Title: A practical Open Source Ionospheric Channel Simulator for Ham use.

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***Intro**:* This Article introduces a practical high-performance stand-alone and OS independent Ionospheric Channel Simulator. More details of the project and simulator are available in QEX and full open source documentation is available at ……ARSFI Git Hub link URL.

What is An Ionospheric Simulator?

Every ham learns that much of our communication relies heavily on radio wave propagation through the Ionosphere layer. This layer reflects radio waves and can create single or multiple hop paths from station to station. While most radio waves involve this type of propagation it is not trivial to model the constantly changing Ionosphere to test and optimize the performance of our radios and protocols. On-air tests are notoriously unpredictable and difficult or impossible to duplicate at another time.

In 1970 a landmark paper [1] by Watterson, Juroshek, and Bensema was presented in the IEEE Transaction on Communication Technology. They described a mathematical process (model) that could fairly accurately model and simulate radio propagation over narrow band HF. This and follow-on papers by others and the CCIR/ITU [2] defined a set of standardized “representative test channels” that would allow computer software or hardware simulators to statistically model HF radio propagation by manipulating the modulating audio. This has been used over the years to develop, test, and improve many of the various digital and digital voice protocol we use today.

The Ionospheric Simulator Project:

A modest cost simulator [3] described and provided by Johan B. Forrer, KC7WW was used extensively in our development of the popular WINMOR, ARDOP and similar ARQ protocols. However, with the demise of the Analog Devices DSP test-set, we found that we needed an affordable device that would be easy to use and allow us to evaluate the performance of current and new protocols for use in the Winlink system. So, in December 2019, we set out on a project to find a solution, that had several objectives:

First was to survey and evaluate some of the current high-performance yet modest cost single chip processors like the Teensy [4] series of microprocessors. We also wanted to learn and validate their programming environment using the popular and free Arduino Development tools to see if they would have the performance needed for this project.

Second was to evaluate libraries like the Teensy Audio library [5] and how they might be applied in amateur radio audio DSP.

Finally, we developed a protype simulator to test and see if a good-performing, stand-alone low-cost ionospheric channel simulator could be built using the Teensy 4.0 microprocessor with its DSP functions based on the Watterson model above.

Upon completion of the design we performed extensive beta testing and ran comparison tests using other simulators for several popular HF and VHF/UHF Ham protocols.

What we developed shown in Fig 1 (Ionos Simulator Functions and Specification Summary) and Fig 2 (Photo of prototype simulator) is a valuable tool for hams to use in the development, evaluation and optimization of new protocols.

How is the Ionospheric Simulator Used?

The beauty of the Watterson model is that is can be realized just by manipulating the *audio* of the modem, TNC or terminal unit. This means there is no need for a transmitter, receiver, or RF noise generators to perform representative tests over standardized channels. The simulator simply replaces the radio path and components with an audio connection and some complex audio processing described in the Waterson model as shown in Fig 3 (Ionos Simulator audio connections for Half Duplex).

What does the Simulator Show and how can it be of benefit to Hams?

The Ionos Simulator has several functions that are useful in modelling different propagation paths over a wide range of Signal to Noise (S:N) values that are useful in both HF and VHF/UHF propagation. For HF the standardized CCIR/ITU channels **[2]** are often used as they represent a range of representative channel "Goodness" ranging from very good (WGN ….White Gaussian Noise) to poor multipath channels (MPP …Multipath Poor). The simulator can also model more extreme conditions (MPD …Multipath Disturbed) that model higher latitude HF or aurora propagation. Figures 4 (Multipath Good channel for 5 HF protocols) and 5 (Multipath Poor channel for 5 HF protocols) show typical simulator use plotting the measured performance of 5 different HF adaptive ARQ protocols for Multi Path Good and Multi Path Poor CCIR/ITU channels over a range of S:N from -5 to +40 dB.

Each dot or symbol on the above charts represents a simulator run of 5-10 minutes to accommodate the slow changing channel and the ability of the ARQ protocol to select and shift to the fastest mode for the current channel conditions and S:N. The performance of the single carrier high baud rate (1.9 KHz Bandwidth) Pactor 4 protocol with its automatic continuous path equalization is impressive in the two representative simulation runs (Multipath Good (MPG), and Multipath Poor (MPP) above.

The Ionos Simulator also has the capacity to model VHF/UHF propagation anomalies such as Doppler shift and flat fading or flutter (sometimes called "picket fencing"). Figure 6 (WGN for 4 VHF FM Packet protocols) shows the comparison of WGN runs of 4 popular protocols that are normally used over VHF.

This clearly shows the improved performance range available using modern protocols like VARA FM compared to original AX.25 packet. It also shows the ability of the simulator to confirm incremental protocol improvements as shown in the VARA FM rev 3.06 and rev 3.08 runs.

But why can't we just test over the air?

This question is heard often especially from those that have little experience in developing or testing more complex adaptive protocols (usually ARQ protocols that automatically adjust to accommodate changing conditions). While the above charts show smooth curves, these are the result of many runs sending thousands of bytes over long periods (sometimes over 10 minutes per test) to get accurate and repeatable results. Often small changes are made to a protocol's functions (e.g. how and when to shift to faster or more robust modes) that require a statistically near identical set of propagation conditions which are almost impossible to duplicate over the air. In fact, in the preparation and verification of the above curves for this article a combination of small improvements to the modem driver software in the client program (Winlink Express) and an update to the firmware in the Pactor 4 modem itself were discovered that improved the net throughput of the Pactor 4 protocol up to 15% on certain channels. For protocol development, automating complex regression tests with a simulator provide quick feedback on the effects of a change. Like for evolution, good mutations in protocol development are rare and repeatable, complex tests are the key to quickly evaluating a new idea. Imagine also the HF bandwidth saved by using such a tool!

Find out more on how to get, use or build one for yourself or club.

This project was sponsored by the Amateur Radio Safety Foundation Inc (a 501c(3) public charity) . A more extensive QEX article includes additional details of implementation. All details of this open source project (Schematics, PC layout, parts list, C++ Source Code, manuals, and presentation) are available on the ARSFI.org Git Hub site (need URL) .

The ARSFI will provide a limited number of completed and tested simulators at cost ($250) to radio clubs or individuals on a first come first served basis. The ARSFI will also supply a limited number of PCBs (require surface mounting components) for cost of $35. Contact Tom Lafleur KA6IQA for details or availability.

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References:

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[2] CCIR/ITU Rec. 520-2 1 9E2c: Influence of the ionosphere RECOMMENDATION 520-2 USE OF HIGH FREQUENCY IONOSPHERIC CHANNEL SIMULATORS (1978-1982-1992)

[3] A Low-Cost HF Channel Simulator for Testing and Evaluating HF Digital Systems. Johan B. Forrer, KC7WW ARRL/TAPR DCC 1999

[4] https://www.pjrc.com/teensy/

[5] https://www.pjrc.com/teensy/td_libs_Audio.html

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