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OMEGA HAWAII ANTENNA SYSTEM: MODIFICATION AND VALIDATION TESTS.--ETC(U)

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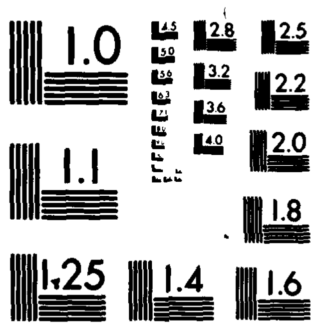

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OMEGA HAWAII ANTENNA SYSTEM: MODIFICATION AND VALIDATION TESTS

Volume 1: Report Proper

J C Hanselman, Megatek Corp.

19 October 1979

Final Report

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US Coast Guard

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NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

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Electronic measurements were performed on the Hawaii Omega Antenna System during the months of May and June 1978 and March and May 1979. The work was performed under NOSC project MP01538B10 with Megatek as contractor. The electrical height of the antenna is 169 metres for all frequencies. The station can easily radiate more than 10 kW on all frequencies. There is no measurable deviation from omnidirectional radiation due to the proximity of the Haiku Valley walls to the south, west and north of the antenna. The apparent capacitance of the antenna was measured. Also, the inductance of the spare variometer and its variation was measured. From these preliminary measurements, the optimum location of the 11.050 kHz helix

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tap was determined and connected. The value of the antenna system's resistance was measured on three days of different weather conditions and found to vary. This variation is related to the degree of salt deposit on the antenna insulators. A recommended set of gear ratios for the variometer gear boxes is determined.

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I. INTRODUCTION

1. The work described in this report was performed by the Megatek Corp. for the Naval Ocean Systems Center under Task assignments 005, 025 and 030 of Contract No. N00123-78-C-0043.

2. The scope of work in task assignment 005 consisted of modifying the Antenna Tuning System to enable transmission on the fourth OMEGA frequency of 11.05 kHz, deletion of 11.55 kHz which was one of the unique frequencies, correcting the antenna tuning servo system gear ratios to provide better tracking and determination of the correct antenna matching transformer taps. This work was performed in May and June 1978.

3. The work performed under task assignment 025 in March 1979 consisted of the following items (for detailed informal report, see appendix I):

(a) To search for suitable helicopter calibration sites, examine the proposed radial routes and prepare an estimated flight schedule.

(b) Measure the self-generated electrical noise of the helicopter, determine the optimum loop orientation, and design a new loop mounting if required.

(c) Select, locate and obtain permission to use sites for distance measuring equipment (DME) which will be used to determine the helicopter positions while making field intensity measurements.

(d) Generate DME range data consisting of transponder base lines, and vectors from the OMEGA station to the D1 transponder site and prepare transponder antenna aiming data.

(e) While not specifically called for in the task assignment, during the first trip to Hawaii it became apparent that a trap would be required to reduce the 23.4 kHz signal from NAVCOMSTA Lualualei.

4. The field intensity measurements, from which antenna characteristics are determined, were conducted under task 030 in May 1979.

II. INSTALLATION OF THE FOURTH OMEGA FREQUENCY, 11.05 kHz.

MEASUREMENT OF APPARENT CAPACITANCE

1. Prior to retapping the helix the apparent capacitance of the antenna was measured. This was done on the roof of the helix building since it was impractical to build a platform over the helix inside. The jumper between the exit bushing and the tripod insulator was disconnected to isolate the antenna.

2. The apparent capacitance was measured by the substitution method. The procedure is to resonate the antenna, using the antenna tuning system, at a frequency very close to each of the operational frequencies, at a very low power level. The antenna is then disconnected and variable capacitances are substituted for the antenna. Without changing the frequency, or the inductance of the antenna tuning system, the variable capacitors are adjusted to produce resonance. The value of the substitute capacitors is the apparent capacitance (C_{app}) of the antenna. To this value is added the capacitance of the exit bushing and the ball gap assembly. This value may be compared to those measured at the inside terminal of the exit bushing, prior to installation of the helix, to detect changes in the antenna. Data Sheets DS 1-1 through DS 1-5 (volume 2) show the values of the variable capacitors for each frequency and the summation that gives the apparent capacitance. Tables 1 and 2 give the calibration data for the decade and variable capacitors used.

TABLE 1. CALIBRATION DATA.

(DECADE CAPACITOR, G-R 1419-B, SERIAL 1793)

R. L. Denton, Consultant
J. C. Hanselman, Megatek Corporation

22 May 1978

Direct measurement by ESI Model SP1049 (701 System)
Capacitance Bridge, Serial 425001, at 1 kHz

Shunt Capacitance: 48.09 pF

Switch Dial (100 pF)	Measured Capacitance (pF)	Actual Step Capacitance (pF)
1	149.16	101.07
2	246.85	198.76
3	347.85	299.76
4	445.73	397.64
5	549.07	500.98
6	650.10	602.01
7	745.87	697.78
8	846.96	798.87
9	Defective	--
10	Defective	--

Switch Dial (1,000 pF)	Measured Capacitance (pF)	Actual Step Capacitance (pF)
1	1,049.0	1,000.9
2	2,045.8	1,997.7
3	3,046.6	2,998.5
4	4,045.1	3,997.0
5	5,056.9	5,008.8
6	6,057.7	6,009.6
7	7,052.7	7,004.6
8	8,053.6	8,005.5
9	9,052.3	9,004.2
10	10,051.9	10,003.8

Switch Dial (10,000 pF)	Measured Capacitance (pF)	Actual Step Capacitance (pF)
1	10,059	10,011
2	20,064	20,016
3	30,074	30,026
4	40,097	40,049
5	50,094	50,046

TABLE 2. CALIBRATION DATA

(PRECISION AIR VARIABLE CAPACITOR, G-R 722-N, SERIAL 2456)

R. L. Denton, Consultant
J. C. Hanselman, Megatek Corporation

22 May 1978

Direct measurement by ESI Model SP1049 (701 System)
Capacitance Bridge, Serial 425001, at 1 kHz

Dial Reading (pF)	Measured Capacitance (pF)	Correction Required (pF)
100	100.51	+ 0.51
200	201.03	+ 1.00
300	301.02	+ 1.02
400	401.77	+ 1.77
500	502.24	+ 2.24
600	602.04	+ 2.04
700	702.14	+ 2.14
800	802.21	+ 2.21
900	902.42	+ 2.42
1,000	1,002.13	+ 2.13
1,100	1,101.75	+ 1.75

3. Note that the value of the exit bushing capacitance, paragraph 6 of Data Sheets 1 through 5 is a value different than previously shown as the "Manufacturers Data." This new value of the bushing and spark gap assembly was measured at OMEGA La Reunion at a later date but included here to produce more precise numbers.

4. During any measurement of an antenna system, which involves excitation of the antenna, it is necessary to use a frequency a few above or below the assigned frequencies and at an absolute minimum power level to avoid interference to users of the OMEGA system. For example, a radiated signal having a power level of one will produce a field of approximately 320 microvolts per meter at a distance of 30 kilometers from the antenna. This may be equal to a usable OMEGA signal from a distant station.

5. A graph of apparent capacitance versus frequency was plotted as figure 1. An interpolation from the curve was performed to determine the apparent capacitance of the antenna at 11.05 kHz. This value will be used later, during calculations of helix inductance, to locate the position of the helix tap for 11.05 kHz.

VARIOMETER INDUCTANCE MEASUREMENTS

1. The original inductance measurements of a variometer, and associated buswork, were made during December 1971 at OMEGA North Dakota. This seemed to be a good opportunity to remeasure the inductance of another installation using different equipment but in the same manner.

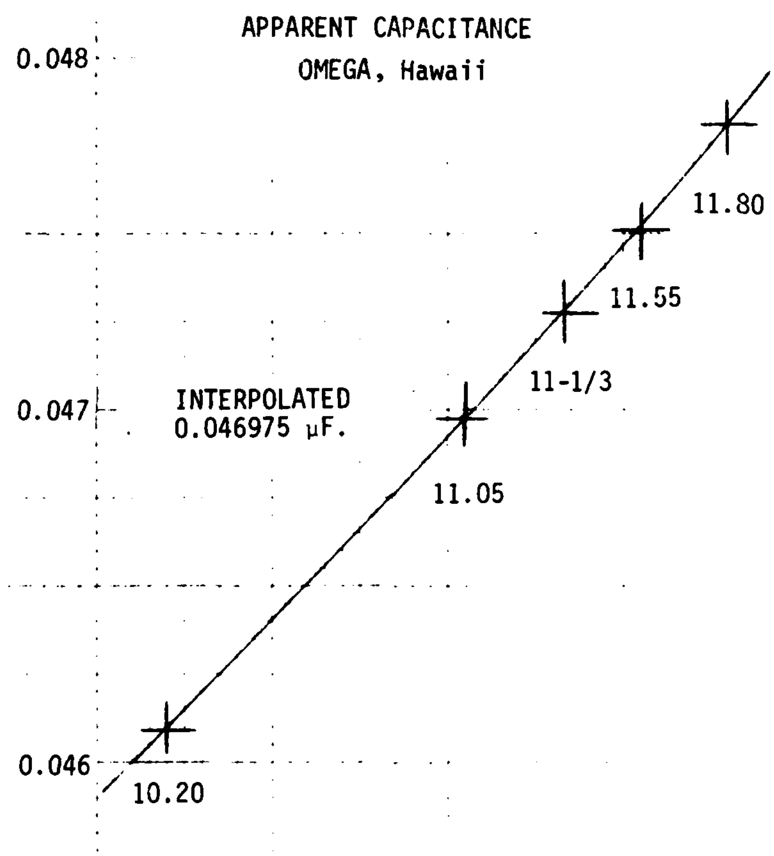


Figure 1. Apparent capacitance.

2. Both sets of measurements were made by applying radio frequency power to the antenna tuning system input terminals, terminating the output of a variometer room by a known fixed capacitor, determining the resonant frequency of many different variometer positions, and calculating the inductance required for resonance. See figure 2 for a schematic drawing.

3. The 1971 measurements made use of an Altec-Lansing 260A amplifier and a General Radio capacitor decade box set to 0.3 μF. The results are shown in table 3.

4. One of the 1978 measurements made use of McIntosh MC-100 amplifier and a General Radio capacitor decade box set to 0.05 μF. The results are shown in table 4 and a curve drawn as figure 4.

5. The second 1978 measurement was made by a General Radio Type 1650-A Impedance Bridge, at 1000 Hertz, replacing the decade capacitor needed for resonance. The amplifier remained energized, but with no input or output signal, to complete the circuit and maintain the same configuration as the resonance measurements. See figure 3 for a schematic drawing. The resulting values of inductance were extremely close to the values obtained by resonance and are also shown in table 4. Comparison of the values obtained in 1971 (table 3) with the values obtained in 1978 (figure 4) shows good agreement.

6. As a spot check of the five remaining variometer rooms all were set to -30.0 inches (-76 cm). The inductance values were only measured by the General Radio Type 1650-A bridge. The results are shown in table 5. No attempt is made to explain the 4.7% discrepancy between the spare

TABLE 3. VARIOMETER INDUCTANCE, 1971

(Spare variometer and all buswork)

Inner Coil Position (Inches/cm down from top)		Resonant Frequency (Hz)	L Resonance (mH.)
-0	-0	13,018	0.498
-12	-30	12,180	0.569
-24	-61	11,024	0.695
-36	-91	10,107	0.827
-48	-122	9,517	0.932
-54	-137	9,327	0.971
-60	-152	9,170	1.004
-65	-165	9,090	1.022
-70	-178	9,030	1.035

TABLE 4. VARIOMETER INDUCTANCES, 1978

(Spare Variometer and all buswork)

Inner Coil Position Position (Inches/cm down from top)		Resonant Frequency (Hz)	L Resonance (mH.)	L 1650-A Bridge (mH.)
-5.5	-14	31,165	0.521	0.517
-7.5	-19	30,822	0.532	0.531
-10.0	-25	30,296	0.551	0.551
-12.5	-32	29,703	0.573	0.572
-15.0	-38	29,090	0.598	0.595
-17.5	-44	28,458	0.624	0.623
-20.0	-51	27,854	0.652	0.651
-22.5	-57	27,268	0.680	0.679
-25.0	-64	26,720	0.708	0.708
-27.5	-70	26,194	0.737	0.735
-30.0	-76	25,703	0.765	0.762
-32.5	-83	25,244	0.793	0.790
-35.0	-89	24,823	0.821	0.815
-37.5	-95	24,438	0.847	0.844
-40.0	-102	24,086	0.872	0.867
-42.5	-108	23,768	0.895	0.890
-45.0	-114	23,485	0.917	0.914
-47.5	-121	23,228	0.937	0.934
-50.0	-127	23,002	0.956	0.951
-52.5	-133	22,798	0.973	0.970
-55.0	-140	22,618	0.988	0.984
-57.5	-146	22,459	1.002	1.000
-60.0	-152	22,322	1.015	1.010
-62.5	-159	22,205	1.026	1.015
-65.0	-165	22,105	1.035	1.026
-67.5	-171	22,026	1.042	1.035
-70.0	-178	21,960	1.049	1.041

TABLE 5. OTHER VARIOMETER ROOMS

(All at -30 inches/-76 cm)

Room (Frequency) kHz	L (1650-A Bridge) mH
10.20	0.799
13.60	0.800
11-1/3	0.798
11.80	0.800
11.55 (11.05)	0.793
Spare	0.762

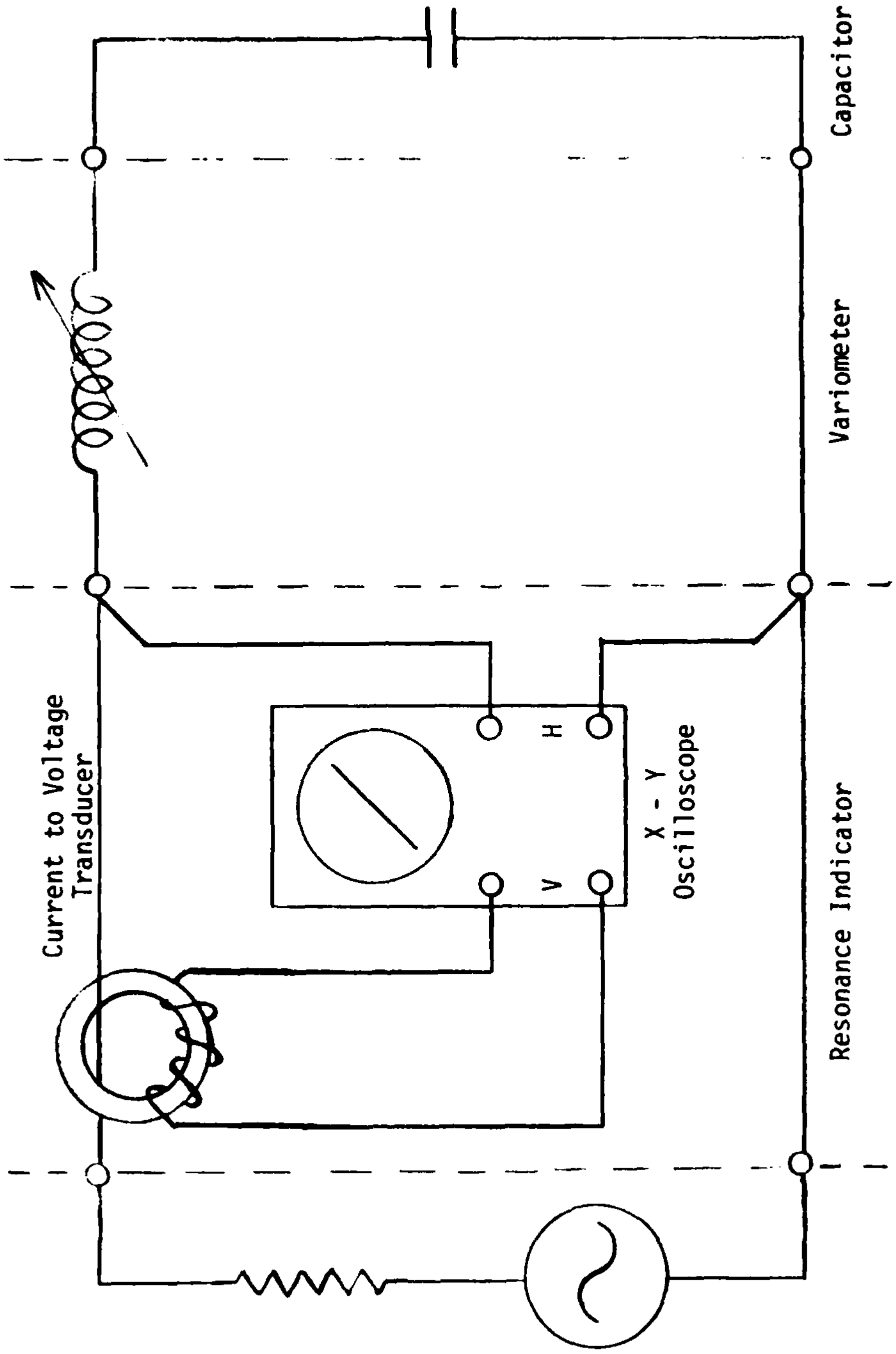


Figure 2. Variometer inductance by resonance

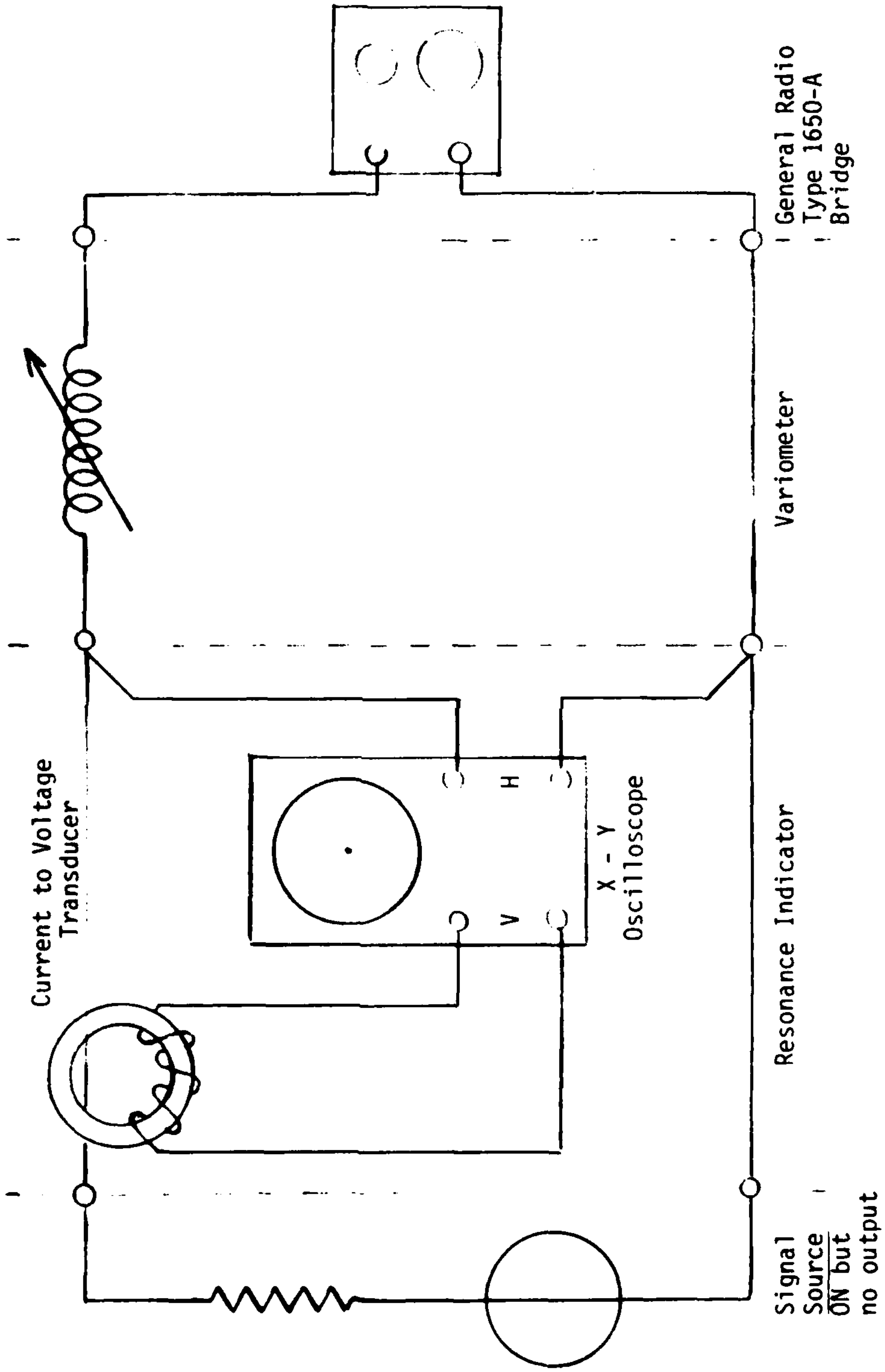


Figure 3. Variometer inductance by bridge

variometer room and all the dedicated variometer rooms. This difference will result in a 2.5 inch (6.35 cm) difference of inner coil position.

HELIX INDUCTANCE CALCULATIONS AND TAP LOCATION

1. Immediately following the termination of transmissions, variometer inner coil position measurements were made. These are shown in centimeters down from the top (-cm). The variometer inductance for each position measurement was taken from figure 4. Both variometer position and inductance are entered in appropriate columns of table 6.

2. The measured and interpolated values of apparent capacitance, previously determined, are entered in the appropriate column of table 6.

3. The total inductance required to resonate the antenna at each frequency was calculated, using the apparent capacitance, and entered in the L_{TOTAL} column of table 6.

4. The variometer inductances were subtracted from the L_{TOTAL} values to obtain the required helix inductance at each frequency. These values were recorded in the column for helix inductance in table 6.

5. The number of helix turns for each of the originally installed frequencies, shown in figure 5, was recorded in the appropriate column of table 6. The number of helix turns for 11.05 kHz will be determined and entered later.

6. A graph was plotted, as figure 6, of helix turns versus helix inductance for as many frequencies as possible near 11.05 kHz. In this case the plotted frequencies were 11.80 kHz, 11.55 kHz, and 11-1/3 kHz.

TABLE 6. DATA of 31 MAY 1978.

(Recalculated 11 January 1979)

Freq. kHz	C_{app} μF	L_{TOT} mH	Vario pos -cm	L_{VARIO} mH	L_{HELIX} mH	Helix Turns
10.20	0.046097	5.282	-72	0.745	4.537	44-1/12 (44.08)
11-1/3	0.047272	4.172	-74	0.755	3.417	35-4/12 (35.33)
11.55	0.047504	3.997	-78	0.772	3.225	33-11/12 (33.92)
11.80	0.047805	3.805	-74	0.755	3.050	32-5/12 (32.42)
13.60	0.050257	2.725	-72	0.745	1.980	23-6/12 (23.50)

Notes:

(1) 11.05 0.046975 4.416 -76 ⟶ 0.765 ⟶ 3.651 ⟶ 37-4/12
(Interpolated) (Optimum)

(2) -84 ⟵ 0.802 ⟵ 3.605 ⟵ 36-11/12
(Predicted)

(3) -81 ⟶ 0.785 ⟶ 3.622
(Actual)

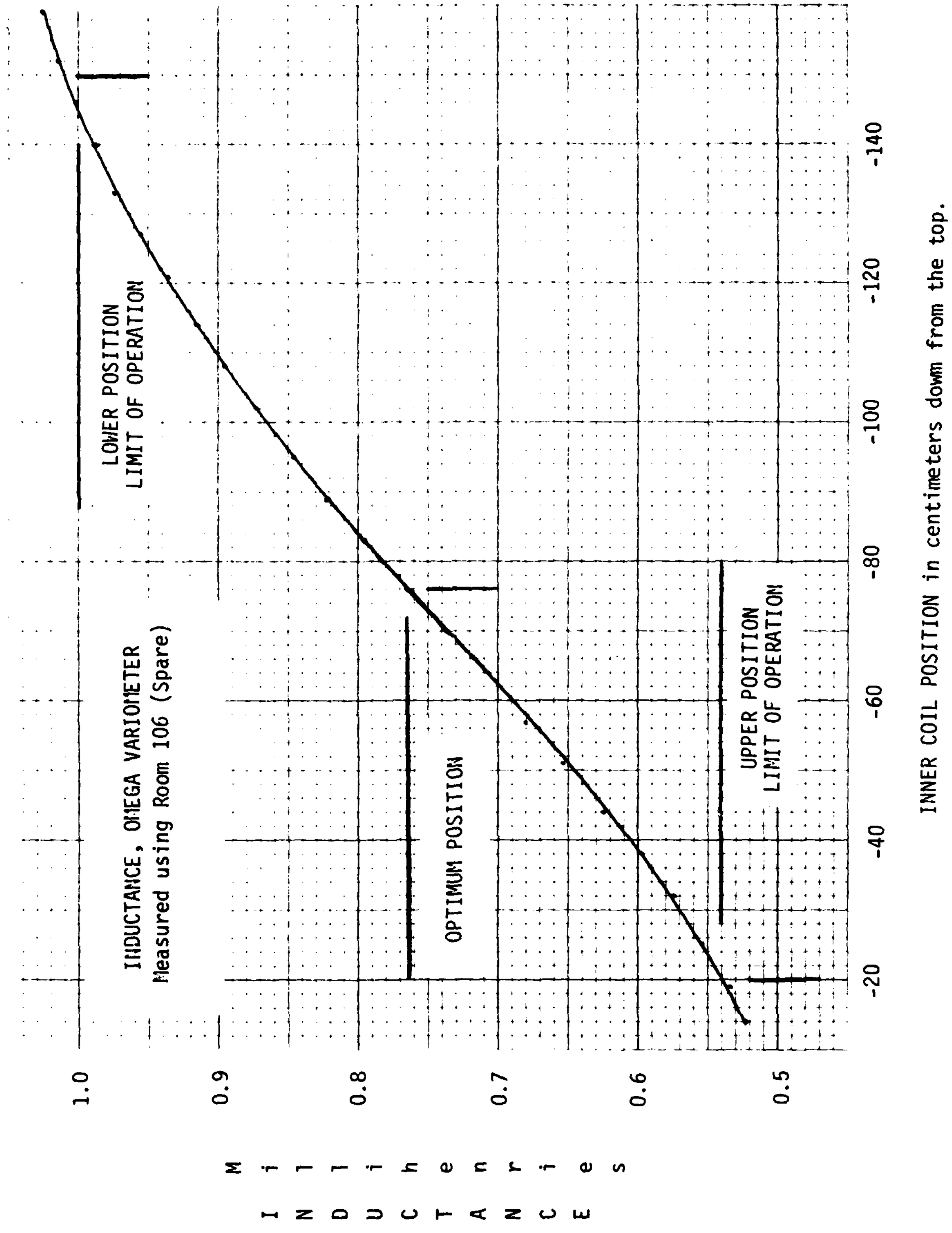


Figure 4. Inductance, OMEGA variometer.

HELIX PLAN

HAWAII — Location

31 MAY 1978 — Date

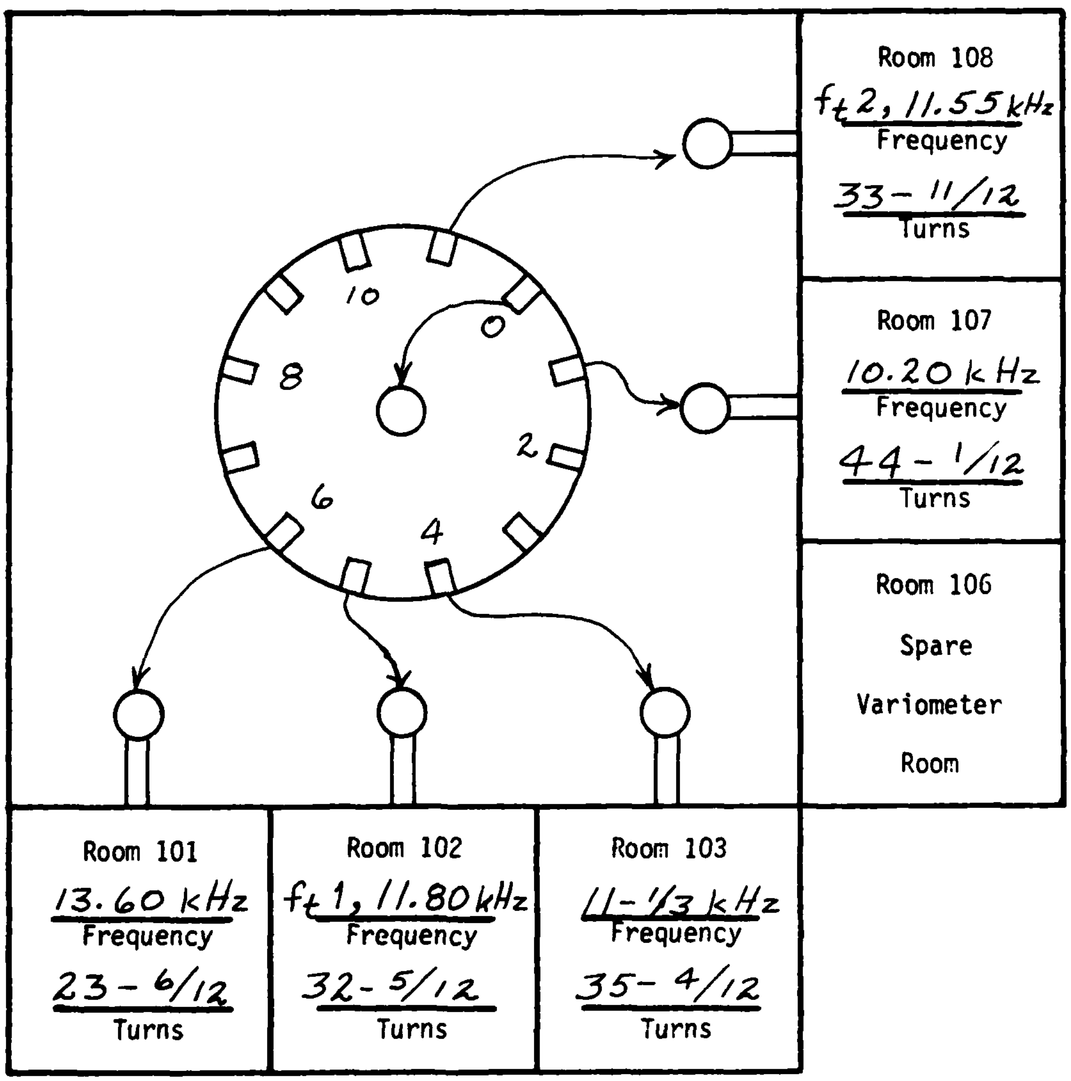


Figure 5. Helix and variometer room floor plan, original.

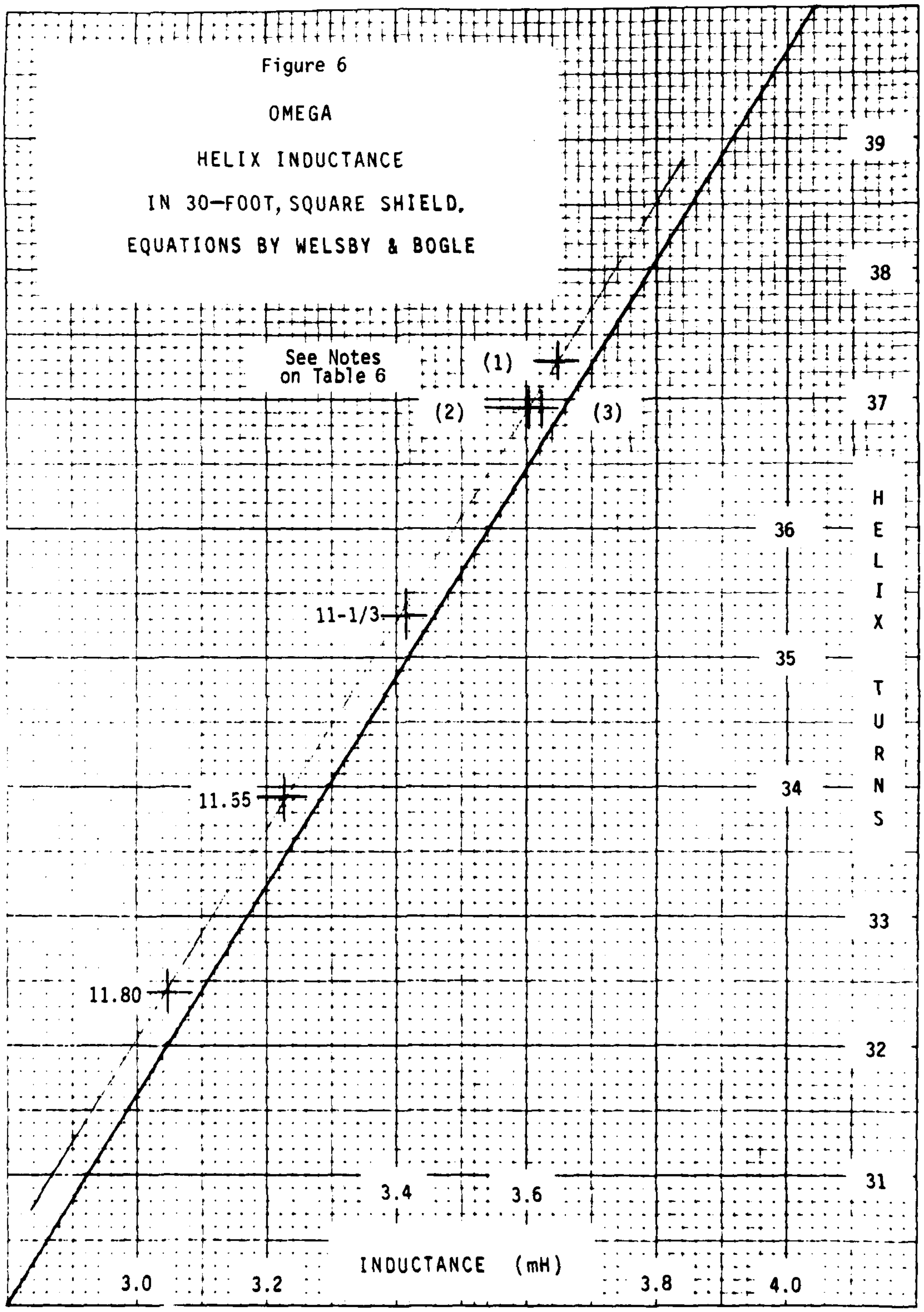


Figure 6
OMEGA
HELIX INDUCTANCE
IN 30—FOOT, SQUARE SHIELD,
EQUATIONS BY WELSBY & BOGLE
See Notes on Table 6
(1)
(2)
(3)
11-1/3
11.55
11.80
39
38
37
36
35
34
33
32
31
HELIX TURNS
3.0
3.2
3.4
3.6
3.8
4.0
INDUCTANCE (mH)

A calculated curve was also plotted to aid in extrapolation. The plotted curve of measured inductance was extended parallel to the calculated curve until it intersected the required helix inductance for 11.05 kHz. This occurred at 37-4/12 turns. These calculations and data are shown in Note (1) of table 6.

7. Variometer room number 108 was made available for use on 11.05 kHz because of the deletion of 11.55 kHz. This room is best connected to the helix from a tap on column 11 of the helix. This means that the number of helix turns to produce the required inductance must be NN-11/12. The calculated number of turns (37-4/12) is closest to 36-11/12. Working backward through figure 6 and figure 4 the predicted variometer position was calculated. These calculations are shown in Note (2) of table 6. The predicted variometer position is in an acceptable portion of the variometer operation range.

8. The 11.05 kHz tap was inserted at 36-11/12 turns of the helix and connected to variometer room 108.

9. The 11.05 kHz variometer position was measured after completion of the tapping and recorded as Note (3) of table 6. These data indicate that the helix inductance and/or the apparent capacitance have been determined with an error of less than 1%.

10. A floor plan of the helix house showing frequency assignments to the variometer rooms and the tap locations on the helix is shown as figure 7. Column "0" designates the start of the helix inductance. Due to the direction of winding the column numbers increased in a clockwise direction when viewed from the top.

HELIX PLAN

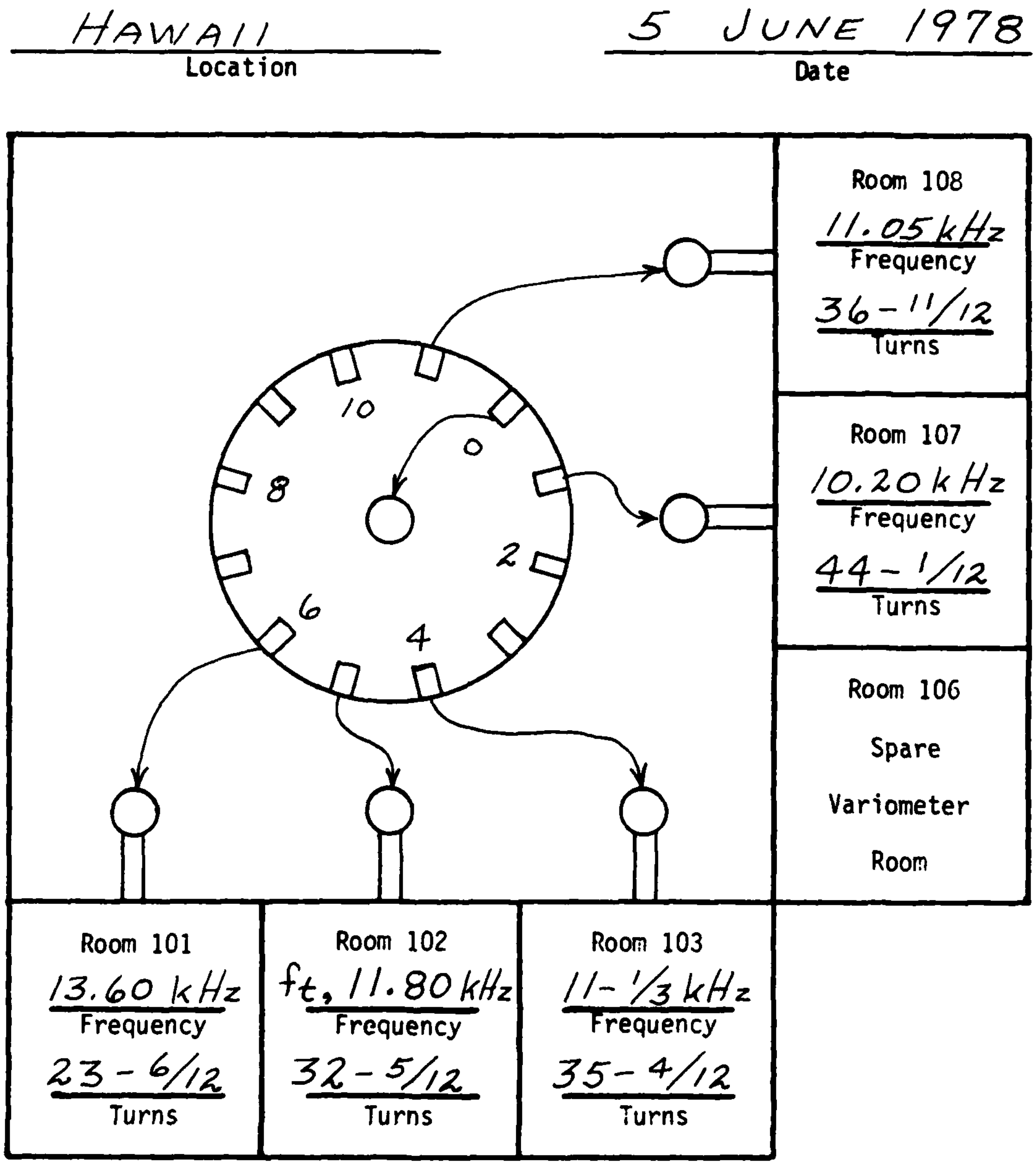


Figure 7. Helix and variometer room floor plan, final.

III. ANTENNA SYSTEM RESISTANCE

INTRODUCTION

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.

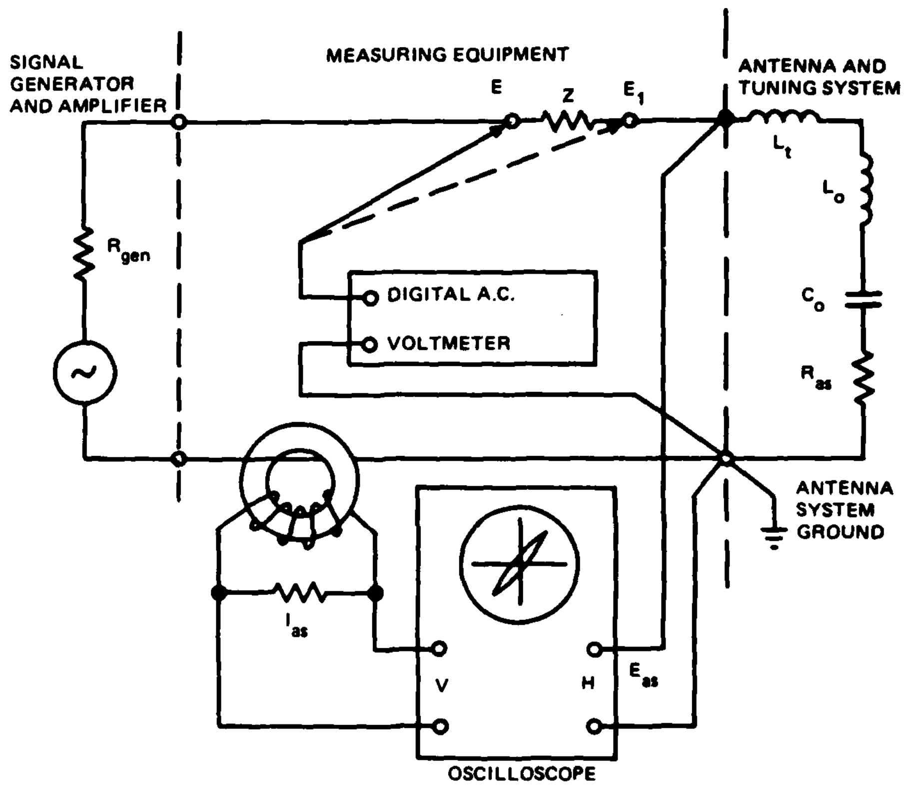
PROCEDURE

1. The equipment required for this measurement, the schematic diagram of the instrumentation, and the step-by-step procedure are shown in figure 8.

2. If a good non-inductive resistor is used for Z, it may not be necessary to include the inductance in the value. This would simplify the calculations.

3. It is normally proper to make several measurements, re-resonating the antenna system each time, to establish the values of E_1, E_2 and the calculated value of R_{as}.

4. These data are recorded on Data Sheets 2, using at least one data sheet for each frequency.



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 8. R_{as} measurement, incremental voltage method

TABI 7. ANTENNA SYSTEM RESISTANCE, R_{as}.

Frequency kHz	R_{as} Ohms 1978 5 June	11 June	12 June
10.20	0.718	(1) 1.376 (2) 1.476 (3) 1.415	0.929
11.05	0.751	(2) 1.297	0.924
11-1/3	≈1.0*	(2) 1.380	0.911
11.80	0.746	(2) 1.310	0.903
13.60	0.769	(1) 1.194 (2) 1.158	0.901

Notes:
* Defective Relay
(1) Values measured prior to, and the reason for, cleaning the insulators.
(2) Values measured after cleaning of insulators.
(3) Value measured one-half hour after series (2) as a test of trend.

5. The mean values of R_{as} calculated are also shown in table 7 in a column under the date of measurement.

6. If, as in some cases, there is a large amount of noise present, it is necessary to measure the rms value of the noise and subtract the noise from the voltmeter reading to obtain the true value of the signal. In this report the rms subtraction was performed if there was enough noise to change the last digit, of a four-digit number, by one.

7. If time permits, it is always prudent to make these measurements any time the weather conditions change. For this report, measurements were made on three days having markedly different weather conditions and, as expected, produced quite different values of R_{as}.

RESULTS

1. As previously noted, these measurements were made on three different days. The dates were 5, 11 and 12 June 1978. The weather conditions are noted below with other substantiating comments regarding the differences in values measured.

(a) 5 June 1978. Rain had been falling intermittently all day and varied between moderate and heavy. The clouds' bases were at the downlead connection to the lower valley span top load wire. All of the span insulators were in clouds. The wind, while from the normal north-easterly direction, was lower in velocity than the usual trade winds. The transmitter had been operating briefly at normal output. Note that on this day the 11-1/3 kHz antenna relay was defective as indicated by abnormally high resistance values. This relay could not be exchanged in time to be included in this series of measurements.

(b) 11 June 1978. The three previous days were marked by little precipitation and strong north-east trade winds. Measurements were begun within 30 minutes of the time the transmitter was secured. All of the transmitter meter readings indicated a nominal load resistance on the transmitter. The antenna matching transformer tap was set to the chosen value of 0.74 ohms based on the previous measurements. When the first three trials of 10.2 kHz showed an abnormally high value (almost double the values for 5 June 1978), the measurements were secured while exit bushing and tripod insulators were cleaned. The next series of measurements on 10.2 kHz showed even higher values of R_{as}. The series of measurements were continued on the remaining frequencies with similar, and variable, results. A last series of 5 measurements was performed on 10.2 kHz 30 minutes later also with variable results. It was now 2100 LST so the station was brought on the air, slowly. The increased grid current (0.7A. on 10.2 kHz) before full output was achieved confirmed the increased load resistance. As time went by, the grid current dropped slowly while the required drive level decreased slightly. This indicated that the load resistance was dropping as time, at power, passed. After several hours the transmitter was producing its nominal output with normal grid and anode currents.

(c) 12 June 1978. These measurements were made between 0900 and 0945 LST. The transmitter had been in operation all night at normal power. The weather was cool and dry with the normal northeast trade winds blowing. NOTE: The 11-1/3 kHz relay was repaired and installed for the measurements of 11 and 12 June 1978. Note that the resistances measured on 11-1/3 kHz are now in conformity with the values for the other frequencies.

CONCLUSIONS

1. The values of R_{as} measured on 5 June 1978 probably are the correct values which would be found in a clean antenna. Any surface contamination on the span insulators, the tie-off insulators, the tripod insulators or the exit bushing insulator had been washed away and all were bathed in "pure" rainwater. These values must be considered official unless future conditions change.

2. The values of R_{as} measured on 11 June 1978, which showed a marked increase in resistance shortly after the transmissions were secured, are probably the result of contamination by salt spray. The process of contamination is possibly as follows. Salt spray, picked up and carried onshore by strong trade winds, is deposited primarily on the span insulators. This salt spray would be dried by leakage current during normal operation resulting in the antenna system resistance remaining at the value for clean antenna insulators. The station was secured, for

measurement, after sunset during the time of increasing relative humidity. The increased moisture and surface salt increased the leakage across the span insulator surfaces. This is translated to an increased series loss resistance. Further credence is given to this hypothesis by the slow return to normal after placing the station in operation.

3. The values of resistance, measured on 12 June 1978, were calculated from data taken between 0900 and 0945. The weather was cool and dry. The relative humidity was probably down from the usually higher night time values. Note that the resistance values are also intermediate to those of 5 and 11 June 1978.

4. It has been noted, in prior unrecorded conversations with people responsible for the station installation, that at times the transmitter meter readings indicate a higher than normal antenna system resistance at the onset of rain. It was not determined whether the readings came back to normal as the rain persisted. I must conjecture that they probably would have, if the rain was heavy enough and lasted for a sufficient interval to clean the insulators.

5. Due to the inaccessibility of the span and tie-off insulators there is nothing to be done, when dirty insulators are indicated, except keep the transmitter at the maximum safe power and wait for nature to clean them.

6. The Antenna Matching Transformer had been strapped for impedance matching of a 50 ohm line to a load of 0.74 ohms. The connections are

shown in table 8. There is no reason to make a change since the usual R_{as}, under power, is very close to the value.

TABLE 8. ANTENNA MATCHING TRANSFORMER CONNECTIONS

50	Impedance (ohms)	0.74
Primary	Terminals	Secondary
1 connected to 7		14
and		and
6 connected to 12		16

IV. ANTENNA TUNING SERVO GEAR RATIO TESTS

INTRODUCTION

1. In order to design a gear box for the antenna tuning system, and specify preliminary gear ratios which would perform on a number of widely different antennas, it was necessary to make the following assumptions:

(a) All of the capacitance of the antenna was lumped at the top.

(b) All of the inductance was lumped in the tuning system.

(c) And, the variable inductance was linear with position over the entire range of movement.

None of these assumptions is true in a real installation, however, the approximation is close enough to provide a base for further refinement.

2. The original gear ratios were based on the ΔL required to retune a ΔC using the equation $f = \frac{1}{2\pi LC}$. A further requirement was equal spacing of the ratios about 1:1. This produced a ratio of 4/3 for 10.2 kHz and 3/4 for 13.6 kHz. This is a desirable concept to prevent absurd ratios but is not always possible with the discrete numbers of teeth which are on available sprockets.

3. It must be assumed that the self-inductance of the antenna will remain virtually constant and the variable, that causes a change in tuning capacitance, is neither apparent or measurable. This ΔC must be simulated by addition of capacitance outside of the exit bushing of the helix house.

In this case the only accessible place is on the roof of the helix house at the exit bushing.

TEST PROCEDURES

1. The procedure of Appendix F Revision 1 was used with the following details:

(a) The switchable capacitor was located on the roof of the helix building, near the exit bushing, and connected to the bushing corona ring.

(b) The capacitor spacing was 11/16 inches producing a capacitance of approximately 800 pF. A spacing of one inch, while providing a capacitor of a reasonably high voltage rating, did not produce enough capacitance. The main servo drive shaft rotated only 14 turns. The spacing was reduced to 11/16 inch which caused the shaft to rotate approximately 22 turns. This number of turns was acceptable but the lower voltage rating of the capacitor dictated a reduction in antenna current to 30 amperes. This is a marginally low level for automatic antenna tuning.

(c) Step 12, of the Appendix F Revision 1 procedure, was repeated 5 times. The shaft rotation was counted in each direction which produced 11 readings and 10 values of counter differences or drive shaft revolutions. These data are recorded, in the table 9 through 13, for each frequency. The mean number of drive shaft revolutions (MDSR) was calculated and entered in table 9 through 13 and table 14, which is produced as shown in the Appendix F Revision 1 procedures for Data Sheet F2 Rev 1.

CALCULATIONS

1. Table 14 is completed as described in Appendix F Revision 1.

2. An inventory of all available sprockets is shown in table 15. From this list all the available ratios are calculated and arranged in ascending order as described in Appendix F Revision 1. These are shown in table 16.

3. Table 17 is patterned after Data Sheet F4 Rev 1 of Appendix F Revision 1. The LSR Ratio, from table 14, is entered on the appropriate line under the proper frequency. The procedure of Appendix F Revision 1 for Data Sheet F4 Rev 1 was followed to complete table 17.

RESULTS

1. Examination of the completed table 17 showed that three sets of gears had identical peak-to-peak errors. Quite arbitrarily the sets, shown in table 18, are labeled 1, 2, and 3.

2. Set 1 was selected for installation. The chosen pair of sprockets was installed on the shafts at the position nearest the input end of the input shaft in each of the five dedicated variometer rooms. All five gear ratios were installed in the spare variometer room gear box in order of increasing frequency starting at the input end. The sixth position was fitted with a 36/36 tooth pair of sprockets for an arbitrary 1:1 ratio.

TABLE 9. MDSR for 10.2 kHz.

Frequency (kHz)	ΔC (830 pF.)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
10.20	OFF	170.95	
			22.55
	ON	193.10	
			22.00
	OFF	171.10	
			22.45
	ON	193.55	
			21.95
	OFF	171.60	
			22.35
	ON	193.95	
			22.90
	OFF	171.05	
			22.60
	ON	193.65	
			22.80
	OFF	170.85	
			22.80
	ON	193.65	
			22.95
	OFF	171.70	
	Mean drive shaft revolutions (MDSR)		22.54

TABLE 10. MDSR for 11.05 kHz.

Frequency (kHz)	ΔC (830 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
11.05	OFF	170.85	
			22.90
	ON	193.75	
			22.25
	OFF	171.50	
			22.20
	ON	193.70	
			22.95
	OFF	170.75	
			23.25
	ON	194.00	
			23.40
	OFF	170.60	
			22.80
	ON	193.40	
			22.45
	OFF	170.95	
			22.50
	ON	193.45	
			23.50
	OFF	170.40	
	Mean drive shaft revolutions (MDSR)		22.78

TABLE 11. MDSR for 11.33 kHz.

Frequency (kHz)	ΔC (830 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
11.33	OFF	172.20	
			20.95
	ON	193.15	
			21.75
	OFF	171.40	
			21.90
	ON	193.30	
			21.45
	OFF	171.85	
			21.25
	ON	193.10	
			21.06
	OFF	172.04	
			21.26
	ON	193.30	
			21.70
	OFF	171.60	
			21.90
	ON	193.50	
			21.90
	OFF	171.60	
	Mean drive shaft revolutions (MDSR)		21.51

TABLE 12. MDSR for 11.80 kHz

Frequency (kHz)	ΔC (830 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
11.80	OFF	171.80	
			20.90
	ON	192.70	
			20.80
	OFF	171.90	
			21.40
	ON	193.30	
			21.70
	OFF	171.60	
			20.70
	ON	192.30	
			20.80
	OFF	171.50	
			21.50
	ON	193.00	
			21.35
	OFF	171.65	
			20.50
	ON	192.15	
			21.00
	OFF	171.15	
	Mean drive shaft revolutions (MDSR)		21.12

TABLE 13. MDSR for 13.60 kHz

Frequency (kHz)	ΔC (830 pF)	Main Drive Shaft Counter Reading (Turns)	Drive Shaft Rotation (Turns)
13.60	OFF	170.90	
			19.50
	ON	190.40	
			19.15
	OFF	171.25	
			20.00
	ON	191.25	
			19.00
	OFF	172.25	
			18.95
	ON	191.20	
			20.05
	OFF	171.15	
			20.20
	ON	191.35	
			18.75
	OFF	172.60	
			18.15
	ON	190.75	
			18.65
	OFF	172.10	
	Mean drive shaft revolutions (MDSR)		19.24

TABLE 14. PRELIMINARY GEAR RATIO CALCULATIONS.

Frequency (kHz.)	MDSR (Turns)		Installed Gear Ratio (2)		LSR (Turns) (2)		LSR Reference (1 & 2)		LSR Ratio (2)
10.20	22.54	X	1.33333 (48/36)	=	30.0533	:	14.4300	=	2.08270
11.05	22.78	X	1.08000 (54/50)	=	24.6024	:	14.4300	=	1.70495
11-1/3	21.51	X	1.08000 (54/50)	=	23.2308	:	14.4300	=	1.60990
11.80	21.12	X	1.00000 (36/36)	=	21.1200	:	14.4300	=	1.46362
13.60	19.24	X	0.75000 (33/44)	=	14.4300	:	14.4300	=	1.00000

NOTES

(1) While any of the LSR values may be chosen, it is easier to use the value of 13.60 which will produce whole number ratios for the next step.

(2) Even though the precision of measurement does not warrant it, keep 6 significant figures to avoid rounding errors.

TABLE 15. INVENTORY OF SPROCKETS FROM SIX INSTALLED GEAR BOXES.

Teeth (No.)	Quantity Per box	Quantity Total
33	1	6
36	5	30
44	1	6
48	1	6
50	2	12
52	1	6
54	1	6

TABLE 16. AVAILABLE GEAR RATIOS

Ratio	Sprockets Input-Output	Ratio	Sprockets Input-Output
0.61111	33-54	1.00000	50-50
0.63462	33-52	1.03846	54-52
0.66000	33-50	1.04000	52-50
0.66667	36-54	1.04167	50-48
0.68750	33-48	1.08000	54-50
0.69231	36-52	1.08333	52-48
0.72000	36-50	1.09091	36-33
0.75000	33-44	1.09091	48-44
0.75000	36-48	1.12500	54-48
0.81481	44-54	1.13636	50-44
0.81818	36-44	1.18182	52-44
0.84615	44-52	1.22222	44-36
0.88000	44-50	1.22727	54-44
0.88889	48-54	1.33333	44-33
0.91667	33-36	1.33333	48-36
0.91667	44-48	1.38889	50-36
0.92308	48-52	1.44444	52-36
0.92593	50-54	1.45455	48-33
0.96000	48-50	1.50000	54-36
0.96154	50-52	1.51515	50-33
0.96296	52-54	1.57576	52-33
1.00000	36-36	1.63636	54-33

TABLE 17. REQUIRED AND AVAILABLE GEAR RATIOS, AND PEAK-TO-PEAK ERRORS

Frequency (kHz)	13.60	11.80	11-1/3	11.05	10.20
LSR Ratio	1.00000	1.46362	1.60990	1.70495	2.80270
Required Ratio	0.61111	0.89443	0.98383	1.04191	1.27276
Available Ratio		0.88889	1.00000	1.04167	1.22727
Error (%)	5.35 p-p	-0.62	+1.64	-0.02	-3.71
Required Ratio	0.63462	0.92884	1.02167	1.08200	1.32172
Available Ratio		0.92593	1.03846	1.08333	1.33333
Error (%)	1.96 p-p	-0.32	+1.64	+0.12	+0.88
Required Ratio	0.66000	0.96599	1.06253	1.12527	1.37458
Available Ratio		0.96296	1.08000	1.12500	1.38889
Error (%)	1.96 p-p	-0.32	+1.64	-0.02	+104
Required Ratio	0.66667	0.97575	1.07327	1.13664	1.38847
Available Ratio		0.96296	1.08000	1.13636	1.38889
Error (%)	1.96 p-p	-1.33	+0.63	-0.03	+0.03
Required Ratio	0.68750	1.00624	1.10681	1.17215	1.43186
Available Ratio		1.00000	1.09091	1.18182	1.44444
Error (%)	2.34 p-p	-0.62	-1.46	+0.83	+0.88
Required Ratio	0.69231	1.01328	1.11455	1.18035	1.44187
Available Ratio		1.00000	1.12500	1.18182	1.44444
Error (%)	2.27 p-p	-1.33	+0.94	+0.12	+0.18
Required Ratio	0.72000	1.05381	1.15913	1.22756	1.49954
Available Ratio		1.04167	1.13636	1.22727	1.50000
Error (%)	2.03 p-p	-1.17	-2.00	-0.02	+0.03
Required Ratio	0.75000	1.09772	1.20743	1.27871	1.56203
Available Ratio		1.09091	1.22222	1.22727	1.57576
Error (%)	5.42 p-p	-0.62	+1.23	-4.19	+0.88

As originally installed

Required Ratio	0.75000	1.09772	1.20743	1.27871	1.56203
Available Ratio		1.00000	1.08000	1.08000	1.33333
Error (%)	18.4 p-p	-9.8	-11.8	-18.4	-17.2

TABLE 18. SELECTED GEAR RATIOS

Frequency (kHz)	Set 1	Set 2	Set 3
10.20 (Input/Output)	1.38889 (50/36)	1.38889 (50/36)	1.33333 (44/36) (48/36)
11.05	1.13636 (50/44)	1.12500 (54/48)	1.08333 (52/48)
11-1/3	1.08000 (54/50)	1.08000 (54/50)	1.03846 (54/52)
11.80	0.96296 (52/54)	0.96296 (52/54)	0.92593 (50/54)
13.60	0.66667 (36/54)	0.66000 (33/50)	0.63462 (33/52)

3. During this period it was known that spacers were under procurement which would replace unneeded sprockets in the dedicated variometer rooms. These spacers would reduce the inertia of the rotating parts of the tuning set and thereby reduce the loading due to acceleration. The spacers were not yet available so the station personnel, showing great initiative, had spacers manufactured locally. They were installed during this down-time precluding the requirement for off-air time in the future.

4. A helix and variometer room plan showing the installed gear ratios is presented as figure 9.

CONCLUSIONS

1. Live with these values for a year, noting any problems in tracking that occur during the changing seasons.

2. These ratios, and the resulting errors, are selected from sprockets available on station and are probably larger than the optimum values if all possible sprockets were available. After all the stations have been tested, and operated for a time, it may be advantageous to order the sprockets required for the most precise ratios possible for all stations.

HELIX PLAN

HAWAII
Location

12 JUNE 1978
Date

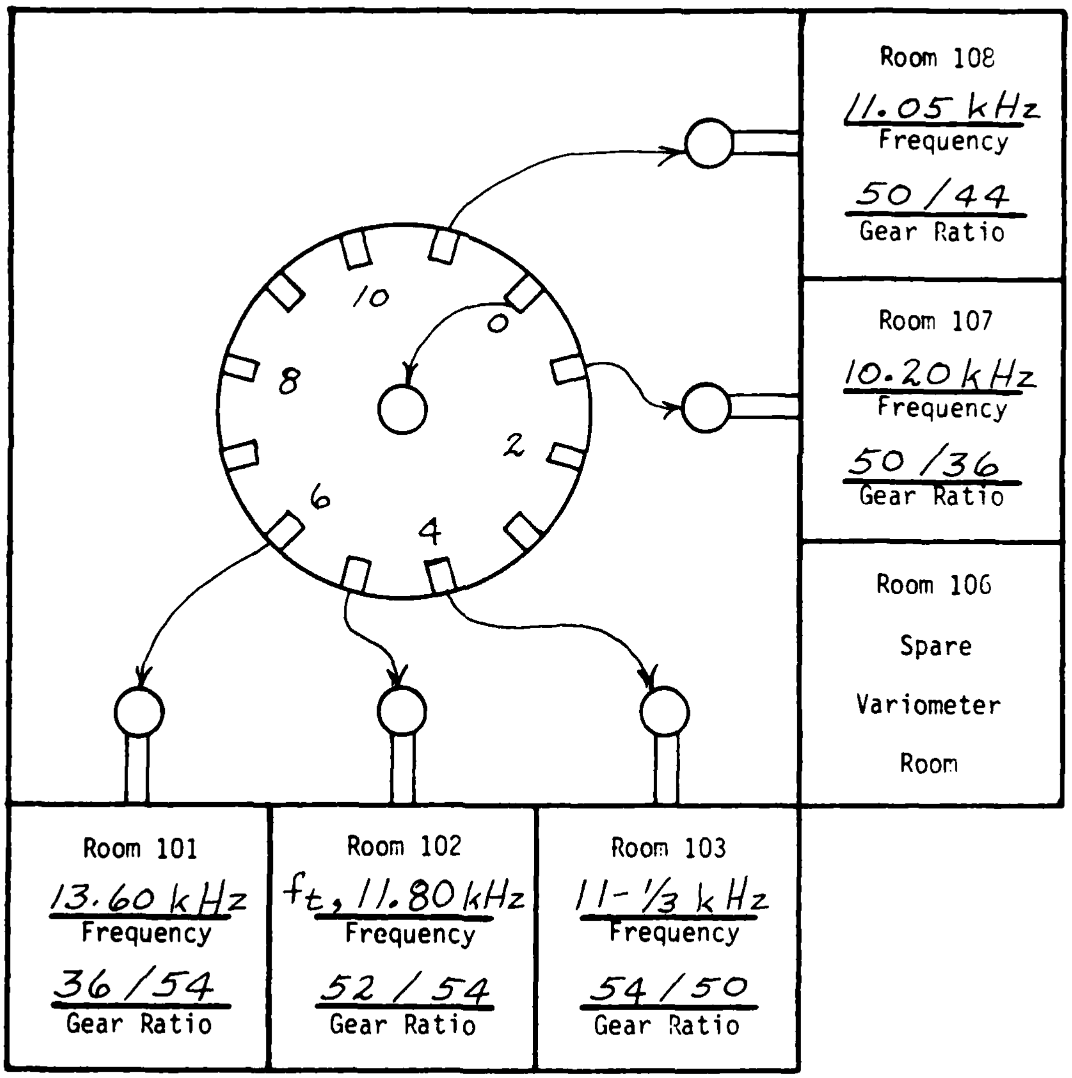


Figure 9. Helix and variometer room floor plan, gear ratios.

V. MISCELLANEOUS

INTRODUCTION

In the course of field measurements information is often discovered that should be preserved for the future, even though it was not part of the task. Two such bits of information are preserved herein.

HELIX TAP INSTALLATION

In order to install a tap in the helix inductor it is necessary to have some extra litz wire to reach the top plate after installation of flange connectors. The amount of extra wire and some pertinent dimensions are given in figure 10.

USE OF A SELECTIVE VOLTMETER FOR ANTENNA SYSTEM RESISTANCE MEASUREMENTS

1. Some OMEGA antennas are in poor environments with regard to atmospheric noise and other nearby VLF transmitters. In some cases it is possible to measure the noise and make an rms subtraction to obtain the true value of signal. It was suggested that a Hewlett-Packard Model 3581-C Selective Voltmeter be used to reduce the bandwidth of the measurement and so reduce the noise. Following are observations regarding the precision of this kind of measurement.

2. The Fluke 8600 digital multimeter has been used as a measuring device for measurements of R_{as}. Its linearity was believed to be excellent and a test proved this to be correct. The test consisted of measuring the

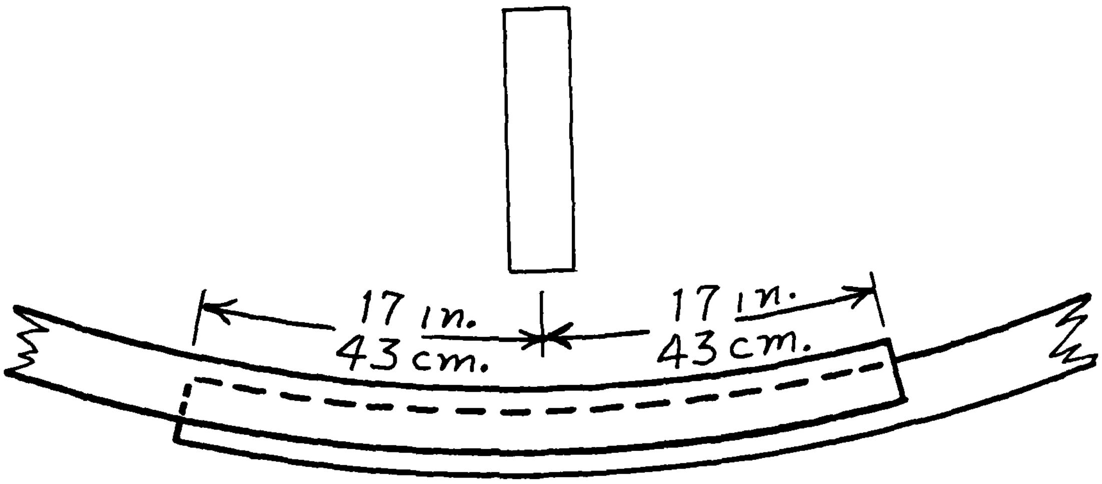


Figure 10. Overlap required for helix tap.

voltages across the pair of resistors used for R_{as} measurements. These resistors have been carefully measured and found to have a ratio, in this configuration, of 1:0.5002. (This same resistor set will be used in all of the following tests.) A signal having a frequency of 13.6 kHz was applied to the pair of resistors connected as a voltage divider. The Fluke 8600 was used to measure the input and divided voltage. The ratio calculated was 1:0.5005. Comparing this to the ratio of the voltage divider produced an error of +0.06%, an excellent value.

3. The Hewlett-Packard 3581-C uses a panel meter for an indicator. Even though it is of a high quality there are limitations on reading the values indicated. The scheme for measurement of R_{as} relies only on the linearity of the readings taken and not the accuracy of the instrument. A pointer type meter not only may have linearity errors but it is difficult to read values near full and half scale to the precision desired. Using the panel meter, and the same resistive voltage divider and signal generator, readings were taken of the input and divided voltage. The ratio calculated was 1:0.4917. This gives an error of -1.73%. In all honesty most of this error is due to the difficulty of obtaining a precise value from the meter scale and pointer, however panel meters usually have some linearity errors. (Digital meters may also have linearity error but the reading error is minimized.)

4. On the back panel of the H-P 3581-C is a jack labeled Restored Output. This is purported to be a noise-free replica of the input signal. Using the same voltage dividers and measuring the restored output with the Fluke 8600 digital meter produced an astonishingly precise value for the ratio - 1:0.5016. This is an error of only +0.28%

5. These observations were only of one selective voltmeter. If noise and/or interference are a problem it is recommended that the selective voltmeter restored output be tried after determination of the linearity of the instrument. The panel meter is usually not good enough for the incremental voltage method of R_{as} measurement.

6. Table 19 shows these measurements and the results.

TABLE 19. SELECTIVE VOLTMETER TESTS

Function Measured	Instruments: Fluke 8600	H-P 3581-C Panel Meter	H-P 3581-C Restored Fluke 8600
Input Voltage	4.042	3.00	2.532
Divided Voltage	2.023	1.475	1.270
Ratio Calculated	1:0.5005	1:0.4917	1:0.5016
Error	+0.06%	-1.73%	+0.28%

VI. FIELD INTENSITY MEASUREMENT POSITION LOCATION

INTRODUCTION

1. The search for, and selection of, sites for measurements and sites for position locating equipment was done earlier and reported in Megatek Corp. Informal Report, R2018-025-IF-1 (Appendix I), which covered items not germane to this report. Only those portions applicable are reprinted here. The method of position location is detailed in Appendix G.

MEASUREMENT SITES

1. The radial directions to be flown and the distances from the OMEGA transmitting antenna were chosen to be representative of the different paths the signal takes while departing. Some departures from uniformly spaced radial directions were dictated by installations such as airports, gunnery ranges, and mountains. The radials and distances used for measurement are shown in figure 11. Also in figure 11 are the Distance Measuring Equipment (DME) transponder locations.

DME RANGE DATA

1. In order to select geometrically acceptable transponder locations, maps were examined. Some choices were made only considering the location within the proposed operating area. After checking the accessibility of, and flying over, several of the sites, some of those originally selected were summarily discarded and others not originally considered were

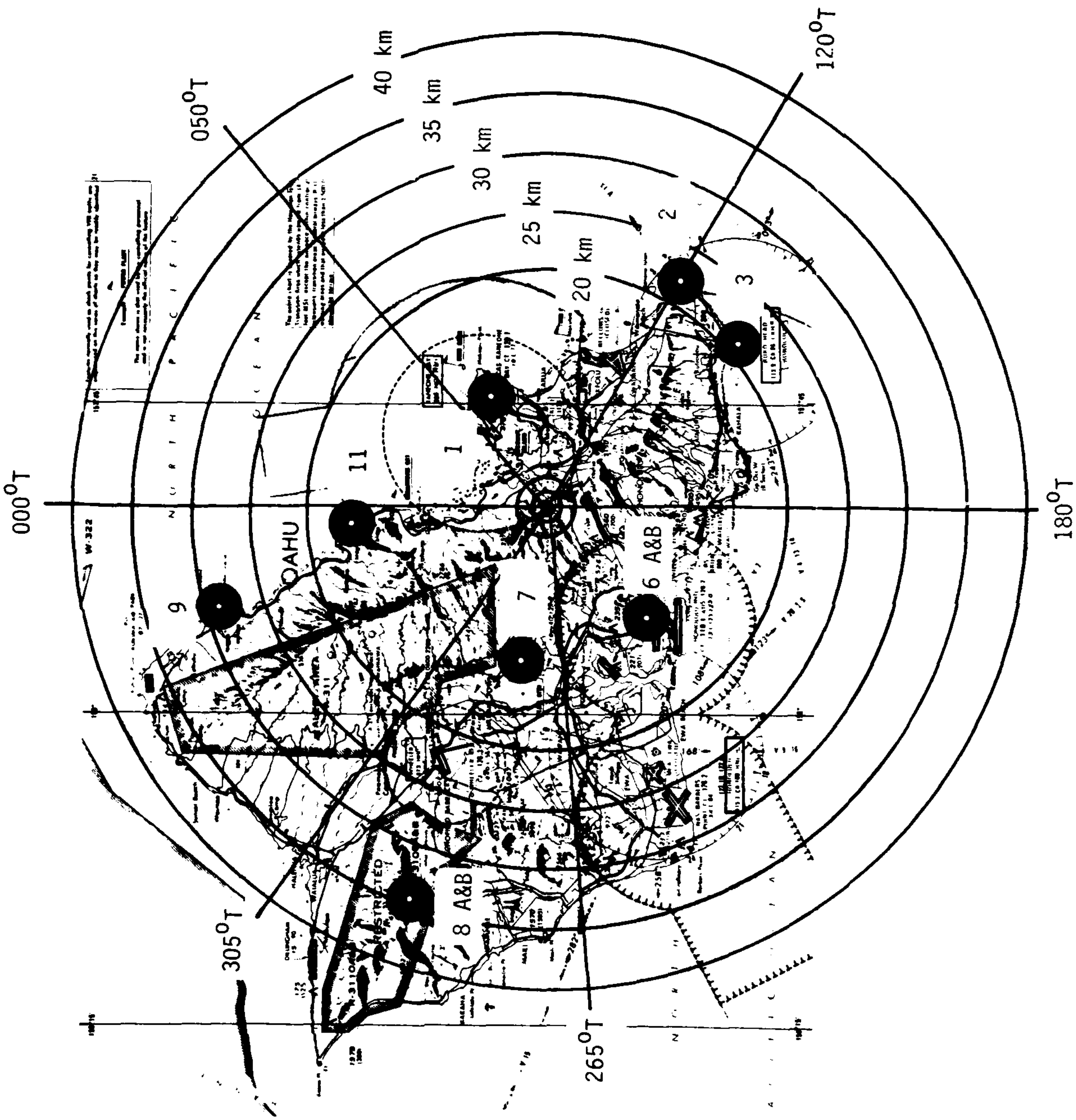


Figure 11. Radials, distance circles and transponder locations.

substituted. The metric grid locations of the sites finally selected are given in table 20.

TABLE 20. TRANSPONDER SITE LOCATIONS.

Site Number	Metric Grid North	Metric Grid East
OMEGA STATION	23-67-793 N	6-20-906 E
1	23-72-626 N	6-28-566 E
2	23-57-366 N	6-39-655 E
3A	23-52-538 N	6-34-342 E
3B	23-52-151 N	6-34-158 E
6A	23-59-643 N	6-11-719 E
6B	23-59-672 N	6-11-729 E
7	23-70-483 N	6-09-657 E
8A	23-78-958 N	5-88-498 E
8B	23-78-903 N	5-88-637 E
9	23-94-702 N	6-12-057 E
11	23-84-551 N	6-18-570 E

2. Since this was a one-time operation no formal drawings or sketches were produced. The team of transponder operators was taken to each site and given verbal instructions. The individual team members took any notes they deemed necessary.

3. Position fixing by DME requires a baseline, between transponders, of known length and azimuth. The law of cosine is used to solve for the angle between the base line and one vector to the helicopter, the distance being one of the measurements. The angle from the chosen (D1) transponder to the helicopter is added to the azimuth of the baseline to produce a vector (degrees true) from the D1 transponder to the helicopter. This vector is then added to the baseline from the OMEGA station to the D1 transponder, which locates the helicopter in terms of azimuth and distance from the OMEGA station. The program for the Hewlett-Packard (HP) calculator(s) used in the helicopter was taken from H-P Programs MATH 1-20A and NAV 1-24A with considerable modification to present both distance in kilometers and azimuth in degrees true on a single display line. Tables 21 through 26 show the baselines used for each of the measurement radials. The values of azimuth and distance are given to 10 significant figures only to minimize rounding errors in the computational process. Exponential notation is used. The clockwise (CW) or counterclockwise (CCW) Solution refers to the position of the helicopter with respect to the hemisphere on either side of the baseline between the transponder for D1 to D2. The transponder antenna aiming data is given in degrees Magnetic. All baselines include an average grid azimuth correction of +0.372°T.

TABLE 21. BASELINES, RADIAL 000° T.

Site Number	Metric Grid North	East
11 (D1)	23-84-551 N	6-18-570 E
9 (D2)	23-94-702 N	6-12-057 E
Station	23-67-793 N	6-20-906 E

Site 9 to 11:	Az.	3.276 872 958 EX2	°T.
	Dist.	1.206 076 158 EX4	m.
Station to Site 11:	Az.	3.524 363 277 EX2	°T.
	Dist.	1.692 003 132 EX4	m.

CW Solution.

Transponder Antenna Azimuth	
Site 11	015°M.
Site 9	080°M.

TABLE 22. BASELINES, RADIAL 050°T.

Site Number	Metric Grid North	East
1 (D1)	23-72-626 N	6-28-566 E
2 (D2)	23-57-366 N	6-39-655 E
Station	23-67-793 N	6-20-906 E

Site 1 to 2:	Az.	1.443 671 812 EX2	°T.
	Dist.	1.886 355 006 EX4	m.
Station to Site 1:	Az.	5.812 253 540 EX1	°T.
	Dist.	9.057 234 070 EX3	m.

CCW Solution.

Transponder Antenna Azimuth	
Site 1	040°M.
Site 2	000°M.

TABLE 23. BASELINES, RADIAL 120°T.

Site Number	Metric Grid North	East
1 (D1)	23-72-626 N	6-28-566 E
3A (D2)	23-52-538 N	6-34-342 E
Station	23-67-793 N	6-20-906 E

Site 1 to 3A:	Az.	1.643 302 126 EX2	°T.
	Dist.	2.090 191 187 EX4	m.
Station to Site 1:	Az.	5.812 253 540 EX1	°T.
	Dist.	9.057 234 070 EX3	m.

CCW Solution.

Transponder Antenna Azimuth	
Site 1	130°M.
Site 3A	055°M.

TABLE 24. BASELINES, RADIAL 180°T.

Site Number	Metric Grid North	East
6A (D1)	23-59-643 N	6-11-719 E
3B (D2)	23-52-151 N	6-34-158 E
Station	23-67-793 N	6-20-906 E

Site 6A to 3B:	Az.	1.088 352 869 EX2	°T.
	Dist.	2.365 688 584 EX4	m.
Station to Site 6A:	Az.	2.287 950 269 EX2	°T.
	Dist.	1.228 102 068 EX4	m.

CW Solution.

Transponder Antenna Azimuth	
Site 6A	135°M.
Site 3B	240°M.

TABLE 25. BASELINES, RADIAL 265°T.

Site Number	Metric Grid North	East
7 (D1)	23-70-483 N	6-09-657 E
8A (D2)	23-78-958 N	5-88-498 E
Station	23-67-793 N	6-20-906 E

Site 7 to 8A:	Az.	2.922 000 164 EX2	°T.
	Dist.	2.279 317 674 EX4	m.
Station to Site 7:	Az.	2.838 207 198 EX2	°T.
	Dist.	1.156 616 190 EX4	m.

CCW Solution.

Transponder Antenna Azimuth	
Site 7	240°M.
Site 8A	140°M.

TABLE 26. BASELINES, RADIAL 305°T.

Site Number	Metric Grid North	East
6B (D1)	23-59-672 N	6-11-729 E
8B (D2)	23-78-903 N	5-88-637 E
Station	23-67-793 N	6-20-906 E

Site 6B to 8B:	Az.	3.101 595 065 EX2	°T.
	Dist.	3.005 115 347 EX4	m.
Station to Site 6B:	Az.	2.288 654 298 EX2	°T.
	Dist.	1.225 430 414 EX4	m.

CW. Solution.

	Transponder Antenna Azimuth
Site 6B	330°M.
Site 8B	055°M.

VII. INSTALLATION OF EQUIPMENT ON THE HELICOPTER

1. During installation of the loop antenna and the DME transponder on the helicopter a problem arose concerning structural additions to the helicopter. Initially it was believed that an experimental license or a waiver to the regular license should be obtained. This is a very time consuming procedure and involves many departments of the Federal Aviation Agency (FAA). During a meeting, with the FAA, about this problem a solution was derived.

2. Since this work was in response to a government contract, and for the duration of these flights only, the helicopter could be declared to be an aircraft in the public service of the U.S. Government. This was accomplished for expediency.

VIII. FIELD INTENSITY MEASUREMENTS

INTRODUCTION

1. Field intensity measurements were made on the surface of the earth (loop height of approximately 2 meters) for both helicopter calibration and benchmark data using the method of Appendix C. Airborne field intensity measurements were made over six radial directions, at distances nominally of 20, 25, 30, 35 and 40 kilometers, and at altitudes nominally 1000 feet above the surface, using the procedures of Appendix E.

2. Antenna current was maintained at 400 amperes, for all measurements, using Procedure B of Appendix D (Revision 2).

HELICOPTER CALIBRATION

1. Helicopter calibration sites were originally considered at:

   a. NAS Barbers Point (Navy)

   b. Dillingham Airfield (Private)

   c. Kuilima Air Park (Private)

2. The site of Dillingham airfield was rejected; partly because of the distance from the OMEGA station but primarily because of nearby wires both on poles and on the ground.

3. The administrative details could not be addressed in the short time available to use NAS Barbers Point. Therefore, permission was obtained

to investigate Honolulu International Airport. Tests performed at the center of Honolulu International Airport showed the effects of underground wires which cause large changes in field intensity with small changes in position. Therefore, this site was not suitable.

4. Bellows Air Force Base (closed), which had been used for a test of the DME, was ruled out when permission to use it for helicopter calibration was not granted.

5. The remaining candidate site, C1, was located at Kuilima Air Park which is owned by Hyatt Hotels. Permission to use it was obtained by the enthusiastic cooperation of Mr. John Kirk, manager of the Kuilima Hyatt Hotel. The only requirement was a few hours advance notice so their guests using the adjacent bridle path could be advised of our presence. Since this was our only calibration it was used twice, on two consecutive days, with as much separation as possible (approximately 1 kilometer).

6. Calibration measurements were taken on two consecutive days at the locations mentioned above. At each site three complete sets of measurements were made, at each frequency, on a tripod without the presence of the helicopter, and by the helicopter mounted loop, at the same loop height, in both directions of the loop pattern.

7. A summary of the mean values of these measurements and the calculation of the mean values of the vehicle factors (K_3) are given in tables 27, 28, and 29.

TABLE 27. SUMMARY OF HELICOPTER CALIBRATION MEASUREMENTS.

24 May 1979

Surface Measurements

Frequency (kHz)	Mean E_g (mV)	Mean E_m (mV)
10.20	23.0	22.8
11.05	26.2	25.9
11-1/3	27.4	27.1
11.80	28.2	27.9
13.60	31.4	31.1

Airborne Measurements

Nose generally toward the station

Frequency (kHz)	Mean E_g (mV)	Mean E_m (mV)	Surface Mean E_m (mV)	Ratio (K_3)
10.20	22.0	22.0	22.8	1.04
11.05	25.2	25.2	25.9	1.03
11-1/3	26.4	26.4	27.1	1.03
11.80	27.1	27.1	27.9	1.03
13.60	30.1	30.1	31.1	1.03
			Mean	1.03

Nose generally away from the station

Frequency (kHz)	Mean E_g (mV)	Mean E_m (mV)	Surface Mean E_m (mV)	Ratio (K_3)
10.20	22.2	22.2	22.8	1.03
11.05	25.1	25.1	25.9	1.03
11-1/3	26.5	26.5	27.1	1.02
11.80	27.4	27.4	27.9	1.02
13.60	30.1	30.1	31.1	1.03
			Mean	1.03

TABLE 28. SUMMARY OF HELICOPTER CALIBRATION MEASUREMENTS.

25 May 1979

Surface Measurements

Frequency (kHz)	Mean E_g (mV)	Mean E_m (mV)
10.20	23.2	23.0
11.05	26.4	26.1
11-1/3	27.4	27.1
11.80	28.0	27.8
13.60	31.6	31.3

Airborne Measurements

Nose generally toward the station

Frequency (kHz)	Mean E_g (mV)	Mean E_m (mV)	Surface Mean E_m (mV)	Ratio (K_3)
10.20	22.3	22.3	23.0	1.03
11.05	25.6	25.6	26.1	1.02
11-1/3	26.6	26.6	27.1	1.02
11.80	27.2	27.2	27.8	1.02
13.60	30.5	30.5	31.3	1.03
			Mean	1.02

Nose generally away from the station

Frequency (kHz)	Mean E_g (mV)	Mean E_m (mV)	Surface Mean E_m (mV)	Ratio (K_3)
10.20	22.1	22.1	23.0	1.04
11.05	25.0	25.0	26.1	1.04
11-1/3	26.0	26.0	27.1	1.04
11.80	26.8	26.8	27.8	1.04
13.60	29.9	29.9	31.3	1.05
			Mean	1.04

TABLE 29. SUMMARY OF K_3.

Date	Flight Configuration	Ratio K_3
24 May 1979	Nose Toward	1.03
	Nose Away	1.03
25 May 1979	Nose Toward	1.02
	Nose Away	1.04
	Mean K_3	1.03

8. It should be noted that a second set of measurements were made at Site C1. The position was approximately 30 meters from the center of the runway and marked Site C1A on DS-5. This set of readings was used to verify the uniformity of the field in this area. The difference was less than 2%, showing little or no field distortion.

9. In the afternoon of 24 May 1979, following the first calibration flight, a test was made on radial 265 (figure 11). This test was to look for the source of intermittent noise which had occasionally been observed during the calibration flights. The cause of the intermittent noise was an occasional ground loop which closed when the signal generator and the loop amplifier accidentally touched in the helicopter. The ground loop was opened by cutting out a 2-inch portion of the Twin-ax shield near the loop amplifier.

C. MEASUREMENTS

1. A total of 372 airborne field intensity measurements were made at 30 sites in 6 radial directions from the transmitting antenna.

2. Measurement sites are identified by a three- and two-digit hyphenated number. For instance, the 120-20 measurement was taken at 120 degrees true and 20 kilometers from the transmitting antenna.

3. Radials 000, 050, 120 and 180 were generally over water. The measurement altitude, for all over water sites, was 1000 feet above sea level with the exception of site 120-20. An altitude of 2000 feet above sea level was required at site 120-20 to obtain line of sight to a DME transponder.

4. Radial 265, which is all over land, was flown at 4000 feet primarily to obtain line of sight to a DME transponder. A height-gain measurement was taken at 265-35 on two consecutive days. The mean difference was 1.5% indicating no significant change.

5. Radial 305, which is all over land, was flown at 3000 feet. Since a previous measurement over land showed no significant height-gain, and the clouds prevented a higher flight altitude, this was determined to be acceptable.

6. All measurement data were recorded on data sheets DS-5. A position fix was obtained for each measurement because it is nearly impossible to hover over a fixed position at the altitudes being flown.

7. All appropriate data were transcribed from data sheets DS-5 to data sheets DS-6. Calculations were made to complete all data sheets DS-6.

8. Only the normalized field-distance product ($E_r d/I_a$) was used for statistical processing.

9. Effective height and radiation resistance of the antenna were calculated, from the mean value of the normalized field-distance product, for each frequency.

10. Summaries of antenna and station parameters for each frequency are shown in tables 30 through 34.

TABLE 30. FIM SUMMARY, 10.2 kHz.

$E_r d/I_a$	:	$\bar{X}$ = 2.169, N = 75, S_x = 0.074
h_e	:	169 meters, 555 ft.
R_r	:	0.0523
$I_a(P_r = 10)$	:	437 A.
$I_{as}(P_r = 10)$	:	446 A.
		For R_{as} = 0.718
I_{as}(Max)	:	457 A.
P_r(Max)	:	10.488 kW

TABLE 31. FIM SUMMARY, 11.05 kHz.

$E_r d/I_a$	:	$\bar{X}$ = 2.363, N = 76, S_x = 0.054
h_e	:	170 meters, 558 ft.
R_r	:	0.0620
$I_a(P_r = 10)$	:	401 A.
$I_{as}(P_r = 10)$	:	410 A.
		For R_{as} = 0.751
I_{as}(Max)	:	447 A.
P_r(Max)	:	11.901 kW.

TABLE 32. FIM SUMMARY, 11-1/3 kHz.

$E_r d/I_a$	:	$\bar{X} = 2.411$, $N = 76$, $S_x = 0.054$
h_e	:	169 meters, 555 ft.
R_r	:	0.0646
$I_a(P_r = 10)$	:	393 A.
$I_{as}(P_r = 10)$	:	402 A.
		For $R_{as} = 0.750$*
I_{as}(Max)	:	447 A.
P_r(Max)	:	12.406 kW.

*Estimated value. The original relay was defective and was replaced. The weather was bad during the remainder of the measurement period.

TABLE 33. FIM SUMMARY, 11.80 kHz.

$E_r d/I_a$	:	$\bar{X} = 2.489$, $N = 74$, $S_x = 0.063$
h_e	:	168 meters, 551 ft.
R_r	:	0.0688
$I_a(P_r = 10)$	:	381 A.
$I_{as}(P_r = 10)$	:	389 A.
		For $R_{as} = 0.746$
I_{as}(Max)	:	448 A.
P_r(Max)	:	13.293 kW.

TABLE 34. FIM SUMMARY, 13.6 kHz.

$E_r d/I_a$	:	$\bar{X}$ = 2.903, N = 71, S_x = 0.077
h_e	:	170 meters, 557 ft.
R_r	:	0.0936
$I_a(P_r = 10)$	:	327 A.
$I_{as}(P_r = 10)$	:	333 A.
		For R_{as} = 0.769
I_{as}(Max)	:	442 A.
P_r(Max)	:	17.542 kW.

11. The antenna in Haiku Valley is one of two valley-spanning antennas in the OMEGA system. It is the only valley-spanning antenna around which a comprehensive set of measurements was possible. A summary, showing the percentage deviation from a circular pattern, is given in table 35 by radial direction and frequency.

12. If any consideration had been given to the possible distortion, and shielding, of the radiation pattern it should be dispelled by table 35. Note that the signals from the open end of Haiku Valley, to the north and east are very slightly lower than to the south and west through or over the Koolau mountain range.

D. LUALUALEI VLF TRAPS

1. NAVCOMSTA Lualualei is the location of a high powered VLF transmitting site. While the frequency is higher than the OMEGA frequencies, some interference could be expected due to the large difference in estimated field intensity at the closest point of approach to Lualualei. It was

TABLE 35. ANTENNA RADIATION PATTERN.

Freq. kHz	All Radials		$E_r d/I_a$ Radials 000	050	120	180	265	305
10.2	2.169		2.146	2.144	2.269	2.176	2.176	2.101
		Δ%	-1.1	-1.2	+4.6	+0.3	+0.3	-3.2
11.05	2.363		2.313	2.341	2.404	2.387	2.387	2.335
		Δ%	-2.2	-0.9	+1.7	+1.0	+1.0	-1.2
11-1/3	2.411		2.360	2.389	2.472	2.435	2.391	2.391
		Δ%	-2.2	-0.9	+2.5	+1.0	+1.0	-0.8
11.80	2.489		2.436	2.466	2.540	2.496	2.515	2.468
		Δ%	-2.2	-0.9	+2.0	+0.3	+1.0	-0.9
13.60	2.903		2.850	2.833	2.967	2.931	2.958	2.872
		Δ%	-1.9	-2.5	+2.2	+1.0	+1.9	-1.1
	Mean	Δ%	-1.9	-1.3	+2.6	+0.7	+1.0	-1.4

estimated that the OMEGA signals would be approximately 32 millivolts per meter at a distance of 30 km while the signal from Lualualei would be approximately 950 millivolts per meter at a distance of 10 km, a ratio of 30 to 1.

2. Instead of asking Lualualei to abstain from transmissions during the measurement period of approximately a week it was decided to try to eliminate the interfering frequency. Low pass filters were considered but

rejected because of the low and variable termination resistance of the LPA-1A loop amplifier. Series and shunt traps on each leg of the balanced line were tried and tentatively accepted subject to a field test.

3. Quantitative results were not attempted since this would have required an instrumented shielded enclosure (room). A subjective test was performed using the usual field intensity measurement equipment, including the traps, at a location approximately 30 km. from the OMEGA Station and 10 km. from the VLF stations at Lualualei. The traps were very successful since it was not possible to determine if the VLF transmitter was on the air during the test. A telephone call was required to verify that the VLF station was indeed operating.

4. Since this was a test under the estimated worst case no difficulty was to be expected during the regular measurement period.

5. The traps are mounted in a metal box with compartmental shields. Input and output connectors are the UHF series Twinax jacks. A schematic diagram is shown in figure 12.

6. It should be noted that insertion of the traps in the loop antenna to the LPA-1A loop amplifier transmission line makes it necessary to retune the tuned circuits of the amplifier.

E. CONCLUSIONS

1. Table 36 gives antenna system parameters determined and the values of antenna system current (I_{as}) required to radiate 10 kilowatts on all frequencies. It also shows the maximum I_{as} possible with the transmitter output power available.

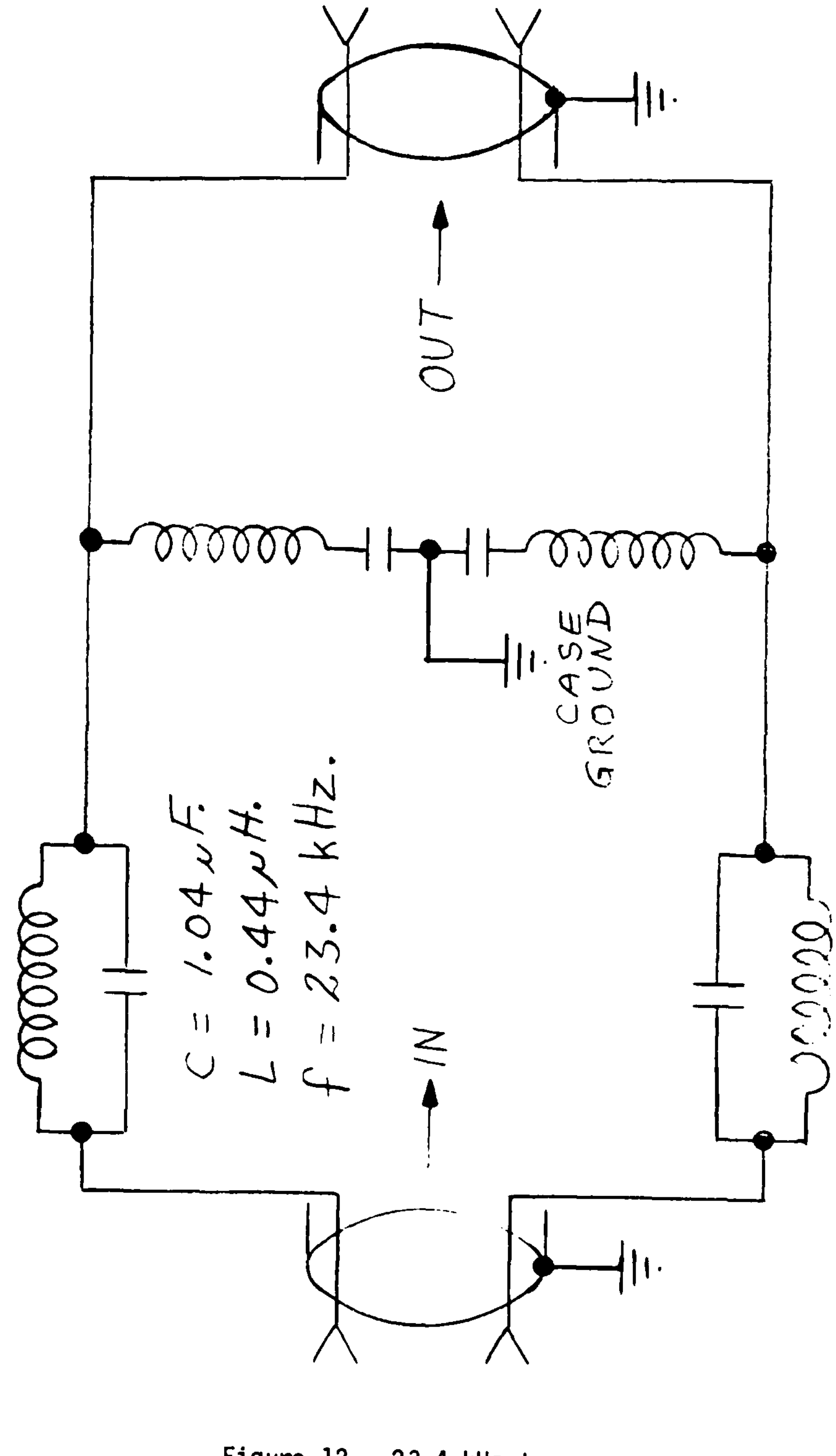


Figure 12. 23.4 kHz traps.

TABLE 36. STATION OPERATING PARAMETERS, ANTENNA.

Frequency (kHz)	R_r (Ohms)	I_a (10kW) (A.)	I_{as} (I_a/0.98) (A.)	R_{as} (Ohms)	I_{as} Max.* (A.)	P_r Max. (kW)
10.20	0.0523	437	446	0.718	457	10.5
11.05	0.0620	401	410	0.751	447	11.9
11-1/3	0.0646	393	402	0.750	447	12.4
11.80	0.0688	381	389	0.746	448	13.3
13.60	0.0936	327	333	0.769	442	17.5

*Transmitter power limited to 150 kW.

Note: I_{as} is the value indicated by the antenna current meters located in the Timing and Control racks.

2. OMEGA Hawaii will radiate in excess of 10 kilowatts on all frequencies during normal weather conditions. During periods of high humidity or light rain, following a dry period of time with high velocity sea breezes, the antenna system resistance will rise; requiring some increase in the transmitter input signal. Usually this will return the radiated output to the required 10 kilowatts.

IX BENCHMARK LOCATIONS

INTRODUCTION

1. In order to make field intensity measurements (FIM) in the future, for detection of changes in the antenna system, it is necessary to have reference measurements for comparison. These reference measurements were taken at selected sites known as Benchmarks.

SITE SELECTION

1. For meaningful comparisons in the future, the local environment of the sites must not change.

2. The usual procedure is to select sites under control of the agency operating the station if this is possible.

3. Two of the sites chosen were under the control of the U.S. Government and one is beside a pineapple field belonging to the Del Monte Corporation.

4. None of these sites are likely to be subject to change of environment.

5. Figures 13, 14 and 15 show the approximate locations and approaches to the benchmark sites. Table 37 gives descriptive information on the location of the benchmark sites.

6. The benchmark site is marked by a stake driven into the ground.

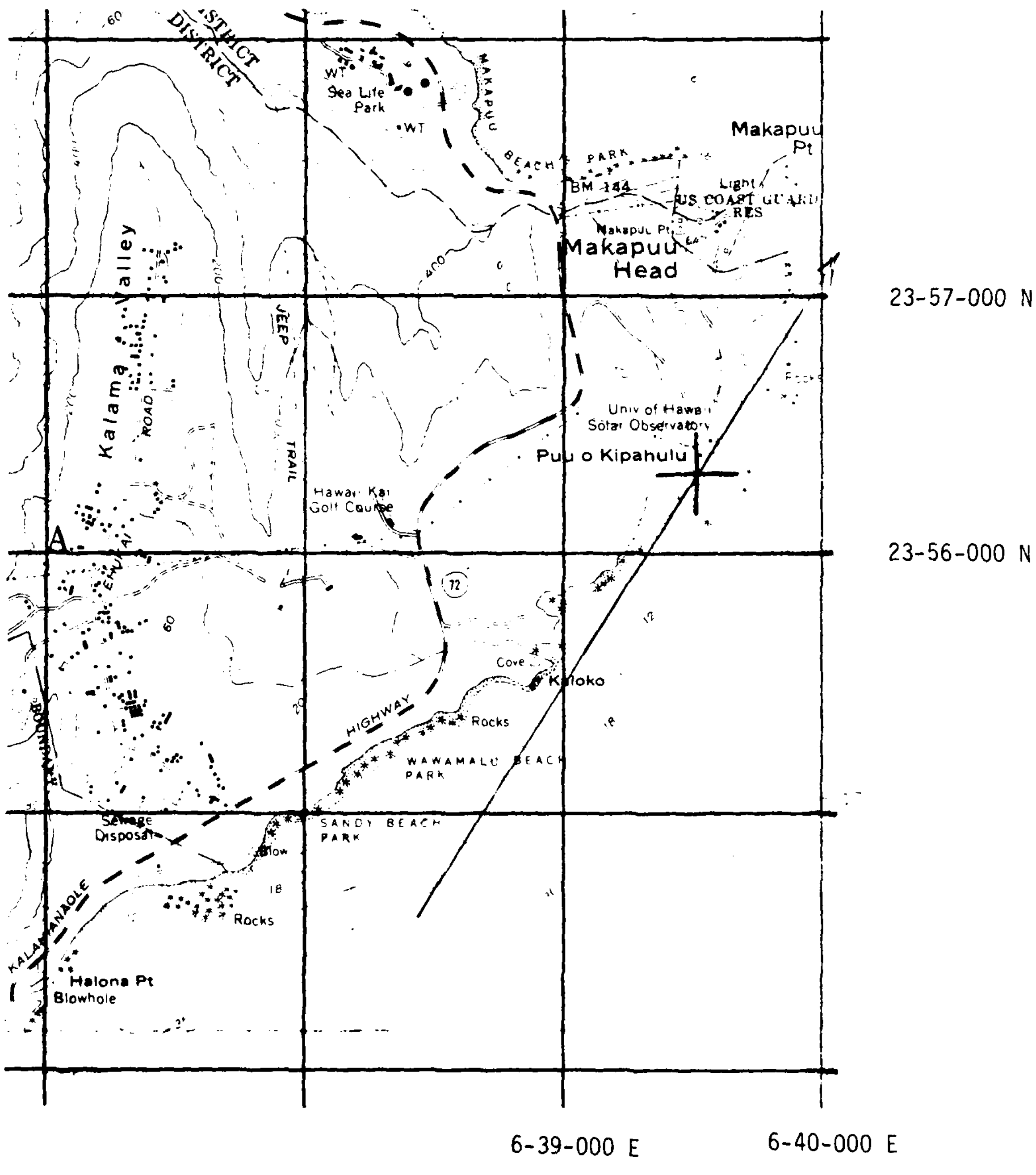


Figure 13. Benchmark Site A.

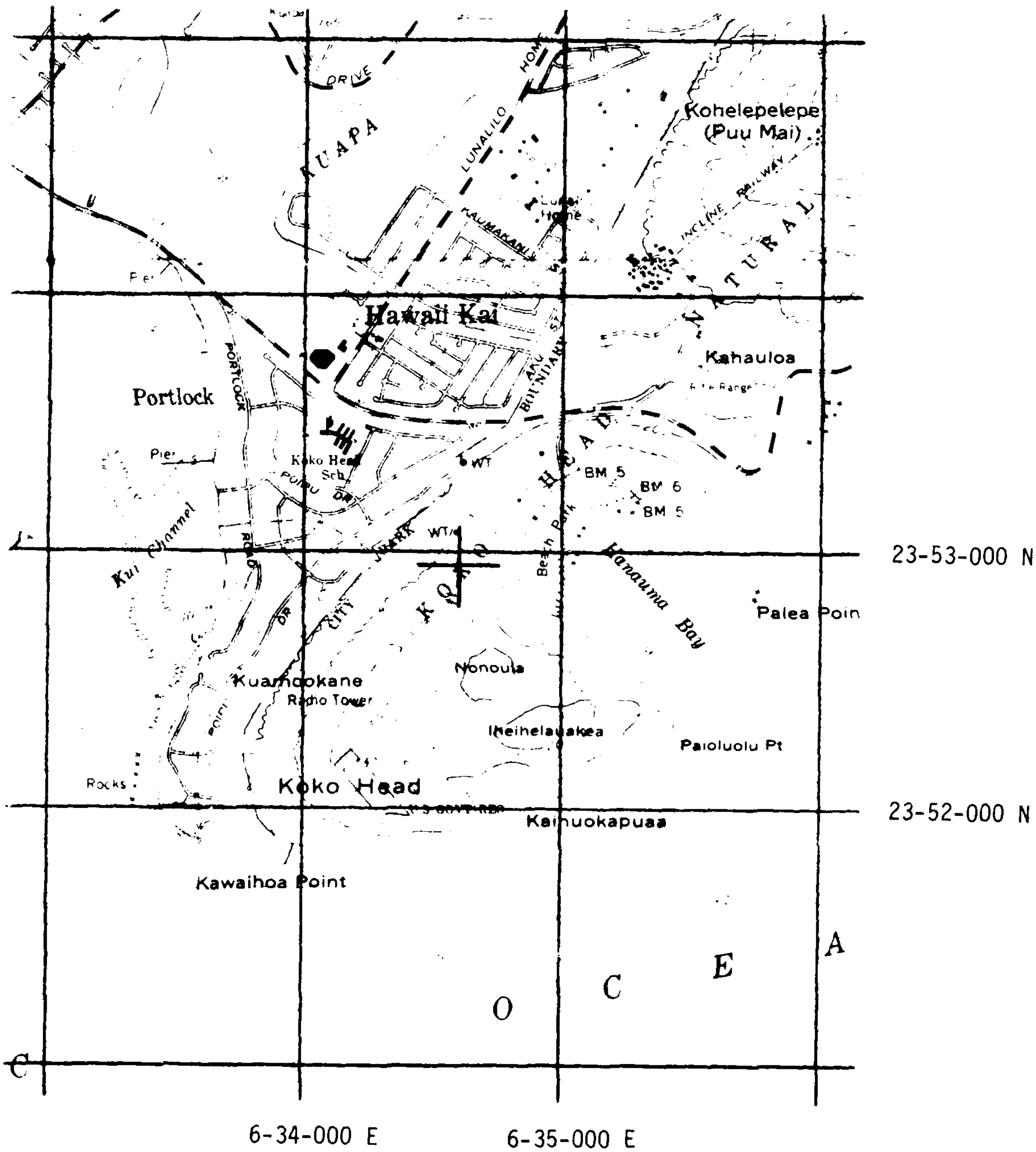
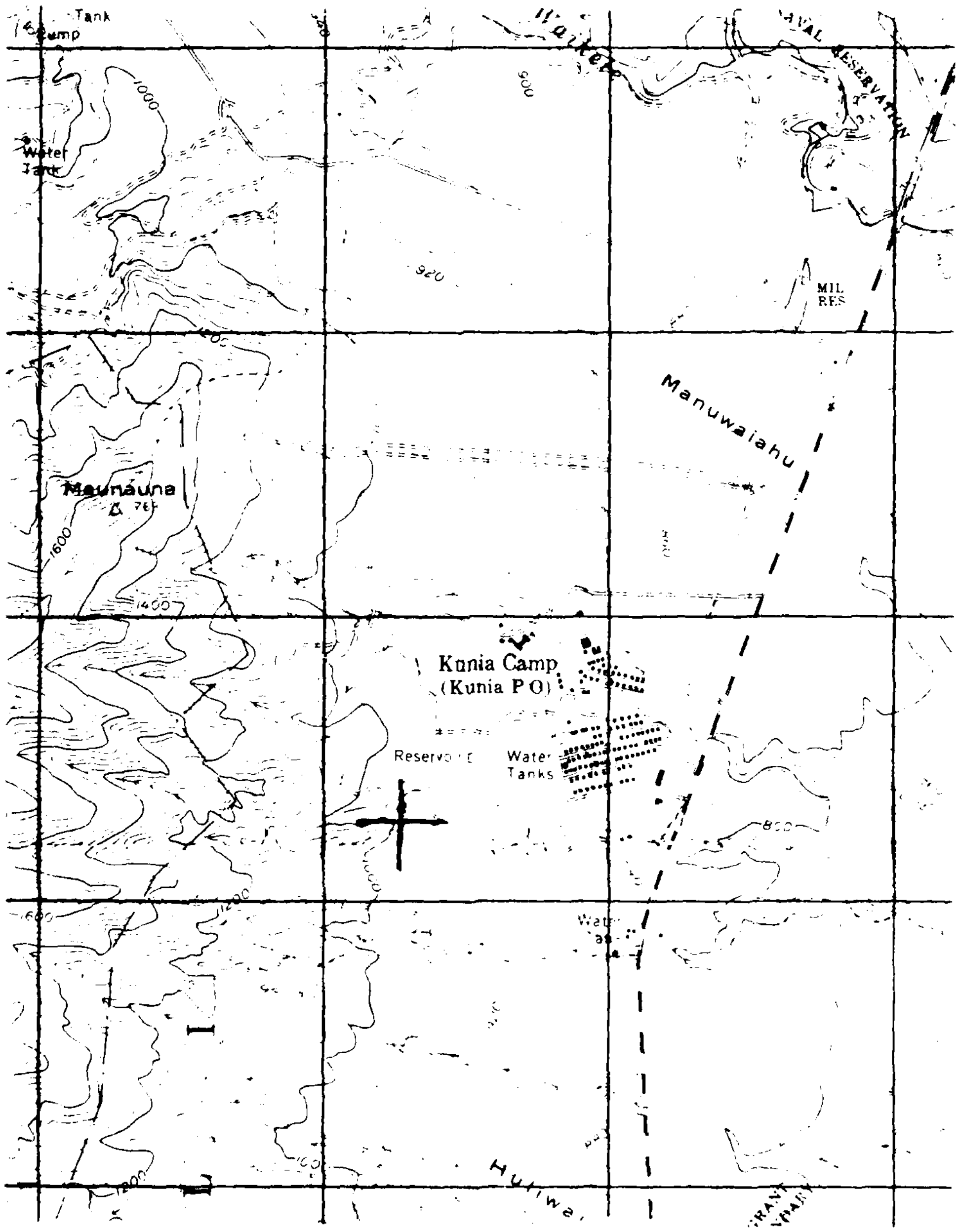


Figure 14. Benchmark Site B.



23-74-000 N

23-73-000 N

5-96-000 E 5-97-000 E

Figure 15. Benchmark Site C.

TABLE 37. LOCATIONS OF THE BENCHMARK SITES.

Site	Map Data	Description
A	Koko Head Quadrangle 7.5 minute series metric grid 23-56-326 N 6-39-523 E Distance: 21.865 km. Azimuth: 112°T (Station to Site)	Makapuu Head. Go up to the major curve in the road as shown by the cross in Figure 13. From the point the curve ends, measure 15 meters farther up the road. The tripod is then set 2 meters to the left of the left edge of the road. There is a stake marking the spot.

Note: This area is under the jurisdiction of the USCG. The gate keys are at the OMEGA Station.

Site	Map Data	Description
B	Koko Head Quadrangle 7.5 minute series Metric Grid 23-52-942 N 6-34-616 E Distance: 20.197 km. Azimuth: 138°T. (Station to Site)	Koko Head. From the "Y" in the road near the Telephone Company building go 0.64 miles down hill (Northeast) to the point in the center of the road as shown by the cross in figure 14. From this point, go 18 meters east to a point near the cliff. There is a stake marking the spot.

Note: This area is primarily under the jurisdiction of the F.A.A. In June of 1979 the responsible person was: Mr. Stan Rivers, Air Services Building, (Lagoon Drive), Tel: (808) 836-0727.

TABLE 37 (cont)

Site	Map Data	Description
C	Schofield Barracks Quadrangle 7.5 Minute Series Metric Grid 23-74-287 N 5-96-273 E Distance: 25.475 km. Azimuth: 285°T. (Station to Site)	Kunia Camp. From the Del Monte Corporation office take a road which generally goes in a direction of 260°T. The road meanders a bit but generally goes toward a high point of land at the edge of the plantation. This point of land, shown by the cross in figure 15, is approximately 8 feet high. The selected site is 10 meters north and 5 meters west of the road intersection. A stake marking the site is driven into the ground.

Note: Contact the plantation superintendent for permission to enter the fields. In June 1979 this was: Mr. Norman Blomberg, P.O. Box 100, Kunia, Hawaii 96759, Tel: (808) 621-5658.

MEASUREMENTS

1. Field intensity measurements were made, using the procedures of Appendix C, under the same controlled conditions as during the airborne measurements.

2. Antenna current was maintained at a constant value following procedures of Section B of Appendix D.

3. Data were recorded on data sheets DS-5 and calculations completed on data sheets DS-6.

SUMMARY

1. Mean values of the normalized field-distance products, for each frequency and each site, were calculated for comparison to the airborne data.

2. Ratios between the benchmark values and the airborne values were calculated for each site. These are summarized in tables 38, 39 and 40.

3. Processing of benchmark measurements, using the equations of Appendix B, are facilitated by the use of the calculated ratio as K_3.

TABLE 38. BENCHMARK SUMMARY.

Site A (Makapuu Head)

Frequency	E_rD/I_a		Ratio
(kHz)	Site A	Airborne	Air/Surface
10.20	2.558	2.169	0.848
11.05	2.728	2.363	0.866
11-1/3	2.780	2.411	0.867
11.80	2.936	2.489	0.848
13.60	3.368	2.903	0.862
		Mean Ratio	0.858

Multiply FIM readings at Site A by 0.858, calculate values of h_e and R_r, then compare with published values.

TABLE 39. BENCHMARK SUMMARY.

Site B (Koko Head)

Frequency	$E_r d/I_a$		Ratio
(kHz)	Site B	Airborne	Air/Surface
10.20	2.412	2.169	0.899
11.05	2.579	2.363	0.916
11-1/3	2.634	2.411	0.915
11.80	2.791	2.489	0.892
13.60	3.221	2.903	0.901
		Mean Ratio	0.905

Multiply FIM readings at Site B by 0.905, calculate values of h_e and R_r, then compare with published values.

TABLE 40. BENCHMARK SUMMARY.

Site C (Kunia Camp)

Frequency	$E_r d/I_a$		Ratio
(kHz)	Site C	Airborne	Air/Surface
10.20	2.167	2.169	1.001
11.05	2.373	2.363	0.996
11-1/3	2.417	2.411	0.998
11.80	2.513	2.489	0.990
13.60	3.002	2.903	0.967
		Mean Ratio	0.990

Multiply FIM readings at Site C by 0.990, calculate values of h_e and R_r, then compare with published values.

APPENDIX A. ABBREVIATIONS AND ACRONYMS

A	Amperes
Az	Azimuth angle, transmitter to measurement site
BIA	Base insulator assembly
C	Capacitance
ΔC	Capacitance change
C_{app}	Apparent capacitance (antenna)
cm	Centimeter
COGARD	Coast Guard
D	Distance (a readout)
d	Distance (km)
DME	*Distance measuring equipment*
DMU	Distance measuring unit
DSRC	Drive shaft revolution counter
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
FDP	Field distance product per ampere
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	Kilometer
L	Inductance
ΔL	Induction change
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)
OMSTA	OMEGA station
ONSOD	OMEGA navigation systems operations detail
P_r	Radiated power (kW)
P_v	Variometer position, cm down from the top
R_{as}	Antenna system resistance
R_r	Radiation resistance (ohms)
STA	Station (antenna)
S_x	Standard deviation
TR	Transponder
$\bar{x}$	Mean
ηas	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

$$R_r = \frac{P_r \times 10^3}{I_a^2} \text{ or } \frac{1}{90}\left(\frac{E_r d}{I_a}\right)^2$$

7. Field Distance Product, Normalized

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

*It is noted that this expression for correcting total field to radiated field applies for magnetic field type measurements, such as were performed in this work using a loop antenna. Although the results are given to E, electric field, strictly speaking H, magnetic field, was actually measured. The complete correction for E involves a 3rd term, not shown here.

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 X 1.83 = 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.

APPENDIX C: FIELD INTENSITY MEASUREMENTS, SUBSTITUTION METHOD

(Revision 1)

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.

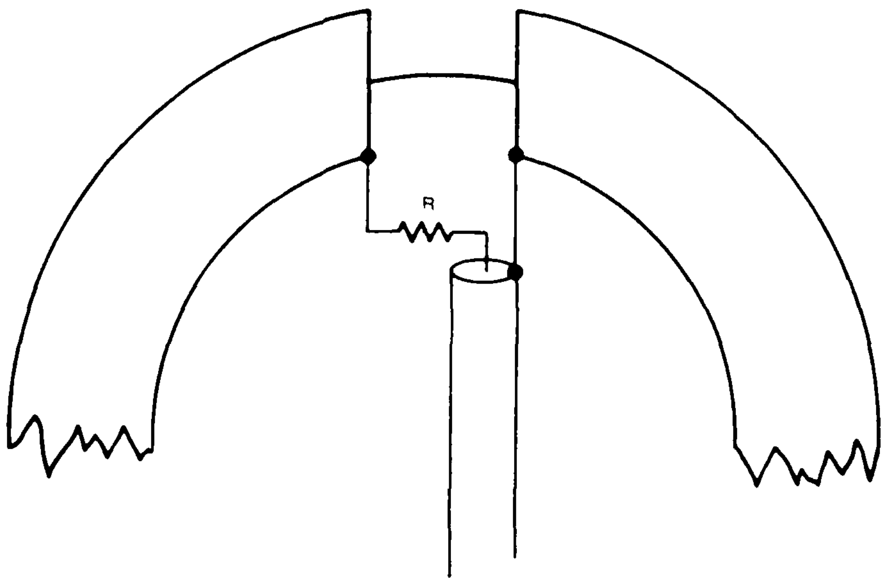


Figure C1

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).

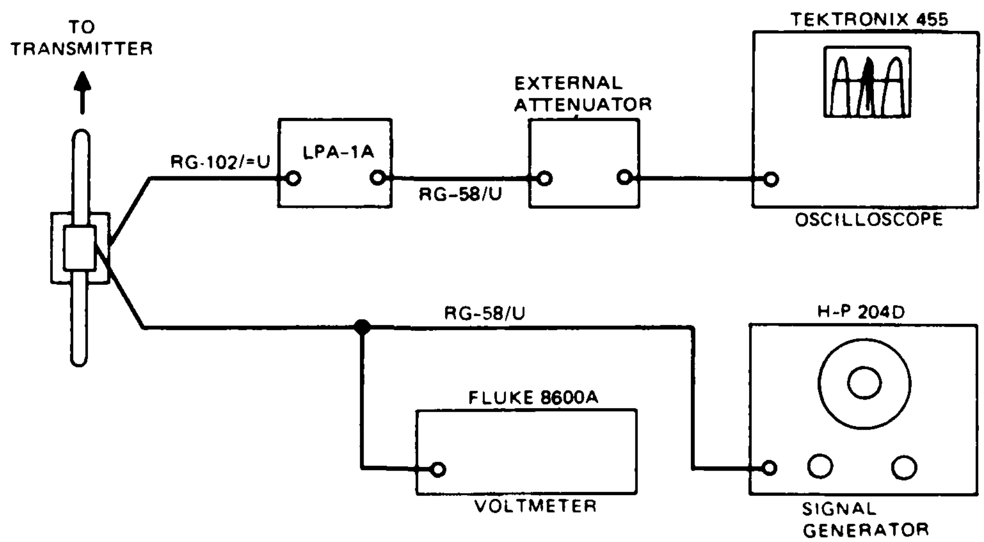


Figure C2

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 minimum loss (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 X 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 or switch the carrier OFF if a switch is available.

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.

Note: One or more Data Sheets may be required to calculate the distance from the transmitting antenna to the measurement site.

DATA SHEET 4-A

RADIO FIELD INTENSITY

SITE LOCATION

BENCHMARK & CALIBRATION

DATE: ____________

SITE NUMBER: ________

OMEGA STATION, ____________________

1. LOCATION OF MEASUREMENT:

   Description: ____

2. GEOGRAPHIC COORDINATES: (Map or Chart Scale. 1: ____________)

   ____ ° ____ ' ____ " ( ) ____ . ________ = Lat. ____ . ________ ° ( )
   (DD) (MM) (SS) (Inches) (DD) (dd)
   Nearest Lat. Line ± Dist. to position N or S

   ________ . ________ ( ) ____ . ________ = ________ . ____ ( )
   Nearest Metric Grid (MM) (m)

   ____ ° ____ ' ____ " ( ) ____ . ________ = Long. ____ . ________ ° ( )
   (DDD) (MM) (SS) (Inches) (DDD) (dd)
   Nearest Long. Line ± Dist. to Position E or W

   ________ . ________ ( ) ____ . ________ = ________ . ____ ( )
   Nearest Metric Grid (MM) (m)

3. LOCATION OF TRANSMITTING ANTENNA:

   Description, if other than tower.

   Lat. ____ . ________ ° ( )
   (DD) (dd)
   N or S

   Metric Grid ________ . ____ ( )
   (MM) (m)

   Long. ____ . ________ ° ( )
   (DDD) (dd)
   E or W

   Metric Grid ________ . ____ ( )
   (MM) (m)

   ____

   ____

   ____

   ____

   ____

4. SIGNAL PATH; TRANSMITTER TO RECEIVER SITE: Azimuth: ________ °T. Distance: ________ km.

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OMEGA HAWAII ANTENNA SYSTEM: MODIFICATION AND VALIDATION TESTS.--ETC(U)

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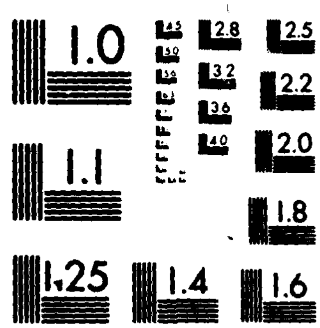

MICROCOPY RESOLUTION TEST CHART

DATA SHEET 4-B
RADIO FIELD INTENSITY
SITE LOCATION
D M E BASELINE

OMEGA STATION, ____________________

DATE: ____________

RADIAL NUMBER: ________

1. LOCATION OF TRANSPONDERS.

<u>No. 1</u> (Map or Chart Scale. 1:____________)

____ (DD) ° ____ (MM) ' ____ (SS) " ( ) ____ . ______ (Inches) = Lat. ____ (DD) . ______ (dd) ° ( )

Nearest Lat. Line ± Dist. to position N or S

______ . ____ Nearest Metric Grid ( ) ____ . ______ = ______ (MM) . ____ (m) ( )

____ (DDD) ° ____ (MM) ' ____ (SS) " ( ) ____ . ______ (Inches) = Long. ____ (DDD) . ______ (dd) ° ( )

Nearest Long. Line ± Dist. to Position E or W

______ . ____ Nearest Metric Grid ( ) ____ . ______ = ______ (MM) . ____ (m) ( )

<u>No. 2</u> (Map or Chart Scale. 1:____________)

____ (DD) ° ____ (MM) ' ____ (SS) " ( ) ____ . ______ (Inches) = Lat. ____ (DD) . ______ (dd) ° ( )

Nearest Lat. Line ± Dist. to Position N or S

______ . ____ Nearest Metric Grid ( ) ____ . ______ = ______ (MM) . ____ (m) ( )

____ (DDD) ° ____ (MM) ' ____ (SS) " ( ) ____ . ______ (Inches) = Long. ____ (DDD) . ______ (dd) ° ( )

Nearest Long. Line ± Dist. to Position E or W

______ . ____ Nearest Metric Grid ( ) ____ . ______ = ______ (MM) . ____ (m) ( )

2. TRANSPONDER BASELINE, 1 TO 2.

Azimuth: ____ . ____________ °T.

Distance: ____ . ____________ km.

DATA SHEET 4-C

RADIO FIELD INTENSITY

SITE LOCATION

ANTENNA TO TRANSPONDER BASELINE

OMEGA STATION, ____________ DATE: ____________

RADIAL NUMBER: ________

1. LOCATION OF TRANSMITTING ANTENNA. (Map or Chart Scale. (1:__________)

___ ° ___ ' ___ " ( ) ___ . ______ = Lat. ___ . ______ ° ( )
(DD) (MM) (SS) (Inches) (DD) (dd)
Nearest Lat. Line ± Dist. to Position N or S

__________ . ___ ( ) ___ . ______ = ______ . ___ ( )
Nearest Metric Grid (MM) (m)

___ ° ___ ' ___ " ( ) ___ . ______ = Long. ___ . ______ ° ( )
(DDD) (MM) (SS) (Inches) (DDD) (dd)
Nearest Long. Line ± Dist. to Position E or W

__________ . ___ ( ) ___ . ______ = ______ . ___ ( )
Nearest Metric Grid (MM) (m)

2. LOCATION OF TRANSPONDER 1
(From DS-4-B)

Lat. ___ . ______ ° ( )
(DD) (dd)
N or S

Metric Grid ______ . ___ ( )
(MM) (m)

Long. ___ . ______ ° ( )
(DDD) (dd)
E or W

Metric Grid ______ . ___ ( )
(MM) (m)

3. TRANSMITTING ANTENNA TO TRANSPONDER 1. Azimuth: ___ . ______ °T.

Distance: ___ . ______ km.

DATA SHEET 4-D

RADIO FIELD INTENSITY

SITE LOCATION

MEASURED BY D M E

OMEGA STATION, ____________ DATE: ________

1. LOCATION OF MEASUREMENT SITE NUMBER: ________

   Description: ______________________________

2. TRANSPONDER 1 to 2 BASELINE: Azimuth ____ . ____________ ^{o}T.

   Distance ____ . ____________ km.

3. ANTENNA TO TRANSPONDER 1: Azimuth ____ . ____________ ^{o}T.

   Distance ____ . ____________ km.

4. DMU READINGS: D_1 ________ km, D_2 ________ km.

5. CALCULATED POSITION OF VEHICLE, ANTENNA TO VEHICLE.

   Distance ____ . ____ km.

   Azimuth ____ . ____ ^{o}T.

DATA SHEET 5 (DS-5)

RADIO FIELD INTENSITY MEASUREMENTS

OMEGA STATION:______________ SITE NO._____ DATE:________________________

I_{as}________ A. K_1 ____ . _____ K_2 ____ . _____ K_3 ____ . ____

LOOP HEIGHT ____________ (m./ft.) TRIPOD _______ HELICOPTER _______
(ABOVE: SURFACE - SEA LEVEL)

TYPE OF MEASUREMENT: HELICOPTER CAL. ____ BENCHMARK ____ ROUTINE ____

TIME (LOCAL)	FREQUENCY (kHz)	E_g (mV)	HEADING (Mag.)	D M E D1	D2	DIST. km.	AZ. °T.
	10.20						
	13.60						
	11.1/3						
	11.05						
	F_t						
	10.20						
	13.60						
	11-1/3						
	11.05						
	F_t						
	10.20						
	13.60						
	11-1/3						
	11.05						
	F_t						

COMMENT

DATA SHEET 6 (DS-6), REV 1

RADIO FIELD INTENSITY CALCULATIONS

HELICOPTER CAL. ______. BENCHMARK ______ ROUTINE ______

LOOP HEIGHT ______ (m./ft.) TRIPOD ______ HELICOPTER ______

(Above Surface/S.L.)

OMEGA STATION: ______ SITE NUMBER: ______ DATE: ______

Distance: ______ . ______ km., K_1 = $\frac{\text{\_\_\_\_\_}}{I_a/I_{as}}$ K_2 = $\frac{\text{\_\_\_\_\_}}{\text{Loop Factor}}$ K_3 = $\frac{\text{\_\_\_\_\_}}{\text{Vehicle Factor}}$

(If constant)

Dist. (km.)	Freq. (kHz)	I_{as} (A)	E_q (mV)	I_a (A)	E_m (mV/m)	E_r (mV/m)	P_r (kW)	h_e (m)	R_r (Ohm)	E_{rd}/I_a (Units)
.	10.20									
.										
.										
.	13.60									
.										
.										
.	11-1/3									
.										
.										
.	11.05									
.										
.										
.										
.										
.										
.										
.										

APPENDIX D: ANTENNA CURRENT MEASUREMENTS, SUBSTITUTION METHOD

(Revision 2)

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, known to have good waveform, 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 ($\leq$ 1%), the accuracy of the voltmeter ($\leq$ 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.

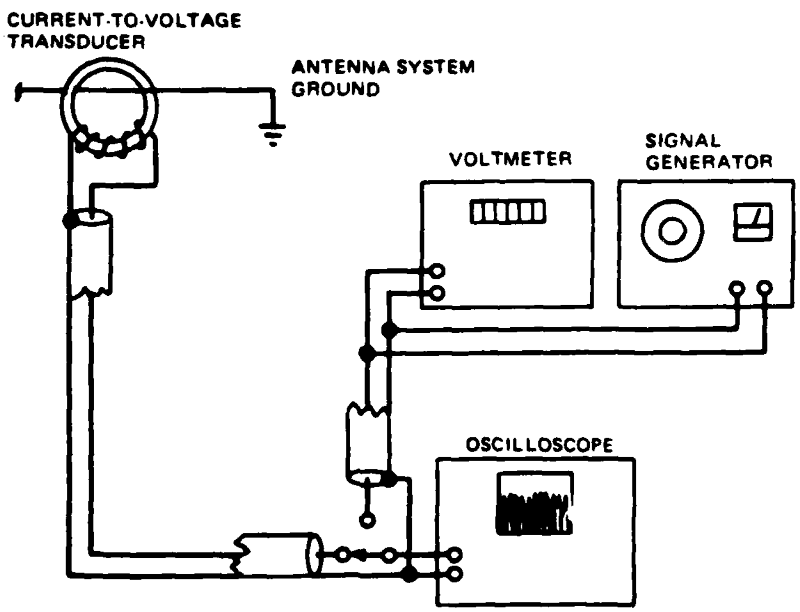

Figure D1

II. PROCEDURES

A. BASIC CURRENT MEASUREMENT

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. Check to be sure the signal is not limiting. If limiting occurs, change ranges and if necessary, use an external attenuator.

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.

B. CURRENT MONITORING FOR FIELD INTENSITY MEASUREMENTS

1. Set up the equipment as shown in paragraphs A1, 2, and 3 above.

2. Choose the one highest value of antenna current that will be possible to hold all day for all frequencies. Typically, this will be the maximum current that may be so maintained on 10.2 kHz.

3. Multiply this value of antenna current by the transfer factor of the current-to-voltage transducer to obtain the required output voltage from the signal generator. Adjust the signal generator to this value.

4. Connect the signal generator to the oscilloscope. Adjust the vertical gain control of the oscilloscope to place the top peaks of the waveform on the second highest horizontal line of the graticule. Do NOT change the vertical position control from the full down (CCW) position.

5. Switch the oscilloscope from the signal generator to the current-to-voltage transducer.

6. Using the individual and master attenuators of the Timing and Control Set, adjust the current of each frequency so the peaks of each waveform touch the same line chosen in paragraph B4. This ensures that all frequencies are at the same current and may be maintained there during the entire period of field measurements.

7. Periodically recheck the calibration of the oscilloscope as in Paragraph B4. Experience and the stability of the oscilloscope will determine the frequency of recalibration.

8. Using the procedure of this section reduces the amount of logged data and also the opportunity for error. Only the chosen current, or a new current if necessary, need be logged and time noted.

III. CONCLUSIONS

1. Procedure A is most useful during routine operation to verify the accuracy of the antenna current meters of the Timing and Control Set.

2. Procedure B is preferred during field intensity measurements because, in addition to the previously noted advantages, it simplifies the calculation procedures.

DATA SHEET 3

RADIO FIELD INTENSITY

ANTENNA CURRENT

DATE: ________________

OMEGA STATION: ____________________________ SHEET NUMBER: ________

ANTENNA SYSTEM CURRENT (I_{as})

TIME (Local)	10.20 (kHz)	13.60 (kHz)	11-1/3 (kHz)	11.05 •(kHz)	F_t ________ (kHz)

APPENDIX E: FIELD INTENSITY MEASUREMENTS BY HELICOPTER
(Revision 1)

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 noise source of the vehicle.

2. Each kind of helicopter presents its own set of mounting problems. It is practical to position the loop approximately five (5) feet from either side of the cabin. Additionally the loop should be mounted on the side opposite the tail rotor in case of a mounting failure. While the Hughes 500C helicopter produced no noise problems, with the loop mounted parallel to the longitudinal axis, other helicopters did. In these cases the loop was oriented to pick up the least noise from the helicopter. 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 relative to the helicopter. Mounting to other helicopters must be arranged on site if a specimen is not available prior to departure. A rotating mount for the loop must be provided to allow positioning the null on the noise source. 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 null 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 monitored and maintained, by the substitution method outlined in Appendix D, Section II B, and entered on Data Sheets 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, and over the same position, 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 values determined in step 5 by the values 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 or a grid system. Since coordinates of the transmitting antenna are known the distance may be calculated by great circle navigation equations or by rectangular to polar conversion.

b. Over water, over land which has few identifiable features, or over land at altitudes high enough to make visual positioning difficult, it is necessary to use radio distance measuring equipment to establish position. Any number of simple triangulation and vector addition calculations may be used to obtain the distance and azimuth of the measurement site from the transmitting antenna.

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 using visual position fixing.

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 or dye marker 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: REV. 1

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 the required inductance change is an exact inverse function of frequency, that each variometer was operating in the same part of its travel and the inductance change is linear. In practice none of these assumptions are correct but provided a starting point to allow preliminary operation and test. After installation and preliminary operation, the necessity of adjustment of the calculated values becomes apparent. As the antenna capacitance changes, from any cause, the antenna tuning will attempt to keep all the frequencies tuned simultaneously. When the antenna capacitance changes, if the gear ratios are incorrect, there will be hunting back and forth as each frequency is keyed. This not only causes unnecessary wear in the tuning system components but, if the error is large, can prevent the antenna from being tuned during the short period of one transmission segment. The procedure reported herein allows selection of the best gear ratios from the sprockets available.

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)	Estimated Capacitance (pF)	Measured Capacitance (pF)
0.5	1000	......
1.0	520	585
1.5	360	405
2.0	280	322
2.5	230	272

B. PROCEDURE

1. Disengage all of the clutches, in the variometer rooms, except the clutch to the variometer gear box being tested.

2. Adjust the transmitter output to the minimum value that will allow good antenna tuning and will allow the servo motor to start running, in the proper direction, to retune the antenna when the test capacitor is switched in or out of use.

3. With the test capacitor switch OFF, allow the antenna to be tuned automatically.

4. Read the main shaft revolution counter and enter the number on the appropriate line of Data Sheet F1 Rev 1.

5. Change the test capacitor switch to ON and allow the antenna to be tuned automatically.

6. Read the main shaft revolution counter and enter the number on the appropriate line of Data Sheet F1 Rev 1.

7. Enter the difference in the two counter readings, without sign, on a line of Data Sheet F1 Rev 1 between the two counter readings. This column is labeled "Drive shaft rotation" in turns.

8. Change the test capacitor switch to OFF and allow the antenna to be tuned automatically.

9. Read the main shaft revolution counter and enter the number on the next appropriate line of Data Sheet F1 Rev 1.

10. Perform the same subtraction and entry as in step 7.

11. This completes one full cycle of readings and produces two (2) values of "Drive shaft rotation."

12. Repeat steps 3 through 10 until satisfied that a good mean value may be calculated.

13. Calculate the mean value of the column of numbers labeled "Drive shaft rotation." Enter the mean value on the appropriate lines of Data Sheet F1 Rev 1 and F2 Rev 1.

14. Repeat steps 1 through 13 for each frequency. If this test is being made at the same time as installation of 11.05 kHz connect the chain to the sprockets for 11-1/3 kHz. in the variometer room for 11.05 kHz, as a temporary measure.

15. Enter the actual gear ratios used for this test on appropriate lines of Data Sheet F2 Rev 1.

16. The Data Sheets of this appendix will probably be reproduced as tables in a report of this test.

III. CALCULATION

1. Multiply the MDSR by the installed gear ratio, or the ratio actually used for this test. to obtain the number of turns the lead-screw made to retune the antenna (LSR). Enter these numbers in the LSR column of Data Sheet F2 Rev 1.

2. Choose the LSR for 13.60 kHz as the value of LSR (Reference). See Note 1 of Data Sheet F2 Rev 1. Divide the LSR (Turns) by the LSR (Ref.) to obtain the value of the LSR Ratio. Enter this number in the proper column of Data Sheet F2 Rev 1 and the appropriate line of Data Sheet F4 Rev 1.

3. Calculate all of the possible gear ratios, using the sprockets that are available at the station, and tabulate in ascending order on Data Sheet F3 Rev. 1.

4. Assign the lowest available gear ratio, from Data Sheet F3 Rev 1, to 13.60 kHz on Data Sheet F4 Rev 1. Multiply this gear ratio by the LSR ratio, for each frequency. entering these new values on the line for the Required Ratio in appropriate columns of Data Sheet F4 Rev 1. Continue assigning higher values to the column for 13.6 kHz until the calculated value of gear ratio required for 10.20 kHz exceeds the highest gear ratio available.

5. Tabulate the nearest available gear ratio immediately under the required gear ratio. Calculate the errors for each frequency on each line. Select the line with the smallest peak to peak error as the selected set of gear ratios. Install the sprockets indicated, for each selected ratio as shown on Data Sheet F3 Rev 1, in the appropriate variometer room.

6. If there are enough sprockets, install pairs of these new sprocket selections in the spare variometer room (106). If not, try the selection having the next higher error for the spare variometer room.

DATA SHEET F1 REV. 1

Frequency (kHz)	ΔC (____ pF)	Main Shaft Counter Readings (Turns)	Drive Shaft Rotation (Turns)
________	OFF	NNN · nn	
			NN · nn
	ON	___ · __	
			___ · __
	OFF	___ · __	
			___ · __
	ON	___ · __	
			___ · __
	OFF	___ · __	
			___ · __
	etc.		

Mean drive shaft revolutions (MDSR)	___ · __

DATA SHEET F2 REV. 1

Frequency (kHz)	MDSR (Turns)		Installed Gear Ratio (2)		LSR (Turns) (2)	(1&2)		LSR Ratio between Frequencies (2)
10.20	NN · nn	X	N · nnnnn	=	NN · nnnn	÷ LSR (Ref.)	=	N · nnnnn
11.05	__ · __	X	_ · ____	=	__ · ___	÷ LSR (Ref.)	=	_ · ____
11-1/3	__ · __	X	_ · ____	=	__ · ___	÷ LSR (Ref.)	=	_ · ____
f_t	__ · __	X	_ · ____	=	__ · ___	÷ LSR (Ref.)	=	_ · ____
13.60	__ · __	X	_ · ____	=	__ · ___	÷ LSR (Ref.)	=	_ · ____

NOTE 1. While any one of the LSR values may be chosen it is easier to use the value of 13.60 kHz to produce whole number ratios for the next step.

NOTE 2. Even though the precision of measurement does not warrant it, keep at least 6 significant figures to avoid rounding errors.

DATA SHEET F3 REV. 1

Available Gear Ratios

Gear Ratio	Sprocket Teeth (Input-Output)	Gear Ratio	Sprocket Teeth (Input-Output)
0.61111	33-54		
0.63462	33-52		
–			
–			
–			
–			
1.44444	52-36		
1.45455	48-33		
etc.			

DATA SHEET F4 REV. 1

Required gear ratios

Available gear ratios

Peak-to-peak error of each selected set

Frequency (kHz)	13.60	ft	11-1/3	11.05	10.20
LSR Ratio	1.00000	1.46362	1.60990	1.70495	2.08270
Required Ratio	0.61111	0.89443	0.98383	1.04191	1.27276
Available Ratio		0.88889	1.00000	1.04167	1.22727
Error (%)	5.35 p-p	-0.62	+1.64	-0.02	-3.71
Required Ratio	0.63462	0.92884			
Available Ratio		0.92593	etc.		
Error (%)		-0.32			

NOTE 1. When making selections from a limited number of sprockets which are available it is possible that large errors will appear on some lines. Visual inspection will allow the calculation to be stopped on that line, saving some effort.

APPENDIX G. POSITION FIXING OF A VEHICLE BY RADIO DISTANCE MEASURING EQUIPMENT (DME)

I. INTRODUCTION

1. In order to calculate the radiated power of a transmitting station, it is necessary to make field intensity measurements (FIM) of the radiated signal and to precisely know the distance between the transmitting and measuring antennas.

2. The usual vehicle used to measure field intensity above the surface of the Earth is the helicopter because of its capability of remaining stationary over a position while many measurements are made.

3. Visual determination of the precise position at the usual altitudes of 300 to 1000 meters is very difficult. The use of general purpose forms of radio navigation is neither as precise or as fast as desired.

4. DME, such as the Trisponder manufactured by Del Norte Technology, is capable of producing suitable measurements that satisfy both the precision and speed requirements.

5. An additional on-board computer (programmable calculator) is required to calculate the distance and azimuth from the transmitting antenna.

II. REQUIREMENTS

1. For a number of reasons, FIM, on frequencies in the 10 to 14 kHz navigation band, are conducted at distances of 20 to 40 kilometers from the

transmitting antenna. To ensure a reasonable amount of accuracy in the final calculations, an attempt is made to limit each contributing error to a practical minimum.

2. The parameters measured to calculate radiated power are tabulated in order of increasing difficulty in measurement accuracy.

a. Distance from the transmitting antenna

b. Antenna current

c. Field intensity.

3. At the measurement ranges, an error of ±0.5% is 100 to 200 meters. It should be easy to do better, probably near ±0.25%.

4. The azimuth must be known, to a lesser accuracy, to identify the radial direction of the measurement.

III. METHOD

A. INTRODUCTION

1. The method chosen consists of triangulation to locate the helicopter on a vector from a transponder location; and vector addition to locate the helicopter with respect to the transmitting antenna. This solves the problem for both azimuth and distance. All of the position measurement is done in the helicopter; facilitating navigation to a position for FIM and ensuring simultaneous position fixing with the FIM.

B. RANGE SELECTION

1. Two transponder locations are chosen near the measurement area. Consideration is given to the "line of sight" requirement of the DME and to the geometrically acceptable operational area as shown in figure G-1. Figure G-1 is constructed as follows:

a. Using a drafting compass, set the drawing radius to the distance along the baseline.

b. Strike arcs above and below the baseline at intersecting points.

c. From the two intersecting points draw arcs, as shown in figure G-1, between the transponder positions.

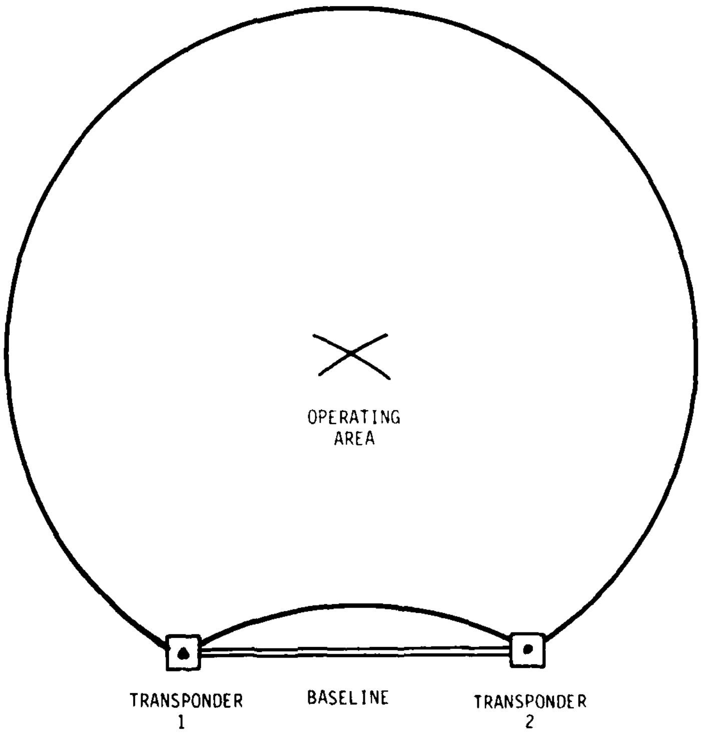

Figure G-1.

2. The operating area, for FIM along a radial, must fall in the area bounded by the arcs.

3. Check the coverage of the transponder antennas to ensure that the intended operating area is within the pattern angle. If using 180° antennas there should be no problem. With 90° antennas some of the geometrically correct area will not be covered.

4. The transponder location nearest the transmitting antenna is usually defined as the primary and is used to obtain D1 on the distance measuring unit (DMU) in the helicopter. The transponder baseline is now the vector from the primary (D1) to the secondary (D2) transponder. Triangulation is done on this baseline.

5. The azimuth and distance from the transmitting antenna to the D1 transponder is the second vector and will be added to the D1 to helicopter vector.

C. PREFLIGHT PREPARATION

1. Select all transponder sites.
2. Calculate the transponder baseline azimuths and distances between all the transponder pairs to be used.
3. Calculate the baseline azimuths and distances from the station to the primary transponder of each pair.
4. If the positions of the transponders and the station are in grid coordinates, be sure to add the grid correction to obtain true North.

5. Record baseline data and solution steps on a program card of the on-board computer (calculator). Label the card and protect it against accidental erasure.

6. To check for gross errors, either in program or baseline data on the cards, it is advisable to perform a test position solution obtaining D1 and D2 by measurement on a map, checking the solution on a map.

D. FLIGHT PROCEDURES

1. After take-off, use deduced reckoning to navigate the helicopter to the proposed site of measurement. Deploy the DME antenna if required to be retracted while on the ground.

2. On estimated arrival at the site, measure D1 and D2. Calculate the position and give corrective directions to the pilot.

3. After confirmed arrival over the site, the pilot will pick a hover reference point and try to stay at the site. Over water, a marker (preferably dye) should be dropped in the water as a hover reference.

4. The DME should be allowed to run in the AUTO mode until a FIM reading is completed; then switched to MANUAL to lock the readings until they may be recorded.

IV. CALCULATIONS, ERRORS AND PROGRAMS

A. CALCULATIONS

1. In position determination by DME, the known values are the baseline azimuth, the baseline length and the two remaining sides of a triangle. The known values of the triangle are the three sides. The law of cosine is used to calculate the angle between the baseline and the vector to the helicopter from the primary (D1) transponder. This angle is added to the azimuth of the baseline to obtain the true azimuth from D1 to the helicopter. The distance to the helicopter from D1 is measured directly by the distance measuring unit (DMU) located in the helicopter.

2. To obtain the location of the helicopter, with respect to the transmitting antenna, the station to D1 vector is added to the D1 to helicopter vector. The resultant vector is the azimuth and distance from the station to the helicopter.

B. ERRORS

1. Several sources of errors are present in this method of position fixing. They are, but not necessarily limited to, the following:

   a. Errors in the maps used to determine the range parameters and in the locations plotted on them

   b. Ranging errors by the DMU

   c. Slant range versus true horizontal distance when the helicopter and transponders are at different heights

d. Calculation errors caused by using a finite number of significant figures, and

e. Errors in rounding off the calculated values to provide a practical display.

They may be minimized, disregarded as inconsequential, or accepted as a contribution to the total error.

2. Map errors of cartography are not known so are not considered. Errors in printing, caused by paper shrinkage, may be corrected by measurement and calculation of a scale change. The use of precision calipers or dividers helps minimize the plotting errors. In any case, it is estimated that a position may be located, on a map having a scale of approximately 1:25000, to a precision of ±10 meters.

3. The Del Norte Technology DME, after being calibrated on a test range, is expected to be within 3 meters of the indicated ranges at distances of 100 meters through 80 kilometers. It is claimed that, in practice, the error is most likely 1 meter or less at ranges of 150 meters to 70 kilometers. These errors are inconsequential.

4. Slant range errors may be kept to values small enough to be ignored by selection of the transponder locations. If possible, select positions as close as possible to the operating altitude of the helicopter. If this is not possible, keep the distance between the helicopter and the transponder large; for example, at 20 kilometers, with a difference in height of 500 meters. The error is 6.25 meters. Try not to allow the slant range error to exceed 10 meters. Of course, a powerful on-board computer can correct for slant range errors.

5. By using calculators or computers which perform calculations using 10 or more significant figures, instead of plotting position, the calculation errors are minuscule.

6. In the program to be presented later, the displayed azimuth is improperly rounded, which results in possible errors of almost 1 degree. Since the azimuth is only used to identify the radial direction, and the distance is properly treated, this is also unimportant.

7. In summary, the largest contribution to the total error is in locating the transponders by map interpretation. If it is possible to locate the transponders relative to surveyed benchmarks this source of error will be minimized. The second largest contributor, slant range, can be reduced by site selection, distance selection or increased computational power.

C. PROGRAMS

1. The only programmable calculator available to the author was the Hewlett-Packard HP-65. It has a limited number of program steps (100) and a limited number of storage registers (8), because of trigonometric functions.

2. The display desired gives the position of the helicopter in polar coordinates from the transmitting antenna, all on one display line. The distance is presented in kilometers and thousandths (1 meter resolution) and the azimuth in degrees, with a rounding error of 0 to -0.999-- degree.

3. Using the law of cosine, the angle between the transponder baseline (D1 to D2) and the vector from D1 to the helicopter is calculated. This angle is added to the baseline azimuth to produce the true azimuth of D1 to the helicopter. The true distance has been measured by the DMU as D1. The clockwise (CW) and counterclockwise (CCW) solutions refer to the position of the helicopter, with respect to the baseline, as viewed from D1.

4. The helicopter vector is added to the vector from the transmitting antenna to transponder D1.

5. The resultant vector gives the helicopter position.

6. This program runs in approximately 7 seconds which is sufficiently fast for on-board navigation. Other, more elaborate programs to correct for slant range errors, will probably run longer.

7. An additional feature that could be added, using a more powerful computer, would be for corrective navigation instructions to the pilot during the travel to a measurement site. The courses should be done in degrees magnetic to simplify the pilot's work.

8. Programmable calculators such as the HP-67 and HP-41C would have the capacity to do slant range and course correction.

9. The range data program is shown in tables G1 and G2.

10. The position solution program is shown in tables G3 and G4.

TABLE G-1.

HP-65 User Instructions

Title: Position by DME - Range Parameters Page 1 of 2

Programmer: J. C. HANSELMAN Date 20 Apr 1979

Range Parameters - Format
LOAD RCL 1 RCL 2 RCL 3 RCL 4

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	ENTER FORMAT CARD				
2	INITIALIZE POINTER		RTN		
3	SWITCH TO W/PRGM				
4	ENTER PROGRAM FOR LBL A AS SHOWN ON THE		LBL		
	REVERSE SIDE, ENDING WITH RTN.		A		
			etc.		
5	RECORD ON SIDE 2 OF A "POSITION BY DME" CARD		RTN		
	AND PROTECT. (TO TEMPORARILY STORE THE				
	COMPLETED PROGRAM, RECORD ON SIDE 2 OF THIS				
	CARD - UNPROTECTED)				
6	DO NOT KEY IN LBL's B, C, D, OR E. THEY				
	WERE ON THE FORMAT PROGRAM PREVIOUSLY ENTERED.				

TABLE G-2.

HP-65 Program Form

Title Position by DME - Range Parameters Page 2 of 2

SWITCH TO W/PRGM PRESS f PRGM TO CLEAR MEMORY

KEY ENTRY	CODE SHOWN	X	Y	Z	T
LBL	23				
A	11				
D					
.	83				
d					
d					
d					
d					
d					
d					
d					
d					
d					
EEX	43				
N					
N					
STO 1	33 01				
M					
.	83				
m					
m					
m					
m					
m					
m					
m					
m					
m					
EEX	43				
N					
N					
STO 2	33 02				
D					
.	83				
d					
d					
d					
d					
d					
d					
d					
d					
d					
EEX	43				
N					
N					
STO 3	33 03				
M					
.	83				
m					

KEY ENTRY	CODE SHOWN	X	Y	Z	T
m					
m					
m					
m					
m					
m					
m					
m					
EEX	43				
N					
N					
STO 4	33 04				
f	31				
STK	42				
DSP	21				
9	09				
RTN	24				
LBL	23				
B	12				
RCL 1	34 01				
R/S	84				
f	31				
STK	42				
RTN	24				
LBL	23				
C	13				
RCL 2	34 02				
R/S	84				
f	31				
STK	42				
RTN	24				
LBL	23				
D	14				
RCL 3	34 03				
R/S	84				
f	31				
STK	42				
RTN	24				
LBL	23				
E	15				
RCL 4	34 04				
R/S	84				
f	31				
STK	42				
RTN	24				

TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM

REGISTERS

- R_1 TR1→TR2 Baseline Az. (°T)
- R_2 TR1→TR2 Baseline Length (m)
- R_3 STA→TR1 Azimuth (°T)
- R_4 STA→TR1 Distance (m)
- R_5
- R_6
- R_7
- R_8
- R_9

LABELS

- A LOAD
- B RCL 1
- C RCL 2
- D RCL 3
- E RCL 4
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9

FLAGS

- 1
- 2

TABLE G-3.

HP-65 User Instructions

Title: Position by DME, Distance and Azimuth from Station — Page 1 of 2

Programmer: J. C. HANSELMAN — Date: 4 January 1979

Card: Position by DME CW CCW (Program 2) | SPARE PROGRAM

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	ENTER: RANGE PARAMETER PROGRAM CARD (SIDE 2)				
2	STORE RANGE PARAMETERS		A		
3	ENTER: POSITION BY DME PROGRAM CARD (SIDE 1)				
4	KEY IN: DMU 1	Meters	ENT		
	DMU 2	Meters			
5	EXECUTE IF VEHICLE IS CLOCKWISE (RIGHT)		A		
	OF BASELINE				
6	EXECUTE IF VEHICLE IS COUNTERCLOCKWISE (LEFT)		B		
	OF BASELINE				

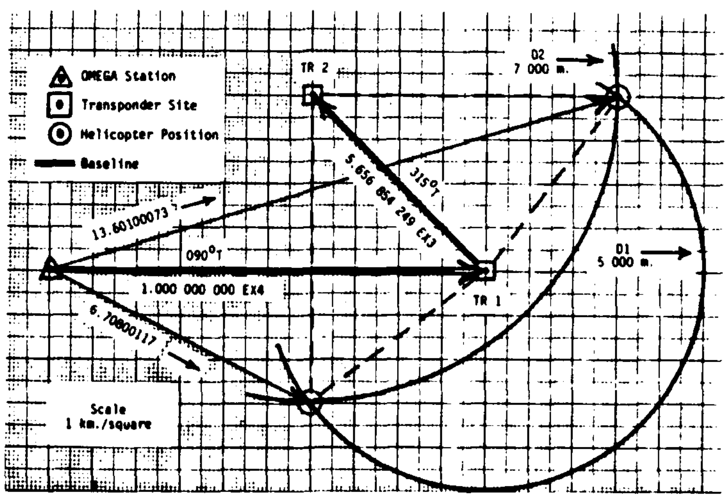

TABLE G-4.

HP-65 Program Form

Title Position by DME, Distance and Azimuth from Station Page 2 of 2

SWITCH TO W/PRGM PRESS f PRGM TO CLEAR MEMORY

KEY ENTRY	CODE SHOWN
LBL	23
A	11
D	14
RCL 1	34 01
+	61
3	03
6	06
0	00
g x≤y	35 22
-	51
g x⇌y	35 07
g x⇌y	35 07
STO 5	33 05
E	15
RTN	24
LBL	23
B	12
D	14
RCL 1	34 01
g x⇌y	35 07
-	51
0	00
g x>y	35 24
3	03
6	06
0	00
+	61
+	61
STO 5	33 05
E	15
RTN	24
LBL	23
D	14
STO 8	33 08
g R↓	35 08
STO 6	33 06
RCL 2	34 02
f-1	32
√x	09
RCL 6	34 06
f-1	32
√x	09
+	61
RCL 8	34 08
f-1	32
√x	09
-	51
2	02
÷	81
RCL 2	34 02

KEY IN: DMU 1 (Meters)

PRESS : ENTER↑

KEY IN: DMU 2 (Meters)

KEY ENTRY	CODE SHOWN
RCL 6	34 06
x	71
÷	81
f-1	32
COS	05
RTN	24
LBL	23
E	15
RCL 3	34 03
RCL 4	34 04
f-1	32
R→P	01
RCL 5	34 05
RCL 6	34 06
f-1	32
R→P	01
g x⇌y	35 07
g R↑	35 09
+	61
g x⇌y	35 07
g R↑	35 09
+	61
f	31
R→P	01
f	31
INT	83
EEX	43
3	03
÷	81
g x⇌y	35 07
0	00
g x>y	35 24
3	03
6	06
0	00
+	61
+	61
EEX	43
8	08
÷	81
+	61
DSP	21
.	83
8	08
RTN	24

DISPLAY

M M . m m m 0 0 D D D

Distance (km) Azimuth (°T)

Station to Vehicle

REGISTERS	
R_1	TR1 → TR2 Baseline Az. (°T)
R_2	TR1 → TR2 Baseline Length (m)
R_3	STA → TR1 Az. (°T)
R_4	STA → TR1 Distance (m)
R_5	B1
R_6	b
R_7	Not Used
R_8	c
R_9	USED

LABELS	
A	CW
B	CCW
C	
D	Δ SOL.
E	+ VECTOR
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

FLAGS	
1	
2	

TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM

11. A sample range and position diagram is shown as figure G-2. The range and position data is scaled directly from the grid or calculated using the Pythagorean Theorum with the exception of the azimuths of the two helicopter positions. These may be obtained by scale from the grid and use of trigonometry. This sample illustrates the precision of the program by independent calculation.

12. The notation "EX(N)" means the exponent of 10. This form is used because of the keyboard of the calculator used.

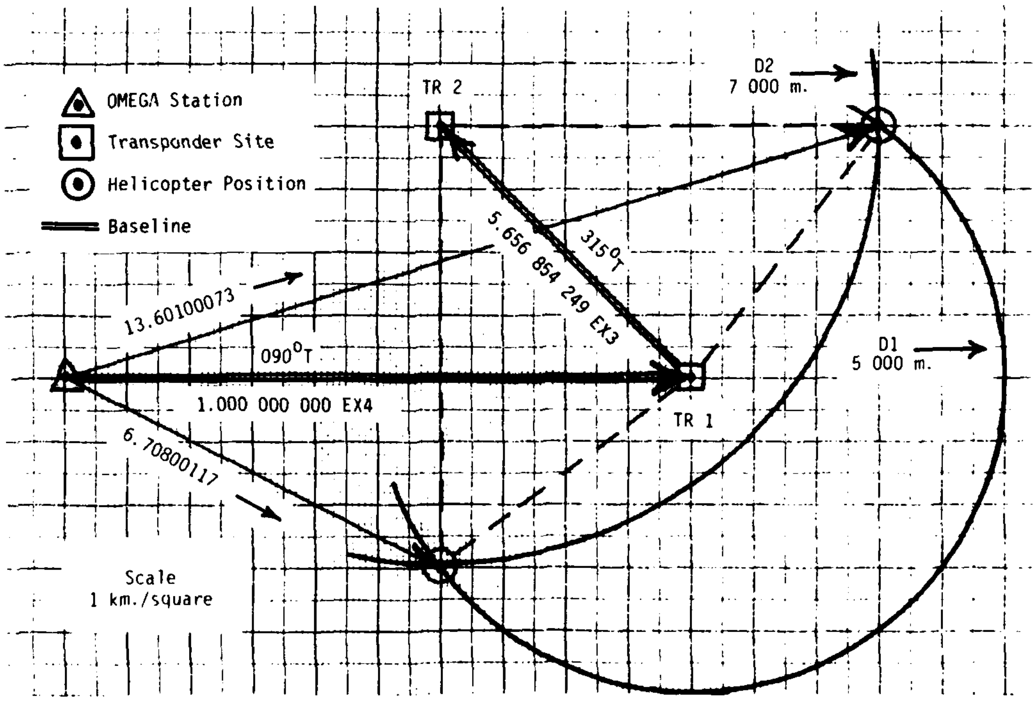

Figure G-2.

APPENDIX H. EQUIPMENT FOR FIELD INTENSITY MEASUREMENTS

Equipment furnished specifically for field intensity measurements.

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

TABLE H-1

Equipment	Mfgr	Model No.	Serial	Decal
Loop Antenna	Stoddart	90117-3	None	1723
VLF Tuned Amplifier	Megatek	LPA-1A	500294	1848
Signal Generator	Hewlett Packard	204-D	05230	1744
Digital Volt-Ohm-Meter	Fluke	8600A-01	0445277	1752
Current Transformer	Pearson	1114-4	2283-2	1779
Oscilloscope	Tektronix	455	B044144	1772
Battery Power Supply	Tektronix	1106	B023362	1771
Tripod	Leitz	7536-20	None	None
Twinax Cable (50 ft)	—	RG-108/U	None	None
Coax Cable (50 ft)	—	RG-58/U	None	None
Ext. Attenuator for LPA-1A	Megatek	None	None	None

APPENDIX I. PREPARATION FOR FIELD INTENSITY MEASUREMENTS AT OMEGA HAWAII

INTRODUCTION

1. The work herein described was performed under Contract No. N00123-78-C-0043, task assignment 025. Company report R2018-025-IF-1, is dated 14 May 1979. The task consisted of the following items:

   a. To search for suitable helicopter calibration sites, examine the proposed radial routes and prepare an estimated flight schedule.

   b. Measure the self-generated electrical noise of the helicopter, determine the optimum loop orientation, and design a new loop mounting if required.

   c. Select, locate and obtain permission to use sites for distance measuring equipment (DME) which will be used to determine the helicopter positions while making field intensity measurements.

   d. Generate DME range data consisting of transponder base lines, vectors from the OMEGA station to the D1 transponder site and prepare transponder antenna aiming data.

   e. While not specifically called for in the task assignment, during the first trip to Hawaii it became apparent that a trap would be required to reduce the 23.4 kHz signal from NAVCOMSTA Lualualei.

HELICOPTER CALIBRATION SITES AND FLIGHT SCHEDULE

1. The selected helicopter was a Hughes 500C operated by Lacy Steel of Kamuela, Hawaii. This model was selected because the loop mounting hardware already existed, the machine has a relatively low level of electrical noise, has sufficient lifting capability and duration of flight to accomplish the mission.

2. The helicopter was flown over the proposed operating areas at various altitudes to visually check the proposed transponder locations and to select site(s) for helicopter calibration.

3. Helicopter calibration sites were considered at:

a. NAS Barbers Point.

b. Dillingham Airfield (Private).

c. Kuilima Air Park (Private).

The site Dillingham Airfield was rejected partly because of the distance from the OMEGA station but primarily because of nearby wires both on poles and on the ground. It was assumed that NAS Barbers Point would be available since this is a Navy contract. The Kuilima Air Park is owned by Hyatt Hotels. The manager of the Kuilima Hyatt Hotel, Mr. John Kirk, was contacted for permission to use the airfield. Permission was granted provided a few hours of advance notice was given.

4. After flying over some of the proposed routes a meeting was held with the helicopter pilot to provide an estimated flight schedule and to determine reasonable contingency plans. The admittedly pessimistic schedule is shown in table I-1.

TABLE I-1. HELICOPTER FLIGHT SCHEDULE.

Type of Flight	Number of Flights	Maximum Duration (Hours)		Total Flight Time (Hours)
Calibration	2	3		6
Height-Gain	2	3		6
Radials	6	3		18
			Sub Total	30
Contingencies (Weather or Equipment)	3 (aborted)	3		9
			Total	39

ELECTRICAL NOISE and LOOP MOUNTING

1. While the Hughes 500C helicopter generates a small amount of electrical noise, experience with other helicopters showed that it might be advantageous to test the loop orientation to minimize it.

2. The usual field intensity measurement equipment was mounted in the helicopter cabin. The loop antenna was hand-held in the approximate position in lieu of installing the boom assembly.

3. While the helicopter power plant and rotor was operating at full speed, the loop was oriented for minimum noise. The azimuth of the plane of the loop was 50° clockwise from parallel to the axis of the helicopter.

4. Since the normal mounting plate of the loop did not allow the required azimuth setting a new loop plate was designed and constructed. This plate will allow azimuth settings from 5° counterclockwise to 95° clockwise which covers all eventualities. A sketch of the plate, which was made of ¼ inch micarta sheet, is shown as figure I-1.

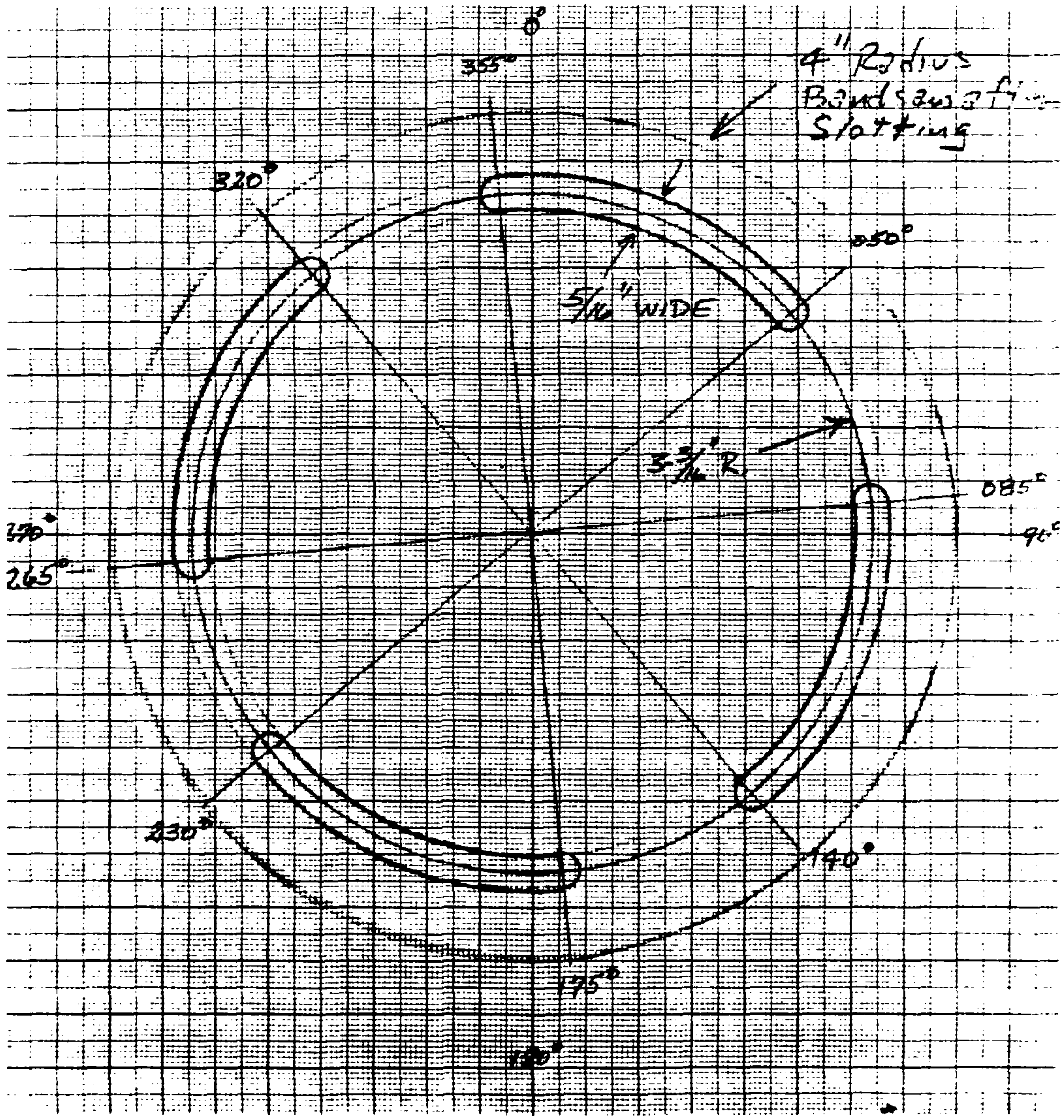

Figure I-1. Loop mounting plate.

DME RANGE DATA

1. In order to select geometrically acceptable transponder locations, maps were examined. Some choices were made only considering the location within the proposed operating area. After checking the accessibility of, and flying over, several of the sites originally selected were summarily discarded and others not originally considered were substituted. The metric grid locations of the sites finally selected are given in table I-2.

TABLE I-2. TRANSPONDER SITE LOCATIONS

Site Number	Metric Grid North	Metric Grid East
OMEGA Station	23-67-793 N	6-20-906 E
1	23-72-626 N	6-28-566 E
2	23-57-366 N	6-39-655 E
3A	23-52-538 N	6-34-342 E
3B	23-52-151 N	6-34-158 E
6A	23-59-643 N	6-11-719 E
6B	23-59-672 N	6-11-729 E
7	23-70-483 N	6-09-657 E
8A	23-78-958 N	5-88-498 E
8B	23-78-903 N	5-88-637 E
9	23-94-702 N	6-12-057 E
11	23-84-551 N	6-18-570 E

2. Since this was a one-time operation no formal drawings or sketches were produced. The team of transponder operators was taken to each site and given verbal instructions. The individual team members took any notes they deemed necessary.

3. Position fixing by DME requires a baseline, between transponders, of known length and azimuth. The law of sines is used to solve for the angle between the base line and one vector to the helicopter, the distance being one of the measurements. The angle from the chosen (D1) transponder to the helicopter is added to the azimuth of the baseline to produce a vector (degrees true) from the D1 transponder to the helicopter. This vector is then added to the baseline from the OMEGA station to the D1 transponder, which locates the helicopter in terms of azimuth and distance from the OMEGA station. The program for the Hewlett-Packard (HP) calculator(s) used in the helicopter was taken from H-P Programs MATH 1-20A and NAV 1-24A with considerable modification to present both distance in kilometers and azimuth in degrees True on a single display line. Tables I-3 through I-8 show the baselines used for each of the measurement radials. The values of azimuth and distance are given to 10 significant figures only to minimize rounding errors in the computational process. Exponential notation is used. The clockwise (CW) or counterclockwise (CCW) solution refers to the position of the helicopter with respect to the hemisphere on either side of the baseline between the transponder for D1 to D2. The transponder antenna aiming data is given in degrees Magnetic. All baselines include an average grid azimuth correction of + 0.372° T.

TABLE I-3. BASELINES, RADIAL 000°T.

Site Number	Metric Grid North	Metric Grid East
11 (D1)	23-84-551 N	6-18-570 E
9 (D2)	23-94-702 N	6-12-057 E
Station	23-67-793 N	6-20-906 E

Site 9 to 11:	Az.	3.276 872 958 EX2 °T.
	Dist.	1.206 076 158 EX4 m.
Station to Site 11:	Az.	3.524 363 277 EX2 °T.
	Dist.	1.692 003 132 EX4 m.

CW Solution.

Transponder	Antenna Azimuth
Site 11	015°M
Site 9	080°M

TABLE I-4. BASELINES, RADIAL 050°T.

Site Number	Metric Grid North	Metric Grid East
1 (D1)	23-72-626 N	6-28-566 E
2 (D2)	23-57-366 N	6-39-655 E
Station	23-67-793 N	6-20-906 E

Site 1 to 2:	Az.	1.443 671 812 EX2 °T.
	Dist.	1.886 355 006 EX4 m.
Station to Site 1:	Az.	5.812 253 540 EX1 °T.
	Dist.	9.057 234 070 EX3 m.

CCW Solution.

Transponder	Antenna Azimuth
Site 1	040°M
Site 2	000°M

TABLE I-5. BASELINES, RADIAL 120°T.

Site Number	Metric Grid North	East
1 (D1)	23-72-626 N	6-28-566 E
3A (D2)	23-52-538 N	6-34-342 E
Station	23-67-793 N	6-20-906 E

Site 1 to 3A: Az. 1.643 302 126 EX2 °T.

Dist. 2.090 191 187 EX4 m.

Station to Site 1: Az. 5.812 253 540 EX1 °T.

Dist. 9.057 234 070 EX3 m.

CCW Solution.

Transponder Antenna	Azimuth
Site 1	130°M
Site 3A	055°M

TABLE I-6. BASELINES, RADIAL 180°T.

Site Number	Metric Grid North	East
6A (D1)	23-59-643 N	6-11-719 E
3B (D2)	23-52-151 N	6-34-158 E
Station	23-67-793 N	6-20-906 E

Site 6A to 3B: Az. 1.088 352 869 EX2 °T.

Dist. 2.365 668 584 EX4 m.

Station to Site 6A: Az. 2.287 950 269 EX2 °T.

Dist. 1.228 102 068 EX4 m.

CW Solution.

Transponder Antenna	Azimuth
Site 6A	135°M
Site 3B	240°M

TABLE I-7. BASELINES, RADIAL 265°T.

Site Number	Metric Grid North	Metric Grid East
7 (D1)	23-70-483 N	6-09-657 E
8A (D2)	23-78-958 N	5-88-498 E
Station	23-67-793 N	6-20-906 E

Site 7 to 8A:	Az.	2.922 000 164 EX2 °T.
	Dist.	2.279 317 674 EX4 m.
Station to Site 7:	Az.	2.838 207 198 EX2 °T.
	Dist.	1.156 616 190 EX4 m.

CCW Solution.

Transponder Antenna Azimuth	
Site 7	240°M
Site 8A	140°M

TABLE I-8. BASELINES, RADIAL 305°T.

Site Number	Metric Grid North	Metric Grid East
6B (D1)	23-59-672 N	6-11-729 E
8B (D2)	23-78-903 N	5-88-637 E
Station	23-67-793 N	6-20-906 E

Site 6B to 8B:	Az.	3.101 595 065 EX2 °T.
	Dist.	3.005 115 347 EX4 m.
Station to Site 6B:	Az.	2.288 654 298 EX2 °T.
	Dist.	1.225 430 414 EX4 m.

CW Solution.

Transponder Antenna Azimuth	
Site 6B	330°M
Site 8B	055°M

LUALUALEI VLF TRAPS

1. NAVCOMSTA Lualualei is the location of a high powered VLF transmitting site. While the frequency is higher than the OMEGA frequencies some interference could be expected due to the large difference in estimated field intensity at the closest point of approach to Lualualei. It was estimated that the OMEGA signals would be approximately 32 millivolts per meter at a distance of 30 km while the signal from Lualualei would be approximately 950 millivolts per meter at a distance of 10 km, a ratio of 30 to 1.

2. Instead of asking Lualualei to abstain from transmissions during the measurement period of approximately a week, it was decided to try to eliminate the interfering frequency. Low pass filters were considered but rejected because of the low and variable termination resistance of the LPA-1A loop amplifier. Series and shunt traps on each leg of the balanced line were tried and tentatively accepted subject to a field test.

3. Quantitative results were not attempted since this would have required an instrumented shielded enclosure (room). A subjective test was performed using the usual field intensity measurement equipment, including the traps, at a location approximately 30 km. from the OMEGA Station and 10 km. from the VLF stations at Lualualei. The traps were very successful since it was not possible to determine if the VLF transmitter was on the air during the test. A telephone call was required to verify that the VLF station was indeed operating.

4. Since this was a test under the estimated worst case, no difficulty was to be expected during the regular measurement period.

5. The traps are mounted in a metal box with compartmental shields. Input and output connectors are the UHF series Twinax jacks. A schematic diagram is shown in figure I-2.

6. It should be noted that insertion of the traps in the loop antenna to the LPA-1A loop amplifier transmission line makes it necessary to retune the tuned circuits of the amplifier.

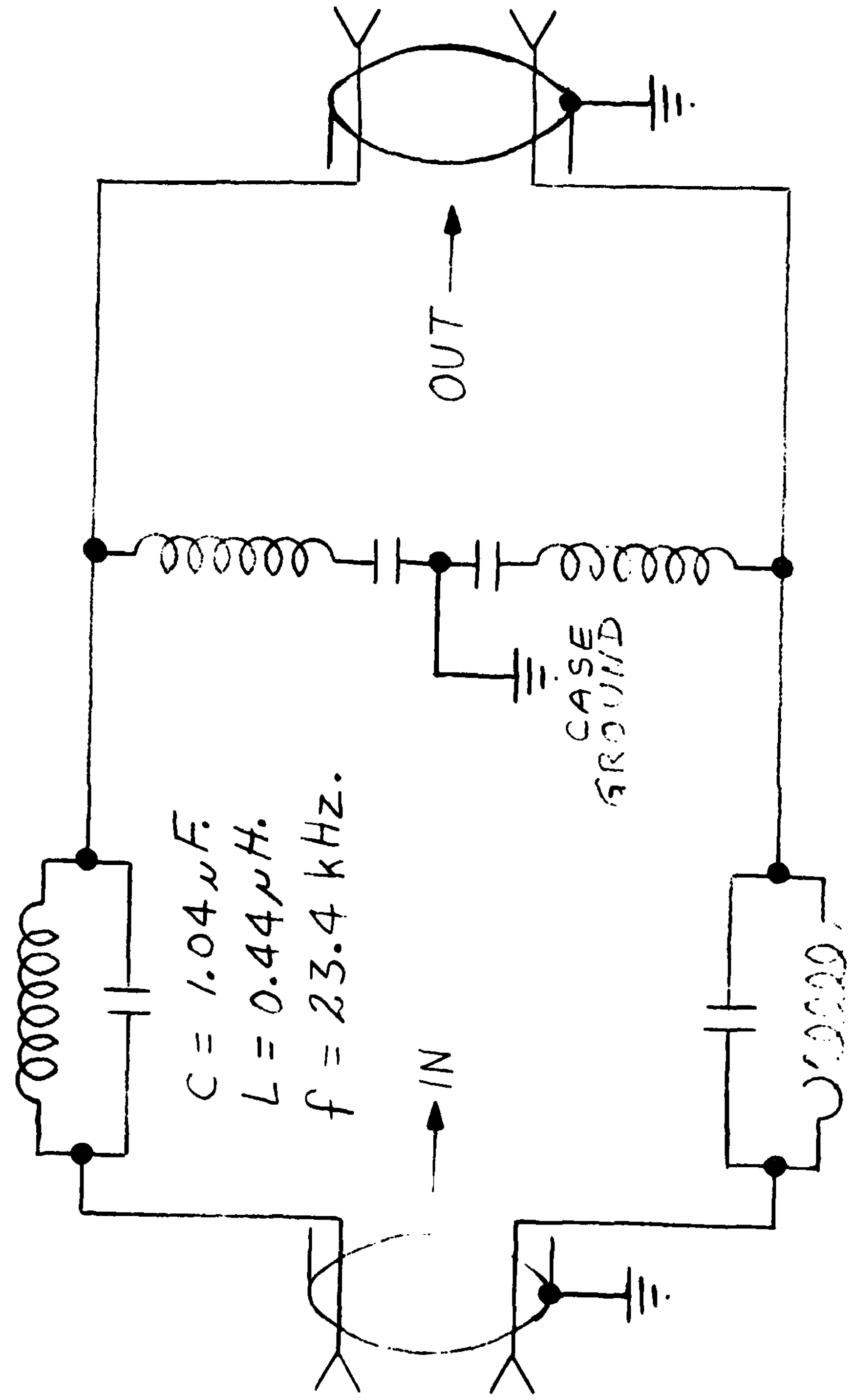

Figure I-2. 23.4 kHz traps.