Addendum – Quantized Time-Scale Hologram

Inventor and Author: Lawrence Byng
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During development and testing of the LB28 I3 modes that utilize pulse train standing waves, specifically the testing of fixed absolute phase recovery with extrapolation, it has become apparent that not only are these effective techniques for phase recovery, but that the signal produced by the interposed three phase signal generator is in fact a quantized time-scale hologram with some very useful properties. These include:

- increased resilience to phase noise
- characters in the message having the appearance of being locked together or entangled thus eliminating phase drift
- ability to take multiple samples from the hologram to further enhance noise resilience by averaging out the noise.

This document aims to explore these capabilities of the I3 modes and the related noise reduction techniques.

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Quantized Time-Scale Holographic Photons / Phonons

Utilizing pulse train standing waves for phase extraction requires a signal generated by the interposed three phase signal generator or similar as detailed in the earlier published LB28 design document.

The signal generated by this process is analogous to a time-scale hologram and can be thought of in similar terms to that of a photon or phonon...i.e. a packet of light or sound quantized by the number of pulses in the packet; depending on weather the transmission utilizes electromagnetic waves or sound waves, the process is somewhat similar. For electromagnetic waves, the signal creates a quantized time-scale photon hologram and for sound waves it creates a quantized time-scale phonon hologram.

The hologram / observer have two degrees of freedom; time and scale. These translate to the disposition i.e. the start of the decoding process relative to the signal start representing time and the number of pulses utilized in the pulse train for a specific decode representing scale.

The hologram can be processed from multiple perspectives. The number of permutations / perspectives is derived from the triangular number for the given mode. For example a mode with 64 pulses per block, i.e. 32 pulses per 3 bit sequence has T_{32} or 528 permutations. In reality, this number is T_{32} -3 as the pulse train length is truncated to a useable length of pulse train length divisible exactly by 3.

Any of these 525 permutations can be used to make a successful decode. The more noise resilient decodes are from signals that contain the highest number of pulses.

Extrapolation

Extrapolation to acquire a single sample with the maximum number of extraction points has proven not only that the three phase signal functions as a time-scale hologram, but has also proven to be a highly effective method to further reduce noise and increase signal decode accuracy. However, regardless of the signal to noise ratio, extrapolation of a single sample, although highly effective, is not yet sufficient to achieve a 0.0 BER over a tested 348 bit sample; in combination, all of the techniques described are able to bring the decode to a level near 4 e^{-3}. Interestingly at high SNR the 1 or 2 bit errors always occurred at exactly the same place in the test with the same character sequence for example ck often resolved to dk. This is a future area for further research to determine how character sequencing impacts the decode and to test if techniques such as differential encoding and gray codes are the answer for this method of phase extraction.

Additional techniques such as forward error correction have been successfully incorporated to increase decode accuracy even further.

Forward Error Correction

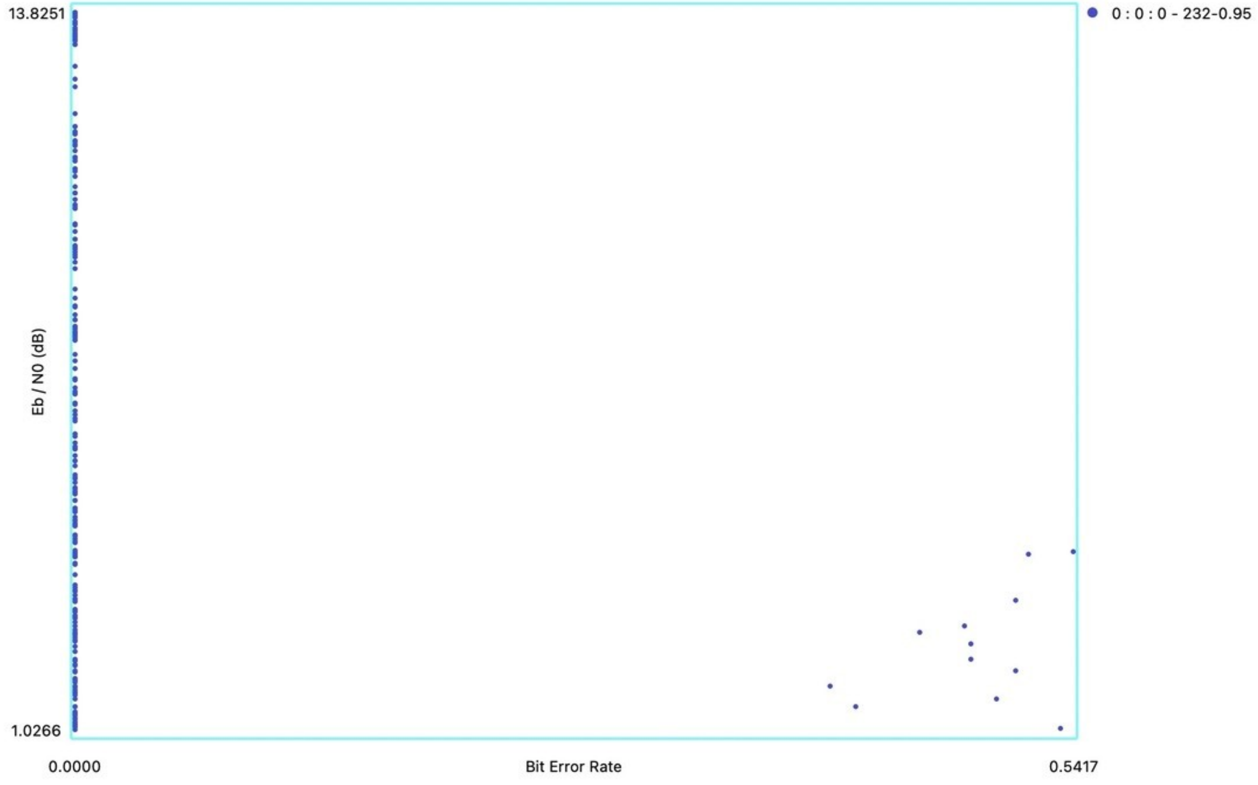
Viterbi + Custom Polynomials

The following diagram shows the combined effect of multiple techniques including interpolation, extrapolation, fixed absolute phase rotation based on rotation tables, pulse train standing waves and Viterbi error correction. The mode in the diagram has a carefully designed signal generator phase pattern along with carefully selected root raised cosine alpha and T coefficients as well as a number of other carefully designed processes.

The Viterbi decoder process utilizes a ½ convolutional code encoder with custom generator polynomials and no puncture code i.e. 1 bit in and 2 bits out.

The combination of all of the above techniques is a 95% success rate at Eb/N0 above 1.0 to bring the error rate to 0.0 BER for a perfect decode. In the test, 1.0 Eb/N0 is equivalent to a -26.67 SNR level.

LB28-6400-64-2-37-I3E8-FEC (Viterbi + Custom Polynomials) over AWGN Channel. 95% of decodes at 0.0 BER



Extrapolation with Multiple Hologram Samples

These techniques can be extended to take several samples of the quantized time-scale hologram and then aggregate the bit sequences into a single bit sequence and send this to the Viterbi decoder for final processing. This is currently a work in progress for the prototype to determine the extent to which this impacts the decode quality.

Maximum Bit Rate

Other than higher capacity constellation encoding such as 16 QAM, 32 QAM etc, there are a number of techniques that the holographic I3 modes can utilize to increase bit rate. These include:

- Reducing the number of pulses per block
- Reducing the block size
- Frequency Multiplexing
- Reducing the number of pulses required to encode bits
- More efficient FEC algorithm

Through experimentation, all of these these techniques have proven to be effective with some limitations. Currently the highest bitrate achievable, using a non-frequency multiplexed LB28 I3 mode with a 37Hz carrier spacing, is 64.44 bits per second. This mode utilizes 8 pulses per block, a 400 sample block size, 8kHz sample rate, 37 Hz carrier frequency separation with ½ convolutional code FEC and can achieve a 0.0 BER at around 6 Eb/N0 dB (-11.7 SNR).

Holographic Frequency Multiplexing

With frequency multiplexing, bit rate can be multiplied many times over; preliminary testing using the latest prototype indicates that the quantized time-scale hologram can be paired with another similar hologram at a different frequency to double the bit rate while also achieving a 0.0 BER with no Inter-Symbol Interference.

For example, a single hologram can be combined with a second hologram with equal characteristics using a frequency separation of around 76 Hz. As a point of note, solving for hologram frequency separation and downconvert shift simultaneously provides an effective technique to derive the precise values required for holographic frequency multiplexing. This combined hologram is also able to achieve a 0.0 BER. Constraints such as orthogonal carriers or signal spacing buffer zones are unnecessary.

This combined hologram can then be paired again with a similar combined hologram but using a different separation frequency of around 160 Hz. This can also achieve a 0.0 BER. This pair of pairs combination increases bit rate fourfold.

Using this holographic frequency multiplexing pairing technique, the bit rate has been increased from 64.44 bit per second to 257.76 bits per second using approximately 320 Hz of spectrum. Extending this out, a similar mode can theoretically achieve a 1933 bit rate over a 2400Hz spectrum by using holographic frequency multiplexing.

Bit rate can be further increased by reducing the number of pulses used to encode a character from 8 to 4 or 2 i.e. a twofold and fourfold increase respectively, however this will require a switch from I3 type modulation to I2 or I1. As a point of note, the number of phases used to generate the standing waves is a separate and distinct concept from the way in which pulses are combined. The I3 modes currently use 3 phases and 3 pulse groupings for combining. An I1 mode would use multiple phases but essentially eliminate the combining step thus relying on adjacent pulse addition only in the downconvert stage. An I2 mode can utilize multiple phases along with 2 pulse combinations. These are currently areas for further research to determine effectiveness.

Additionally, using a more efficient FEC encoding or removing FEC entirely could potentially double this rate again. Combining these different techniques has the potential to match and even exceed both the bit rate and noise resilience characteristics of the high performance Orthogonal Frequency Division Multiplexing (OFDM) modes. Although currently theoretical, the building blocks for this have already been successfully proven.