Technical Report 1742
April 1997

Technique for Building and Calibrating VLF/LF Receive Loop Antennas

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ADMINISTRATIVE INFORMATION

The work detailed in this report was performed for the Naval Computer and Telecommunications Command, Code N42C, by the Naval Command, Control and Ocean Surveillance Center RDT&E Division, Advanced Electromagnetic Technology Branch, Code D856.

Released by
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Division

SB

EXECUTIVE SUMMARY

The strategic VLF/LF submarine communications program involves several VLF and LF transmitter antennas located around the world. The Naval, Command Control and Ocean Surveillance Center (NCCOSC) Research, Development, Test and Evaluation Division (NRAD) is often tasked to baseline the antenna's performance before and after changes are made. One parameter useful in this process is measurement of the VLF/LF transmit antenna's magnetic field strength. The antenna's magnetic field strength provides information on the antenna's effective height, radiated power, and efficiency.

Prior to making these measurements, the VLF/LF receive loop must first be calibrated in a Helmholtz coil. Determining magnetic field strength can then be accomplished by taking readings with the VLF/LF receive loop antenna while in the field of the transmit antenna. The voltage induced around the receive loop is measured by a selective level meter (Hewlett Packard 3586C). Distance from the transmitting antenna to the VLF/LF receive loop is provided using Global Positioning System (GPS) instruments. Antenna current is measured in the helix house of the transmit antenna with a time stamp data recorder. Many of the transmit antenna's performance characteristics can be derived with the above measurements.

This document details the construction method for building the VLF/LF receive loop antenna as designed by Mr. Don Watt of Watt Engineering.

The second portion of this report describes the Helmholtz loop calibration procedure.

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CHAPTER 1

BUILDING THE VLF/LF RECEIVE LOOP ANTENNA

1.1 INTRODUCTION

This very-low-frequency/low-frequency (VLF/LF) receive loop antenna can be used to measure magnetic field-strength at all of the VLF/LF Navy antenna transmitter sites. The antenna is used for similar measurements at non-Navy facilities such as the WWVB time station signal at Fort Collins, Colorado. This particular design is lightweight and fits safely in a briefcase.

1.2 SPECIFICATIONS

The specifications of the VLF/LF receive loop antenna are as follows:

Effective area: 0.078 Square Meters

Number of turns: 60 turns

Resonant frequency: 200 kHz

Operating frequency: 1 to 100 kHz

Connectors: BNC female

Cal loop: One-turn wire loop

1.3 PARTS LIST

The following parts are used to construct the VLF/LF receive loop antenna:

- Blue foam, initial rough dimensions approximately 35 cm X 50 cm, 4-cm width
- Nichrome wire-cutting fixture
- Rheostat
- Magnet wire, AWG #30 enamel-insulated winding wire
- Wire-winding fixture
- BNC female bulkhead connectors (quantity, 2)
- Antenna bracket, 3/16-inch aluminum of dimensions 15 cm X 10 cm
- Tripod mount, ¼-inch aluminum of dimensions 6.5 cm X 3.6 cm
- BNC mount plate, 3/16-inch aluminum of dimension 7.5 cm X 3.8 cm
- Soft copper shielding material, 0.010-inch thick, 6-inch width, 4-foot length
- Electrical tape

- Medium weight fiberglass cloth
- Fiberglass resin mix, Evercoat #499

1.4 FOAM CORE CONSTRUCTION

Follow these steps to construct the foam core:

1. Place the nichrome wire between the two test lead alligator clips in the nichrome wire-cutting fixture as shown in figure 1.

Figure 1. Nichrome wire-cutting fixture.

2. Set the AC rheostat to 14 volts AC.

3. Use the heated nichrome wire to cut the foam core to a length of 39.5 cm and a width of 27.4 cm elliptical shape and cut the inner section out to form an inner elliptical loop with cross-sectional dimension of 3.8 cm by 4.0 cm.

4. Cut a couple of equidistant 1/8-inch slots ½ -inch deep on a circular table saw to hold the two bundles of 30-turn magnet wire. Figure 2 shows the foam core with the two slots for holding the wire.

The two bundles of 30-turn wire will make up the total 60 turns of continuously wound wire. The magnet wire is enamel-insulated, AWG #30. The loop uses one turn for calibration purposes and 60 turns (or two bundles of 30-turn wire) for the actual field measurement. The purpose of the individual bundling of 30 turns is twofold: 1) to increase the resonant frequency of the loop antenna; and 2) to lower the distributed capacitance.

The nichrome wire changes tension when heated and therefore needs a counterweight to provide the appropriate "hot" tension for cutting the blue foam.

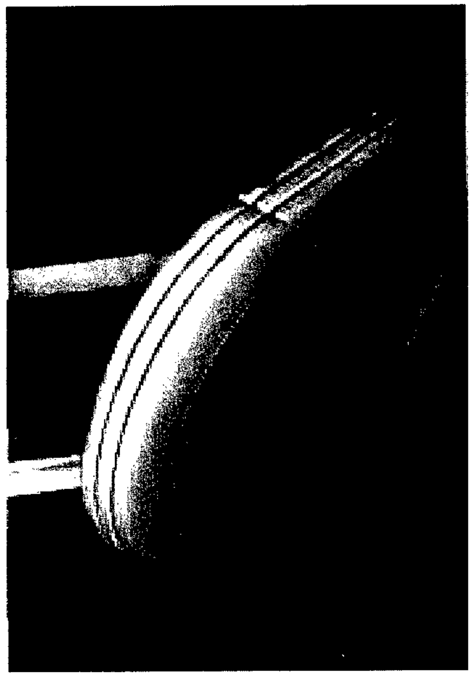

Figure 2. Foam core with two slots for wire.

1.5 CAL LOOP WINDING AND 60-TURN WINDING

Follow these steps to perform cal loop winding and 60-turn winding onto the foam core:

1. Wind one loop of wire in a slot around the foam core to make up the cal loop.

2. Starting with another line of wire, wind the first 30 turns to occupy the same slot as the calibration wire slot.

3. Make a small diagonal cut between slots in the foam and continue the previous 30-turn winding onto the other slot, filling it with the remaining 30 turns. Both loop sets share a common ground that is also tied to the copper shield with buss wire that connect the BNC chassis ground.

4. Mark the 60-turn wire bundle end with "ground" and "60 turn." Also mark the single-turn winding as "ground" and "1 turn."

5. Store the ends of the wires within the slightly bored hole space the BNC terminal ends will occupy. Figure 3 shows the winding fixture held in a vise with wood clamps holding the foam core loop in place while still being able to rotate the wind wire onto the foam core loop.

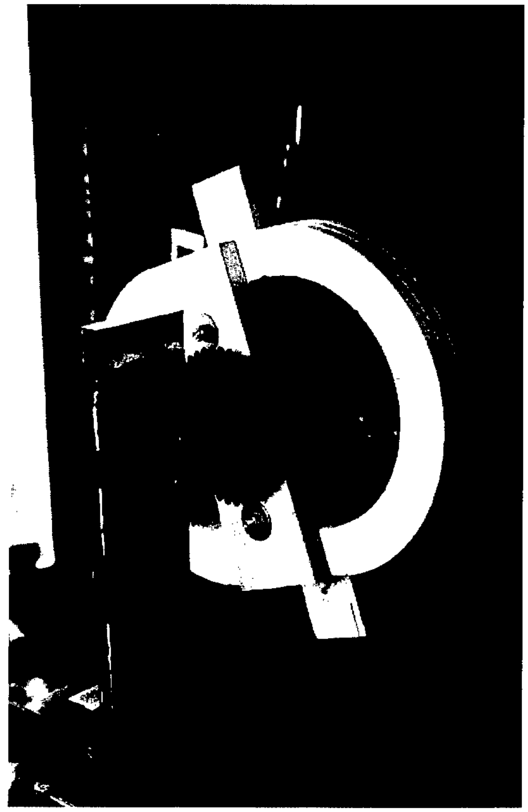

Figure 3. Wire-winding fixture.

1.6 SHIELDING

As Arthur Watt states in his book, *V.L.F. Radio Engineering*, shielding is critical in protecting the loop from electric field influence:

"If a loop has a high impedance, or is operated unbalanced to ground, it is important that it be shielded to reduce the response to electric fields. The size and construction of the shield must be carefully considered both in determining its effectiveness in reducing E field response and in modifying the effective area of the loop. The shield structure must be small enough to keep the capacity of the shield to the windings small." [1]

Follow these steps to construct shielding for the loop:

1. Bend the antenna bracket to a "C" shape to fit against three surfaces of the foam core. The antenna bracket will later hold the tripod mount plate and BNC mounting bracket.

2. Use a 6-inch width, 0.010-inch thick, soft copper material to shield the loop from electric field influence. Turn the copper around the outer circumference of the loop, leaving a 3/8-inch gap at the top.

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[1] Arthur D. Watt, V.L.F. Radio Engineering," Pergamon Press, (1967): 419

3. Cut 1-inch copper width fingers with shears around the sides of the foam core loop (figure 4). Each side of the foam core loop will have a set of these copper fingers that are folded in and around it to make up the protective shield. The 3/8-inch gap at the top prevents an unwanted continuous conductive loop (figure 5).

Figure 4. Copper shielding with 1-inch fingers.

Figure 5. Copper shielding folded into place.

1.7 TRIPOD MOUNT PLATE AND BNC MOUNT PLATE

Follow these steps to mount the tripod plate and the BNC plate.

1. Temporarily test-fit the tripod mount plate to the antenna bracket.

2. Use two #8 panhead screws to attach the tripod mount plate to the antenna bracket. The ¼-20 thread hole in the center of the tripod mount plate will attach the tripod.

3. Test-fit the female bulkhead BNC connectors to the BNC mount plate and test-fit that assembly to the antenna bracket.

4. Remove both mount plates and plug the tapped holes with temporary dummy screw plugs prior to taping and coating with fiberglass resin. Figure 6 shows the tripod mount plate with countersunk holes and the surface for the BNC mount plate attachment area.

Figure 6. Tripod mount plate and surface for BNC mount plate.

1.8 TAPING, FIBERGLASS CLOTH WRAP, AND FIBERGLASS COATING

Follow these steps to tape, fiberglass cloth wrap, and fiberglass coat:

1. Wrap the loop with electrical tape (figure 7). Start wrapping on opposite ends of the antenna bracket to properly tension and position the copper shield. Be sure that during the final taping that a 3/8-inch gap still exists at the top of the loop.

2. Mask the BNC holes of the antenna bracket with tape to protect the loose wires and save a space for the BNC connectors.

3. Wrap segments of single layer medium-weight 2.5-inch width strips, fiberglass cloth around the loop in a spiral fashion. Individual lengths of 18 to 24 inches work best. Overlap the beginning and ending fiberglass segments with slight tension so they will hold together.

4. Paint the loop with up to three coats of fiberglass finish resin (figure 8).

5. Lightly sand between the coats to smooth the rough edges and high spots. Keep a very thin coat of fiberglass resin near the mount area for the BNC mounting bracket.

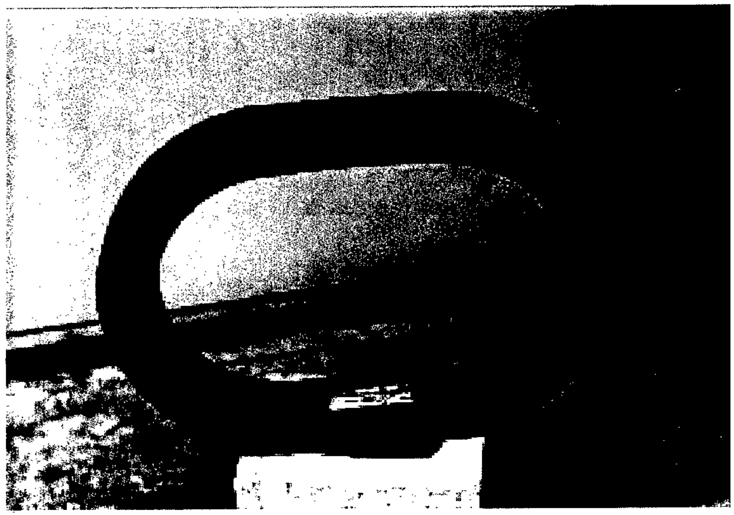

Figure 7. Loop wrapped with electrical tape.

1.9 FINAL ASSEMBLY

Follow these steps to attach the tripod mount plate and wire assembly of the BNC mounting bracket:

1. A buss wire attaches from the BNC chassis lug to the copper shield. Solder the buss wire to the copper shield and also at the BNC chassis lug side.

2. Solder the two winding wires marked as "ground" to the ground lug.

3. Attach the one-turn and 60-turn wires to their respective BNC center conductors.

4. Check that the 60-turn BNC measures about 22 ohms between the center conductor and ground. Also check that the one-turn BNC measures about 4 ohms between the center conductor and ground.

5. Paint the loop with polyurethane paint. Let the loop dry at room temperature. The complete loop antenna is shown in figure 9.

Figure 8. Fiberglass and fiberglass cloth wrapping.

Figure 9. Completed VLF/LF receive loop antenna.

CHAPTER 2

CALIBRATING THE VLF/LF RECEIVE LOOP ANTENNA

2.1 GENERAL INFORMATION

Part of the calibration process involves using a Helmholtz coil with the VLF/LF receive loop antenna. The Helmholtz coil can provide a known, uniform magnetic field in which to calibrate the loop antenna prior to its use in field strength measurement of VLF/LF transmitting antennas. The following sections describe the use of the auto-calibration system for collection of data using the Helmholtz coil located at NRAD, San Diego. Before an actual receive loop antenna is calibrated, proper equipment setup is verified by measuring a four-turn water bottle loop. The four-turn water bottle loop is a test receive loop with which to check out the equipment configuration. It uses a simple 5-gallon water bottle for the shape of the loop. The general concept is to send specific frequencies and signal levels into the Helmholtz coil and then measure the voltages induced on the loop antenna located within the Helmholtz coil. From the two voltages, V-Helm and V-Loop, the magnetic field strength in amps/meter can be determined.

Once the equipment is properly configured, the data collection is done automatically using a computer with an IEEE-488 interface to control the selective level meters and signal generator. Two main programs are used during a typical loop antenna calibration.

The first program collects frequency response data. The program reads in frequencies automatically from 1 to 400 kHz and writes to a file forming four columns of data containing each frequency sampled (FREQ), the amplitude of the HP3325 generator (AMP-dBm), the voltage of the loop (V-LOOP), and the voltage of the Helmholtz coil (V-HELM). The program takes approximately 90 seconds to run.

The second program takes measurements from the VLF/LF receive loop antenna at a fixed frequency and looks at amplitudes ranging from 23.98 dBm and stepped down in 10-dB increments to the noise level for a linearity check of the loop antenna. A table is generated and written to a file with corresponding values of V-Helm and V-Loop for each amplitude measured. This program runs in about 40 seconds. The follow-on spreadsheet analysis provides effective height (he) for that VLF/LF receive loop antenna.

2.2 HELMHOLTZ BUILDING AND PAD

To prevent external influences on the fields measured, the Helmholtz pad and building were specially constructed of non-ferrous materials. The material used in the pad is a special mix of limestone gravel, sand, and fiber-mesh. The limestone concrete pad uses fiberglass rebar for reinforcement, and the test cell building consists of non-magnetic fastening materials such as aluminum and brass. Any additional extraneous metallic objects should be kept as distant from the building as possible. Only the actual measurement equipment should be near the Helmholtz fixture. Support props used for the loop antenna during field measurements should be included during the Helmholtz loop calibration. In particular, the aluminum tripod antenna stand used during magnetic field strength measurements should be located within the Helmholtz coil.

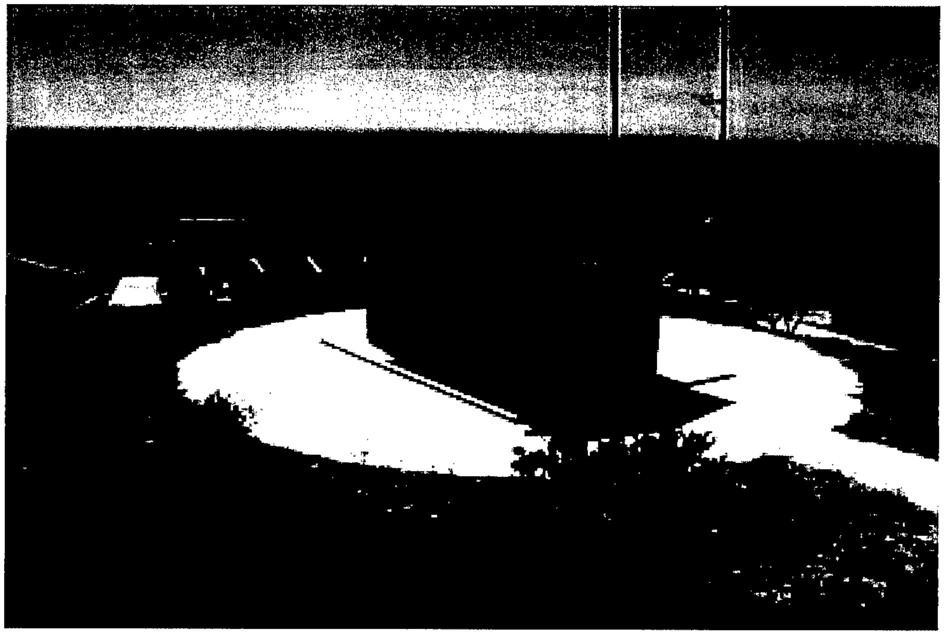

Figure 10. Helmholtz coil building and pad.

2.3 HARDWARE DESCRIPTION

Use the following hardware to calibrate the VLF/LF Receive Loop Antenna:

1. Helmholtz coil
2. HP3586C Selective Level Meter (V-Loop, Address 16)
3. HP3586C Selective Level Meter (V-Helm, Address 20)
4. HP3325 Synthesizer/Generator (Power, Address 17)
5. Two RG223 coax cables about 20 ft long
6. GPIB cables (3)
7. Computer with GPIB NI-488 card
8. Power strip and 100-foot extension cord
9. Test antenna, four-turn water bottle loop

2.4 EQUIPMENT SETUP

Follow these steps to set up equipment for calibration of the receive loop antenna:

1. Center the four-turn water bottle loop antenna in all three dimensions within the Helmholtz fixture (figure 11).

2. Place the actual wire windings on the four-turn water bottle loop in the same plane as the sides of the Helmholtz fixture.

3. Center the actual wire windings on the four-turn water bottle loop equidistantly between each side of the Helmholtz coils. Each test loop used needs to have the windings centered on the same center axis as the Helmholtz fixture.

4. Connect a coax cable between the HP3325 synthesizer output BNC and the BNC marked "power" on the Helmholtz cable interface box.

5. Connect a coax cable between the HP3586C (V-Helm, Address 20) input and the Helmholtz cable interface box marked "V, 10 Ohm."

6. Connect a coax cable between the second HP3586C (V-Loop, Address 16) input and the receive loop output under test.

7. Connect GPIB IEEE-488 cables from the computer's GPIB card to the three GPIB controlled instruments; the HP3325 and the two HP3586Cs.

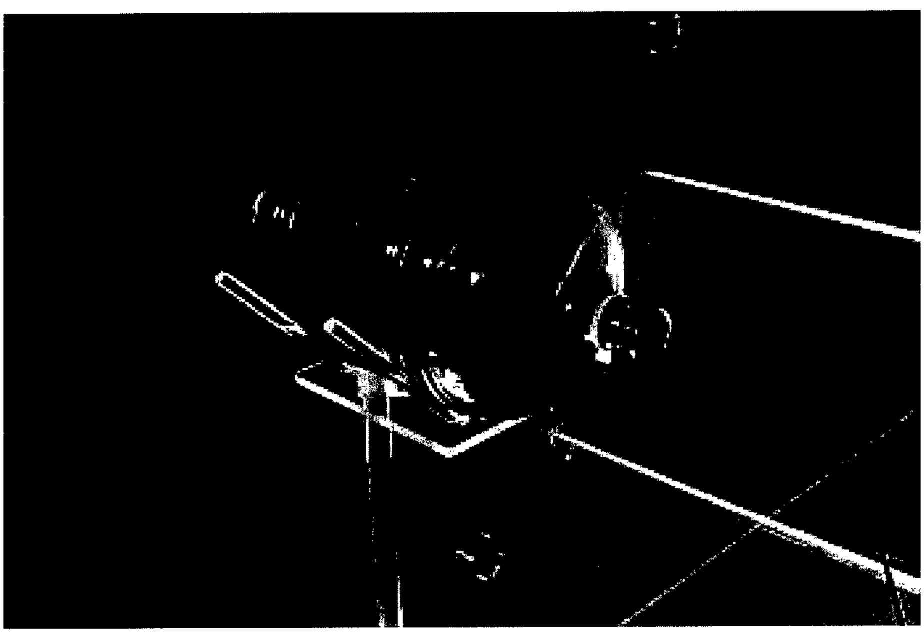

Figure 11. Four-turn water bottle loop.

2.5 SYSTEM CHECKOUT: FOUR-TURN WATER BOTTLE LOOP

Follow these steps to perform system checkout of the four-turn water bottle loop:

1. Turn on the instruments and computer.

2. From the computer keyboard type "**GPIBPC**" at the **C:>** prompt. The GPIB software will be initialized and the computer should display the menu for loading and running basic programs.

3. Load the program, **PRGM2A**, by typing "**F3**" followed by the program name.

4. Type "**F2**" to begin running the program

5. Enter the information requested. PRGM2A performs a frequency sweep from 1 to 400 kHz at constant amplitude, recording corresponding voltages for V-Loop and V-Helm. An example of the raw form of data collection is included in figure 12. Note the headings and comment information within the raw data must be deleted after the file is imported into the spreadsheet.

6. When importing data files, select the data file for import as **Comma and "Delimited File"** (for QPRO spreadsheets).

7. Figure 13 shows a plot of Vmeas/Vcalc (dB) vs. Frequency (kHz) with a difference that is less than 0.05 for frequencies from 1 to 100 kHz. A difference of 0.05 or less between voltage measured of the loop, and voltage calculated for the loop confirms that the setup is correct. Once this level of measurement is reached and demonstrated in a plot similar to that shown in figure 13, the actual receive loop antenna can be calibrated as described in section 2.8.

2.6 FORMULAS

This sections defines the formula contents in each data column of the QPRO spreadsheet for the water bottle calibration data displayed in figure 14.

Column 5, titled ***Calc Hhelm A/m***, has magnetic field (H) in amps/meter:

$$H = \frac{I}{(a)\cdot\left[\left(\frac{5}{4}\right)^{\left(\frac{3}{2}\right)}\right]}$$

where (a) is the radius of the Helmholtz coil which equals 1 meter and

(I) is the current in amps measured from the Helmholtz coil.

FREQ	AMP-dBm	V-LOOP	V-HELM
1.0	23.98	U-105.162	N-026.053
2.0	23.98	U-099.156	N-026.081
5.0	23.98	U-091.193	N-026.085
10.0	23.98	U-085.201	N-026.073
15.0	23.98	U-081.651	N-026.075
20.0	23.98	U-079.173	N-026.081
25.0	23.98	U-077.240	N-026.061
30.0	23.98	U-075.664	N-026.067
35.0	23.98	U-074.316	N-026.057
40.0	23.98	U-073.164	N-026.081
45.0	23.98	U-072.143	N-026.085
50.0	23.98	U-071.229	N-026.095
55.0	23.98	U-070.404	N-026.075
60.0	23.98	U-069.650	N-026.081
65.0	23.98	U-068.933	N-026.079
70.0	23.98	U-068.296	N-026.077
75.0	23.98	U-067.699	N-026.067
80.0	23.98	U-067.139	N-026.077
85.0	23.98	U-066.614	N-026.075
90.0	23.98	U-066.119	N-026.073
95.0	23.98	U-065.648	N-026.081
100.0	23.98	U-065.204	N-026.091
200.0	23.98	U-059.133	N-026.085
300.0	23.98	U-055.576	N-026.065
400.0	23.98	N-052.961	N-026.035

Figure 12. Sample raw data collected during system checkout.

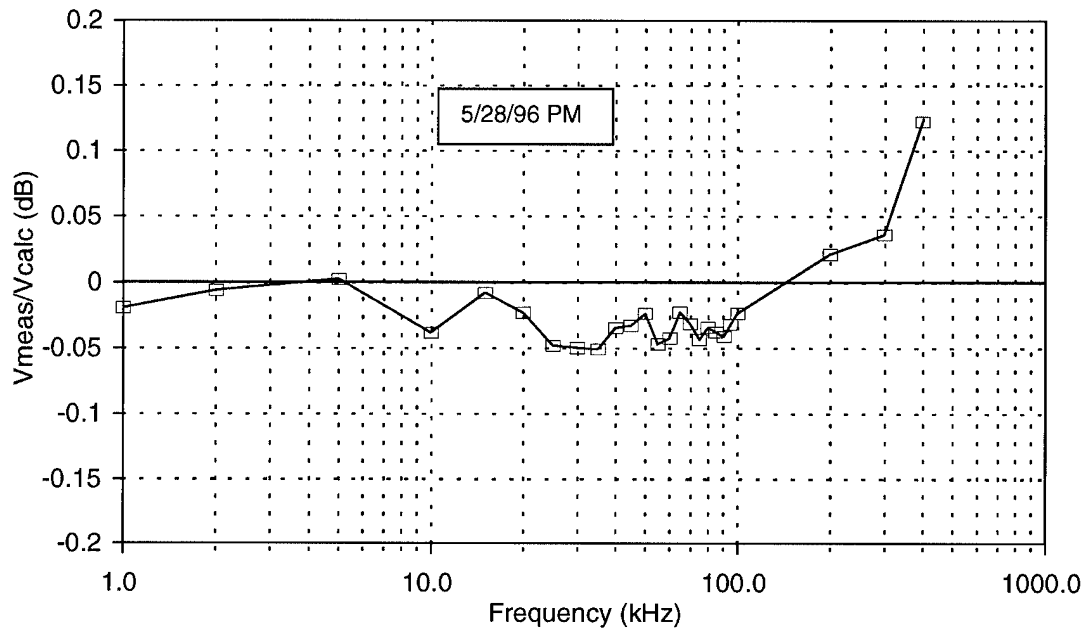

Figure 13. Four-turn water bottle calibration loop.

For (I), with the 10-ohm precision resistor in the Helmholtz coil circuit:

$$I = \frac{10^{\left(\frac{VHELM}{20}\right)}}{10}$$

V-Helm is the measured voltage from the Helmholtz coil in dBV (figure 14, column 4) as read from the HP3586C selective level meter. The numerator of the above expression converts dBV to volts. By substitution, the magnetic field (H) can be expressed as

$$H = \frac{10^{\left(\frac{VHELM}{20}\right)}}{(10)\cdot(1)\cdot\left[\left(\frac{5}{4}\right)^{\left(\frac{3}{2}\right)}\right]}$$

Note that all of the data collection programs available in table 1 measure V-Helm in the unterminated mode. Using the unterminated mode allows us to keep the precision resistance of 10 ohms across the Helmholtz coil and to use the above formula as written.

Column 6, titled ***Calc Vloop V***, has V-Loop in volts. The formula for VLOOP is:

$$\text{V-Loop} = 2\pi\,(f)\,(u_o)\,(n)\,(A)\,(H)$$

- f = frequency (kHz)
- u_o = $4\pi\,(10^{-7})$
- n = number of wire turns of receive loop
- A = loop area (square meters)
- H = magnetic field strength (amps/meter)

Column 7, titled ***Calc Vloop dBV***, changes V-Loop units from volts to dBV,

VLOOP(dBV) = (20) Log (VLOOP).

Column 8, titled ***Vmeas/Vcalc dB***, is the difference between column 3 (Measured V-loop) and column 7 (Calculated V-loop).

Vmeas - Vcalc is the difference in measurements in dBV units.

2.7 SPREADSHEET FORMULA EXAMPLES FOR THE FOUR-TURN BOTTLE LOOP

The following are examples of each formula above as translated into a QPRO spreadsheet formula. Remember the cells selected are arbitrarily chosen from figure 14, row 15, and some cells will represent constants defined at the top of the spreadsheet dealing with antenna dimensions and other fixed values. The first four columns of this spreadsheet contain the imported raw data.

In column 5, row 15, ***Calc Hhelm A/m***, is written as

1/10*10^(D15/20)/(5/4)^(3/2).

In column 6, row 15, ***Calc Vloop V***, is written as

2*@PI*A15*1000*$A:$H$6*$A:$E$7*$A:$E$6*E15

A15*1000 refers to frequency (kHz), f.

$A:$H$6 is the constant, u_o.

$A:$E$7 refers to the number of turns, n.

$A:$E$6 refers to loop area, A.

E15 refers to magnetic field strength, H.

In column 7, row 15, ***Calc Vloop dBV***, is written as

20*@LOG(F15).

In column 8, row 15, ***Vmeas/Vcalc dB***, is written as the difference in dB:

C15-G15.

WATER BOTTLE CALIBRATION DATA
Spreadsheet H2O5-28E.WB1, Data file H2O5-28E, Graph file H2OBOTTLE
Helmholtz Calibration Data, Jim Birkett, 5/28/96 PM
Calibration by standard antenna technique
Standard antenna is a four-turn loop D = 9.8477 Inches
on a 5-gallon water cooler bottle, A = 0.04914 m^2u0 = 1.3E-06
15 feet coax attached n = 4 Turns
V Helm HP-3586 PA38816 50 Ohm UnTerm dBV 10 dB 400 HZ
V Loop HP-3586 PA25693 50 Ohm UnTerm dBV 10 dB 400 HZ

fKHz	Synth Out Vpp	Meas Vloop dBV	Meas Vhelm dBV	Calc Hhelm A/m	Calc Vloop V	Calc Vloop dBV	Vmeas Vcalc dB
1	23.98	-105.162	-26.053	0.003564	0.000006	-105.143	-0.019233
2	23.98	-99.156	-26.081	0.003553	0.000011	-99.150	-0.005833
5	23.98	-91.193	-26.085	0.003551	0.000028	-91.195	0.002367
10	23.98	-85.201	-26.073	0.003556	0.000055	-85.163	-0.038233
15	23.98	-81.651	-26.075	0.003555	0.000083	-81.643	-0.008058
20	23.98	-79.173	-26.081	0.003553	0.000110	-79.150	-0.022833
25	23.98	-77.24	-26.061	0.003561	0.000138	-77.192	-0.048033
30	23.98	-75.664	-26.067	0.003559	0.000166	-75.614	-0.049658
35	23.98	-74.316	-26.057	0.003563	0.000194	-74.265	-0.050594
40	23.98	-73.164	-26.081	0.003553	0.000221	-73.130	-0.034433
45	23.98	-72.143	-26.085	0.003551	0.000248	-72.111	-0.032483
50	23.98	-71.229	-26.095	0.003547	0.000275	-71.205	-0.023633
55	23.98	-70.404	-26.075	0.003555	0.000303	-70.358	-0.046487
60	23.98	-69.65	-26.081	0.003553	0.000331	-69.608	-0.042258
65	23.98	-68.933	-26.079	0.003554	0.000358	-68.911	-0.022500
70	23.98	-68.296	-26.077	0.003555	0.000386	-68.265	-0.031194
75	23.98	-67.699	-26.067	0.003559	0.000414	-67.656	-0.043458
80	23.98	-67.139	-26.077	0.003555	0.000441	-67.105	-0.034033
85	23.98	-66.614	-26.075	0.003555	0.000469	-66.576	-0.037611
90	23.98	-66.119	-26.073	0.003556	0.000497	-66.078	-0.041083
95	23.98	-65.648	-26.081	0.003553	0.000524	-65.616	-0.031705
100	23.98	-65.204	-26.091	0.003549	0.000551	-65.181	-0.023233
200	23.98	-59.133	-26.085	0.003551	0.001102	-59.154	0.021167
300	23.98	-55.576	-26.065	0.003559	0.001657	-55.612	0.036342
400	23.98	-52.961	-26.035	0.003572	0.002217	-53.084	0.122567

Figure 14. Spreadsheet of bottle calibration data.

2.8 VLF/LF RECEIVE LOOP CALIBRATION

With success at achieving a plot similar to that in figure 13, the actual loop can be calibrated. Included is an example using the frequency for the VLF site at NCTS Cutler, Maine, in October 1996. The station frequency is 24.0 kHz. A different program is used, measuring the antenna loop's response curve at one particular frequency. The station frequency remains constant while the amplitude of the synthesizer is decreased in 10-dB steps. Program "**PRGM5A**" was selected to accumulate data in unterminated mode for the voltage,V-LOOP. Figure 15 contains the graph of effective height, [he(mm)], versus magnetic field, [H(mA/m)], and also has a trace line showing the corresponding average, he(mm).

2.9 VLF/LF RECEIVE LOOP SPREADSHEET INFORMATION

Figure 16 includes an example of the blue loop #1 calibration data spreadsheet from which the calibration graph figure 15 was derived. Figure 17 shows a Helmholtz coil with blue loop. After executing PRGM5A, the raw data, figure 18, was imported into the first four columns of the QPRO spreadsheet titled "Blue Loop Calibration Data 10/10/96."

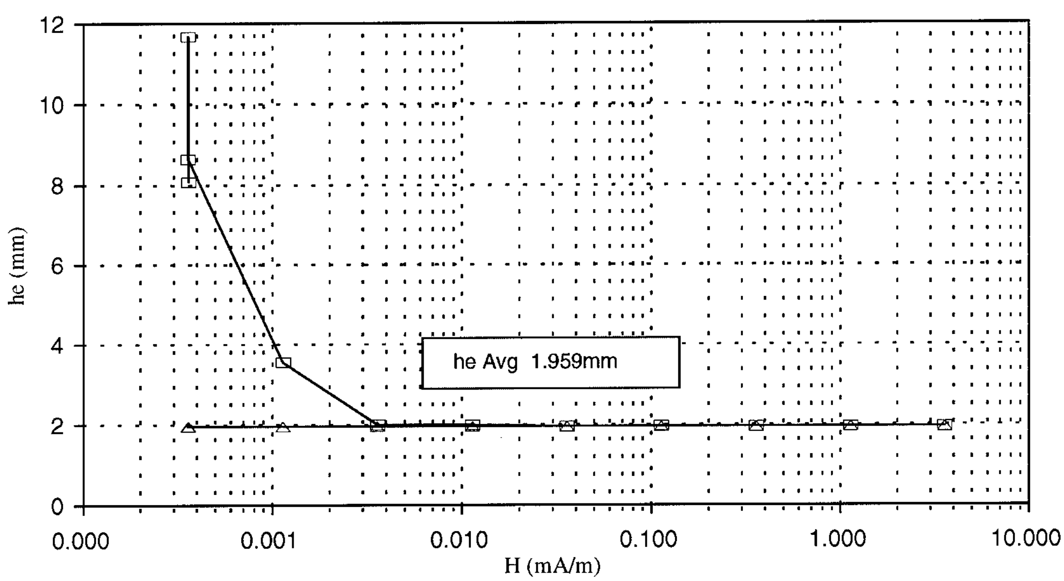

Figure 15. Blue loop #1 calibration, 24.0 kHz unterminated, 10 October 1996.

Examples of the spreadsheet formulas used to produce the calibration graph, follow.

In column 5, row 14, ***Calc Hhelm (A/m)*** is calculated using the same method as the previous spreadsheet:

1/10*10^(D14/20)/(5/4)^(3/2)

Column 6, row 14, ***Calc Hhelm (mA/m)*** translates Hhelm units from (A/m) to (mA/m):

+E14*1000

Column 7, row 14, ***Calc Eeqhelm (V/m)*** is the E equivalent Helmholtz expression:

120*@pi*E14

Column 8, row 14, ***Meas V-loop V*** changes measured V-Loop from dBV to volts:

10^(C14/20)

Column 9, row 14, ***Meas he(mm)*** is given from measured V-Loop(volts) divided by Eeqhelm (V/m)*1000:

+H14/G14*1000

Column 10, ***Avg he(mm)*** is the average of the first five data values

@AVG(I14..I18)

FREQ (kHz)	AMP (dBm)	Meas V-LOOP (dBV)	Meas V-HELM (dBV)	Calc Hhelm	Calc Hhelm (mA/m)	Calc Eeqhelm (V/m)	Meas V-loop (V)	Meas he (mm)	Avg he (mm)
24	23.98	-51.559	-26.014	3.58E-03	3.58E+00	1.350E+00	2.64E-03	1.9579	1.9594
24	13.98	-61.529	-35.995	1.13E-03	1.13E+00	4.278E-01	8.39E-04	1.9604	1.9594
24	3.98	-71.557	-46.003	3.58E-04	3.58E-01	1.352E-01	2.64E-04	1.9558	1.9594
24	-6.02	-81.503	-56.008	1.13E-04	1.13E-01	4.271E-02	8.41E-05	1.9692	1.9594
24	-16.02	-91.579	-66.015	3.58E-05	3.58E-02	1.350E-02	2.64E-05	1.9536	1.9594
24	-26.02	-101.383	-75.998	1.13E-05	1.13E-02	4.276E-03	8.53E-06	1.9943	1.9594
24	-36.02	-111.381	-86.022	3.58E-06	3.58E-03	1.349E-03	2.70E-06	2.0002	1.9594
24	-46.02	-116.339	-95.989	1.14E-06	1.14E-03	4.281E-04	1.52E-06	3.5607	1.9594
24	-56.02	-118.663	-106.016	3.58E-07	3.58E-04	1.349E-04	1.17E-06	8.6434	1.9594
24	-66.02	-116.045	-106.016	3.58E-07	3.58E-04	1.349E-04	1.58E-06	11.6838	1.9594
24	-76.02	-119.209	-105.972	3.60E-07	3.60E-04	1.356E-04	1.10E-06	8.0758	1.9594

Figure 16. Spreadsheet blue loop #1 calibration data.

Figure 17. Helmholtz coil with blue loop.

a:bls1unt.dat

10 foot RG223 VLOOP-PA50532 VHELM-PA39263 UNTERM

FREQ	AMP-dbm	V-LOOP	V-HELM
24.0	23.98	N-051.559	N-026.014
24.0	13.98	U-061.529	N-035.995
24.0	3.98	U-071.557	N-046.003
24.0	-6.02	U-081.503	U-056.008
24.0	-16.02	U-091.579	U-066.015
24.0	-26.02	U-101.383	U-075.998
24.0	-36.02	U-111.381	U-086.022
24.0	-46.02	U-116.339	U-095.989
24.0	-56.02	U-118.663	U-106.016
24.0	-66.02	U-116.045	U-106.016
24.0	-76.02	U-119.209	U-105.972

Figure 18. Raw data from linearity data collection.

2.10 SUMMARY

Following the guidelines provided in this document will assist in producing similar results for future VLF/LF receive loop calibrations. There are many different types of receive loop antennas that can be calibrated using this process. Another commonly used loop at NRAD is the briefcase loop. This loop antenna is actually built into a briefcase. Some versions have preamplifiers installed within the case also. The calibration process remains the same and there is a significant time savings in running these automated data collection programs as opposed to manually recording the data.

In some instances, an interactive data collection program, (**PRGM4**), series is used. Keyboard entry to the computer of frequency settings and signal amplitudes from the frequency synthesizer provide another useful form of automated data collection.

Table 1. Data collection programs.

Program Title	Description	3586C V-Loop Settings Address 16		3586 V-Helm Settings Address 20	
		Bandwidth	Term	Bandwidth	Term
PRGM2A	Frequencies (1 to 400 kHz) for water bottle loop	400 Hz	Unterm	400 Hz	Unterm
PRGM2B	Frequency response (1 to 400 kHz)	3100 Hz	Unterm	3100 Hz	Unterm
PRGM2C	Frequency response (1 to 400 kHz)	3100 Hz	50 Ohm	3100 Hz	Unterm
PRGM2D	Frequency response (1 to 400 kHz)	400 Hz	50 Ohm	400 Hz	Unterm
PRGM4A	Interactive-manual input of frequency & V-PP	400 Hz	Unterm	400 Hz	Unterm
PRGM4B	Interactive-manual input of frequency & V-PP	3100 Hz	Unterm	3100 Hz	Unterm
PRGM4C	Interactive- manual input of frequency & V-PP	3100 Hz	50 Ohm	400 Hz	Unterm
PRGM4D	Interactive-manual input of frequency & V-PP	400 Hz	Unterm	400 Hz	Unterm
PRGM5A	Linearity check Fixed frequency	3100 Hz	Unterm	400 Hz	Unterm
PRMG5B	Linearity check Fixed frequency	3100 Hz	50 Ohm	3100 Hz	Unterm
PRMG5C	Linearity check Fixed frequency	400 Hz	50 Ohm	3100 Hz	Unterm
PRMG5D	Linearity check Fixed frequency	400 Hz	50 Ohm	400 Hz	Unterm

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1997	Final April 1997

4. TITLE AND SUBTITLE

TECHNIQUE FOR BUILDING AND CALIBRATING VLF/LF RECEIVE LOOP ANTENNAS

5. FUNDING NUMBERS

PE: OMN
AN: DN305512
WU: D85-CH94

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
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San Diego, California 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

TR 1742

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Computer & Telecommunications Command
4401 Massachusetts Avenue
Washington, DC 20390

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The strategic VLF/LF submarine communications program involves several VLF and LF transmitter antennas located around the world. The Naval Command, Control and Ocean Surveillance Center (NCCOSC), Research, Development, Test and Evaluation Division (NRaD) is often tasked to baseline the antenna's performance before and after changes are made. One parameter useful in this process is measurement of the VLF/LF transmit antenna's magnetic field strength. The antenna's magnetic field strength provides information on the antenna's effective height, radiated power, and efficiency.

Prior to making these measurements, the VLF/LF receive loop must first be calibrated in a Helmholtz coil. Determining magnetic field strength can then be acccomplished by taking readings with the VLF/LF receive loop antenna while in the field of the transmit antenna. The voltage induced around the receive loop is measured by a selective level meter (Hewlett Packard 3486C0). Distance from the transmitting antenna to the VLF/LF receive loop is provided using Global Positioning System (GPS) instruments. Antenna current is measured in the helix house of the transmit antenna with a time stamp data recorder. Many of the transmit antenna's performance characteristics can be derived with the above measurements.

The purpose of this document is to detail the construction method for building the VLF/LF receive loop antenna as designed by Mr. Don Watt of Watt Engineering. The second portion of this report describes the Helmholtz loop calibration procedure.

14. SUBJECT TERMS

Mission area: Communications
antennas — very low frequency (VLF)
high–voltage — low frequency (LF)
measurement

15. NUMBER OF PAGES

31

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

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NSN 7540-01-280-5500

Standard form 298 (BACK)

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