# Audio Communication Systems

The audio file compressed and transmitted in this communication system is a well-known piano piece of Fur Elise recorded on Youtube [2]. The audio was read as sampled quantized double values, 12 bits per sample. Recorded at 44kHz, only few seconds snippets were utilized to observe and analyze the results due to computational complexity.

The overarching program is ran using main.m. An outline of the hierarchy is shown here:

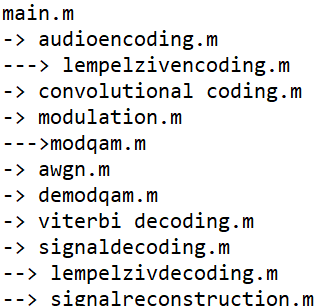


Figure 0: Program Hierarchy

## 1 Lempel-Ziv Encoding

The lossless compression scheme utilized is the Lempel-Ziv encoding scheme that does not require source probabilities ( Pg 280-282). This maps variable-length codes to a fixed-length code. It accomplishes this by populating a dictionary of entries for bits with new unique sequences as they appear in the data. For example, for the sequence of ‘0100001100001010000010100000110000010100001001001', the first few entries are ‘0’,’1’,’00’,’001’ etc. After filling up all of the dictionary entry space, the data appends continues to grab sequential bits until the first largest sequence of data not in the dictionary is obtained. Then the last bit becomes the codeword and the previous bits are replaced by a series of bits for the *location* in the dictionary. If the sequence to encode is ‘01010’ with the fifth dictionary entry of ‘0101’ of a 3-bit compression, then the compression would be 101 0. The 0th entry is reserved for the empty character set. In the compression mapping to dictionary entries results in each sequence being mapped to bits to include the codeword as well.

**Show compression rate at different bits**

The compression rate, defined as the ratio between number of bits after compression and before compression, was found to be roughly 12.5% for a 12-bit mappings.

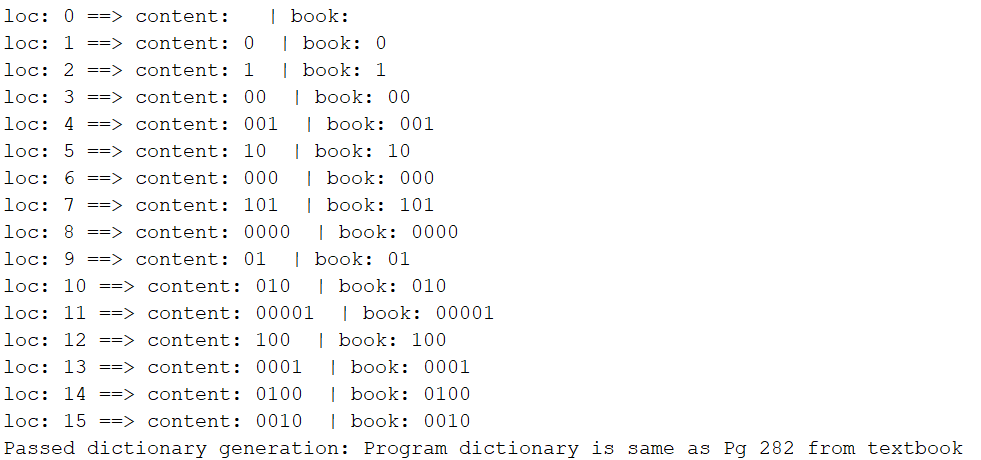
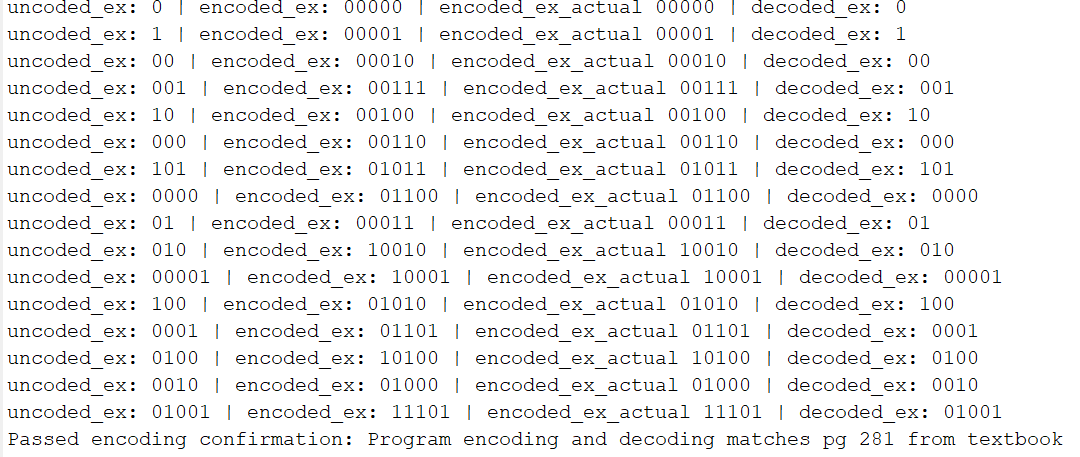
 

Figure 1.1: Test cases from [1] confirmed working for LZ encoding

### LZ Encoding Program

Within, the lempelzivencoding.m function is utilized that utilizes the uncoded bitstream, number of bits, and bits per phrase to encode the data producing an encoded bit stream and the associate encoding dictionary.

The testing work assessed based on known examples from the book. The book utilized the aforementioned sequence to generate a predetermined dictionary for 4-bits that was evaluated. The results of running the test code is shown here **show results.**

## 2 Convolutional Codes

### 2.1 Coding

### 2.1.1 Coding Test

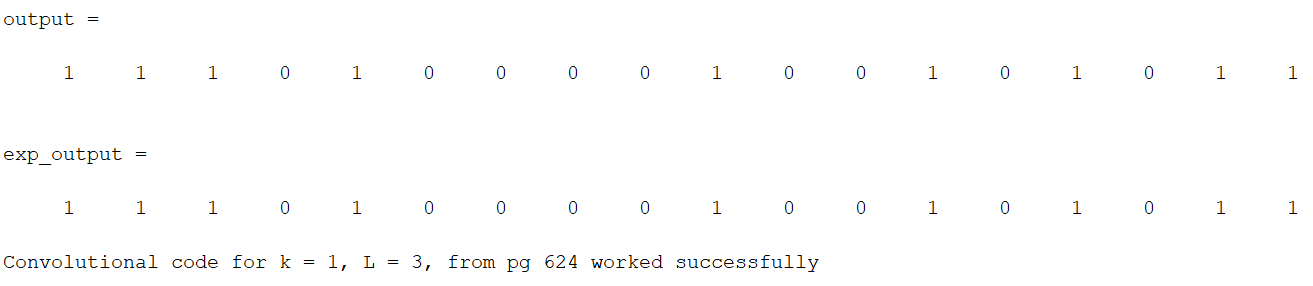


Figure 2.1.1.1: Convolution Code example from [1, Pg 624]

### 2.2 Decoding

### 2.1.2 Decoding Test

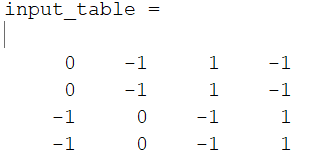
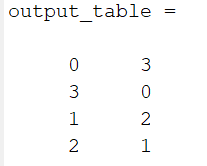
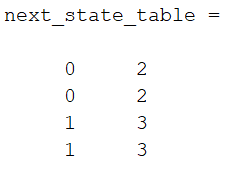
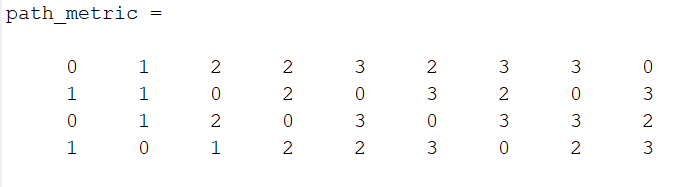


Figure 2.1.2.1: Three tables shown: 1) Next state(NS) table (given CS and input bit) 2) Output Table (given CS and input bit) and 3) Input Table (given CS and NS) returning the input bit or not possible(-1)



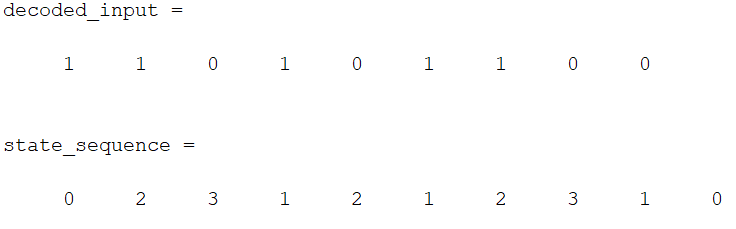


Figure 2.1.2.2: Dynamic Programming of Hamming distance Path Metric at each state within each stage that is used to reverse the state sequence history and decoded input

## 3 Quadrature-Amplitude Modulation

Quadrature-Amplitude Modulation (QAM) [1, Pg 357-360] is a bandpass modulation that encodes the data in both the amplitude and phase. As compared to PSK and the likes, each symbol does not have equal energy, but it allows a higher bit rate at a specified power.

### 3.1 Modulation

QAM has a constellation diagram shown in Figure 3.1.1 where each point is always at least a certain distance away from any other point so it is shaped as a square. Treating the in-phase(I) and quadrature(Q) component as a complex number, the magnitude and phase for ith codeword, is . The bandpass signal is modulated into the signal given an amplitude A, window function , carrier frequency , and carrier phase . Also shown below, the amplitude and phase can be written as a sum of two oscillators shifted by 90 degrees as separately amplified cosine and sine waves.

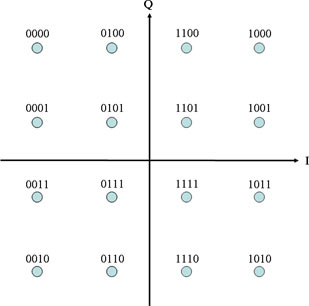


Figure 3.1.1: 16-QAM example.

A 16-QAM modulation scheme was chosen that transmits 4 bits with each symbol. The carrier phase was set to 0 in this project and synchronicity was assumed for simplicity. The window function is a pure window with no regard for phase discontinuity in the transmitted signal. For a symbol period of , 4 bit are transmitted for a bit rate of . Four codewords were transmitted and plotted for example.

In the program, the function modulation.m that takes the bitstream, sample frequency, modulation scheme, and associate parameters is used that runs the modqam, currently only setup for 16-QAM that takes in the before variables plus additional parameters: bitstream, amplitude scaling, M-ary setup, carrier frequency, symbol period, and sampling frequency.

The test code verified successful QAM modulation, how two symbols appear, showing via simulation the amplitude and phase vs in-phase and quadrature results, and showing the output of correlator to an example, and finally generating BER and SNR curves for QAM alone.

### 3.2 Demodulation

The demodulation assumes an accurate carrier phase estimation or locking. The analysis with a phase offset produces detrimental effects on the SNR which is understood for observations but will not be implemented in the system. Given the synchronicity assumption, windows of the received signal is correlated with the in-phase and quadrature basis functions, and scaled appropriately to the below equation from continuous to discrete domain and correlation. The energy of the gate function that has value of 1 from. The output of is an estimate for I and Q constellation point respectively. With the below equation, in the absence of noise, the constellation had accurate correlate value. The respective I and Q point are then compared with distance to all constellations and chosen whichever Euclidean distance is smallest.

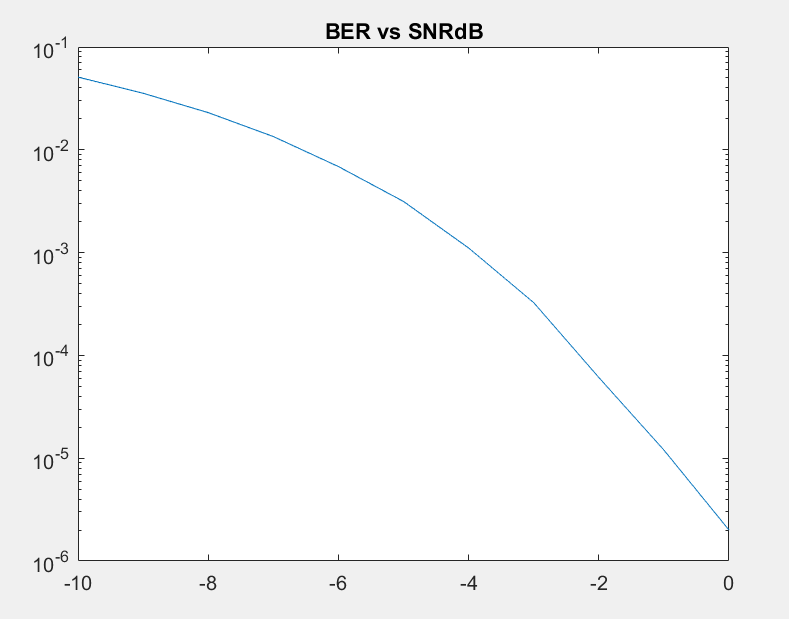


Figure 3.1.2: BER vs SNR for QAM

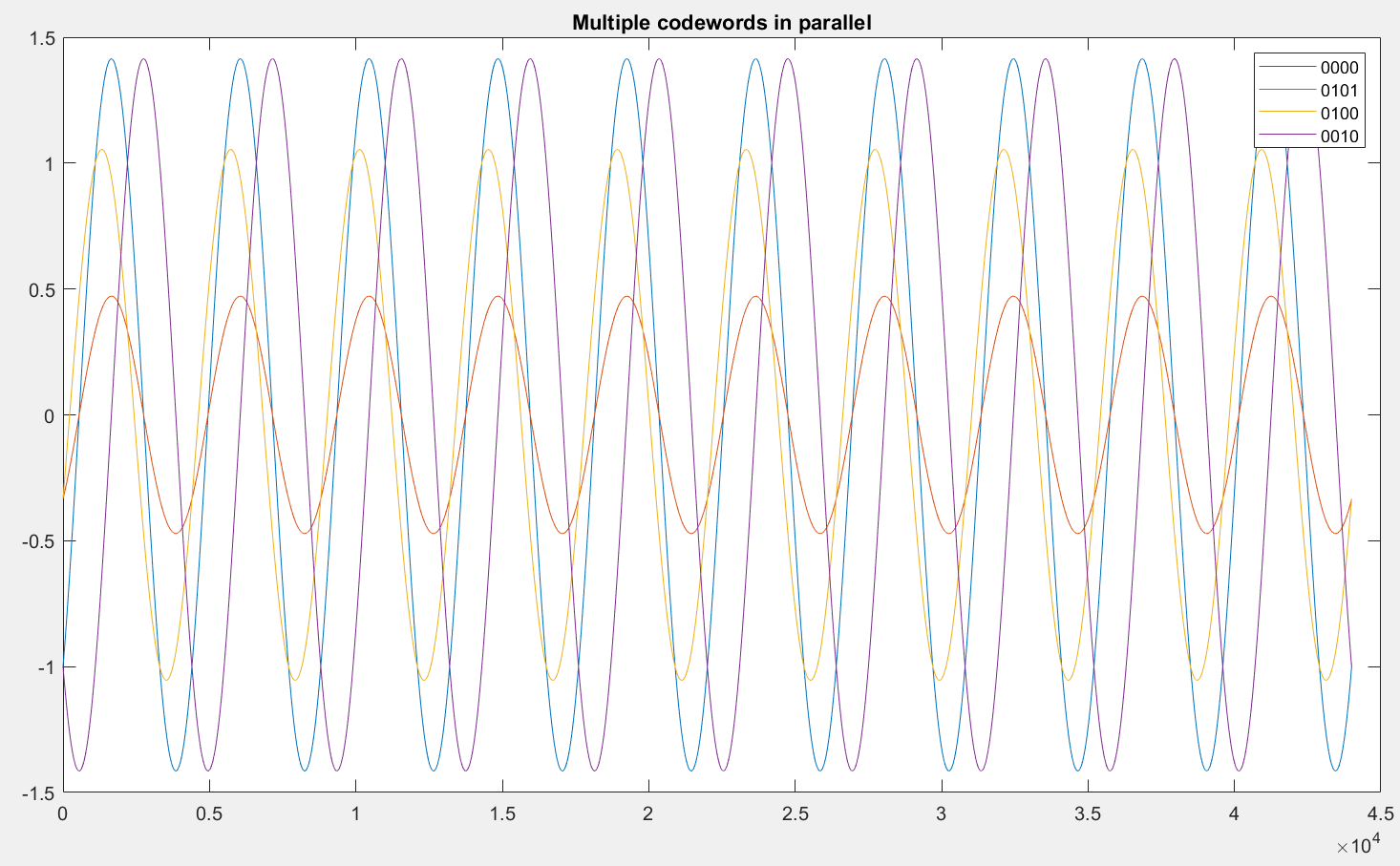


Figure 3.1.3: Time-domain output of QAM overlapping for different codewords for comparison. 0101 and 0000 have same phase but different amplitude for example.

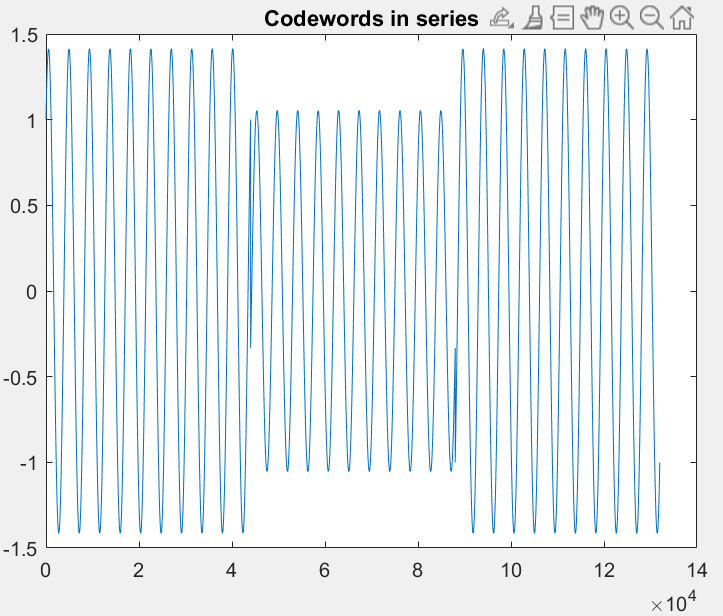


Figure 3.1.4: Codewords in series showing phase discontinuities at window edge due to perfect gate windowing.



Figure 3.1.5: Few I and Q components demodulated for comparison of result.

## 4. Channel

The channel is a simple additive white Gaussian noise(AWGN) channel for explicit analytical solution. A specified SNR in decibel determined the additive noise while keeping the transmitted signal constant.

## 5. Conclusion and Future Work

In conclusion, this project gave the opportunity to not only learn the theoretical material in communication system engineering, but also apply, via software, and observe various effects on the result. The Lempel-Ziv encoding scheme was popular in the late 1900’s widely spread amongst computers, during the time of the textbook’s release. It was used in many sources from that time such GIF, PDF, and more, but has been beaten by other compression techniques like in gzip that produced better ratios. The compressed bit stream is then encoded for stronger strength and separation in convolutional coding.Afterwards, QAM is applied that is widely used in networking devices like WiFi, cable television, and more. 5G emergence implements Orthogonal Frequency Division Multiplexing techniques that has roots from QAM and Frequency Division Multiplexing [5].

Future work on this project can include implementation of alternatives. This can include another audio encoding that transmits parameters such as Analysis-Synthesis Technique, or an alternative coding with Turbo Codes, or the newer Polar codes. For Modulation, implementing OFDM would be interesting to observe. On a similar vein, as QAM modulate a sinusoids parameters of amplitude and phase, OFDM modulating amplitude, phase, and frequency. In the detection and estimation class had works from Stoica found an algorithm to develop an estimator for Cramer-Rao lower bound on these sinusoidal parameters. Especially for the carrier phase issue mentioned, one such approach could be applied as an alternative to synchronization and phase lock loops.

## 6. References

[1] Communication Systems Engineering, 2nd edition, by Proakis

[2] Fur Elise Recording: <https://www.youtube.com/watch?v=_mVW8tgGY_w>

[3] QAM image: <http://ecelabs.njit.edu/ece489v2/lab5.php>

[4] Lempel-Ziv Uses: <https://en.wikipedia.org/wiki/Lempel%E2%80%93Ziv%E2%80%93Welch#Uses>

[5] 5G OFDM: <https://www.5gtechnologyworld.com/the-basics-of-5gs-modulation-ofdm/>