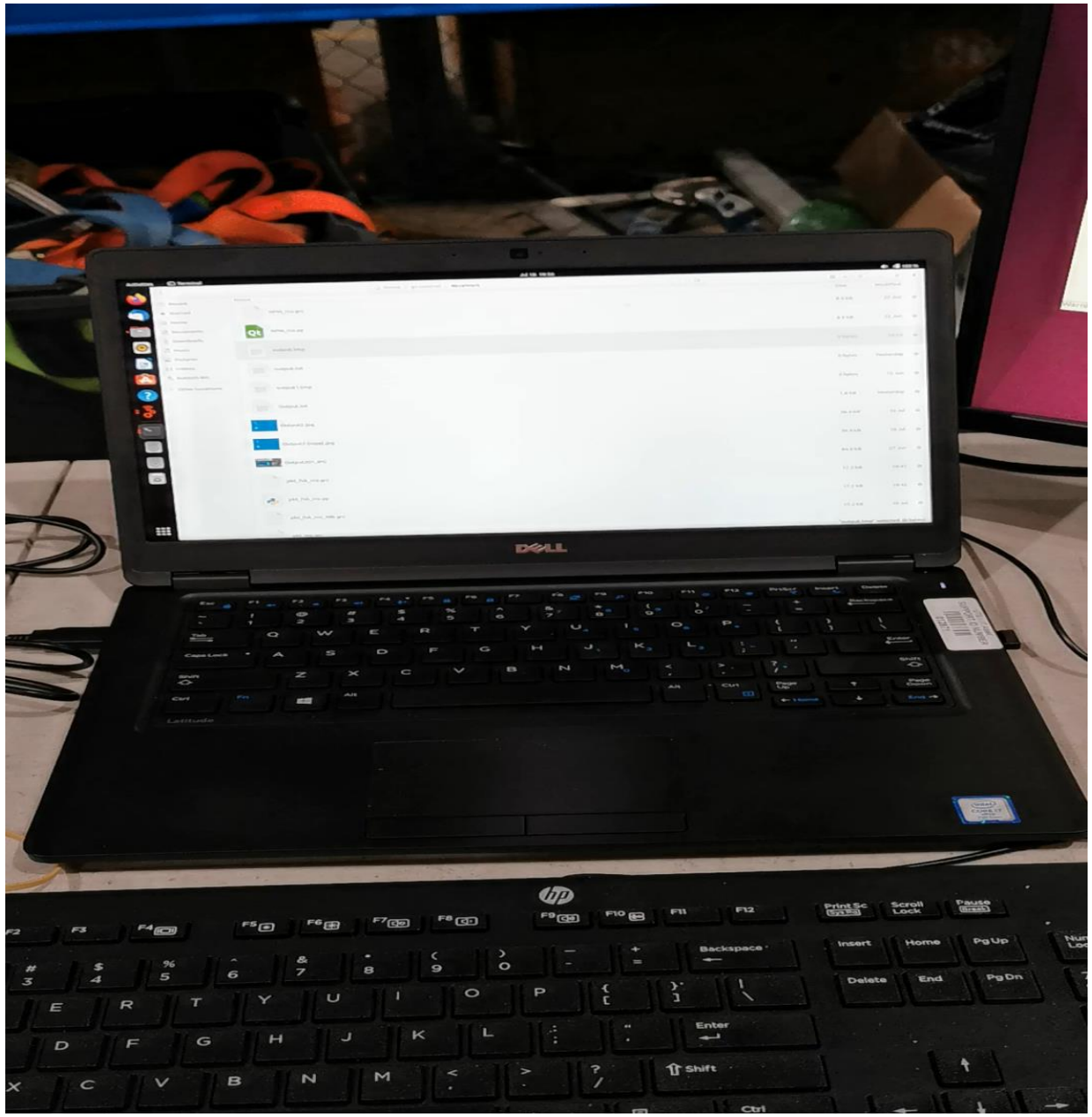
Now we are engaged in a great civil war, testing whether that nation or any nation so conceived and so dedicated can long endure. We are met on a great battlefield of that war. We have come to dedicate a portion of that field as a final resting-place for those who here gave their lives that that nation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

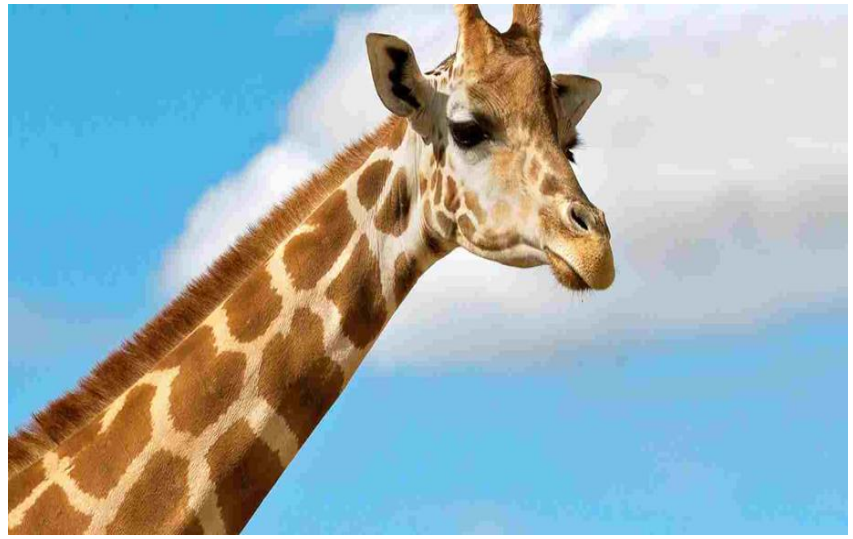
Video TX/RX in AIR

The video show the successful transmittal of an image of a Giraffe from a TX to RX source in air. The image size was approximate 30kBs

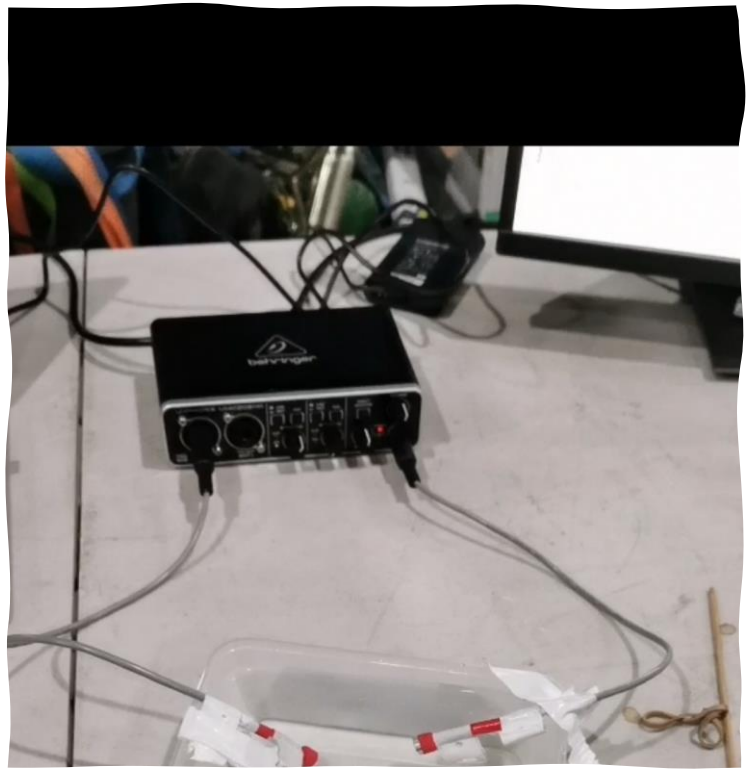


Transmitted Image (Air)

- The image of the Giraffe was transmitted from source to target
- The image size was approximate 30kBs
- The output.tmp file overwrites an target jpg image when the preamble is stripped
- A blue screen test images was used as the target



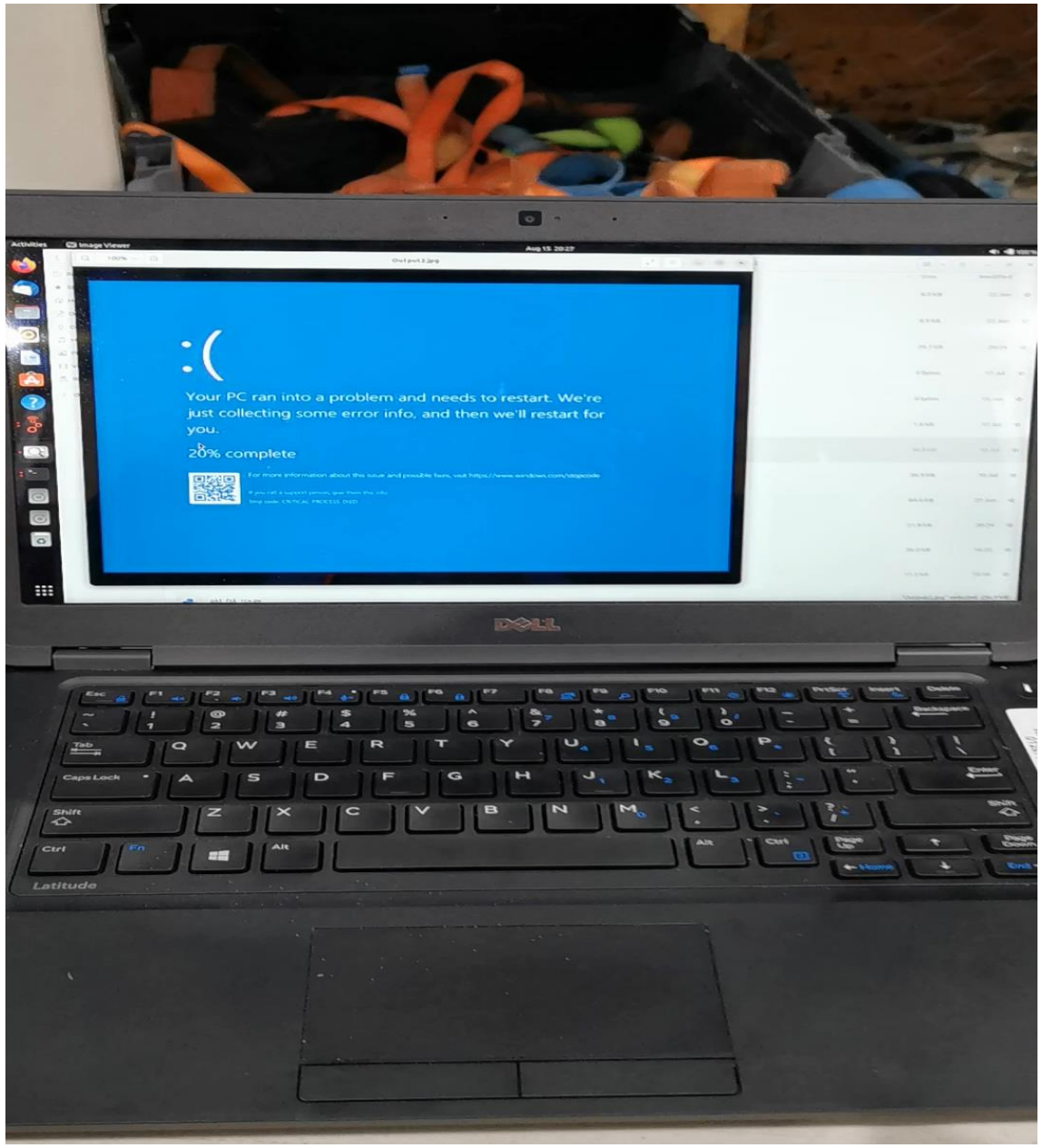
Ultrasonic transducers test in water



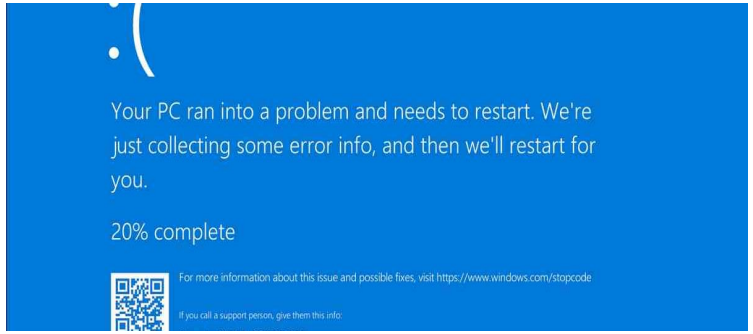
Video TX/RX in water

The video show the successful transfer of an image (chimpanzee) in water

The image size was approx. 30kB



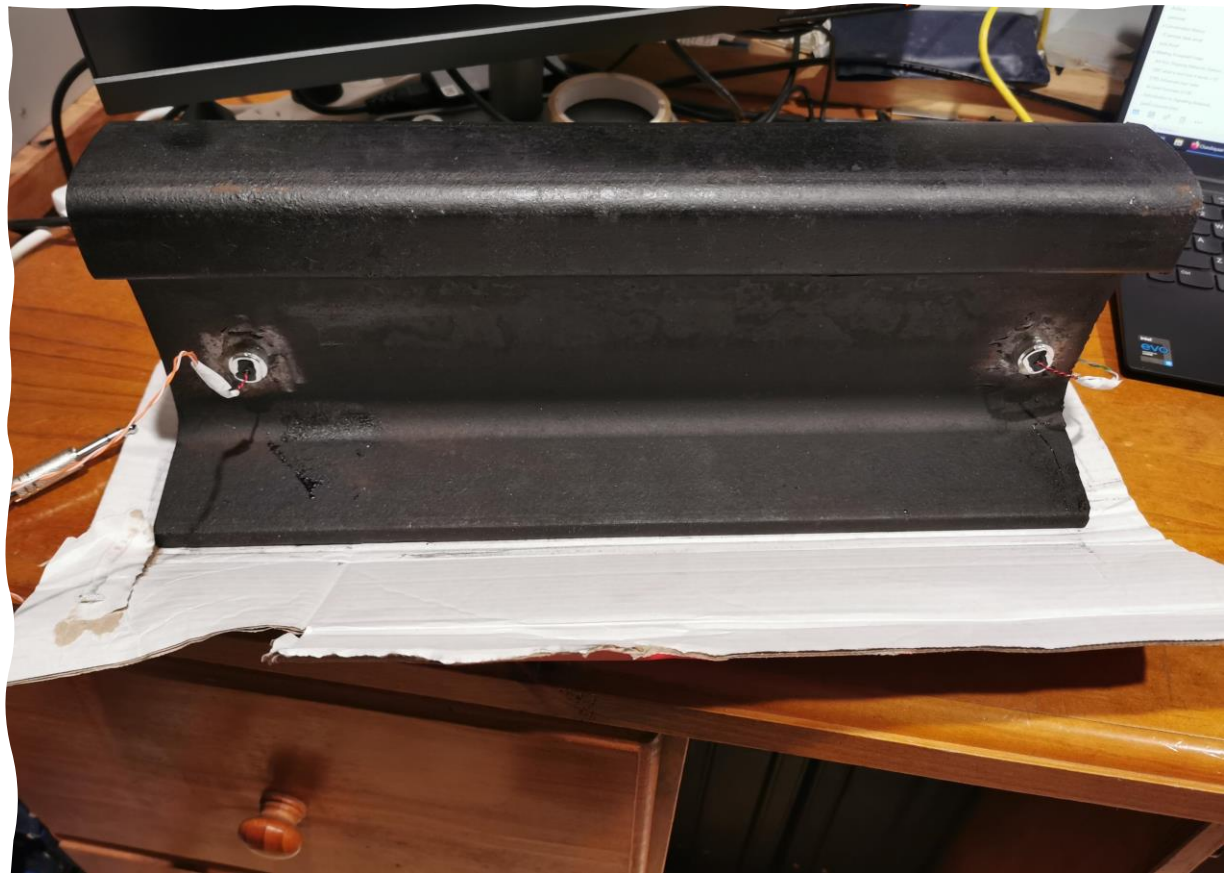
Transmitted Image (Water)



- The first attempt was not successful as can be seen in the image which is distorted. This image size was approx. 80Kb
- I suspect the transducer moved and the test failed
- Better results on the next attempt
- The image of the chimpanzee was transmitted from source to target
- The image size was approximate 30kBs
- The output.tmp file overwrites an target jpg image when the preamble is stripped
- A blue screen test images was used as the target

Short section of 60KG Rail Track (500mm)

- I attached 40khz and 48Khz transducer but was unable to synchronise the data because of the issue mentioned.
- They were tested in air to confirm they worked before getting attached to the rail
- I suspect the type of transducer used may be why the modulated signal is not synchronising
- It is possible a different modulation protocol will improve the results with this configuration
- There is still work to do in this area



Thank you and Acknowledgement

- Professor Robin Braun & Dr Zenon Chaczko for there support in achieving these results
- Barry Duggan for help with the software, especially the preamble
- GNU Radio Organising committee for there invitation to GRC
- UTS and friends who work there
- Support from employer LOR to approve leave 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

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