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OMEGA NORWAY ANTENNA SYSTEM CHARACTERISTICS: MODIFICATION AND V--ETC(U)

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

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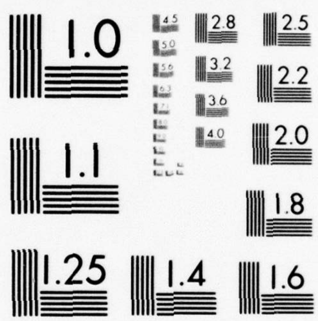

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ADMINISTRATIVE INFORMATION

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 metres 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 metres. 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.

CONTENTS

VOLUME 1. REPORT TEXT

I. INTRODUCTION

Under a scope of work defined in (a) NOSC ltr ser 722-32 of 25 Apr 1977 and (b) NOSC Technical Agreement 7220-90, Contract N00123-75-C-0328, electronic measurements were performed on the Bratland Omega Antenna System in July and August of 1977.

The recommended value for effective height for this antenna at 10.2 kHz in the intermediate (1975) elevation is 205 metres and for the high (1973) position, 229 metres. Effective height appears to increase with the fifth root of frequency. Details of this dependence and the corresponding physical heights are given in this report.

A part of the scope of work for NOSC under project MP01537B10 was an examination of the ground system, as well as other physical aspects of the installation, in particular the geometry of the downlead system and its possible relation to the loss budget. These questions were addressed during the trip to the site in July 1977.

The work by Megatek under the above contract consisted of two sub-tasks substantially different in nature:

a. The first sub-task required that the Antenna Tuning Set, AN/FRQ-18(V)-(U), be modified by removing f_{t2} and replacing it with 11.05 kHz. Additionally the Timing and Control Set, AN/FRN-30, was modified to provide excitation and keying in a new format originally disclosed in TR 1966, Naval Electronics Laboratory Center, dated 8 October 1975.[1]

b. The second sub-task required that the radio field intensity be measured as extensively as possible, both on the surface and at various altitudes above the surface, to determine the radiation pattern and the radiated power of the station. Additionally a remeasurement of the antenna system resistance was necessary to assess the efficiency of the antenna and tuning system and to facilitate optimum matching of the transmitter to the antenna. The second sub-task also required that "bench mark" locations be identified and a calibration provided for each site.

II. INSTALLATION OF THE FOURTH OMEGA FREQUENCY, 11.05 kHz

A. INSTALLATION

1. Planning for the installation of the helix tap for 11.05 kHz made extensive use of Megatek Report LR 2001-16, Antenna System Measurements, OMEGA Norway, dated 12 December 1973.[2] Unless specific mention is made of another source all references to "1973" data will mean the above report. During 1975 the antenna span tension was relaxed, which lowered the antenna and increased the capacitance.

2. Measurements were made of the apparent capacitance (C_{app}) at the original frequencies including f_{t1} and f_{t2} but, due to the lack of an auxiliary inductor, not at 11.05 kHz. These data are recorded on Data Sheets 1 and shown in Table 1 under the heading "1975" Antenna Position. Comparative data taken in 1973 are also shown in Table 1. The values given in this table are the capacity external to the bushing, i.e., the antenna alone as viewed from the end of the downlead attachment outside the helix house.

3. TR 1966 gives the new format for Omega stations. F_{t2} is replaced by 11.05 kHz and f_{t1} increased to four (4) segments with two (2) segments on each side of 11.05 kHz. Since f_{t2} is eliminated, 11.05 kHz is considered as the new frequency for the f_{t2} variometer room. Appropriate tap location requires careful estimation of the number of

TABLE 1

Frequency (Hz)	$C_{apparent}$ (μF)	
	1973	1975
10200	0.036477	0.036959
11333	0.037488	0.037970
12100	0.038275	0.038760
12350	0.038542	0.039039
13600	0.040070	0.040671

(Average increase in capacitance is 1.3%)

helix turns required. The antenna will eventually be pulled up to the 1973 level so it is also required that the 11.05 kHz tap be proportioned to fit either the 1975 or 1973 capacitance.

4. Calculations based on 1973 data are shown in Table 2. These show what was to be expected after 1 turn was removed from the helix specified in 1973. Inductance (L) is given in mH, P_V (variometer position) is given as distance "down" from minimum inductance position (variometer shorted turn fully meshed with stator).

5. An interpolation was made of the C_{app} curve, shown in Figure 4 of LR2001-16, to obtain 0.0374 μF for C_{app} at 11.05 kHz. This produced the calculated values of inductance shown in Table 3. Because of the location of the variometer room the helix must be wound to N + 8/12 turns. Therefore the nearest number of turns for the 11.05 kHz tap in the helix will be 46-8/12. This produces the second set of calculated data for 11.05 kHz also shown in Table 3.

TABLE 2. ANTENNA TUNING SYSTEM, AS BUILT (1973)

f kHz	N (turns)	L_H mH	L_T mH	L_V mH	P_V (cm)
10.2	54-8/12	5.85	6.65	0.80	-85
11-1/3	44	4.49	5.24	0.75	-74
12.10	37-11/13	3.72	4.50	0.78	-80
12.35	36-8/12	3.56	4.29	0.73	-68
13.6	29-2/12	2.63	3.41	0.78	-80

TABLE 3. ANTENNA TUNING SYSTEM, MODIFIED (1977)

f	N	L_H	L_T	L_V	P_V (cm)
11.05	46-5/12	4.79	5.55	0.76	-76
11.05	46-8/12	4.82	5.55	0.73	-68

6. As noted in paragraph 10, page 17, of LR 2001-16, sufficient slack had been included in the loop of the 10.2 kHz lead to allow insertion of a tap point between 10.2 and 11-1/3 kHz. No spare tap lead support material was available so rope slings were fabricated.

7. The 12.35 kHz tap plate was removed, the Litz wire shortened and a splice joint installed. The old tap plate was installed in the new 11.05 kHz position.

8. The antenna was allowed to retune, in the normal automatic mode of antenna tuning, and the variometer positions were measured. The results are shown in Table 4.

9. The positions shown in Table 4 are in the upper portion of the variometer operating region. This will change to a position closer to the center of the region when the antenna is repositioned to its full height. Since this would also change the gear ratios required no test of the ratios, or changes in them, were made. The mathematical ratio for 11.05 kHz was calculated to be 1:1.1361. The only sprockets available are those originally installed. These are also calculated, not measured, ratios and are shown in Table 5. The nearest ratio to the required value for 11.05 kHz, which can be generated by the sprockets on site, is 1:1.1364 produced by 50 to 44 teeth. The gear box in the room for 11.05 kHz was modified by exchanging the positions of the 50 tooth and the 40 tooth sprockets. This converts the pair of gears originally assigned to 12.35 kHz (deleted) to the calculated pair of gears for 11.05 kHz. In the process the gear ratio set for 11-1/3 kHz is deleted. It is unnecessary for normal operation or maintenance.

TABLE 4. VARIOMETER POSITIONS MEASURED
(ANTENNA AT 1975 HEIGHT)

f	P_V (in)	P_V (cm)
10.2	-19-7/8	-50.5
11.05	-15-3/8	-39.1
11-1/3	-18-3/4	-47.6
13.6	-23-1/2	-59.7

TABLE 5. ANTENNA TUNING GEAR RATIOS, NORWAY

f	INPUT SHAFT	OUTPUT SHAFT	RATIO
10.2	48	36	1.3333 (4/3)
11-1/3	54	50	1.0800
13.6	33	44	0.7500 (3/4)
12.1	36	38	0.94736
12.35	40	44	0.90909
(ARBITRARY)	36	36	1.0000
11.05	–	–	1.1361
11.05	50	44	1.1364

10. To install a set of sprockets for 11.05 kHz in the gear box in the Spare Variometer Room it was necessary to exchange sprockets with an external spare gear box. The 40 tooth sprocket of the Spare Room box was exchanged with the 50 tooth sprocket of the extra gear box. This makes the spare room capable of substituting for any other room.

11. Changes to the Timing and Control Set AN/FRN-30 (T & C) are explicitly delineated in TR1966.[1] New cards, which had been adjusted and tested in a spare T & C, were provided. The modification consisted of replacing cards and plugs with one exception. The time constant divider of the phase shifter must be set to a value long enough to prevent signal drop-out when a step error is applied. In Norway this value was 4 X 8 = 32.

B. ANTENNA TUNING SET MODIFICATION AND ADJUSTMENT

1. Comments and recommendations were presented in Sections V and VI of the 1973 report.[2] Most of these were ignored and in fact the changes made in 1973 were reversed and the equipment was restored to the original condition. In addition filters were installed in the Antenna Tuning Phase Detector reference and signal lines.

2. Sometime between the fall of 1973 and summer of 1975 the Transmitters, AN/FRT-88, had driver stage modifications installed which reduced the distortion in the output signal. No tests or modification of the Antenna Tuning Set were noted.

3. The following changes in the Antenna Tuning Phase Detector were made:

a. The filters in the signal and reference lines were removed.

b. 6A1R14 of the NULL ADJUST circuit was again removed.

c. 6A1R5 of the GAIN ADJUST circuit was changed from 3.3 k ohms to 680 ohms, 1/2 watt, 5%.

d. Terminating resistors of 1.8 k ohms, 1/2 watt, 5% were installed across the secondary windings of 6A1T1 and 6A1T2. Physically these resistors were mounted on printed circuit board socket 6A1XA1. Terminals A through S are all connected to ground. The resistors were installed from terminals 3 and 5 respectively to convenient grounded terminals of socket 6A1XA1.

4. The changes noted in paragraphs 3a through 3c have been adequately discussed in the 1973 report[2]. The terminations noted in paragraph 3d were required to reduce the remaining distortion which appears at the Phase Detector through transformers 11T1 and 6A1T1. To provide the same loading, and phase shift, an identical termination resistor was applied to the current sample transmitted through transformers 11T2 and 6A1T2. The unterminated transformers exhibited better transmission at the higher (harmonic) frequencies which resulted in enhancement of the distortion. The termination ensures that the signals are transmitted "as is" through the transformers.

III. FIELD INTENSITY MEASUREMENTS

A. INTRODUCTION

1. For convenience in entering data for record the choice of some units used to describe the field intensity and radiation parameters of the antenna system are submultiples of MKS. Abbreviations of the units used will be found in Appendix A.

The expression of field intensity, while receiving the signals on a loop antenna, should be in terms of magnetic field. It is a more common practice to express field intensity in volts per metre, of antenna effective height, as if it were a vertical whip. This appears to give many operators a better feeling for the signal magnitudes produced by their antennas. Data reduction formulas used in this report properly account for the fact that where observation locations involve significant "near zone" field contributions, there is no electrostatic term in the observed field due to the fact that the receiving antenna is a loop and is responding to magnetic field which has only radiated and induction terms. The calibration procedure for the loop antenna supplies the necessary transformation to obtain volts per metre.

Once the field intensity has been determined, radiated power may be calculated. Radiated power (P_r) and antenna current (I_a) are used to calculate radiation resistance (R_r) and effective height (h_e), both equally fictitious and diversely useful parameters. The effective height is more familiar to an antenna designer but the radiation resistance is more useful to an operator who needs to know the efficiency of his station and its output as a function of antenna current. Both are calculated and tabulated.

2. Additionally, a field-distance product, normalized to one ampere of antenna current, is tabulated for comparison of the various radial directions and sites chosen. Ideally this number for radiation component only would be a constant for each frequency regardless of distance and direction if all sites were perfect and the antenna radiation pattern was circular. Its variation from the ideal gives a means for evaluating groundwave attenuation factor, if this is significant.

Equations for these calculations and others will be found in Appendix B.

3. The "substitution" method of measuring the radio field intensity of the Omega transmitting stations is a means of calibration for a loop antenna and receiver devised by Dinger and Garner of the Naval Research Laboratory. The complete technique is thoroughly discussed in Appendix C to this report. While there are other measurement methods that could have been utilized, most of them depend upon fast acting meters or recorders. These instruments are, at best, difficult to read to a precision of 1%. Unless synchronous, or coherent, detection is employed the noise content must be extracted before the signal value is known. Precision of measurement can be obtained by synchronous detection and long time constant filtration, but for a quick and precise measurement for most station technicians the process described in Appendix C seems superior. Appendix G lists the equipment used for the field intensity measurements.

At the close distances and high signal-to-noise situation realized for the present measurements, the visual method of signal averaging provides a good value against which to substitute, and by comparison to obtain the identical amplitude from, a signal locally provided from a generator. No knowledge of the amount of noise present is necessary and no calculation is required to extract the pure signal amplitude from the noisy received signal.

B. PROCEDURE

1. Suitable sites for calibration of the loop antenna, mounted on the helicopter, were chosen. The first two were also chosen to be the official "bench mark" sites. The others were selected, as the work progressed, by visual appraisal of the location and accessibility. Seven sites were used as helicopter calibration sites. There seemed to be no clear trend to associate with frequency or site. Therefore the data were considered to be equally valid. Table 6 shows the location, readings and ratio for each frequency. The mean value

TABLE 6. HELICOPTER CALIBRATION FOR K_3

Nose toward transmitter

Location	f (kHz)	E_m (mV) Tripod	Helo*	Ratio K_3
Hestmandoen	10.2	31.4	28.5	1.102
Radials	13.6	42.6	38.0	1.120
I & II	11-1/3	34.0	30.8	1.103
	11.05	32.8	29.5	1.111
Vargård	10.2	9.5	8.9	1.068
Radial I	13.6	13.7	12.9	1.059
	11-1/3	11.1	10.0	1.109
Myken	10.2	10.1	9.5	1.063
Radial II	13.6	15.4	14.6	1.058
	11-1/3	12.8	11.6	1.101
	11.05	12.0	11.3	1.060
Lammöyen	10.2	9.8	9.4	1.043
Radial III	13.6	15.1	13.8	1.098
	11-1/3	12.4	11.2	1.105
	11.05	12.5	11.1	1.124
Tomma	10.2	28.9	28.0	1.034
Radial IV	13.6	39.6	37.6	1.053
	11-1/3	32.5	30.8	1.054
	11.05	31.9	29.8	1.072
Steinmyr-	10.2	21.0	19.5	1.076
fjellet	13.6	28.0	26.3	1.065
	11-1/3	23.6	22.0	1.071
	11.05	22.7	21.9	1.035
Relöya	10.2	27.9	25.6	1.091
Radial VI	13.6	37.0	33.9	1.092
	11-1/3	30.1	27.3	1.102
	11.05	29.5	26.8	1.101
		Nose Toward Mean Ratio =		1.08

Nose away from transmitter

Location	f (kHz)	E_m Helo (Toward)	Helo (Away)	Ratio K_3
Hestmandoen	10.2	29.0	30.6	0.95

Nose Toward (Ratio)	1.08
X	0.95
Nose Away (Ratio)	1.03

*"Helo" = helicopter

for K_3* shown on the bottom of Table 6, is 1.08. A measurement of the signals received with the nose toward and away from the station was made at Hestmandoen. The factor of 0.95 is applied to the value of 1.09 to obtain the ratio of 1:1.03 for the condition of tail toward the station.

2. Six (6) radial paths were chosen for measurement flights. The directions were picked to produce a diversity of topography while permitting accurate navigation and flight safety, that is, over known islands and paths that did not include great stretches of open water. Figure 1 shows the map of the region and the numbering scheme for the radials. The weather was normally cooperative except that the cloud ceiling prohibited overland flights. except for one day.

3. During each measurement period antenna system current (I_{as}) was measured by the substitution method shown in Appendix D. This would normally have been recorded at regular intervals on Data Sheet 3. Since at Bratland very experienced operators were available at both the transmitter and the helix house, and good radio communication was provided, the Data Sheet 3 was not used. Antenna system current was typically held to the same value for all frequencies and was recorded directly on the flight log sheet. This information is shown on the Data Sheet 5. Data sheets are provided in Volume 2. Procedures used in a helicopter are detailed in Appendix E.

4. As each site was used a mark was made on the map and so identified. The mark was located, with respect to latitude and longitude lines, by a precision measurement and so recorded on Data Sheet 4. These measurements were translated to precise latitude and longitude values. The position of the transmitting antenna is recorded on the same Data Sheet 4. Distance and azimuth were calculated by use of Great Circle Navigation Equations programmed into an HP – 65 calculator. The basic program of NAV 1 – 10A was modified to accept degrees, minutes and seconds and also convert the distance from nautical miles to kilometres. The distance is transcribed to Data Sheet 6 for the applicable site. The azimuth may be compared to the direction of the loop maximum as an aid in site evaluation.

5. As soon as the following parameters are entered on Data Sheet 6 –

a. Distance, in km;

b. K_1, $I_a/I_{as} = 0.975$; I_a is antenna, or exit bushing, current;

c. K_2, Loop Factor;

d. K_3, Vehicle Factor;

e. Frequency, in kHz;

f. I_{as}, in amperes;

g. E_g, signal generator output in mV –

calculation may proceed to obtain all the remaining tabular values using appropriate equations from Appendix B.

6. Summary Sheets were prepared for each frequency. The processing of the data available on the summary sheet is discussed below.

The summary sheets are shown as Tables 7, 8, 9 and 10 in Section C.

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*Vehicle Correction Factor

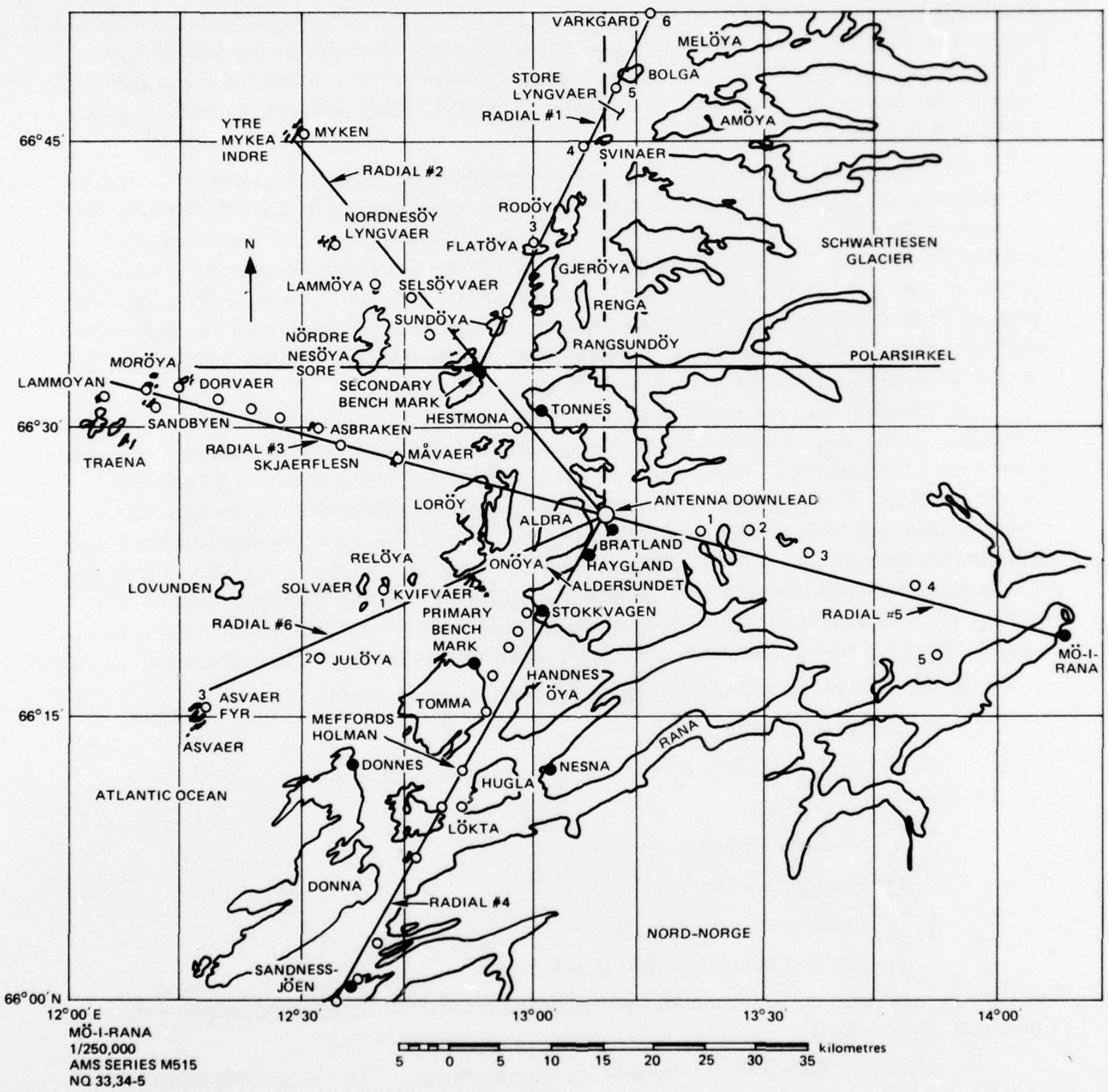


Figure 1. Sketch map of field strength measurement sites in Norway.

C. DATA ANALYSIS

1. Completion of a line of Data Sheet 6 produces three (3) numbers, normalized for distance and transmitter output, any of which may be used to evaluate a site and the antenna. These are the Effective Height (h_e), Radiation Resistance (R_r) and the Field Distance Product ($E_r d/I_a$). The values of effective height at radial distances are plotted for each frequency in Figures 2 and 3. These figures were used as a visual check of the mean values calculated.

2. Only airborne data were selected for analysis to determine the parameters of the antenna. Data taken at ground level are contaminated by unknown variation in the conductivity of the surface over which propagation occurs and by diffraction around obstacles. Numerous spot tests showed that at heights greater than 500 feet the field intensity, at a given site, was constant, and the fields were homogeneous and uncontaminated by local effects.

Tabular data, arranged by frequency, is shown for individual radials and sites. Averages and standard deviations are shown for each radial only as a matter of interest. Since there was no information to indicate the superiority of data taken at any particular site all sites were initially considered to be equal. Visual interpretation of the curves of effective height versus distance seemed to show no significant trends, therefore again it was decided to give equal weight to each value measured, while hovering, and refine the data arithmetically. Tables 7 through 10 give a summary of the procedure.

TABLE 7. 10.2 kHz SUMMARY

Airborne – Hover

Radial	Site	d (km)	h_e	R_r
I	1	18.25	220	0.0885
	2	21.6	212	0.0817
	3	27.1	205	0.0770
	4	36.2	196	0.0700
	5	41.9	200	0.0730
	6	48.7	183	0.0612
		$\overline{x}$	203	0.0752
		S_x	12.9	0.0095
II	1	18.25	213	0.0825
	2	37.5	199	0.0722
	3	49.7	144	0.0376
		$\overline{x}$	185	0.0641
		S_x	36.5	0.0235
III	1	21.1	216	0.0849
	2	51.1	205	0.0769
		$\overline{x}$	211	0.0809
		S_x	7.8	0.0057

TABLE 7. (Continued)

Airborne – Hover

Radial	Site	d (km)	h_e	R_r
IV	1	27.8	215	0.0842
	1	27.8	210	0.0807
	2	48.0	233	0.0995
		$\bar{x}$	219	0.0881
		S_x	12.1	0.0100
V	1	9.4	175	0.0559
	2A	13.1	201	0.0734
	2E	12.9	211	0.0811
	3A	19.4	182	0.0603
	3B	20.2	186	0.0635
	4A	30.5	195	0.0694
	4G	30.8	187	0.0637
	5A	33.4	197	0.0708
		$\bar{x}$	192	0.0673
		S_x	11.5	0.0080
VI	1	21.8	214	0.0832
	2	31.1	219	0.0873
	3	42.9	208	0.0790
		$\bar{x}$	214	0.0832
		S_x	5.5	0.0042

1. Average of all readings (25).

$\bar{x}$	201.0	0.0743
S_x	18.2	0.0127

$x \pm S_x$ = 182.8 to 219.2

2. Considering all values within these limits (20).

$\bar{x}$	203.6	(Omitted)
S_x	10.6	

$x \pm S_x$ = 193.0 to 214.2

3. Considering all values within these new limits (14).

$\bar{x}$	204.7	0.0765
S_x	6.7	0.0050

TABLE 8. 11.05 kHz SUMMARY

Airborne – Hover

Radial	Site	d (km)	h_e	R_r
I	1	18.25	–	–
	2	21.6	–	–
	3	27.1	–	–
	4	36.2	–	–
	5	41.9	–	–
	6	48.7	–	–
		$\bar{x}$	–	–
		S_x	–	–
II	1	18.25	213	-0.0970
	2	37.5	–	–
	3	49.7	165	0.0581
		$\bar{x}$	189	0.0776
		S_x	33.9	0.0275
III	1	21.1	217	0.1013
	2	51.1	223	0.1062
		$\bar{x}$	220	0.1038
		S_x	4.2	0.0035
IV	1	27.8	214	-0.0983
	2	48.0	209	-0.0932
		$\bar{x}$	212	0.0958
		S_x	315	0.0036
V	1	9.4	174	0.0651
	2D	14.0	218	0.1020
	3A	19.4	176	0.0661
	4D	30.5	198	-0.0841
	4E	29.5	193	0.0799
	4F	31.0	219	0.1026
	5D	34.4	193	0.0795
		$\bar{x}$	196	0.0828
		S_x	17.9	0.0151
VI	1	21.8	198	-0.0838
	2	31.1	224	0.1075
	3	42.9	209	-0.0932
		$\bar{x}$	210	0.0948
		S_x	13.1	0.0119

Radial I: Frequency not available.

1. Average of all readings (21).

$\bar{x}$	202.7	0.0886
S_x	18.4	0.0155

$x \pm S_x$ = 184.3 to 221.1

TABLE 8. (Continued)

Airborne – Hover

		h_e	R_r
2. Considering all values within these limits (11).			
	$\bar{x}$	207.4	(Omitted)
	S_x	10.1	
	$\bar{x} \pm S_x$ = 197.3 to 217.5		
3. Considering all values within these new limits (7).			
	$\bar{x}$	208.3	0.0930
	S_x	7.6	0.0068

TABLE 9. 11-1/3 kHz SUMMARY

Airborne – Hover

Radial	Site	d (km)	h_e	R_r
I	1	18.25	205	0.0948
	2	21.6	205	0.0944
	3	27.1	203	0.0926
	4	36.2	212	0.1015
	5	41.9	204	0.0936
	6	48.7	185	0.0772
		$\bar{x}$	202	0.0924
		S_x	9.1	0.0081
II	1	18.25	212	0.1016
	2	37.5	–	–
	3	49.7	165	0.0613
		$\bar{x}$	189	0.0815
		S_x	33.2	0.0285
III	1	21.1	219	0.1076
	2	51.1	225	0.1142
		$\bar{x}$	222	0.1109
		S_x	4.2	0.0047
IV	1	27.8	211	0.0999
	2	48.0	212	0.1016
		$\bar{x}$	212	0.1008
		S_x	.71	0.0012

TABLE 9. (Continued)

Airborne Hover

Radial	Site	d (km)	h_e	R_r
V	1	9.4	179	0.0721
	2C	13.8	214	0.1029
	3A	19.4	183	0.0754
	4C	29.7	186	0.0776
	5C	33.4	195	0.0855
		$\bar{x}$	191	0.0827
		S_x	13.9	0.0123
VI	1	21.8	207	0.0961
	2	31.1	216	0.1050
	3	42.9	217	0.1060
		$\bar{x}$	213	0.1024
		S_x	5.5	0.0055

1. Average of all readings (20).

$\bar{x}$	202.8	0.0930
S_x	15.7	0.0139

$\bar{x} \pm S_x$ = 187.1 to 218.5

2. Considering all values within these limits (13).

$\bar{x}$	208.7	(Omitted)
S_x	6.2	

$\bar{x} \pm S_x$ = 202.5 to 214.9

3. Considering all values within these new limits (10).

$\bar{x}$	208.5	0.0979
S_x	4.1	0.0040

TABLE 10. 13.6 kHz SUMMARY

Airborne – Hover

Radial	Site	d (km)	h_e	R_r
I	1	18.25	220	0.1571
	2	21.6	220	0.1574
	3	27.1	220	0.1565
	4	36.2	213	0.1472
	5	41.9	200	0.1300
	6	48.7	199	0.1286
		$\bar{x}$	212	
		S_x	10.1	0.0136

TABLE 10. (Continued)

Airborne – Hover

Radial	Site	d (km)	h_e	R_r
II	1	18.25	227	0.1668
	2	37.5	–	–
	3	49.7	173	0.0973
		$\overline{x}$	200	0.1321
		S_x	38.2	0.0491
III	1	21.1	225	0.1636
	2	51.1	213	0.1472
	2	51.1	225	0.1646
		$\overline{x}$	221	0.1585
		S_x	6.9	0.0098
IV	1	27.8	217	0.1527
	2	48.0	223	0.1616
		$\overline{x}$	220	0.1572
		S_x	4.2	0.0063
V	1	9.4	159	0.0816
	2B	15.0	221	0.1588
	3A	19.4	188	0.1151
	4B	29.9	202	0.1330
	5B	33.9	187	0.1135
		$\overline{x}$	191	0.1204
		S_x	22.7	0.0283
VI	1	21.8	212	0.1453
	2	31.1	227	0.1671
	3	42.9	214	0.1482
		$\overline{x}$	218	0.1535
		S_x	8.1	0.0118

1. Average of all readings (21).

$\overline{x}$	208.8	0.1427
S_x	18.6	0.0240

$\overline{x} \pm S_x$ = 190.2 to 227.4

2. Considering all values within these limits (17).

$\overline{x}$	216.4	(Omitted)
S_x	9.0	

$\overline{x} \pm S$ = 207.4 to 225.4

3. Considering all values within these limits (12).

$\overline{x}$	218.6	0.1550
S_x	4.7	0.0068

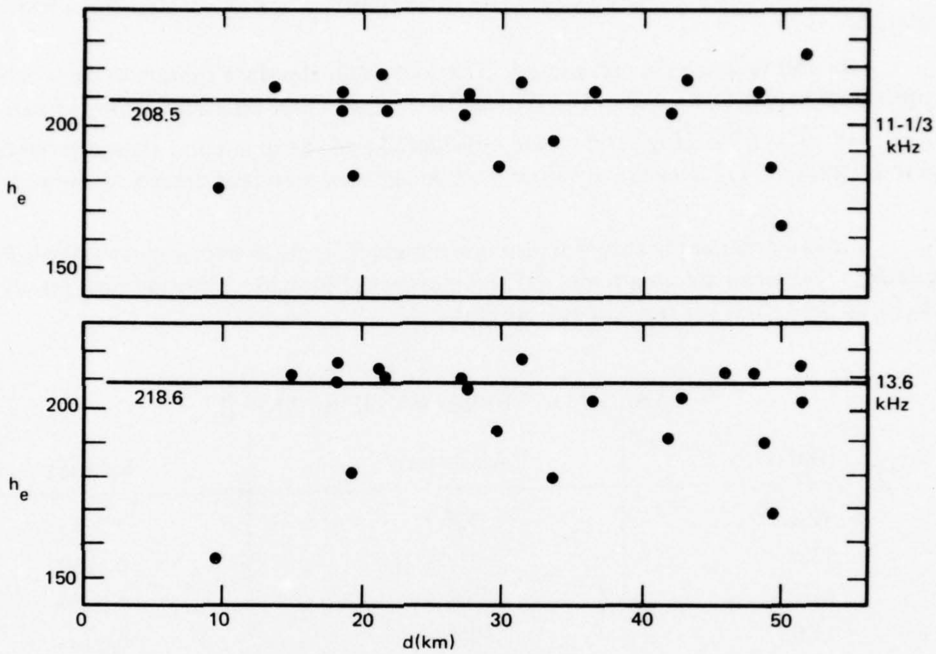


Figure 2. Effective height vs. distance.

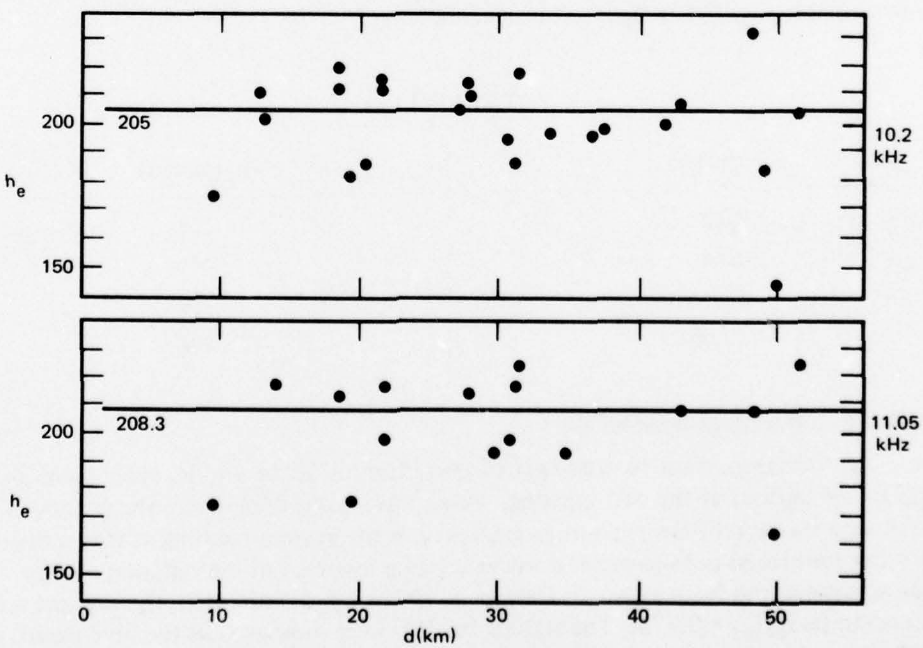


Figure 3. Effective height vs. distance.

3. Refinement of the values of effective height and radiation resistance was done in three steps.

a. All values were considered. The mean and standard deviation were calculated. All individual values farther than the standard deviation from the mean were thrown out.

b. The remaining values were considered and the mean and standard deviation were re-calculated. Once again all values outside the new standard deviation were thrown out.

c. The remaining values were considered. The mean and standard deviation were calculated. The mean values are plotted and shown as Figure 3. They are also tabulated in Table 11 as the values for the Norway Antenna.

TABLE 11a. SUMMARY OF h_e AND R_r

f(kHz)	h_e(metres)	R_r(ohm)
10.2	204.7	0.0765
13.6	218.6	0.1550
11-1/3	208.5	0.0979
11.05	208.3	0.0930

d. The above refinement procedure indicates no significant change of mean with sample size. The standard deviation is approximately 5 metres, and therefore the values of h_e to permissible significant figures are the following:

TABLE 11b

f(kHz)	h_e (metres)
10.2	205
13.6	219
11-1/3	209
11.05	208

Figure 4 shows the results graphically.

e. It is important to note that all these figures for h_e and R_r refer these characteristics to the current at the exit bushing. Since there is significant shunt capacity in the helix house, a fraction of the current as measured at the system feed point (the matching transformer terminals) goes to ground without being involved in the radiated energy. This fraction was measured both at North Dakota in 1972 and at Norway in the present series and found to be $I_a/I_{as} = 0.975$. The figures for R_{as} were measured at the feed point, not the bushing, and in consequence when calculating the antenna system efficiency the figures for R_r in tables 7 through 11 must be referred to the same point by multiplying them by $(I_a/I_{as})^2 = (0.975)^2 = 0.951$

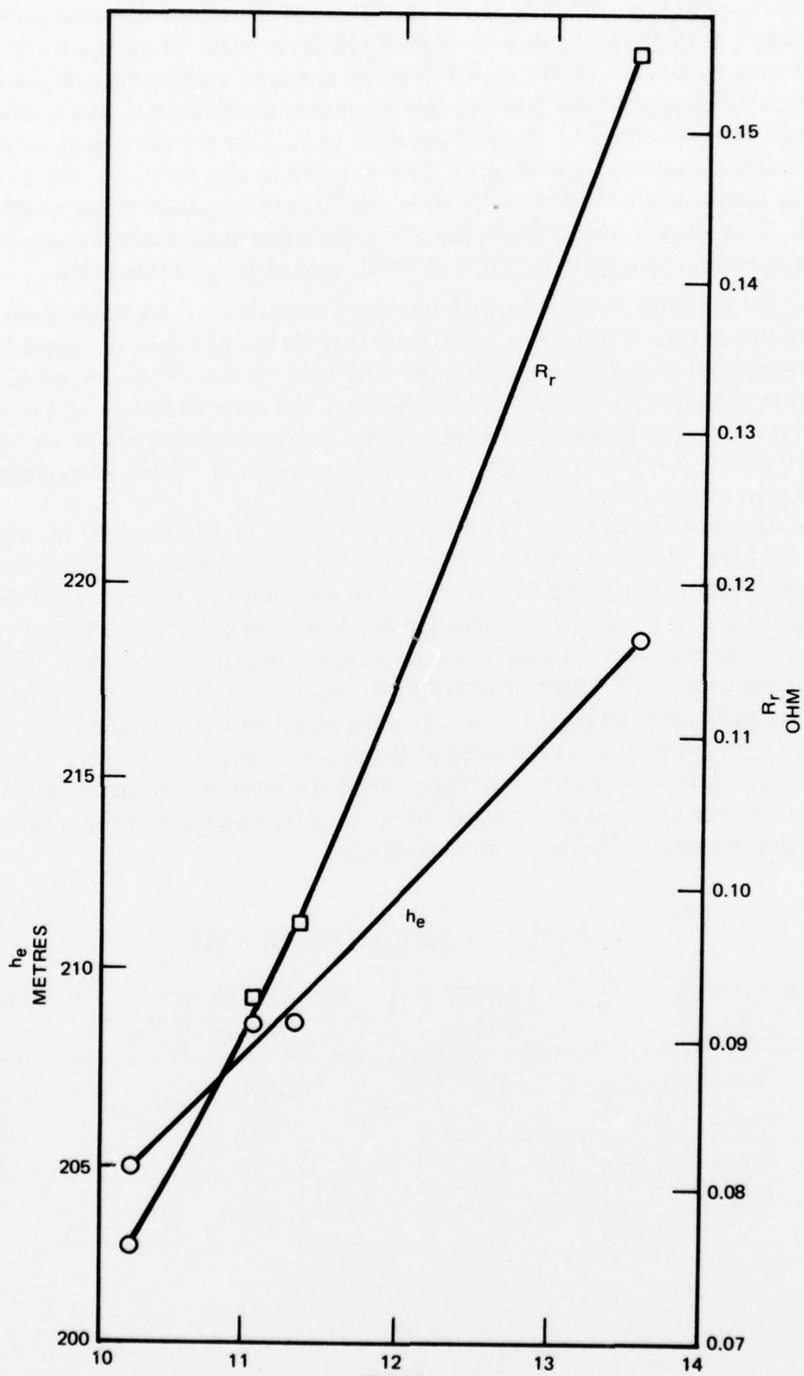


Figure 4. Effective height vs. frequency for 1975 (intermediate) elevation.

IV. VARIATION OF EFFECTIVE HEIGHT WITH PHYSICAL HEIGHT

A. During a portion of the early bench mark calibration tests comparison measurements were made of the total field versus span location as related to winch position. Readings were taken with the antenna at its highest (1973) position at 10.2, 11-1/3, 13.6 kHz. The spans were then slacked off two winch turns at a time, and readings repeated at 10.2 kHz for each position until the position corresponding to 1975-1977 was reached, for simplicity taken to be 12 turns, or the average of 14 and 10 for the two spans separately. The full set of three frequencies was used for field strength at this position. The lowering process was then continued until the payout was 22 turns, corresponding roughly to 70 feet of payout. This was the lowest limit, and it was determined by the minimum bending radius for one of the current jumpers attached at the downlead-to-span junctions.

B. The readings were taken with reference to antenna current and then normalized to constant current for comparison. The results are shown in Figure 5, where 100% or unity effective height (relative) is taken as that for 10.2 kHz for the 1973 configuration. The ratios used in subsequent calculations are read from the smooth curves for the Tomma observations only. The Hestmandoen figures show some inconsistency in the relationship between 10.2 and 13.6 to 11-1/3, and were therefore ignored. Table 12 summarizes the results in terms of numerical values for effective height.

An interpolated figure of 188.5 metres would be surmised for the lowest elevation at 11.05 kHz. However, in view of the variance of ±5 metres calculated for the results based on observed scatter in the data it cannot be said that the difference in effective height in the range 10.2 to 11-1/3 kHz is defensible as a real observed effect, although on the other hand it is unlikely that there is a discontinuous change in effective height in going from this range of frequencies to 13.6 kHz. Therefore the continuous values shown versus frequency appear to be reasonable. This is reinforced by the trend with height and frequency directly observed on the continuous run obtained at the project site in one three-hour period. The slight increase in effective height with frequency is also expected from the way in which charge tends to concentrate more toward the span ends at high elevation as the operating frequency rises toward the self-resonant frequency.

TABLE 12. EFFECTIVE HEIGHT

FREQUENCY kHz	LOWEST -22 turns	INTERMEDIATE -12 turns	HIGHEST 0 turns
10.2	187	205	229
11.05	–	208	231
11-1/3	189	209	233
13.6	197	219	242

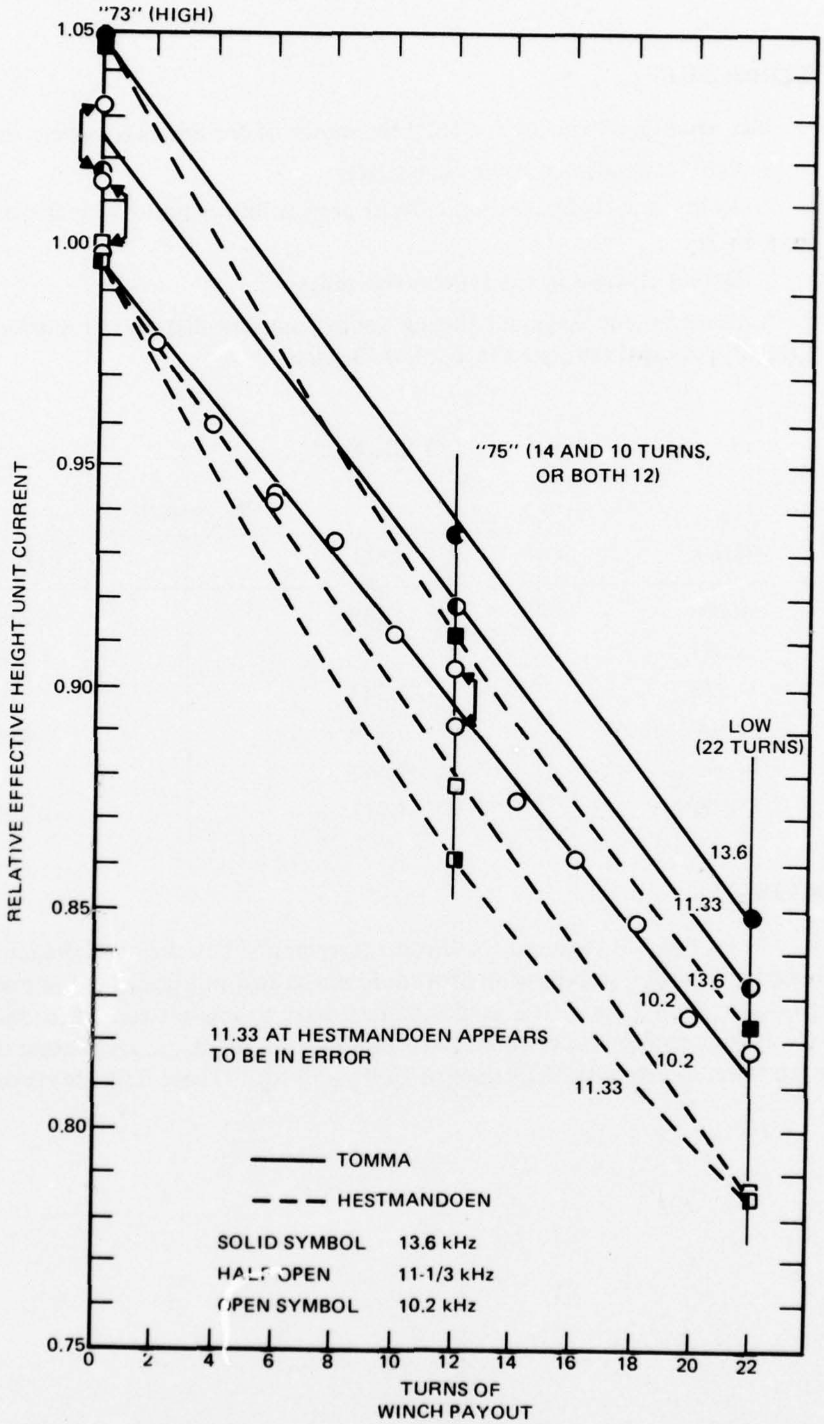


Figure 5. Relative effective height from bench mark measurements.

V. ANTENNA SYSTEM RESISTANCE

A. INTRODUCTION

1. It is necessary to know the total resistance of the antenna system in order to:

a. Correctly terminate the transmitter.

b. Determine the maximum current permissible as limited by the transmitter output capability

c. Detect changes in the station efficiency.

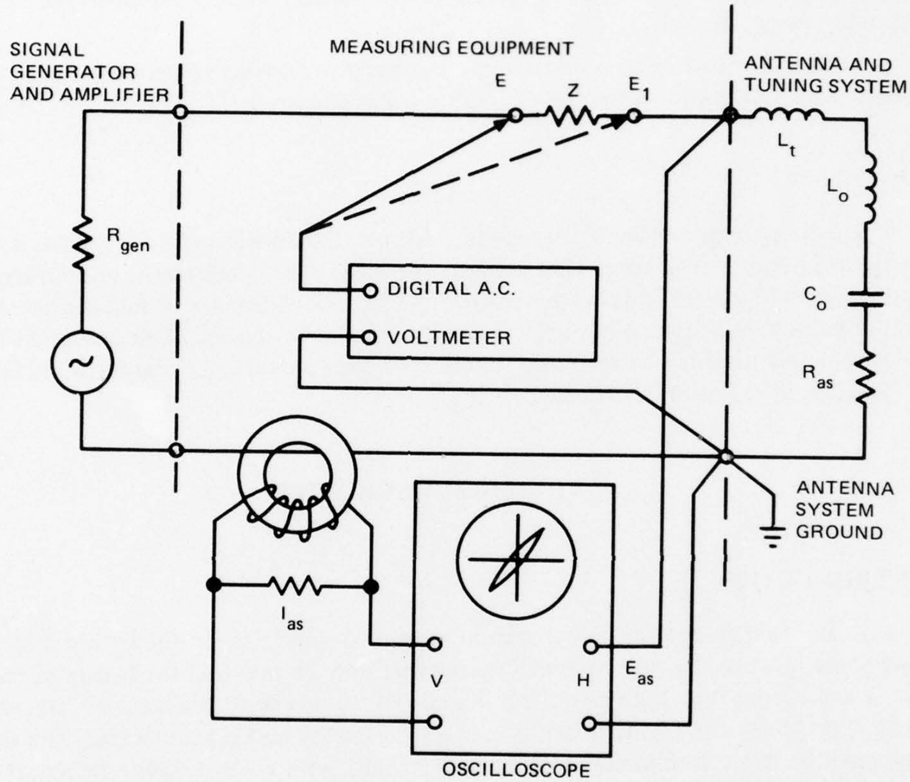
2. A measurement was made during the original installation as reported in Megatek Report LR2001-16[2] and tabulated in Table 13 under "1973".

TABLE 13

f (kHz)	R_{as} (ohms)	
	1973	1977
10.200	1.249	1.216
11.091		1.289
11.333	1.345	1.310
12.100	1.418	1.374
12.350	1.440	
13.600	1.572	1.518

B. PROCEDURE

1. The equipment required for this measurement, the schematic diagram of the instrumentation, and the step-by-step procedure are shown in Figure 6. If a good non-inductive resistor is used for Z, it may not be necessary to include the inductance in the value of Z. It is normally proper to make several measurements, re-resonating the antenna system each time, to establish the values of E, E_1 and R_{as}. These data are recorded on Data Sheet 2.



1. Select Z approximately equal to R_{as} (estimated).
2. Set the generator to the frequency of measurement.
3. Tune the antenna to resonance as indicated by zero (0) degrees phase angle between I_{as} and E_{as}.
4. Adjust antenna current (I_{as}) to the maximum value allowable through Z.
5. Measure E and E_1.
6. Solve for: $\frac{E_1 Z}{E - E1} = R_{as}$

Figure 6. Incremental voltage method for antenna system resistance (R_{as}).

C. RESULTS

1. The value of R_{as} for each frequency is taken from Data Sheet 2 and tabulated in Table 13 under "1977".

2. It will be noted that the mean decrease in R_{as} is 3%. This may be due in part to the weather which was warm and rainy for 1977. In 1973 the weather at the time of measurement was colder and drier. The most significant factor is likely the difference in effective height (see D, below).

3. It is comforting to note that good correlation exists between the two sets of measurements and that no apparent degradation has occurred.

D.

The measurements were not repeated for other than the 1975-77 condition because time did not permit. It is noted that most of the difference between the gross resistance as measured in 1977 and 1973 is accounted for by the 25% difference in radiation resistance expected from the difference in physical heights for the two years. This is evident from the ratio of effective heights observed as a function of span payout, and the resulting (square law) variation in radiation resistance.

VI. BENCH MARK SITES

A. INTRODUCTION

1. In order to determine the station output at some time in the future it is necessary to have some locations known as bench marks that may be revisited for taking of measurements. Calculations may then give the radiated output power of the station. The two most important features of the benchmark sites are accessibility and repeatability. The sites chosen must be likely to remain unchanged, especially with respect to the electrical environment, for the foreseeable future.

2. All measurements made to verify the output power of the station were taken at an altitude of at least 800 feet above the terrain. A sufficient number of measurements at the bench mark sites must be made to allow calculation of the ratio of ground based values to the airborne values. This ratio constitutes the bench mark calibration. Future variation in radiated field versus antenna current can then be directly related to observations at the bench mark site.

B. SITE LOCATION

1. Several attempts were made to establish bench mark locations on the mainland adjacent to the station. The terrain limits the number accessible either on foot or by vehicle. All of these sites failed the basic visual and electrical (null direction and/or depth) test for acceptability, in part because of presence of nearby power lines.

Two island sites were chosen, one generally to the northwest (Hestmandoen) and the other generally to the southwest (Tomma). They both are accessible by small boat and

Tomma is on a regular ferry route. Each requires considerable travel on foot to reach the designated site. The site locations are indicated below:

a. On the northeast part of the island of Tomma is a spit of land named Kyrhaugen. On the highest point of the most northerly part of this spit is a rock pyramid. The loop antenna was set up within 5 metres of this pyramid. The geographic coordinates are Latitude 66° 17′ 38″ N and Longitude 12° 52′ 25″ E. The distance to the exit bushing of the helix house is 18.8 km. See figure 7.

b. On the eastern part of the island of Hestmandoen near a rock with a red "x" painted on it. This rock will become a permanent marker of the NGO. The geographic coordinates are Latitude 66° 32′ 39″ N and Longitude 12° 52′ 51″ E. The distance to the exit of the helix house is 18.25 Km. See figure 8.

2. Of the two sites Tomma is the better. The null is deep, better than 40 dB, and points directly to the antenna. The null on Hestmandoen is deep but the orientation is to the left 5 to 10 degrees. Moving the loop around did not change the orientation or depth of null. Hestmandoen was retained because there were no other good sites from which to choose. Since the measurements were consistent the site should be of value. Moreover it is close to the present monitor site for the station, i.e., within 2 km by road.

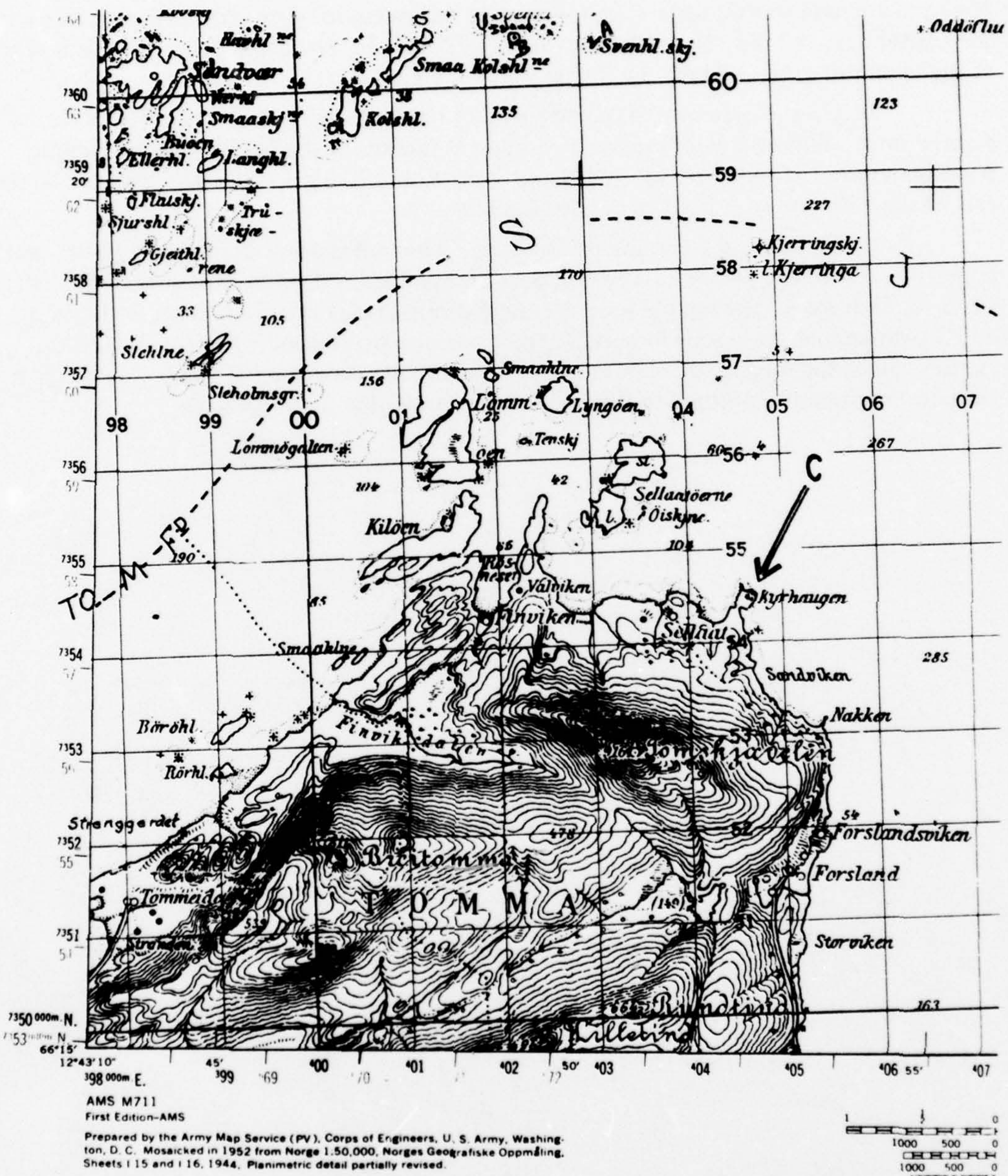


Figure 7. Tomma bench mark site indicated on a portion of the 1:50000 scale map AMS series M711, 1827 I, Luröy, Norway.

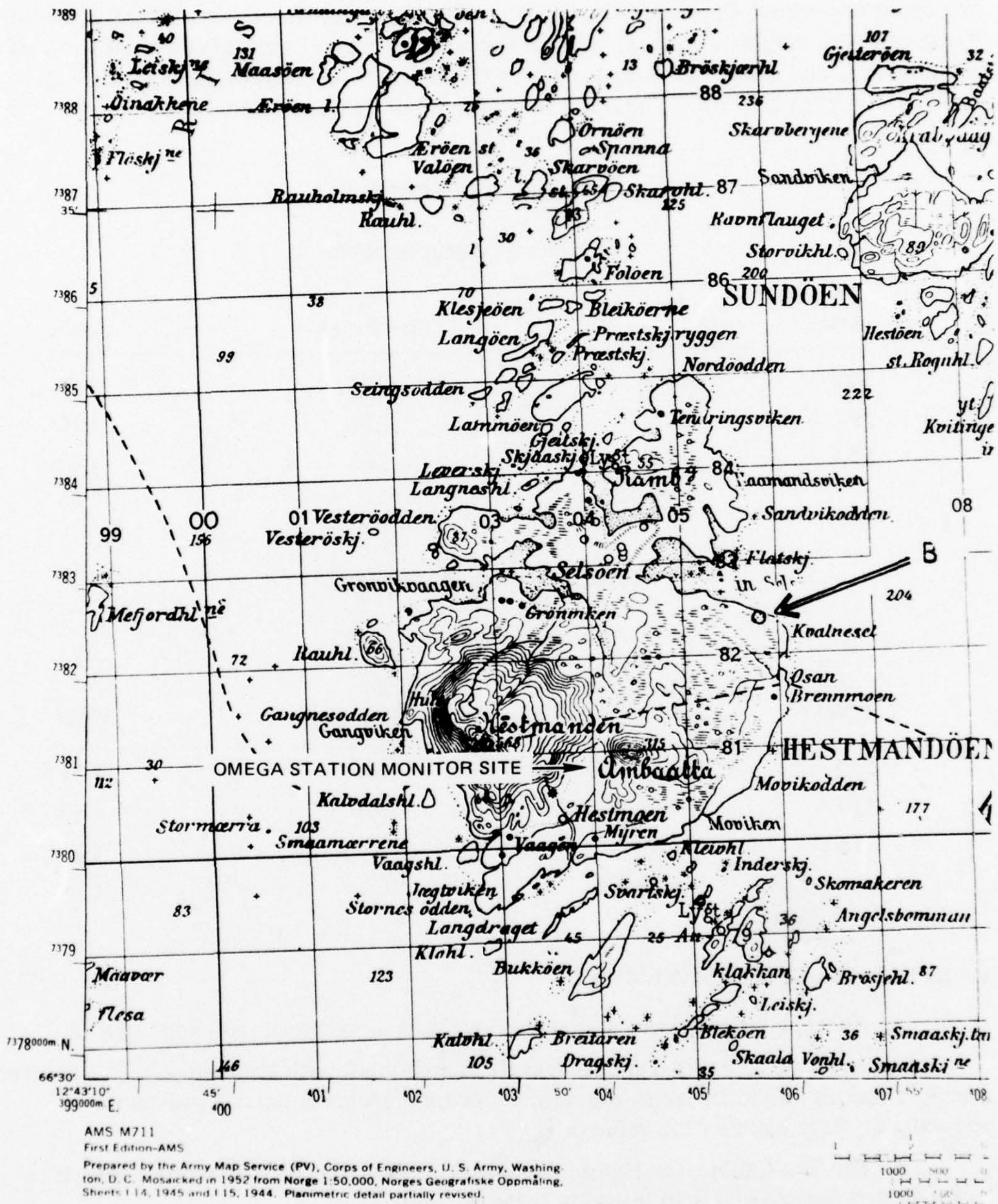


Figure 8. Hestmandoen bench mark site indicated on a portion of the 1:50000 scale map AMS series M711, 1828 II, Rödöy, Norway.

C. SITE CALIBRATION

Several measurements of field intensity for each frequency were made, with the loop at the bench mark location, using the substitution method of Appendix C. The data were processed to produce the effective heights for the values measured, as outlined in section These effective heights were compared to the mean effective heights calculated from all the airborne data and a ratio for each frequency obtained. The mean of these ratios is the calibration factor for that site. These ratios are shown in Tables 14 and 15.

TABLE 14. TOMMA

Benchmark Calibration, Ratio

f (kHz)	h_e (All sites)		h_e (Benchmark)		Ratio
10.2	204.7	÷	174	=	1.18
11-1/3	208.5	÷	179	=	1.16
13.6	218.6	÷	182	=	1.20
	Mean Ratio		$\overline{x}$	=	1.18

TABLE 15. HESTMANDOEN

Benchmark Calibration, Ratio

f (kHz)	h_e (All Sites)		h_e (Benchmark)		Ratio
10.2	204.7	÷	164	=	1.25
11-1/3	208.5	÷	161	=	1.30
13.6	218.6	÷	169	=	1.29
	Mean Ratio		$\overline{x}$	=	1.28

D. BENCH MARK MEASUREMENTS

1. Antenna current is measured and logged in accordance with appendix D.

2. The loop antenna is set up near the bench mark with the center height approximately 2 metres. Field Intensity Measurements are made by using the procedure of appendix C. This will give the value of E_g.

3. The Site Calibration Ratio is used as K_3. (K_3 was the helicopter calibration factor during the original field intensity measurements.)

4. The calculation of the measured total field is performed: $E_m = E_g K_2 K_3$

5. E_r, P_r, h_e and R_r are calculated by using appropriate equations from appendix B.

6. These values may now be compared with data measured during the summer of 1977 and tabulated in Section III of this report.

VII. BRATLAND ANTENNA CONFIGURATION SURVEY

A. As a portion of the Bratland Omega Station evaluation, it was proposed to sight elevations and azimuths from opposite ends of a new baseline (to be established) to each of several principal points of each span and downlead of the Bratland antenna. Sufficient information was generated from this survey to permit determination of span and downlead geometry, in particular the span clearance to the water as a function of payout and winch tension. The new reference baseline was defined by a point on the grade immediately west of the transmitter building and a second point on the large prominent rock lodged at the shoreline approximately 450 metres southeast of the helix house.

After establishing point A with reference to the transmitter house, azimuths and elevations from point A were measured to the following listed points on each of spans 1 and 3:*

1. Highest point of large rock on shoreline as above mentioned, and sea level intersection with shoreline;
2. To topmost point of anchorage tower on Aldertind;
3. To east end of western insulator, i.e. center pin of "hot" end bridle;
4. To west end of vibration damper clamp for damper "X", approximate span low point;
5. To center upper hole of plate linking the two parts of the main spans;
6. To west end of eastern insulator, i.e. center pin of "hot" end bridle;
7. Entry of haulage line item 56 into sheave housing on Liatind;
8. Downlead hinge point;
9. Top of bushing hardware.

The instrument was then set up at point B, a point on the rock. Reverse azimuth and elevation were taken on point A. Then all azimuth and elevation measurements were repeated for all points on both spans called out above.

The baseline between Aldertind anchorages was used as reference to locate the new baseline between points A and B, using the angles sighted. Elevations were calculated to the various points mentioned on the spans from the ends of this baseline with reference to the tilted plane containing the line, and afterward were corrected to mean sea level.

The procedure was done for both "73" and "75" condition. These conditions were maximum and intermediate span clearance, respectively, determined by number of turns paid out by the haulage winch. It had been intended to repeat the sights for the lowest permissible position, but time and weather did not permit.

B. Figures 9 through 12 give a self-contained description of the site geometry and new baseline location, the method for calculating the baseline length and elevation, the locations of the cardinal points of the spans in terms of the visual sightings and the baseline geometry, and finally the determination of the grid coordinates of the baseline end points from the sight angle and the locations of the Aldera anchorages assumed to be accurately located in previous surveys. Tables 16a, b, and c give the numerical results. It can be seen that the NOSC survey of 1977 agrees well with the previous work, except that there is a significant

*The span numbering is from south to north, spans one and three being the only ones installed. Span 2, the center span, was never raised as the system attained sufficient effective height and capacity to meet bandwidth and voltage requirements without it.

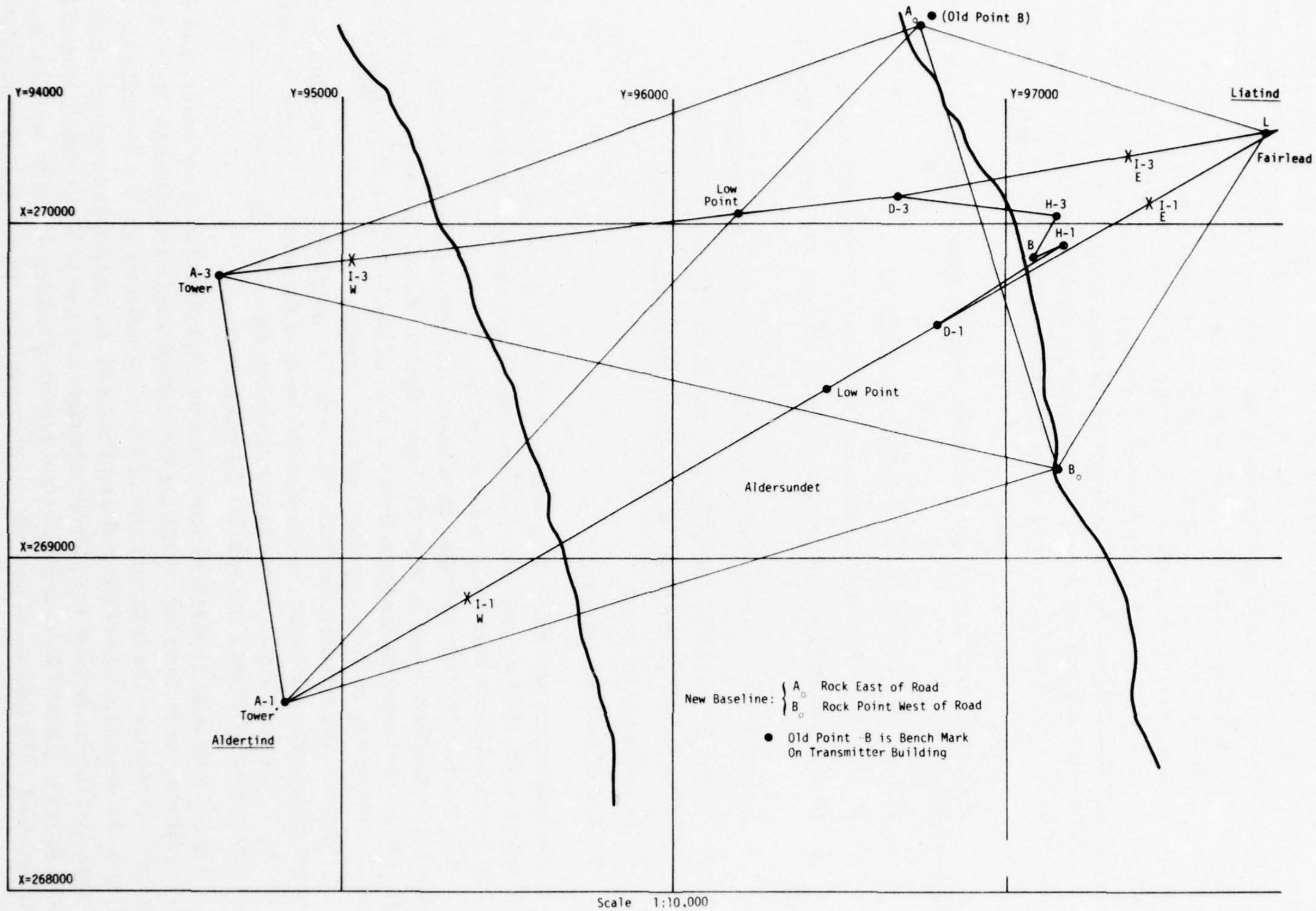
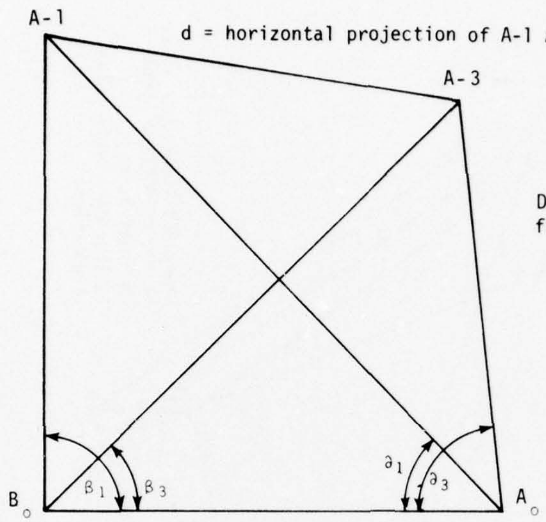


Figure 9. Plan of Bratland antenna 1977.

d = horizontal projection of A-1 A-3 = 1287.99 m



Determination of new Baseline from sight angles to old.

$\partial_1 = 60.6713° \pm 0.0033°$

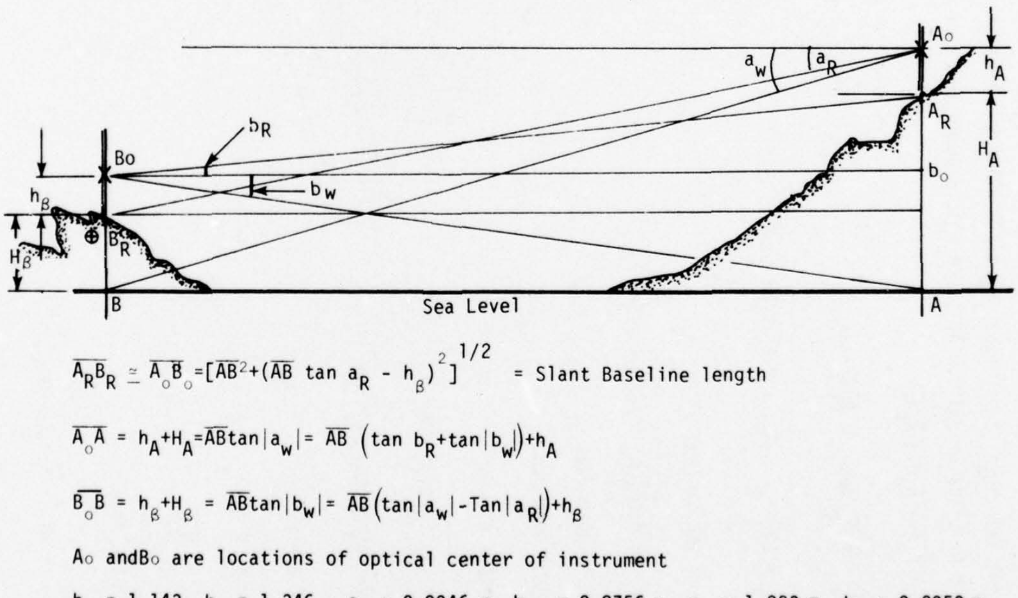
$\partial_3 = 89.8571° \pm 0.0009°$

$\beta_1 = 89.3744° \pm 0.0031°$

$\beta_3 = 59.8365° \pm 0.0042°$

$$\overline{AB} = d\left[\frac{\sin^2\beta_1}{\sin^2(\partial_1+\beta_1)} + \frac{\sin^2\beta_3}{\sin^2(\partial_3+\beta_3)} - 2\,\frac{\sin\beta_1\sin\beta_3\cos(\partial_3-\partial_1)}{\sin(\partial_1+\beta_1)\,\sin(\partial_3+\beta_3)}\right]^{-1/2}$$

= horizontal projection of A_oB_o = 1385.61+0.5



$\overline{A_RB_R} \simeq \overline{A_oB_o} = [\overline{AB}^2 + (\overline{AB}\tan a_R - h_\beta)^2]^{1/2}$ = Slant Baseline length

$\overline{A_oA} = h_A + H_A = \overline{AB}\tan|a_w| = \overline{AB}\left(\tan b_R + \tan|b_w|\right) + h_A$

$\overline{B_oB} = h_\beta + H_\beta = \overline{AB}\tan|b_w| = \overline{AB}\left(\tan|a_w| - \tan|a_R|\right) + h_\beta$

Ao andBo are locations of optical center of instrument

$h_B = 1.143$, $h_A = 1.346$ $a_R = 0.9946$ g $b_R = 0.8756$ g $a_W = 1.223$ g $b_W = 0.2950$ g

Figure 10. Baseline geometry including determination and cross checking for consistency of sighting points height above sea level, locations of baseline and end points, and slant length.

$\partial_1, \partial_3, \beta_1, \beta_3, \varepsilon_{d_1}, \varepsilon_{\partial_3}, \varepsilon_{\beta_1}, \varepsilon_{\beta_3}$ are observed traverse and elevation angles relative to baseline projection $\overline{AB}$ (or $B_o b_o$), assumed to be at sea level.

(1) $\overline{a_o B_o} = \overline{A_o A} - \overline{B_o B} = \overline{A_o b_o}$

(2) $\overline{A_o' b_o} = \overline{a_o B_o}/\tan\varepsilon_2 = \overline{B_o a_o}/\tan\varepsilon_\partial$

(3) $\overline{A_o' B_o} = [\overline{A_o' b_o}^2 + \overline{AB}^2 - 2\,\overline{A_o' b_o}\,\overline{AB}\cos(130° - \partial)]^{\frac{1}{2}}$

(4) $\sin\partial' = [\overline{AB}\,\sin(180 - \partial)]/\overline{A_o' B_o}$

$\sin(\beta' - \beta) = [\overline{A_o' b_o}\,\sin(180 - \partial)]/\overline{A_o' B_o}$

(5) $\cos\partial'' = \cos\partial' \cos\varepsilon_\partial$

$\cos\beta'' = \cos\beta' \cos\varepsilon_\beta$

(6) $\gamma = 180 - \partial'' - \beta''$

(7) $\overline{B_o P} = [\overline{A_o' B_o}\,\sin\partial'']/\sin\gamma$

$A_o' P = [A_o' B_o \sin_{\beta''}]/\sin\gamma$

(8) $h' = B_o P \sin\varepsilon_\beta$

$h' = A_o' P \sin\varepsilon_\partial$

(9) $h = h' + \overline{B_o B}$

(10) $\overline{B_o P'} = h'/\tan\varepsilon_\beta$

$\overline{A_o P''} = [h' - \overline{A_o b_o}]/\tan\varepsilon_\partial$

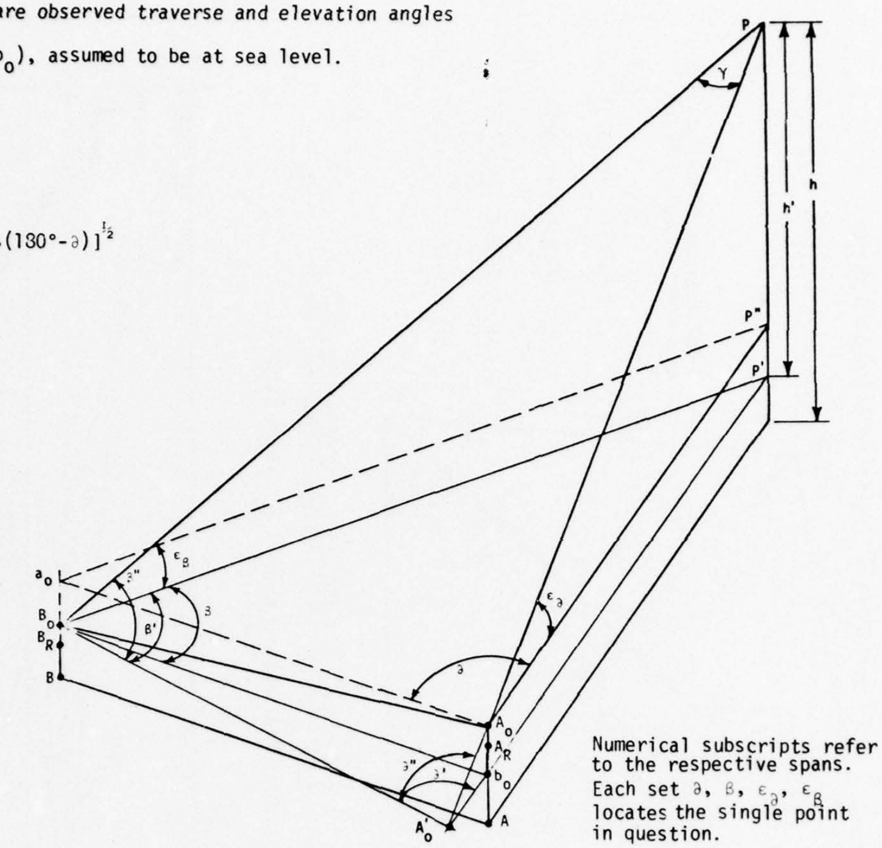


Figure 11. Reduction of baseline data to heights and projected distances.

$Y_A = Y_1 + \overline{1A} \cos(\varepsilon+\nu)$

$X_A = X_1 + 1A \sin(\varepsilon+\nu)$

$Y_B = Y_1 + \overline{1B} \cos \varepsilon$

$X_B = X_1 + \overline{1B} \sin \varepsilon$

$\nu = 180 - \partial_1 - \beta_1$

$\varepsilon = \tan^{-1}\left(\frac{X_3 - X_1}{Y_3 - Y_1}\right) - \rho$

$\rho = 180 - (\beta_1 - \beta_3) - (\sigma - \chi)$

$\sigma - \chi = \sin^{-1} \frac{\overline{1B}}{d} \sin(\beta_1 - \beta_3)$

$\overline{1B} = \overline{1A} \frac{\sin \alpha_1}{\sin \beta_1}$

$d = \left[(X_1 - X_3)^2 + (Y_1 - Y_3)^2 \right]^{1/2}$

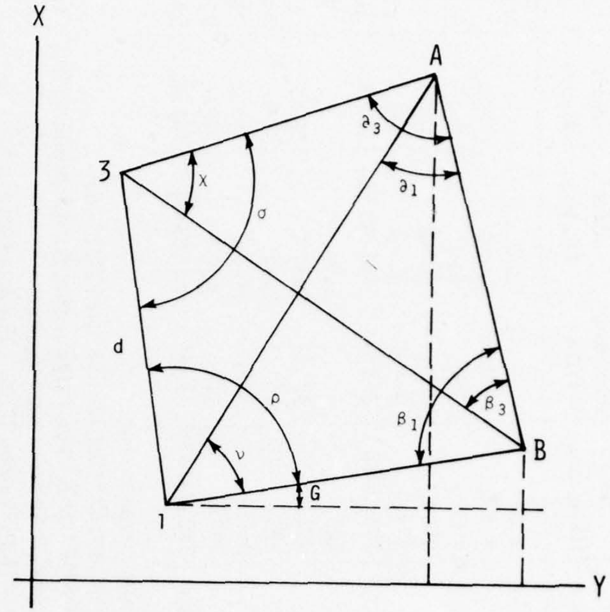
$= 1287.99$

$X_1 = 268{,}575.92$

$Y_1 = 94{,}829.03$

$X_3 = 269{,}847.74$

$Y_3 = 97{,}789.25$



$$\overline{1A} = \frac{d \sin(\partial_3 + \beta_3)}{\left\{ \sin^2(\partial_3 - \partial_1) \sin^2(\partial_3 + \beta_3) + \left[\frac{\sin \partial_1}{\sin \beta_1} \sin(\beta_1 - \beta_3) + \sin(\partial_3 - \partial_1) \cos(\partial_3 + \beta_3) \right]^2 \right\}^{1/2}}$$

Figure 12. Coordinates of new baseline endpoints from visual sights on applied anchorages.

TABLE 16a. OMEGA NAVIGATION STATION, BRATLAND, NORWAY, ANTENNA ELEVATIONS.

Year	Liatind Anchor	Liatind Insulator	Feed Connection	Approximate Low Point	Aldra Insulator	Aldra Anchor	Hinge
1968	–	664.	425.	–	502	–	116.
1969	887.3	656.9	412.4	372.3	492.3	732.9	–
1970	887.	658.	402.	380.	514.	730.	226.
1973	886.7	659.3	403.8	(380)	509.8	730.1	224.4
1975	886.7	638.6	374.6	344.6	489.0	730.1	220.5
1977	885.4	629.3/673.8	376.3/428.2	348.7/-	496.4/523.4	733.3/-	221.5/224.2
1968	–	668.	443.	–	479.	–	79.
1969	887.3	661.2	431.4	371.0	467.2	580.5	–
1970	887.	631.	392.	354.	461.	578.	230.
1973	886.7	637.1	395.0	(345)	463.1	578.0	228.3
1975	886.7	617.0	367.1	327.6	449.4	578.0	224.3
1977	886.8/-	626.5/652.6	372.1/413.9	331.4/	453.3/474.2	581.4/-	233.6/233.7

1) All elevations are in metres above mean sea level
2) 1968 elevations based on Tron Horn Drawing 228-208 dated 29/2 – 68
3) 1969 elevations based on NORD-NORSK Oppmaling Drawing dated September 1969
4) 1970 elevations based on Holmes & Narver antenna design
5) 1973 elevations based on Tron Horn Drawing 228X – 78A dated 9/17 – 74
6) 1975 elevations based on Tron Horn Drawing 228X – 107 dated 5/8 – 75
7) 1977 elevations for ("1975" Tension)/("1973" Tension), based on NOSC Survey 07/21-25/77, referred to mean sea level for the 3 separate observations. Accuracy is ± 0.5 metre

TABLE 16b. HORIZONTAL PROJECTIONS OF SPAN CHORDS.

Year of Survey	Span 1 (A-1 to L)	Span 3 (A-3 to L)	A-1 to A-3	A_0B_0
1968/1969	3412.53	3192.63	1287.99	–
1973/1975	3413.34	3193.96	–	–
1977	3413.8	3192.4	–	1385.61

TABLE 16c. BASELINE COORDINATE LOCATIONS

POINT		GRID COORDINATES 1968/1969	GRID COORDINATES 1977 (accuracy ±0.5 metres)
A-1	H	732.9	733.3
	Y	94829.03	–
	X	268575.92	–
A-3	H	580.5	581.4
	Y	94625.24	–
	X	269847.74	–

TABLE 16c. (Continued)

POINT		GRID COORDINATES 1968/1969	1977 (accuracy ±0.5 metres)
L	H	887.3	886.1
	Y	97789.25	97797.47
	X	270273.60	270271.69
A	H		26.3
	Y		96742.4
	X		270585.7
B	H		6.90
	Y		97149.6
	X		269260.98

and unexplainable difference between the elevations of the spans in 1973 and in 1977 in the so-called 1973 configuration (0 turns of payout from maximum tension). The 1975 configuration is the intermediate elevation determined by paying out 14 turns for span 1 and 10 1/2 turns for span 3; for simplicity the 1977 equivalent was taken to be 12 turns for both. The lowest position was determined by the permissible bend imposed on one of the downlead power bond connectors, and this turned out to be 22 turns of payout, for both spans.

C. Tables 17a through d are a compilation of sight angles from the two end points of the new baseline to the cardinal points of the spans. These are furnished for reference in the event that future changes in span configuration require comparison with the old. It can be seen that in the ranges of span changes observed in the present work, the elevation angles are very nearly proportional to the absolute elevations of the spans over the water. Since effective height change is nearly proportional to span elevation change, it follows that the elevation angles provide a ready index of relative antenna performance, e.g. efficiency.

Also herewith supplied is a set of 12 photographs, Appendix H, the first six of which give the visual definitions of the extremities of the new baseline. The second set of six shows the two bench mark sites for field strength measurements that were established for future reference.

TABLE 17a. TRAVERSE ANGLES TO BRATLAND ANTENNA REFERENCE POINTS LOOKING FROM BASELINE POINT A. ALL ANGLES IN GRADS.*

POINT	Span 1	Span 3
Aldera Anchorage	67.413	97.621
Bushing	-9.267	–
Liatind Anchorage	-62.347	-62.630

*1 grad = 0.9 degree

TABLE 17a. (Continued)

POINT	Intermediate	High	Intermediate	High
West Insulator	62.350	62.225	94.745	95.000
Low Point	35.476	–	67.533	–
East Insulator	-37.767(?)	-41.151	-44.642	-45.551
Downlead Link	14.217	13.248	24.974	23.789
Downlead Hinge	-18.227	-17.831	-20.013	-18.307

All angles ±0.005 grad

TABLE 17b. TRAVERSE ANGLES TO BRATLAND ANTENNA REFERENCE POINTS LOOKING FROM BASELINE POINT B. ALL ANGLES IN GRADS.

POINT	SPAN 1		SPAN 3	
Aldera Anchorage	99.306		66.484	
Bushing	-10.928		–	
Liatind Anchorage	-55.111		-54.988	
	Intermediate	High	Intermediate	High
West Insulator	94.381	94.263	62.781	62.701
Low Point	59.305	–	37.161	–
East Insulator	-40.670	-41.564	-32.189	-33.010
Downlead Link	22.506	20.851	13.127	12.346
Downlead Hinge	-21.771	-21.293	-18.307	-18.307

TABLE 17c. ELEVATION ANGLES TO BRATLAND ANTENNA REFERENCE POINTS LOOKING FROM BASELINE POINT A. ALL ANGLES IN GRADS.

POINT	SPAN 1		SPAN 3	
Aldera Anchorage	15.930		15.517	
Bushing	-0.513		–	
Liatind Anchorage	42.360		42.416	
	Intermediate	High	Intermediate	High
West Insulator	13.408	14.230	14.291	14.929
Low Point	17.922	–	24.135	–
East Insulator	39.353	40.745	44.102	45.230
Downlead Link	24.053	27.406	38.424	42.209
Downlead Hinge	15.37	15.630	17.969	18.350

TABLE 17d. ELEVATION ANGLES TO BRATLAND ANTENNA REFERENCE POINTS LOOKING FROM BASELINE POINT B. ALL ANGLES IN GRADS.

POINT	SPAN 1		SPAN 3	
Aldera Anchorage	18.650		13.963	
Bushing	+1.425		–	
Liatind Anchorage	40.443		40.339	
	Intermediate	High	Intermediate	High
West Insulator	16.650	17.647	12.580	13.051
Low Point	27.750	–	16.675	–
East Insulator	40.861	41.885	36.536	32.612
Downlead Link	37.124	40.989	23.516	26.075
Downlead Hinge	19.889	20.162	19.000	18.710

VIII. GROUND SYSTEM INSPECTION AND OTHER TESTS

A. A part of the scope of work for NOSC was to be an examination of the ground system, as well as other physical aspects of the installation, in particular the geometry of the downlead system and its possible relation to the loss budget. These questions were addressed during the trip to the site in July, with the following observations:

1. While the E-field ground losses associated with the present low dog-leg configuration for the downlead are significant, a change to a more vertical orientation for the lower portion probably will not reduce them sufficiently to raise transmitter-limited radiated power to ten kilowatts without also raising the spans.

2. Improvement in effective height by probable allowable downlead straightening will be slight, at most 5 to 10 metres, and this also will be insufficient to permit ten kilowatts radiated power without also raising the spans.

3. The loss budget change associated with removing the original inner overhead ground system built in 1966 and retaining the then-radius of 250 metres was analyzed in great detail during design and afterward as a result of measurements made in August 1969, and at that time the conclusion was that significant reduction in ground system losses would only be achieved by increasing the radius to 400 metres, which was deemed too expensive to be practical, and by improving the terminations of the wires to the rock. The loss budget was determined to be tolerable by providing an improved helix, which was done. Apparently there has been little change since the final installation in which the 250 metre radius was retained and the entire ground system was placed in or on the ground.

4. There are details of conditions that should be attended to, which will yield perhaps as much as 0.05 ohm reduction in ground loss. The wires have stretched and slid away from their ideal equally spaced condition, and this should be remedied, especially where easily accessible between the road and the rock shield above the exposed rock slab east of the road. It would be of some value to double up the number of radials between the helix house peripheral bus and the first peripheral cross connection where the old elevated system was terminated. The number of cross connections between the buses along the road shoulder should be increased, and a greater number of sea terminations should be used. The condition of the sea terminations where observed appeared to be satisfactory.

B. Since desired performance can be obtained by raising the spans to their originally intended (1973) position, no significant change in downlead configuration other than that attendant upon the span raising is recommended. Detailed improvements in the ground system such as those outlined in paragraph A4 above are recommended as low-level effort carried out in conjunction with a fairly careful maintenance program.

C. As a portion of the intended series of tests at Bratland, the motion of the individual variometer drive trains to correct antenna tuning in response to a deliberately introduced antenna system capacity increment was to have been determined. The purpose of the test was to assure that the variometer motion is indeed in the right ratio to correct the reactance change (as a function of frequency) for a detuning occurring as a result of wind deflecting the antenna so that as the keyer steps from one frequency to the next during the transmitted format the auto-tune system is required to make as little further step changes in tuning as possible. The mechanical system that brings this about involves the use of sprockets with tooth ratios selected inversely to the frequency ratios. In actual installation, the ratios selected were not necessarily optimum, and it was desired to test whether further optimization was necessary (or even possible) with the sprockets available on site.

In actually performing the test sequence, actual use of the 12.1 kHz unique frequency could not be made at the time, and the material available for making the incremental capacitor had to be obtained locally and assembled by one of the station technicians using insulators that were suitable for use only in dry weather. When the tests could be scheduled in relation to other ongoing work, the weather turned cold and very wet, prohibiting safe use of the incremental capacitor on the roof of the helix house where it had to be installed in a high voltage environment. It was therefore decided to delete the tests, especially in view of the observation during previous system operation that the tuning system motion indicated near-optimum selection of the gear ratios.

Details of the procedure to be used in the gear ratio test are given in Appendix F. This same procedure is to be used at the other Omega stations.

IX. ANTENNA PERFORMANCE

A. With the effective height values of Table 11b and Figure 5 (or equivalently Table 12) turned into radiation resistance referred to the feedpoint as before discussed, the gross resistance values of Table 13 can be used to develop the efficiencies of Table 18, below. Because of the scatter in effective height it is not useful to retain more than two significant figures in the tabulation. Assuming full transmitter power of 150 kW delivered to the gross resistance as seen at the feed point at the matching transformer terminals, the antenna current maxima can be inferred to be the values indicated, and the values for radiated power then follow.

The voltages on the antenna at the top of the bushing are calculated by using the reactances appropriate to the base capacities observed there as given in Table 1. The final column in Table 18 shows these voltages. The approximate voltages on the span tips corresponding to these base voltages can be computed from the reactance of the static capacity multiplied by the antenna current supplied at the top of the bushing. The difference between base and span tip voltage is the "rise" on the antenna structure. In this case all such differences are small, in the worst case, 13.6 kHz, being at most 25%.

It is noted that only the voltage corresponding to the intermediate, or 1975, position is given, as the small changes in current required for maintaining 150 kW delivered almost compensate for opposite changes in reactance as the antenna configuration is changed. It can be seen that in no case is the insulation limit, nominally 250 kV on the bushing and 220 kV on the spans, ever even closely approached. The system is clearly transmitter power limited.

B. A detailed calculation of power performance comparisons is shown in the summary below.

1. Examination of this 10.2 kHz summary shows that the antenna at the 1975 height can radiate approximately 9 kilowatts. If the antenna is raised to a level of -6 sheave turns from the 1973 level it would be possible to radiate 10 kilowatts with no reserve for degradation of the antenna or transmitter. If the antenna be raised to its 1973 height (original design) this will allow for some degradation of both the antenna and the transmitter while maintaining the required 10 kilowatts of power radiated on 10.2 kHz.

TABLE 18. BRATLAND OMEGA ANTENNA OPERATING CONDITIONS.

f kHz	Condition	h_e m	I_{as}† A	R_r* ohm	R_{as} ohm	η_{as}**	P_r hw	V_b kV‡
10.2	L	187	354	0.059	1.20	0.050	7.40	
	I	205	351	0.072	1.21	0.059	8.85	141
	H	229	348	0.090	1.23	0.073	10.9	
11.05	L	188	354	0.071	1.270	0.056	8.9	
	I	208	341	0.086	1.288	0.067	10.0	127
	H	231	340	0.110	1.302	0.084	12.7	
11-1/3	L	190	339	0.077	1.295	0.059	8.85	
	I	209	339	0.093	1.310	0.071	10.7	119
	H	233	337	0.116	1.320	0.088	13.2	
12.1	L	192	333	0.089	1.352	0.066	9.87	
	I	212	330	0.109	1.374	0.079	11.9	108
	H	234	328	0.133	1.396	0.095	14.3	
13.6	L	197	317	0.125	1.489	0.084	12.6	
	I	219	314	0.152	1.518	0.10	15.0	88
	H	242	311	0.189	1.553	0.122	18.3	

*Normalized to feed point by (bushing current/feed current)^2 = $(0.975)^2$ = 0.951. This is because the derivation of h_e from measured field uses bushing current I_a as reference.

**$\eta_{as} = P_r/P_{as} = R_r/R_{as}$, where R_r is normalized to the same reference point current as is R_{as}. This is antenna system efficiency.

†I_{as} = feedpoint current as measured at the output terminals of the matching transformer by the toroidal current transformers. The figures for P_r assume approx 150 kW delivered by the transmitter into R_{as}.

‡$V_b = \dfrac{(I_{as})(0.975)}{2\pi f C_a}$, $I_a = I_{as}(0.975)$

C. A detailed calculation of power performance is shown in the summary below.

1. At 1975 height

a. Calculated R_r = 0.0765 ohm

b. For 10 kW radiated:

I_a = 361.6 A.

I_{as} = 370.8 A.

c. Using measured R_{as} = 1.214 ohms

166.9 kW Trans. output required for 10 kW radiated

d. Since $P_{out} \leqslant 150$ kW

$I_{as} \leqslant 351.5$ A.

$I_a \leqslant 342.7$ A.

e. This produces P_r = 8.98 kW maximum

f. For 10 kW radiated

$R_r \geqslant 0.0851$ ohms

2. Minimum height required

a. Ratio of h_e for new $R_r = \sqrt{\frac{0.0851}{0.0765}} = 1.055$

b. From measurements at Tomma.

h_e = 173 (1975 height)

× 1.055

h_e = 182.5

or −6 sheave turns from the 1973 height.

3. Original height (1973)

a. From measurements at Tomma.

$$\frac{h_e\,(1973) =}{h_e\,(1975) =} \left(\frac{194}{173}\right)^2 = 1.258$$

b. R_r (1975) = 0.0765

× 1.258

R_r (1973) = 0.0962

c. I_a (max) = $(342.7)^2$

R_r (1973) × 0.0962

P_r (1973) = 11.3 kW (max)

d. For 10 kW radiated

$$I_a = \sqrt{\frac{10{,}000}{0.0962}} = 332.4 \text{ A.}$$

$$I_{as} = \frac{322.4}{0.975} = 330.7 \text{ A.}$$

$$P_{out} = (I_{as})^2 R_{as} = (330.7)^2\ 1.214 = 132.8 \text{ kW}$$

X. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The present Bratland OMEGA antenna does not radiate 10 kW under a transmitter limitation of 150 kW.

2. The condition of the spans and of the ground system appears to be as good as can be expected under the climatic conditions common to the site.

3. The elevation of the spans back to their original configuration will permit 10 kW to be radiated within the limits of the present transmitter without further alteration or modification of the station in any way.

4. Under full power operation the voltages are at most 70% of the design limit, so that substantially increasing power output by providing more or bigger transmitters appears to be practicable, up to a limit of a factor of two.

5. The optical survey of antenna height as a function of winch payout agrees well with previous surveys.

B. RECOMMENDATIONS

1. The spans should be raised back to their full design height when a suitable fixed anchorage has been provided.

2. The ground system inner radials should be carefully repositioned to their intended equally spaced positions and should be doubled in number.

3. The sea connections should be regularly inspected (say every summer) and increased in number.

4. The newly established baseline should be used for an annual survey of antenna height.

5. The Tomma bench mark site should be used as the performance reference, and at least annually measurements from it should be made to coordinate with recheck of the antenna geometry.

6. Recommendations about tuning and matching the transmitter, and replacement of tubes have been made separately to ONSOD and should be observed.

7. Use of the optimum tap setting on the matching transformer should be routinely confirmed after recheck of base resistance characteristics, which should be made if any significant degradation of antenna performance is noted.

XI. REFERENCES

1. Swanson, E.R., J.E. Britt and J.J. Wilson of NELC and J.C. Hanselman of Megatek Corporation, "OMEGA Format Optimization," NELC TR 1966, 8 October 1975.

   Subject: Suggests addition of a fourth commutated frequency and deletion of transmissions at the second unique frequency.

2. Hanselman, J.C., "Antenna System Measurements, OMEGA Norway," Megatek Corporation LR 2001-16, 12 December 1973.

   Subject: Antenna Systems Measurements and Tuning System Installation Calculations.

XII. APPENDICES

APPENDIX A: ABBREVIATIONS

A	Amperes
Az	Azimuth angle, transmitter to measurement site
C	Capacitance
C_{app}	Apparent capacitance (antenna)
cm	Centimetre
d	Distance (km)
E	Potential (volts)
E_g	Output voltage, signal generator (mV)
E_m	Field Intensity, corrected for instrumentation (mV/m) (Loop and Vehicle Factors)
E_r	Radiation Field Intensity, corrected to remove Induction Field (mV/m)
f	Frequency
h_e	Effective height (metres)
Hz	Hertz
I	Current (amperes)
I_a	Current, Antenna, corrected for losses in Helix House
I_{as}	Current, Antenna System
in.	Inch
K_1	Ratio of I_a/I_{as}
K_2	Loop Injection correction factor (1090/R)
K_3	Vehicle correction factor
kHz	Kilohertz
km	Kilometre
L	Inductance
L_H	Inductance of Helix (mH)
L_T	Inductance required to resonate C_{app} at f (mH)
L_V	Inductance of variometer at position indicated (mH) (–cm = distance inner coil is down from the top)

m	Metre
mV	Millivolts
N	Number (of turns in an inductor)
P_r	Radiated power (kW)
P_v	Variometer position, cm down from the top
R_r	Radiation resistance (ohms)
S_x	Standard deviation
$\overline{x}$	Mean
η_{as}	Antenna system efficiency

APPENDIX B: EQUATIONS

1. Antenna Current

$$I_a = I_{as}K_1$$

2. Measured Field

$$E_m = E_g K_2 K_3$$

3. Radiation Field

$$E_r = \frac{Em}{\left[1 + \left(\frac{300}{2\pi fd}\right)^2\right]^{1/2}}$$

4. Radiated Power

$$P_r = \left(\frac{E_r d}{300}\right)^2$$

5. Effective Height

$$h_e = \frac{10^4 E_r d}{4\pi I_a f}$$

6. Radiation Resistance

$$R_r = \frac{P_r \times 10^3}{I_a^2}$$

7. Field Distance Product, Normalized

$$FDP = \frac{E_r d}{I_a}$$

8. Distance, Great Circle, Nautical Miles

$$d = 60 \cos^{-1} [\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos (\lambda_2 - \lambda_1)]$$

(nautical miles (μs) × 1.852 = kilometres)

*(HEWLETT-PACKARD NAVIGATION PAC 1, NAV 1-10A)

9. Azimuth, Initial

$$A_z = \cos^{-1}\left[\frac{\sin L_2 - \sin L_1 \cos (d/60)}{\sin (d/60) \cos L_1}\right]$$

*(HEWLETT-PACKARD NAVIGATION PAC 1, NAV 1-10A)

10. Mean

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

*(HEWLETT-PACKARD STANDARD PAC, STD 02A)

11. Standard Deviation

$$S_x = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}{n-1}}$$

*(HEWLETT-PACKARD STANDARD PAC, STD 02A)

*Equations 8, 9, 10, and 11 are all taken from the appropriate programs for the HP-65 calculator which was used to prepare this report.

12. $$\eta_{as} = \frac{P_r}{R_{as}} = \frac{R_r}{R_{as}} = \frac{I_a^2 R_{r(bushing)}}{(I_{as})^2 R_{as(feed)}}$$

where R_r and R_{as} are referred to the same point

$$= \frac{\overline{R}_{r(feed)}}{R_{as\ feed}}$$

$$\left[\text{Since } \overline{R}_{r(feed)} = \frac{I_a^2 \overline{R}_{r\ bushing}}{(I_{as})^2} \right]$$

APPENDIX C: FIELD INTENSITY MEASUREMENTS, SUBSTITUTION METHOD

I. INTRODUCTION

This kind of Field Intensity Measurement is made feasible because of a method of calibrating field strength measuring equipment developed by Dinger and Garner of Naval Research Laboratory. This technique is described and justified in their NRL Memorandum Report 83, "A New Method of Calibrating Field Strength Measuring Equipment," dated 14 November 1952. Basically this method consists of injection of a constant current (high resistance source) into the loop shield which is considered to be unity coupled to the winding of the loop. A loop antenna, modified in accordance with illustrations given in this report, is employed. (See figure C1.) The signal path, for both the received signal and the calibrating signal, occupies common equipment eliminating the requirement of known gain from the antenna to the indicator. Only the value of a resistor in the loop modification and the accuracy of the voltmeter are required to establish the precision of the measurement. It is possible to determine both of these by independent means.

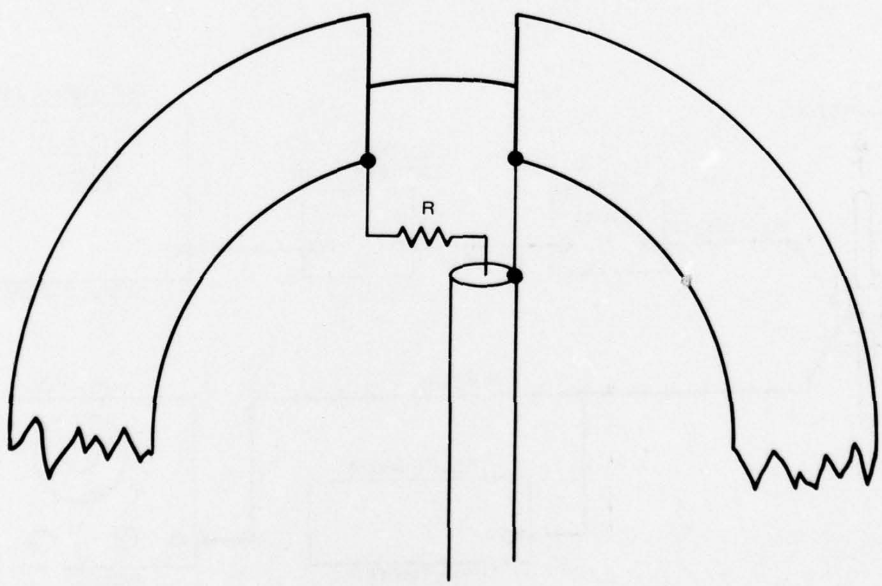


Figure C1

II. PROCEDURE

A. In Section B a step-by-step procedure for taking a measurement will be given. This procedure must be tempered by a certain amount of judgement based on experience. Experience is best gained by making a large number of measurements. However, some guidelines may be helpful:

1. Visual observation of fences, pipes, structures, power lines (especially those which could directly carry a signal from the transmitter to the measurement site) and the location of your own vehicle could show that a site is less than desirable.

2. One of the tests of a site is to orient the loop for a null (minimum signal on the indicator). The following two features of the null may indicate that a site is undesirable:

   a. The minimum signal level of the null is greater than 1% of the maximum signal.

   b. The direction of the null (right angle to the plane of the loop) is more than five (5) degrees from the direction to the transmitting antenna.

3. Compare the measured field strength with the expected field strength based on the design goals of the antenna. If there is a radical difference try other measurement sites nearby, correcting for any change in distance to the transmitting antenna. A large difference could be caused by invisible (possibly buried) conductors such as pipes or wires.

B. Select a site using the visual criteria of Section A.1.

1. Set up the loop antenna approximately 15 metres from the other measuring equipment in such a location that the direction to the transmitting antenna and the direction to the measuring equipment differ by approximately 90 degrees. (See figure C2).

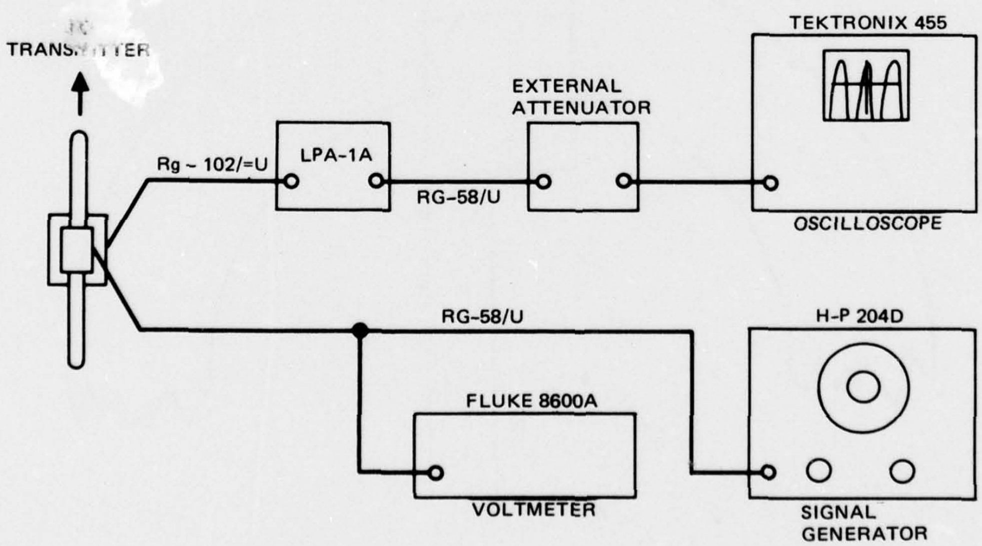


Figure C2

2. Set the Frequency Selector Switch, of the LPA-1A, to the frequency having the highest duty cycle. If f_t is being transmitted on four segments it would be used. If not, use the frequency on the segment having the longest duration.

3. Attach the LPA-1A external attenuator to the CH2 input jack of the Tektronix 455 Oscilloscope. Adjust the external attenuator to full gain (CW).

4. Set the controls of the oscilloscope as follows:

a. Power Switch: DC, ON

b. Horizontal Display: A

c. Trigger Mode: AUTO

d. Coupling Source: AC, Normal

e. A Trigger Level: 0

f. A and B Time/Div: 0.2 ms, Calibrated

g. Intensity, Focus, Horizontal and Vertical Position: As necessary to center the display on the screen.

h. Vertical Channel Selector: CH2

i. Vertical Coupling Switch: AC

5. With the plane of the loop aimed at the transmitting antenna, set the oscilloscope vertical gain control to the Calibrated position and the vertical attenuator to produce an "on screen" waveform.

6. Calculate the attenuator setting and waveform size if the normal voltage was reduced to 1%. Set the vertical attenuator to this value.

7. Turn the loop approximately 90 degrees either direction then adjust the loop position for minimum signal (null) as indicated on the oscilloscope.

8. If the amplitude of the signal, at the null, is $\leqslant 1\%$ of step 5 check the bearing of the null (90 degrees to the plane of the loop). If the bearing of the null is within ±5 degrees of the direction to the transmitting antenna and the amplitude is $\leqslant 1\%$ the site is probably acceptable. If the site fails this test move a few hundred metres, preferably at a constant distance to the station, and remeasure. Statistical tests, after all data are taken, may indicate anomalies not detected above.

9. If satisfied with the site, turn the plane of the loop toward the transmitting antenna to obtain the maximum signal.

10. Set the controls of the Textronix 455 Oscilloscope as follows:

a. Vertical Position: Full CCW (down)

b. Vertical Attenuator: 10 mV/div, calibrated, AC

c. A and B Time/Div: 20 μs, calibrated

d. Adjust the LPA-1A External Attenuator control so the tips of the waveform are between 6 and 8 cm high.

e. Adjust the horizontal position so one of the waveform tips is over the vertical centerline of the screen.

11. Turn the signal generator ON. Adjust the output of the generator to the exact frequency of the Omega signal selected by the loop amplifier (zero beat frequency).

12. Remove the signal generator output in the manner shown below:

a. If using a Hewlett-Packard 204D oscillator as a signal generator move the Range Selector switch to × 1K during periods of time that the generator voltage is unneeded. Do not switch OFF.

b. If using a special oscillator as a signal generator switch the frequency control to an intermediate step.

13. Observe the tip of the waveform in the center for 2 or 3 successive pulses, noting the vertical position.

14. Turn the loop antenna to the null position. (If it is impractical to turn the antenna to the null position, such as is the case in a helicopter, the next step may be accomplished during the 200 ms spaces between transmissions.)

15. Return the signal generator output, that was removed in step 11, to the selected frequency. Adjust the signal generator output control to produce a waveform identical in amplitude to the one noted in step 12.

16. Read the digital voltmeter to obtain the value of the signal generator output. Enter this value on Data Sheet 5.

17. Switch the LPA-1A to each frequency being measured, repeating steps 9 through 15 for each frequency.

18. Transcribe the necessary information from Data Sheets 3, 4, and 5 to the appropriate spaces on Data Sheet 6. Perform the required calculations to complete Data Sheet 6.

APPENDIX D: ANTENNA CURRENT MEASUREMENTS, SUBSTITUTION METHOD

I. INTRODUCTION

1. The Omega transmission consists of a series of pulses whose lengths are between 900 and 1200 milliseconds, inclusive. Very few measuring instruments respond quickly enough to allow direct measurement to the degree of precision desired. One of the more simple methods of measuring a current or voltage is to employ an indicator (oscilloscope) that responds quickly to the signal being measured, a means of storage (operator's memory) and a signal source, of a similar character known to have good accuracy, that may be substituted for comparison. (See figure D1.) In this method it is required to know the accuracy of the current-to-voltage transducer ($\leqslant 1\%$), the accuracy of the voltmeter ($\leqslant 1\%$) and the precision with which the comparison can be made ($< 1\%$).

2. A new current-to-voltage transducer is being permanently installed on the ground leg of the antenna tuning system. This device has an output of 0.01 volt per ampere and is accurate to $< 1\%$. Its purpose is primarily to provide a means of accurately measuring antenna current in order to calibrate the panel meters in the Timing and Control racks. However, during field measurement activities it will be used to provide antenna current data directly.

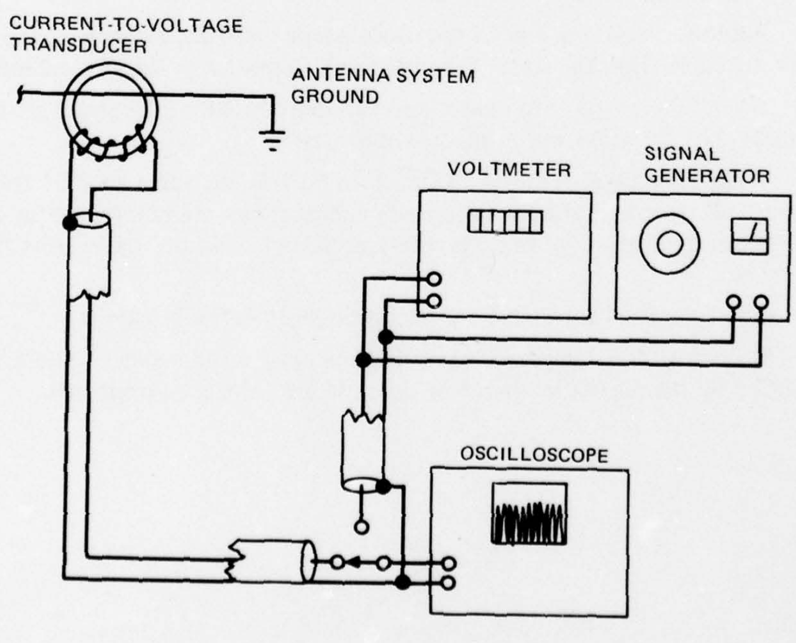


Figure D1

II. PROCEDURES

1. Assemble the equipment as shown in figure D1.
2. Set the frequency of the signal generator to 12 kHz.
3. Set the controls of the Tektronix 455 Oscilloscope as follows:
   a. Horizontal Display: A
   b. Trigger Mode: AUTO
   c. Coupling Source: AC-Normal
   d. A Trigger Level: 0
   e. A and B Time/Div: 1 ms, calibrated
   f. Vertical Mode: CH2
   g. Input Selector Switch: AC
   h. Vertical Position (CH2): Full down (CCW)
   i. Vertical attenuator and variable control: As necessary to position the top of the waveform being measured approximately 7 cm from the bottom of the screen.
   j. Test the frequency response of the vertical presentation over the range of Omega frequencies to be sure that the comparisons may always be made at 12 kHz. (An error was once found, in an oscilloscope, over the range of 10 to 14 kHz.)

4. With the output of the current-to-voltage transducer connected to the vertical input of the oscilloscope adjust the oscilloscope as required by step 3i. Note the position of the top of the waveform being measured.

5. Without disturbing any of the oscilloscope controls, disconnect the transducer and connect the cable from the signal generator and voltmeter to the vertical input.

6. Adjust the output attenuator and variable control of the signal generator to produce a display of the same amplitude noted in step 4.

7. Read the voltage required in step 6 and divide the value by 0.01 to obtain the current in amperes. (Note that even though the comparisons are being done by peak measurements the voltmeter readings, in volts rms, are valid because the waveforms are essentially sine waves.)

8. Repeat steps 4 through 7 for each frequency being transmitted.

9. Record all the data required by Data Sheet 3 on that sheet. The time interval will be specified by the person in charge of the field intensity measurements.

APPENDIX E: FIELD INTENSITY MEASUREMENTS BY HELICOPTER

I. INTRODUCTION

1. Some of the Omega stations are located in sites which are almost impossible to measure on the ground. These are either volcanic islands such as Hawaii and Reunion, the mountainous island of Tsushima, or the mountainous coast of Norway. These areas, besides being almost impassable, are characterized by poor and variable ground conductivity. These conditions dictate a measurement site remote from the poorly conducting ground plane and above the impassable terrain. Due to the low duty cycle pulses of the Omega signals a moving vehicle (fixed wing aircraft) is a very unattractive platform. The length of time required to obtain an accurate measurement requires a stationary platform. Above the terrain this means a helicopter.

II. INSTRUMENTATION

1. To reduce the pattern distortion, and consequent calibration factors, it is desirable to mount the loop antenna as far from the helicopter structure as practical, while placing the null of the antenna pattern directly on the largest mass of the vehicle.

2. Each kind of helicopter presents its own set of mounting problems. Suffice to say that any means of placing the plane of the loop parallel to the axis of the vehicle and about five (5) feet from the outside of the skin is acceptable. Since the Hughes 500C was available at both Norway and North Dakota the mounting (to the steps) was designed to telescope and rotate while keeping the loop in a fixed position with respect to the helicopter. Other machines will be dealt with as the need arises. It is important that the mounting hardware be made of insulating material and the fastenings be nonmagnetic. The loop and mounting assembly must withstand forward speeds of 100 knots and also the down wash of the main rotor.

3. All wires and cables, associated with the loop assembly, must be secured in such a manner that they will withstand the airstream during flight. They should be spirally wrapped around tubular sections, of the loop mount, to aid in vortex shedding.

III. PROCEDURE

A. CALIBRATION

1. Calibration of the helicopter mounted loop must precede measurement flights. It should be done as near the station as practical in order to have a strong, noise free signal. The suggested distance would be 18 to 22 kilometres.

2. All the equipment necessary for field intensity measurements shall be aboard the helicopter. A tripod mounted loop antenna is placed about 15 metres from the helicopter at a position that places the helicopter in the hull of the antenna pattern when the plane of the loop is aimed at the station. Auxiliary cables, approximately 15 metres in length, are used to connect the tripod mounted loop to the measuring equipment in the helicopter.

3. Have the antenna current measured, by the substitution method outlined in Appendix D, and entered on Data Sheets 3, 5 and 6.

4. Perform Field Intensity measurements, using the substitution method of Appendix C, with the tripod mounted loop. Record the readings on Data Sheet 5.

5. Transcribe the required values to Data Sheet 6 and, using 1.0 for K_3, calculate $E_r d/I_a$ for each frequency.

6. Disconnect the external antenna and connect the helicopter antenna to the measuring equipment.

7. Lift the helicopter off the ground and hover with the loop at the same height as the tripod mounted loop. Swing the helicopter right and left to determine the direction of maximum signal. Do not try to get a null.

8. With the helicopter hovering in the direction of maximum signal measure all frequencies. Record the data on Data Sheet 5.

9. Transcribe the necessary data to Data Sheet 6 and, using 1.0 for K_3, calculate $E_r d/I_a$ for each frequency.

10. Divide the value determined in step 5 by the value determined in step 9 to obtain the true value of K_3, the Vehicle Correction Factor.

11. Repeat steps 7 through 10 with the helicopter pointed away from the station.

B. MEASUREMENTS

1. The determination of distance from the measurement site to the transmitting antenna is very important.

a. If a position can be found on a chart or map it may be described in terms of latitude and longitude. Since the latitude and longitude of the transmitting antenna are known the distance may be calculated by great circle navigation equations.

b. Over water it will be necessary to use radio Distance Measuring Equipment (DME) in conjunction with bearing information to obtain a fix and establish the position. Once the position is known the calculation for distance is carried out by great circle navigation equations.

2. The altitude chosen for measurements is a compromise value – high enough to ensure readings unaffected by changes in altitude and low enough for accurate maintenance of position by visual reference. One thousand (1000) feet above the terrain has been selected for helicopter operations.

3. The step-by-step procedure used to obtain a measurement follows:

a. Choose the location over which the measurement is to be taken. Note a sufficient number of landmarks to facilitate maintenance of the position. Over water it might be advisable to drop a floating smoke generator to provide a visual reference.

b. Tune in the Omega frequency having the longest duty cycle. Swing the helicopter (loop) plus or minus a few degrees about the estimated direction to the station to establish the direction of the maximum signal.

c. Point the helicopter in the direction of the maximum signal while hovering over the exact position of the site at the chosen altitude.

d. Perform the substitution type field intensity measurements on all the frequencies desired.

e. Most helicopters are difficult to control in a hover with the wind from behind. In some cases it will be necessary to use the tail toward the station orientation. Be sure to use the correct Vehicle Factor (K_3) for this direction.

APPENDIX F: MEASUREMENT OF ANTENNA TUNING SYSTEM GEAR RATIOS

I. INTRODUCTION

Gear ratios for the gear boxes of the Antenna Tuning Set were calculated under the assumptions that each variometer is operating in the same part of its travel and that the inductance change is linear. In practice neither of these assumptions is correct. After installation and preliminary operation, the necessity of adjustments to the calculated values will become apparent. As the antenna capacitance changes, from any cause, the antenna tuning will attempt to keep all frequencies tuned simultaneously. If the ratios are not correct there will be hunting, back and forth, as each frequency is keyed. The procedure reported herein will allow selection of the best gear ratio provided by the gear box.

II. MEASUREMENT

A. EQUIPMENT

1. An adding and subtracting turns counter is mounted on the main drive right angle support frame in Room 101. This should be direct drive and indicate 1/10 turn of the shaft.

2. A switchable step capacitor is attached to the antenna near the exit bushing. If any prior knowledge of the excursion of the antenna capacitance is available, try to adjust the added capacitance to this value. If no prior knowledge is available, use the maximum capacity change that will allow the variometers to operate in the reasonably linear, or useful, range. The plate spacing, however, must be sufficient for the minimum voltage that will allow proper automatic antenna tuning. If the new switchable test capacitor is used, spacing gauge blocks are provided for 1, 1-1/2 and 2 inch spacings. Minimum spacing is approximately 1/2 inch and maximum approximately 2-1/2 inches. Table F1 gives estimated capacitances at various spacings.

TABLE F1

Spacing (inches)	Capacitance (pF)
0.5	1000
1.0	520
1.5	360
2.0	280
2.5	230

B. PROCEDURE

1. Disengage all the clutches, in the variometer rooms, except the variometer gear being tested.

2. Adjust the output of the transmitter to the minimum value that will allow good automatic antenna tuning.

3. With the test capacitor switch open, allow the antenna to tune automatically.

4. Read the main shaft revolution counter and enter the number in the appropriate box of the calculation sheet.

5. Switch on the test capacitor and allow the antenna to retune automatically.

6. Read the main shaft revolution counter and enter the number in the appropriate box of the calculation sheet.

7. Repeat steps 3 through 6 until satisfied with the repeatability of the numbers.

8. Repeat steps 1 through 7 for each frequency.

III. CALCULATION

A. PRELIMINARY

1. Perform the indicated arithmetic operations on Data Sheet F1. Transfer the numbers in column 6 to column 2 of Data Sheet F2. Both are entitled "Lead Screw Rotation to Tune ΔC."

2. Examine the numbers in column 4, "Shaft Rotation to Tune ΔC," of Data Sheet F1 for any that are less than 2% apart. If two or more of the numbers are less than 2% apart, use the mean value for column 3, "Selected Normal Shaft Rotation to Tune ΔC," of Data Sheet F2. If no two are within 2%, select the value for 10.2 kHz.

B. FINAL

1. Perform the indicated arithmetic operations on Data Sheet F2.

2. Obtain or prepare a table showing all available gear ratios possible with the gear box used.

3. Select the nearest available gear ratio and enter the value on Data Sheet F2.

4. Install the appropriate sprockets for this gear ratio.

DATA SHEET F1. GEAR RATIOS, AS INSTALLED, CALCULATION OF CORRECTED RATIO.

Frequency (kHz)	Counter Readings at Min. Capacity		Counter Readings at Max. Capacity		Shaft Rotation to Tune △ C		Installed Gear Ratio		Lead Screw Rotation to Tune △ C
10.2	____.______	-	____.______	=	____.______	X	___.____	=	___.____
13.6	____.______	-	____.______	=	____.______	X	___.____	=	___.____
11-1/3	____.______	-	____.______	=	____.______	X	___.____	=	___.____
11.05	____.______	-	____.______	=	____.______	X	___.____	=	___.____
f_t	____.______	-	____.______	=	____.______	X	___.____	=	___.____

DATA SHEET F2. GEAR RATIOS AS INSTALLED, CALCULATION OF CORRECTED RATIO.

Frequency (kHz)	Lead Screw Rotation to Tune △ C		Selected Normal Shaft Rotation to Tune △ C		Corrected Gear Ratio	Nearest Available Gear Ratio
10.2	___.____	÷	____.______	=	___.____	____.______
13.6	___.____	÷	____.______	=	___.____	____.______
11-1/3	___.____	÷	____.______	=	___.____	____.______
11.05	___.____	÷	____.______	=	___.____	____.______
f_t	___.____	÷	____.______	=	___.____	____.______

APPENDIX G: LIST OF EQUIPMENT

I. INTRODUCTION

Equipment furnished specifically for field intensity measurements.

1. The equipments listed below were delivered to Omega Norway for retention and use in conducting future field intensity measurements.

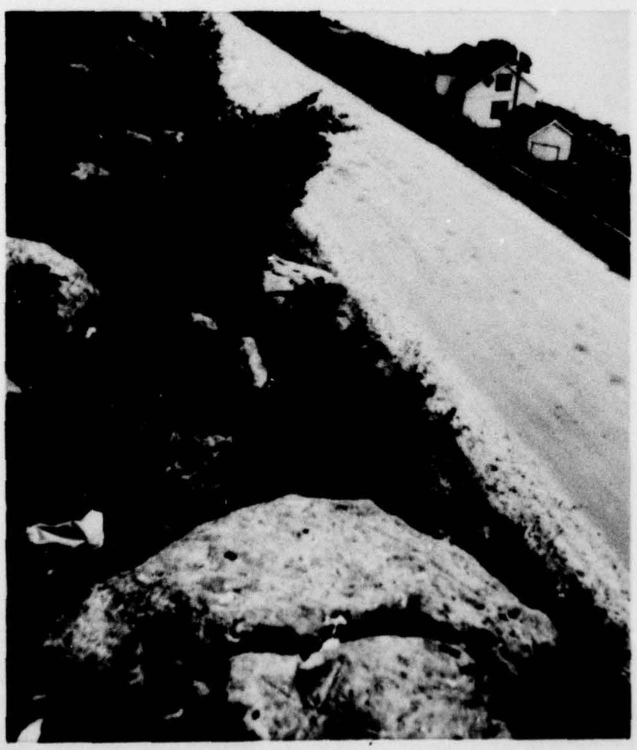
TABLE G1

Equipment	Mfgr	Model No.
Loop Antenna	Stoddart	90177-2
VLF Tuned Amplifier	Megatek	LPA-1A
Signal Generator	Hewlett Packard	204-D
Digital Volt-Ohm-Meter	Fluke	8600A-01
Current Transformer	Pearson	114-4
Oscilloscope	Tektronix	445
Battery Power Supply	Tektronix	1106
Tripod	Leitz	7536-20
Twinax Cable (50 ft)	–	RG-108/U
Coax Cable (50 ft)	–	RG-58/U
Ext. Attenuator for LPA-1A	Megatek	None

APPENDIX H: BRATLAND BASELINE AND BENCH MARK PHOTOS

The following 12 photographs show the locations of the end points of the newly established baseline for span survey reference, and the locations of the field strength measurement "bench marks."

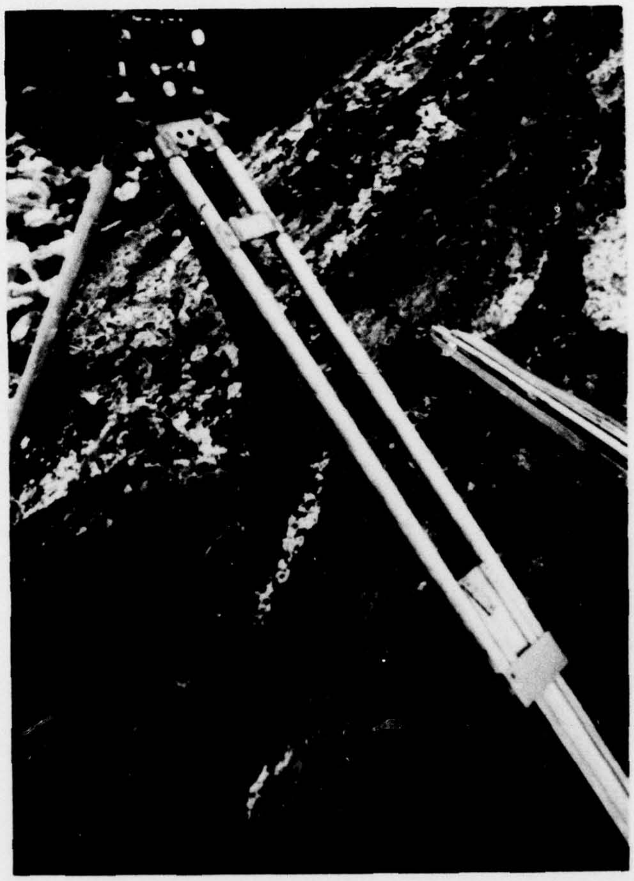
H1. Baseline point "A," looking NW toward Hestmandoen. This point is immediately west and about 20 metres lower in elevation than the transmitter building, and is in view from the administrative office window.



H2. Baseline point "A," looking S toward helix house and baseline point "B."

H3. Baseline point "B" as viewed by telephoto from "A." The actual point is just right of the lower of the two points on the rock.

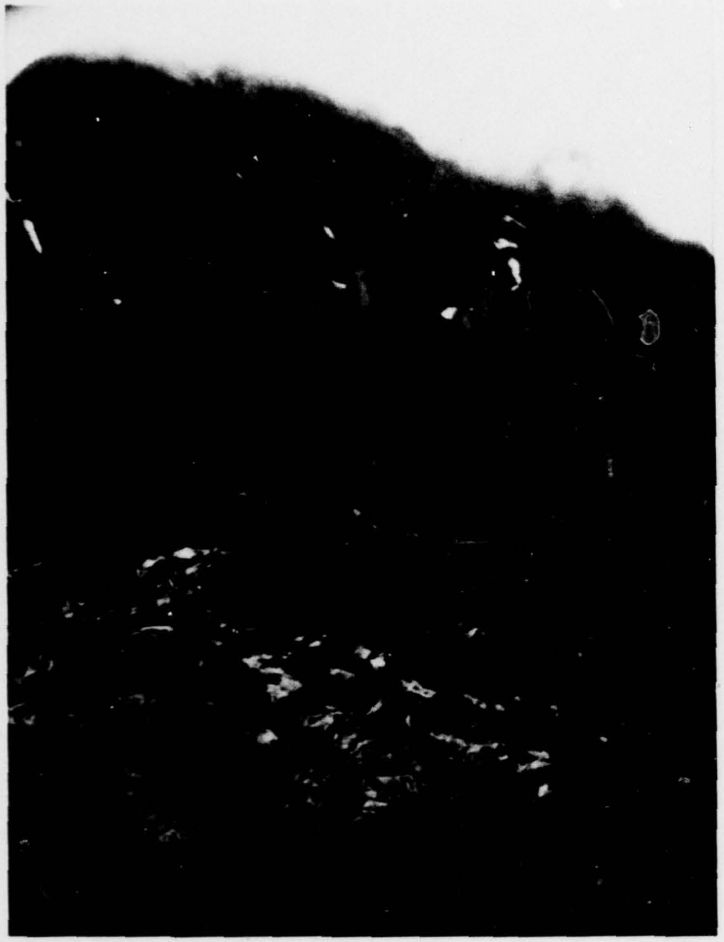
H4. Transit set up on "B." When viewed from "A," the vertical cross-hair of the transit is just tangent to the right side of the red bull's-eye, and bisects a small flat located where the piece of timber in the picture passes behind the rock surface below the transit.



H5. Transit at point "B." The extreme end of the timber points at a bolt driven into the rock that may have been the corresponding point used by surveyors in 1968.

H6. Point "A" viewed from "B." It is located just above the road embankment between the house near the shore and the transmitter building. The house is the same as in picture H2. To view it through the transit requires erection of a small cairn of rocks over the "X," marked with a strip of white paper. The original point is a bench mark on top of the transmitter building; this is the circled "X" in figure **H1**.

H7. Bench mark site "B" on Hestmandoen, looking toward the NW. The orange pennant is the marker left by members of NGO, who are establishing a new series of bench marks on various islands: this site will become one of these.

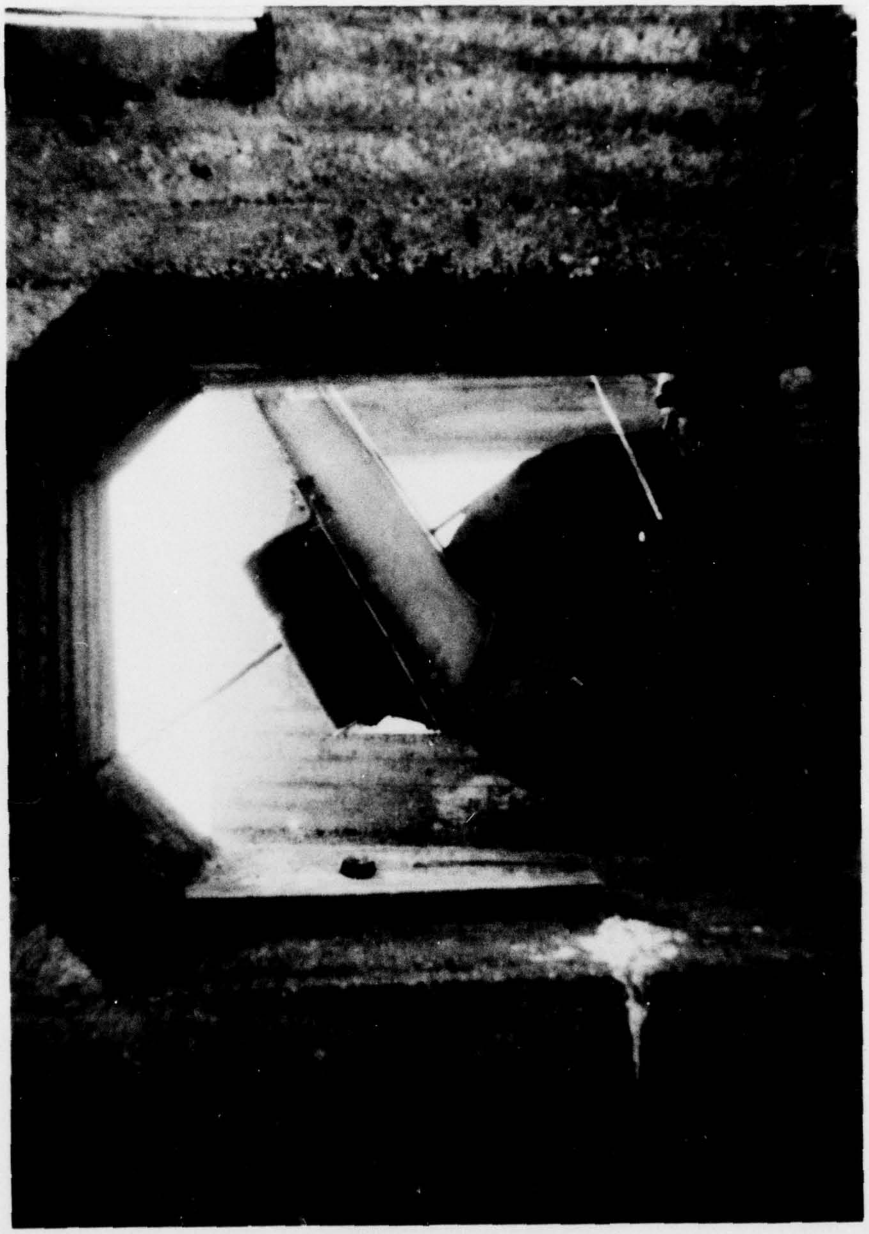


H8. Bench mark site "C" on Tomma, on the small peninsula Kyrhaugen, looking approximately SSW from the helicopter just prior to touchdown. The actual site is a small cairn of rocks about 3/8 inch below the crest of the nearer of the two knolls, on a small flat.

H9. Site "C," looking NNW toward Liatind, which is the center peak with its head in the clouds. The loop is not properly aimed.

H10. General arrangement of equipment at site "C."

H11. Aldera tower anchorages viewed from helicopter on 2 August 1977. Span 1 is closest, view is toward north. Departure angle is -25.4°. Note finish coat of orange paint is almost entirely stripped.



H12. Liatind toward anchorage fairlead, span 3, viewed from span 2 position. Departure angle is -34.5°.

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