

A comparison of Winlink® digital mode performance based on simulation results using the Teensy IONOS Simulator¹

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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. The much less expensive VARA HF did especially well across the range of conditions tested. The SCS modems and VARA could run long test cases without losing a connection while ARDOP and WINMOR were slow and unable to run many of the cases. VARA FM crushed AX.25/FX.25 VHF cases.

Overview:

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 (ARSAFI) 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

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

² Amateur Radio Safety Foundation, Inc. <https://www.arsfi.org/>

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 wideband Gaussian noise and multipath with noise cases across a range of signal to noise values. These channels are based on the well-documented Watterson model³ used in many expensive laboratory grade instruments.

For HF, both wideband modes (PACTOR 3, PACTOR 4, VARA, ARDOP and WINMOR) 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.

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.



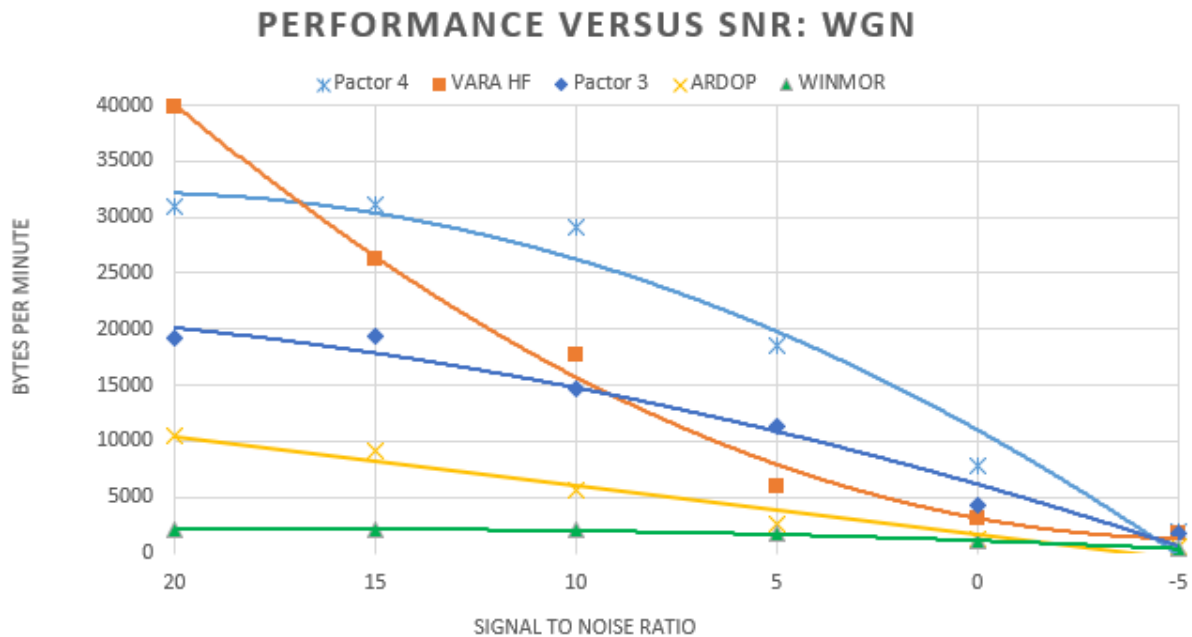
Figure 1 Test setup at N5TW using an early prototype IONOS Simulator

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

Here are those results:

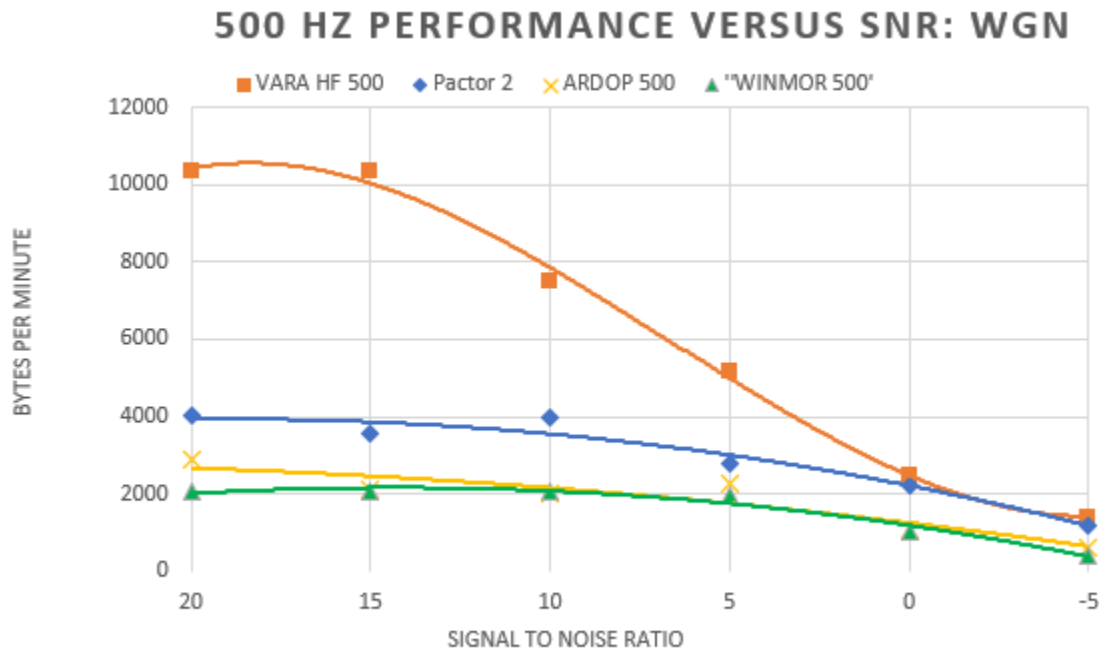
HF Testing:

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



All modes were able to operate over this range of signal to noise ratio. With an excellent quality 20dB SNR, VARA performance exceeds a PACTOR 4 TNC. VARA exceeds PACTOR 3 for this model for greater than 10dB SNR conditions. ARDOP exceeds WINMOR performance across the entire SNR range but both ARDOP and WINMOR have performance a small fraction of the speed of the other modes.

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



A beta version of the new VARA 500 mode dominated performance over the other modes with wideband Gaussian noise.

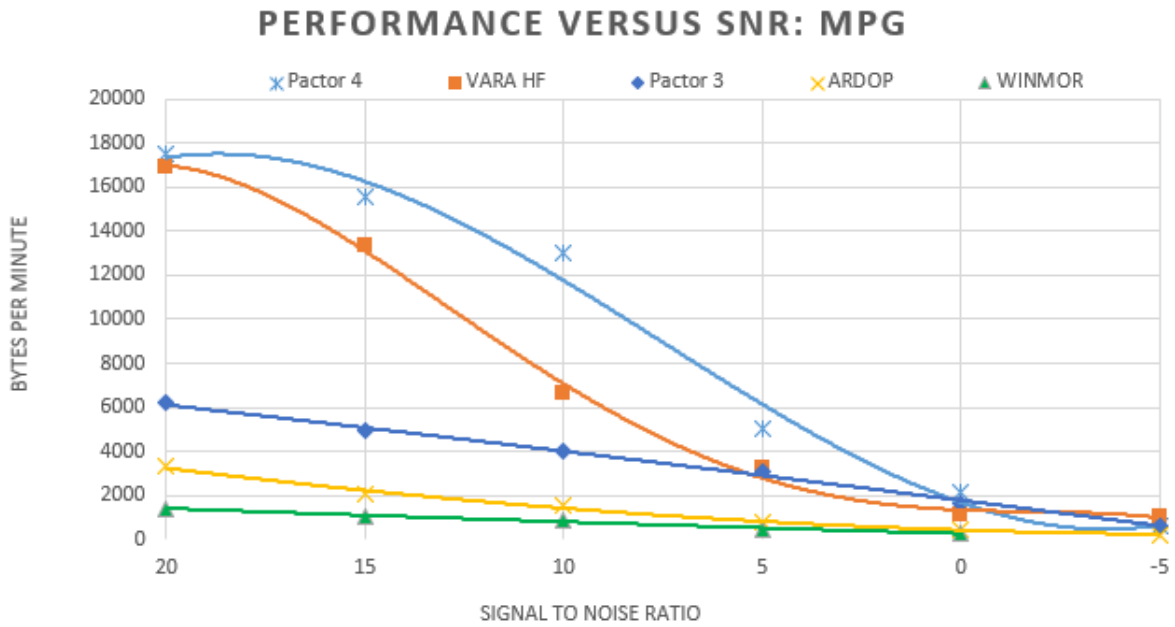
HF Multipath simulation:

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 three levels of multipath models: MPG (good conditions), MPM (moderate conditions) and MPP (poor conditions). Each of these multipath levels can be run using a 2, 3 or 4 ray model.

Channel Type	Spread Hz	Delay	Fade Depth
WGN	0	0 ms	
FADE (FLAT)	0		0 to 40 dB
MPG	.1	.5 ms	
MPM	.5	1 ms	
MPP	1	2 ms	
MPD	2.5	5 ms	

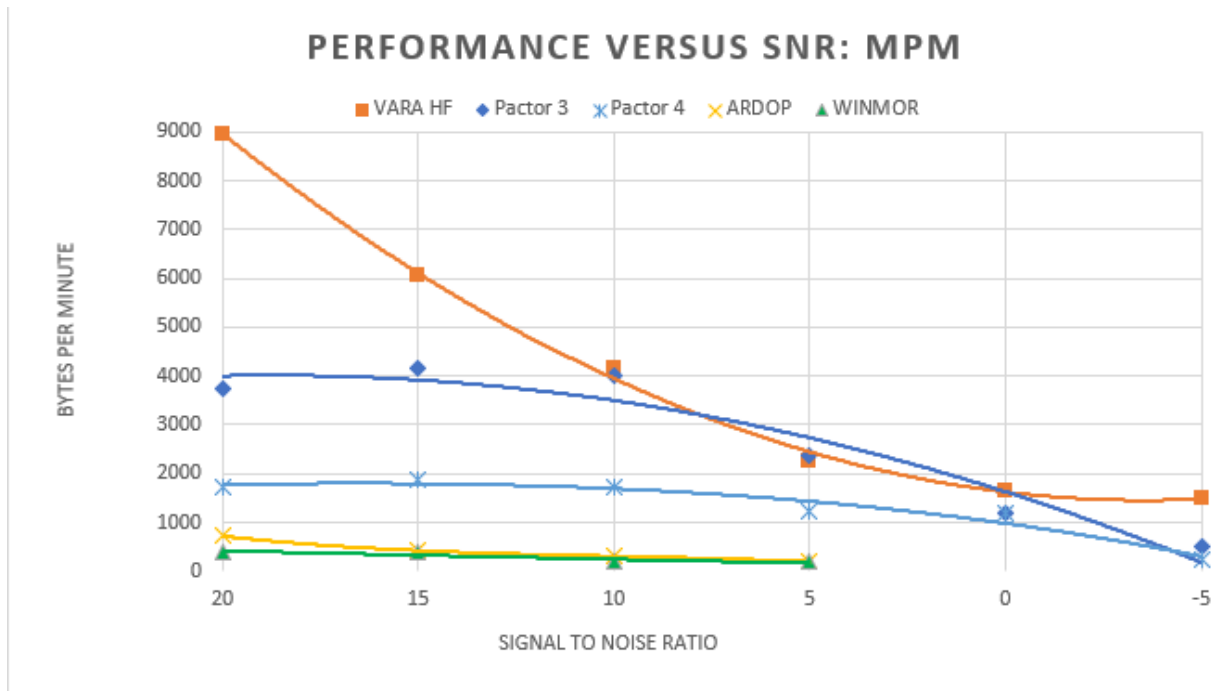
For the tests in this paper, the MPG, MPM and MPP levels of multipath are run all with a 3-ray model.

Multipath MPG (Good) Results:



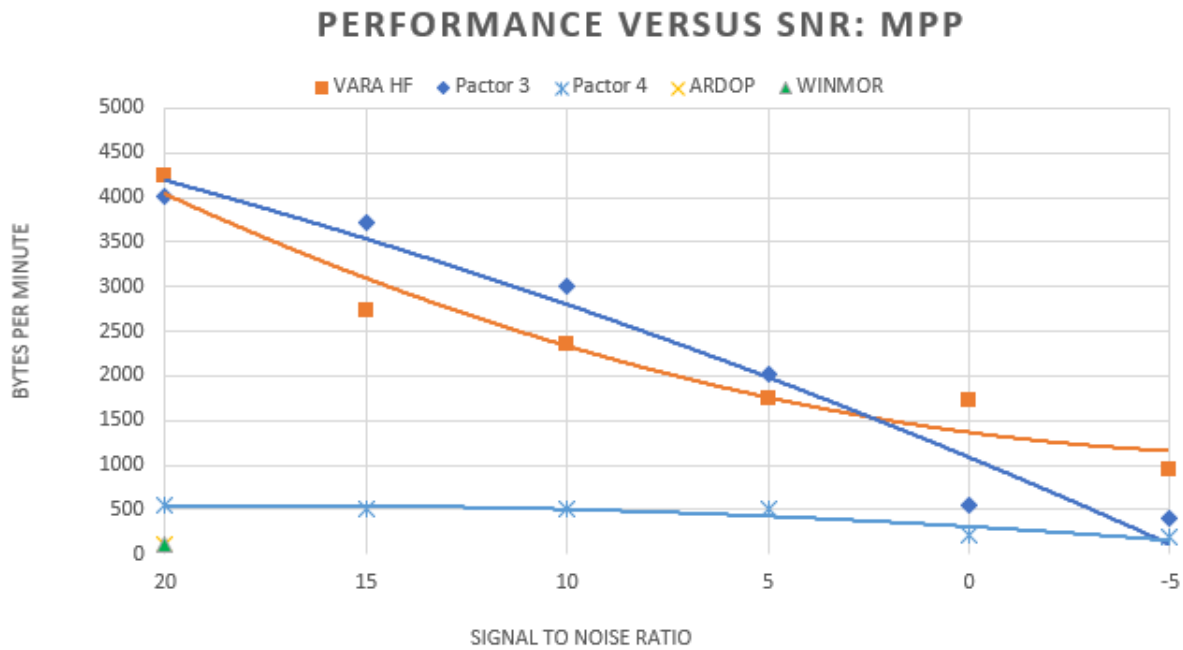
PACTOR 4 was the clear leader in the MPG case with VARA in a respectable second place. WINMOR would not pass traffic reliably at -a 5dB SNR.

Multipath MPM (Medium) Results:



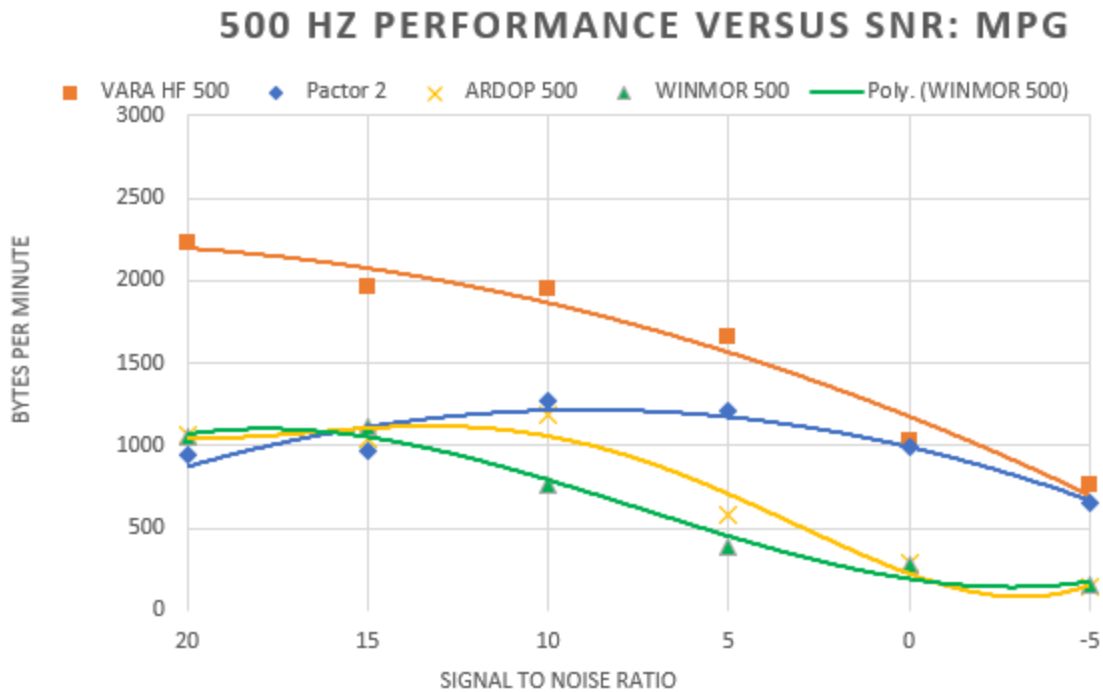
PACTOR 4 did relatively poorly in the MPM case being beaten by VARA and PACTOR 3 across the board. VARA was the clear leader for this case acquitting itself well versus PACTOR 3. WINMOR and ARDOP were miserably slow and unreliable even at a 5dB SNR.

Multipath MPP (Poor) Results:



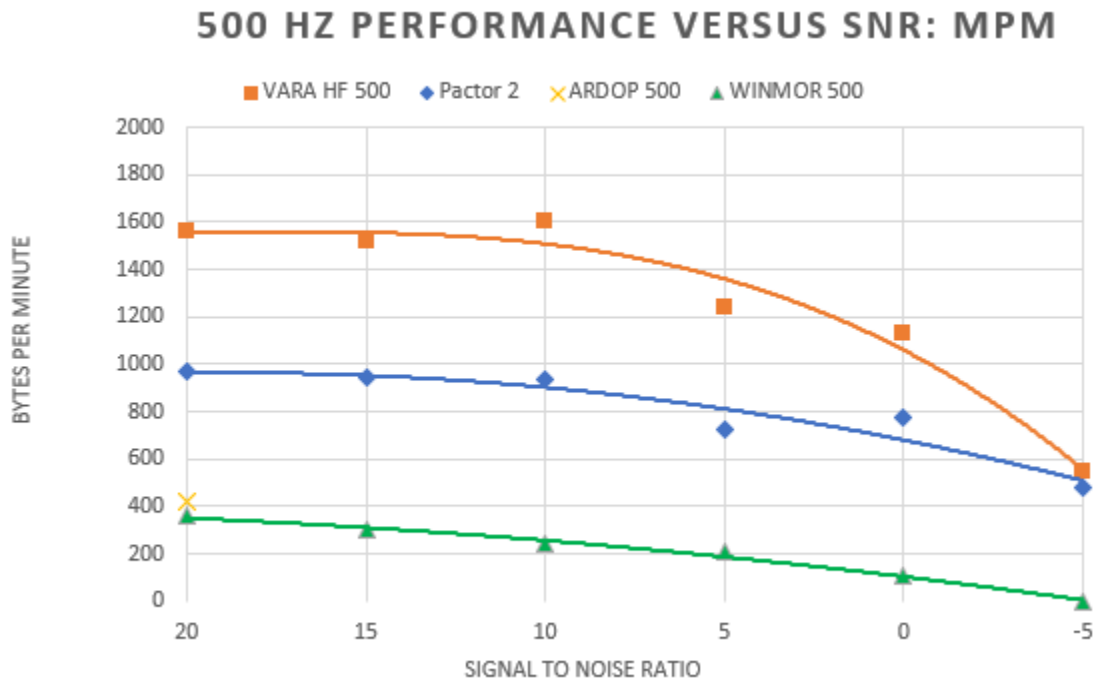
My conclusion is that MPP conditions are best avoided. WINMOR and ARDOP were unusable even at a 20dB SNR. PACTOR 4 performance was crushed by MPP. PACTOR 3 managed similar performance to MPM conditions until the SNRs got low. VARA's performance was reduced from MPM but held its own reasonably versus PACTOR 3 and performed best of the group in 0dB and -5dB cases.

Multipath MPG (Good) 500Hz Results:



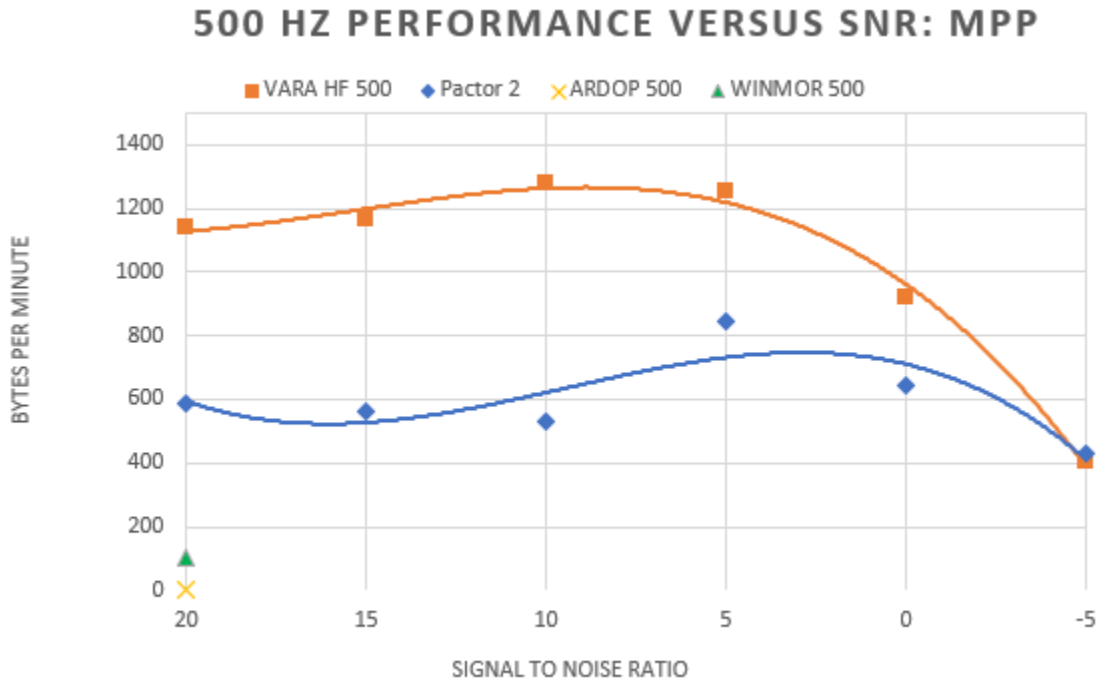
VARA 500 (using a beta version of this software), far exceeded the other modes at 500Hz. PACTOR 2 performed slightly better at a 10dB SNR than at 20dB and this was a very repeatable result. Best guess, this is some effect of how PACTOR 2 responded to the mix of multipath and wideband noise. WINMOR and ARDOP performance slowed to a crawl for the low SNR cases.

Multipath MPM (Medium) 500Hz Results:



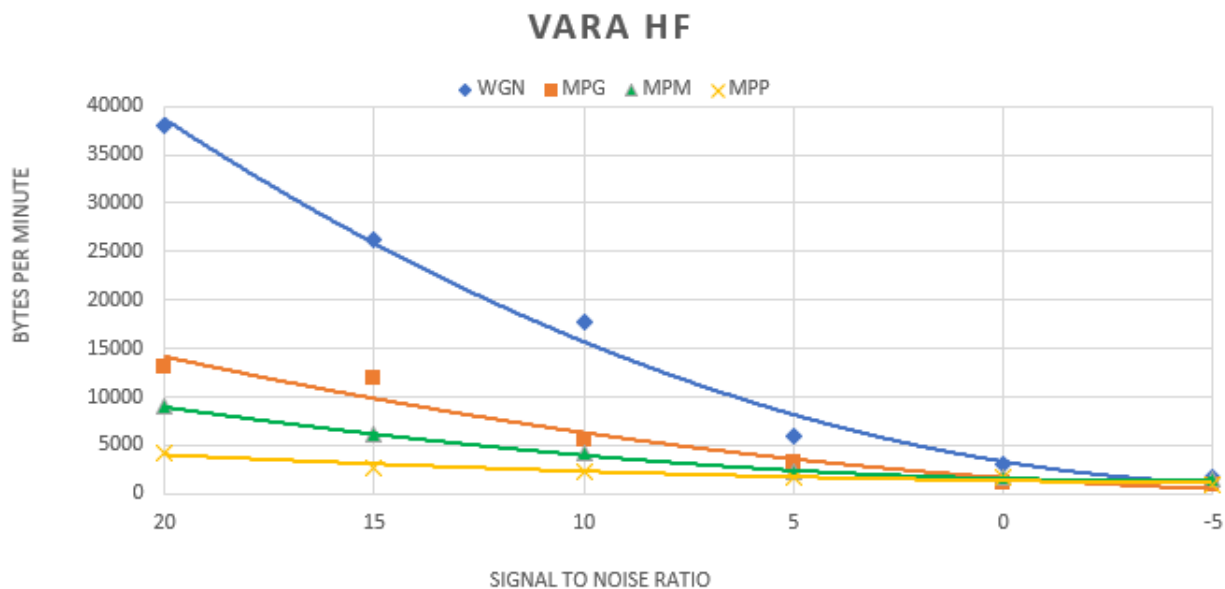
PACTOR 2 results were not that different for MPM versus MPG. VARA was reduced somewhat with MPM but still dominated the other modes. I was unable to get ARDOP to work below a 20dB SNR with MPM. WINMOR did better albeit slowly.

Multipath MPP (Poor) 500Hz Results:

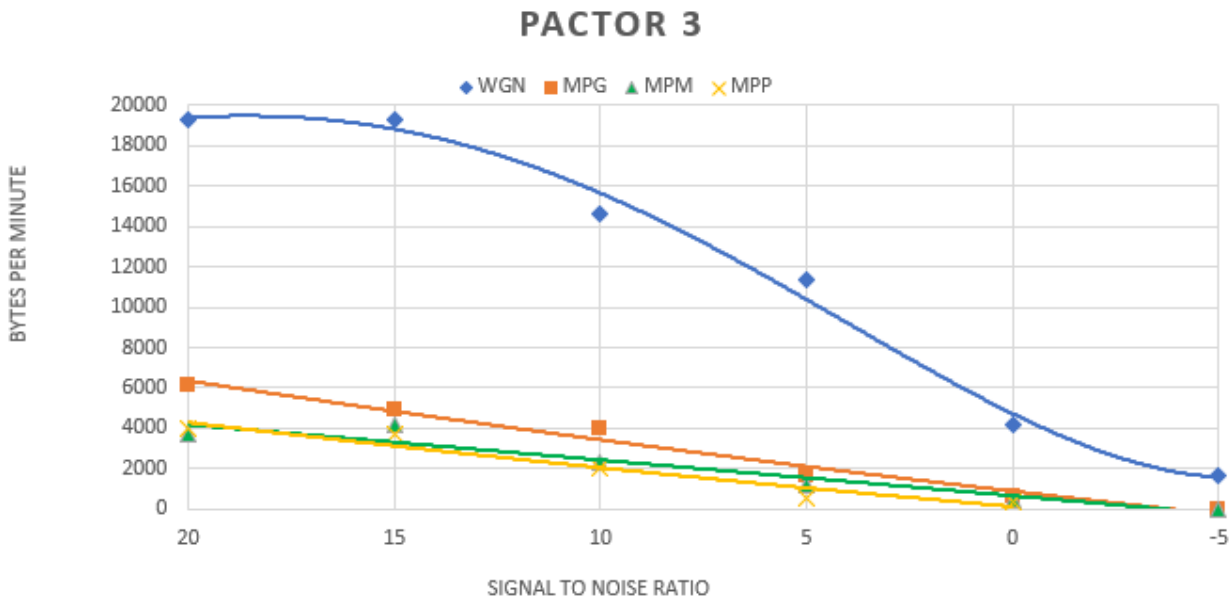


As with the wideband cases, MPP was brutal but VARA and PACTOR 2 worked across the range with VARA in the lead. ARDOP and WINMOR were unusable.

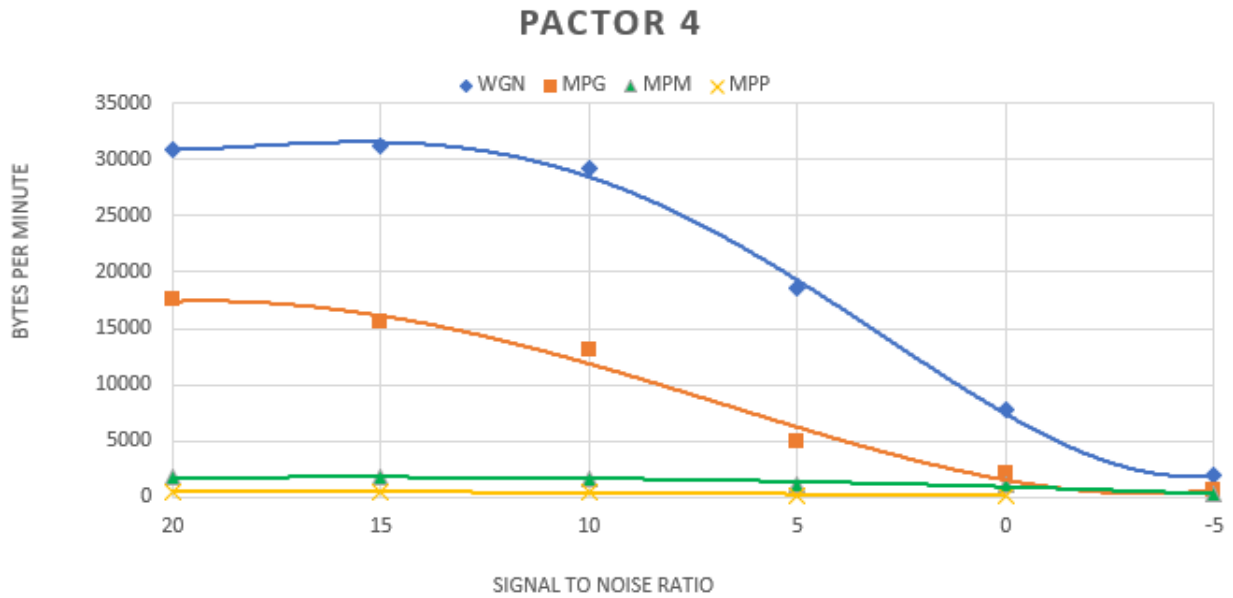
Results Summary: VARA



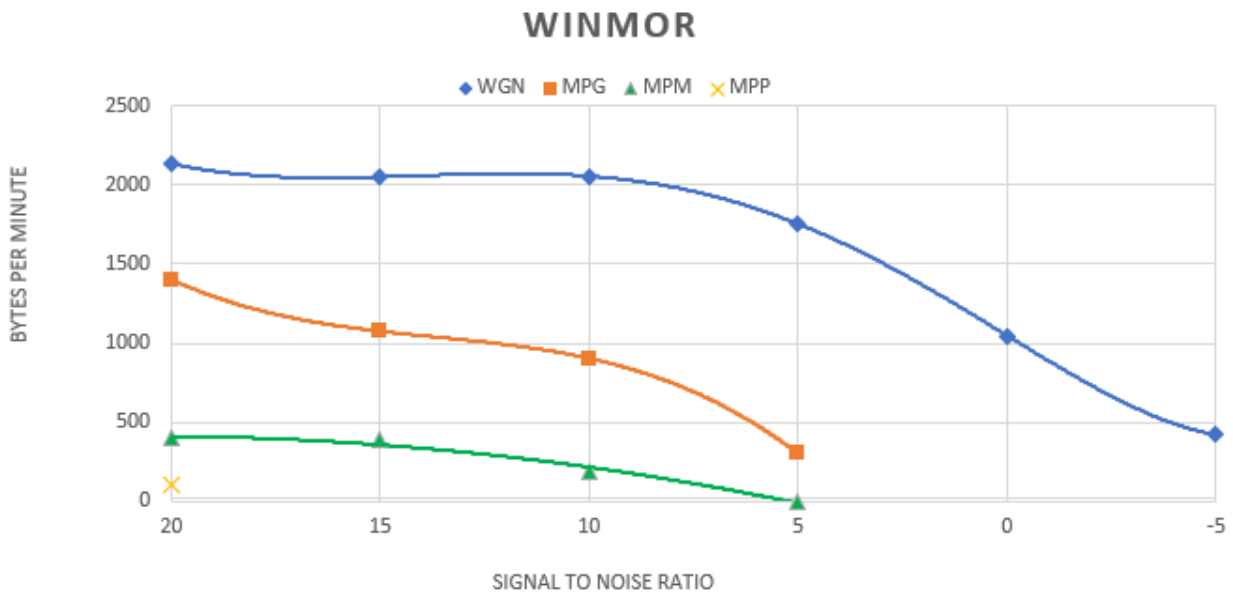
Results Summary: PACTOR 3



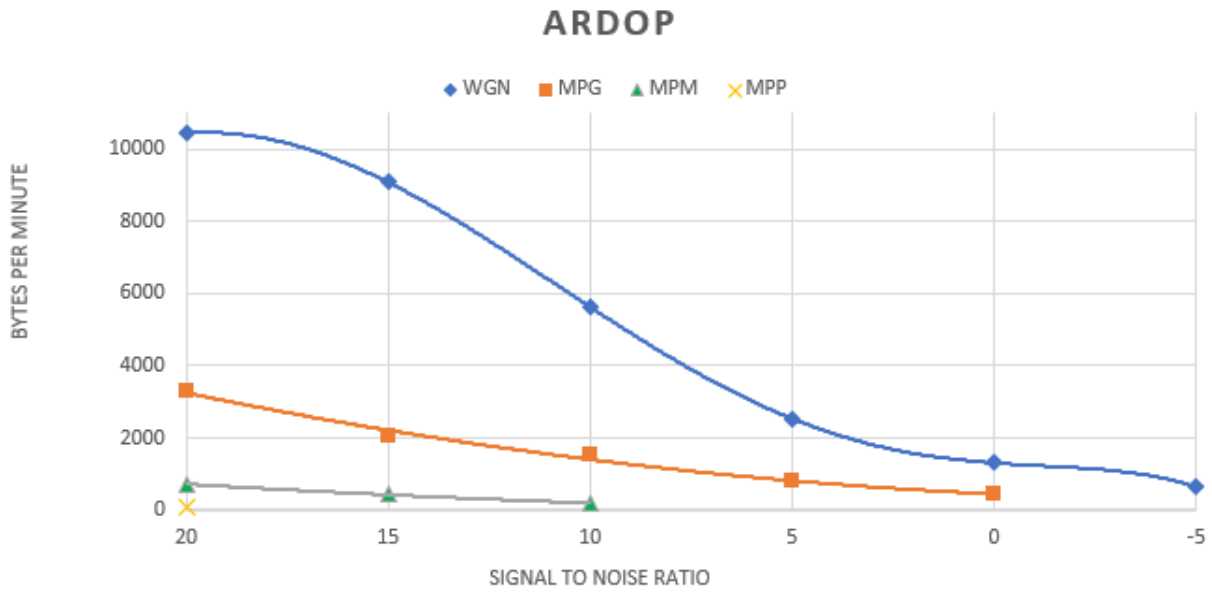
Results Summary: PACTOR 4



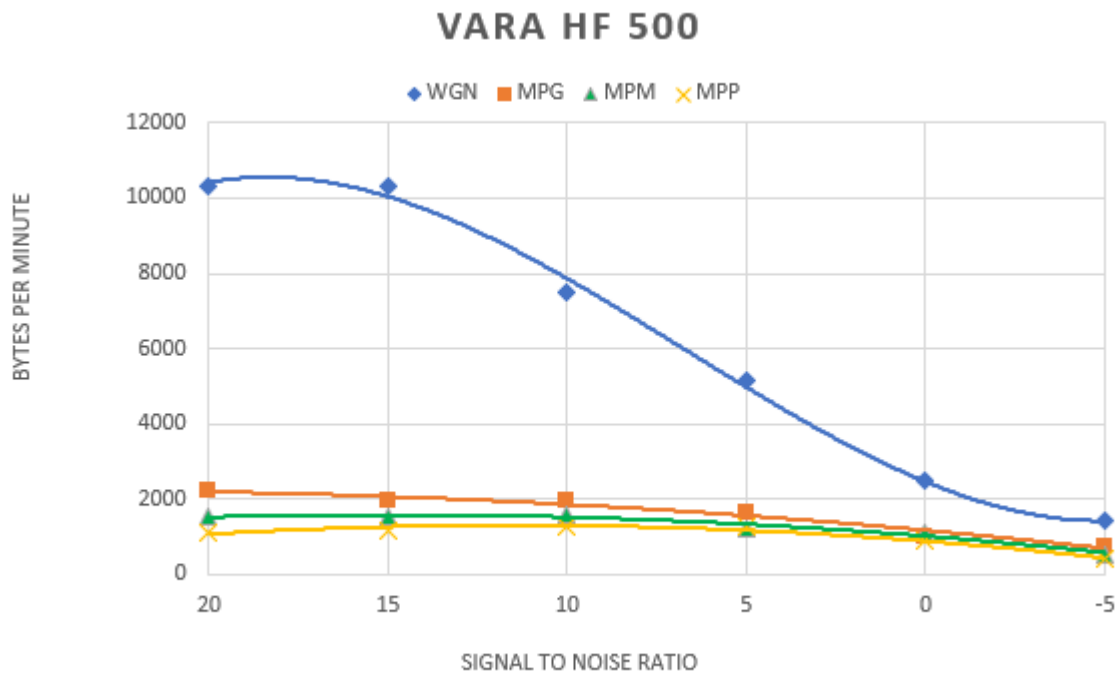
Results Summary: WINMOR



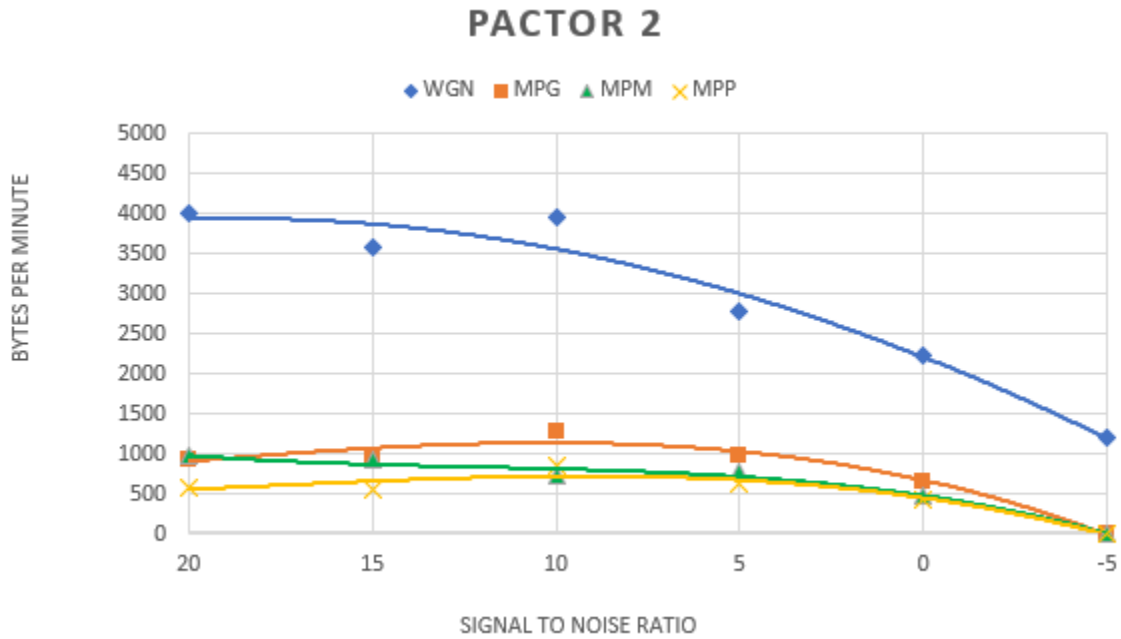
Results Summary: ARDOP



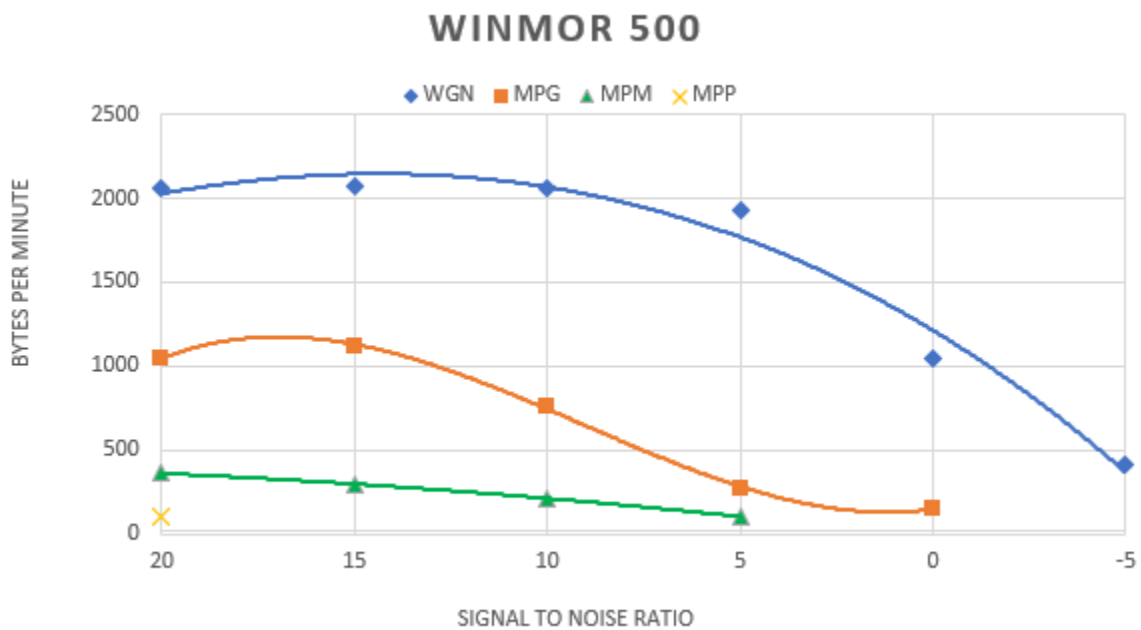
Results Summary: VARA 500



Results Summary: PACTOR 2



Results Summary: WINMOR 500

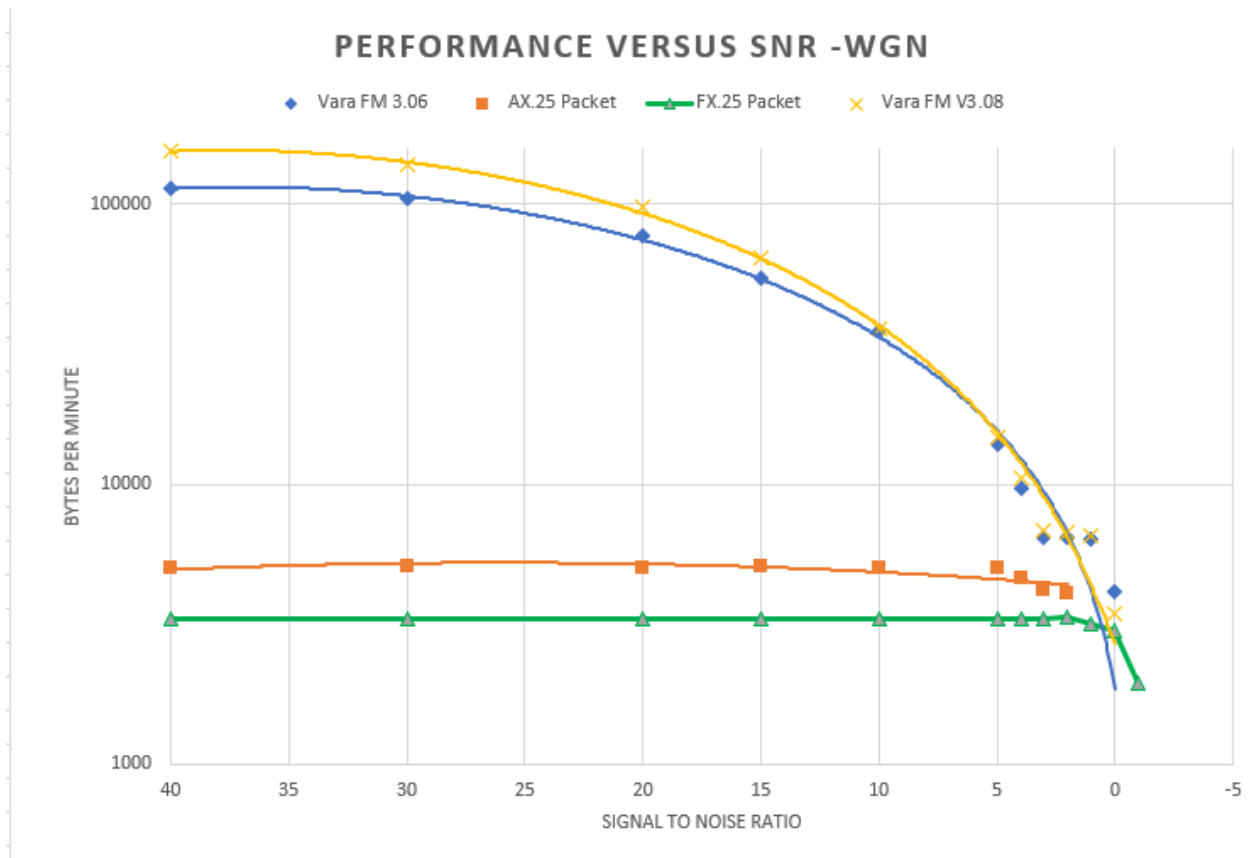


Results Summary: ARDOP 500



FM VHF Simulator Results:

VARA FM, AX.25 Packet and FX.25 Packet were simulated. A later version of VARA FM was released during this effort and I decided to add this new version as an additional case. The UZ7HO Soundcard Modem⁴ 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 wideband Gaussian noise are shown below. Because VARA FM is so much faster than packet, a log scale was used.



You can see in the later version of VARA FM, performance improved across the board. 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 wideband Gaussian noise 30dB signal to noise.

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

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 quite excellent performance even exceeding the far more expensive SCS TNCs in many cases. 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. One benefit from this systematic testing and Rick's efforts is a simulator that I feel people can have confidence in.

73,

Tom Whiteside N5TW

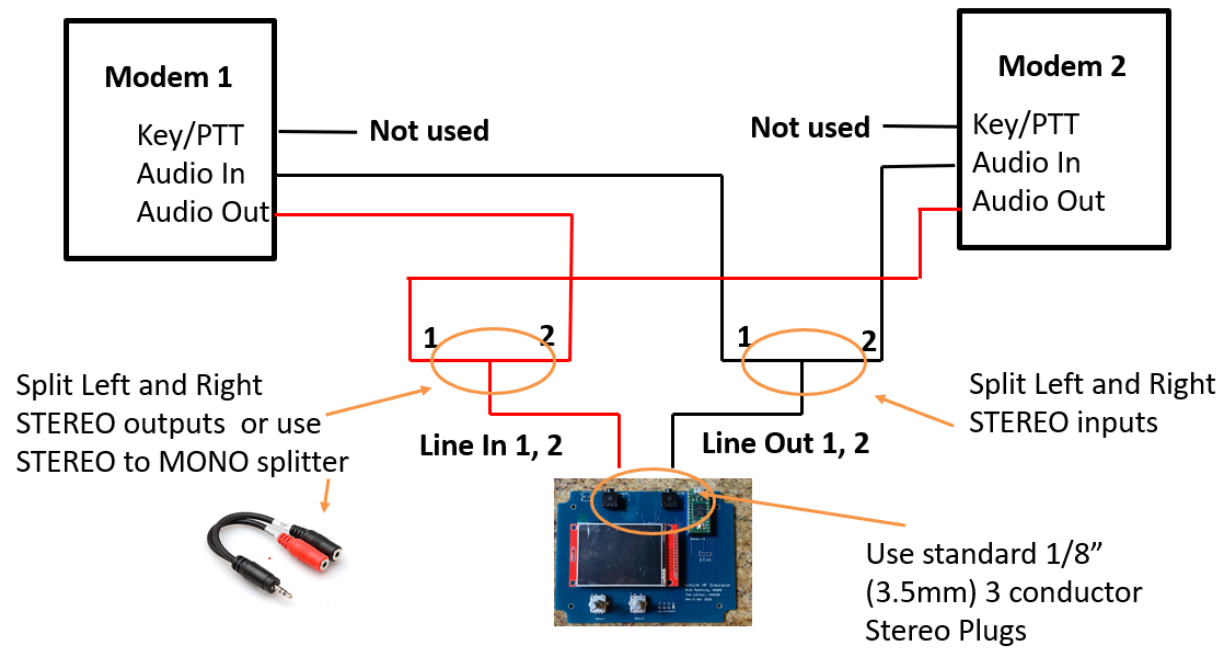
Appendix – Test Methodology

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.