Engineering the All-Weather Antenna Tuning Unit For NDGPS Applications

USCG photo by PA3 Beth Reynolds.

by LT Chris A. Treib, CWO Paul K. Gingras, Michael W. Parsons, and David B. Wolfe
C2CEN

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ABSTRACT
The U. S. Coast Guard is part of the Department of Transportation (DOT) team to expand the maritime Differential Global Positioning System (DGPS) service into a national transportation safety system. The U. S. Coast Guard's role is to implement a Nationwide DGPS (NDGPS) expansion effort to more than double the existing number of broadcast sites. The NDGPS system is designed to meet all surface transportation navigation requirements in the United States and will provide double terrestrial DGPS coverage across the continental United States.

The USCG uses 285-325 kHz (Medium Frequency) to broadcast corrections which provide signal for up to 250 nautical miles. Unfortunately, this frequency range typically requires 340-foot towers for short monopole (tenth of a wavelength) implementation typically discussed in textbooks. Because of the unusually long wavelength, several years of consulting, modeling, and testing were required before fully understanding how to meet system requirements given the severe constraints imposed by practical implementation. The electrically short antennae places increased pressure and complexity for the Antenna Tuning Unit (ATU) to maintain a 50 + 0j Ohm

load for all weather conditions. Legacy equipment lacks the sophistication to maintain a 50 Ohm, low VSWR condition, resulting in transmitter mismatches, amplifier failures, extended off-air periods, excessive technician call outs and exhausted sparing and depot maintenance. An all weather ATU presents itself as a tool to significantly improve system availability.

The desire to develop, build, and field an all weather ATU started with a carefully laid out plan to incorporate the engineering process with the required contracting process to serve as a vehicle to evaluate emerging technology fairly while providing options for design improvement, quality control, and efficient production and fielding. Results are presented from C2CEN baseline testing to prototype evaluation for seven DGPS sites for 5 months. The results show the all weather ATU provides a 50 + 0j Ohm match upon install and an ability to automatically maintain this match through periods of changing weather conditions. Availability through the prototype period increased from 97.52% to 99.26%, a marked improvement toward achieving the system availability of 99.7%.

The successful fielding of the all weather ATU increases system availability and provides timely relief for maintenance and depot commands, with full fielding expected for maritime DGPS application by September 2006 and for nationwide DGPS application by December 2007. The ATU also provides new possibilities to remotely monitor far field coverage in real time via antenna current monitoring as well as a method to improve system bandwidth for rapid fielding of enhanced modulation schemes.

INTRODUCTION

The United States Department of Transportation (DOT) is coordinating the implementation of a network of DGPS broadcast sites across the continental United States, Alaska, Hawaii and Puerto Rico. Several Federal and state agencies, including the Federal Railroad Administration (FRA), Federal Highway Administration (FHWA) and the United States Coast Guard (USCG), are involved in the effort to install the NDGPS Broadcast Network. When completed, the nationwide broadcast network will consist of over 126 broadcast sites and provide a standardized signal for DGPS service throughout the United States.[1]

The USCG was selected as the lead agency in implementing NDGPS based on its success in building its existing network of USCG maintained maritime broadcast sites. The USCG's role in the project is to implement the expansion of new sites and provide maintenance and support for each transmitting facility. Although the NDGPS system uses identical reference station and integrity monitoring equipment as the maritime DGPS sites, the NDGPS sites have several differences. These include larger transmitters, larger, more efficient broadcast towers, and various back-up power systems. The NDGPS System is the integration of smaller networks, including the U.S. Air Force (USAF) Ground Wave Emergency Network (GWEN) conversion sites, Army Corps of Engineer sites, and the Maritime USCG sites.

At the same time the NDGPS project was assigned to the USCG, the USAF was in the process of decommissioning its GWEN sites. Although the GWEN sites were designed for a different purpose, the layout of each site and transmit antenna was well suited for DGPS broadcasts. The USAF transferred ownership of many of the GWEN sites, as well as assets that were staged to build additional GWEN sites. The USCG is in the process of converting the GWEN sites to NDGPS sites and has observed excellent coverage and availability of the signal.

The U.S. Army Corps of Engineers (ACoE) also had built several DGPS sites near the inland river system. The USCG partnered with the ACoE in standardizing the transmitters, couplers, and message format, as well as agreeing to work together for preventative and corrective maintenance issues. However, each ACoE site has a unique antenna system, using a variety of inefficient wire antenna designs. Although the sites provide adequate coverage, the availability of the signal is troublesome as the sites are easily influenced by weather.

The USCG maritime DGPS sites also have a variety of antenna heights and configurations. The USCG has studied the past performance of each of various designs and is making continuous improvements in design as more is learned about successful antenna configurations. Site performance varies widely regarding coverage and availability.

The Federal Communications Commission has allocated 285-325 kHz for DGPS use. Each station uses 1 kHz of bandwidth and currently supports 100 or 200-bit per second (bps) Multi-Shift Keying (MSK) modulation scheme. Stations frequencies are allocated to prevent interference and allow users to receive multiple stations at the same time. The information contains corrections for GPS satellite pseudo ranges, applicable to the coverage area. The accuracy of the correction is best at the reference station and degrades with range. Typically, the corrections are considered useful for a range of up to 250 nautical miles.[2,3]

The USCG maritime sites have been declared Fully Operationally Capable (FOC) with a requirement to provide coverage 99.7% of the time. For single coverage areas, this means the site is only allowed 2 hours of maintenance per month. Dual coverage is common to allow scheduled maintenance for tower and transmitter inspection. NDGPS will ultimately achieve dual terrestrial coverage in the continental United States with a signal availability of 99.9%.[1]

The USCG Command and Control Engineering Center (C2CEN) is the System Management and Engineering Facility (SMEF) and has overall system engineering responsibility for DGPS systems. To meet these high standards, C2CEN established the Radio Frequency Working Group (RFWG) to pool corporate knowledge and to ensure system wide success. The working group is comprised of USCG electrical engineers, civil engineers, technical experts, installation experts, navigation experts, and USCG Academy professors. The mission of the RFWG is to design an antenna system and ATU requiring minimal training for operation and maintenance as well as meeting coverage and availability requirements. The Enhanced Series N/DGPS antennas will provide more efficient and wider bandwidth antennas, but will take several years to upgrade all sites. While field units upgrade antennae, C2CEN focused on engineering an all-weather ATU as a second major improvement for system availability.

Commercially available ATUs all featured the same basic design, with primary differences in implementation. All ATUs are able to account and tune for changes in antenna capacitance, which is essential for antennae one-tenth of a wavelength or less. All ATUs also feature an autotransformer, which multiplies the antenna's real resistance to achieve a near 50 Ohm match. Some ATUs featured up to 11 matching positions, but all provided a finite number of matches, which typically provided some reflected power upon installation. Having observed weather patterns, changes in antenna resistance and transmitter failures, we deduced that the antenna resistance changed seasonally, which legacy ATUs cannot adjust for. The result is a match which can stray from 50 Ohms to as low as 30 Ohms, causing an overcurrent situation in the transmitter, along with amplifier failures and loss of broadcasting signal. Although DGPS uses two reference stations and two amplifiers, unless the ATU mismatch is corrected, the second amplifier will also fail, rendering the site off-air and requiring maintenance personnel to correct the ATU match. Therefore, it became obvious that if the ATU provided a 50 Ohm match regardless of changes in antenna resistance, transmitter failures will decrease significantly.

The purpose of this paper is to propose new concepts and is not intended to reflect USCG direction or policy. Use of company names, trademarks, or copywrited material is not an endorsement of any product or service.

REQUIREMENTS DEVELOPMENT

The goal of this study was to engineer a commercially available all-weather ATU for N/DGPS application. Engineers worked closely with contracting officers and contractors to allow the engineering process to be completed while providing options to fix any problems encountered in the design and to move seamlessly into production level effort. The result appealed to industry, contracting officers, supporting units, and the USCG Navigation Center. The engineering team evaluated COTS [Commercial-Off-The-Shelf] ATUs (none were all-weather), developed a requirement, released a request for proposals, evaluated proposals, awarded a contract, installed prototype units, held a critical design review, and purchased equipment for all maritime DGPS sites.

The evaluation of existing COTS ATUs was [a] key factor [to] the success of this project. Although none of the ATUs were capable of tuning the resistive component of the antenna in real time, the different technical approaches identified areas to evaluate and test each new ATU. Ninety-one (91) areas were identified for testing and evaluation, covering all areas from bandwidth observed via network analyzer; to placement and shielding of tuning cards; to recommended RF feed; to the antenna. Core requirements were ATU efficiency and system bandwidth observed via network analyzer.

Recall the circuit equivalent of the RF Datalink is:

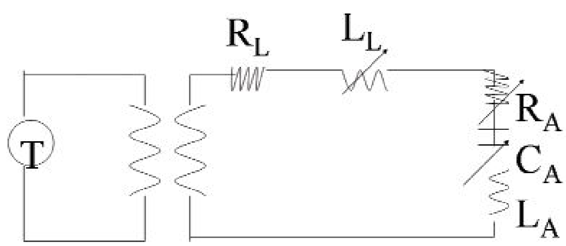

Figure 1. Norton-Thevenin Equivalent Circuit for DGPS Datalink.

Where R (var), C (var), and L represent the antenna and the remaining components represent an existing COTS ATU which is unable to automatically compensate for changes in antenna resistance. Recall that antenna resistance can be broken down into:

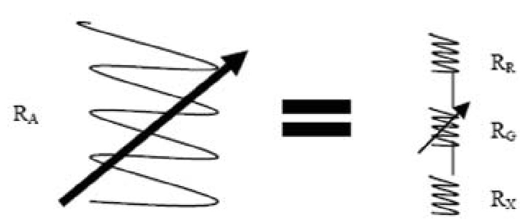

Figure 2. Breakdown of Antenna Resistance.

Where RR is radiation resistance, RG is ground resistance and RX is connections throughout the RF path. Note that as the antenna ground plane becomes moist, dry, or changes conductivity as the seasons change, the overall antenna changes. C2CEN has concluded that rain, snow, fog, and ice have changed RG and that an ATU capable of compensating in real time for this change would (a) ensure a 50 + 0j Ohm match at time of install and (b) this match would be maintained, allowing the system to operate in adverse weather, improving system availability.[4]

An important distinction of this project is that C2CEN did not require higher efficiency or more bandwidth via the ATU. Changing RL has a dramatic effect on both efficiency and bandwidth; however, in replacing the ATU, improvements in efficiency necessarily mean decreasing bandwidth and vice versa. To ensure the equipment maintained present coverage, all designs were baselined from the far field using C2CEN's 90' Rohn antenna with the existing equipment to ensure coverage would not be degraded. Decreases would not be tolerated; meeting the same level or slightly improving coverage would be ideal; dramatic increases would lead to poor evaluation.

MEASUREMENTS

Bandwidth was measured directly via network analyzer on C2CEN's 90' Rohn antenna. Bandwidth is defined as the difference between two frequencies at a consistent level or mark. For the purposes of our test, we used 1.7:1 VSWR and 1.1:1 VSWR as defining points in measuring bandwidth. To illustrate ideal configuration, here is a typical network analyzer plot showing bandwidth is shown below for a 150' Rohn antenna with the new all-weather ATU:

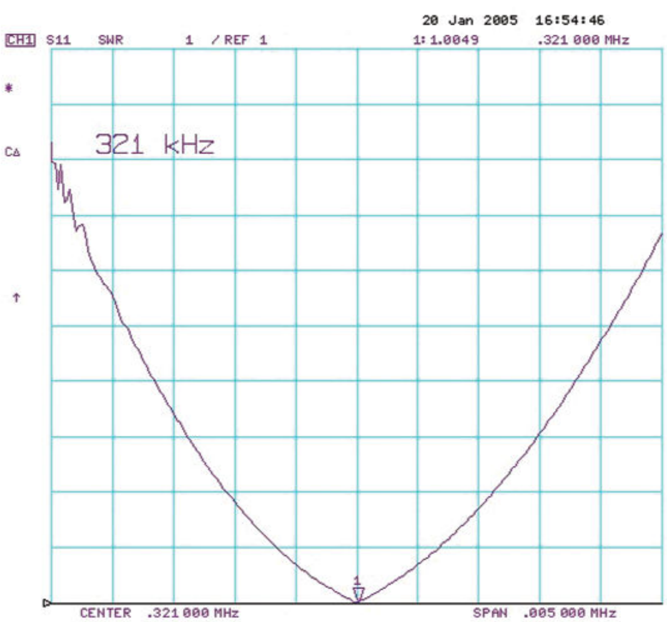

Figure 3. All Weather ATU VSWR Bandwith.

Note that the plot nearly touches at the bottom of the screen, nearing 1.00 VSWR. The minimum VSWR is observed from this screen and bandwidth can be measured by scrolling the cursor to the respective 1.7 and 1.1 areas, recording frequencies, and performing the arithmetic to measure the span of frequencies available for broadcast use. The next figure shows the same 150' Rohn antenna with the legacy equipment:

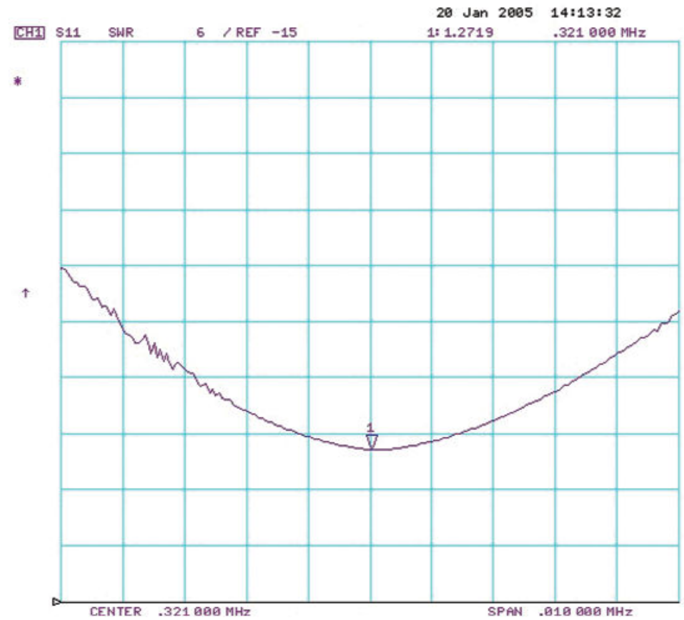

Figure 4. Legacy ATU VSWR Bandwith.

In this case, the antenna is considered tuned as the capacitive part of the antenna has been equalized by the ATU loading coil. However, the ATU is not matched to a 50 Ohm load or the VSWR would near the bottom of the graph. Thus, the ATU starts with a higher than required minimum VSWR at 1.27:1. The bandwidth observed at 1.1 VSWR is non-existant since our minimum VSWR is above that threshold. Note that the 1.7:1 VSWR bandwidth is distorted as the measurement will be taken across two broad points here, rather than in two more narrowly defined points above. The overall power distribution is optimized when the VSWR at the carrier frequency is nearly 1.00 when referring to narrowband broadcasts (<1 kHz) such as DGPS.

The Smith chart is also a very useful tool when determining the quality of a tuned antenna. The VSWR chart represents a 2D representation of the map where it is clear whether the antenna capacitance is balanced by the loading coil, but it is not clear which direction or what value the resistive match is made to. The Smith chart most accurately describes the match using a vector from the center of the chart (50 + 0j Ohms) which indicates how close the match is to minimize VSWR.

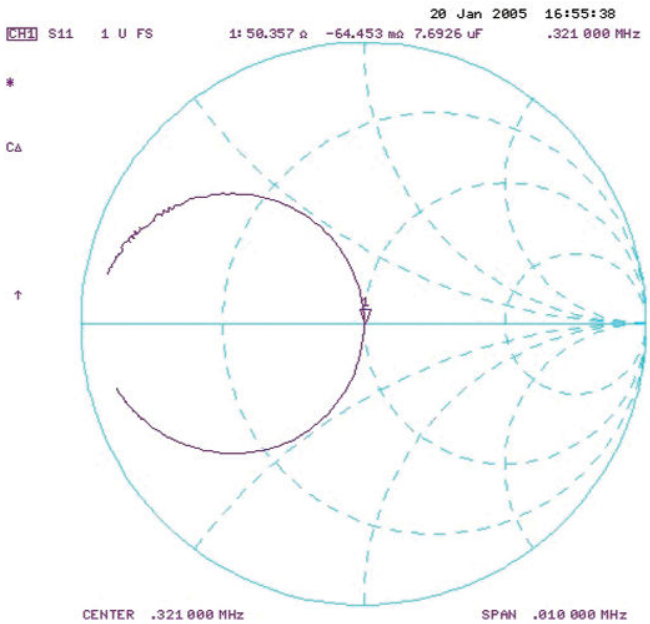

Figure 5. All Weather ATU Smith Chart.

Figure 5 shows the same 150' Rohn antenna with the all weather ATU. Note that the cursor is at carrier frequency and shows a match of 50.3 + 0.06 j Ohms. This is very near an ideal match. The all-weather ATU operates on a RF feedback loop to keep the ATU at the point whenever RF is present. However, using the network analyzer, the components were manipulated manually to achieve this match; in reality, the match obtained would be even closer than what is observed here.

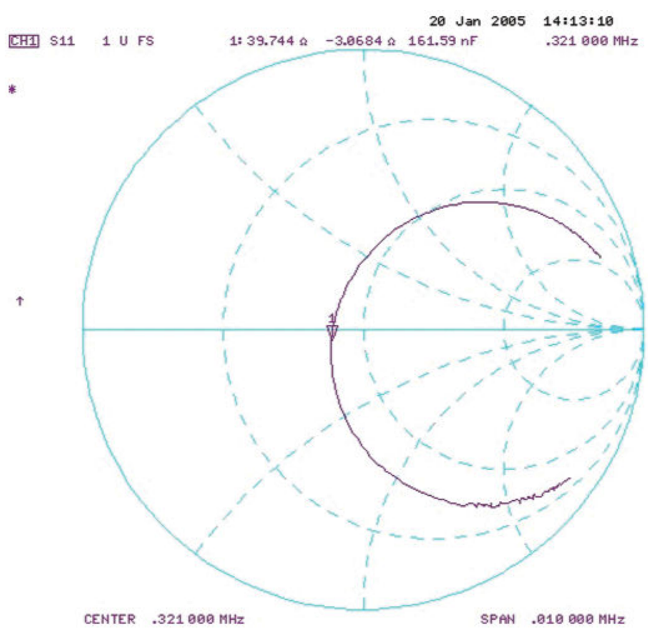

Figure 6. Legacy ATU Smith Chart.

Figure 6 shows the same 150' Rohn antenna with the legacy equipment. The match is far from ideal and was found at 39.7 - 3 j Ohms. Although the legacy equipment does tune for changes in antenna capacitance, the motor operating the variable loading coil is not smooth and changes are erratic. More disturbing is the distance from the 50 Ohm match. The legacy equipment cannot automatically adjust for changes in resistance and thus, even a small change in resistance is multiplied by the impedance matcher. Note that this change will force transmitter currents to surge and pull, often causing an overcurrent state of the match drops too low. It is also worth pointing out that there is a 180 degree difference in phase between the legacy equipment and the all weather ATU. The legacy equipment uses a very simple circuit; the all weather ATU uses a more sophisticated circuit which actually inverts the phase through their patented matcher.

The network analyzer is invaluable to gather an objective description of the antenna match and to provide basic guidelines for required bandwidth. All prospective entries submitted products to demonstrate the functionality of their match and ensure the match could be recreated, predicted, and repeated for future installs.

The requirement measured bandwidth at the 1.1:1 mark and at the 1.7:1 mark. The present equipment generally meets the 1.7:1 ratio, which coincides with the transmitter folding back into a protected, reduced power output. However, the present equipment is not guaranteed to meet a 1.1:1 match as the equipment has a discrete number of impedance taps which attempt to match the total system resistance to 50 Ohms. The result is almost assured reflected power during static weather conditions, with variations sure to increase or decrease the 50 Ohm match, which has been linked to transmitter failures, high call out rates, depleted spare kits, and low system availability.

Two sets of bandwidth were taken using the VSWR function on the network analyzer to show improved bandwidth at 1.1:1 by simply providing a better 50 Ohm match and to compare bandwidth at 1.7:1 as a check for far field measurements. These measurements would be repeated in the field for each antenna type to determine suitability for increased bandwidth requirements for future DGPS correction modulation schemes.

ALL WEATHER ATU EVALUATION

The requirement was released with great interest from industry, especially since the requirement did not require the vendor to use a particular technology. Several L-L, R-L, and L-C designs were possible, but to maximize the number of vendors and explore the technologies together, C2CEN specifically abstained from requiring any circuit, motor, or component combinations. The evaluation would be based off efficiency, bandwidth, and the remaining quality assurance items to ensure the equipment was hearty and technician friendly. Unfortunately, several potential vendors were unable to meet the timeline as contracting and legal review times were underestimated. Two vendors used two different technologies to submit technical proposals via paper and on-site demonstration at C2CEN. Both proposals were evaluated per the posted 91 requirements and C2CEN submitted the results with a technical recommendation. The contracting office considered the recommendation and cost to achieve the best value to the government. The contract was awarded to Nautel Maine for its submission of the "ATU-HP" in September 2004.

Seven sites representing each major antenna type were selected for prototype installation, which started in December 2004 and ended in January 2005. During the installs, the ATU efficiency and bandwidth was measured during the System Operation and Validation Tests. The sites were remotely monitored for approximately 5-months to observe seasonal changes in the ground plane, antenna icing, and general response to DGPS system requirements.

NAUTEL ATU-HP

The Nautel ATU-HP, an all-weather ATU, functions much differently than the legacy ATU and is important to understand the basic operation to fully appreciate how it meets the USCG requirement. It has the same fundamental design as the legacy ATU in that it uses a loading coil to cancel the antenna capacitance and uses an autotransformer to match the antenna resistance close to a 50-Ohm load. The new design inserts a balanced tank circuit which is appropriately named the matcher.

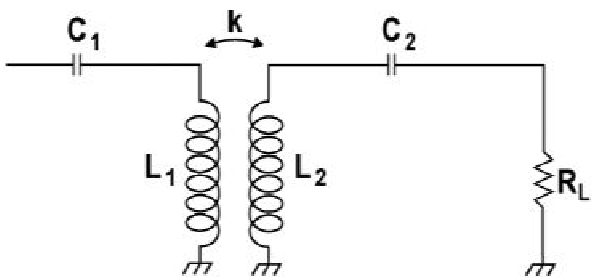

Figure 7. Nautel Matcher.

The design maximizes the capacitance by selecting a low value for the coils. For DGPS applications, L1 and L2 are 46 uH. C2 is a fixed capacitance at 7000 pF and C1 is nearly 7000, but varies slightly depending on the carrier frequency. Rather than use a large vacuum variable capacitor for C1, Nautel uses a binary series of capacitors in parallel to choose the correct frequency. The circuit provides a DC path to ground, which prevents the capacitors from failure if the antenna collects a DC charge from the wind flowing through the antenna. Note that since the design uses a large variable loading coil, C2 is technically optional, although the design has not been implemented without it. RL represents the antenna, loading coils, and resultant match from an autotransformer. Since the antenna reactance will be equalized by the loading coils, the antenna will appear as a resistive match which the tank circuit will tune.

The function of the matcher is to provide a smooth 50 Ohm match for the transmitter. This is possible since L1 and L2 are mutually coupled with an air gap between them. The inner coil is 80% of the diameter of the larger and is slightly longer to maintain the 46 uH and remain resonance. The inner coil is placed on a screw type drive to slowly move the coils in and out of each other. The movement of the coils does not change their inductance, but rather changes their coupling factor (k). For example, if the coils were directly on inside each other, the coupling factor would be very high; if the coils were barely overlapping, the coupling factor would be very low.[5]

$$k = \frac{m}{L}$$

Equation 1. Coupling factor.

In equation 1, k is the coupling factor, m is the inductance shared by the coils, and L is the inductance of each coil (46 uH for our application). Ergo, if a change in RL is observed, k must change, which means the mutual coupling between the coils must change, and a screw drive serves to automatically find the new point of resonance and keeps the transmitter input impedance at 50 + 0j Ohms.[5]

$$Z_{in} = \frac{k^2 X_L^2}{R_L}$$

Equation 2. Transmitter Input Impedance.

The changing of this coupling factor is what is needed to account for changes in antenna resistance. The requirement was to provide a + and - 50% change from the original antenna resistance, a significant change, but since radiation resistance, ground resistance, and loss to connections is low, any slight variation is magnified. From a centered 50 Ohm position, we have observed the capability to artificially match as low as 3 Ohms and as high as 194 Ohms on C2CEN's 90' Rohn antenna, with each major motor increment equating to 0.1 Ohms, resulting in a smooth transition as real antenna resistance changes. For short antennas, the change in the coupling factor is observed to be almost purely related to the resistive term; the all-weather ATU controls reactance and resistance with two different vectors.

The goal during installation is to center the coils so they are approximately 50% coupled to allow tuning conditions for both dryer and wetter grounding conditions. The coupling factor also provides transmitter protection in the event an open or shorted condition occurs, either through fracturing the RF feed, icing over guy insulators or icing over the base insulators. This ATU is in fact, an all-weather ATU in that it will protect the transmitter from a variety of changing extreme conditions.

The Nautel ATU-HP also features an optional resistor bank, which is mounted on top of the ATU and is protected from the elements via a solar shield. Although not part of the requirement, this feature allows the installer to add 0 to 5.6 Ohms in approximately 0.8 Ohm increments. The benefit of this equipment is that for very short antennas, where bandwidth is very narrow, additional bandwidth may be inserted by adding series resistance. This is not the preferred method to increase bandwidth as it sacrifices signal efficiency, but the Nautel ATU-HP has a Q-factor on the order of 1000; the legacy equipment's Q-factor is near 700 when optimally loaded, but for shorter antennas, the Q-factor degrades to 500. Thus, there is a noticeable difference in bandwidth and efficiency for the shorter antennas. This feature ensures the customer may maintain, increase, or decrease bandwidth as desired. C2CEN has elected to maintain bandwidth for DGPS applications. However, if lower output power conditions became acceptable, series resistance could be added to provide wider bandwidth for emerging modulation schemes.

Nautel provided another feature which was not part of the original requirement -- the ability to measure and report ATU information digitally. The Nautel ATU-HP has a serial port which uses RS-485 protocol to communicate up to 5000 feet. Previous communication between the transmitter and ATU were unthinkable as the ground planes for most antennae extend at least 100 feet, if not 1000 feet at some sites. The ability to communicate locally over large distances in RF saturated environments brings new possibilities. The ATU-HP samples and reports output power, reflected power, ATU current and ATU temperature via the RS-485 port. The output power and reflected power provide easy reference for spotting line loss and also provide instant feedback whether the ATU is tuned and if enough RF is present to warrant hazardous conditions. The ATU current is provided as it is the most reliable and stable source of information to indicate signal propagation. Legacy practices calibrate near field antenna probes to the appropriate level as fringe antenna measurements are taken. The antenna probes are susceptible to decay over time, along with degraded signal as lightning protection wear, and cable loss. The ATU current sampling is performed via iron core torroid, which is very stable and is wound to 1% precision. If sampled in real time, the ATU current can provide real time coverage information with fairly straightforward calculations. This technology could provide the NAVCEN [Navigation Center] the ability to monitor coverage in real time and accurately predict tertiary, dual, and single coverage. The ATU CPU monitors ATU temperature and controls two cooling fans, which simply circulate air from the bottom of the unit to the top of the unit. The Nautel ATU-HP uniquely met all of our requirements and also laid the foundation for significant improvement in DGPS RF engineering by considering many elements of the future and incorporating them in to the present design.

RESULTS

The seven sites were selected for the prototype represent each of the major antenna types-Sloping-T, Longwire, 90' Rohn, 120' Rohn, 150' Rohn, 150e, and 295' GWEN. The 90e and 120e antennas were not selected as they were still prototypes and had not performed through the winter; the USCG also uses 70' Valcom whip antennas at 4 sites, which are gradually being phased out. The site locations were selected to include a variety of weather, including ice and lightning. Site output power was also a factor -- all sites used a minimum of 750 Watts output power to test the durability of the RF components. Previous site availability was also a factor, especially where cases of poor all-weather performance was documented. The final list of prototype sites and locations are listed in the table below.

Antenna Type	Site Location
Sloping-T	Omaha, NE
Longwire	St. Louis, MO
90' Rohn	Brunswick, ME
120' Rohn	Tampa, FL
150' Rohn	Lompoc, CA
150e	Angleton, TX
295' GWEN	Driver, VA

Table 1. Prototype Site Locations.

The contract required the contractor to provide and install the ATU; USCG engineers and technicians were on site for all installs to check the configuration of the ATU. C2CEN engineers made the determination on site to finalize the amount of series resistance to achieve approximately the same coverage and bandwidth as observed with the previous equipment. Antenna reactance and antenna resistances were carefully measured to develop a table so that all future antenna orders with the exception of the Sloping-T and Longwire antennas could be factory configured, ready for installation. Future installs will not require a network analyzer and will save approximately 2-3 hours from an evolution that could easily take 8 hours. Additionally, every setting, including meter ranges and power options on the ATU can be factory set, thus saving additional off-air and on-site time.

The first measurement considered was the minimum VSWR. Sites with the lowest VSWR coincided with sites which were most recently visited and adjusted prior to C2CEN arrival. In real time, conditions vary so an array of measurements coincides with expected VSWR values, which varied greatly with the existing equipment, from 1.01 to 1.21, with a standard deviation of 0.074. The all weather ATU consistently attained values lower than 1.02 with a standard deviation of 0.007. Actual VSWR and reflected power was lower than the hand tuned values recorded below.

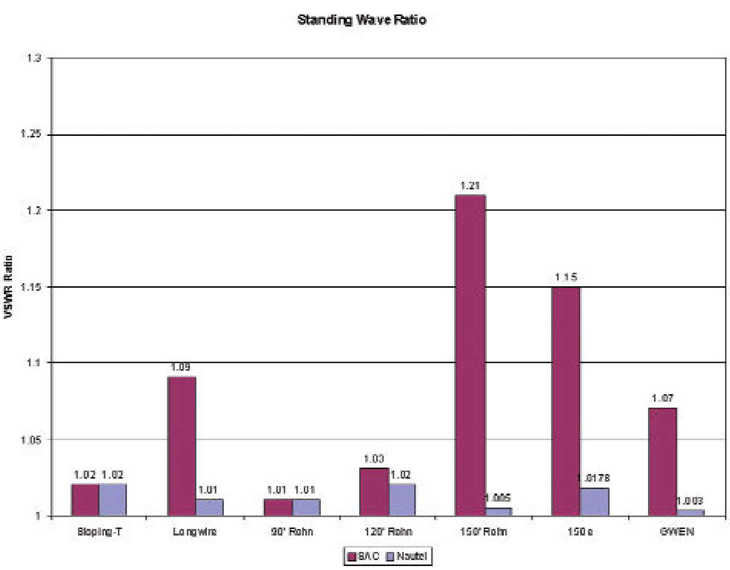

Figure 8. Minimum VSWR.

The data indicates the resistive match and reactive match worked constantly for all antenna types, as observed at the C2CEN berm when manually tuning. The tuning motors moved with great precision, allowing an analog match to achieve nearly 1.00 VSWR manually with less than 2 watts reflected. A much lower VSWR indicates the transmitter is nearly perfectly aligned, reducing stress and prolonging the expected life of the transmitter.

The 1.7 to 1 VSWR bandwidth indicates series resistance was successfully manipulated to neither gain bandwidth nor improve efficiency, preserving the envelope. This is key to the study as it would have been very easy to insert too much bandwidth to provide a larger tuning buffer for the ATU and increase availability; unfortunately, this would come at the expense of our coverage area. This is also a useful baseline for the maximum data channel available for future modulation schemes.

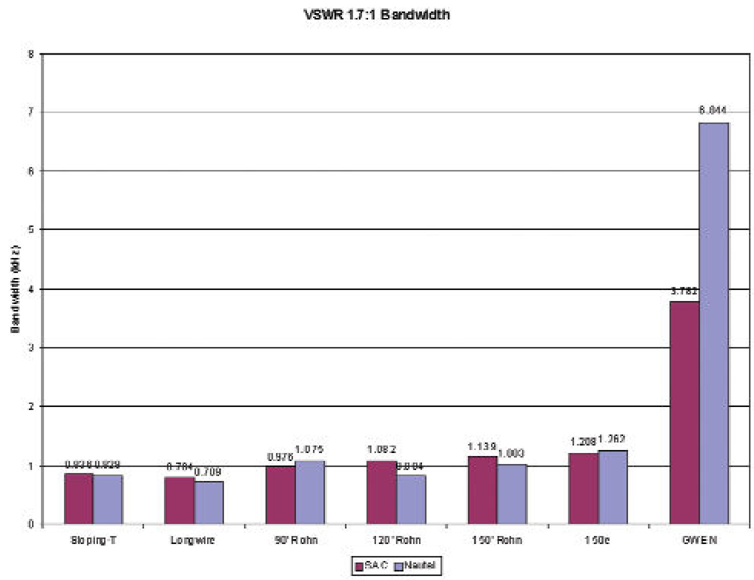

Figure 9. 1.7:1 VSWR Bandwidth.

Note the GWEN antenna has a much larger bandwidth than the other antennae; this is largely due to the significant size difference and its' near resonant frequency. The GWEN antenna uses very little inductance and with the Nautel ATU-HP, the loading coils are actually configured in parallel to maximize efficiency, so we would normally expect a lower value. Referring back to Figure 4, recall that the GWEN antenna was not very well matched; the new ATU provided a better match and also provided wider bandwidth in the process.

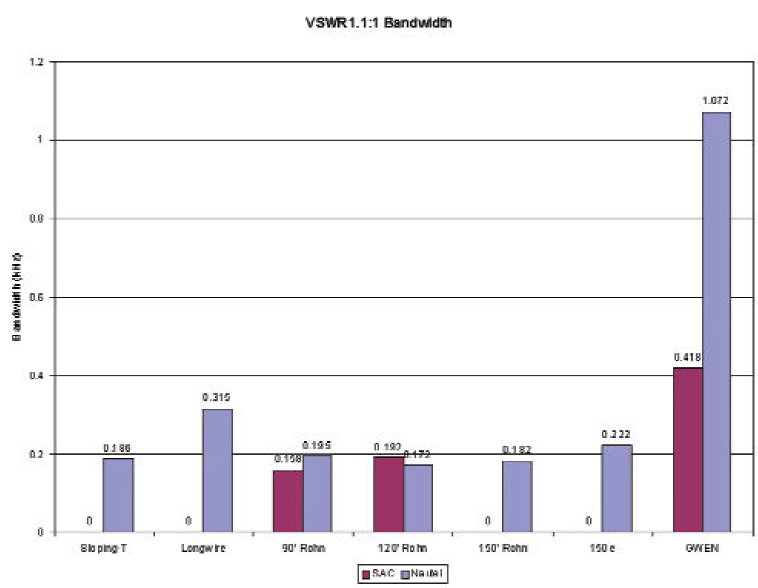

Figure 10. 1.1:1 VSWR Bandwidth.

The 1.1:1 VSWR bandwidth indicates the reduction in stress the transmitter is expected to have for each particular antenna type. Note that in many cases, the minimum VSWR was greater than 1.1:1 and had no measurable bandwidth. It is important to note that with the new ATU, this measurement is always possible as the minimum VSWR is always less than 1.02:1.

It should not be surprising that the GWEN, again, has plethora bandwidth, which increased as we improved the initial match with the new ATU.

After the bandwidth measurements were completed, C2CEN measured signal coverage and ensured all systems were working correctly. Upon completing the System Operation and Validation Tests (SOVT), C2CEN turned the site over to the watch stander located either at Navigation Center West (Petaluma, CA) or Navigation Center East (Alexandria, VA) for 24/7 monitoring and data collection.

Transmitter output power, transmitter reflected power, and Integrity Monitor Near Field Probes A and B were remotely monitored and archived. The data was collected from time of install to May 6, 2005 and compared with the same dates last year to simulate similar weather conditions with the old equipment. Actual humidity and temperatures were found and correlated via NOAA's database. Figure 11 shows a comparison for the 90' Rohn antenna in Brunswick, ME for Feb. 2004 and Feb. 2005:

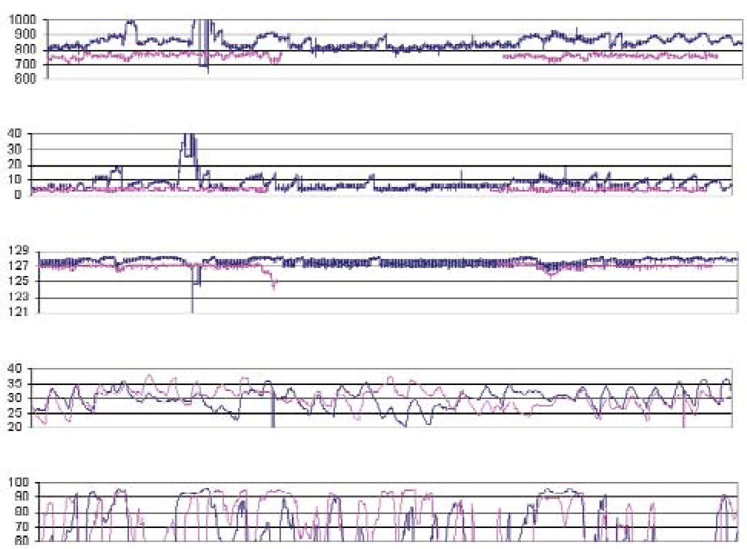

Figure 11. 90' Rohn in February 2004/2005.

Note that approximately 1/3 into the month in the blue, 2004 data, humidity rises and temperature drops, indicating either snow or ice. Reflected power increases and output power decreases, indicating that an antenna mismatch is made and the transmitter is in a protected, folded back state. Since the transmitter is not operating under normal power, it is not able to cover the full range of the coverage area and this time is considered off-air time due to low beacon signal strength. Some of the 2005 data is not available due to communications outage, so another example will be used to illustrate the new ATU maintaining a match during ice storms.

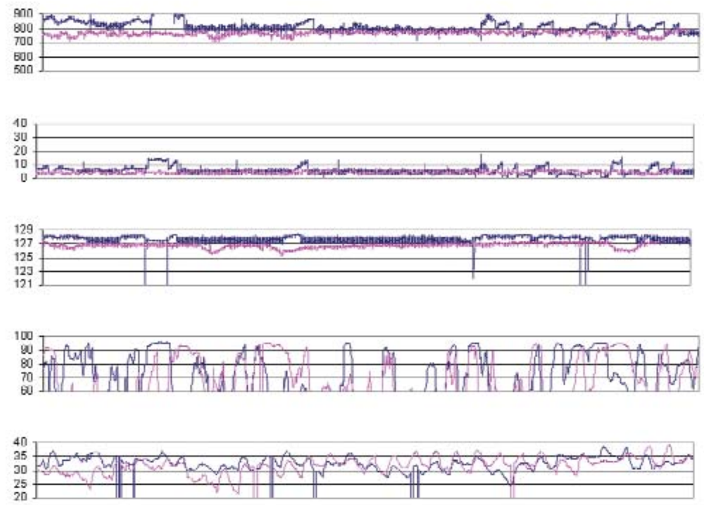

Figure 12. 90' Rohn in March 2004/2005.

Several extended humps in the humidity for March 2005 with low temperatures indicate freezing conditions. Reflected power remains low during this period and only a slight loss of signal strength is observed, but within alarm tolerance. Thus, the site remained on-air with the transmitter at full power. The small decrease in signal strength is likely since the antenna ground plane resistance was changing and thus, the efficiency of the antenna was changing as well. A more thorough study of the issue is now available since the Nautel ATU-HP can report output power, reflected power, ATU current and ATU temperature via a RS-485 communications link. Although this link is not being used, monitoring ATU current will provide a more objective method for studying and understanding far field conditions based on measurements available in the near field.

In addition to remotely monitoring transmitter and near field sensors, C2CEN also monitored overall on-air time from December 2003-May 2004 (old equipment) and December 2004-May 2005 (new equipment). The report was formed based on the weekly on-air reports from the USCG Navigation Center and removed off-air time attributed to other equipment failures. The 90' Rohn (Brunswick) data is as follows:

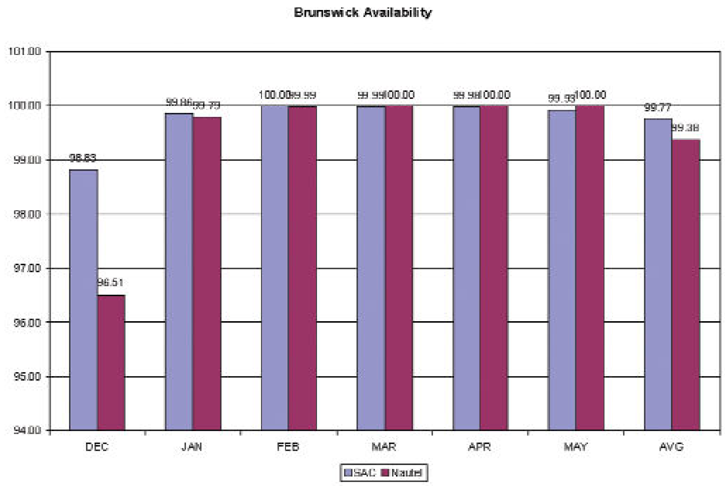

Figure 13: 90' Rohn Availability.

Although the data reports were submitted weekly, the nature of the December 2004 data is misleading in that the site was off-air experiencing a casualty at the time of install. Thus, some of the December 2004 data actually is the old ATU.

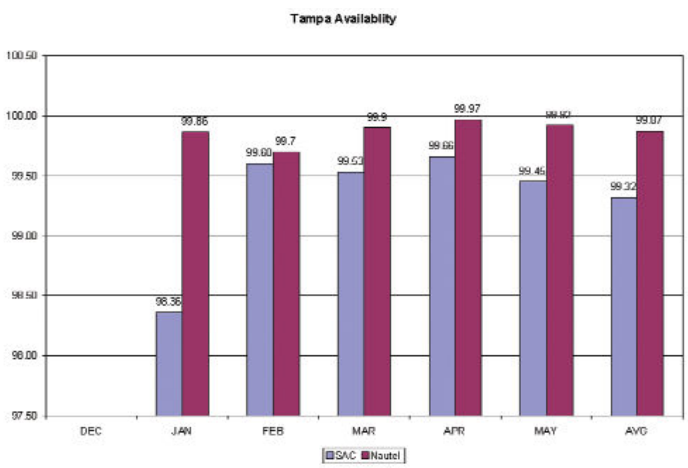

Figure 14. 120' Rohn Availability.

For the 120' Rohn, although 100% availability is not achieved, it is an improvement from previous equipment.

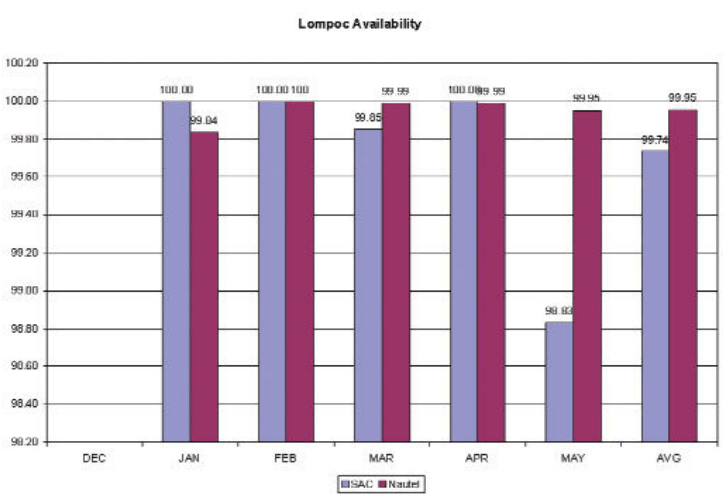

Figure 15. 150' Rohn Availability.

The 150' Rohn shows issues with previous year's data; this year's data meets the availability goal of 99.7%.

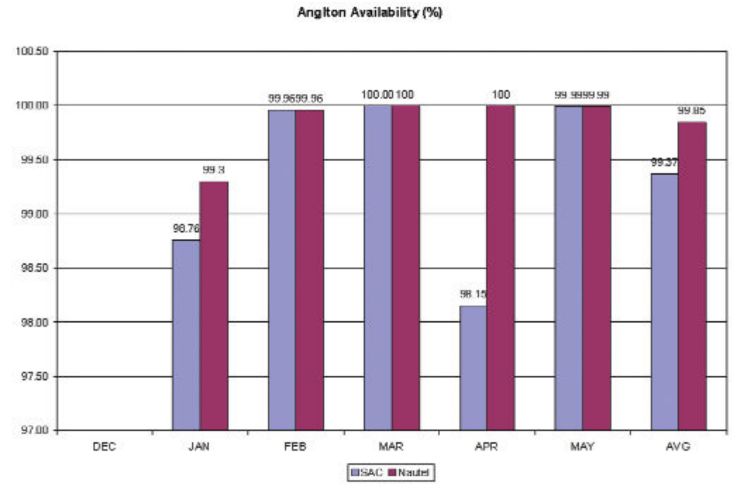

Figure 16. 150e Availability.

The 150e also shows consistent improvement. The low value for April 2004 is likely due to a communications outage rather than an RF outage. Specific details for previous years data was unavailable.

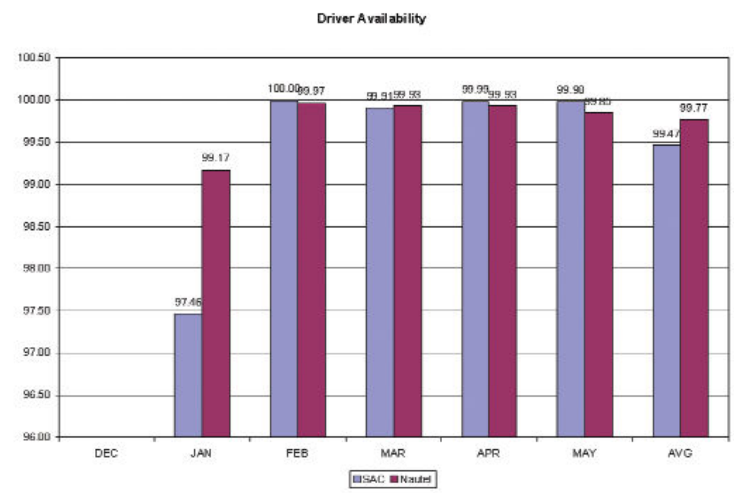

Figure 17. 295' GWEN Availability.

The 295' GWEN antennae have normally been high performing antennas, although they are susceptible to icing as they lack ribbed insulators. In general, the ATU improved performance at this site.

The Sloping-T antennas, particularly Omaha, NE, are poor performing sites. The unstable wire is often carried by the wind, which requires continual tuning of the loading coil. Notice that although this site is not meeting the 99.7% goal consistently, there are more cases for it meeting the requirement with the new ATU than with the old ATU. Additional antenna work is required to stabilize the antenna to achieve 99.7% availability.

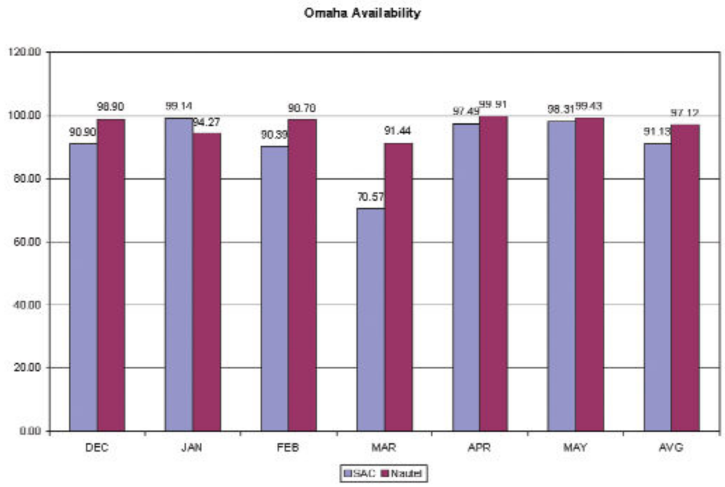

Figure 18. Sloping-T Availability.

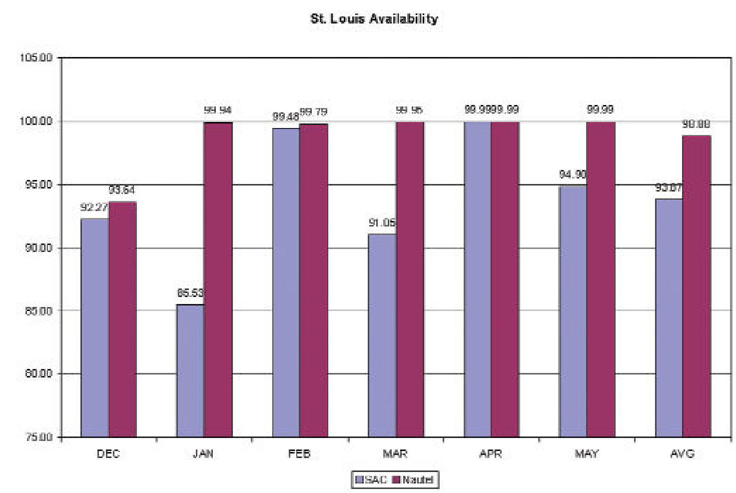

Figure 19. Longwire Availability.

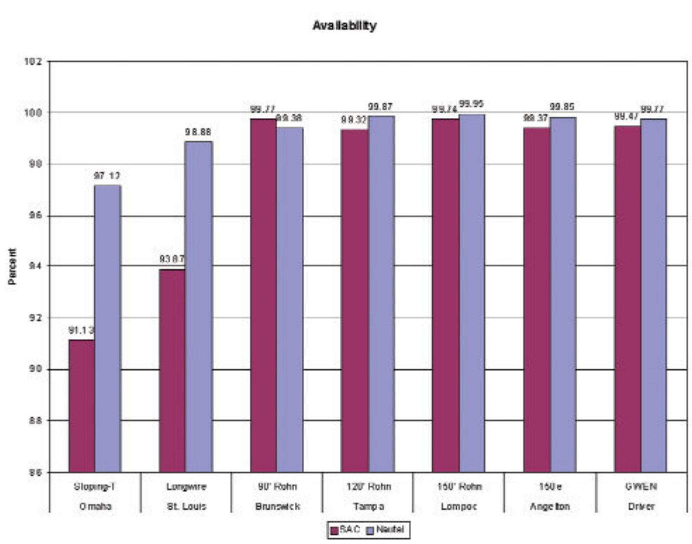

Figure 20. Availability Summary.

This longwire antenna has experienced a dramatic improvement in performance. The site typically shut down due to ice and weather but since the install of the new ATU, the site consistently exceeds availability of 99.7%.

To summarize the results of availability, before and after availabilities were summed and each antenna type was placed on the same chart to show the difference in performance between the antenna types.

The Nautel ATU-HP has improved system availability for the sites prototyped on average from 97.52% to 99.26%. The impact is most noticeable on the weaker sites, bringing them from the 90-95% range to the 95-97% range -- a significant stride forward toward meeting our overall goal of 99.7% system availability.

CONCLUSION

The install of the all-weather ATU has improved DGPS system performance by (a) ensuring the install achieves a 50 Ohm match with VSWR of less than 1.02 and (b) maintaining a 50 Ohm match automatically, keeping the DGPS site on-air when experiencing changes in weather.

While the upgrade of the antennas are still necessary to improve antenna efficiency and bandwidth to harden the site, the all weather ATU provides immediate relief for transmitter amplifier issues and a cost savings in technician call out, travel costs, equipment repair, and the logistics strain for seasonal failures of transmitter amplifiers.

The all weather ATU opens the door to many future capabilities. For example, the ability to add system resistance and bandwidth at all sites may prove invaluable if enhanced modulation schemes require additional bandwidth and all sites have not received antenna upgrades. Operators can weigh the benefit of the added modulation scheme with adjacent site coverage to closely manage the fielding and roll out of the new signal.

The all-weather ATU introduces antenna current monitoring and reporting as a possible tool for remote site monitoring. Present datalink performance monitoring is accomplished using near field probes which are calibrated using far field measurements. Antenna current will provide a much more intuitive metric for determining signal coverage -- one that will readily account for changes in antenna efficiencies and near field instability. By monitoring antenna current in real time, it is possible to predict coverage real time, showing areas of single, double, and no coverage. If transmitter output power is remotely controlled, the coverage could be held constant, or even increased if adjacent sites were off-air for maintenance.

ACKNOWLEDGEMENTS
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The purpose of this paper is to present initiatives and propose new ideas for exploration. It is not intended to reflect USCG direction or policy. Use of company names, trademarks, or copywrited material is not an endorsement of any product or service.

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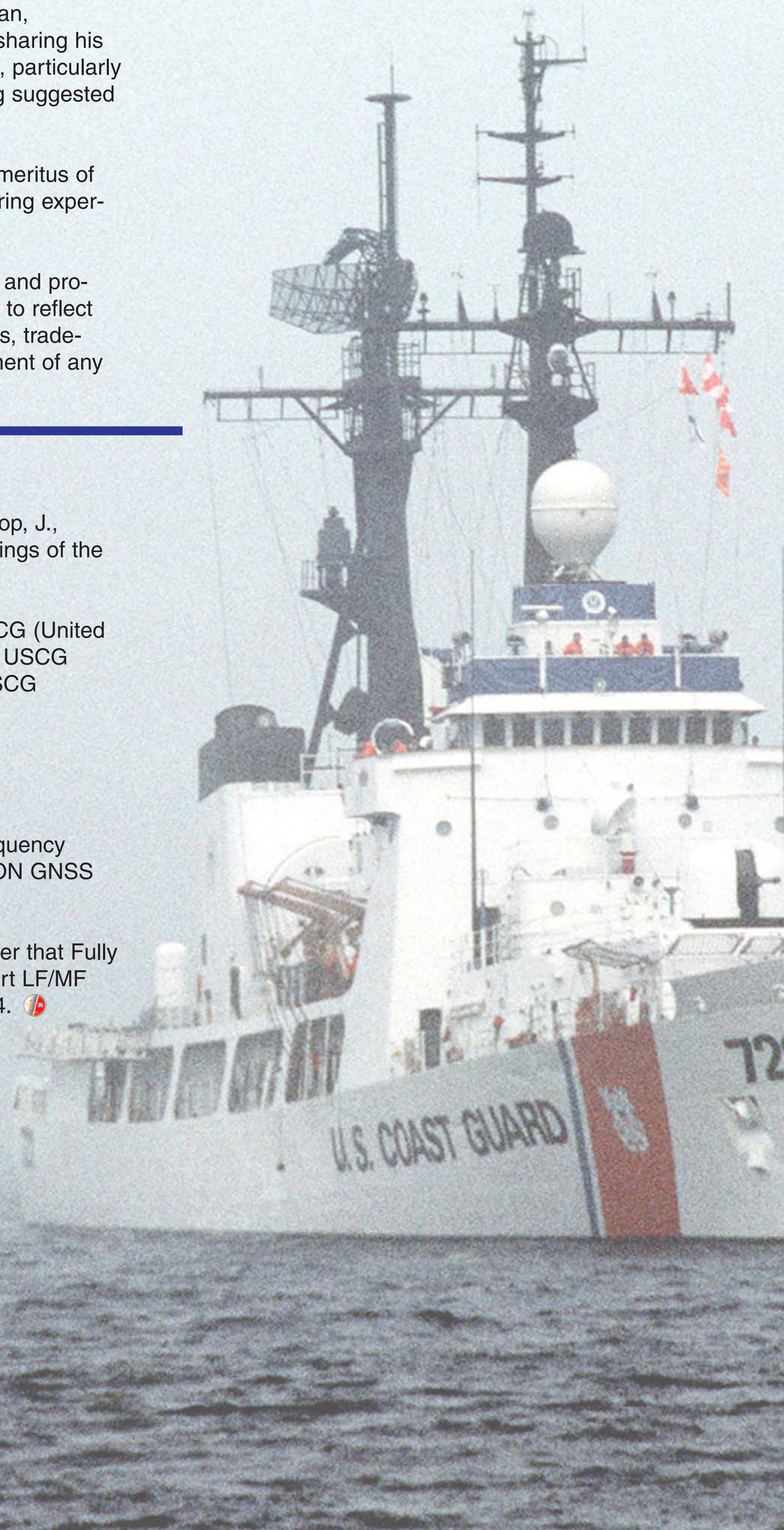

U.S. Coast Guard photo by PA1 Rob Wyman.