Development of an Integrated GNSS-eLoran Signal Simulator

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ABSTRACT

As Loran-C transitions to eLoran, commercial manufacturers are developing eLoran receivers. These devices are typically single box, integrated GPS-eLoran receivers. As these are being developed, a critical need of both manufacturers and system evaluators is the ability to assess receiver performance under the expected signal-in-space situations; this includes performance using GPS or eLoran separately as well as the algorithms for integrating the two (including how it handles the loss of one or the other of the signals). To do so under a variety of signal conditions requires a signal simulator that generates both eLoran and GPS signals, synchronized for the test locations and receiver trajectories of interest (similar to existing GPS simulators). An effective eLoran simulator should support the current Loran-C/eLoran implementations as well as be adaptable to changes in the system itself and the developing international eLoran standard. These include the employment of additional secondary factors, both E-field and H-field antennas, and the data carrying capability provided by the Loran Data Channel.

In response to this clear need, Alion Science and Technology has recently developed a signal simulator to test integrated GPS/eLoran receivers, implementing all of the existing Loran-C/eLoran specifications and fully capable of supporting a wide variety of potential changes to the eLoran specification. This paper describes the simulator.

INTRODUCTION

The need for eLoran as a complementary radionavigation system to the Global Positioning System (GPS[1]) is already well documented in the proceedings of this and prior ILA conferences; enough said. As government and industry users migrate to the eLoran system, there is a need for controlled testing of receiver equipment to verify stated and required performance. A key component of any such testing system will be an eLoran signal generator. Since many people in the navigation field believe that future positioning, navigation, and timing (PNT) systems will integrate the data from various sensors (GNSS, eLoran, other radio frequency (RF) signals of opportunity, inertial navigation systems (INS), etc), integrating an eLoran simulator with a GNSS simulator is a reasonable place to start. This paper describes our effort to produce such a device as a commercial product; specifically, the marriage of a commercially available GNSS simulator to our newly developed eLoran simulator. The discussion should be of interest to manufacturers, navigation service providers, government agencies, universities, and others

[1] GPS refers specifically to the United States system; the more generic term is Global Navigation Satellite System (GNSS). Since all GNSS systems in operation or proposed share similar characteristics, the more generic term will be used in the remainder of the paper.

interested in the performance of Loran based PNT systems. The simulator allows the testing of all aspects of Loran receiver performance:

- Ability to operate in the presence of noise, skywave, and crossrate interference.
- Ability to recognize blink and other system faults.
- Ability to demodulate the eLoran data channel.
- It provides the ability to test Loran / GNSS integration:
  - assess the position accuracy and reliability of the integrated solution;
  - test robustness and reaction of a receiver to GNSS and/or Loran outages.
- It allows researchers to test possible eLoran system changes:
  - implement new chains / rates;
  - modify pulse configuration and phase codes;
  - other wild and crazy ideas.

While the complexity of the signal structure of Loran-C and the details of the proposed eLoran modifications are what makes the development of the integrated simulator an interesting task, this paper does not get too far into those details; instead the basics of Loran are described briefly and references to the relevant literature are provided. Instead, this paper describes both features and limitations of the resulting eLoran simulator, presents examples showing these features, and outlines future plans to improve the product.

A BRIEF INTRODUCTION TO LORAN-C AND ELORAN

The Loran system is based upon the transmission of the "Loran pulse" as shown in Figure 1; a teardrop-shaped envelope modulated by a 100 kHz sinusoid. The important axis in this figure is the abscissa, showing time in μsec (the ordinate is less important since received signal strength will vary with the power of the transmitter and the receiver's distance from it). A Loran transmitter broadcasts a "group" of 8 such pulses spaced 1000 μsec apart (if the station is a "Master," an additional pulse appears 2000 μsec after the 8^{th}). Further, this group is repeated in time with a period called the Group Repetition Interval (GRI), in the range of 50,000 to 100,000 μsec. The individual pulses in a pair of GRIs, called a Phase Code Interval (PCI), are modulated with a sequence of +1s and –1s, the so-called phase code. Finally, several geographically nearby stations will broadcast in a time-orthogonal sense at the same GRI, called a "chain." Figure 2 shows a typical observation of the Loran signal, showing the four stations in this example chain with varying amplitudes. This signal structure is detailed in the Loran-C Signal Specification [1]. Further described in this specification are implementation details including a warning system called "blink" and the need for a procedure for a transmitter to resolve simultaneous requests to transmit groups from different rates, called "blanking."

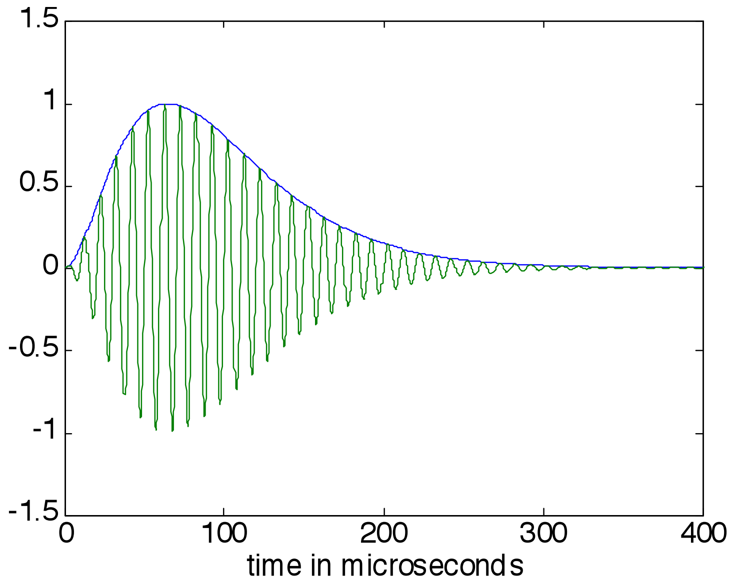

Figure 1: The Loran pulse.

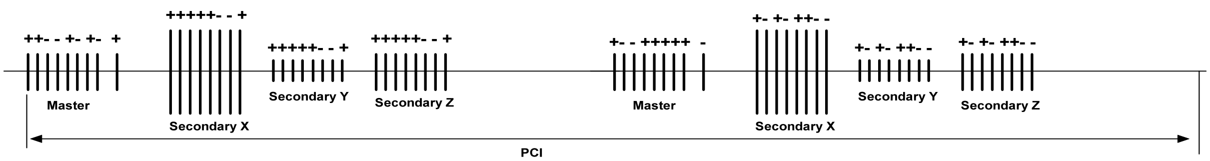

Figure 2 – A typical observation of a Loran chain.

Accurate reception of Loran signals at a user's site depends upon a variety of issues: the local signal strength relative to noise levels, interference due to Loran signals from other nearby chains with different GRIs (called cross rate interference or CRI), delay in the signal time due to path propagation effects (usually separated into a term linearly dependent upon the distance from the transmitter plus other correction factors), multipath interference due to ionospheric reflections (called sky wave), plus signal degradations at the transmitter itself.

One component of eLoran relevant to simulator construction is the addition of a data carrying capacity called the Loran Data Channel (LDC). In the U.S. the current LDC approach under testing is called "9th pulse" and consists of 32-ary pulse position modulation of an additional, non-navigation pulse which appears at the end of a group as shown in Figure 3 [2]; Loran stations in Europe and elsewhere use a different LDC approach called "Eurofix" which consists of pulse position modulation of 6 of the 8 pulses in a Loran group [3].

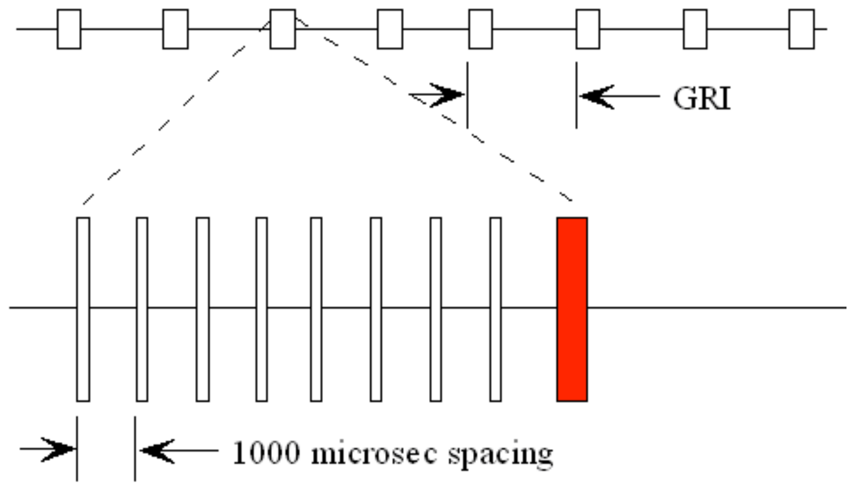

Figure 3 – A Loran group with 9th pulse LDC.

THE GELSIM 100

As noted above, the GeLsim is an integrated GNSS-eLoran signal simulator. The GNSS and eLoran signals are synchronized in both time and space, generating the GNSS and eLoran signals as a user's receiver would observe them at the current position and at the current time. For moving vessels the signals share a common scenario (currently generated on the GNSS simulator) and are tied together with a common clock. The two sets of signals are synchronized using a 1 PPS strobe to start the scenario. Figure 4 contains a block diagram representation of the integrated simulator. As executed, the eLoran simulator hardware is mounted within the enclosure of the GNSS simulator, and the entire system mounted in a rack providing a neat and clean appearance (Figure 5).

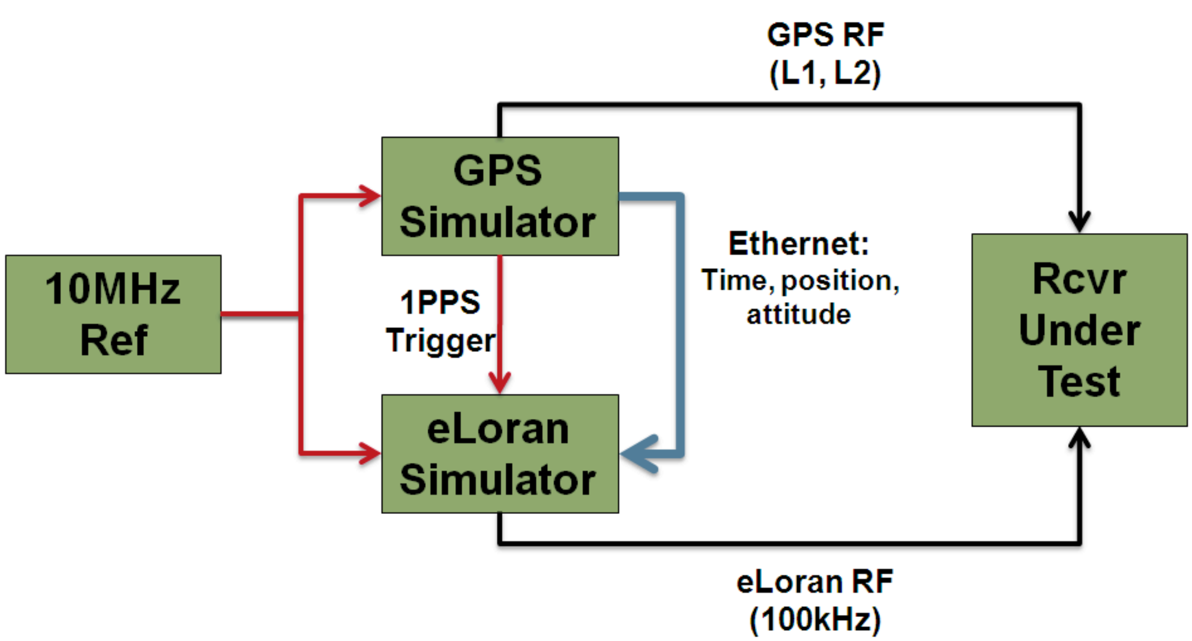

Figure 4 – Block diagram of the simulator.

The GNSS portion of the GeLsim 100 system is a commercially available unit, Spirent's GSS8000 (see Figure 5), which nominally simulates GPS L1; hardware upgrades to provide L2, L5, Glonass, Galileo, DGPS, WAAS, and various interference options are also available [4]. Accompanying this hardware is quite a sophisticated scenario planning tool. The GSS 8000 outputs this scenario information as input to the eLoran side of the simulator.

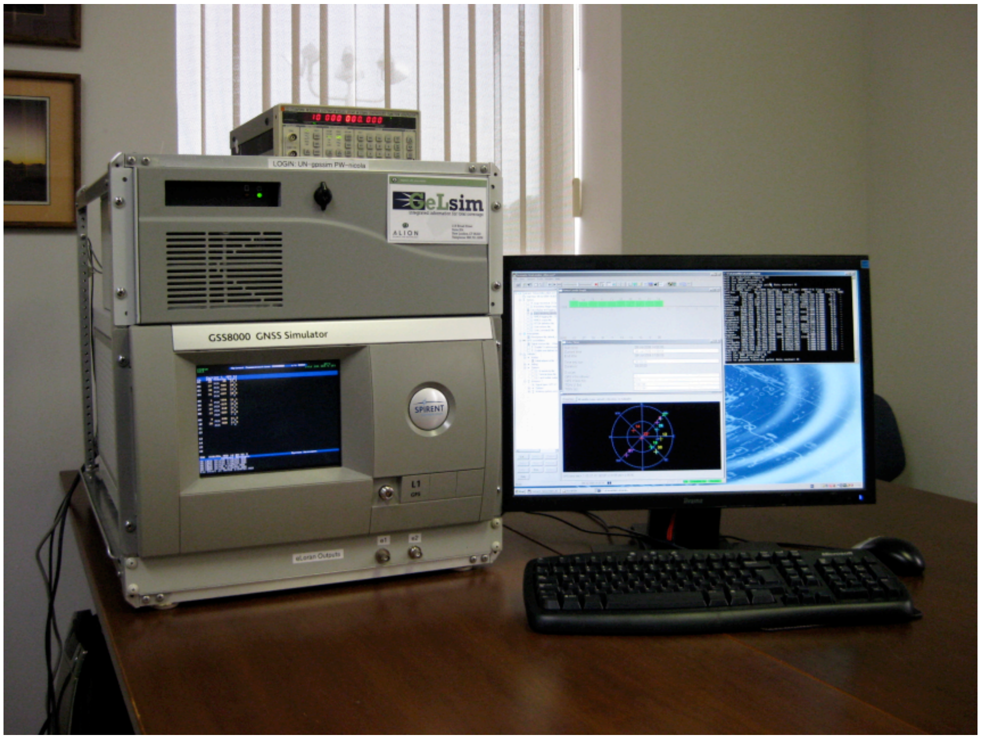

Figure 5 – The GeLSim 100.

The eLoran portion of the system is designed to:

- be fully configurable with respect to Loran system parameters such as station locations, rates, emission delays, etc.
- include position-based ASFs and signal strengths.
- properly compute times of arrivals by employing the Vincenty method and includes the standard primary factor and secondary factor calculations.
- generate Loran Data Channel (LDC) signals.
- provide E and H-field antenna outputs.

VERSION 1.1

In this subsection we review the features and characteristics of the current version of the GeLsim 100. Its operation is based upon a "configuration file" which sets parameters for the simulation; some of these are simulation wide (*global*) while some are station-specific (*individual*). Currently the simulator is preprogrammd for Loran stations in the continental United States (CONUS); individual parameters are initially set to match the current Loran-C specification as listed in the Loran Handbook [5].

Global settings include:

- whether or not to apply ASF values to all signals – currently predicted CONUS grids are supplied (generated using BALOR [6]); users can modify these grids with their own values if desired.
- whether or not to apply atmospheric noise to all signals – currently this is additive Gaussian noise with either a specified global noise value or a grid based on CCIR models.
- whether or not to apply skywave to all signals.
- what PCI strobe to output (i.e. the GRI).
- antenna type – E- or H-field antenna outputs.
- whether or not to generate 9^{th} pulse LDC – currently either sequential symbols (0-31 repeating) or a user specified file of symbols.
- output power scaling – either a fixed (specified) scale factor or auto-scaling.
- data output (either RF or written to file) – if file output is chosen, each file is one epoch of passband data sampled at 1 MHz and is written to a user-specified directory.
- antenna orientation – both rotation offsets and upside down or not can be set.

Individual station options include:

- turning individual stations on/off – the current hardware can support more than 30 parallel Loran stations.
- user configurable chains/rates – while existing chains and rates are predefined in the configuration file, these can be easily changed by the user on a station-to-station basis.
- user configurable emission delays – while existing system values are predefined, these can be changed by the user.
- user configurable ECDs – used to set a received ECD value; the default value is 0.0 but can be set to any value by the user.
- user configurable phase codes – currently standard master and secondary codes are pre-set, but these are changeable on an individual station level and can exceed two groups in length if so desired.
- skywave delay parameters of delay and scale factor.
- 9^{th} pulse LDC on any station on/off – as noted above, this is currently the same message on all stations.
- system time bias and jitter – the same bias is applied to all pulses in a group of the station, jitter models a random pulse-to-pulse time variation.
- pulse amplitude variation – allows for variation in the amplitude of individual pulses from the station.
- blink on/off – user selectable for each station

While version 1.1 of the GeLSim 100 is quite capable, we must note it currently is limited to simulating signals from CONUS stations. Specifically, this is due to our not yet acquiring conductivity and terrain databases for Europe, Canada, Asia, etc so as to be able to generate accurate signal strength and ASF grids.

SAMPLE PERFORMANCE

The figures below highlight the features of the GeLsim 100's eLoran signal output – in most of the figures the horizontal axis is time and the vertical axis is voltage:

- Figure 6 shows a typical Loran group (9960 NEUS as seen near New London, CT). The time delays are apparent as is the amplitude variation due to distance from the transmitters.
- Figure 7 zooms in on a master group (8 pulses plus the master pulse).

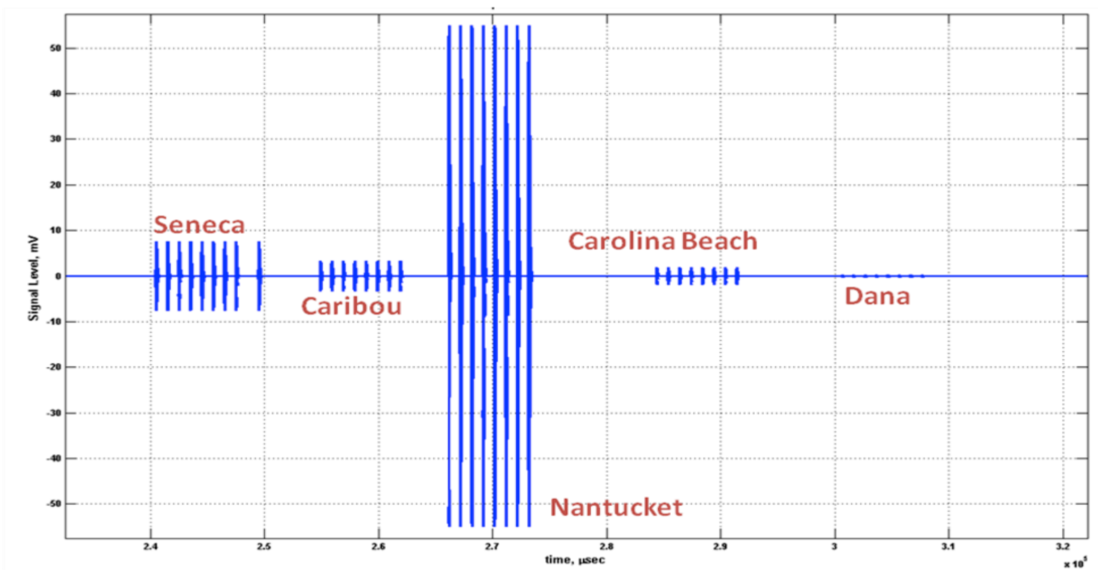

Figure 6 – A typical Loran group.

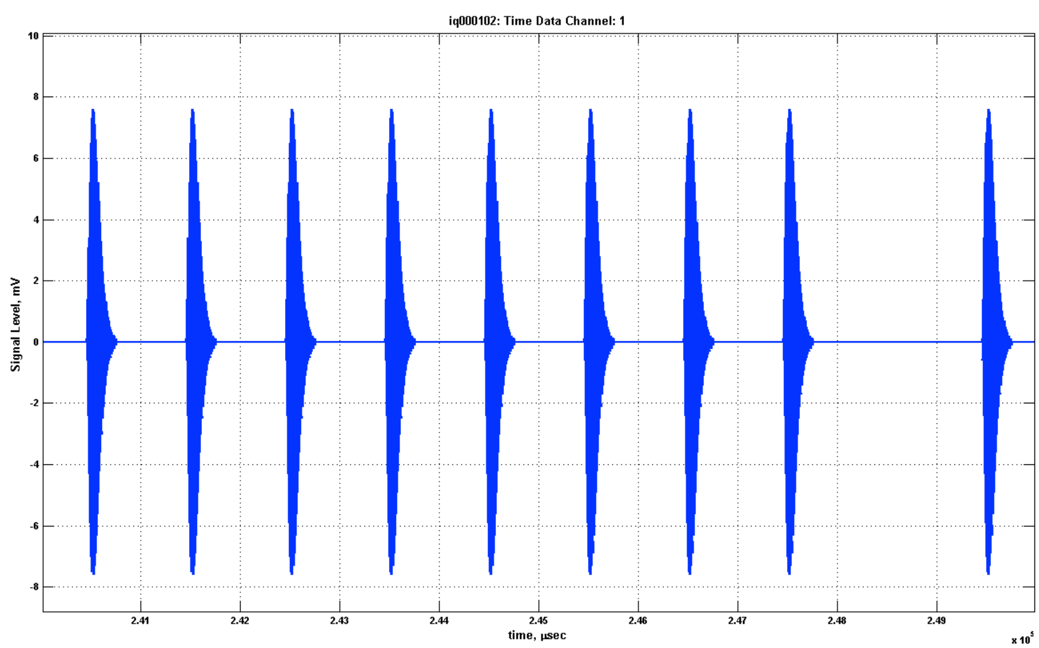

Figure 7 – A master group.

- Figure 8 zooms in even more, showing the traditional Loran pulse.
- Figure 9 shows an occurrence of blink (in this case, on a master group). Blink consists of dropping the first two pulses from a group and is used to indicate out of tolerance conditions on the signal transmission (receivers are expected to recognize and respond to such an alarm condition) and is implemented on a 15/16 duty cycle.

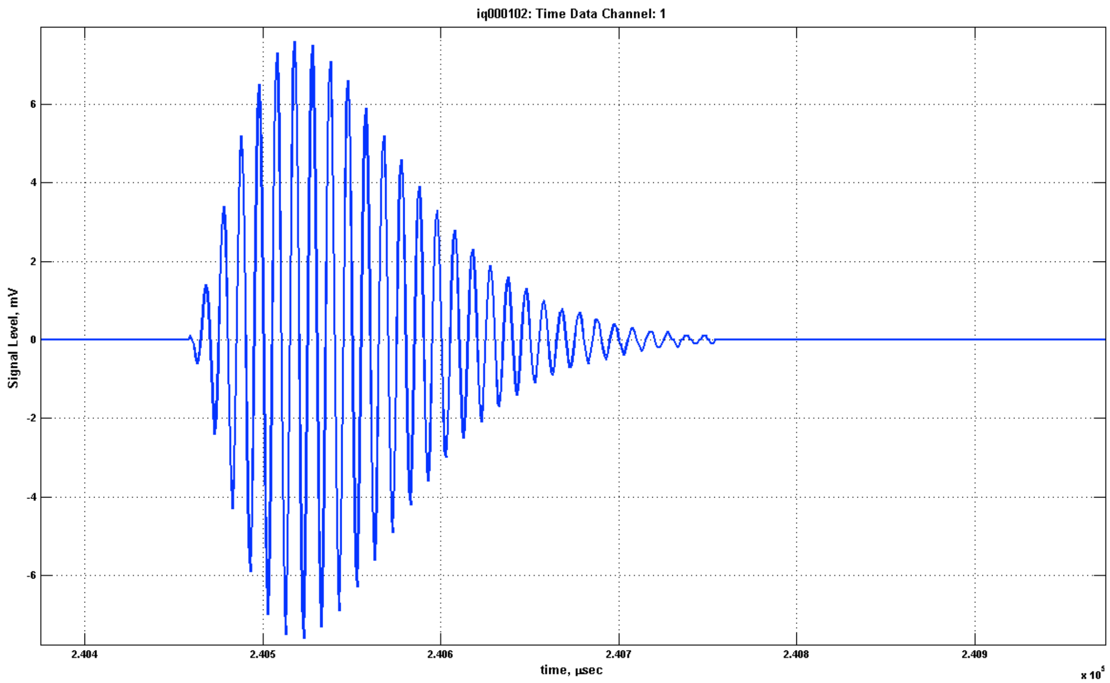

Figure 8 – A single pulse.

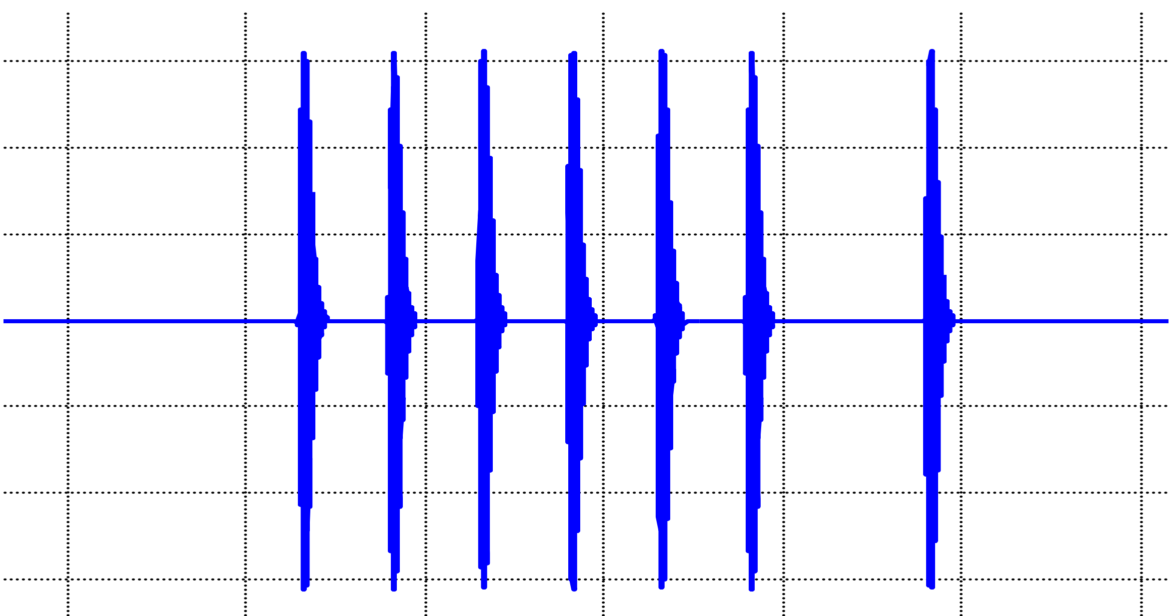

Figure 9 – Blink on a master group.

- Figure 10 shows the simulator creating variation in pulse amplitude. This is shown at an exaggerated level to be visible.
- Figure 11 shows the simulator creating variation in pulse time, again at a grossly exaggerated level to be visible.

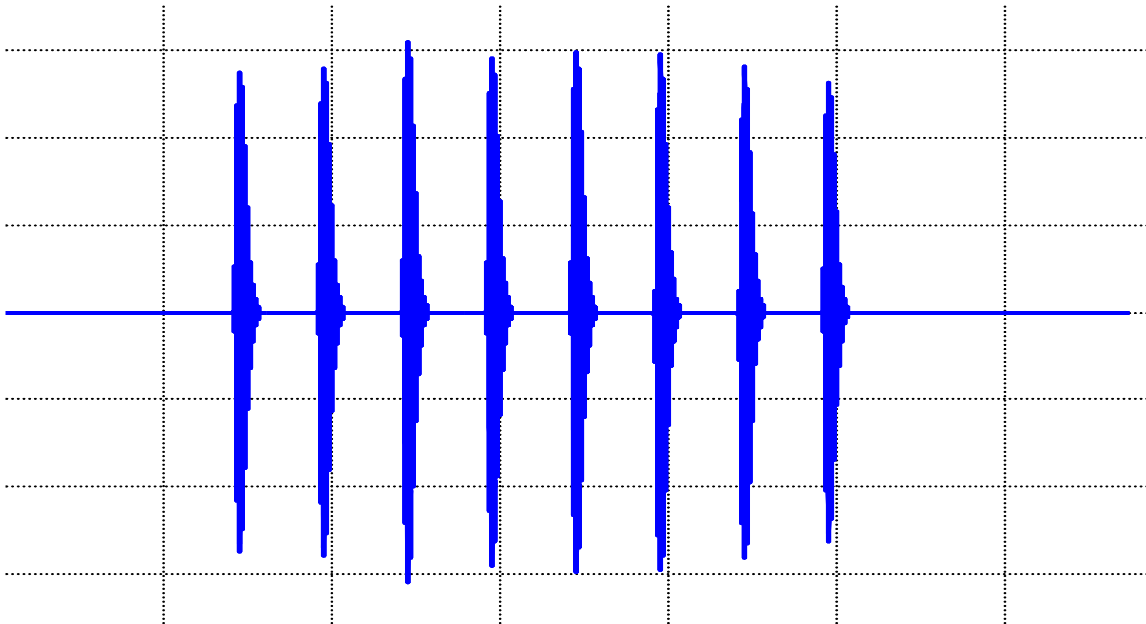

Figure 10 – Pulse amplitude variation.

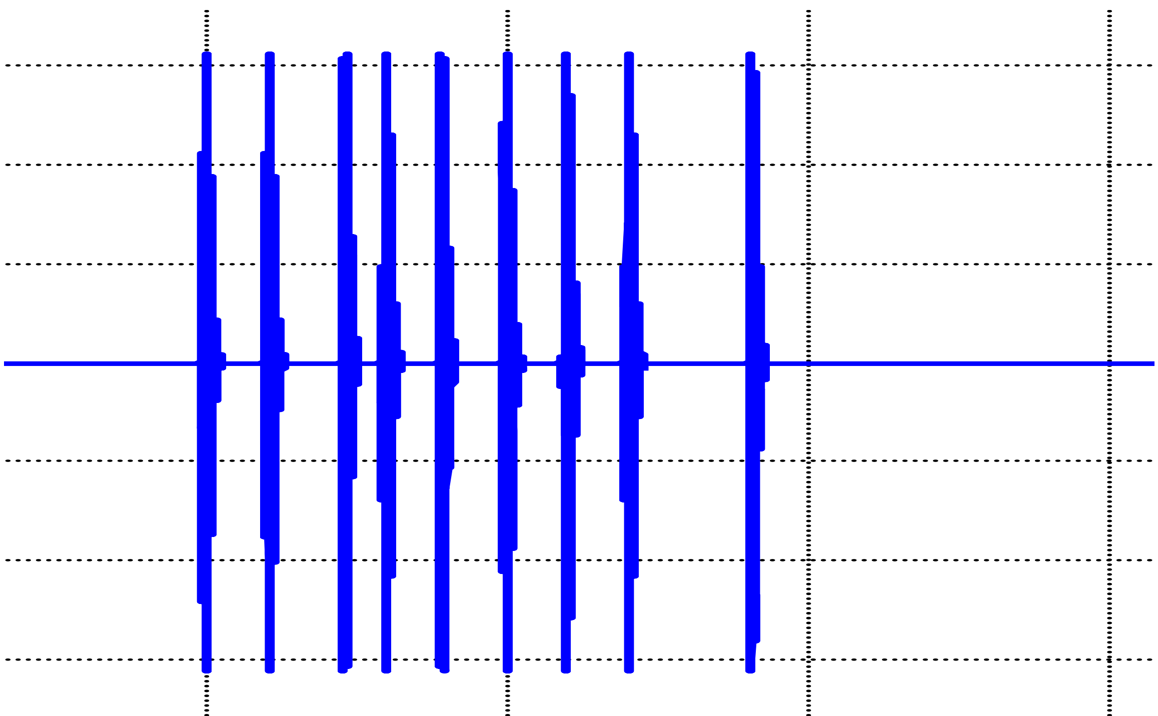

Figure 11 – Pulse timing variation.

- Figure 12 shows an occurrence of blanking in which a dual rated transmitter drops some of the pulses of one group when the system asks it to simultaneously generate pulses for groups at two different rates. (The simulator implements alternate blanking to match current system specifications.) In this example the first group (an 8 pulse secondary) is unaffected while the second group (a master) loses its first 6 pulses.
- Figure 13 shows a group with 9th pulse LDC (the last pulse is pulse position modulated, although this is hard to see at this scale).

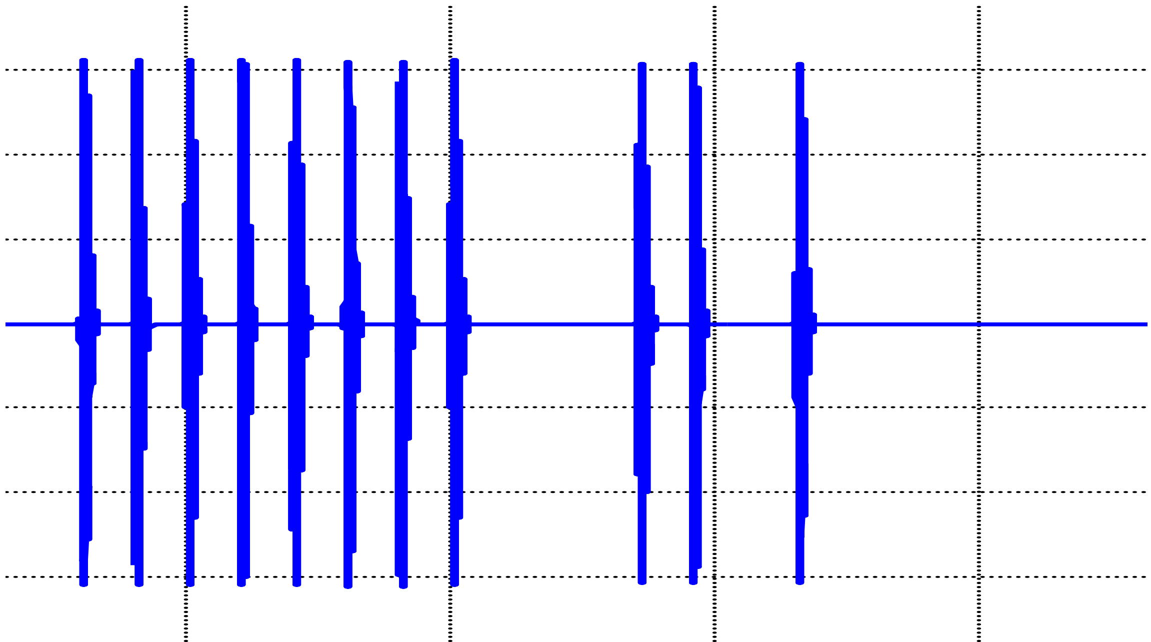

Figure 12 – An example of blanking.

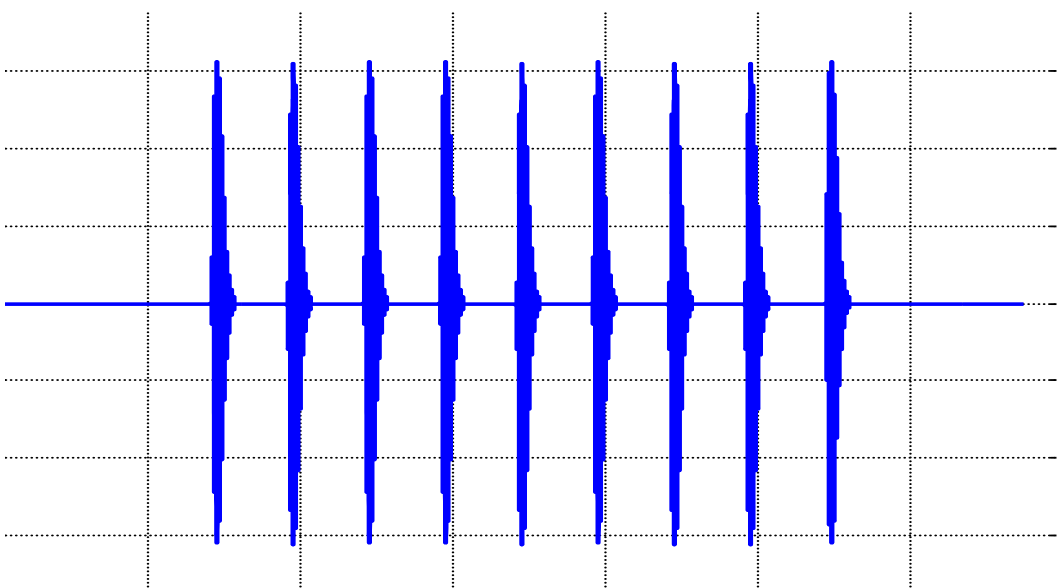

Figure 13 – An example of 9th pulse LDC.

- The next two figures consider the simulator's ability to modify phase codes. Specifically, Figure 14 examines the current phase code for a secondary station: the top portion shows the phase code values for groups A and B in a PCI while the lower portion shows the resulting magnitude frequency spectrum centered about 100 kHz.
- Figure 15 considers a "balanced" phase code (see [7] for a discussion of why this is of interest). The top portion shows the phase code values for groups A and B; the central portion shows the resulting magnitude frequency spectrum centered about 100 kHz. As this spectrum is pretty complex, the bottom subfigure zooms in on the center (near 100 kHz) to show the resulting nulls – most notably the null at 100 kHz.

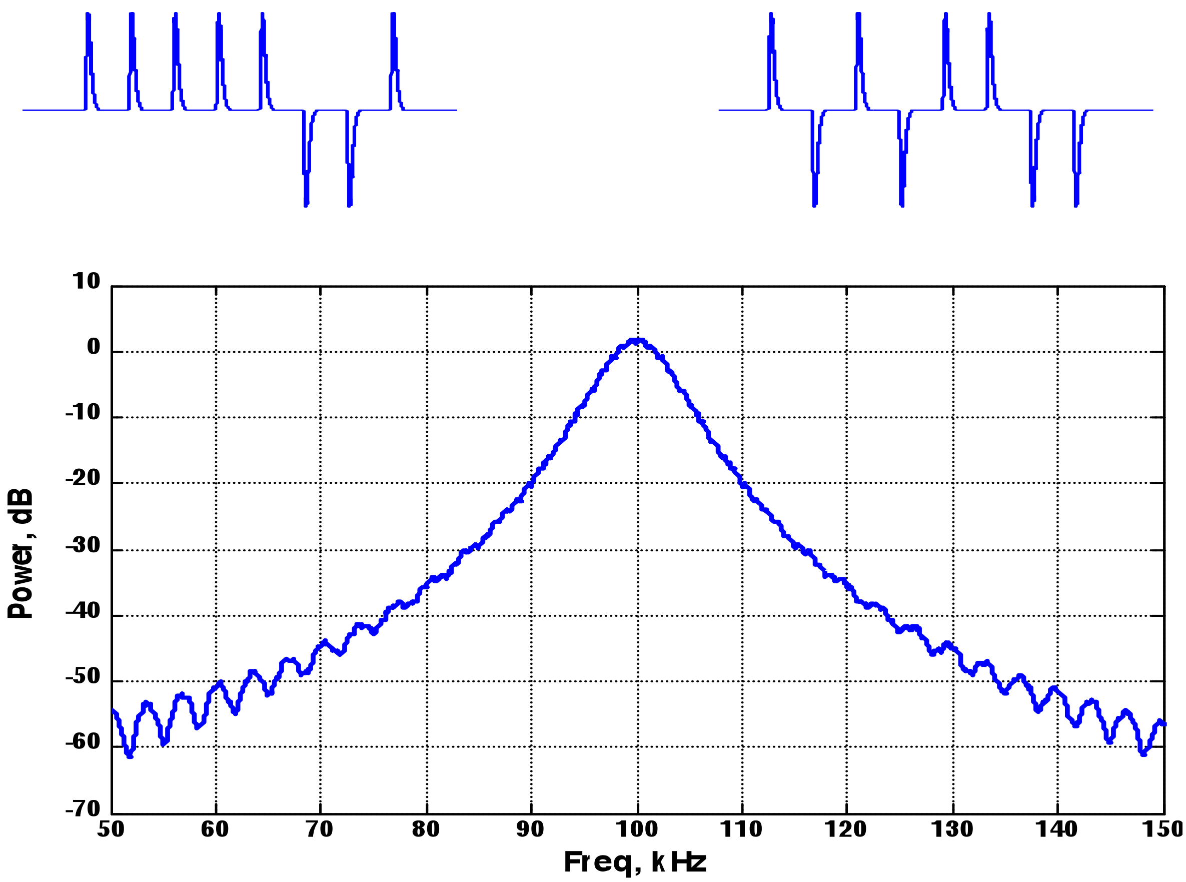

Figure 14 – Phase codes and magnitude spectrum of a current secondary station.

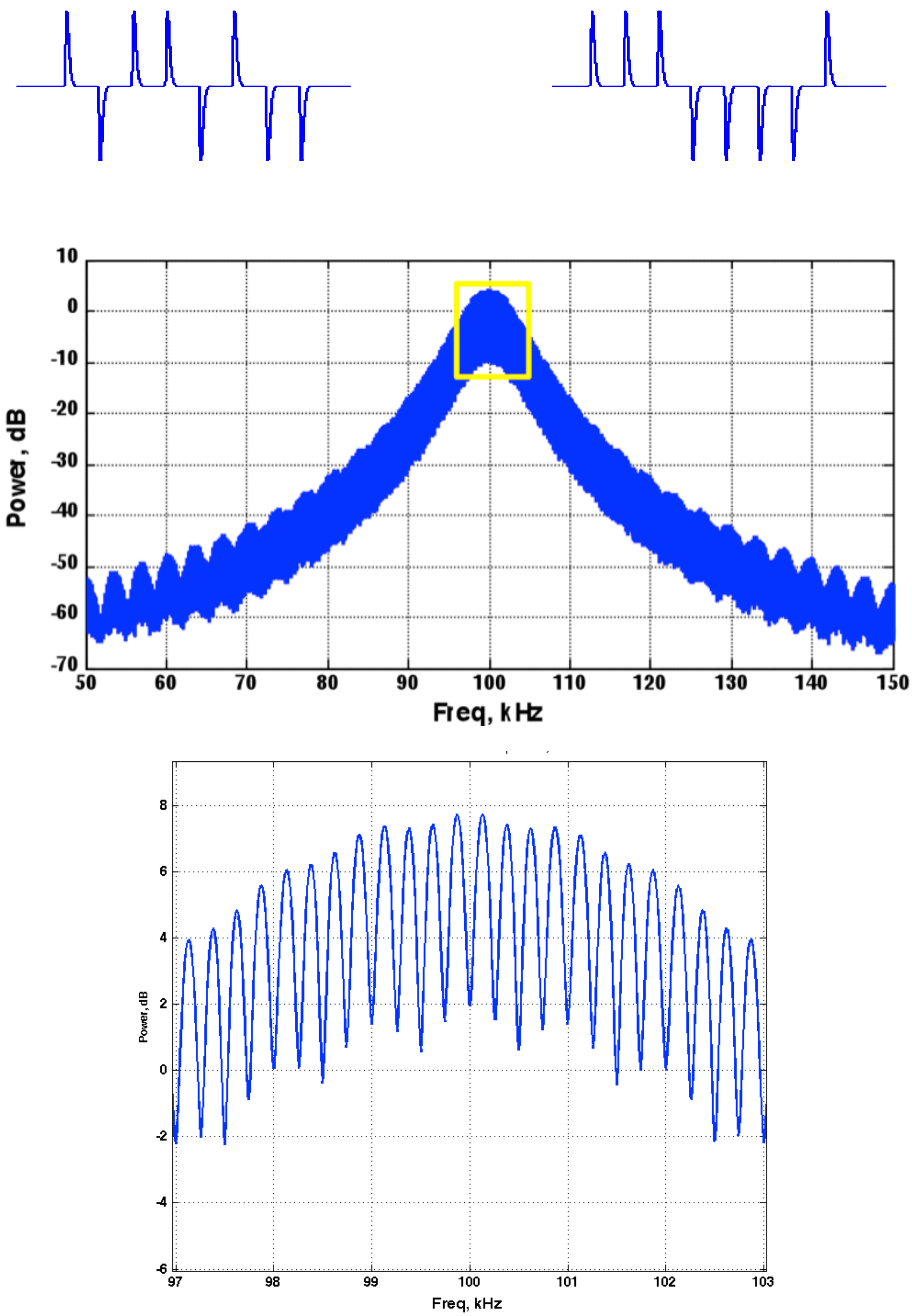

Figure 15 – An example "balanced" phase code, its resulting magnitude spectrum, and a closeup of the spectrum.

- Figure 16 shows example skywaves – early, medium, and late.
- Figure 17 shows noise added to the pulse.

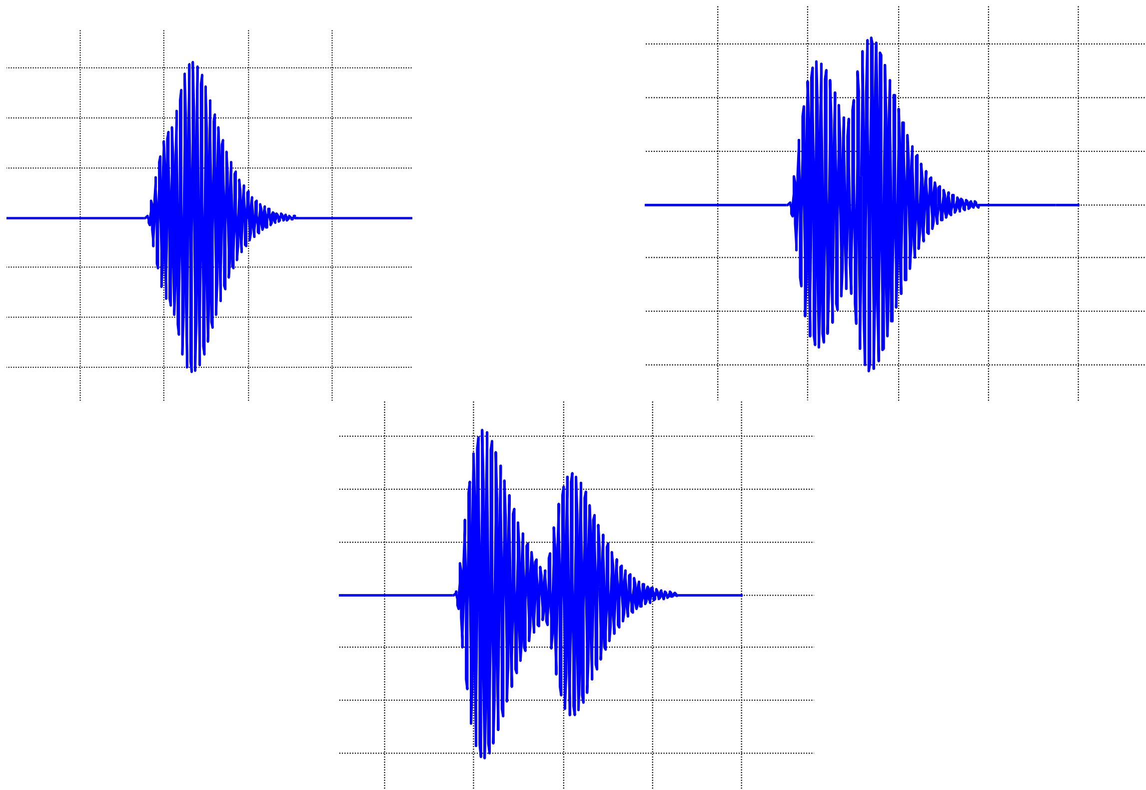

Figure 16 – Examples of skywave at various delay values.

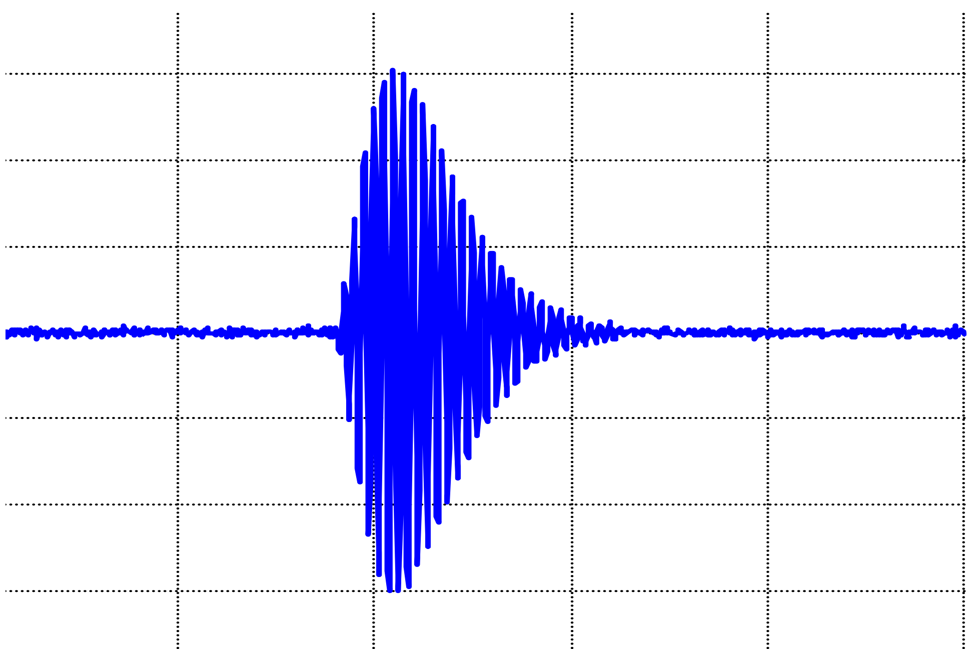

Figure 17 – A noisy pulse.

- Figure 18 shows two channels of outputs (for an H-field antenna) with different levels due to antenna orientation with respect to a signal.
- Figure 19 shows multiple chains simultaneously.

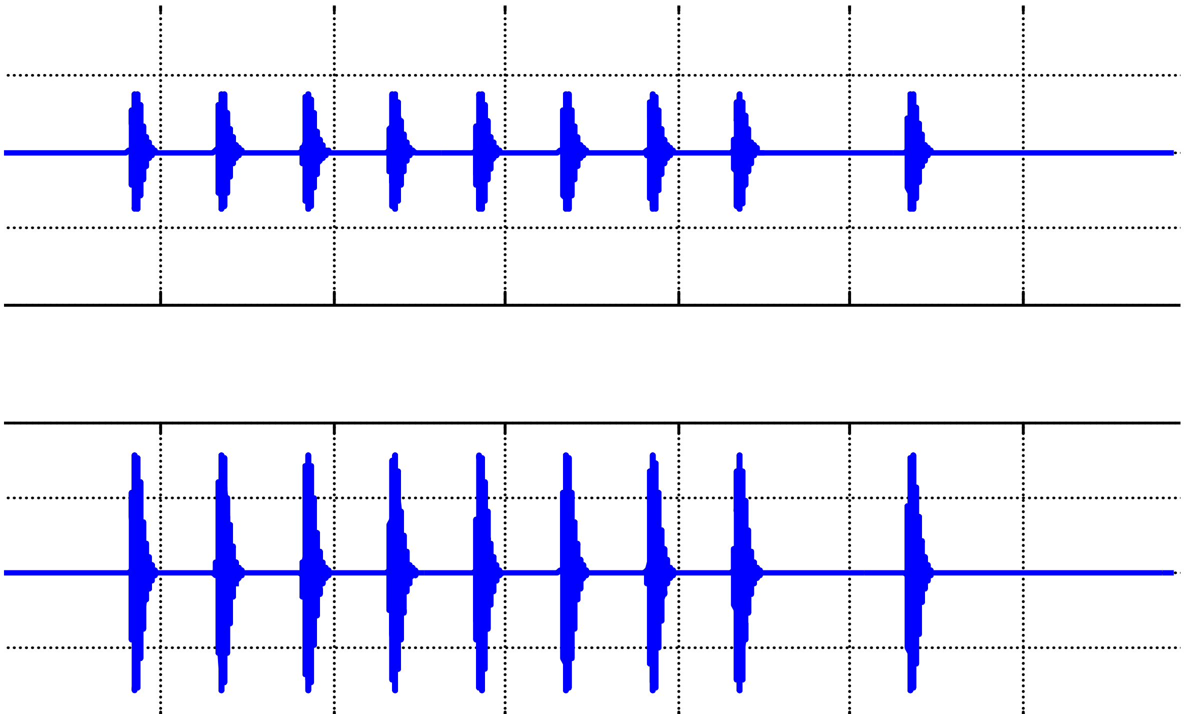

Figure 18 – Two outputs for H-field antennas

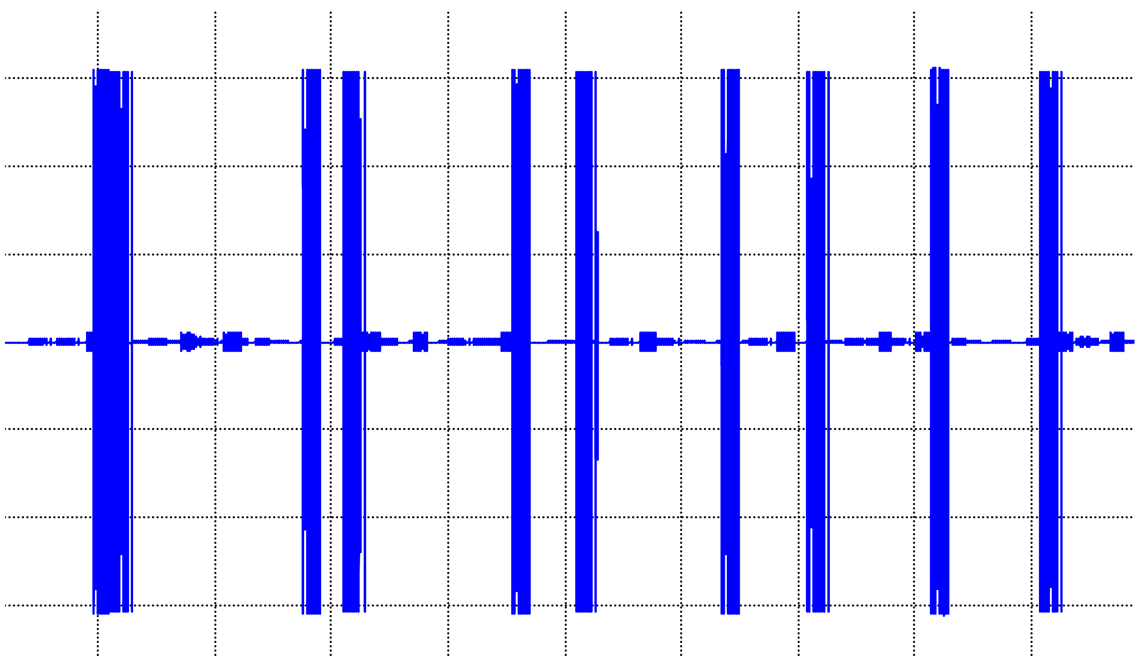

Figure 19 – An example of multiple chains.

VERSION 2.0

We are planning several modifications for version 2.0 of the GeLSim 100. They can be grouped into several categories.

LDC modifications

- Provide the ability to transmit different LDC messages for each station.
- Provide accurate time messages over LDC matched to the UTC time of the simulation.
- Implement Eurofix LDC.

User interface

- Implement a Graphical User Interface.
- Allow for on-the-fly system faults.
- Provide for scenario driven events (including faults).

Signal outputs

- Provide an optional 1 PPS output (instead of PCI strobe).
- Provide simultaneous E- and H-field outputs.

Signal degradation

- Implement Doppler shifts in TOAs due to vehicle velocity.
- Provide a more complex skywave model.
- Add additional interference options including impulsive noise models, CW, and pstatic.

Expansion beyond CONUS

- Add propagation grids (signal strength and ASFs) for non-US towers.
- Develop an alternative propagation model for receivers located outside of the existing signal strength and ASF grids.
- Add Chayka.

CONCLUSIONS/FUTURE WORK

This paper describes the GeLsim 100, an integrated GNSS-eLoran signal simulator, and why it is needed by receiver manufacturers, system and service providers, and researchers. A sample simulator was demonstrated to attendees at ILA 38 in Portland, ME. Further, information on planned improvements to the system are listed.

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