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MAY 78　A N SMITH, J C HANSELMAN　N00123-75-C-0328
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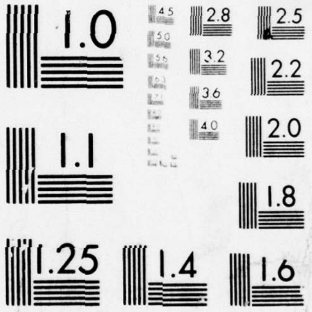

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Technical Report 246
Volume 4

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OMEGA NORWAY ANTENNA SYSTEM CHARACTERISTICS: MODIFICATION AND VALIDATION TESTS.

Volume 4. Test Plan for Field Intensity Measurements.

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Electronic measurements were performed on the Bratland Omega Antenna System during the months of July and August 1977. The work was performed under NOSC project MP01537B10 with Megatek as contractor under NOSC Technical Agreement 7220-90, Contract N00123-75-C-0328.

Volume 1 of NOSC TR 246 is the report proper. Volume 2 contains data sheets. Volume 3 is the test plan for base impedance. Volume 4 is the test plan for field intensity measurements.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electronic measurements were performed on the Bratland Omega Antenna System during the months of July and August 1977. The work was performed under NOSC project MP01537B10 with Megatek as contractor under NOSC Technical Agreement 7220-90, Contract N00123-75-C-0328.

The antenna height had been significantly lowered in 1975, therefore tests were conducted on antenna performance in three configurations, so that a curve of performance for each frequency of operation is now available as a function of antenna span height. A determination of geometry by means of an optical

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survey was carried out by NOSC in the period 21 through 25 July 1977. Reference data for future comparison, in the event the antenna spans are raised, are thus available.

The electrical height of the antenna is 205 meters for 10.2 kHz when the span is in the so-called 1975 or intermediate elevation in which spans 1 and 3 are respectively paid out 14 and 10½ turns from the "high" or 1973 position. The effective height varies directly as the mean span height, so that the percent increases are the same for electrical and geometrical height. For the 1973 position the effective height is 229 meters. There is a small frequency variation which is very nearly proportional to the fifth root of the frequency ratio.

The antenna system efficiency in the 1975 configuration is 5.9%, and in the 1973 configuration is 7.3%; therefore with 150 kW antenna system input power the station will be able to radiate 10 kW when the spans are raised. For this mode of operation the spans are operating at about 70% of their design voltage limit or less; full 10 kW radiated can be obtained by raising the spans back to the full 1973 height.

Portions of this report are reproduced from:

"VLF COMMFACPAC Proof of Performance Detailed Test Plan" under NBy 53166 Bureau of Yards and Docks report "Basis of VLF Antenna Determination", by A.N. Smith, 30 December 1965.

and

"Aldra Antenna Test Plan" dated 25 August 1969 for Westinghouse Research, Report 69-881-Model-R2 "Performance Test of the Bratland OMEGA Antenna", by A.N. Smith etal dated 25 November 1969 under N62477-69-C-0094.

N.H

Radiation Resistance

Determination of radiation resistance is obtained from the radiated field, frequency, and input current when the antenna is used as a radiator. Formulas are given in Appendix I. Accurate measurements of radiated field, distance and antenna current are of prime importance.

The antenna current meters in the Timing and Control Set are not necessarily calibrated and should not be used to measure antenna current. A special current to voltage transducer is installed on the matching transformer ground return. The transducer output is viewed on an oscilloscope. The peak values of the various transmissions are noted then matched by the output of a signal generator which is accurately measured by a digital voltmeter. By offsetting the zero baseline downward and expanding the vertical waveform presentation to bring the positive peaks near the top of the screen it is possible to achieve a comparison accuracy of better than ±1%. The absolute error is the sum of errors of the current to voltage transducer (<±1%), the comparison method (<±1%) and the digital voltmeter (<±1%). Data sheet 4 is provided to record the voltages measured and the antenna currents calculated.

The radiated field is determined by receiving the H-field with a loop mounted on an aircraft which is flown along a number of radials from the transmitting antenna. These radials are selected so that two are sea-going, two are land-going, and two are coastline radials. The detailed selection of the courses flown must be made on site, but these should be adhered to,as suggested,as closely as possible. During the flight the position of the aircraft is plotted by visual sightings as a function of time. Failing this, dead reckoning positions are plotted, after the flight, based on air-speed and elapsed time, corrected for wind velocity as observed by difference of flight time out versus that back at constant air-speed. Appropriate account must be taken of the time used in making a landing (once per radial) for field intensity measurement calibration purposes (FIM).

The instrumentation consists of an oscilloscope, precision digital voltmeter, tuned amplifier, oscillator and a loop antenna modified to permit shield current injection for calibration and comparison signal matching. The loop modification is described in MEGATEK Report 4018 which is included with each loop. The measurement is made by selecting a frequency, offsetting and expanding the loop output voltage as presented on the oscilloscope, turning the loop to a null then matching the oscilloscope presentation by shield current injection. The output of the signal generator feeding the shield current is, by calibration, equal to the hypothetical field strength in volts per meter. This voltage is measured by a precision digital voltmeter and recorded on Data Sheet 3. Spaces are provided for six (6) measurements to be recorded with a space for the average value calculated.

Ideally, when in the far-zone radiated field, the plot of the product of indicated volts from the instrument times distance from the source should be a flat straight line except for attenuation. In this case, considerable departure from this will be observed due to coastline effects and reflection and refraction because of the presence of islands. Also, each of the radial runs will involve readings taken at points much closer than a wave-length distant from the antenna. Because of these aspects, and the way in which the loop is calibrated, and since the instrument basically is measuring magnetic field, not electric field, employing a loop as a sensor, the following procedure is appropriate. All meter indications will be recorded on the data sheet exactly as they appear on the instrument. A separate sheet will be used for each frequency of observation. A column will be shown as absolute volts per meter. In another column will be shown the figures resulting after division by $\eta_0 = 377$ ohms, and this column will be labeled "total H-field", amperes per meter.

The effect of near-zone induction field will be removed from this result, by the following procedure, on a separate Summary Sheet 1:

a. The first column will be for tabulating the "total H-field" transcribed from Data Sheet 3.

b. The second column will be for tabulating the distance from the source transcribed from Data Sheet 3.

c. The third column will be for a calculated factor, F, from the expression: $F = \left[1 + (1/\beta_0 d)^2\right]^{\frac{1}{2}}$, where $\beta_0 = 2\pi/\lambda_0$ and d is the distance in meters.

d. The fourth column is for the result of dividing total H (column 1) by factor F (column 3) which is radiated field in amperes per meter.

e. The fifth, and last column, will show the product of radiated field (column 4) and distance in meters (column 2).

f. Each horizontal line of the form is for one location on a radial and a separate sheet is required for each frequency and radial. This last column will be plotted as a function of distance in meters from the source. Outgoing passes, on a given radial, and incoming passes will be plotted seperately. The best horizontal straight line will be laid on this curve, with judgement and care being excercised concerning diffraction and attenuation effects. The resulting value of (H · d) when multiplied by the ratio (λ_0/I_b) gives apparent effective height h_e for that radial at this frequency. It is important, when making the observation, that a direct communication link with the transmitter enabling an immediate determination of I_b, the antenna base current, at the instant of measuring H, and a log be kept from minute to minute of both H and base current from which the time-coincident values can be afterward determined. This entire procedure will be repeated for each radial at each frequency. The mean of the six determinations at each frequency for the set of six radials will be the effective height of the antenna at that frequency. This should come out somewhere in the neighborhood of 200 meters, and should show only slight frequency dependence. Note that in taking the measurements, each frequency will be recorded in succession in intervals at each observation point. Thus, the position of the aircraft will be slightly different at each observation point for each frequency.

In the above discussion, an initial calibration procedure for the loop pattern aboard the aircraft has been assumed. In the normal course of events, only two points of the pattern will be in use: loop fore-and-aft, aircraft heading away from the antenna and aircraft heading toward the antenna. Since the aircraft will be in straight-away flight, there should be negligible bank angle, so the vertical pattern of the loop on the aircraft should be of no importance, but experience has shown that when mounted on one of the struts outside the door of the craft, there is about 30% correction to the loop sensitivity for sternwise aspect to the source, and a somewhat different correction for nosewise. Some procedure should be used for relative calibration of the loop and field intensity measurements.

A suitable mechanical mounting is devised to mount the loop to the landing gear, preferably to starboard, opposite the tail rotor. The instrumentation is then taken out to some small low-lying island about 10 km off the coast, preferebly fairly well clear of other islands. Upon arrival, the instruments are removed from the aircraft, and set up approximately 50 meters away. A complete reading, with calibration by the nulling and signal-injection procedure, for each frequency is then taken, using the OMEGA antenna in the 10 sec keying mode. The instruments are then placed aboard the helicopter, with the loop mounted in the position used during the flights. The helicopter is oriented so that the tail is toward the source. Readings are repeated for each frequency, but these will be only relative readings, since a nulling procedure is not possible after the loop is mounted in position. The helicopter is then rotated in 15^o increments, and relative readings taken for each frequency in each position. After a complete pattern has been taken on land, a repetition of the cardinal points may be taken at a spot on the water nearby. Next, readings are taken for stern-on and nose-on orientations during a low-level fly-over or hovering at the same locations. Finally, a climb to normal operating altitude is made, and readings taken again for each frequency for fly-overs or hovering at stern-on and nose-on aspects.

During the flights, at least one landing per radial for calibration will be conducted in exactly the same manner, except that a pattern for the loop on the helicopter will not be taken.

An optional cross-check for effective height is obtainable from an open circuit measurement of base voltage developed on the antenna when immersed in an incident electric field. The VLF NATO station at Novik operating on a frequency of about 17 kHz is a convenient source, as is GBR in Great Britian. Cutler and Annapolis will not be usable. The open circuit voltage developed on the antenna is measured by use of the wave analyzer, connected across a suitable bleeder resistor. The incident field at the location of the antenna is the least certain part of the measurement. In the present situation the H-field in some relatively clear spot near the antenna site can be measured; such a location would be out on the water in the middle of Aldersundet, near, but not under the antenna. Recourse must then be made to assuming the relationship of E to H to be by free-space plane wave impedance but this may not really hold due to local refraction and diffraction effects making the field non-plane.

APPENDIX I

RADIATED POWER

Radiated power is measured in terms of vertical radiated field, E_{oz} volts per meter, some distance d meters from the source. If measurement is made closer to the source than about 1 wavelength, then the total electric field measured, E_{oz} (tot), is divided by the factor

$$ {}_EF_r = \left\{ \left[1 - \left(\frac{1}{\beta_0 d} \right)^2 \right]^2 + \left(\frac{1}{\beta_0 d} \right)^2 \right\}^{\frac{1}{2}} \qquad (1) $$

to get the radiation component; $\beta_0 = \frac{2\pi}{\lambda_0}$. The radiation component actually measured is not the same as that for a perfectly conducting, plane, airless earth, which is the quantity E_{oz} in the formula.

$$ P_r = \frac{4\pi}{3\eta_0} \left(E_{oz} \cdot d \right)^2 \text{ watts} \qquad (2) $$

where $\eta_0 = 120\pi$ = impedance of free space. The measured E'_{oz}, must be "de-attenuated" by dividing out the attenuation factor F_e appropriate for the impedance properties of the actual surface over which the measurement is made, i. e., $|E_{oz}| = \frac{|E'_{oz}|}{|F_e|}$. Generally for distances of 1 or 2 wavelengths $|F_e| \simeq 1$, and other effects, such as diffraction or refracted interfering waves from local terrain, and coastline enhancement are far more important. E'_{oz} must be sampled at a multitude of points, both in radial direction and distance, to get a reliable average. The custom is to normalize readings to a standard distance, and then average, or to take average of products $E'_{oz} \cdot d$, weighted by $1/|F_e|$ and by $1/{}_EF_r$ as appropriate.

The quantity ${}_EF_r$ referred to above applies to direct measurement of vertical E with a whip and tuned voltmeter. Alternatively, often a small loop, not a whip, is used to measure "radiated field." The loop actually measures total magnetic field, $H'_{\phi tot}$. The same remark about the relationship of $H'_{\phi tot}$ to $H_{\phi tot}$ through $1/|F_e|$ applies as for E'_{oz} and E_{oz}, but now the radiation component of $H_{\phi tot}$ is $H_{\phi tot}/{}_HF_r$, where

$$ {}_HF_r = \left\{1 + \left(\frac{1}{\beta_0 d}\right)^2\right\}^{\frac{1}{2}} \qquad (3)$$

A loop connected to a voltmeter frequently is calibrated in a far field ($H_\phi = H_\phi$ radiation) so that scale readings are in terms of "volts per meter", obtained by identifying $E_{oz} = \eta_0 H_\phi$. Thus, at closer distances than a wavelength $V_\ell = \omega\mu_0 HAH'_{tot} \cos 0$ ($\cos 0 = 1$ by adjustment to maximum output) must be divided by ${}_HF_r$ to give

$$\frac{V_\ell}{{}_HF_r} = \omega\mu_0 \frac{H'_{\phi tot}}{{}_HF_r} NA = \omega\mu_0 H_\phi NA = \omega\mu_0 \frac{E'_{oz}}{\eta_0} NA = \beta_0 NA\, E'_{oz} \qquad (4)$$

The "effective height" of the loop is thus actually

$$h_{e\ell} = \left\{1 + \frac{1}{\beta_0 d}^{2}\right\}^{\frac{1}{2}} \beta_0 NA = \left\{1 + \frac{1}{\beta_0 d}^{2}\right\}^{\frac{1}{2}} h'_{e\ell} \qquad (5)$$

where $h'_{e\ell}$ is the commonly referred to effective height for the far field only. With this correction to generalize $h_{e\ell}$ to any distance, the radiation component of field derived from loop measurement is

$$E'_{oz} = \frac{V_\ell}{h_{e\ell}} = \frac{V_\ell}{\left({}_HF_r\right) h'_{e\ell}} = E_{oz}|F_e| \qquad (6)$$

This assumes a perfectly balanced loop so that no part of it or its connector acts like a monopole.

The voltage V_{ℓ} may be functionally related to actual voltage read on voltmeter (V dial) through a prior calibration procedure either in a standard field, or by shield injection such as the technique described by Dinger and Garner. The loop shield is a single-turn loop and is nearly unity-coupled to loop turns. Therefore $V_{gap} = \omega\mu_0 AH_{\phi}$ while $V_{loop} = NV_{gap}$*, N = number of turns of the loop; but due to loading what appears on meter face is $V_{dial} = kV_{loop} = K\,NV_{gap}$, $k \leq 1$. By reciprocity, the same V_{gap} can be injected from a moderately high impedance source and measured, while V_{dial} induced in loop, as modified by connecting circuits, is read on meter face, with the loop decoupled from the field to be measured. In equation (6), V_{ℓ} was really loop voltage, so if it is now meter face voltage V_{dial},

$$E_{oz} = \frac{V_{dial}}{k\ {}_{H}F_{r}\ \beta_0\ NA} \tag{7}$$

where k is the ratio of actual voltage read to voltage injected versus the expected voltage to read to voltage injected (which should have been N).

DATA SHEET 3

RADIO FIELD INTENSITY

________________ Date	________________ Time	________________ Frequency Hz

1. A. Signal Generator Output: ________mV ________mV ________mV

________mV ________mV ________mV Average: ________mV

B. Field Intensity: ________ X 10^{-3} V/meter, ________ X 10^{-6} A/meter

2. Location of measurement:

A. Grid Coordinates — Geographic Coordinates

N/S ____________ meters/feet — Lat. ____° ____' ____" ( )

E/W ____________ meters/feet — Long. ____° ____' ____" ( )

B. Narrative Location (Place name or description): ____________

____

____

____

C. Height of loop antenna: Tripod ______(m/ft.) above local surface

Helicopter _______(m/ft.) above m. s. l.

3. Location of transmitting antenna.

Reference point on antenna system: ________________

Grid Coordinates — Geographic Coordinates

N/S ____________ meters/feet — Lat. ____° ____' ____" ( )

E/W ____________ meters/feet — Long. ____° ____' ____" ( )

4. A. Signal path, transmitter to receiver: Az. ____° T., D. ____km.

B. Signal path, receiver to transmitter: Az. ____° T.

5. Transmitting antenna current: _______A.

6. Estimate of quality of data: ________________

____

____

DATA SHEET 4

ANTENNA CURRENT

Pearson Current to Voltage Transducer

Date

Model Serial Output V/A

Sheet No.

Fluke Digital Voltmeter

Model Serial

Time	Frequency	Voltage	Current

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