RADC-TN-61-233

September 28, 1961

RFD ANTENNA TECHNIQUES SURVEY

Armour Research Foundation
of Illinois Institute of Technology
Technology Center
Chicago 17, Illinois

First Quarterly Report
1 June 1961 to 1 September 1961
Contract No. AF 30(602)-2509

Prepared
for
Rome Air Development Center
Air Force Systems Command
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I. ABSTRACT

During the first quarterly period, a review of the pertinent literature has been conducted in an effort to determine the state-of-the-art of VLF and HF antenna techniques. A list of these references was prepared and it is given in this report. In addition, several individuals were contacted at Bureau of Ships in order to collect more detailed information on electrical characteristics of some of the Navy's VLF antenna installations. The results of these contacts are also presented here. Essential VLF-antenna characteristics are tabulated and a brief description of their individual configurations is included.

Future work on this program will be concerned with completing the survey on VLF antenna techniques and reporting the survey information gathered on HF antenna techniques.

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I. INTRODUCTION

The purpose of this project is to determine the state-of-the-art of VLF and HF antenna techniques. This survey is to be made with particular regard to the types of structures used, radiation efficiency, frequency of operation, gain, polarization, bandwidth, beamwidth, side lobe, back lobe, power capability, mechanical limitations, real estate, installation maintenance and other pertinent design criteria of VLF and HF antennas. In accomplishing this purpose a major effort has been made and will be made to collect most of the existing literature on VLF and HF antennas.

II. DISCUSSION

A. VLF Propagation

It has been known for many years that radio waves in the very low-frequency band can propagate to great distances. Nearly always, however, there is pronounced absorption between 2 and 4 kc. On the other hand, for frequencies around 10 kc, there is very little attentutation.[1] Apparently, in the latter case, the ionosphere is behaving as a good reflector with a reflection coefficient near -1, and the ground is also a good reflector with a reflection coefficient near +1. For frequencies in this 10 kc region, the losses in the upper and lower bounding surfaces give rise to an attenuation coefficient of the order of 2 db per 1000 km of path length. At frequencies below the absorption band, the attentuation factor is also small with a typical value of about 3 db per 1000 km of path length at 1 kc. The attenuation of VLF transmission normally decreases with increasing, conductivity, and it is lowest for a sea-water path, which has the highest earth conductivity.

Very low frequency propagation is quite insensitive to the character of the terrain (i. e., the roughness of the earth's surface), because irregularities are usually negligible in comparison with the wavelength used. A VLF communication system is also more reliable, since fading in the normal sense is not believed to occur at these frequencies.[2]

For these reasons, the operating frequency band utilized at present is included in the region from 10 to 30 kc, but a band centered near 200 cps also shows some promise.[2] However, a vertical antenna of a given length would be electrically much taller and more efficient in the higher band. This portion also provides much more spectrum space. It appears then that the higher (10 to 30 kc) frequency band is the most practical for long-distance communications. However, with the development of sufficiently efficient antennas at frequencies of about 200 cps or less, it is possible that long-distance communication systems utilizing such frequencies would be practical, but their bandwidths would be extremely narrow. Calculations have been made[3] indicating that transmission at such low frequencies may be favorable if the antenna efficiency is greater than about 2 or 3 percent of the corresponding figure at 30 kc.

The very low-frequency (below 30 kc) is consigned to radio navigation stations and long-range transmitters for world-wide communication.

The excellent phase stability of VLF transmission suggests that it might be well suited for extremely accurate navigation systems. It is the prohibitive size of conventional transmitting antenna systems which prevents VLF from being used in modern navigation systems.[4]

B. General Principles of VLF Antennas

1. Basic Considerations

The purpose of a transmitting antenna is to launch the RF energy into space with as little loss of power as possible. In the high frequency ranges, where the antenna dimensions are of the order of a wavelength or greater, it is comparatively easy to design antennas which radiate better than 99% of the total radio-frequency power.[5] In the VLF region, antenna dimensions are usually a very small fraction of a wavelength and high radiation efficiencies are difficult and expensive to achieve. Typical radiation efficiencies (i.e., ratio of radiated power to input power) of the order of 10-20% are common in the VLF range. The following terms are very essential in the antenna field:

a) <u>Effective Height</u>

The effective height of a transmitting antenna is that height of an equivalent linear antenna that has the same current I(o) at all points along its length and that radiates the same field intensity as the actual antenna in the direction perpendicular to its length.[6] I(o) is the current at the terminals of the actual antenna.

It can be shown that for a short vertical dipole antenna the effective height is given by the following expression:[6]

$$h = \frac{r\lambda E}{60\pi I(o)} \qquad (1)$$

where

h = Effective height

r = distance in meters from antenna

I(o) = current at the terminals of the antenna

π = 3.14

λ = free-space wavelength

E = Electric field at a distance r meters in a direction normal to the antenna.

Equation (1) can be used to actually determine the effective height of a practical VLF antenna, since the assumption that the antenna be short is valid in this frequency region. First, the field intensity is measured at a given distance and wavelength, and then equation (1) is used to obtain the effective height of the antenna considered.

b) <u>Radiation Resistance</u>

Radiation resistance is defined as follows:

$$R_r = \frac{P_r}{I^2_{eff}}$$

where

R_r = Radiation Resistance

P_r = Radiated Power

I_{eff} = Effective magnitude of antenna current

For an idealized antenna, consisting of a large flat plate and a short vertical wire mounted on a perfectly conducting ground, the radiation resistance, assuming a constant distribution of current is given by the formula:(6)

$$R_r = 160\pi^2 \left(\frac{h}{\lambda}\right)^2 \tag{2}$$

Consequently, after obtaining the effective height of a VLF antenna from Equation (1), it is easy to calculate its radiation resistance from Equation (2).

c) <u>Radiation Efficiency</u>

Definition:

$$\eta = \frac{P_r}{P_i}$$

or

$$\eta = \frac{R_r}{R_r + R} \tag{3}$$

where

P_r = radiated power

P_i = Input power to antenna

R = Resistance due to losses in soil, tuning coils, conductors, insulators and other losses in the antenna system.

These simple formulas are actually used in calculating the efficiency of VLF antennas where the assumption that ($h \ll \lambda$) is certainly valid.

In addition, all practical antennas operating in the VLF region have large heat losses and every effort should be made to keep these losses at a minimum. When large power is used, the voltage, as controlled by corona formation, must also be a primary consideration in the design.

2. Top Loading

The use of a large flat top is beneficial in two ways. First increasing the area of the flat top decreases the capacitive reactance and thus reduces the amount of inductive reactance necessary to tune the system. For this reason, the power loss in tuning coils is reduced. Second, the voltage with respect to ground is reduced, which increases power capability of VLF antennas before corona formation takes place; however, top loading introduces mechanical problems due to wind and ice loading.

3. Antenna Losses

Power losses in VLF antennas are determined primarily by the following factors:[4]

a) Since the antenna current flows to ground through the top loading capacitance, considerable power is lost in the ground itself, and the effective resistance of the best engineered ground system is often larger than the radiation resistance as indicated in Tables I and II.

b) In order to meet the conditions of maximum power transfer, a tuning inductor is connected in series with the antenna feed to resonate the antenna capacitance. There is some power dissipated in this inductor. To keep this dissipation very low at the operating frequency, the quality factor, Q, of the coil must be as large as possible. In order to accomplish this, the coil is as large in diameter as is mechanically practical; the conductor size is also large. Large Litz cable is frequently used.

c) The high operating potentials, due to the small resistance and large reactance of the antenna, cause considerable dielectric loss in the insulating media. To minimize dielectric losses, all corona must be eliminated with corona shields, avoidance of sharp points and use low-loss dielectric materials.

d) The great length of the antenna conductors themselves gives rise to appreciable conductor loss, since relatively poor - conducting high-strength alloy conductors must be used to withstand mechanical loads. Resistance losses are reduced with sufficiently large antenna cables.

e) Losses in the tuning coils (used to tune the capacitance of an antenna) are also present. These losses can be minimized by using physically-large coils wound with Litz wire.

4. Ground Systems

The largest loss occurs in the earth where the antenna charging current flows to ground through the antenna-to-ground capacity and back to the base of the antenna. A properly designed ground system is a very large factor in reducing this loss of power in the ground.[4]

Ground systems used for antennas below 500 kc differ markedly from those used at standard broadcast frequencies and above since, (a) it is impractical to bury electrically long ground wires at these extremely long wavelengths, and (b) at very low frequencies the skin depth of the underlying earth becomes very large and the ground currents extend far deeper than at higher frequencies. Consequently, three general types of ground system are used to reduce the power lost in ground heating:[4]

(a) Radial Buried Wire-System

This ground system consists of 15 to 150 radial wires buried in the soil and centered at the base of the antenna. It is similar to ground systems used at standard broadcast frequencies. However, since these radials are electrically short, several methods are used at VLF to reduce ground current densities.

(1). Vertical ground rods are sometimes attached to the ends of the radials to intercept current at the periphery of the system.

(2). The radials are brought above the ground at an appreciable distance from the base of the antenna, preventing excessive current densities in the ground at the collecting point at the base of the antenna. This above-ground system also forms an electrostatic shield at the base of the antenna, thereby reducing dielectric losses in the ground caused by the intense potential gradients near the base of the antenna.

(3). No closed paths exist in the ground system since they would allow large circulating currents to increase the copper loss.

(4). Conductor sizes are as large as economically possible, and are proportional to the current densities at that point in the ground system.

(b) Multiple Star Ground System

This ground system consists of a number of short buried-wire radial systems, uniformly spaced around the base of the antenna and connected to its base by over-ground buses. In practice, two or more concentric circles of stars are used, with series inductors in the connecting buses of the inner stars to prevent excessive concentration of current in the inner stars. It is generally more efficient to use more stars of shorter radial length than a few stars of long radials.

(c) Counterpoise System

This is a large insulated network of radial conductors supported above the ground. The effect of the counterpoise is to distribute the ground currents uniformly over its area. The capacitance between counterpoise and grounds is as large as possible to reduce the potential from counterpoise to ground, which may still cause considerable hazard to personnel. However, if the cost and danger of the counterpoise system can be tolerated, it is generally preferable to the multiple-star and buried-wire systems. All three systems possess above-ground conductors at the antenna base.

5. Multiple Tuning

Most of the high power VLF antennas are of the multiple tuned type. A multiple tuned antenna is, in effect, a number of antennas operating in parallel.[5] The antenna at the New Brunswick station (Fig. 1) will serve as an example. This antenna is approximately one mile long and the antenna wires are suspended from triadics strung between pairs of towers. A down-lead is dropped from the triadic between each pair of towers to a tuning inductance. The current is carried from the lower end of the tuning coil through an overhead ground distribution system and fed through various sizes of inductances to the buried ground wires. The combination of multiple tuning together with the ground distributing system results in a very large decrease in the power lost in the ground. The original antenna at New Brunswick was of the "L" type and the current had to flow from the transmitter at one end of the antenna through the ground to the far end of the antenna. The total antenna resistance was 3.8 ohms. After the antenna was multiple tuned and provided with a good ground distributing system, the total resistance was reduced to 0.5 ohms. Further improvements in the system reduced the value to 0.35 ohms. Thus the power radiated from this antenna, for the same input, was increased more than ten times by these changes.

6. Bandwidth and "Q"

It is well-known that

$$\frac{\Delta f}{f_o} = \frac{1}{Q} \tag{4}$$

where

f_o = resonance frequency

Δf = bandwidth at three db points

Q is a measure of frequency bandwidth rather than of particular circuit constants.

An ideal antenna should have a high radiation efficiency together with a low Q. But these two quantities are in natural opposition. If we improve the efficiency of a particular antenna by decreasing the losses in the tuning coils and ground system, we decrease the frequency band, i.e., increase the Q. Of course, it is a simple matter to lower the Q to any desired value by the insertion of losses if one is willing to take a corresponding sacrifice in radiation efficiency. In fact, the ratio of efficiency to Q is independent of the value of loss resistance.[5] To obtain a low Q together with high efficiency, an antenna must be operated near its natural resonance frequency and be designed so as to have a low distributed inductance. A fat quarter-wave stub antenna is an example. For 15 kc such an antenna would be about 3 miles high and of the order of 1000 feet in diameter.[5]

In general, bandwidths of the order of 100 cps or less are typical for most existing VLF antennas. Equation (4) may be used to calculate bandwidth, if Q and the operating frequency of a VLF antenna are known.

7. Matching VLF Antenna Impedances

In order to have maximum power transferred, the antenna impedance must be matched to that of the source or transmitter. This is usually very difficult to accomplish, since one of the most serious disadvantages of VLF antennas is the fact that the antenna input impedance consists almost entirely of a large capacitive reactance. For an analysis of the problem of broadband matching of arbitrary impedances see reference (8). Transmission lines have been used for this purpose between the antenna and source. In addition, in the practical arrangement for connecting up a transmission line, it has been found advantageous to employ transformers of high magnetizing reactance and equipped with grounded grid type shields between the primary and secondary windings.[7] This tends to prevent uncontrollable standing waves resulting from electrostatic pick-up. Sometimes, when the field from the antenna is great in the vicinity of the line, it pays to run ground shield wires above the transmission line.

The correct impedance from the antenna loading circuit can be obtained in several ways.[7] For instance, the secondary of the line transformer may be tapped to the point on the tuning coil which corresponds to this impedance. Another arrangement which provides a wider range of adjustments is to make the antenna tuning unit in two parallel branches and connect the secondary of the line transformer in series with one of the branches. The inductances may be varied so that the correct impedance is obtained.

8. Tuning Coils

Over a period of some thirty years various types of tuning coils all wound with Litz wire have been used.[5] The Litz cables in all of the earlier types of tuning coils were made up of 10 mil Litz wires. The most recent type of coil, which is understood to be in use at some of the U.S. Navy stations, uses a Litz conductor of 16,128 wires each 5 mils in diameter, the Litz conductor being designated as 14/12/96-0.005. This coil has a Q of 4,000 at a frequency of 15 kc and was designed to be highly efficient at 35 kc. These coils have a means radius of 66" and are carried on eight supports and a center support. Each conductor consists of two of these Litz cables in parallel. The table below shows the type of Litz wire used in the tuning coils at several stations.[5]

(a) Original Rocky Point Antenna	9/7/7 - 0.010
(b) Warsaw, Poland	14/7/7 - 0.010
(c) Tuckerton, N.J., Umbrella	30/7/7 - 0.010
(d) New Brunswick, N.J.	18/7/7 - 0.010

9. Power Limitations

The high antenna potentials not only cause appreciable dielectric loss, but also introduce serious problems with flash over and arcing.[4] Eventually, the power input of a VLF antenna is limited by the maximum potential that the system can withstand. Since the antenna potential is proportional to the antenna reactance, careful design must be given to reducing the antenna reactance. In order to reduce potential gradients, conductors of sufficient diameter must be used. Corona shields are also used to reduce gradients at sharp points.

The second aspect of the high potential problem is the proper selection of solid insulators to isolate the antenna conductors from ground and supporting members. Aerial insulators must have both electrical and mechanical strength. They are generally of two basic types: special cylindrical porcelain tubular insulators with cemented end fittings, and the oil-filled safety-core type. These insulators may be as large as six feet long and six inches in diameter. They may have a mechanical strength as high as 1,000,000 lbs. and an electrical strength of several kv/mm. [4]

10. Antenna Supports

The supports are of two main types:[7] self-supporting and guyed structures. The self-supporting type, although often of a higher initial cost than the guyed type, offers several advantages. It is less costly to maintain, has less influence on the antenna capacity and, thus, its effective height, and in certain cases, especially at the shorter waves, it causes less complications in tuning phenomenon and absorption. Self-supporting structures can be conveniently constructed with cross arms. These make it possible to arrange the structure with considerable width without using pairs of supports, thereby providing a relatively large capacity at an effective height which approaches the physical height.

The effective height of the antenna supports should be made as great as possible since the radiation efficiency is proportional to the square of the effective height. However, the cost of the antenna supports increases roughly with the cube of height and, for this reason, the height chosen is usually decided by the cost.

The question whether supports for large antennas to be operated at long waves should be grounded or insulated from the ground is largely an economical one. The insulators are, of necessity, large and expensive and add appreciably to the cost of the supports. Due to the high mechanical loads which the insulators must carry, a number of units are usually used in multiple, and it is very difficult to distribute the load equally among the several units. Replacing damaged insulators adds to the cost of maintenance.

A so-called insulated support is, at best, partially insulated at radio frequencies, because of the electrostatic capacity that exists between the support and ground. It is essential, though, that the antenna supports be either well insulated or well grounded, as a semi-conductive base will introduce relatively high losses.

At the relatively short wavelengths, grounded supports may cause considerable distortion to the field intensity pattern from the antenna.[7]

11. Excessive Mecahnical Loads

The physical size of VLF antennas gives rise to extremely serious mechanical problems. In addition to the tons of conductor and dielectric in the antenna itself, climatic conditions must also be considered. For example, the Jim Creek VLF antenna at Arlington, Washington, was designed to withstand 1/2 in. radial ice in a 65 mph gale.[4] It is frequently necessary to provide means for removing the ice from the antenna by circulating a 60 cps current in the structure without disturbing the radio frequency performance of the antenna. Some antenna systems possess means to release an antenna wire which has become overloaded, in order to prevent loss of a tower from overloading or an unbalanced pull.

Provisions to melt sleet from antennas is justified by two reasons:[7] It is a form of insurance against long delays which would be occasioned by damage to an antenna by excessive sleet loads. (2) It reduces the initial cost of an antenna by permitting the adoption of a structure of moderate strength.

Whenever feasible, the use of counterweights is a very satisfactory method of safeguarding against excessive stresses in an antenna.[7]

C. VLF Antennas

1. Jim Creek

One of the largest VLF antennas in operation today is the U.S. Navy's one megawatt Jim Creek antenna.[4] The toploading for this antenna consists of ten catenary spans suspended in a zig-zag pattern from 200 feet support towers which are erected on the crest of twin mountain ranges. All spans are 500 feet apart at their mid-point except for the fifth and sixth spans which are 1,000 feet apart and divide the antenna into two sections. The conducting element of each span is 1.01 in. cable made from 37 strands of No. 7 extra-high-strength copperweld. Because the valley tapers, the spans vary in length from 8,700 feet to 5,600 feet. To provide a proper safety factor for wind and ice loading, the sags on each span vary from 495 feet for the shortest to 1,063 feet for the longest. The area between the twelve support towers covers 725 acres, 435 of which are covered by active elements of the antenna.

A downlead of 0.92 in. hollow copper tubing is connected to the center of each span and terminates in two spans which are connected to towers at opposite sides of the valley. The downleads are held in tension by concrete counterweight-and-pulley systems. Each half of the antenna is fed by half of the transmitter. Antenna-feed buses which run along the south slope of the valley are supported on 125 feet towers and connected to the download by means of feed spans. The total antenna current is approximately 2,100 amperes and the insulator voltage is 240 kv (see Table II for more information).

2. Haiku, Oahu, T.H.

An antenna similar to the Jim Creek Station is used by the Navy at Haiku, T.H.[4] It consists of four spans about 4,500 feet long, each with a downlead of about 1,450 feet. It is also supported by two moutain tops, but no towers are used. Values of some of the constants are given in Table III.

3. Annapolis, Maryland

At Annapolis, Maryland, the Navy's NSS station uses a triatic type antenna.[4] This consists of a large topload supported by nine 600 ft. towers as shown in Fig. 3. The towers are arranged in two rows of four, each with the ninth tower forming a point at one end. Spacing between rows is about 850 ft. and spacing between towers in a row is about 1,000 ft. Average topload height is 472 ft. Two downleads are used, with a spacing of about 2,000 ft. between downleads. Each downlead has a tuning helix, but only one downlead is fed at a time.

The ground system for this antenna consists of wires buried 10 ft deep and spaced 20 ft. The wires extend over the width of the antenna and are fed from an overhead distributing system through equalizer coils[5] (see Table II for more information).

4. Lualualei, T.H.

A Navy antenna at Laulualei, Oahu, H.H. (see Fig. 4) is very similar to the one at Annapolis.[4] However, it has only seven 600 ft towers supporting the toplead. The spacing between the two rows is 1,000 ft and the spacing between towers in a row is 1,250 ft. Its average topload height is about 440 ft.

There are six pairs of antenna wires, the outside conductors being one inch hollow conductor copper cables and the inside wires being similar cables, but with a diamter of 0.8". The antenna is multiple-tuned at two points; it uses two tuned downleads, with only one downlead being fed. The ground system is similar to that at Annapolis.

5. Summit, Canal Zone

This antenna is similar to Annapolis and has similar characteristics. The buried wires in the ground system are, however, extended considerably beyond the edges of the antenna system.

6. New Brunswick, N.J.

The New Brunswick station was built prior to the first World War by the old American Marconi Co. The original antenna was designed to be an L-antenna. During the first World War the station was taken over by the U.S. Navy and a group of General Electric Co. engineers, under E.F.W. Alexanderson, redesigned and made experiments with the antenna system. The New Brunswick antenna was the first one to be multiple-tuned. The antenna, which is approximately one mile long and 600 ft wide, is supported by guyed tubular masts having a height of 400 ft. The antenna wires are supported by catenaries suspended from each pair of masts. A cage downlead is dropped from the catenary between each pair of towers to a tuning coil of Litz wire located in a copper house. From the base of the tuning coils the current is fed through ground distribution buses to wires buried in the ground. Various sizes of small inductance coils are used in series with the leads to the ground connections in order to give a proper current distribution over the various ground areas below the antenna. During the early experiments an overhead ground screen was also used in addition to the buried wire system. This ground screen was so connected to the tuning coils as to operate at a potential opposite to that of the antenna with respect to ground. The overhead screen was later abandoned for several reasons. It gave considerable trouble during ice storms and made any work in the field difficult.

At New Brunswick the ground conductivity lies about mid-way between the value for salt water marsh and the value for sandy soil. A large number of ground wires, buried about 18", run the length of the antenna.

7. Marion, Mass.

The antenna at this station is practically a duplicate of that at New Brunswick as shown in Fig. 1. The ground conductivity is also of the same order as that at New Brunswick. Values of some electrical characteristics are given in Table I.

8. Tuckerton, N. J. - Old Umbrella Antenna

The original antenna was of the umbrella type supported by a guyed triangular tower 820 ft high.[5] This tower was insulated at the base. A large number of steel towers 20 to 30 ft high were located on the circumference of a circle and supported the outer ends of the antenna wires. Trouble with high voltage across the tower base insulator was later experienced and the insulator was short-circuited by a large buss connected to the ground system.

The old umbrella antenna was re-constructed for use with an Alexanderson alternator and a new triangular antenna built (see Fig. 2) for use with this alternator. Some years after the first World War, during a storm, the top of the original mast blew off and the height of the mast was reduced to 780 ft. It was estimated that the effective height of the old umbrella was only 57 meters.

The ground at the Tuckerton station is a salt marsh and during northeast storms it is completely under water. Even during the driest periods of the year hip boots are necessary when walking around the field below the antenna. Under such conditions it is natural that the conductivity should be extremely high. The ground system consists of a large number of telephone ground rods fed from an overhead distributing system through various size inductances. The inductances are adjusted so as to give an approximately equal current density over the area below the antenna.

9. Tuckerton, N. J. - New Umbrella Antenna

Because of the small effective height obtained with the old umbrella antenna, the system was remodeled using a circle of eight 300 ft masts on the outer rim. This raised the effective height to 96 meters (see Table I for more information). A diagram of this antenna is given in Fig. 5.

10. Tuckerton, N. J. - Triangular Antenna

This antenna is in the shape of a quadrupled triangle wherein three of the six 300 ft guyed towers lie on the circumference of the umbrella. Fig. 2 shows a schematic diagram of this antenna.

11. Rocky Point, N. Y.

At Rocky Point, Long Island there are two VLF antennas each suspended from a line of six self-supporting steel towers. These towers are 412 ft high and have a cross-arm 150 ft long at their tops. The height to the bottom of the cross-arm is 400 ft. The two antennas form two spokes of a planned wagon wheel array. However, no further spokes were built due to the success with higher frequencies in transatlantic communication. The total length of each antenna is 7500 ft, or nearly one and one-half miles. The spans between towers are 1250 ft. Twelve antenna wires are suspended from the cross-arms by means of two 4 ft rod insulators in series. These insulators are each provided with rain shields at the top and corona shields at the bottom. Cage down leads are brought down from each tower and terminate in a large outdoor tuning coil. Two ground system distributing busses, one on each side of the antenna, run the full length of the antenna. These are located on 20 ft poles and inductance coils of variable size are wound around the pole in order to properly equalize the currents fed into the ground system.

The ground conductivity of the Rocky Point soil is probably as low as that to be found anywhere in this section of the country. Consequently, over 200 miles of wires is buried about 18" in the ground in order to obtain a reasonably low power loss in the ground system.

The effective height of these antennas is 83 meters. This value for Rocky Point, as compared to 57 meters for New Brunswick, is due primarily to the use of self-supporting towers rather than guyed masts.

12. Bolinas, California and Kahuku, T.H.

These antennas were taken out of use prior to the last war. Their construction was somewhat similar to that of Marion and New Brunswick.[5]

13. Rugby, England

Another high power VLF transmitter is the 500 kw Rugby radio station of the British Post Office.[4] The antenna for the Rugby station consists of two separate antennas of different capacities which may be used separately or in combination to form a larger antenna. Two 820 ft masts are placed symmetrically about the transmitter, 1,320 ft apart, and are common to both antenna systems. The large antenna is supported on eight masts, arranged in the form of an elongated octagonal shape with

1,320 ft sides. The smaller antenna is supported on six masts with the same spacing, but with no open arms.

The ground system beneath the large antenna consists of No. 12 copper wire, buried a few inches underground. The ground follows the shape of the antenna but exceeds 800 ft beyond the masts. Near the feed point the wires leave the ground and converge on the transmitting building. The ground system beneath the smaller antenna is an insulated couterpoise, averaging 16 ft above the ground. The counterpoise follows the general shape of the antenna. The spacing between individual wires varies from 40 ft (near the transmitter) to 80 ft at the edges.

TABLE I

Some Electrical Characteristics of Existing VLF Antennas

LOCATION	Frequency (kc/s)	Total Resistance (onms)	Radiation Resistance (ohms)	Radiation Efficiency (%)	Q	Reactance (ohms)	Effective Height (meters)	Total Current (amp.)	Allowable Voltage (kv)
1. Marion, Mass.	11.55	0.35	0.0515	14.7	257	90	66	600	90
2. Rocky Point, NY	18.22	0.40	0.0403	10.1	438	175	83	640	150
3. Rocky Point, NY	15.789	0.40	0.0302	7.6	504	202	83	670	150
4. New Brunswick New Jersey	22.140	0.35	0.0398	11.4	301	106	68	615	125
5. Tuckerton, NJ Old Umbrella	17.857	0.80	0.0182	2.3	248	198	57	435	150
6. Tuckerton, NJ New Umbrella	18.000	0.24	0.0524	21.8	740	177.5	96	913	162
7. Tuckerton, NJ Triangular	18.868	0.75	0.0202	2.7	255	191.6	57	400	150
8. Bolinas, California	22.900 19.828	0.65 0.41	0.0259 0.0193	4.0 4.7	305 675	199 277	53 53	425 700	125 200
9. Kahuku, T.H	17.673 18.403	0.35 0.35	0.0154 0.0394	4.4 11.3	384 336	135 135	53 81	500 650	125 125
10. Rugby, England	16.000	0.47	0.101	21.5	357	168	150	720	500*
11. Criggion, England	19.400 29.400	0.66 0.75	0.066 0.065	10.0 8.7	339 378	339 352	100 68	513 -	- -
12. Warsaw, Poland	16.35	0.20	0.033	16.5	-	122	84	1,000	400*
13. San Paolo, Rome	27.3	3.70	0.298	8.	-	473	151.2	158.5	200*

\- Value is not available

*Rated power in kw.

TABLE II

Some Electrical Characteristics of Existing VLF Antennas

STATION	Frequency (kc/s)	Total Resistance (ohms)	Radiation Resistance (ohms)	Radiation Efficiency (%)	Q	Reactance (ohms)	Effective Height (meters)	Total Current (amp.)	Rated Power (kw)
1. Jim Creek	15.3	0.340	0.073	21.5	277	94.5	133	2,110	1,000
2. Cutler (Dual)	14.0	0.160	0.080	50.0	273	43.7	152	-	2,000
3. Cutler (Half)	14.0	0.240	0.080	33.3	364	87.4	152	-	1,000
4. Goliath	15.0	0.180	0.082	45.5	497	89.4	144	-	-
5. Annapolis	15.0	0.265	0.045	17.0	943	250	107	1,378	500
6. Lualualei	15.0	0.200	0.045	22.5	1265	253	107	988	500
7. Summit	15.5	0.480	0.048	10.0	688	330	141	675	300
8. Haiku	16.68	0.864	0.310	35.9	325	280	251	325	200
9. Josami	17.4	-	0.208	-	-	-	198	700	800

- Value is not available.

TABLE III

Some Electrical Characteristics of Navy VLF Installations

STATION	Model	Rated kw	Frequency kc/s	Height (feet)	Height (meter)	Total Current (amp)	Meter (amp)	db Above 1 μv/m at 5000 miles
1. Annapolis	TBj	500	<u>18.0</u>	374	114	1378	157,000	43
2. Summit	TAW-1	300	15.4	443	135	675	91,200	37
3. Summit	TAW-1	300	<u>24.0</u>	407	124	650	80,600	35
4. Lualualei	TAW-a	500(1pt)	26.1	354	108	800	86,400	35
5. Lualualei	TAW-a	500(2pt)	15.4	350	107	988	85,600	38
6. Lualualei	TAW-a	500(2pt)	19.8	350	107	1240	132,700	40
7. Lualualei	TAW-a	500(2pt)	26.1	350	107	1370	146,700	40
8. Jim Creek	AN/FRT-3	1000	<u>14.8</u>	570	174	2110	367,000	49
9. Jim Creek	AN/FRT-3	1000	25.0	478	146	1770	254,200	45
10. Haiku*	ALT.	200	<u>16.7</u>	520	158	325	51,500	32
11. Josami*	ALT.	800	17.4	650	198	700	138,700	40

Normal operating frequencies are underlined.

*Alexanderson Alternators

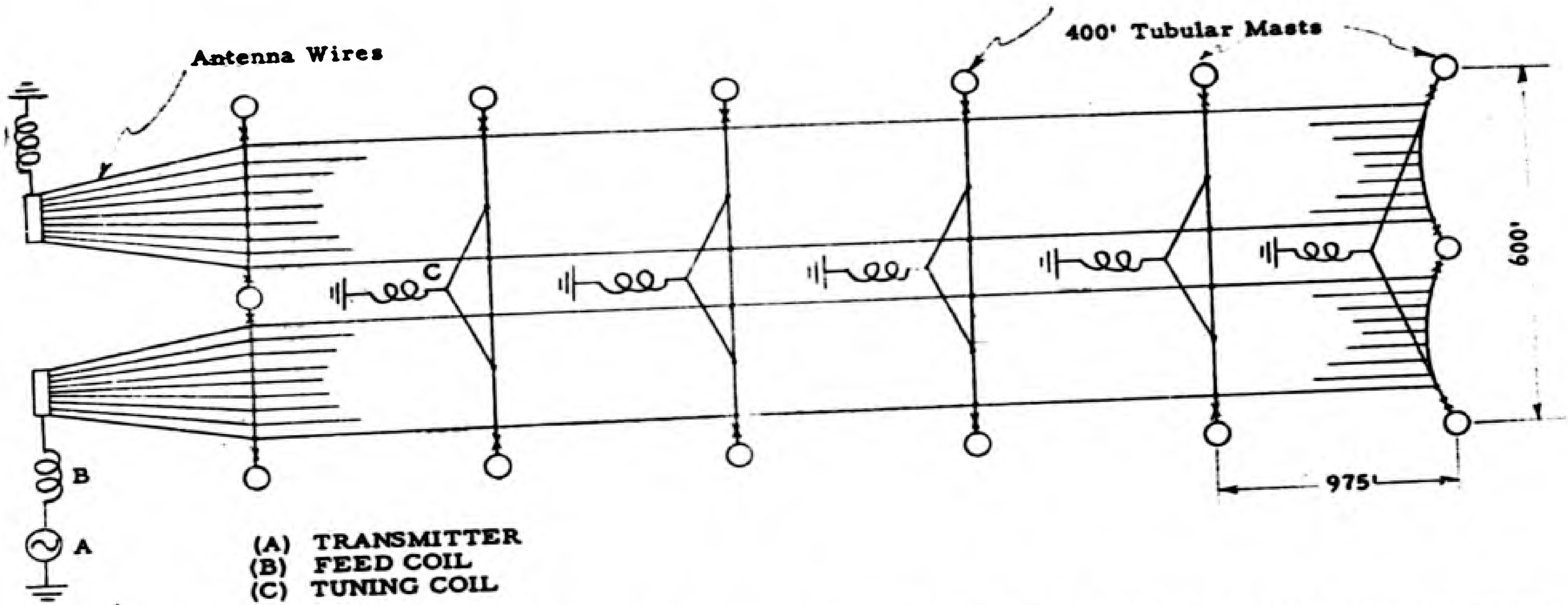


Fig. 1 DIAGRAM OF THE MARION, MASS. AND NEW BRUNSWICK, N. J. VLF TRANSMITTING ANTENNAS

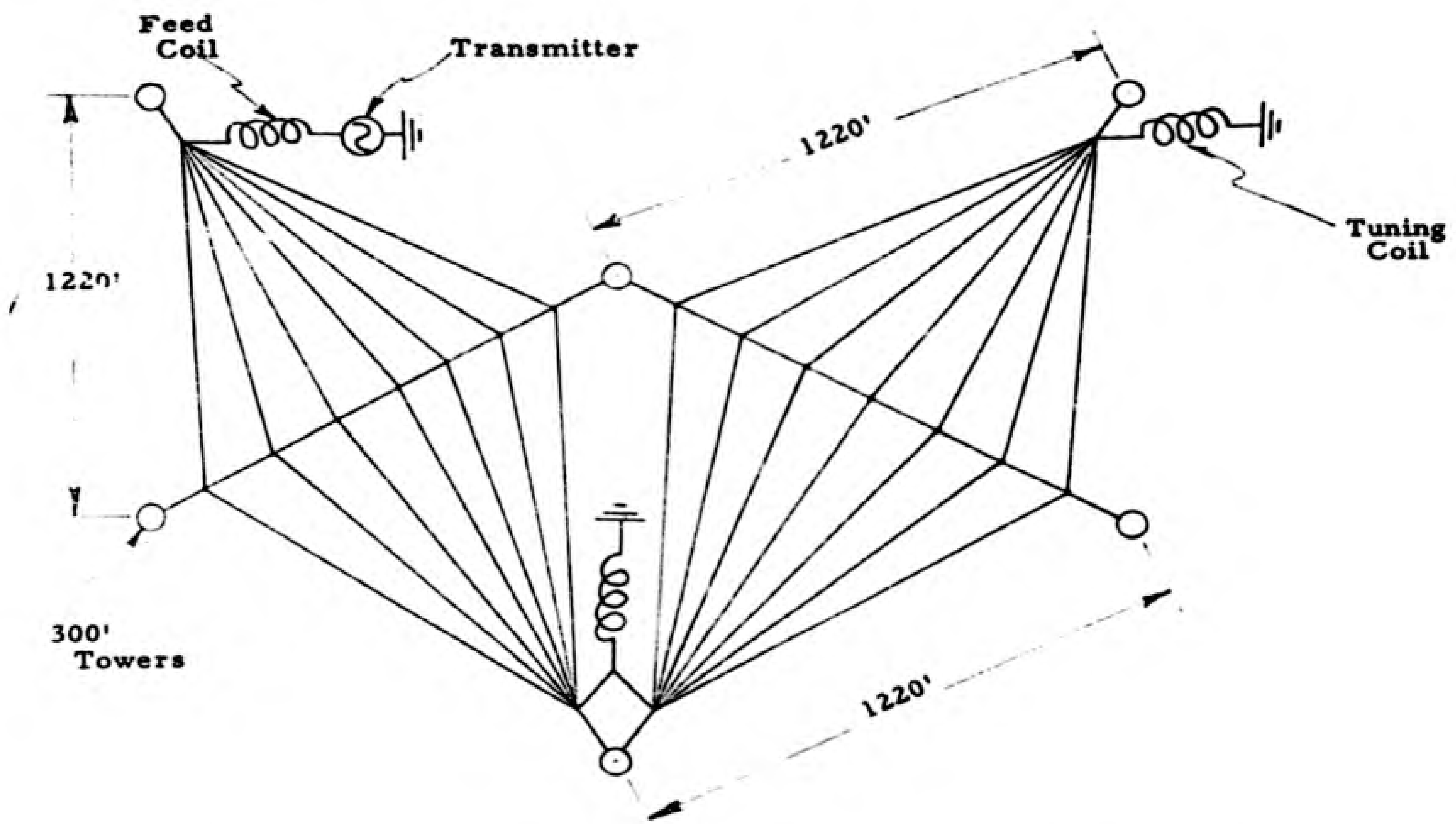
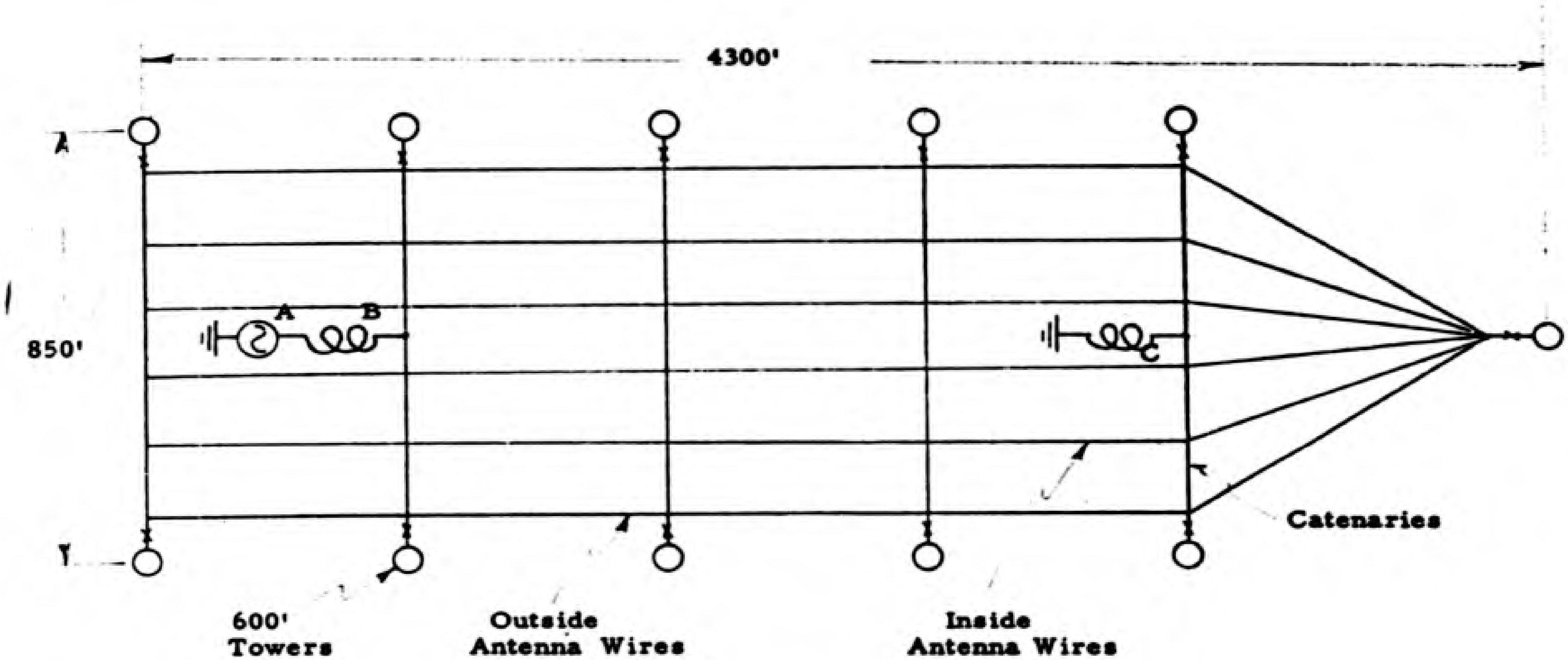
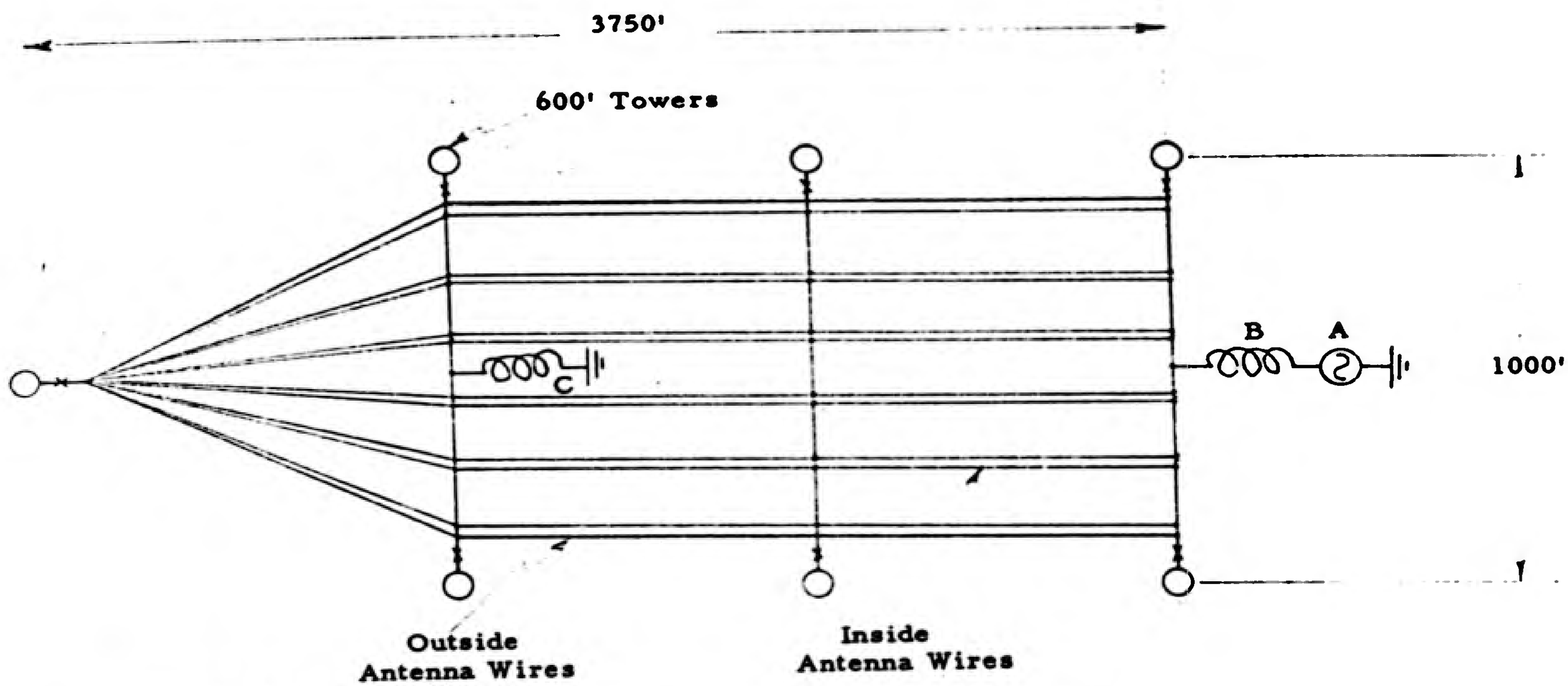


Fig. 2. DIAGRAM OF THE TUCKERTON, N. J. TRIANGULAR ANTENNA



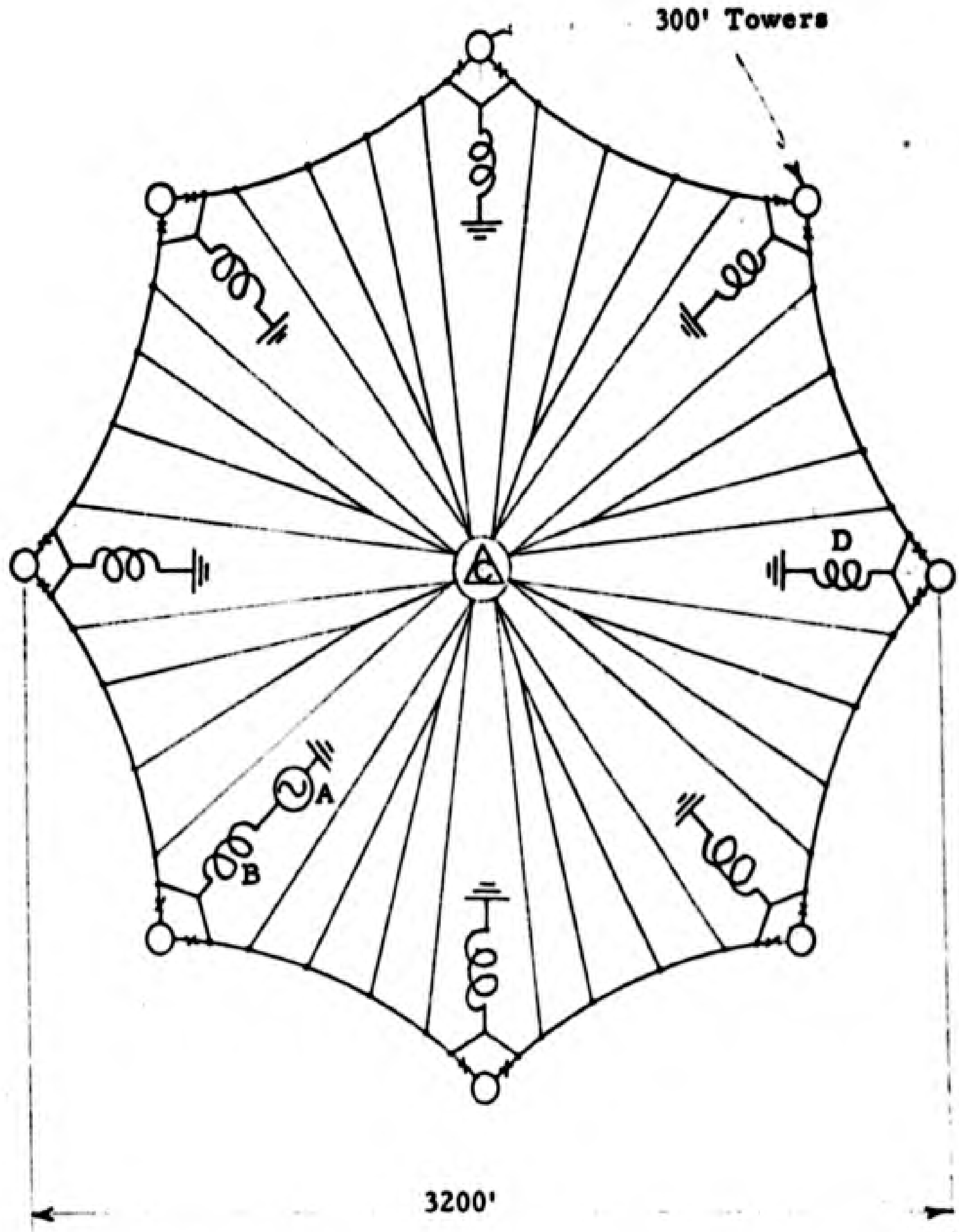
(A) TRANSMITTER
(B) FEED COIL
(C) TUNING COIL

Fig. 3. DIAGRAM OF THE ANNAPOLIS, MD., ANTENNA



(A) TRANSMITTER
(B) FEED COIL
(C) TUNING COIL

Fig. 4. DIAGRAM OF THE VLF ANTENNA AT LUALUALEI, T. H.



(A) TRANSMITTER
(B) FEED COIL
(C) TOWER (780')
(D) TUNING COIL

Fig. 5. DIAGRAM OF THE VLF ANTENNA AT TUCKERTON, N. J.

(UMBRELLA TYPE)

III. TRIP REPORTS AND LITERATURE SURVEY

A. Trip to Bureau of Ships

The following people were contacted at Bureau of Ships:

Messrs:

L. D. Whitelock, Director, Electronics Division, Code 686

V. Marsalon, Director, Electronics Division, Code 686

M. L. Royalance, Project Director, Satellite Communications, Code 687a

K. D. Wilson, Project Director, Shore Installations, Code 679d

In addition the following person was contacted at Bureau of Ships:

A. P. Massey, Assistant Project Director, Pacific Missile Test Range Group

In the initial contact with Mr. Whitelock, a discussion took place concerning the Navy's work in the VLF-HF field which may be of interest to this project. Since the Navy has traditionally been working in the frequency ranges of interest in the subject project, it was felt that their efforts in the design and construction of antennas would be extremely useful.

1. VLF Antennas

It is believed by BuShips that the most advanced thinking to date, in the design of VLF transmitting antennas, is reflected in the design of the Cutler[9] installation which represents a consolidation of techniques employed in the German Goliath[10] and in the Navy triatic antennas. It was determined, that the explicit design information concerning the Cutler installation was contained in the project files at BuShips. These files were investigated and found to be so extensive as to preclude the possibility of a complete review within the time allotted for the trip. Mr. Whitelock assured me that these files would be placed at the disposal of the Foundation and RADC should the need ever arise.

The installation at Jim Creek (AN/FRT-3) was also discussed in detail with Mr. V Marsalon who personally supervised its construction. The design information for this antenna, however, exists in the Files of T. E. Devaney, D. P. Heritage, et. al, at NEL in San Diego, who were immediately concerned with its design. This antenna, while constructed at a relatively low cost of 2.5 million dollars as compared to 65 million dollars for the Culter installation, is not considered to be completely successful by the Navy because it is corona limited at frequencies below 18.0 kc.

Mr. Marsalon also discussed recent efforts on the part of ITT to develop a new VLF monopole. A final report, "VOL Monopole Antenna Study", Vol. I, NObsr-72757, has been supplied to us concerning this work. The subject antenna was designed to handle a power of 6 megawatts. However, it has proven to be limited in bandwidth (6 cycles) and is therefore not being considered for further use.

Additional work has been done for the Office of Naval Research by various organizations on the more exotic VLF antenna types, which are relateed to the slot antenna. BuShips has no direct control over these efforts and therefore could not give much information to us. Some work has been performed by R. L. Tanner and R. B. Harris, Jr. [11] of Stanford Research Institute, who were interested in exciting an island as a slot antenna.

Several novel approaches to the "buried slot" VLF antennas are now being worked on by Dr. Aronld Shostak of ONR. BuShips, however, maintains that Shostak's antennas would have extremely low efficiencies, would be expensive to construct and difficult to support logistically. This is also true of the "island" antenna.

A conference with Mr. M. L. Royalance concerning the LOFTI satellite program indicated that this particular work was under the cognizance of Mr. Emeric Toth, Branch Head of Radio Techniques, of NRL. One report on the LOFTI program has been issued and another will follow within three weeks. As yet no theories have been advanced as to why propagation occurs through the ionoshpere at VLF. This work, while not directly associated with antenna techniques, may have some interesting implications in systems concepts.

In summary, most of the design work on specific existing VLF antennas has been done by W.E. Gustafson of NEL using the service of men such as H. Wheeler, Chu, Carr, Weldon, Pierce, Brown, Beverage, and many others as consultants. These individuals might be contacted if more detailed information, concerning the existing VLF antennas, is required. It should also be mentioned here that Gustafson is presently concerned with the Radiux Omega VLF navigational system.

The electrical characteristics of some of the Navy installations are given in Table III.

In going through the files at BuShips concerning the Cutler design, it was noticed that some work done by W. W. Brown[12] and H. Wheeler[13] particularly documented the different types of VLF antennas now in existance and critically analyzed their relative merits. These documents would also be useful in the present survey.

(2) HF Antennas

In the HF antenna field, the Navy is using the rhombic antenna in their shore installations. However, they are interested in the Log Periodic Antenna (LPA) array for this application because of its wide bandwidth capabilities despite the fact that it is weak in terms of its ability to survive in high winds and ice loading. At the present time Smith Electronics of Cleveland, Ohio has a contract (NObsr 81299) to improve its survival characteristics and to improve the impedance match. Westinghouse is also working on 2-30 mc impedance transformers for these antennas under Contract NObsr 72661.

B. Literature Survey

1. Abstracting Journals

A search for information on the state-of-the-art of VLF and HF antenna techniques is being carried out (May 1961 to present). The major abstracting journals considered pertinent to this study have been covered as follows:

Proceedings of IRE	1911 - 1961 (current issue)
AIEE	1900 - 1961 (current issue)
TAB	1959 - 1961 (current issue)
Engineering Index	1915 - 1961 (June)

Individual issues of current electronic and communications journals have been covered for all 1961 issues to date.

A search was made of the holdings of the Armed Services Technical Information Agency, Arlington, Virginia. The subject categories covered during this visit were VLF and HF antennas, LF bibliography and survey, Loop antennas, and miniturization of antennas. At this time demand bibliographies were requested on:

High Frequency Communications Systems

Low Frequency Communication Systems

Miniturization of Antennas (general)

A further ASTIA search was recommened for a more detailed coverage of the material available on antenna techniques. It was decided that this trip be postponed and hence it has not been completed. The majority of the remaining information is, therefore, being sought through a correspondnece program with individuals working in the field of VLF and HF antenna techniques.

2. Correspondence

Letters have been written* -

a. seeking information on the U.S. Naval Radio Station at Cutler, Maine (photographs have been received of this installation)

b. requesting data from W. W. Brown as a result of his work on VLF antennas

c. seeking Mr. W.E. Gustafson's assistance in obtaining data on the Jim Creek installation, the Triatic, Trideco, and Radax-Omega installations and

d. seeking H. A. Wheeler's cooperation in obtaining information on his antenna studies.

Contacts and requests for assistance have also been made of:

L. D. Whitelock	Navy Bureau of Ships
W. A. Johnson	Royal Aircraft Establishment England
J. A. M. Lyon	Cooley Electronics
C. J. Casselman	U.S. Navy Base, San Diego

*These four contacts appeared to be most beneficial to our work.

F. R. Abbott	San Diego
J. A. Pierce	Cruft Lab.
H. L. Knudson	U. of Denmark
T. Larson	" " "
J. O. Weldon	Continental Electronics
J. R. Wait	Boulder Lab.

Abstracts have been prepared on punch cards for future use in an annotated bibliography. Photostats of articles of interest to the project leader have been ordered, abstract cards prepared, and the articles forwarded to the project leader for his study. The material on hand is now being studies and categorized for use in our bibliography.

The surveillance of current literature, ordering and processing of documents and preparation of abstract cards is planned to be continuous.

As soon as an evaluation of the available information has been made we will begin the editing and final preparation of material for the bibliography.

3. List of Collected Literature

This is just a partial list of the literature collected thus far.

V. L. F. Antennas

AD Number	Author	Title	Date
AD 217 424	Gustafson, W. E., Devaney, T. E., Balli, N. H.	Antenna model studies related to the design of the North Atlantic vlf transmitting station.	12/19/58
	Anon. (ITT Laboratories)	Final Report-VLF monopole antenna study, volume I.	2/20/58- 11/16/59
	Crawford, E. C.	"Two Special Bridges", Marconi Instrumentation Tech. Bulletin.	3/61
	Fano, R. M.	"Theoretical Limitations on the Broadband Matching of Arbitrary Impedances", J. Franklin Inst., 249, 57-84, 139-154.	1/50
	Chu, L. J.	"Physical Limtations of Omni-Directional Antennas", J. Applied Physics, 19, 1163-1175.	12/48
AD 240 606	Anon. (Westinghouse)	Final Dev. Report-Frequency Modulation of LF and VLF Transmitters.	9/1/57- 11/30/59
	Cheng, D. K., Galbraith, R. A.	"Stagger-Tuned Loop Antennas for Wide-Band Low-Frequency Reception", Proc. IRE, 41, 1024-1031.	9/53
	Wait, J. R.	"A Low-Frequency Annular-Slot Antenna", J. NBS, 60, 59-64.	1/58
	Bolljahn, J. T.	"Electrically Small Antennas and the Low-Frequency Aircraft Antenna Problem", IRE Trans., AP-I, 46-54.	10/53

AD Number	Author	Title	Date
	Morgan, M.G.	"An Island as a Natural Very-Low-Frequency Transmitting Antenna", IRE Trans., AP-8, 528-530.	9/60
AD 244 078	Sparks, D., Williams, R.H.	A Trailing Wire VLF Antenna Proposed for use on a Lighter-than-air-Craft	1960
Antenna Ground Systems			
	Knudsen, H.L., Larsen, T.	"The Electric Field at the Ground Plane Near a Top-Loaded Monopole Antenna with Special Regard to Electrically Small L- and T-Antennas", J. NBS, 65D, 139-151.	3/4/60
	Knudsen, H.L.	"Earth Currents Near a Top-Loaded Monopole Antenna with Special Regard to Electrically Small L- and T-Antennas", J. NBS, 62, 283-296.	6/59
	Wait, J.R.	"Earth Currents Near a Monopole Antenna with Symmetrical Top Loading", J. NBS, 62, 247, 255.	6/59
	Wait, J. R.	"On the Calculations of Transverse Current Loss in Buried Wire Ground Systems", Appl. Sci..Res. B, 7, 81-86.	1958
	Wait, J. R.	"Radiation From a Vertical Electric Dipole Over a Stratified Ground", IRE Trans., Part I, 9-11.	7/53
	Wait, J. R., Surtees, W.J.	"Impedance of a Top-Loaded Antenna of Arbitrary Length over a Circular Grounded Screen", J. Appl. Phys., 25, 553-555.	5/54

Antenna Ground Systems - cont.

AD Number	Author	Title	Date
	Wait, J.R., Pope, W.A.	"Input Resistance of LF Unipole Aerials", Wireless Eng., 32, 131-138.	5/55
	Wait, J. R., Pope, W.A.	"The Characteristics of a Vertical Antenna with a Radial Conductor Ground System", Appl. sci. Res. B, 4, 177-195.	1954
	Abbott, F. R.	"Design of Optimum Buried-Conductor RF Ground System", Proc. IRE, 846-852.	7/52
	Abbott, F.R., Fisher, C.J.	Final Report-Design of ground system of radial conductors for a vlf transmitter. (U. S. Navy Electronics Lab.)	2/10/49
	Gustafson, W.E., Devaney, T. E., Smith, A. N.	"Ground System Studies of High Power VLF Antennas", VLF Symposium paper no. 38.	----
	Larsen, T.	Economical Optimum Distance Between Wires of a Ground Wire System. (Tech. U. Denmark)	11/60
	Larsen, T.	A Survey of the Theory of Wire Grids. (Tech U., Denmark)	6/60
	Hansen, J., Larsen, T.	The Electric Field at the Ground Plane Near a Disk-Loaded Monopole. (T. U., Denmark)	11/60

High Frequency Antennas

AD 237 257	Trapp, R. R. (Ramo-Wooldridge)	Vehicular Antenna Research in the HF Region. 3rd Quart. Report.	1-3/60

High Frequency Antennas - cont.

AD Number	Author	Title	Date
AD 243 914	Bailey, A. D., Dyson, J. D., Hayden, E. C., Sydnor, R. L.	Studies and Investigations Leading to the Design of a Radio Direction Finder System for the MF-HF-VHF Range. 4th Quart. Report.	6/30/60
	Lee, F. G. (Westinghouse)	Modification to Antenna AS-861/FRR-52. TN-2.	9/1/60
	Lee, F. G. (Westinghouse)	Modification to Antenna AS-861/FRR-52. TN-1.	6/1/60
AD 253 116	Bailey, A. D., Dyson, J. D., Hayden, E. C., Sydnor, R. L.	Studies and Investigations Leading to the Design of a Radio Direction Finder System for the MF-HF-VHF Range. 6th Quart. Report.	1/30/61
	Wilkins, A. F.	"HF Propagation--Its Present and Future Use for Communication Purposes", IRE (Brit.) 20, 939-51.	12/60
AD 227 781	Ledinegg, E.	Theoretical Study of Triangular Aperture Horn Antenna.	8/1/58-8/31/59
AD 125 438	Ray, jr., H. A. Hagaman, B. G.	High Frequency Vertically Polarized Directional Antenna Array.	3/18/55-12/12/55
AD 242 244	Hagaman, B. G., Simpson, T. L.	Reliable High-Frequency Communications. 6th Quart. Report.	4/1/60-6/30/60
AD 247 195	Hagaman, B. G., Simpson, T. L., Reed, W. R.	Reliable High-Frequency Communications. 7th Quart. Report.	7/1/60-9/30/60
	Anon. (A. P. C.)	An Antenna Brochure	---
	Brueckmann, H. (AVCO)	Theory and Performance of Vehicular Center-Fed Whip Antenna. (Paper)	8/60

High Frequency Antennas - cont.

AD Number	Author	Title	Date
	Gruber, J. R., Seward, G. J.	Antenna Matching Unit for H-F Vehicular Whip. (Paper)	10/60
	Anon. (SERVO Corp.)	Tech. Data Sheets on Long Range Doppler and Direction Finder	1959
	Anon. (Rohde & Schwarz Inc.)	Tech Data Sheets on Communications Antennas, Antenna Multicouplers and Direction Finders.	---
	Anon. (Amer. Elec. Lab.)	Antenna Brochure	6/61
	Guhne, R. D., Hagaman, B. G., Simpson, T. L.	Reliable High-Frequency Communications. 3rd Rpt.	7/1/59-9/30/59
	Guhne, R. D., Hagaman, B. G., Simpson, T. L.	Reliable High-Frequency Communications. 4th Rpt.	10/1/59-12/31/59
	Laport, E. A.	"Design Data for Horizontal Rhombic Antennas". RCA Review, 72-94.	3/52
AD 111 120	Ankers, R. E., Hagaman, B. G., Hice, L. E., McMahon, J. H.	Reliable High-Frequency Communications. 5th Rpt.	4/1/56-7/31/56
AD 232 943	Trapp, R. R. (Ramo- Wooldridge)	Vehicular Antenna Research in the HF Region. 2nd Quart. Rpt.	10/1/59-12/31/59
AD 125 157	Brueckmann, H.	Analysis of Measured Radiation Patterns of Two HF Antenna Arrays and One Rhombic.	1/57
AD 149 168	Brueckmann, H.	HF Broadside Antenna Arrays with Non-uniform Amplitude Distribution	9/57

High Frequency Antennas - cont.

AD Number	Author	Title	Date
AD 227 577	Sykes, D. W.	Design and Development of a High-Frequency Receiving-Antenna Multi-coupler.	10/59
AD 85 019	Webster, R. E., Tai, C. T.	Final Report-Antennas for Ionospheric "Forward Scatter" Propagation.	11/1/55
AD 114 218	Hickey, J. B.	HF Antenna Multicoupler (2-32MC)	3/57
AD 91 792	Dickinson, W.	Antenna System for Ionospheric Scatter Propagation.	1/16/56
AD 50 595	Kleinberger, R.	Research and Experimental Investigations Pertaining to Antenna AS-480( )/FRC.	11/15/54
AD 91 492	Hagaman, B. G.	Final Report-Close Grouping of Rhombic Antennas.	1/26/56
AD 43 901	Lee, P. B.	Impedance Matching Network Utilizing Controllable Inductance Elements.	9/15/54
AD 82 874	Adams, R. T., et. al.	Research on Radiation RF Tank Circuit for HF Band and Antennas. Interim Report.	12/55
	Brueckmann, H., Hagaman, B. G.	"Horn Antennas for HF Long-Range Communication" IRE, AP-8, 523-526.	9/60
AD 71 459	Russell, L.	High Frequency Steerable Antenna (3.8-14.4 mc)	6/55
AD 5621		Development of a High Frequency Steerable Antenna. Interim Dev. Rpt.	1/10/53
AD 39 190		Development of a High Frequency Steerable Antenna. Interim Dev. Rpt.	4/10/53

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AD Number	Author	Title	Date
	Carter, P. S., Hansell, C. W., Lindenblad, N. E.,	"Development of Directive Transmitting Antennas by RCA Communications, Inc.", Proc. IRE, 19, 1173-1842.	10/51
	Lindenblad, N. E., Brown, W. W.	"Main Considerations in Antenna Design", IRE, 291-323.	1926
	Brown, G. H., Lewis, R. F., Epstein, J.	"Ground Systems as a Factor in Antenna Efficiency", Proc. IRE, 25, 753-787.	6/37
	Donisthorpe, H. deA.	"The Marconi Marine Radio Direction Finder", IRE.	10/7/24
	Bruce, E.	"Developments in Short-Wave Directive Antennas", Proc. IRE 19, 1406-1488.	8/31
	Crampton, C., Struszynski, W., deWalden, S., Redgment, P. G.	"Some Principles Underlying the Design of Aerial Systems for High-Frequency Radio Direction-Finders in H. M. Ships", J. IEE, 95, 437-453.	1948
	Alexanderson, F. W.	"Dielectric Hysteresis at Radio Frequencies", IRE 2, 137-164.	1914
	Bechmann, R.	"On the Calculation of Radiation Resistance of Antennas and Antenna Combinations", Proc. IRE, 19, 1471-1480.	8/31
	Baumler, M., Kruger, K., Plendl, H., Pfitzer, W.	"Radiation Measurements of a Short-Wave Directive Antenna at the Nauen High Power Radio Station", IRE 19, 812-838.	5/31

AD Number	Author	Title	Date
	Alexanderson, F. W.	"Transoceanic Radio Communication", AIEE, 1269-1285.	1919
	Dunmere, F. W.	"Continuous-Wave Radio Transmission on a Wave Length of 100 Meters Using a Special Type of Antenna", IRE 11, 243-255.	4/2/23
	Elwell, C. F.	"The Rome Radio Station of the Italian Navy", IRE 8, 193-198.	1920
	Fuller, L. F.	"A Brief Technical Description of the New San Diego, Pearl Harbor, and Cavite High Power Naval Radio Stations", IRE, 7, 11-1[illegible].	1919
	Lush, W. G., Johnston, F. E., Finch, J. L.	"Trans-Oceanic Radio Station-Warsaw, Poland", IRE 13, 571-588.	1/7/25
	Micchiardi, B., Pession, G., Vallauri, G.	"The Radio Telegraphic Station at Rome (San Paolo)", IRE 7, 142-163.	8/25/19

IV. PROGRAM FOR THE NEXT INTERVAL

Future work on this program will be concerned with completing the survey on VLF antenna techniques and reporting the survey information gathered on HF antenna techniques. In addition, the literature survey will be continued to obtain more detailed information on VLF and especially HF antenna techniques.

Respectfully submitted,
ARMOUR RESEARCH FOUNDATION
of Illinois Institute of Technology

Peter Toulios

P. Toulios, Assistant Engineer

Approved by:

J. E. McManus

J. E. McManus, Assistant Director
Electronics Research

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4. W. Rusch, "A New Transmitting Antenna System for Very Low Radio Frequencies", California Institute of Technology, Contract No. AF 18(600)-1552, AD 217 029, June 1959.

5. P.S. Carter, and E.D. Thorne, "Antenna Study in the Very Low Frequency Region", Radio Corporation of America, Contract No. AF-28(099) 110, AD 62391, January 1950.

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10. F. Gutzman, "Transmitter-Goliath", Report from WPAFB, ATIC 169040A, F-TS-8355/U.

11. R.L. Tanner, and F.B. Harris, "Investigation of the Feasibility of Using an Island as a VLF Radiator" (Confidential), Stanford Reseach Institute, January 1961.

12. W.W. Brown, "A Model Study of the Capacities of VLF Antenna Types", in files on Cutler design at Bureau of Ships.

13. H.A. Wheeler, Notebooks 77 and 80, 560308, 560819, VLF Radio Station, in files on Cutler design at Bureau of Ships.

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