A comparison of Winlink® digital mode performance based on simulation results using the Teensy IONOS Simulator[1] - Take Three

By Tom Whiteside, N5TW

The "Take Three" in the title refers to this being yet another significant revision from the earlier version. In a post graduate simulation course, the professor stated that a San Francisco traffic simulator was found to have traffic routed in the opposite directions 10 YEARS AFTER THE SIMULATION WAS PUT INTO USE! His point was to never stop questioning the assumptions a simulation is based on. We are very grateful to Peter Helfert of the SCS Spezielle Communications Systeme GmbH & Co. for his helpful insights isolating additional areas where our simulator needed work to realistically look like a real channel and with much better signal to noise agreement with the real world. After Rick Muething made these changes, the results for PACTOR 4 improved significantly relative to other modes.

Executive Summary:

Hardware SCS modems running PACTOR 2,3 and 4 were evaluated as were sound card modes WINMOR, ARDOP and VARA across a variety of channel models and across a range of signal to noise conditions for HF. VARA testing included a new VARA 500 500Hz mode. VARA FM and AX.25/FX.25 packet were simulated for a VHF channel.

Spoiler alert: The SCS modems did very well as you would expect with PACTOR 4 dominating all other HF modes over the range of tests performed. The much less expensive VARA HF did well across the range of conditions

[1] See "IONOS SIM HF/VHF Channel Simulator BUSY DETECT Busy Channel Detector Instructions and Basic Documentation" by Rick Muething KN6KB https://winlink.org/content/ionos_simulator

tested. The SCS modems and VARA could run long test cases without losing a connection while ARDOP and WINMOR were slow and less reliable for lower SNR MP cases. VARA FM crushed AX.25/FX.25 VHF cases.

<u>Overview:</u>

Rick Muething, KN6KB and Tom Lafleur, KA6IQA developed an inexpensive yet sophisticated simulator that models standard HF and VHF propagation channels based on the Arduino Teensy. Both Rick and Tom are members of the Winlink Development Team and Amateur Radio Safety Foundation, Inc.[2] (ARSFI) board members. Tom is responsible for the hardware design and Rick developed the software.

Simulator testing is important for creating and evaluating digital mode performance in a consistent, repeatable way that simply cannot be done with over-the-air testing where conditions are always changing.   These simulators have been quite expensive in the past, typically costing many thousands of dollars. With today's single chip micros and DSP libraries, Rick and Tom were able to create this simulator with a total parts cost of less than $200.

This simulator was used to evaluate the digital modes supported on the Winlink system over statistically standardized channels of White Gaussian noise and multipath with noise cases across a range of signal to noise values. These channels are based on the well-documented Watterson model[3] used in many expensive laboratory grade instruments.

For HF, both wideband (>2KHz) modes (PACTOR 3, PACTOR 4, VARA 2300, ARDOP 2000 and WINMOR 1600) and 500Hz modes (PACTOR 2, ARDOP 500, WINMOR 500 and an all new VARA 500 mode) were tested.

For VHF, AX.25 based packet, FX.25 based packet and VARA FM were tested.

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[2] Amateur Radio Safety Foundation, Inc. https://www.arsfi.org/

[3] Watterson, C.C., J.R. Juroshek, & W.D. Bensema. 1970 Experimental confirmation of an HF channel model IEEE Transaction of Communication. Technology. Vol COM-18. Pp 792-803 Dec 1970

No simulator can create all the band conditions, QRM, aurora and other effects we can encounter but these results should be a good comparison of performance over a wide range of conditions. All data presented (bytes/minute) is net after FEC corrections, needed repeats and modulation shifts required by the protocols.

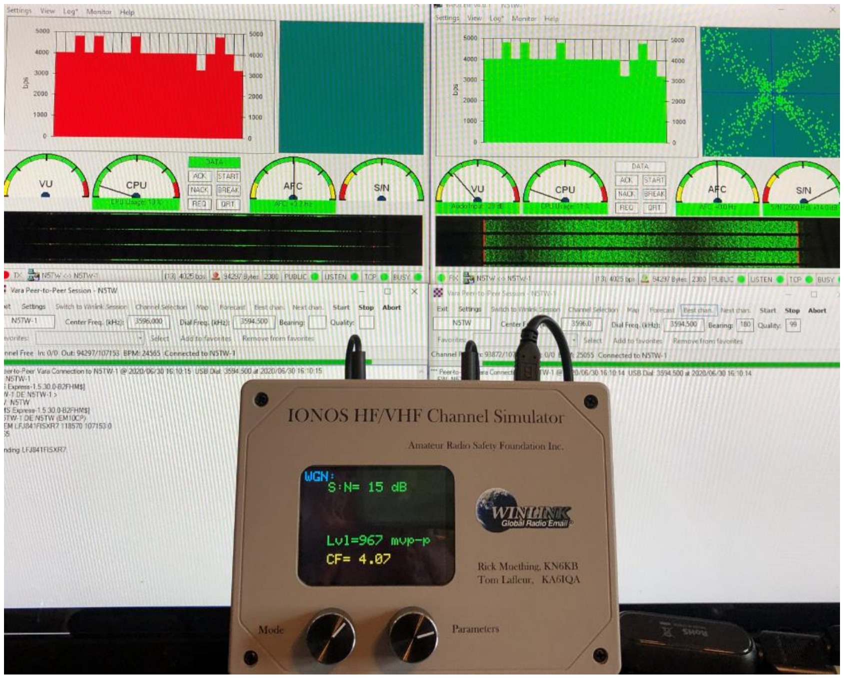
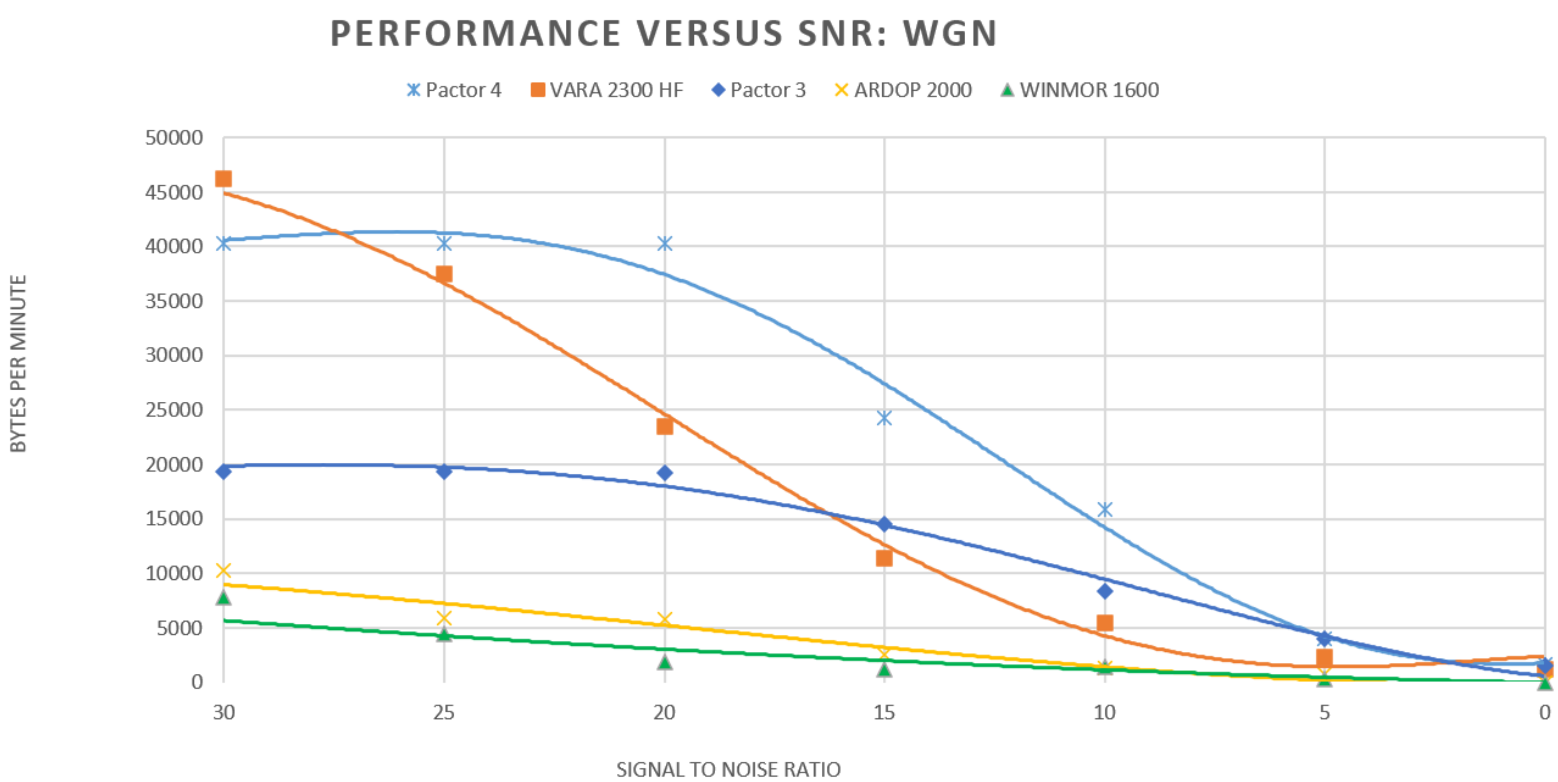


Figure 1 Test setup at N5TW using the IONOS Simulator

Here are those results:

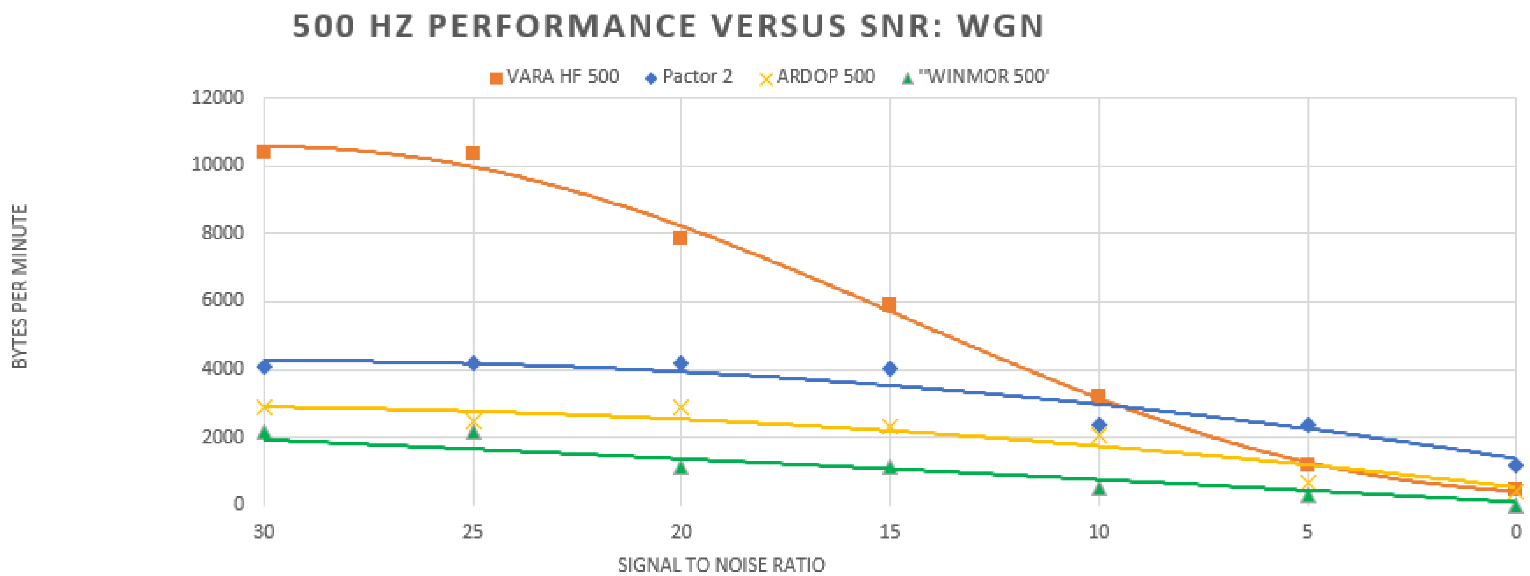
<u>HF Testing:</u>

The first case evaluated was for wide HF Winlink Digital Modes over a range of signal to noise ratios using White Gaussian noise.



All modes were able to operate over this range of signal to noise ratio. With an excellent quality 30dB SNR, VARA performance exceeds a PACTOR 4 TNC but PACTOR 4 dominates over the realistic SNR range. VARA exceeds PACTOR 3 for this model for greater than 17dB SNR conditions. ARDOP exceeds WINMOR performance for strong signals but both ARDOP and WINMOR have performance a small fraction of the speed of the other modes.

Here are the White Gaussian noise results for the 500Hz HF modes:



The recently released all new VARA 500 mode dominated performance over the other modes for greater than 10dB SNR for White Gaussian noise.

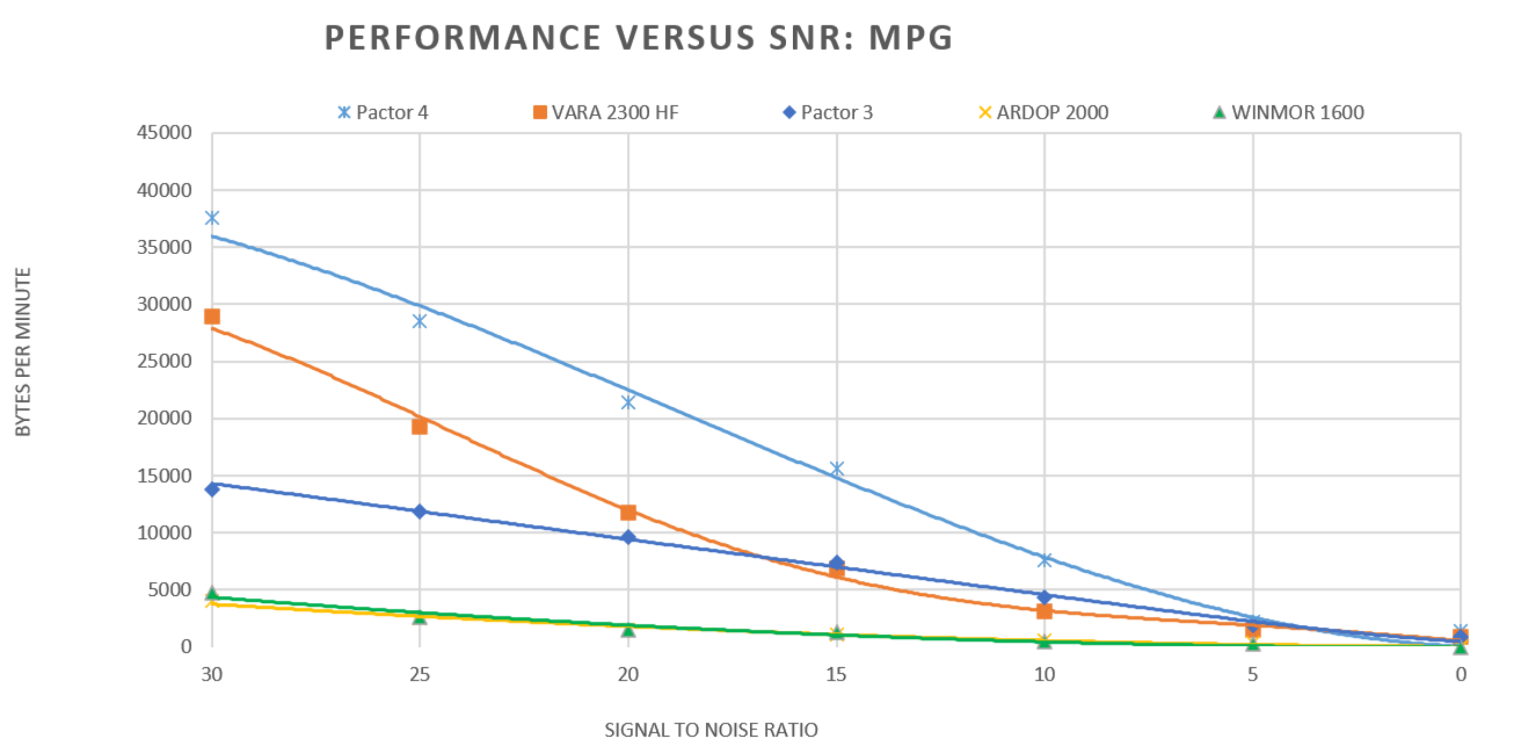
HF Multipath simulation:

The Teensy IONOS Simulator has a rich assortment of multipath test cases. In the real world, all signals experience some degree of multipath distortion whether it is a local VHF/UHF signal arriving directly as well as reflections off various objects or an HF signal experiencing different effects from the ionosphere and/or arriving via different headings. The simulator has four levels of multipath models: MPG (good conditions), MPM (moderate conditions), MPP (poor conditions) and MPD (disturbed conditions). Each of these multipath levels can be run using a 2 Path (each with I and Q) model.

Channel Type	Spread Hz	Delay	Fade Depth
WGN	0	0 ms	
FADE (FLAT)	0		0 to 40 dB
OFFSET/FM	Deviation up to 200 Hz		
MPG	.1	.5 ms	
MPM	.5	1 ms	
MPP	1	2 ms	
MPD	2	4 ms	

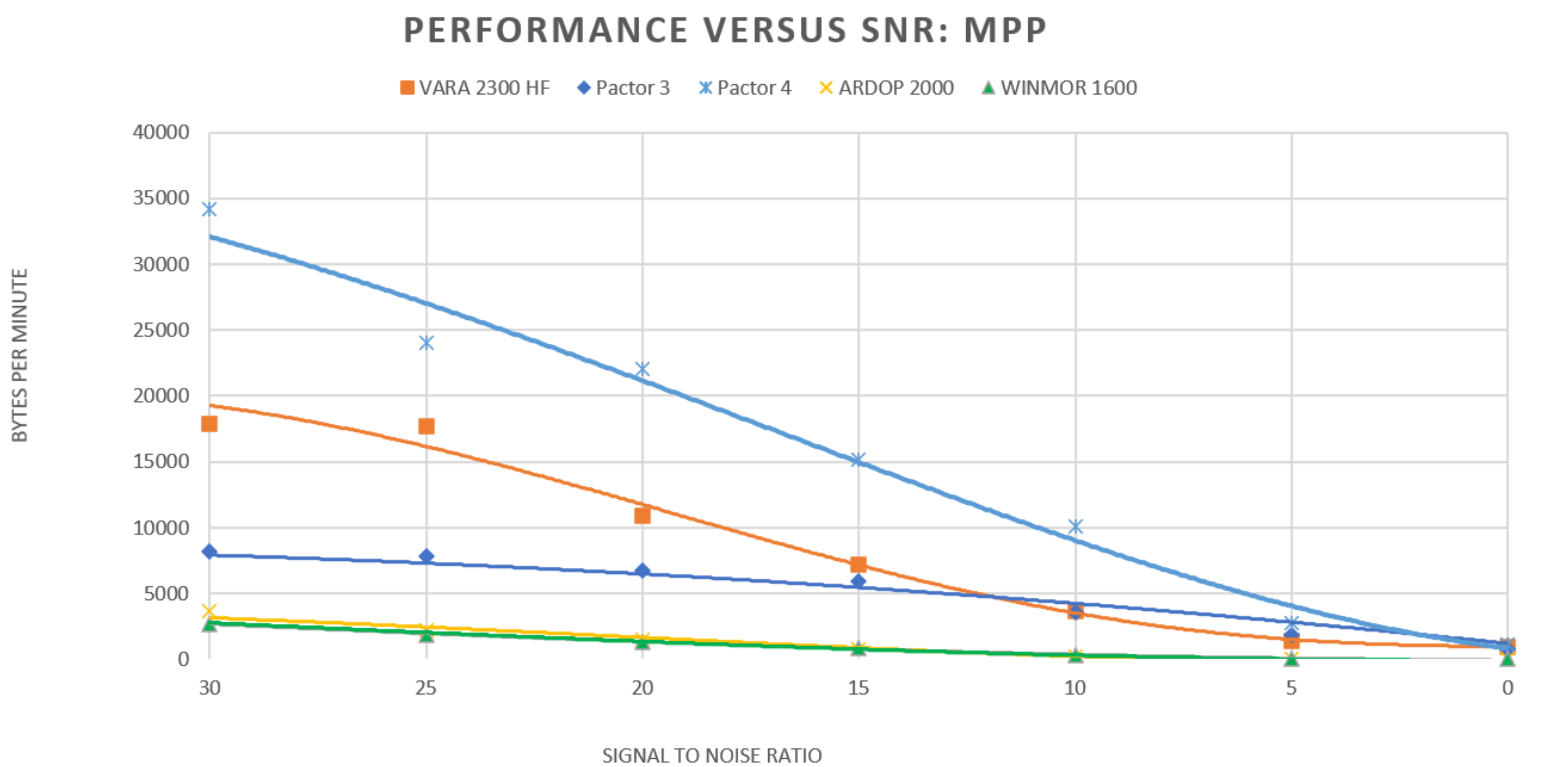
For the tests in this paper, the MPG and MPP levels of multipath are run all with a 2-ray model.

Wideband (>2KHz) Multipath MPG (Good) Results:



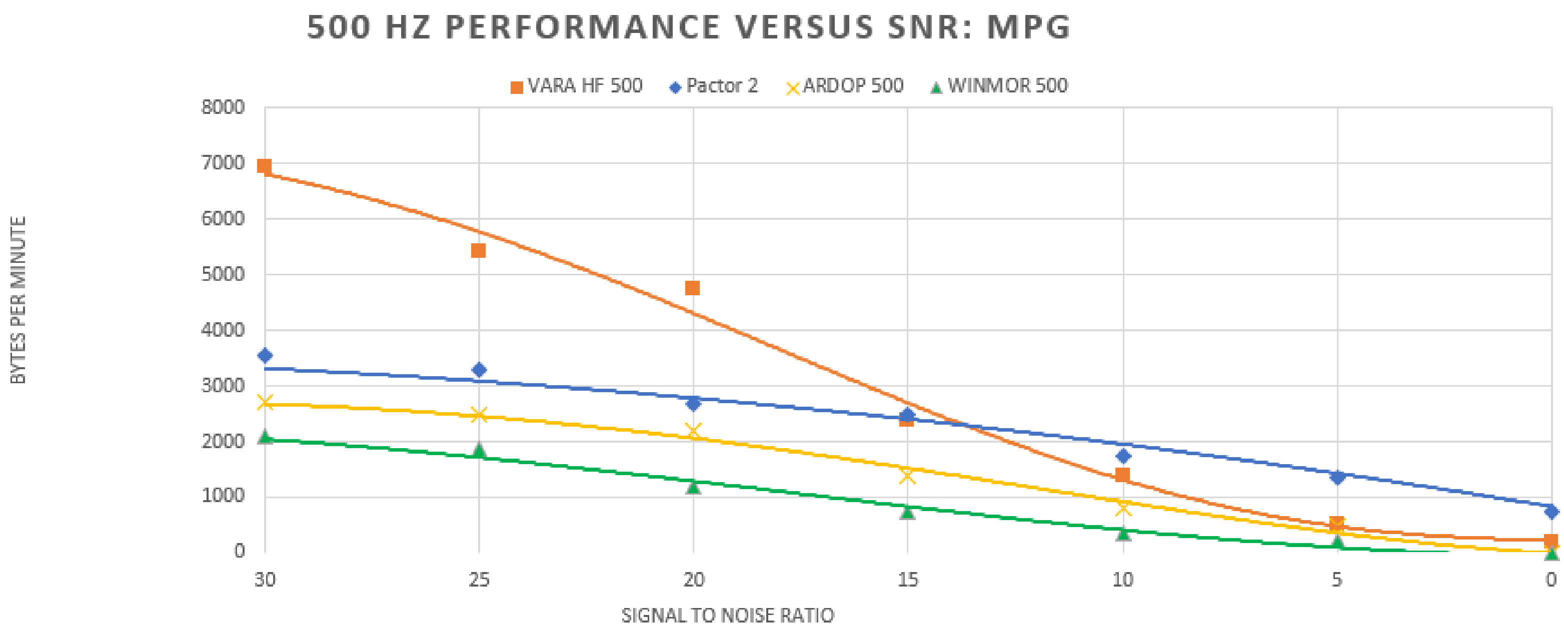
PACTOR 4 was the clear leader in the MPG case with VARA in a respectable second place for SNRs 17dB or greater.

Wideband (>2KHz) Multipath MPP (Poor) Results:



PACTOR 4 was again the clear winner. VARA came in second for SNRs greater than 13dB with PACTOR 3 in third place. WINMOR and ARDOP were significantly slower and often required multiple runs to get tests to complete at low SNRs.

Multipath MPG (Good) 500Hz Results:



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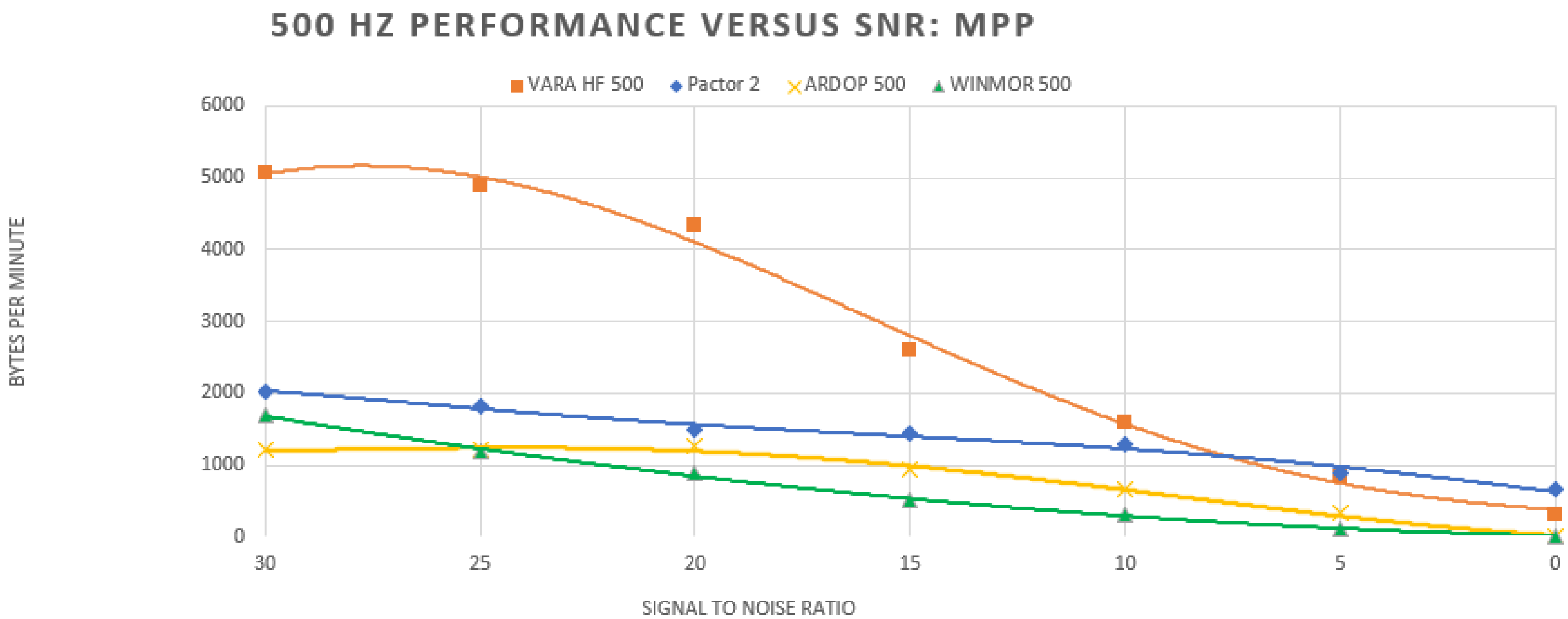
VARA 500 far exceeded the other modes at 500Hz for SNR values greater than 14dB. PACTOR 2 came in second place but was the winner when the SNR was worse than 14dB. WINMOR and ARDOP performance slowed to a crawl for the low SNR cases.

Multipath MPP (Poor) 500Hz Results:



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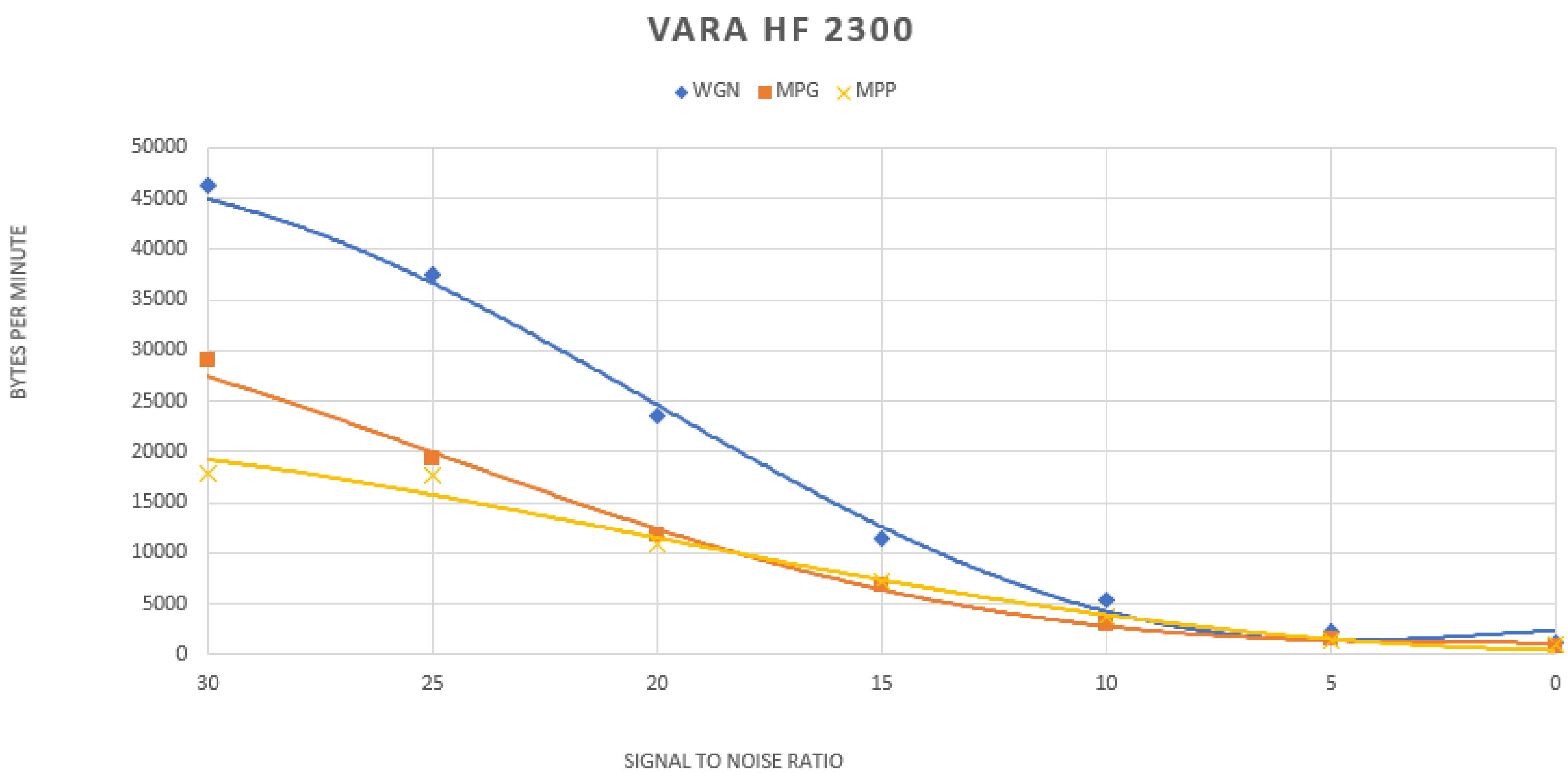
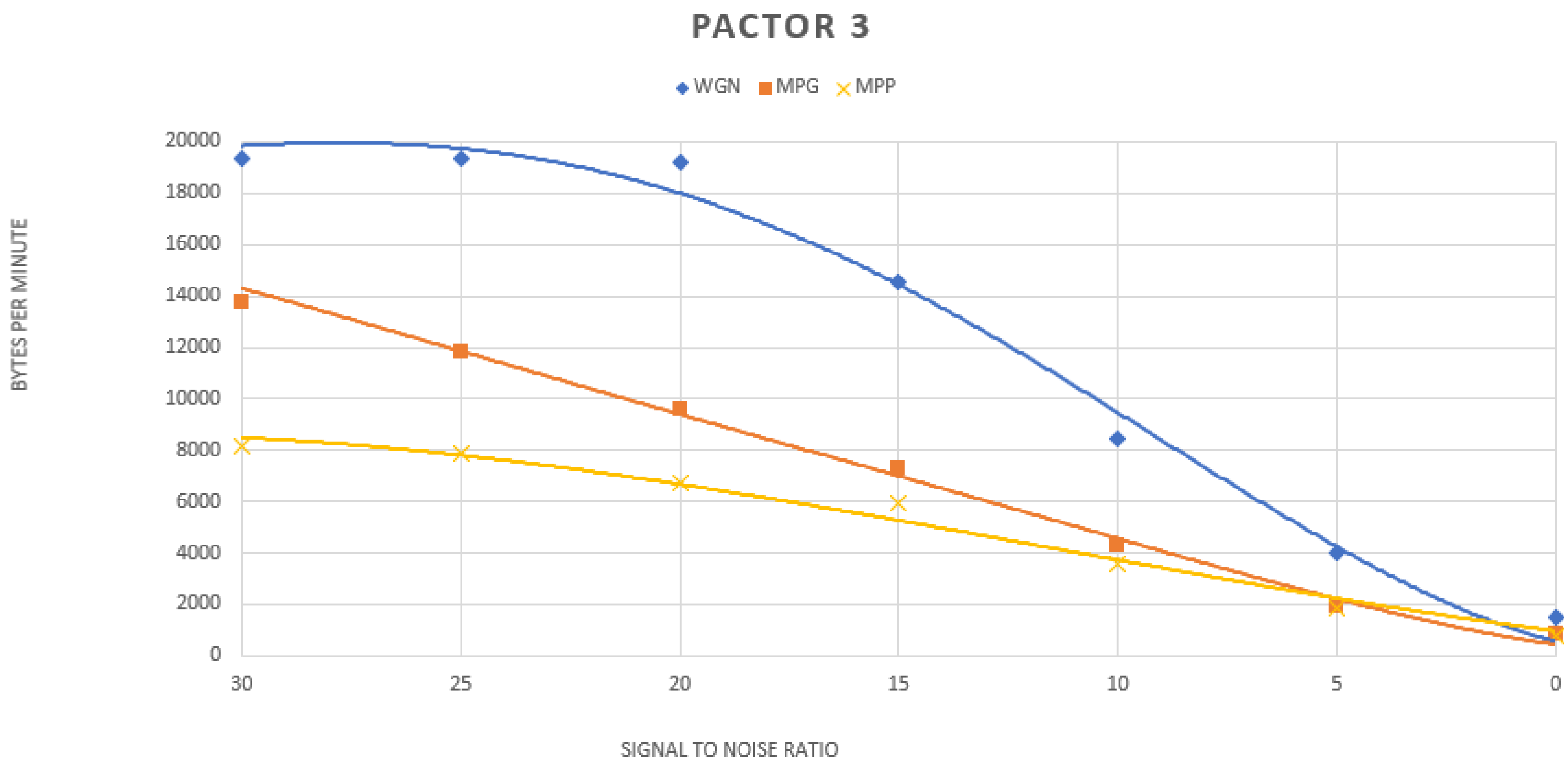
VARA held a clear lead with PACTOR 2 in second place. ARDOP and WINMOR were again much slower and often required multiple runs due to dropped links.

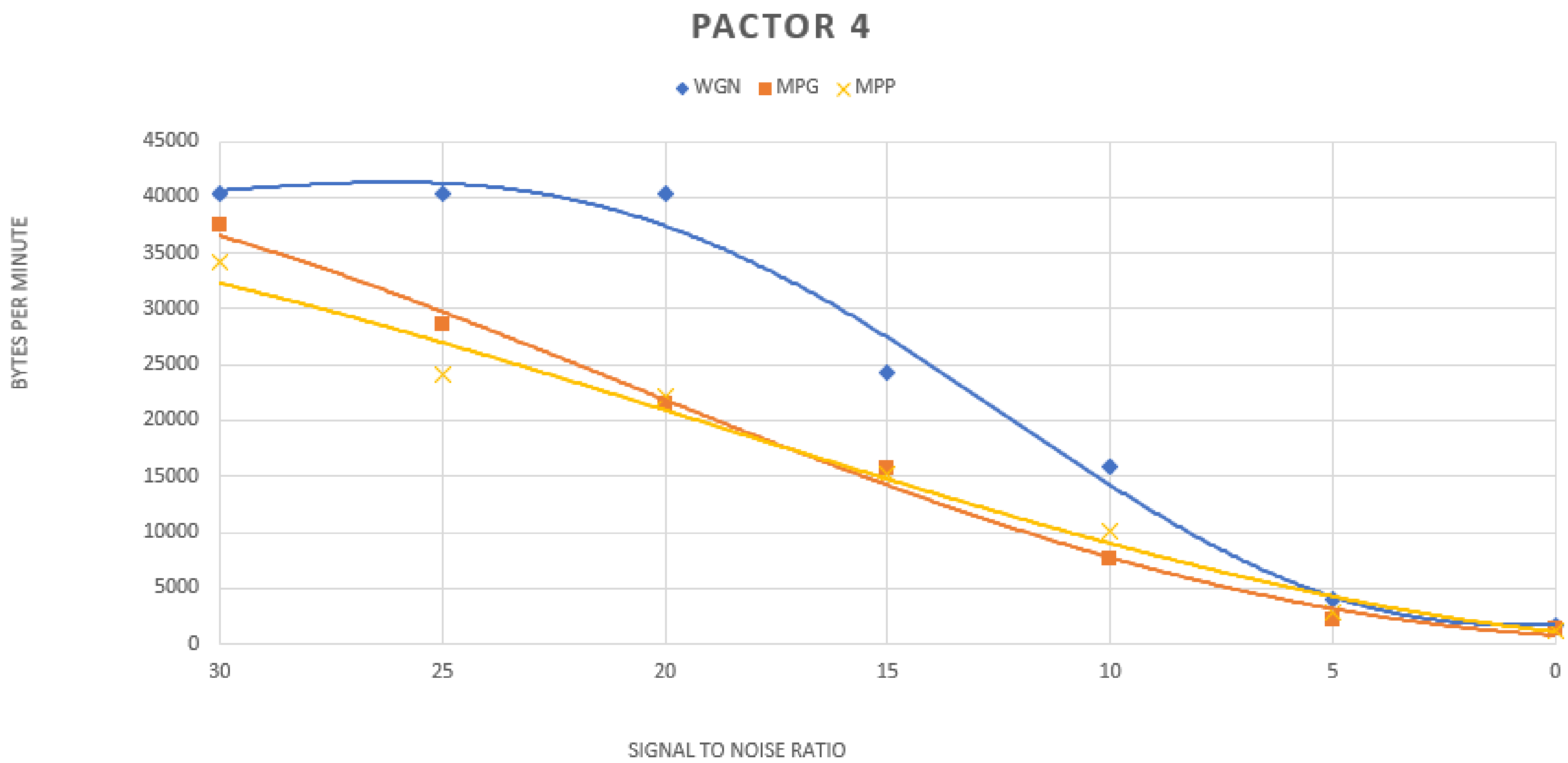
Results Summary: VARA 2300



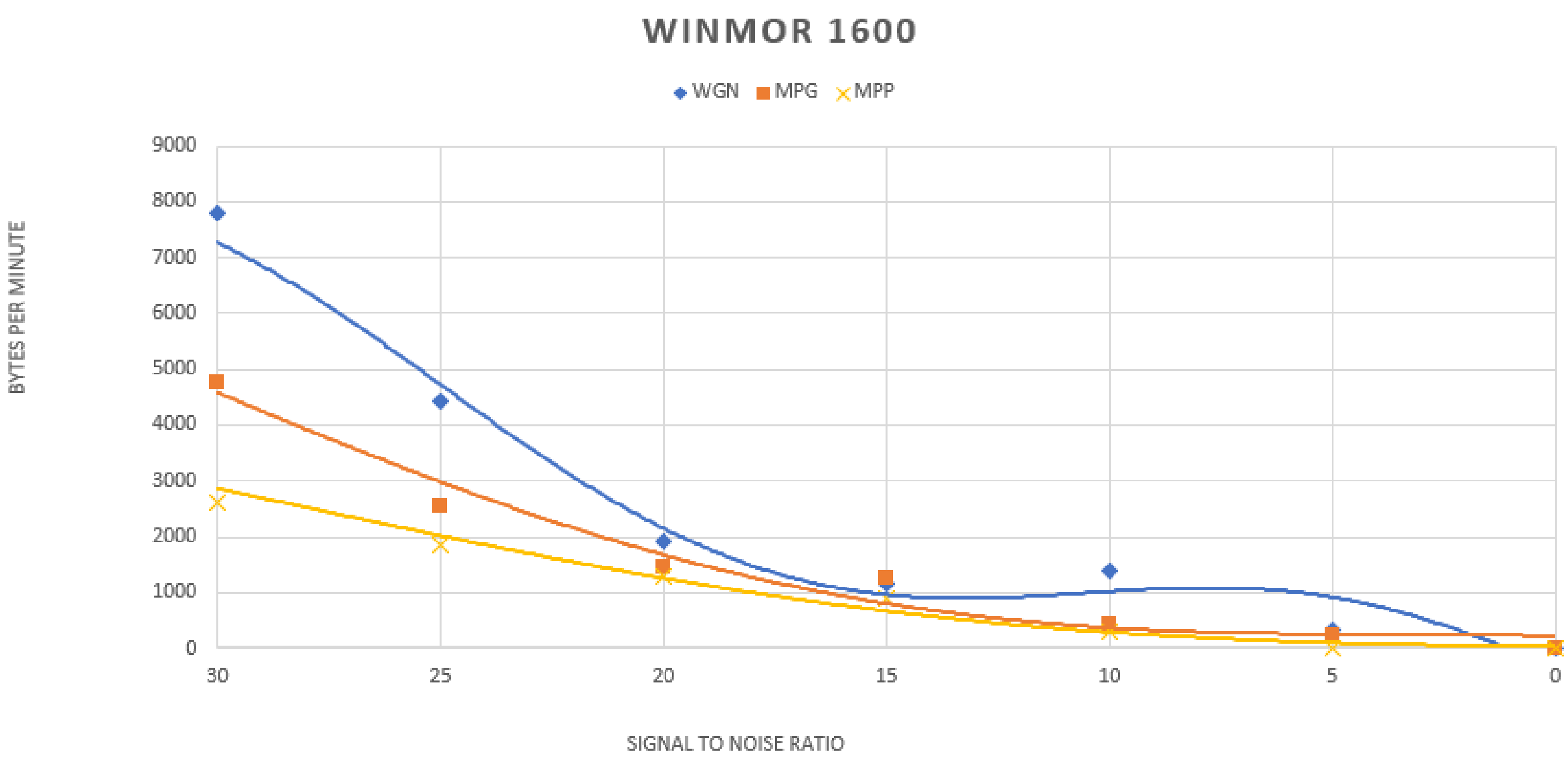
Results Summary: PACTOR 3



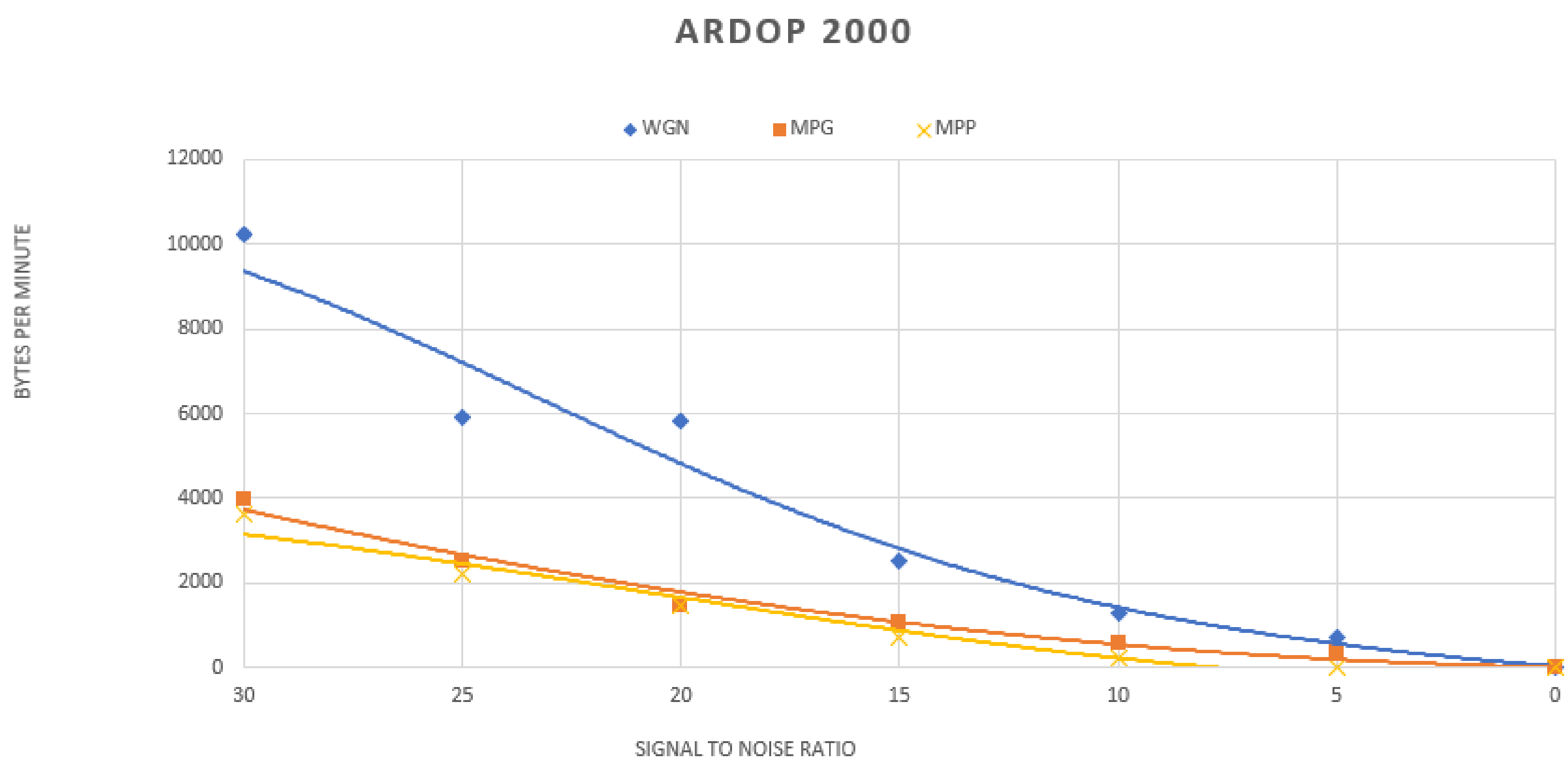
Results Summary: PACTOR 4



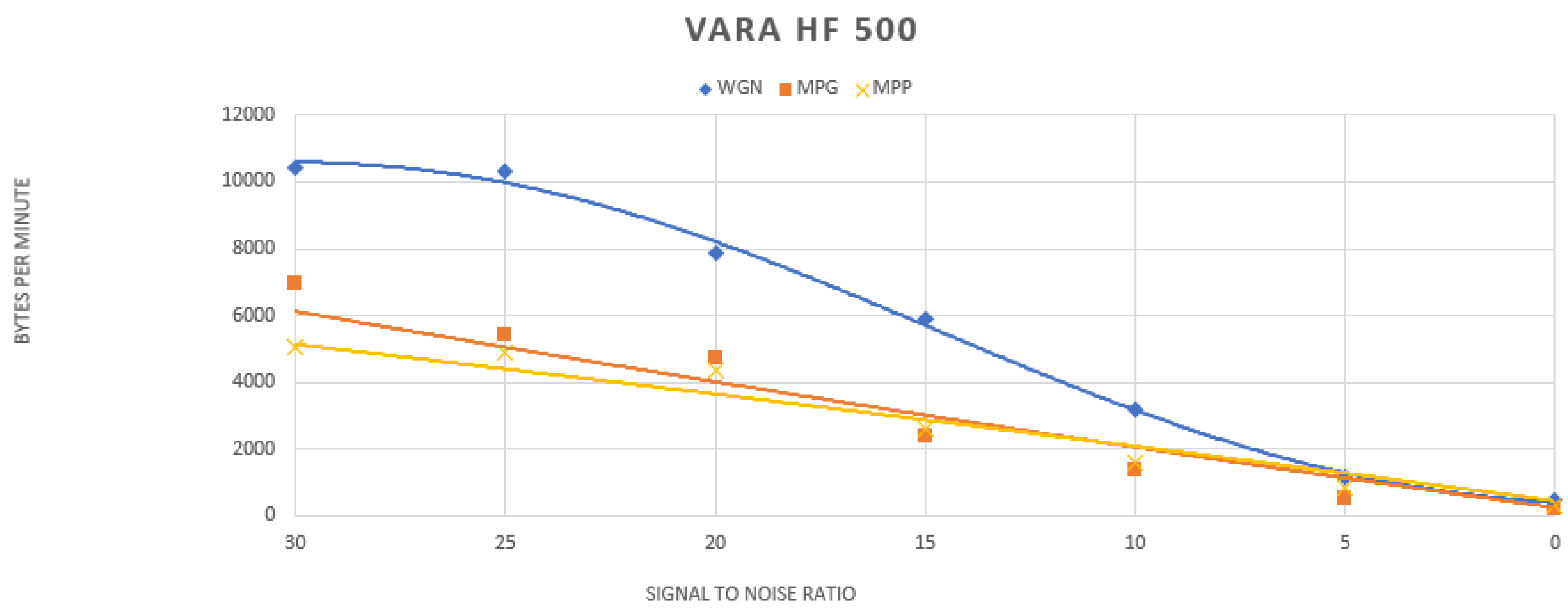
Results Summary: WINMOR 1600



Results Summary: ARDOP 2000



Results Summary: VARA 500



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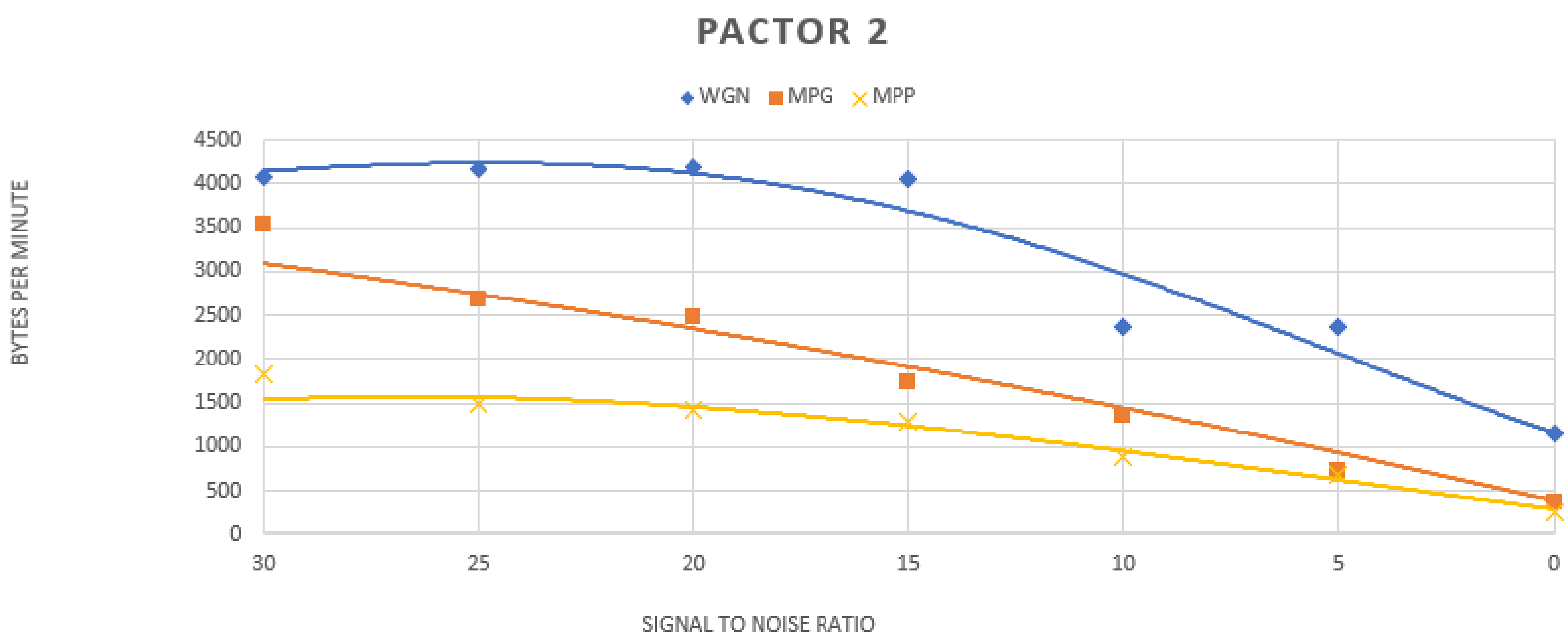
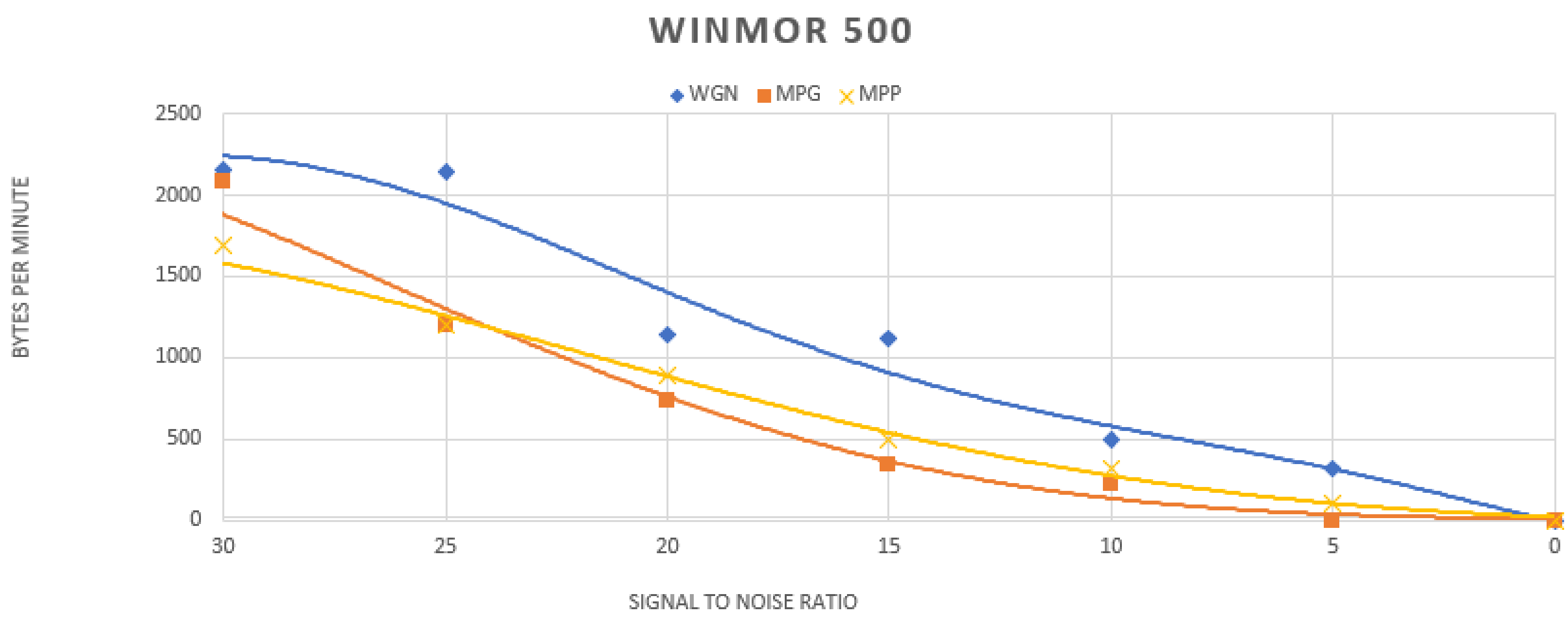
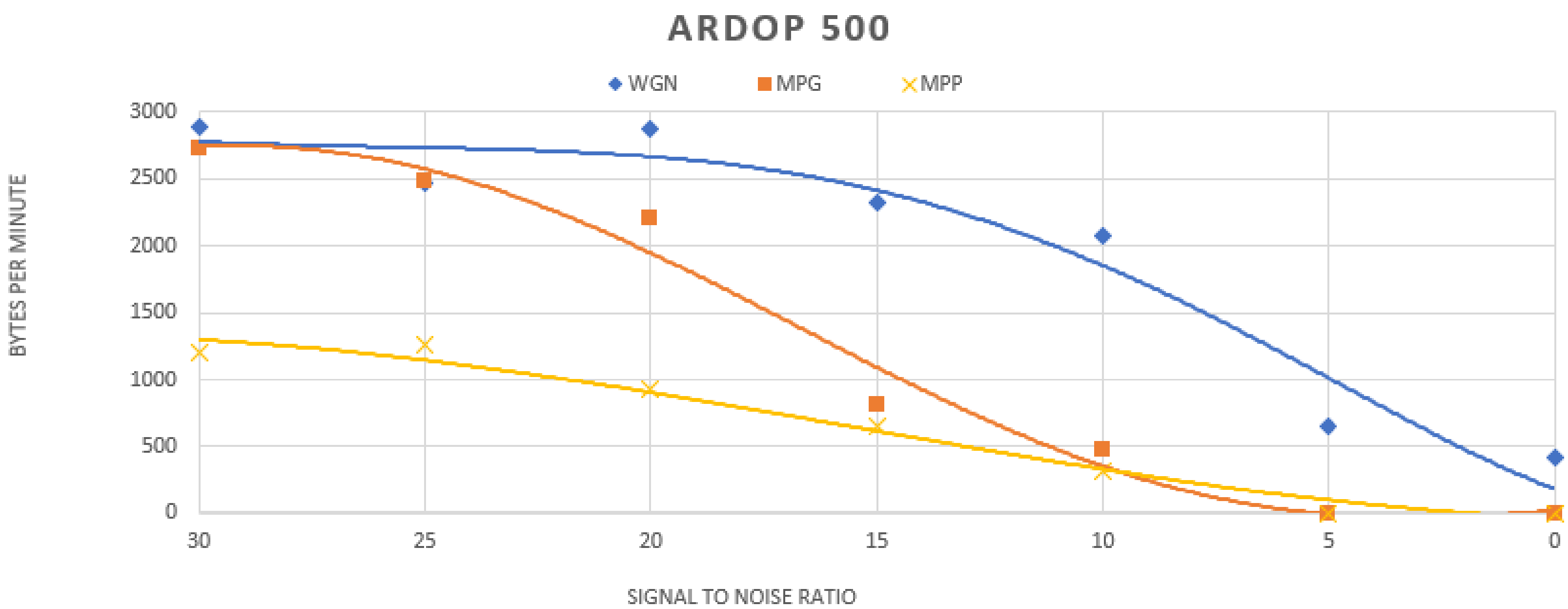
Results Summary: PACTOR 2



Results Summary: WINMOR 500

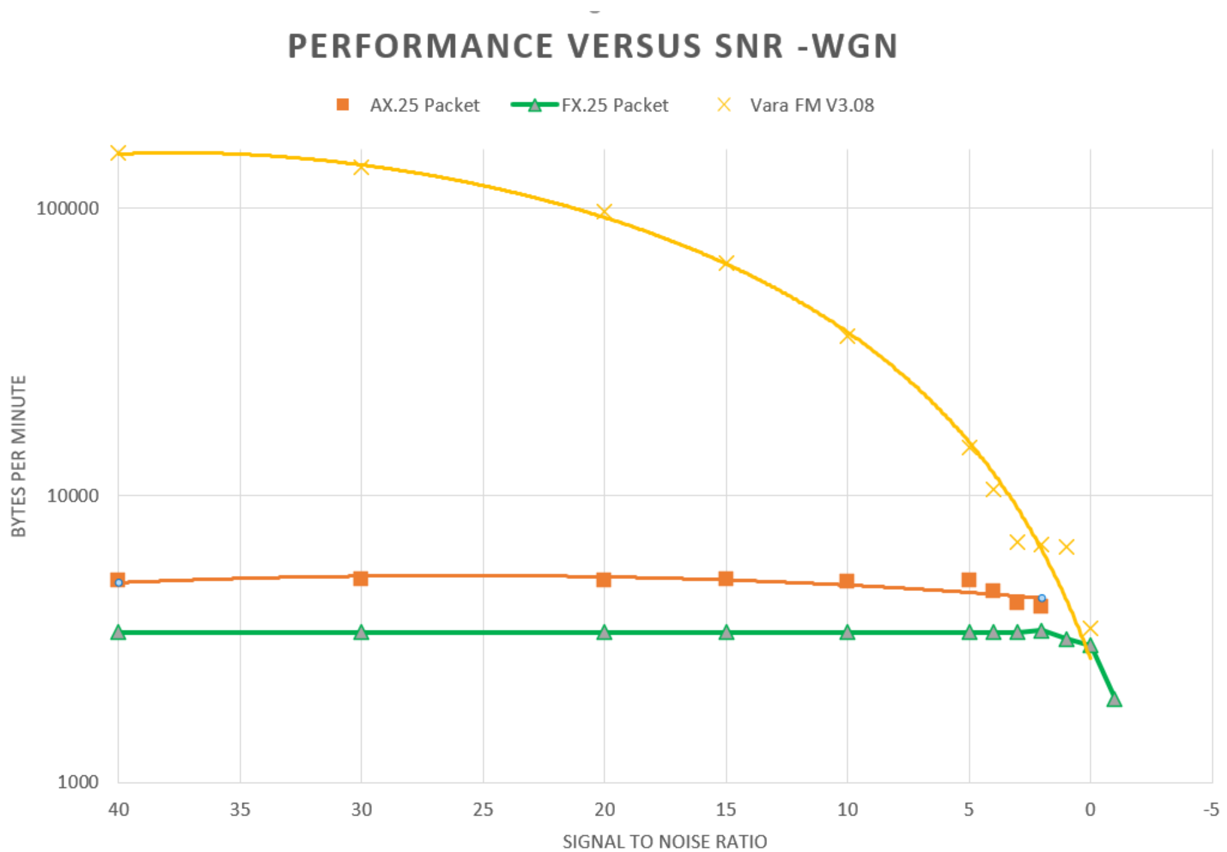


Results Summary: ARDOP 500



FM VHF Simulator Results:

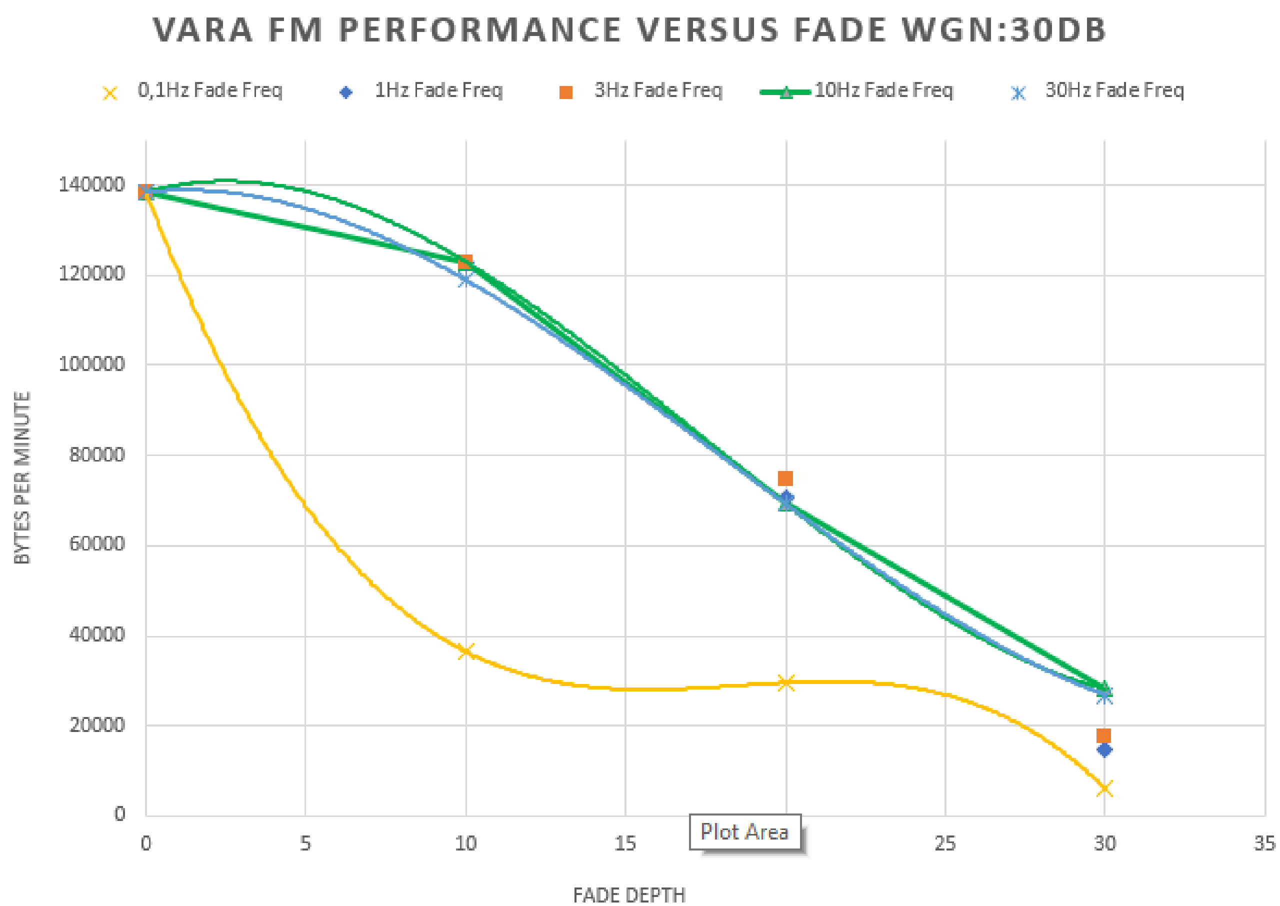
VARA FM, AX.25 Packet and FX.25 Packet were simulated. The UZ7HO Soundcard Modem[4] was used for both AX.25 and FX.25. Andy UZ7HO recently added a beta implementation of FX.25 which was used in this testing. The results with White Gaussian noise are shown below. Because VARA FM is so much faster than packet, a log scale was used.



[4] For more information on the UZ7HO Sound modem see his website: http://uz7.ho.ua/modem_beta/user_guide_v105_EN.pdf

FX.25 has extra overhead with its inclusion of forward error correction data which can be clearly seen relative to the AX.25 plot. I could not get AX.25 to work below a 1dB SNR while FX.25 continued working to a -1dB SNR.

The plot below shows the effects on VARA FM performance versus fade depth for different fade rates with an overall White Gaussian noise 30dB signal to noise. It behaves quite well except for a slow fade. I am not sure how realistic these cases are in the environment most users would see.



Conclusions:

I believe the Teensy IONOS Simulator is a useful tool for evaluating the various digital modes in use today and adds depth perception to over the air experience. For digital mode developers, this tool would be quite useful for evaluating new versions and experiments to supplement on-the-air testing.

Specifically, I think the data presented here is a useful comparison of the various digital modes in use with the Winlink system today. For HF users, over the entire range of conditions, the SCS PACTOR modems have outstanding performance. VARA provides excellent performance across the board.   VARA is a fantastic value and held up quite well across the test cases. SCS and VARA proved extremely reliable over all the test conditions NEVER dropping a connection.

WINMOR and ARDOP were really breakthrough modes when they were first created at a time when computer/sound card technology was much less advanced than today, but their performance lags the other modes by a great deal. They were also much less reliable across the multipath cases with incredibly low rates and frequent connection drops.

Many thanks to Rick Muething for many hours of support during this project and for running the "Take Three" PACTOR cases. One benefit from this systematic testing and Rick's efforts is a simulator that I feel people can have confidence in. And special thanks to Peter Helfert for his considerable assistance with a resulting better simulator and setting the record straight on PACTOR 4.

73,

Tom Whiteside N5TW

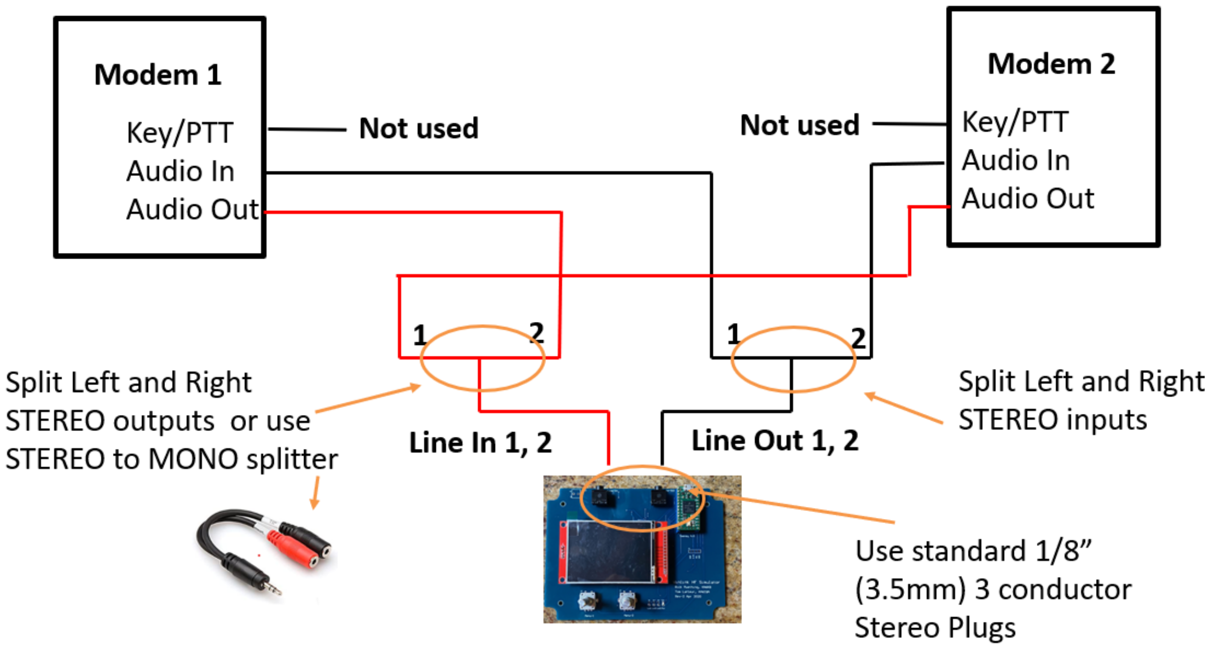
Appendix – Test Methodology

This section is included as an aid for people wanting to reproduce these results or perhaps wanting to evaluate additional conditions or future digital modes.

Tests were run using two Winlink Express instances and running peer to peer sessions to send data through the simulator to each other.

Here is a high-level pictorial of the test setup:

Connecting the simulator: 1 Simulator
Half Duplex, Channels will be symmetric



As you can see, only one simulator was needed for this testing. All is done with audio – there are no radios used in these runs.

PACTOR 3 and 4 testing was done using two SCS DR-7800 TNCs. All inputs and outputs were run through isolation transformers to connect to the simulator to ensure there were no ground loops.

All sound card-based modes used two Masters Communications DRA-30 sound cards:

http://www.masterscommunications.com/products/radio-adapter/dra/dra30.html

As with PACTOR testing, all sound card inputs and outputs were run through isolation transformers to prevent ground loops.

The Teensy IONOS SIM has a loop test menu that I used to set the output levels for the modes to ensure the signal was reasonable to not overrange any of the hardware. To do this, I first removed the output connector from the simulator and sent a test signal from each Winlink Express and adjusted output levels for around 450mV. That provides plenty of input but away from overrange limits.

Input levels were adjusted on the sound cards and the Windows sound level menus for signal levels that stayed within the “green zones” for the various apps. I did this using low SNR multipath settings where the levels can swing to the highest values. I used the simulator default input and output levels of 2V for all testing.

The simulator 3KHz bandwidth was used for all HF testing. 6KHz bandwidth was used for FM testing,

I used large data transfers to give the mode time to do its best and to average out variations. Transfer sizes of 120KB were used for high rate VARA and Pactor cases dropping to 32KB for smaller cases for these modes. For the slower WINMOR and ARDOP modes, sizes ranged from 10KB to 4KB with the smaller sizes for the especially slow cases.