Technical Report

Naval Total Asset Visibility (NTAV) Tests
on the SS Curtiss, Port Hueneme, CA
25 September – 6 October 2000

Appendix A
USC UltRa Lab: Shipboard Environment Characterization

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Naval Facilities Engineering Service Center

Steven J. Gunderson

University of Southern California

Dr. Robert Scholtz
Dr. Keith Chugg
Mr. Robert Weaver
Mr. Joon-Yong Lee
Mr. Carlos Corrada
Mr. Eric Homier
Mr. Robert Wilson

The University of Southern California (USC) Ultra Lab conducted shipboard RF environment characterization of the SS Curtiss immediately following the first week open space tests. Tests were not performed during the second week with containers. Dr. Robert Scholtz led the team of professors and students. The test provided an excellent opportunity for USC to perform channel measurements in a ship. They were funded by ONR Code 313 Marine Corps 6.1 research grant.

Four primary tests were run:

- Pulse Response with Sampling Oscilloscope
- Transfer Function with Network Analyzer
- Pulse Response with a UWB Test Radio
- Interference Check with Spectrum Analyzer

The pulse response with sampling scope test was straightforward, operating similar to container tests conducted by AetherWire at the Port of Oakland. A low-powered pulser was connected to an UWB “diamond” antenna to radiate impulses. Synch reference was provided by coax cable to the sampling oscilloscope. Measurements were made with a 20 Gsample/sec sampling oscilloscope connected to a pre-amplifier and matching “diamond” antenna. Figure A-1 shows the pulse generator and oscilloscope equipment configuration.

The sampling scope had limited memory, thus many readings needed to be spliced together to form a composite picture, lengthening time required for measurement and limiting the number of tests that could be made. The sampling oscilloscope had high background noise, limiting noise floor, preventing measurement to –20 dB. Averaging was not used due to the long measurement times.

The network analyzer was used to improve noise floor. It measured the channel frequency and phase response and the result was Fourier transformed into the time domain. It had 40 to 50 dB lower noise floor than the digital sampling oscilloscope. Ship’s high pressure sodium arc lamps were turned off, as they raised the noise floor 6 dB. Figure A-2 shows the network analyzer test equipment configuration.

The UWB test radios were Time Domain PulsON™ Application Demonstrator (PAD). They operated in pairs, one transmitting and the other receiving. They were used for channel measurements and sampled the environmental response, much the same as a pulse generator/sampling oscilloscope. They did not need a synchronization cable between units, they were able to automatically synchronize between themselves from received pulses. Samples were sent to a connected laptop PC. No pictures were taken of the PADs and no data was made available. Time domain provided the units to USC non-disclosure.

A spectrum analyzer was used to measure interference from shipboard radios and radars.

UWB “diamond” antennas were used for all tests. They are like “bow-tie” antennas, with broad response, but have the “fat” side connected inside resulting in a diamond appearance. The PADs have smaller “diamond” antennas, and the oscilloscope and network analyzer measurements used larger antennas with –3 dB response from 700 MHz to 1.8 GHz. Figures A-3 and A-4 show a test setup in holds 5 and 6. Figures A-5 thru A-7 show the measurement equipment, measurements and data processing equipment.

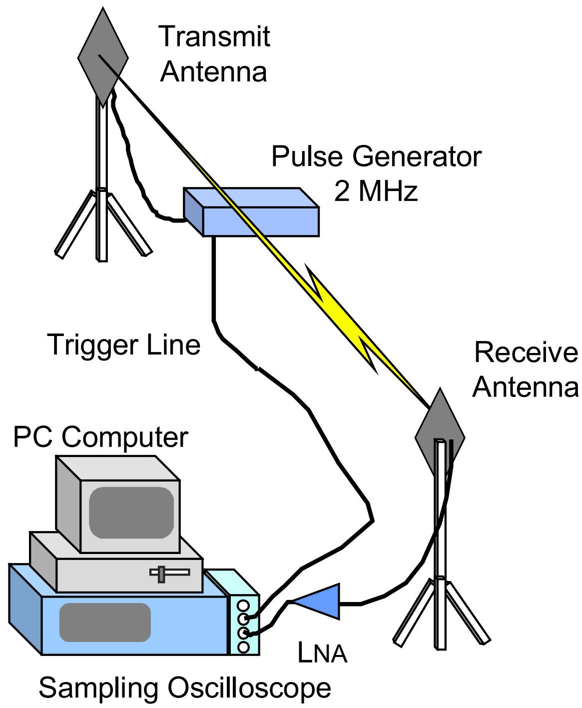

Figure A-1. USC pulse generator and sampling oscilloscope test equipment.

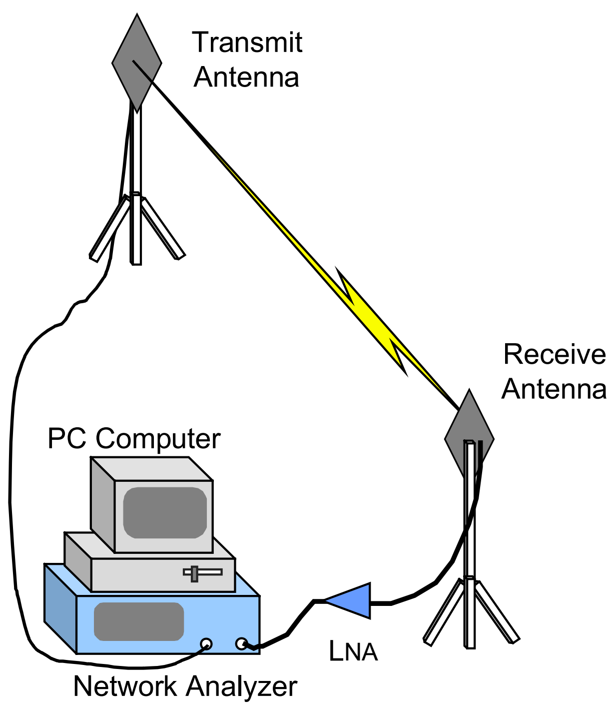

Figure A-2. USC network analyzer test equipment.

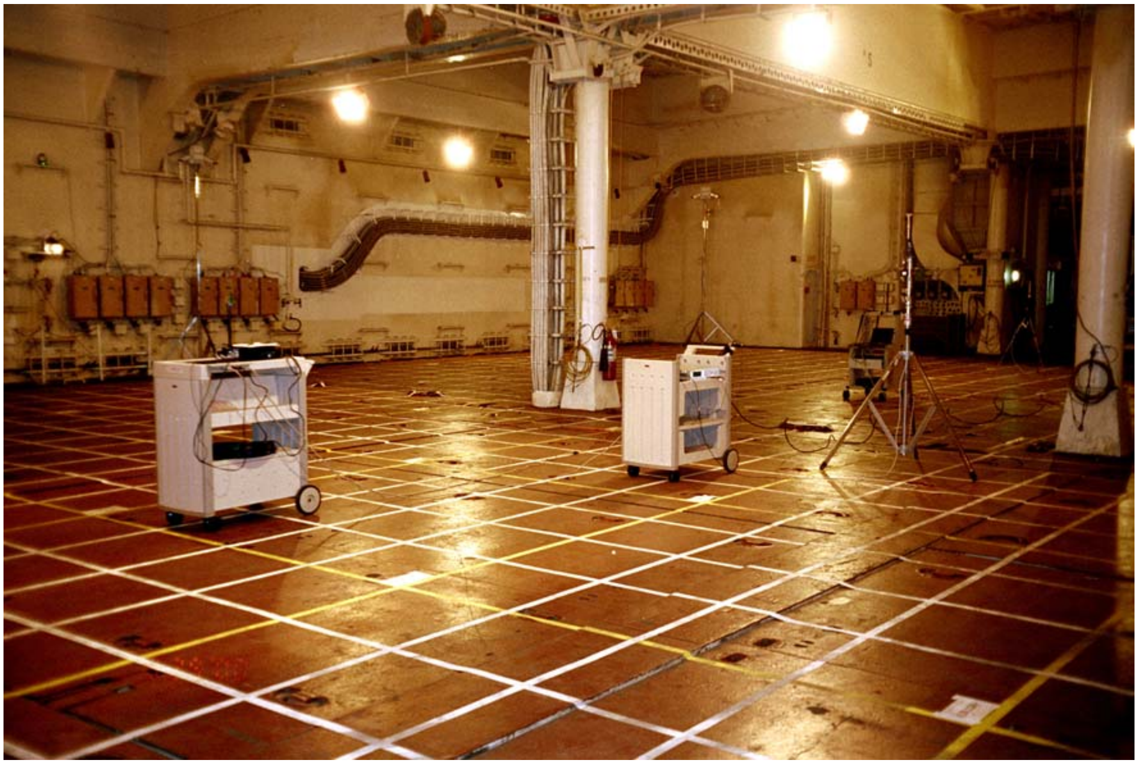

Figure A-3. USC test equipment setup in SS Curtiss Holds 5 and 6, looking port forward.

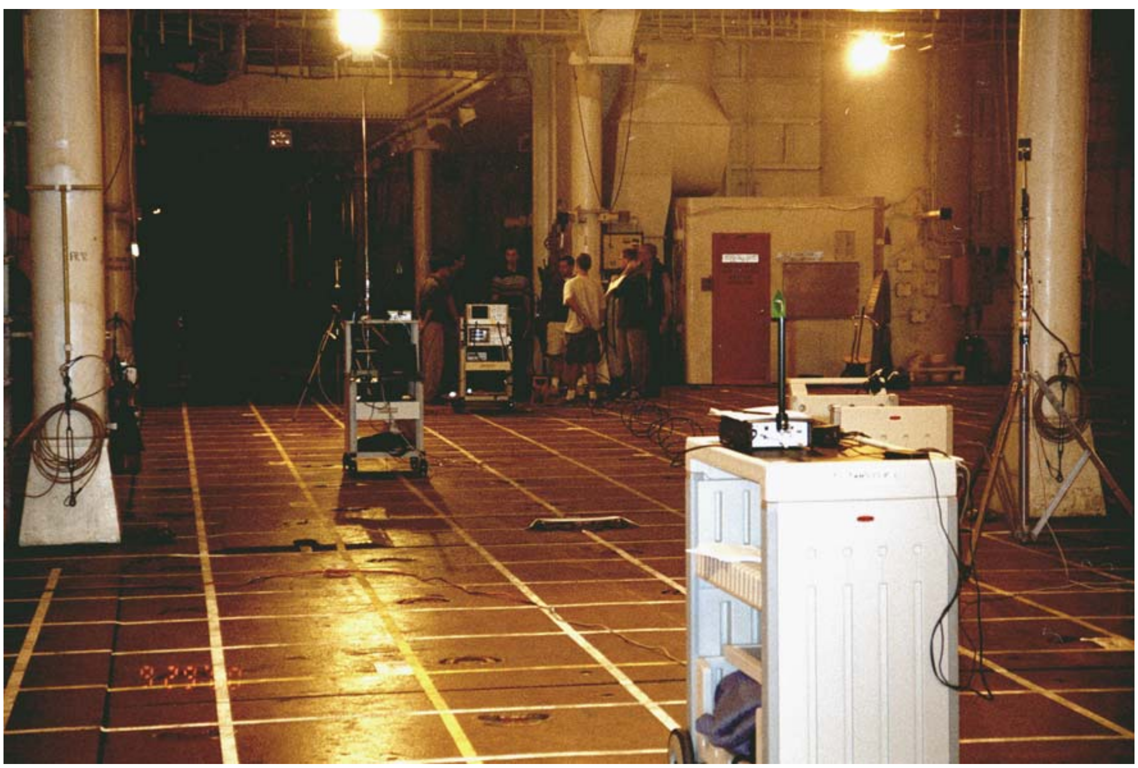

Figure A-4. USC test equipment setup in SS Curtiss Holds 5 and 6, looking forward.

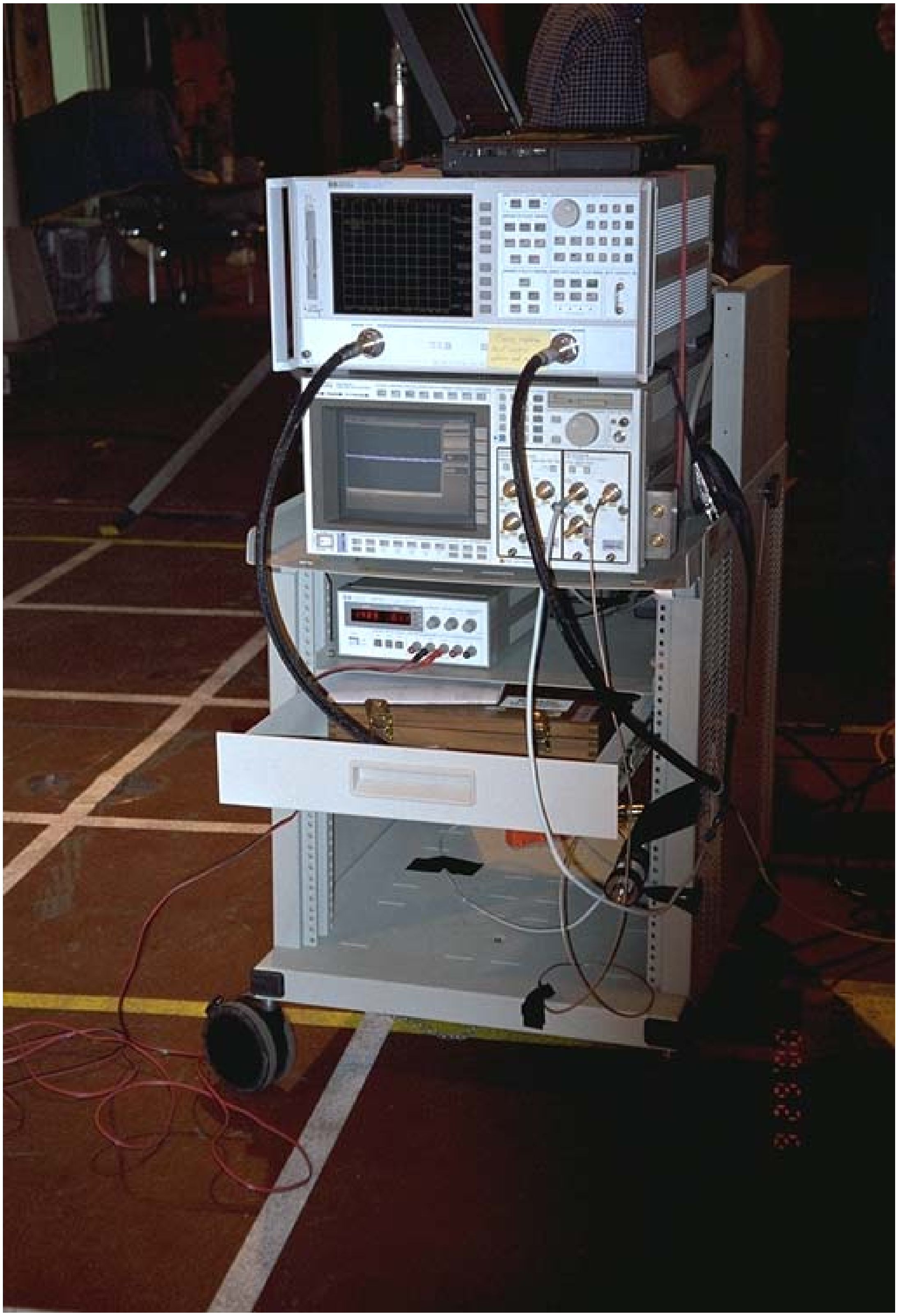

Figure A-5. USC network analyzer and sampling oscilloscope.

Figure A-6. USC team taking measurements.

Figure A-7. USC team processing measurements with PC and MATLAB.

Five different channel measurement tests were made with antennas in different locations, each with sampling oscilloscope and network analyzer. Figures A-8 through A-12 show the test configurations. The transmit antenna is the triangle and the receive antenna is the circle.

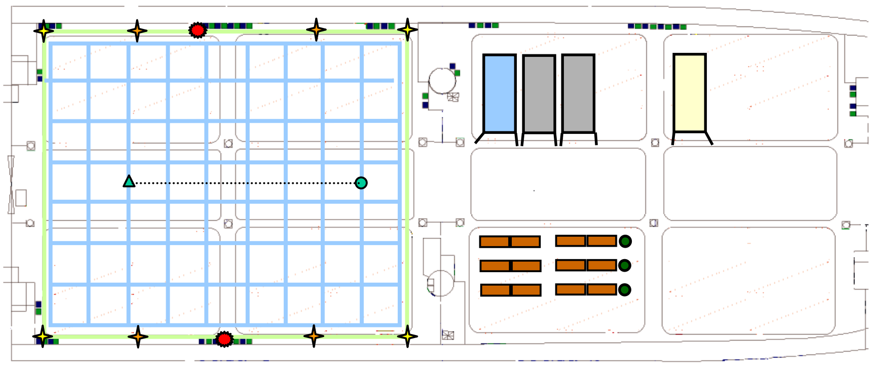

Figure A-8. Test 1 Configuration – 60-foot distance, down the middle.

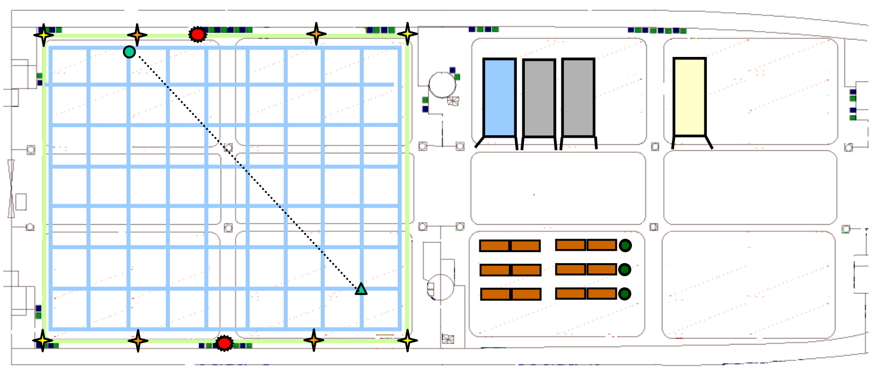

Figure A-9. Test 2 Configuration – 85-foot Distance, through a stanchion.

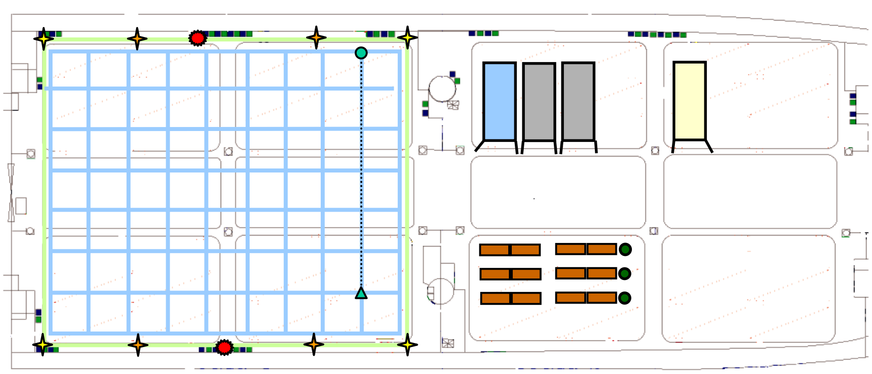

Figure A-10. Test 3 Configuration – 60-foot distance, to a corner.

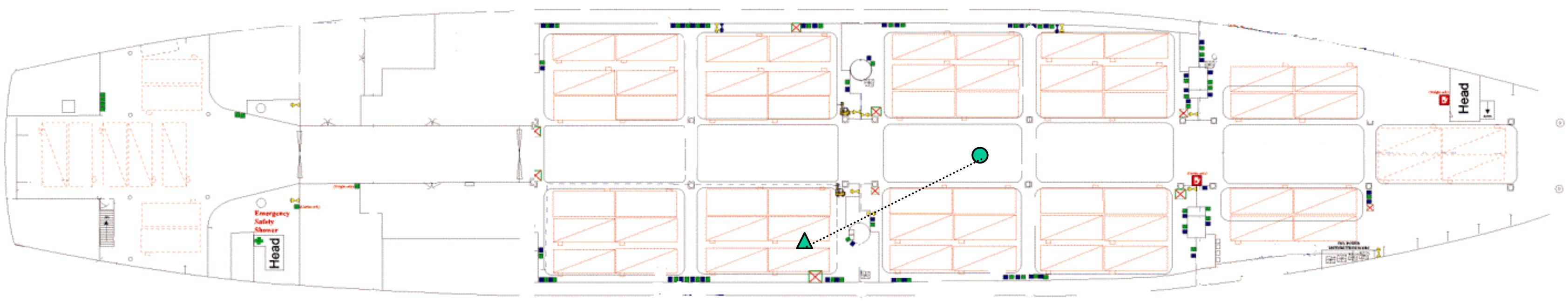

Figure A-11. Test 4 Configuration – 60-foot distance between two compartments and blocked by a bulkhead.

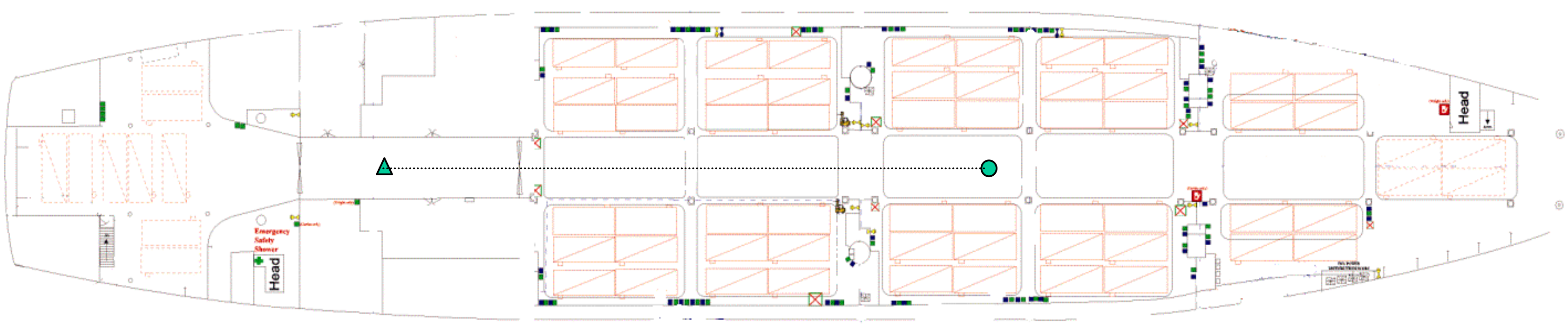

Figure A-12. Test 5 Configuration, 200-foot distance between two compartments and tunnel in direct line of sight.

Figures A-13 through A-17 show the sampling scope test results. Test 1 included 4 µsec of data. Data did not start at 0 µsec and decay times must be adjusted to account for the time offset. The high noise floor of the sampling oscilloscope of – 6 dB masked the final decay to –20 dB, the normal delay spread figure. The – 6 dB point was reached at about 1 µsec. The balance of tests included only 2 µsec of data, reducing time to take measurements. Decay time to – 20 dB is estimated to be 3 µsec.

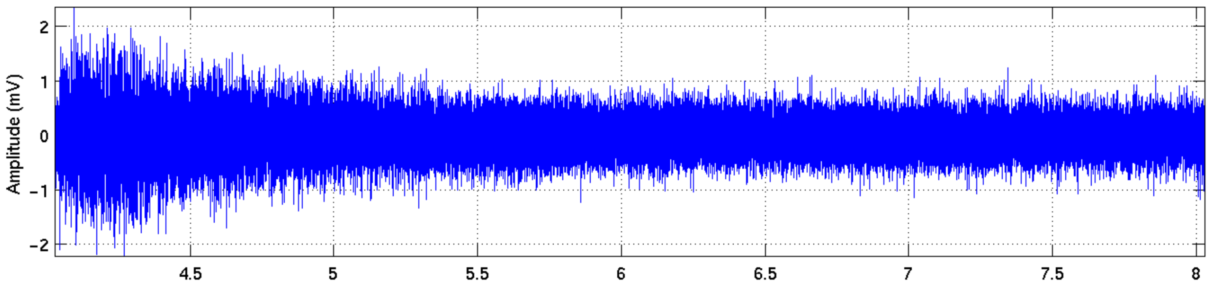

Figure A-13. Test 1 decay, sampling oscilloscope.

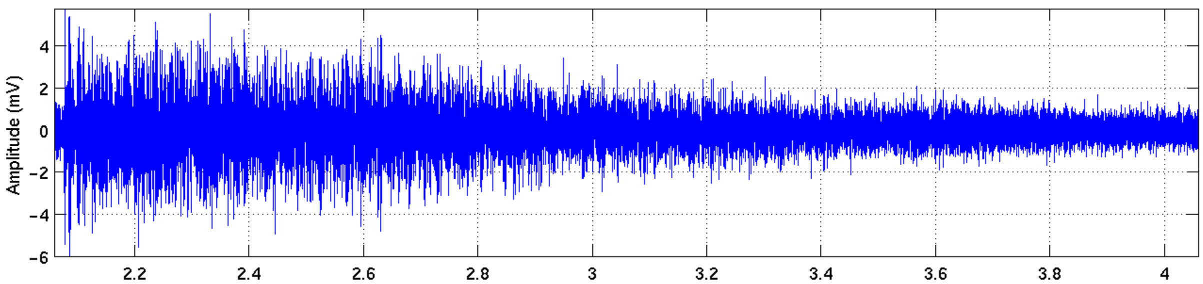

Figure A-14. Test 2 decay, sampling oscilloscope.

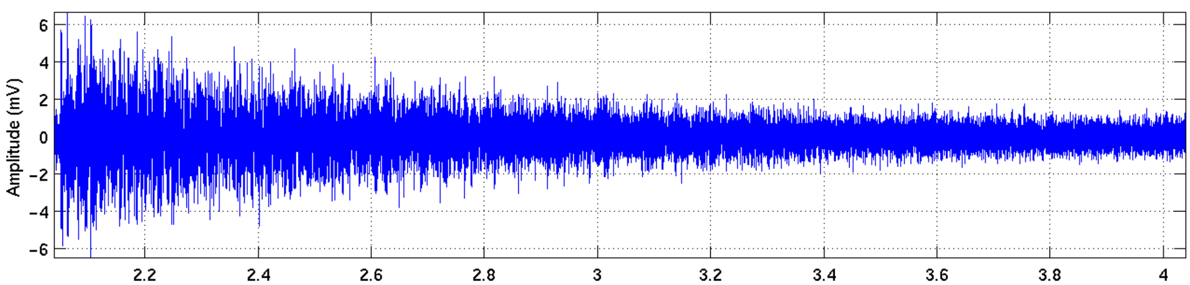

Figure A-15. Test 3 decay, sampling oscilloscope.

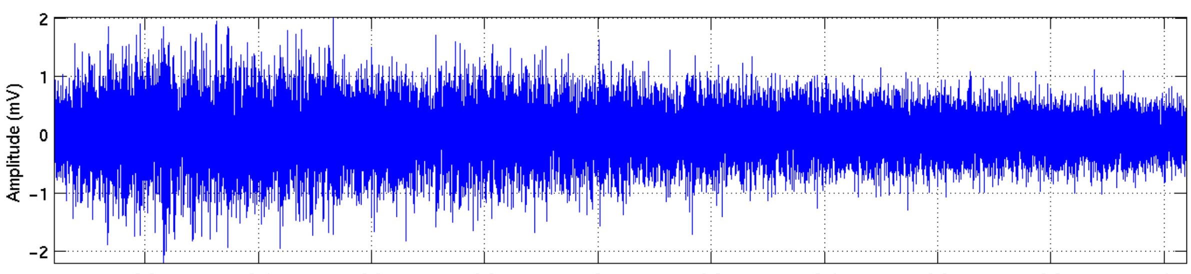

Figure A-16. Test 4 decay, sampling oscilloscope.

Test 4 shows no initial pulse, it was blocked by the bulkhead, and a slow ramp up of reverberation. Reverberation may have coupled between the two compartments through the opening, producing a double integration of energy.

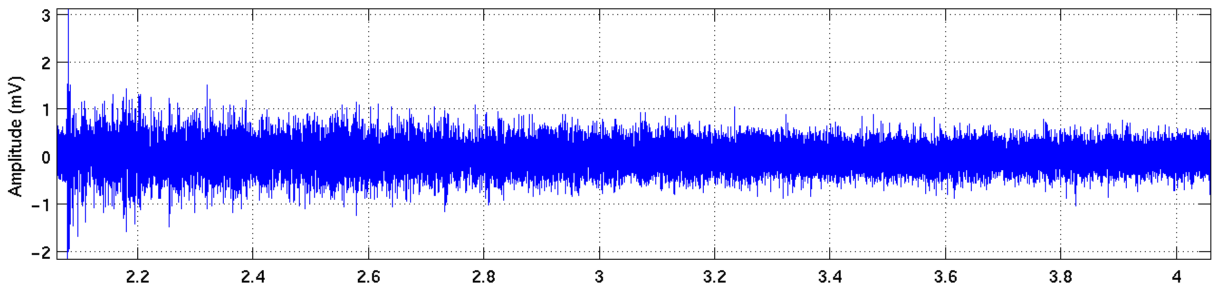

Figure A-17. Test 5 decay, sampling oscilloscope.

Test 5 shows the initial direct impulse is much higher than the overall reverberation. This may be caused by the direct line of sight filtering caused by the tunnel, providing little energy to the intervening compartment for reverberation.

Figures A-18 through A-21 shows the network analyzer measurements and Inverse Fast Fourier Transform (IFFT) for Tests 3 and 5. The network analyzer took 3,200 measurements at 1 MHz steps.

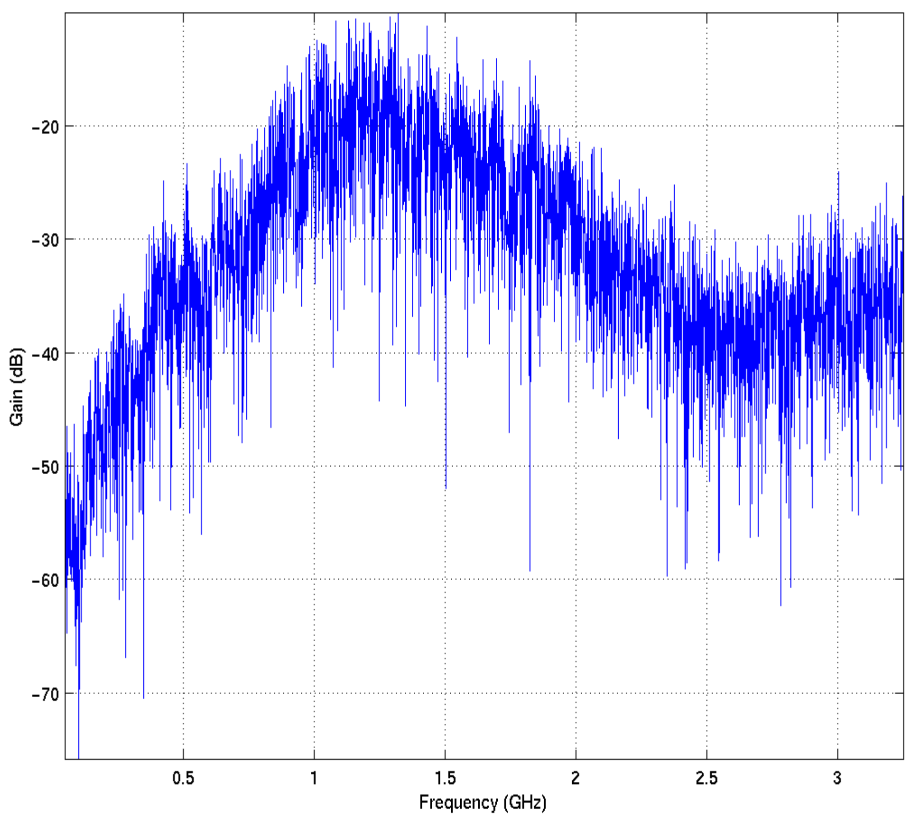

Figure A-18. Test 3 amplitude measurement, network analyzer.

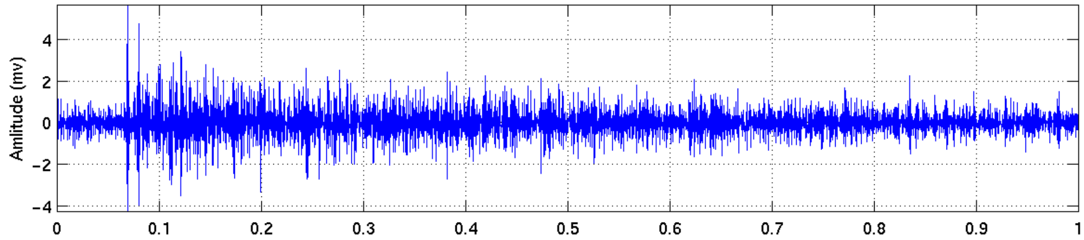

Figure A-19. Test 3 IFFT time response, network analyzer.

Figure A-18, Test 3 amplitude, the magnitude of the envelope of amplitude measurement is largely the square of the antenna responses. -6 dB responses correspond to each antenna's –3dB response. Multipath nulls are visible in the amplitude plot, extending up to 30 to 40 dB below average.

Figure A-19, Test 3 IFFT, shows the initial impulse delayed by 60 nsec, corresponding to 60-foot antenna separation. This provides excellent confirmation of the network analyzer/IFFT measurement technique.

Figure A-20, Test 5 amplitude, multipath nulls are visible in the amplitude plot, extending up to 30 to 40 dB below average.

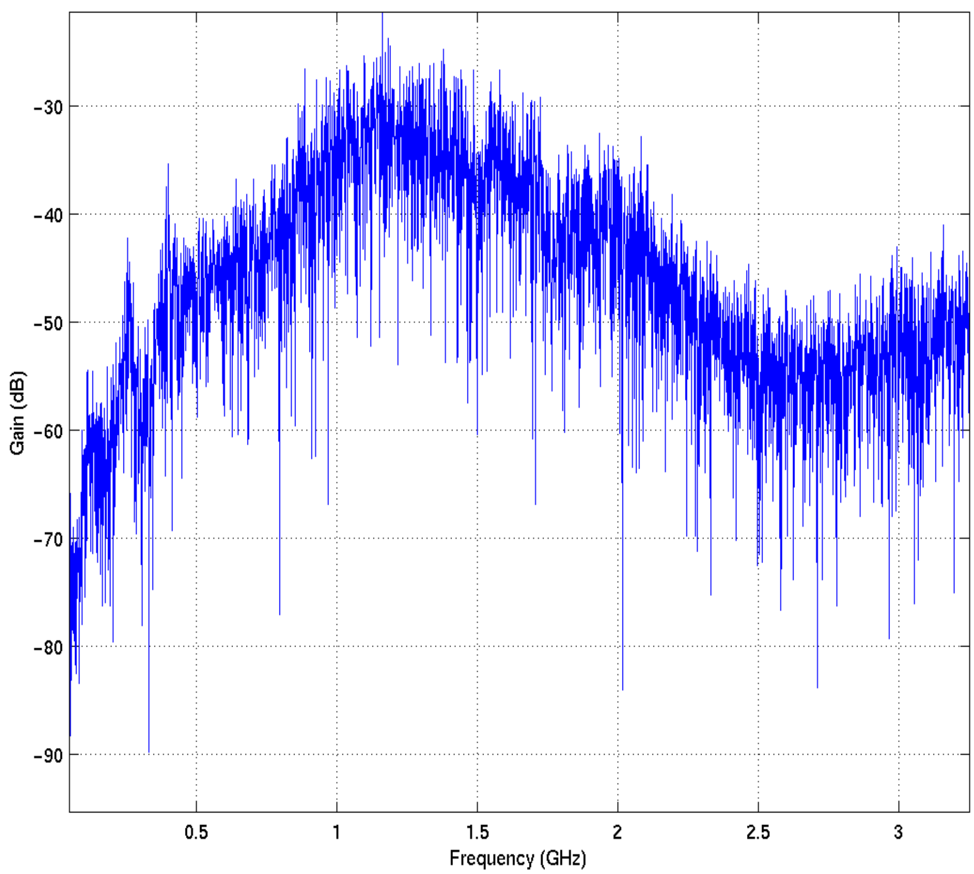

Figure A-20. Test 5 amplitude measurement, network analyzer.

Figure A-21, Test 5 IFFT, shows the initial impulse delayed by 210 nsec, corresponding to the 200-foot antenna separation. This again provides excellent confirmation of the network analyzer/IFFT measurement technique.

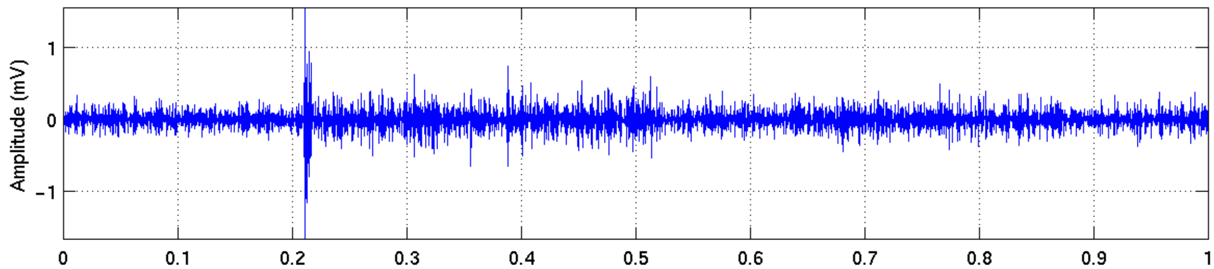

Figure A-21. Test 3 IFFT time response, network analyzer.

Figure A-22 shows a spectral measurement of a shipboard 10 GHz X-band search radar signal through a UWB antenna, made in the enclosed cargo bay of the USS Curtiss. The spectrum analyzer resolution bandwidth was 300 kHz, with *max hold* feature ON. Instantaneous or average measurements did not show significant energy. Peak measurements were required for the radar.   Ship's radar emissions leaked into the closed cargo holds.

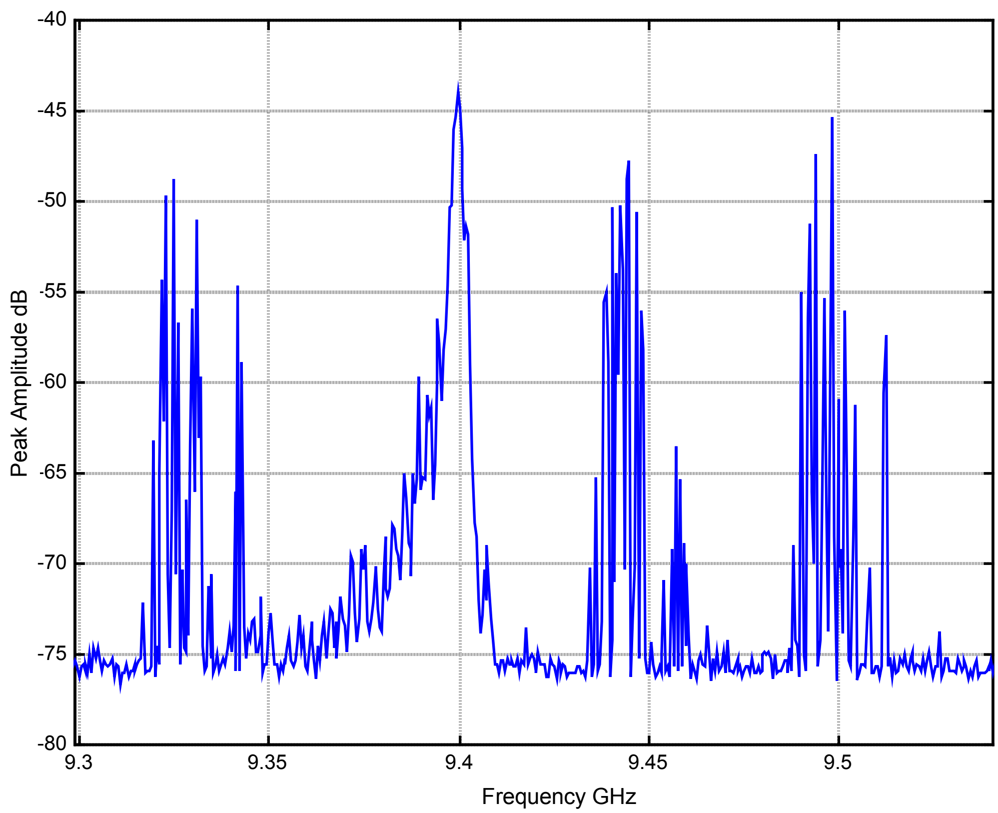

Figure A-22. Radar interference measurement, spectrum analyzer.

The scope data was auto-correlated to look for internal structure, indicating possible resonances. Figure A-23 shows a sample of oscilloscope sampled data and Figures A-24 thru A-26 show the auto-correlation. The auto-correlation showed the antenna impulse responses and no resonances. The passband of the test setup was likely too high to excite the ship's compartment cavity resonances.

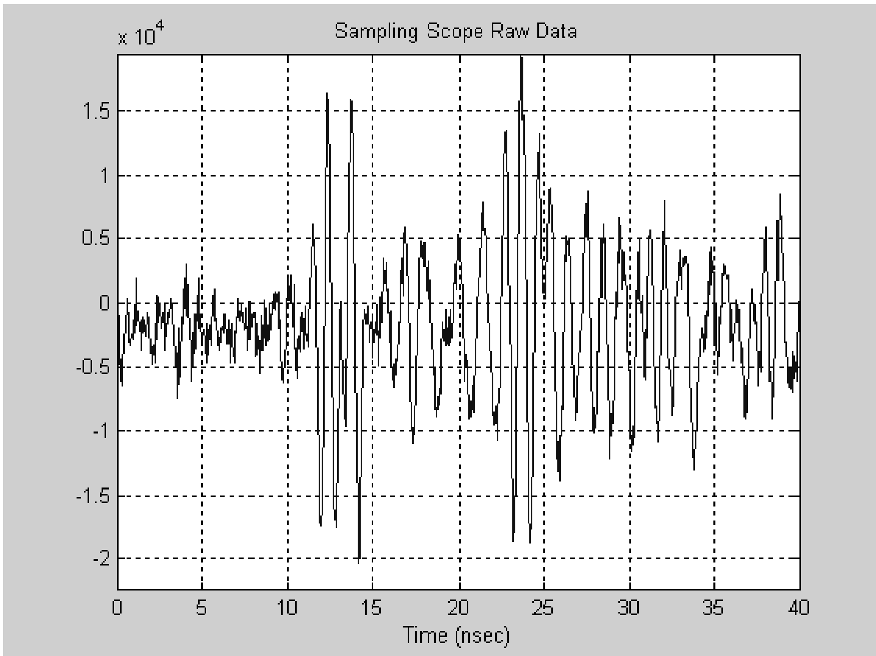

Figure A-23. Sampling scope raw data.

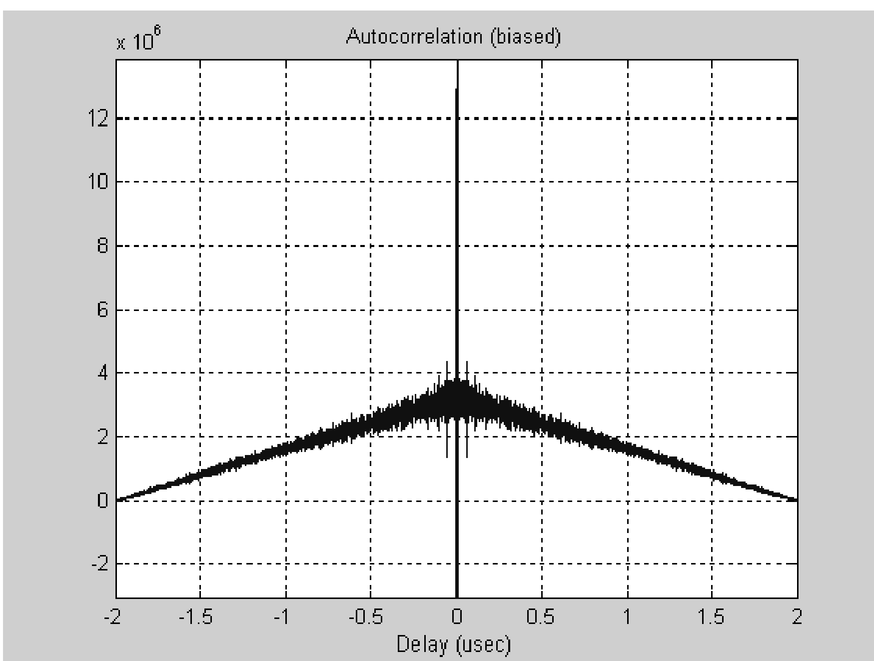

Figure A-24. Self-auto-correlation, ±2 μsec.

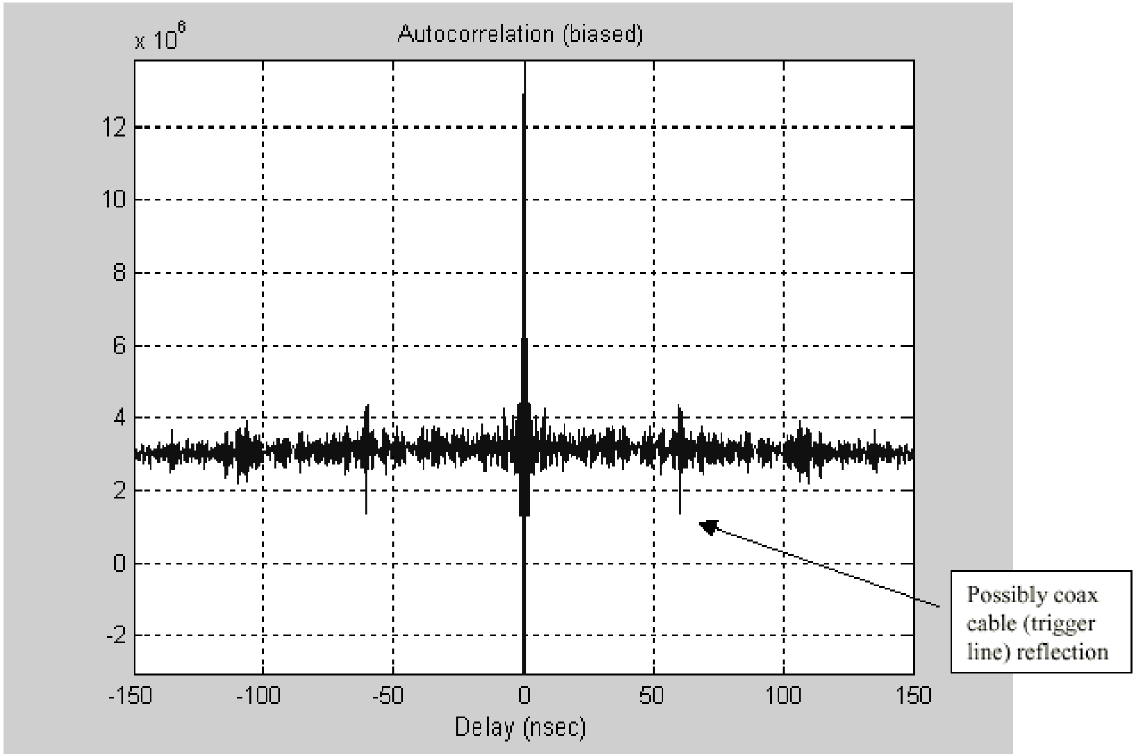

Figure A-25. Self-auto-correlation, ±50 nsec.

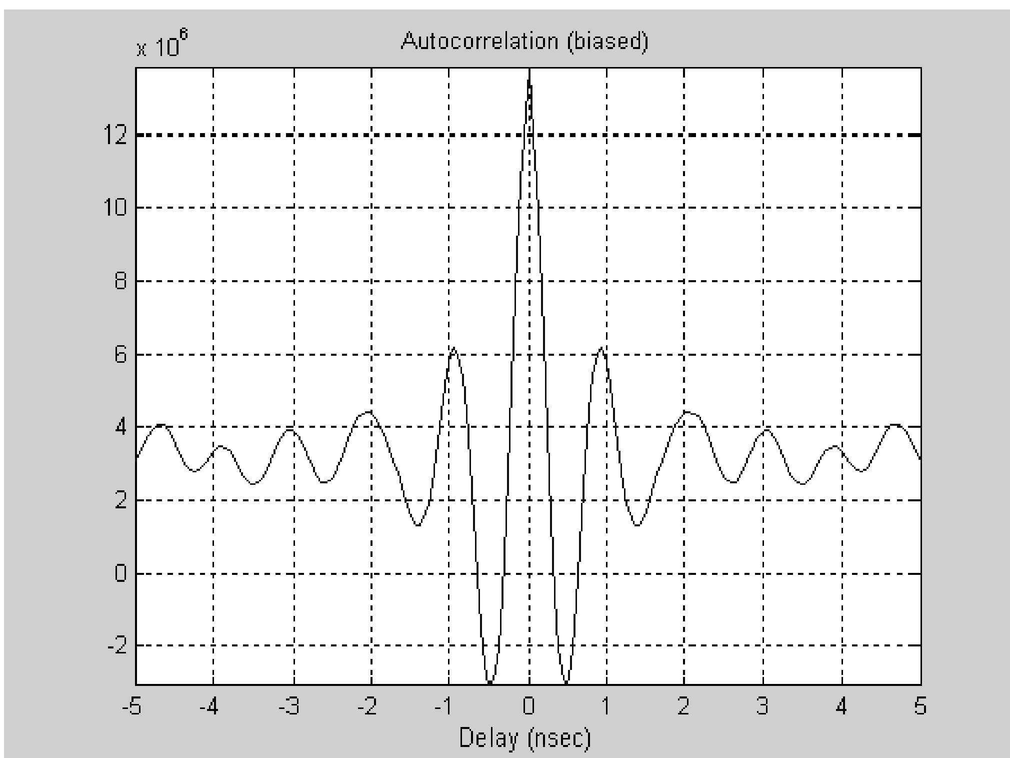

Figure A-26. Self-auto-correlation, ±5 nsec.

CONCLUSION

The SS Curtiss had very long delay spreads, approximately 1 μsec to – 6 dB, and estimated 3 μsec at –20 dB. This is approximately 10 times longer than 200 to 300 nsec typical for office and industrial environments. It is also longer than 1 μsec typical for ISO containers. The WhereNet DSSS system was designed to operate up to 1 μsec delay spread. The ship exceeded that.

Multipath nulls were measured between 30 to 40 dB using a network analyzer. They would greatly affect narrow-band systems. The multipath nulls had little effect on the DSSS system with 60-MHz spread, and the UWB system with 400-MHz instantaneous bandwidth.

The ship's 10 GHz X-band radar leaked into the compartments, but was higher in frequency than the test systems. Ship navigational radars also operated at 3.1 GHz, close but still above the 2.45 GHz ISM II frequency band used by the DSSS WhereNet system. 3.1 GHz is the lower frequency bound for full level FCC Part 15B unlicensed UWB 'C' band operation.

Ships present a challenging RF environment with deep multipath nulls and long delay spreads. Its amazing that either of the tested PAL systems worked at all.

Figures A-27 and A-28 show the USC team.

Figure A-27. USC team.