NRL Memorandum Report 1783

Radiation Parameters of the VLF Transmitting Station NWC, North West Cape, Australia

W. E. Garner, J. E. Raudenbush, and C. B. Brookes, Jr.

Communication Branch
Radio Division

June 21, 1967

NAVAL RESEARCH LABORATORY
Washington, D.C.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONTENTS

ABSTRACT

The U. S. Naval Research Laboratory experimentally determined the radiation parameters, radiation resistance and effective height, of the very low frequency (VLF) transmitting station NWC at the U. S. Naval Communication Station, North West Cape, Australia. The work was carried out in January and February 1967 as part of the Proof of Performance evaluation of this new transmitting station.

The radiation parameters were determined for five operating frequencies; 14.2, 15.5, 19.8, 22.3, and 27.3 kc/s, with the transmitting antenna operating with all six of its top-loading panels. The parameters were also determined for the antenna operating with five panels but at only four frequencies; 15.5, 19.8, 22.3, and 27.3 kc/s.

The values for the radiation parameters of the NWC transmitting system are reported and discussed along with a detailed discussion of the experimental techniques and data reduction processes.

PROBLEM STATUS

This is the final report for this problem.

AUTHORIZATION

NRL Problem R01-39A
Naval Facilities Engineering Command

RADIATION PARAMETERS OF THE VLF TRANSMITTING STATION NWC, NORTH WEST CAPE, AUSTRALIA

1.0 INTRODUCTION

A very low frequency (VLF) transmitting station (call letters NWC) has been constructed for the U. S. Navy at North West Cape, Australia and is scheduled to begin routine operation about 1 June 1967. As a part of the "Proof of Performance" evaluation of this new transmitting station, personnel from the U. S. Naval Research Laboratory (NRL) determined the radiation parameters, radiation resistance and effective height, of its antenna system in January and February 1967. The NWC antenna basically consists of one down-lead with symmetrical, umbrella-type top-loading. This top-loading consists of six diamond-shaped panels, each of which can be lowered and disconnected from the rest of the antenna system. The radiation parameters were measured at five operating frequencies with the antenna system in its normal, six-panel condition, and at four frequencies with it operating with only five-panels; one panel being lowered and grounded for the latter condition.

2.0 MEASUREMENT CONCEPTS AND TECHNIQUES

2.1 General

Most VLF antennas are electrically very short; that is, their physical dimensions are small compared to a wavelength. The VLF transmitting antenna for NWC at the U. S. Naval Communication Station, North West Cape, Australia is such an antenna, employing, in effect, a single vertical element with umbrella-type top-loading. The vertical component of the antenna is the only portion of the antenna directly contributing to the far-field radiation. The top-loading acts to increase the effective current distribution in the vertical component, thereby increasing the radiated field.

The effective height of a transmitting antenna is a measure of its effectiveness as a radiator of electromagnetic energy. The radiation resistance of a transmitting antenna system is a fictitious quantity but can be expressed as the resistance that, when inserted in series with the antenna, will consume the same amount of power as is actually radiated. The radiation resistance, R_r, is used in determining the power, P_r, radiated by the transmitting station from the relation

$$P_r = I_a^2 R_r \qquad (2\text{-}1)$$

Where, I_a is the transmitting antenna current.

For an antenna system such as that at NWC, neither the effective height nor the radiation resistance can be measured directly or theoretically calculated from a practical model to a sufficient degree of accuracy. Both of these parameters can be calculated if the radiated power and corresponding antenna current of the transmitting system are known. The radiated power can be determined from measurements of the field strength existing at a known distance from the transmitting antenna. For the greatest accuracy, these field strength measurements should be made in the region where the field strength, E, is proportional to the inverse of the distance, d, from the transmitting antenna. Since the field strength measurements, even in this region, are affected by local conditions such as abrupt changes in ground conductivity and more so by transmission lines, fences, etc., a large number of measurements must be made at many distances and bearings from the transmitting antenna to insure a high degree of overall accuracy.

The radiation resistance, R_r in ohms, can be determined from the relation

$$R_r = \frac{d^2 E^2}{90 I_a^2} \qquad (2\text{-}2)$$

where, d is the distance from the transmitting antenna in kilometers, E if the field strength in millivolts per meter, and I_a is the antenna current in amperes. Using the same units and the frequency, f in kilocycles, the effective height, h_e in meters, is determined from

$$h_e = \frac{796 E d}{I_a f} \qquad (2\text{-}3)$$

In a theoretical treatment of the radiation characteristics of an electrically short monopole antenna, the antenna current is normally considered to be the current at the base of the monopole. The radiation resistance under this idealized situation is the classical value for the antenna alone. For the practical situations involved with the subject system, the antenna current as measured and stated here is not necessarily the current at the base of the antenna and may include some loss currents. The radiation resistance obtained using these measured antenna currents is therefore an effective value influenced by these losses.

More details of the near-fields from a VLF transmitting antenna are given by Garner and Raudenbush (1).

2.2 Field Strength Measurements

The radiation resistance and effective height of the NWC transmitting system were determined from a large number of field strength measurements at known distances from the NWC antenna in the region where the field strength is proportional to the inverse of the distance. The field strengths were measured using seven DECO Field Intensity Meters, Model C 400-A, manufactured by DECO Electronics. These equipments employ a loop antenna and are calibrated to measure field strengths in dB relative to one microvolt per meter.

Special, two-minute, key-down transmissions were provided by NWC for the field strength measurements. Measurements were made at five operating frequencies, 14.2, 15.5, 19.8, 22.3, and 27.3 kc/s, with the NWC antenna in the six-panel condition. Four of these same frequencies, with 14.2 kc/s being eliminated, were used for the five-panel condition measurements. Starting at the beginning of each hour a two-minute transmission was made at the lowest frequency. A two-minute transmission at the next lowest frequency was then made beginning 10 minutes after the hour with the next frequency being transmitted at 20 minutes after, and so on, for all frequencies used. This cycle was repeated for each hour from 0800 to 1800 local time each day that field strength measurements were made. The six-panel measurements were made on 25, 26, and 31 January, and the five-panel measurements were made on 3 February 1967.

There were between four and six field strength measuring teams operating simultaneously although measurements were not necessarily made each hour by each team. Normally each team would make a measurement at each transmission frequency at a particular site then move to the next site. At each site, the loop of the field strength meter was carefully nulled and then rotated precisely 90 degrees for maximum response. The dB relation of the null to the maximum signal level was then recorded. The magnetic bearing of the loop when oriented for a maximum signal response was also recorded. The magnetic bearing from each measurement site to the NWC antenna was determined from a map. The loop null depth and bearing data were used in the evaluation of the reliability of the data from each measurement site. Metallic objects such as fences, power lines above or below ground, etc., produce local anomalies and can often be detected by poor loop nulls or errors in bearing.

The metering circuit of the C 400-A Field Intensity Meters is such that field changes of 0.1 dB relative to one microvolt per meter are detectable, with estimates to the nearest 0.05 dB being possible. Each of these meters were accurately calibrated in a standard field using the two-loop method of calibration just prior to and following the field measurements. No meter showed a change greater than 0.1 dB relative to one microvolt per meter over the period of the field measurements. Three precision milliammeters with an accuracy of 0.5 percent were checked against each other and were used as the primary reference for the two-loop method of calibration, and also for standardizing each C 400-A meter each morning of the days on which field measurements were made. It is believed that the calibration techniques used resulted in measurement accuracies within plus or minus 0.1 dB relative to one microvolt per meter. To improve the overall measurement accuracy several measurements were made at some sites by different measurement teams.

2.3 Distance Measurements

It can be seen from equations (2-2) and (2-3), that the distance from the transmitting antenna to the field measurement sites should be measured to an accuracy as good or better than that of the field strength measurements in order to determine the radiation resistance and effective height to a high degree of accuracy, since the errors of D and d are additive. The North West Cape area is not accurately mapped, thereby eliminating the usual method of distance measurement for this type of work. Therefore, in preparation for this program, NRL investigated a distance measuring method employing phase tracking techniques. It was found that by employing this method of distance measurement from phase-stable, VLF transmitting stations, an accuracy of 2 percent relative to known reference distances could be obtained.

At North West Cape, the distances from the center of the NWC transmitting antenna to the South Base survey point on the east coast and to the Tantabiddi and Tulki Wells on the west coast were determined by normal surveying techniques. All three of these reference points were near fences. Therefore, NRL personnel established secondary references 500 feet from the surveyed references and the nearby fences; it having been experimentally determined that this distance from a fence was sufficient to avoid anomalies in the phase of the radiated field.

Two vehicles were equipped with VLF phase tracking systems. A rotatable loop antenna was mounted in the center of the roof of the vehicle. This antenna was coupled to a Tracor, Inc. Model 599H, VLF Tracking Receiver. In one vehicle a General Technology Corporation Model 304-B Rubidium Frequency Standard was used as the local oscillator, with a Sulzer Model 2.5 Frequency Standard being used in the second vehicle. The latter frequency standard is a quartz crystal oscillator and was found not suited for mobile operation over the rough terrain of North West Cape. The shock and vibration produced occasional jumps in phase.

Continuous phase-stable transmissions were provided by NWC at 15.5 kc/s for the measurement of the distances to the field measurement sites on the Cape. The phase tracking equipped vehicles were driven to one of the above secondary reference sites and the received relative phase of the NWC transmission was then recorded. The vehicle was then driven to each field measurement site and after remaining stationary at each site for several minutes the relative phase was tabulated for each site. The vehicle was then returned to the initial secondary reference and the relative phase there was again noted. Any change in relative phase occurring between the initial and final readings at the reference site could be caused by a frequency offset between the NWC and local oscillators. The phase readings were corrected for such offsets by linear interpolation, depending upon the elapsed time between the measurement and reference site phase readings. The frequency offset between the rubidium frequency standard used in the vehicle and the NWC standard was measured before and after the distance measurements. This offset was small and did not change, and was such as to account for the change in phase as measured at the secondary reference site. These relative phase measurements were then converted to distances from the NWC antenna to the field measurement sites on the Cape. It is believed that the distances thus obtained have an accuracy of plus or minus 0.1 kilometer.

In addition to the sites on the Cape, three islands in a north-easterly direction from NWC were used for field measurements. The distances to these island sites were scaled from a map published by the Hydrographic Service, Royal Australian Navy and entitled Australia - North West Coast, "Exmouth Gulf", Aus. 182. The accuracy of these distances is believed to be commensurate with those measured on the Cape.

2.4 Antenna Current Measurements

At the time of the subject measurements, the NWC antenna current meter had not yet been calibrated. Therefore, a temporary method for measuring the antenna current was employed. This consisted of a loop antenna rigidly mounted in the antenna switch room and coupled to a voltmeter calibrated to indicate antenna current.

It should be noted that the final calibration of the NWC antenna current meter may not agree precisely with the antenna currents as measured by this loop-voltmeter system. If that is found to be so, the values of radiation resistance and effective height quoted herein may have to be changed to reflect these differences in antenna current indications.

3.0 FIELD STRENGTH MEASUREMENT SITES

A total of 31 sites were used for field strength measurements. One of these, the "monitor site" was more or less continuously used as a reference site for this program and for other proof of performance tests. It is 14.2 km from the NWC antenna on the elevated terrain toward the center of the Cape, west of the Shire of Exmouth. Three other sites were on the islands northeast of the Cape. These islands, Observation, Long, and Anchor, were chosen giving consideration to their distances from NWC, their accessibility by boat, and their relative position with respect to other islands that could produce local anomalies in the field due to discontinuity effects. The remaining 27 sites were on the Cape as shown in Figure 1.

The field sites on the Cape were divided into two groups; those on the east half of the Cape and those on the west half. The Cape sites were chosen, in general, to give an even distribution of sites along the two halves of the Cape at distances between 14 and 70 km. Each site was chosen so as to be well away from any obstacle that was believed to be a possible cause of a local field anomaly. Each site on the Cape was marked by a metal fence post on which was mounted a site identification tag such as that shown in Figure 2. These site markers have been left in place so that they may be used for future work such as this.

Site markers with numbers 1 through 16 were used on the west half of the Cape, and numbers 21 through 31 on the east half. The "monitor site" is marked number 35. For future reference, a description of each field measurement site and its distance to the center tower (T_0) of the NWC VLF transmitting antenna is given below. There is only one road (dirt track) running north and south along the west half of the Cape. All the field sites on the west half are within 50 feet of this road and on the side toward the ocean, except as noted. The east half of the Cape also has only one north-south road but this is hard surfaced for about 40 miles south from Point Murat.

Sites on west half of Cape -

No. 1: Three miles north of Yardie Creek Homestead and one and one-half miles south of fence at Five-Mile Well, and 200 feet from road (d = 14.0 km).

No. 2: One and one-half miles north of Yardie Creek Homestead (d = 16.0km).

No. 3: One and one-half miles south of Yardie Creek Homestead (d = 19.85 km).

No. 4: Four miles south of Yardie Creek Homestead (d = 23.35 km).

No. 5: This is a secondary reference site and is 500 feet from Tantabiddi Well away from NWC (d = 24.6 km).

No. 6: One and one-half miles south of Tantabiddi Well (d = 26.6 km).

No. 7: Five and one-half miles south of Tantabiddi Well and 1.8 miles north of fence at Milyering Well (d = 30.4 km).

No. 8: One and one-half miles south of fence at Milyering Well (d = 35.0 km).

No. 9: Four and one-half miles south of fence at Milyering Well and 1.6 miles north of fence at Tulki Well (d = 39. 0 km).

No. 10: This is a secondary reference site and is 500 feet from Tulki Well toward NWC (d = 40.8 km).

No. 11: Two and one-half miles south of fence at Tulki Well (d = 44.9 km).

No. 12: About 200 feet south of Mandu Mandu Creek and 4.8 miles south of fence at Tulki Well (d = 47.4 km).

No. 13: Two and one-half miles south of Mandu Mandu Creek and 1.3 miles north of fence at Pilgramunna Well (d = 50.6 km).

No. 14: Four miles south of site no. 13 (d = 57.5 km).

No. 15: On the east side of the road one mile north of the fence at Yardie Well (d = 63.3 km).

No. 16: Near the end of the road toward Yardie Creek and 1.3 miles south of the fence at Yardie Well. This site was not used and its distance to NWC was not measured since the road between sites 15 and 16 was impassable during most of the period of this work due to Cyclone Elsie.

Sites on east half of Cape. -

No. 21: This is a secondary reference site based on the South Base survey point and 500 feet from this point (d = 13.43 km).

No. 22: About 0.3 miles west of N-S road just north of Munbowra Creek (d = 20.2 km).

No. 23: One and one-half miles west of N-S road on Shothole Canyon road which is 3.6 miles south of Munbowra Creek (d = 26.6 km).

No. 24: On north side of Charles Knife Road about 500 feet west of N-S road (d = 35.05 km).

No. 25: On north side of Charles Knife Road about 2.7 miles west of N-S road (d = 35.6 km).

No. 26: At end of Charles Knife Road about 7.2 miles from the N-S road (d = 35.6 km).

No. 27: About 1.3 miles west of N-S road on north side of dirt track which is 4.2 miles south of Charles Knife Road (d = 42.5 km).

No. 28: North of the road past the Learmouth airport terminal and about one-quarter mile northwest of the terminal (d = 47.85 km).

No. 29: About 100 feet west of N-S road and 4.1 miles south of road leading to Learmouth airport (d = 54.15 km).

No. 30: About 100 feet from the shore east of Landing Well (see Figure 1) (d = 54.0 km).

No. 31: At benchmark ZJ40 on east side of road running N-S through Exmouth Gulf Homestead and about 2.5 miles south of the Homestead (d = 64.9 km).

Island Sites. -

Observation Island: Near the shore on east side of the island (d = 40.9 km).

Long Island: Near the shore on the southeast extremity of the island (d = 58.5 km).

Anchor Island: Near shore on the southwest extremity of the island (d = 69.6 km).

Prior to carrying out this program, it was believed that the field strengths at many of the sites along the east half of the Cape would have anomalies due to the propagation grazing the coastline. Some of the sites along the east half were chosen to detect this effect while others were chosen to avoid it. The path to site no. 30 was virtually all overwater with little possibility of grazing effects. Three sites, 24, 25, and 26, approximately on an arc from NWC, were used along Charles Knife Road to detect any coastline grazing. The path to site no. 24 was along the shoreline, whereas the path to site no. 26 was all overland. The field strength data showed little coastline grazing effect, if any, as will be discussed later.

4.0 DATA PROCESSING

The field strength measurement data were tabulated on data sheets as illustrated in Figure 3. At the end of each series of measurements, the data were reviewed to determine the reliability of the individual data samples. This review was based on the depths of the loop antenna nulls, the bearing of the maximum loop response, and operator comments. After the data were reviewed and found acceptable, the corrected field strength, E, for each measurement was tabulated after applying appropriate meter correction factors.

The field strength meters, employing a shielded loop antenna, measured the total magnetic field which is the resultant of the induction and radiation fields. The effect of the induction field on the total magnetic field was calculated and the magnitude of this effect was eliminated from the field strength measurements after the meter correction factors had been applied. The induction field effects diminish rapidly as distance and frequency increase. At a distance of 12.43 kilometers (site no. 21) and a frequency of 14.2 kc/s, 0.31 dB of the total magnetic field is the result of the effect of the induction field. At this same frequency, and at a distance of 23.35 kilometers (site no.4), the contribution of the induction field to the total field is reduced to 0.09 dB. At 19.8 kc/s the induction field accounts for only 0.16 dB of the total magnetic field even at the shortest distance used, 12.43 kilometers.

After applying the meter correction factors and taking into account the effects of the induction field, the field strengths were normalized to a constant antenna current for each transmission frequency. For most of the special transmissions for these measurements, the NWC antenna current, I_a, was adjusted to the same value at a particular frequency. The antenna current used for normalization was, therefore, the value most frequently used for each frequency. The corrected field strengths normalized to a constant antenna current were then normalized to a distance, d, of 100 kilometers and identified as E_{Id}.

The number of field strength measurements made at each site and at each frequency were not necessarily the same. Also, the measurements at some sites were consistently low, and at others, consistently high compared to the overall average. In order to avoid giving undue weight to any site, all measurements at a site for a particular frequency were averaged, (arithmetic mean) and these individual site averages were then used in determining the overall average (arithmetic mean) field strength normalized to a constant antenna current and distance, $\overline{E}_{Id}$. Since the average field strength, $\overline{E}_{Id}$ in millivolts per meter, was normalized to a distance of 100 kilometers, the expression for the radiated power P_r, in kilowatts, reduces to

$$P_r = \overline{E}_{Id}^2/9. \qquad (4\text{-}1)$$

The radiation resistances, R_r in ohms, were calculated using the equation

$$R_r = P_r/I_a^2 \qquad (4\text{-}2)$$

where, P_r is the radiated power in watts and I_a is the corresponding nominal value of antenna current in amperes.

The values for the antenna effective height, h_e, in meters, were calculated using eq. (2-3), which, since $\overline{E}_{Id}$ is normalized to a distance of 100 kilometers, reduces to

$$h_e = 7.96\text{X}10^4\,\overline{E}_{Id}/I_a f \qquad (4\text{-}3)$$

where, I_a is the same as used in eq. (4-2) and f is the frequency in kilocycles per second.

5.0 RESULTS AND DISCUSSION

The normal operating condition of the VLF transmitting antenna system for NWC is with the full, six-panel top-loading. However, the antenna can be operated with one of the top-loading panels, lowered and grounded, and therefore the radiation resistance and effective height of the antenna system were measured for both the six-panel and five-panel conditions. However, more field strength measurements were made for the six-panel condition than for the five-panel condition. The field strength measurements for the six-panel condition were made at 29 sites, plus the monitor-site for reference, on 25, 26, and 31 January 1967. These sites consisted of 15 on the west half of the Cape, 11 on the east half, and three islands. Only 23 sites were used for measurements for the five-panel condition on 3 February 1967; 12 on the west half, 9 on the east half, and two of the islands, Observation and Long.

5.1 Six-Panel Operation

The measured field strengths corrected for meter factors and normalized to a constant current, I_a, are presented in Figures 4 through 8 for the NWC antenna operating with all six panels. It can be seen that the data have very little scatter about the average inverse distance curve. These data show much less scatter than similar data recorded when making similar measurements at other VLF transmitting stations. It can be seen from Table 1 that when the data from all measurement sites are considered, the standard deviation is about three percent of the average, normalized field strength.

In spite of the very small scattering of the field strength data, the data do show definite local terrain effects. The standard deviation, as given in Table 1, is considerably higher for the data from the sites on the east half of the Cape than for the data from the west half. Sites number 24, 25, and 26 (Figure 1) were very nearly equidistant from NWC, but the propagation path to each was considerably different. The paths to sites 25 and 26 were all over land. Both of these latter paths were over some of the hilly, central portion of the Cape with the path to site 26 having the larger percentage of the hilly terrain. The central part of the Cape is very rocky and probably has a conductivity much lower than the low, coastal areas. The normalized field strengths at site 24 were always lower than those at site 25, which were in turn always lower than at 26. The data at the monitor site, which was in the hilly, central portion of the

TABLE I

AVERAGE AND STANDARD DEVIATION OF THE FIELD STRENGTHS NORMALIZED TO A CONSTANT ANTENNA CURRENT AND A DISTANCE OF 100 KM FOR SIX-PANEL OPERATION

Freq. kc/s	Sites	No. of Samples	$\frac{\bar{E}}{Id}$ mv/m	σ mv/m	σ % of $\frac{\bar{E}}{Id}$
14.2	W	14	53.4	0.781	1.46
14.2	E	11	53.7	2.14	3.98
14.2	ALL	28	53.4	1.69	3.16
15.5	W	15	53.2	1.35	2.54
15.5	E	11	53.8	1.52	2.82
15.5	ALL	29	53.5	1.42	2.66
19.8	W	15	61.9	1.01	1.63
19.8	E	11	61.3	1.99	3.25
19.8	ALL	29	61.7	1.50	2.43
22.3	W	15	62.2	1.10	1.77
22.3	E	11	62.0	1.98	3.20
22.3	ALL	29	62.1	1.51	2.44
27.3	W	15	71.9	1.44	2.00
27.3	E	11	70.2	2.17	3.09
27.3	ALL	29	71.1	1.95	2.74

Cape, tended to be high compared with the data from the other sites. The propagation paths to many of the sites along the west half of the Cape were over the hilly, central region. The data from these sites however did not show any tendency toward being high compared with the averages. There were no definite tendencies in the data measured at sites grazing the coastline except that the data from the east sites had a greater standard deviation than did the data from the west sites.

The radiation parameters for the NWC antenna system operating with all six panels are given in Table 2 and Figure 8. Because of the way in which the transmitting antenna current was measured, the value for the parameters presented in Table 2 and Figure 8 may be changed slightly following the completion of the NWC Proof of Performance testing as discussed previously in section 2.4.

5.2 Five-Panel Operations

The NWC transmitting system can be operated with one of the antenna top-loading panels lowered and grounded. The radiation parameters for the five-panel condition were measured in the same manner as for the six-panel condition except that fewer measurement sites, and only four frequencis, were used. The field strengths for the five-panel operation are given in Figures 10 through 13 and show the same tendencies as noted for the six-panel operation.

The radiation parameters for the NWC antenna system operating with only five-panels are given in Table 3 and Figure 14. It will be noted that the values of radiation resistance and effective height at 15.5 kc/s for the five-panel condition are slightly higher than those for the six-panel condition. It is believed that the parameters at 15.5 kc/s are equal, or very nearly so, for both the five- and six-panel conditions. The slightly higher values for the five-panel condition are due to the use of fewer measurement sites for this condition. When the data from the same sites are considered for both five- and six-panel conditions, the resulting parameters are essentially equal.

5.3 Monitor-Site Results

During the period of the subject measurement program, the field strength of most of the special NWC transmissions were measured at the monitor site. The field strength measurements made at the monitor site were not used in the

TABLE 2

FINAL RESULTS OF MEASUREMENTS
OF THE RADIATION PARAMETERS
OF THE VLF TRANSMITTING STATION NWC

JANUARY 1967

TRANSMITTING ANTENNA OPERATING WITH SIX PANELS

Freq. kc/s	I_a Amps.	P_r kw	R_r Ohms	h_e Meters	Sites*
14.2	1628	314	0.119	183	ALL
"	"	318	0.120	184	E
"	"	314	0.118	183	W
"	"	301	0.114	179	I
15.5	1488	315	0.142	184	ALL
"	"	320	0.144	185	E
"	"	312	0.141	183	W
"	"	317	0.143	184	I
19.8	1324	423	0.241	187	ALL
"	"	418	0.238	186	E
"	"	426	0.243	188	W
"	"	426	0.243	188	I
22.3	1152	429	0.323	193	ALL
"	"	426	0.321	192	E
"	"	431	0.324	193	W
"	"	430	0.324	193	I
27.3	1049	562	0.511	198	ALL
"	"	547	0.497	195	E
"	"	575	0.522	200	W
"	"	555	0.504	196	I

*E: Sites on east half of Cape.
W: Sites on west half of Cape.
I: Sites on Observation Island, Long Island, and Anchor Island

calculation of the radiation parameters. The monitor site data were compared with the other field strength measurements to yield a calibration factor so that future field strength measurements at that site can be converted to measurements of radiated power.

There were two field strength measuring equipments used at the monitor site; a DECO Field Intensity Meter, Model C 400-A, serial number 003, and an experimental equipment which will be referred to as the DECO "Special" meter. The monitor site calibration data are given in Table 4. The meter correction factors given in Table 4 are, of course, applicable only for the two equipments listed, for correcting their indicated field strengths for meter calibration errors. The site P_r factors can be used to convert any, absolute field strength measurement in dB relative to one microvolt per meter, made for NWC transmissions at the monitor site, to radiated power in dB relative to one kilowatt. The site P_r factor takes into account any local field anomaly and the contribution of the induction field to the total field measured. The monitor site was 14.2 kilometers from the NWC center tower. The contribution of the induction field to the total magnetic field (using a loop antenna) measured at this distance was calculated for the five frequencies used, 14.2, 15.5, 19.8, 22.3, and 27.3 kc/s, and was found to be 0.24, 0.20, 0.13, 0.10, and 0.07 dB, respectively. This means, for example, that, if the NWC field strength at 15.5 kc/s is measured using a loop antenna at the monitor site, the radiated field is 0.20 dB less than the total measured field which includes both the radiated and induction fields. However, as mentioned above, the induction field effect has already been taken into account in determining the site P_r factors given in Table 4.

6.0 ACKNOWLEDGEMENTS

Grateful acknowledgement is hereby made to all of the many persons who participated in conducting the measurement work necessary to evaluate the antenna radiation parameters of the NWC transmitting station; in particular Messrs. Elwood and Kronschnabel of NRL, as well as personnel from DECO Electronics, Inc., and personnel from Continental Electronic and Manufacturing Company.

TABLE 3

FINAL RESULTS OF MEASUREMENTS
OF THE RADIATION PARAMETERS
OF THE VLF TRANSMITTING STATION NWC

FEBRUARY 1967

TRANSMITTING ANTENNA OPERATING WITH FIVE PANELS

Freq. kc/s	I_a Amps.	P_r kw	R_r Ohms	h_e Meters	Sites*
15.5	1488	316	0.143	184	ALL
"	"	320	0.145	185	E
"	"	314	0.142	184	W
"	"	306	0.138	181	I
19.8	1324	412	0.235	185	ALL
"	"	404	0.230	183	E
"	"	418	0.239	186	W
"	"	413	0.235	185	I
22.3	1152	419	0.316	190	ALL
"	"	416	0.313	190	E
"	"	422	0.318	191	W
"	"	424	0.320	191	I
27.3	1049	548	0.498	195	ALL
"	"	537	0.488	193	E
"	"	559	0.508	197	W
"	"	535	0.486	193	I

*E: Sites on east half of Cape.
W: Sites on west half of Cape.
I: Sites on Observation Island and Long Island.

Table 4

MONITOR SITE CALIBRATION

Meter	Freq. kc/s	Meter Correction Factor[1] db	Site P_r Factor[2] db
DECO "Special"	14.2	+0.6	- 87.0
	15.5	+0.7	- 87.0
	19.8	+0.8	- 87.2
	22.3	+0.7	- 87.1
	27.3	See Note	- 87.3
C400-A (003)	14.2	+0.7	- 87.0
	15.5	+0.7	- 87.0
	19.8	+0.8	- 87.2
	22.3	+0.8	- 87.1
	27.3	+0.8	- 87.3

[1] Factor required for converting meter field strength readings to correct field strength in db relative to one microvolt per meter. Correction factors were derived from a "two loop" method calibration.

[2] Factor required for converting corrected field strength measurements in db relative to one microvolt per meter to radiated power, P_r, in db relative to one kilowatt. The meter correction factor must be applied before applying the site P_r factor.

Note: The meter correction factor for the DECO "Special" meter was + 0.8 db at 27.3 kc/s during the six-panel measurements (25, 26, & 31 Jan. 1967) and + 1.2 db during the five-panel measurements (3 Feb. 1967).

7.0 REFERENCES

1. Garner, W. E., and Raudenbush, J. E., "Program for the Determination of the Effective Height and Radiation Resistance of the VLF Transmitting System at NAVCOMSTA, North West Cape, Australia", NRL Memorandum Report 1606, April 23, 1965.

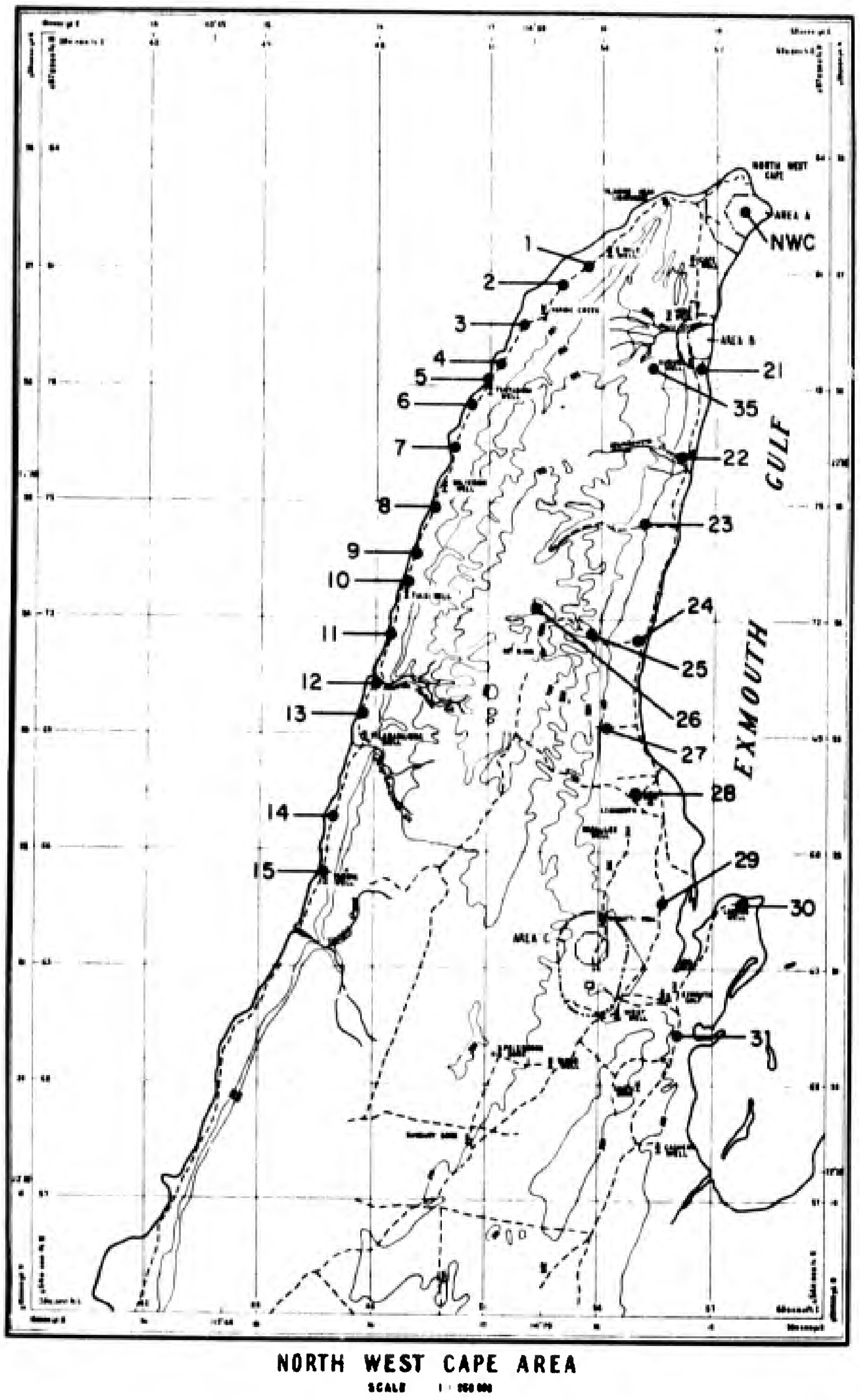

Figure 1 - North West Cape, Australia showing sites used for field strength measurements

Figure 2 - Field strength measurement site identification tag

Data Sheet A

FIELD STRENGTH MEASUREMENTS

Date 26 Jan. '67

Operators: C.B. Brookes, Jr.
W. E. Garner

Time Local	Site Ident.	Bearing Deg. Comp.	Bearing Mag. Loop	Freq. kc/s	Meter Range μV	Meter Read. μV	Cal. Atten. 10 db	Cal. Atten. 1.0 db	Cal. Atten. 0.1 db	E db> 1 μV/m	Remarks
1342	21	015	15	27.3	1 x 10^6	0.555	11	4	5.5	114.55	50 db null
1402	21	015	15	14.2	1 x 10^6	0.44	11	2	6	112.6	
1412	21	015	15	15.5	1 x 10^6	0.425	11	2	3.5	112.35	
1422	21	015	15	19.8	1 x 10^6	0.485	11	3	5	113.5	
1432	21	015	15	22.3	1 x 10^6	0.482	11	3	5	113.5	
1442	21	015	15	27.3	1 x 10^6	0.56	11	4	5.5	114.55	
1502	22	014	15.5	14.2	1 x 10^6	—	10	7	9	107.9	38 db null
1512	22	014	15.5	15.5	3 x 10^5	2.5	10	8	0	108.0	
1522	22	014	15.5	19.8	3 x 10^5	2.73	10	9	1.5	109.15	
1532	22	014	15.5	22.3	3 x 10^5	2.92	10	9	2	109.2	
1542	22	014	15.5	27.3	1 x 10^6	0.34	11	0	4	110.4	
1602	23	018	19	14.2	3 x 10^5	1.83	10	5	4	105.4	53 db null
1612	23	018	19	15.5	3 x 10^5	1.88	10	5	5	105.5	
1622	23	018	19	19.8	3 x 10^5	2.25	10	6	6.5	106.65	
1632	23	018	19	22.3	3 x 10^5	2.17	10	6	6.5	106.65	
1642	23	018	19	27.3	3 x 10^5	2.5	10	7	7	107.7	

E is field strength as measured in db above 1 μV/m

Meter #003

Figure 3 - Sample of data sheet used for recording field strength measurements

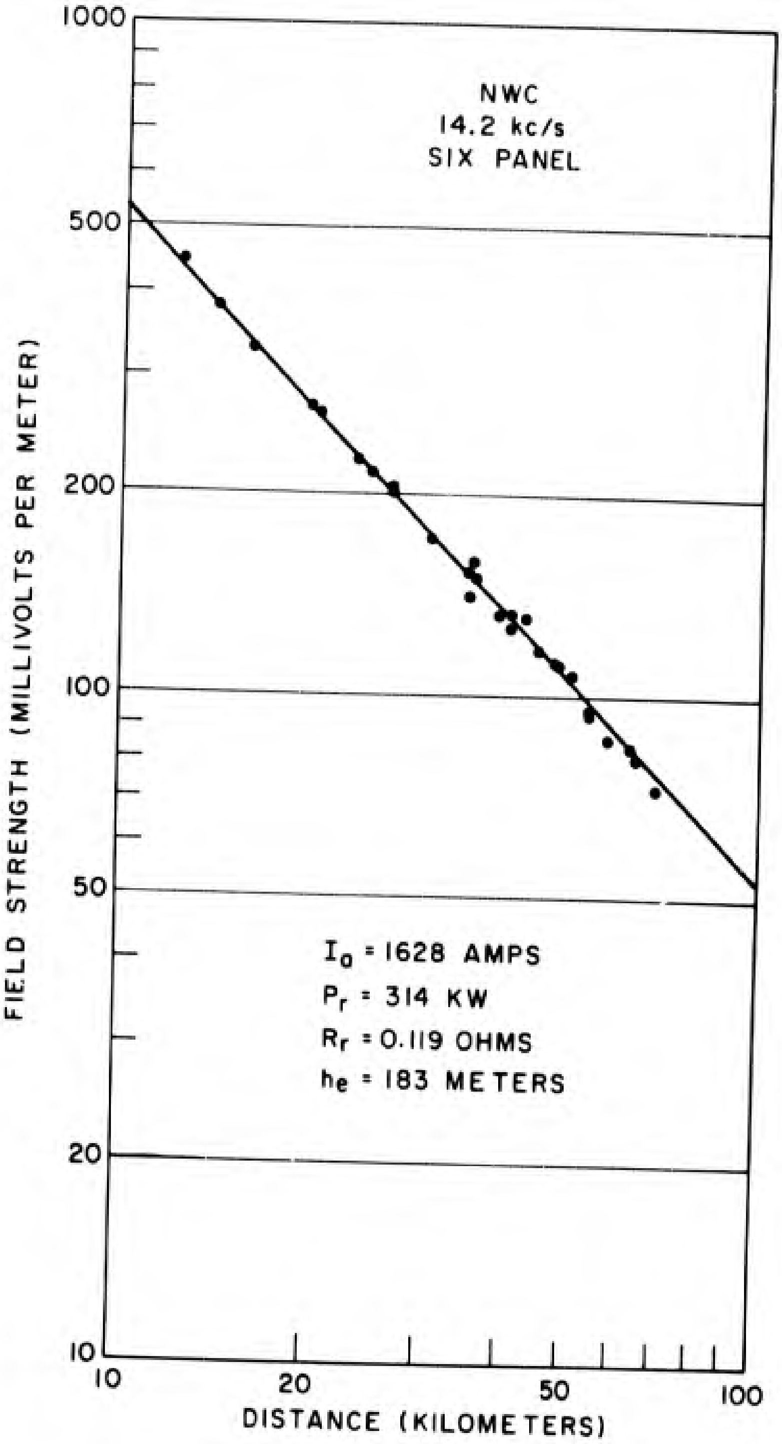

Figure 4 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with six panels at 14.2 kc/s

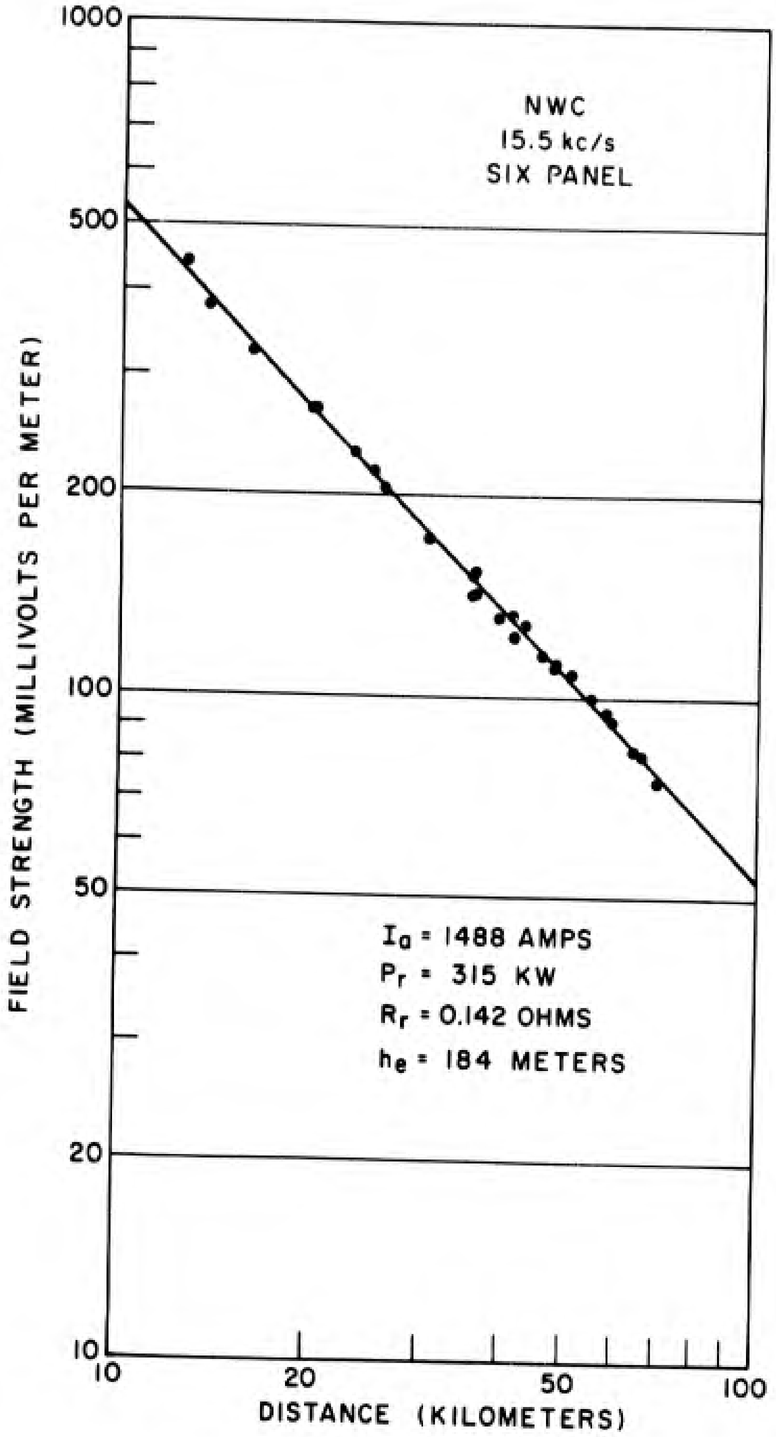

Figure 5 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with six panels at 15.5 kc/s

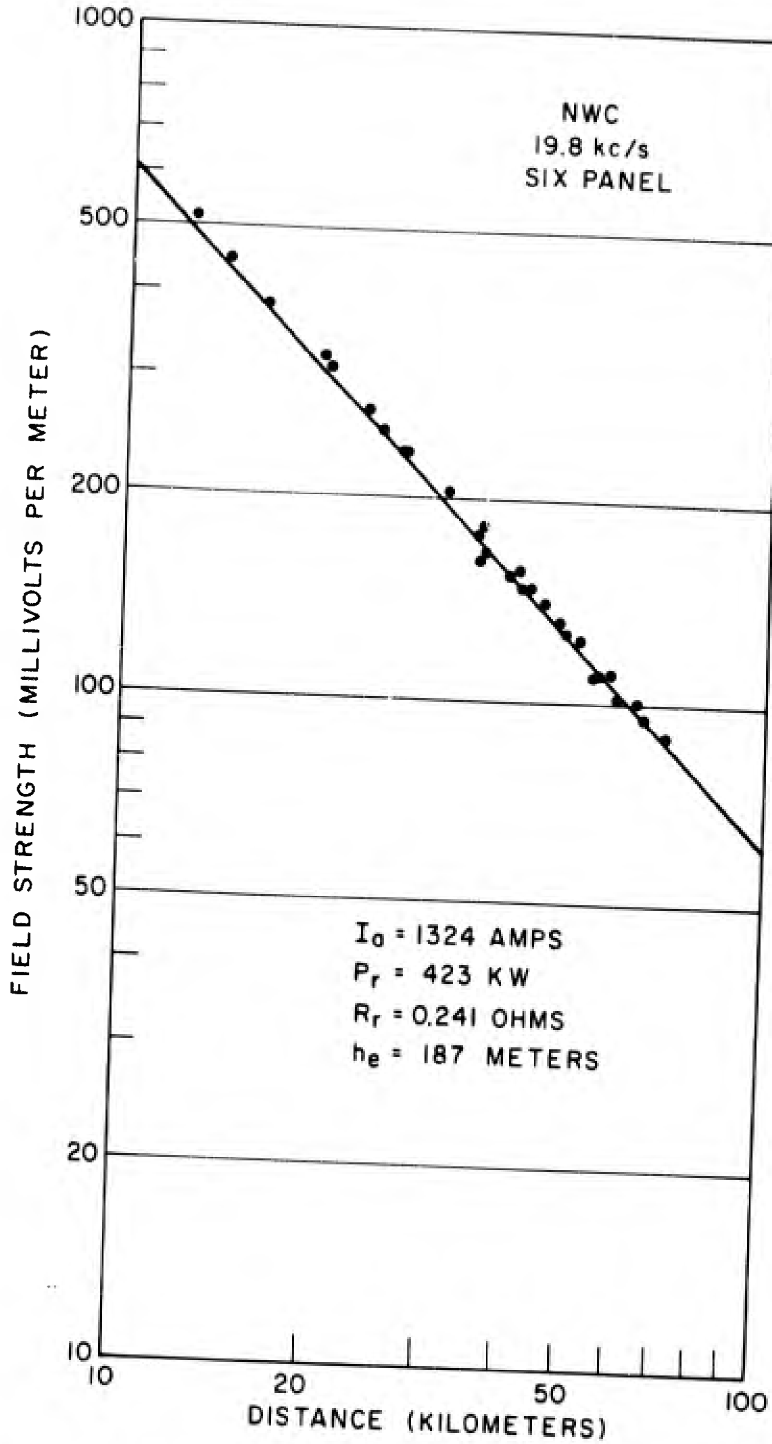

Figure 6 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with six panels at 19.8 kc/s

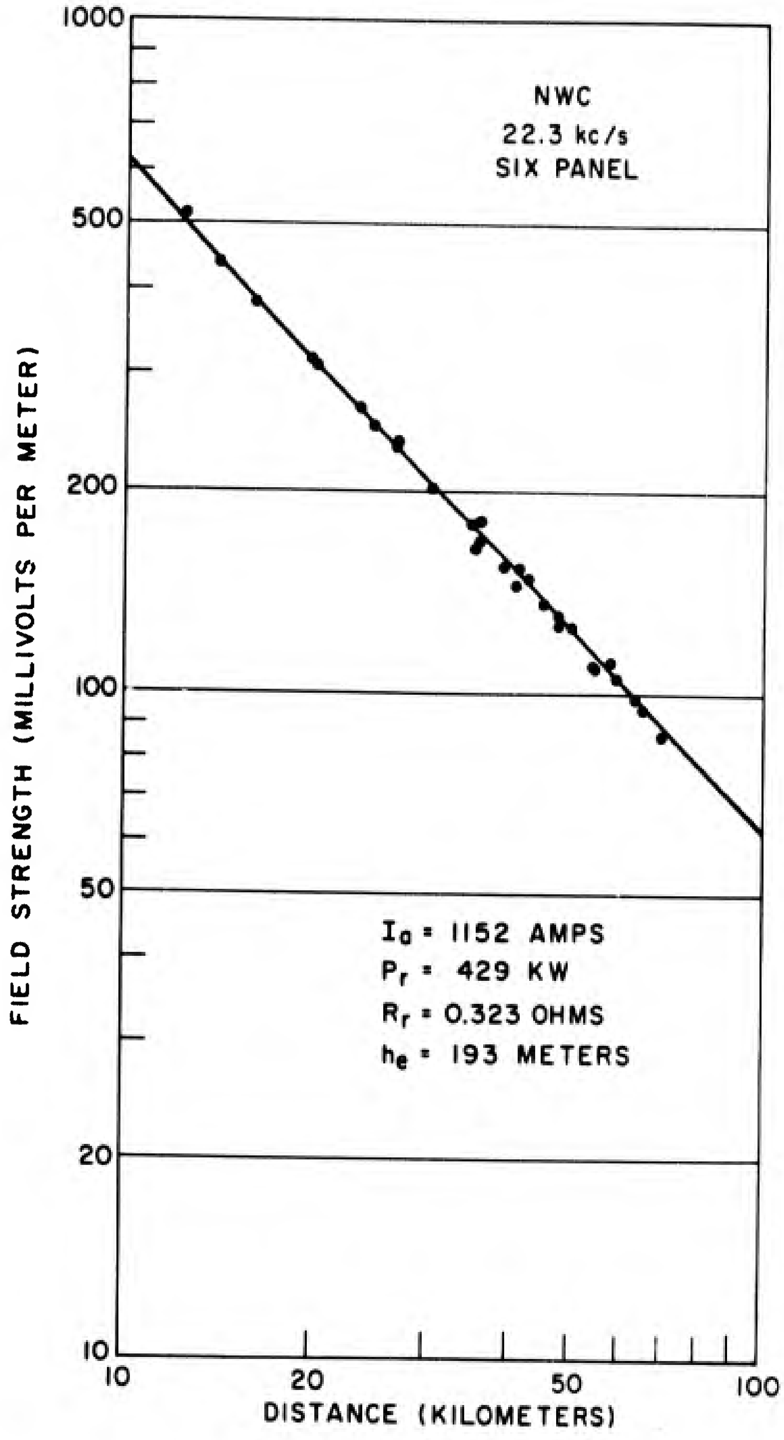

Figure 7 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with six panels at 22.3 kc/s

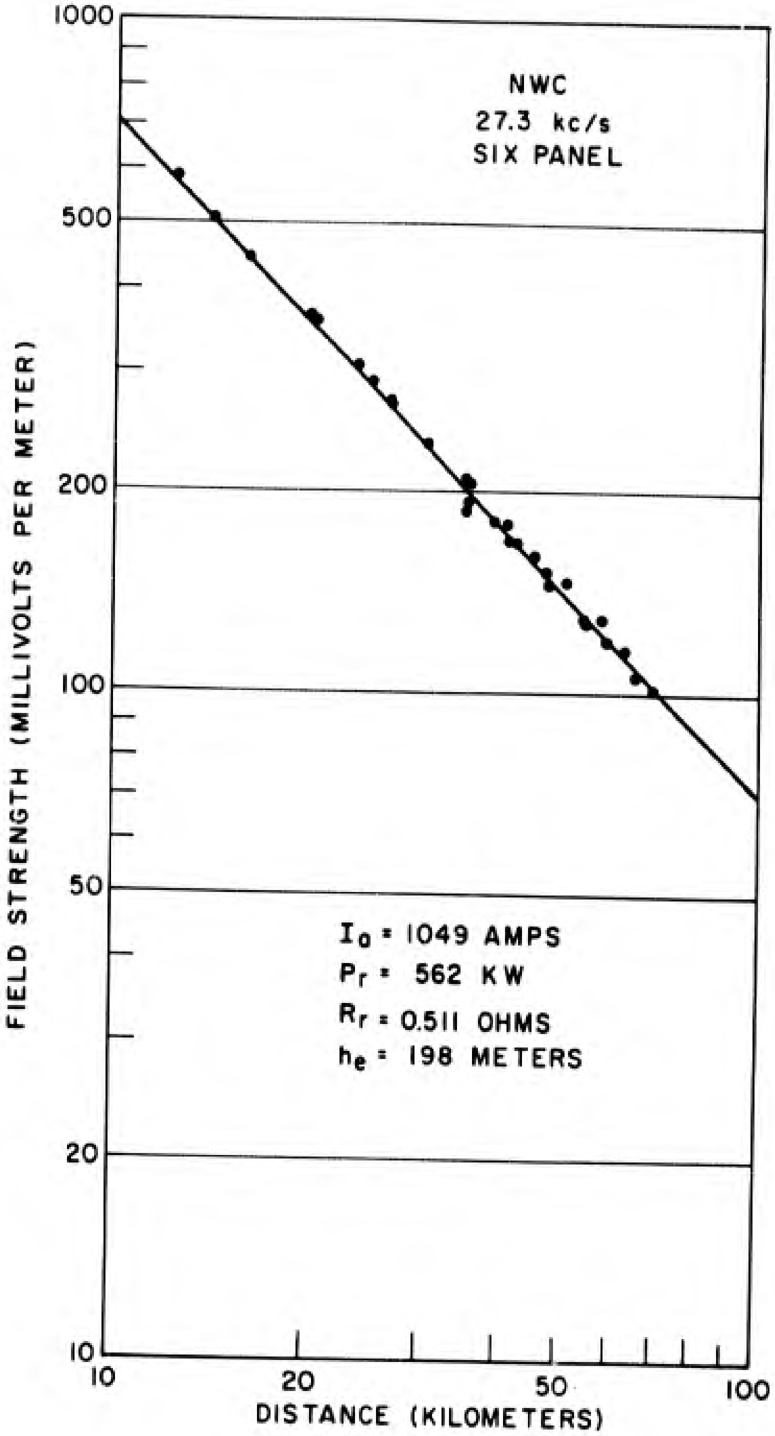

Figure 8 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with six panels at 27.3 kc/s

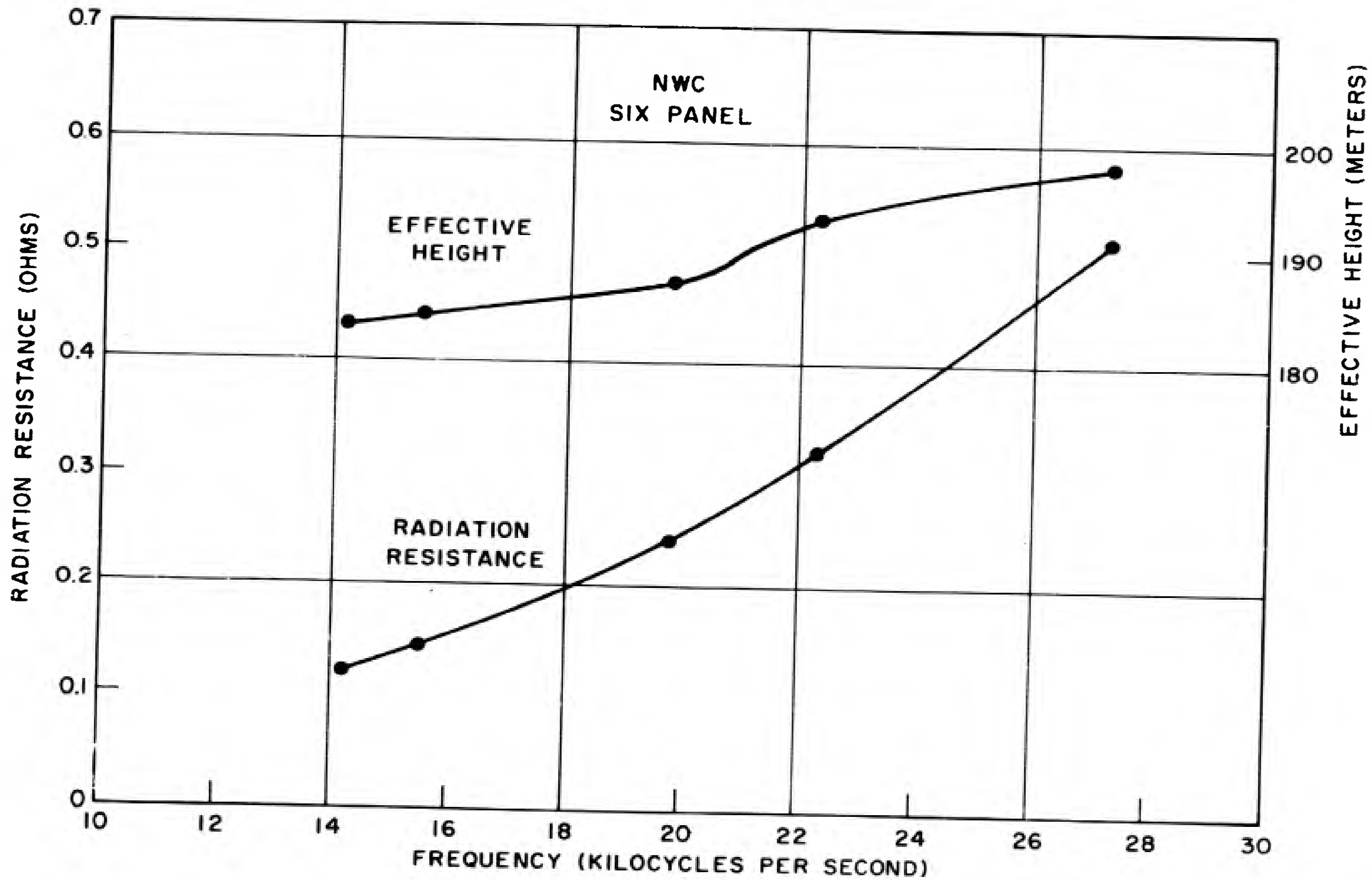

Figure 9 - Radiation resistance and effective height of the NWC antenna system operating with six panels as a function of frequency

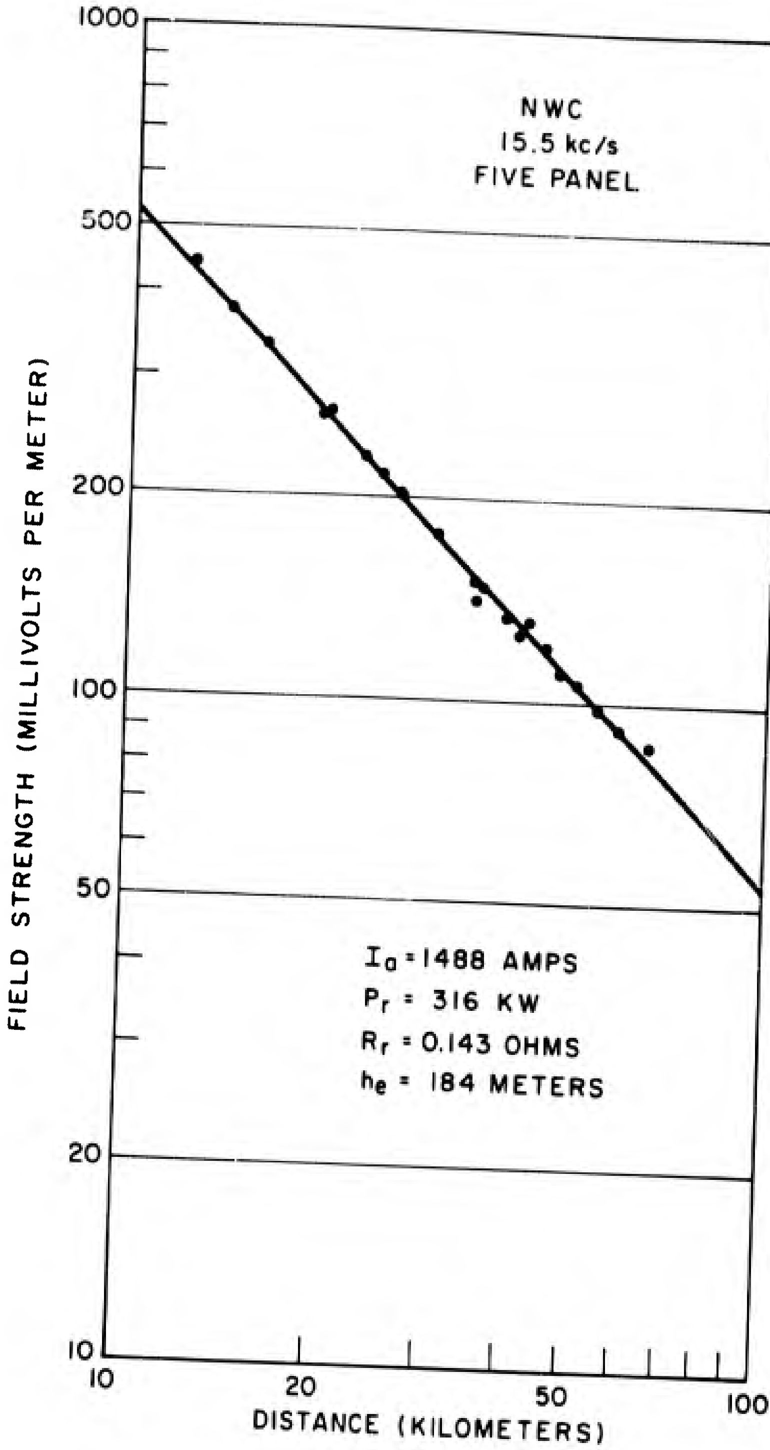

Figure 10 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with five panels at 15.5 kc/s

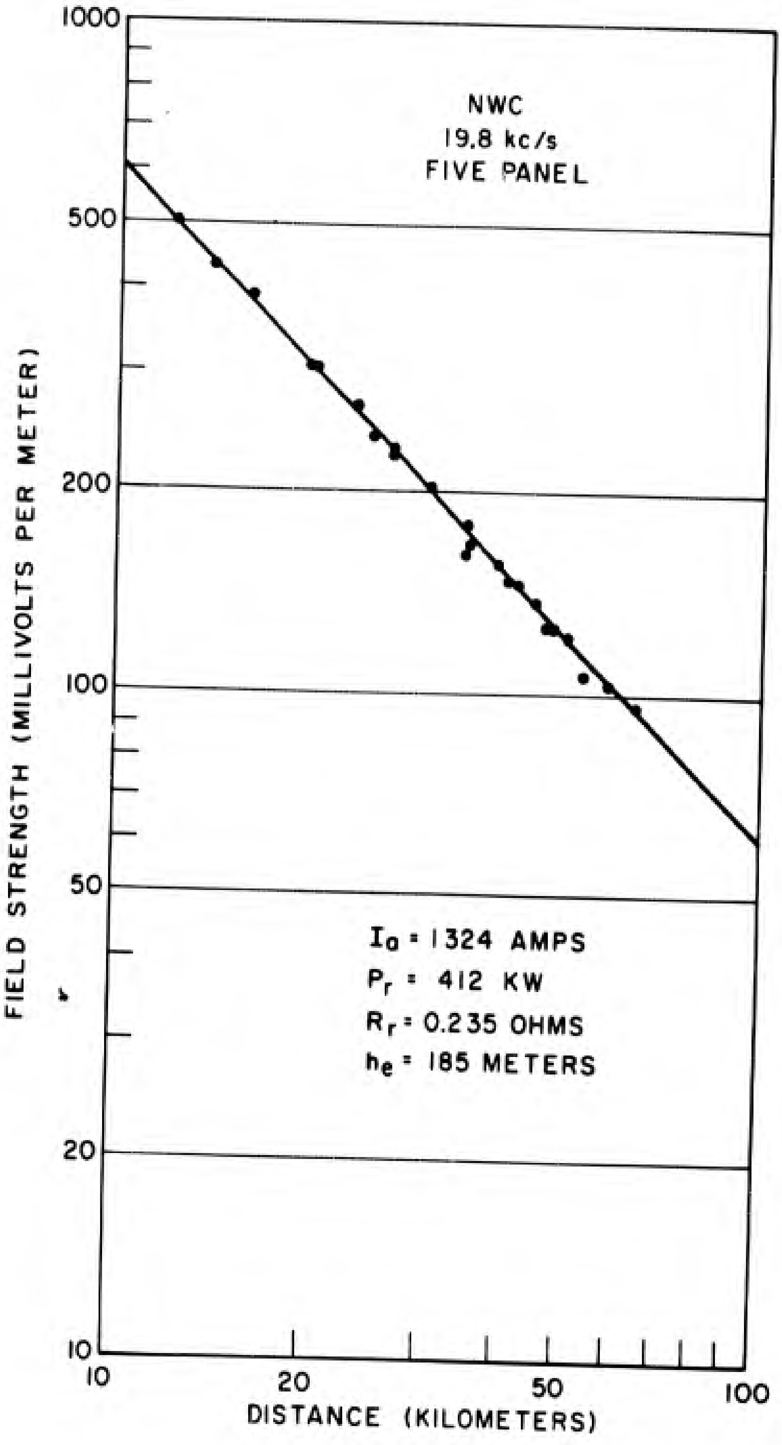

Figure 11 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with five panels at 19.8 kc/s

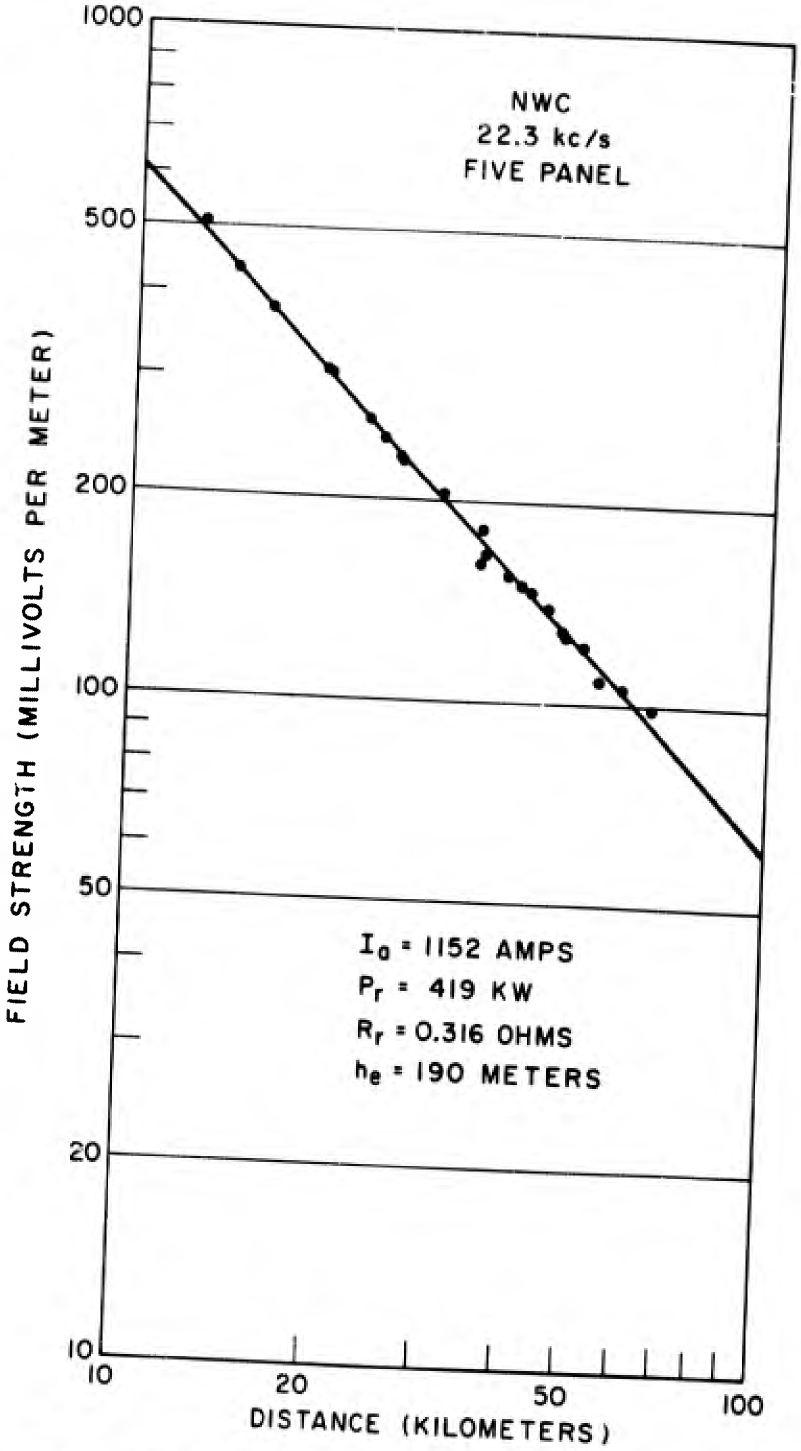

Figure 12 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with five panels at 22.3 kc/s

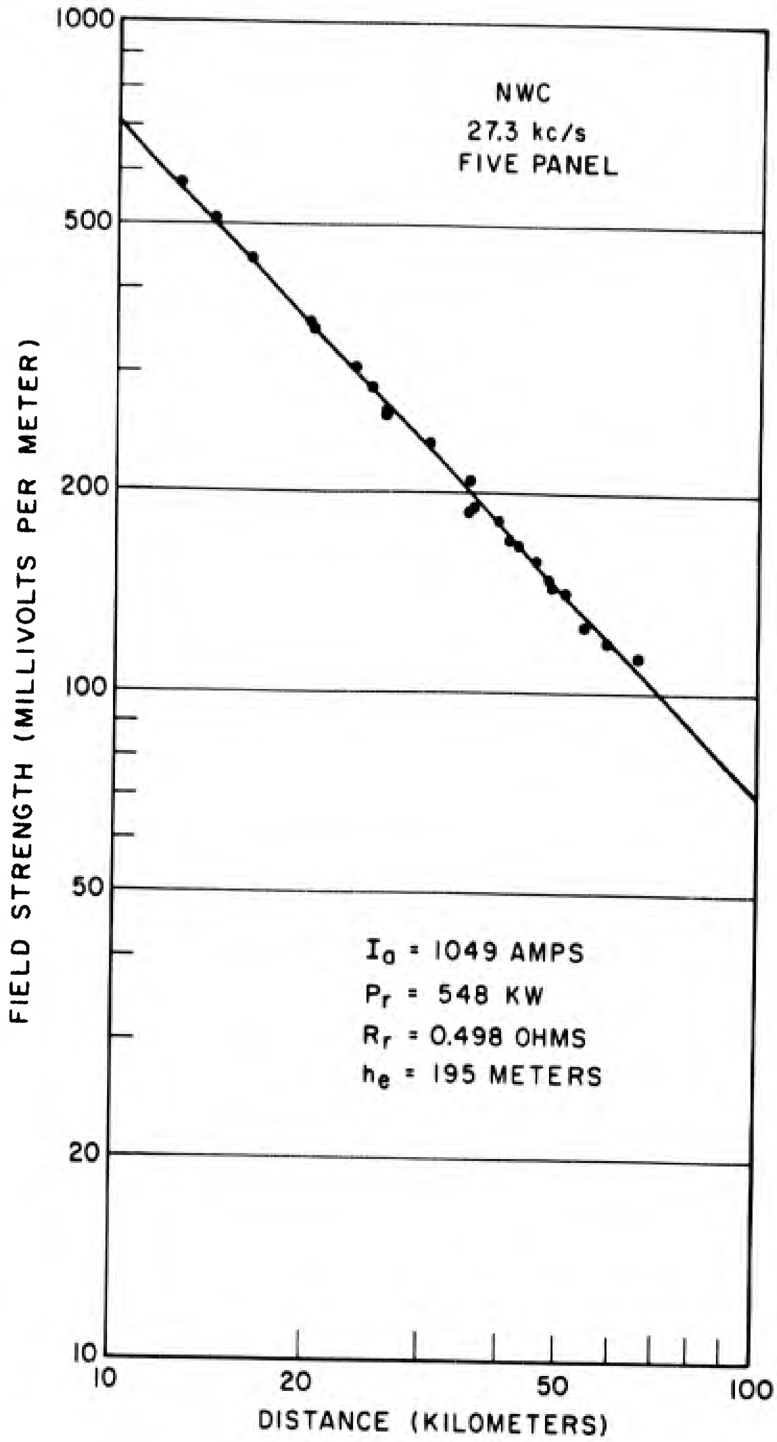

Figure 13 - Field strength normalized to a constant antenna current as a function of distance from the NWC antenna operating with five panels at 27.3 kc/s

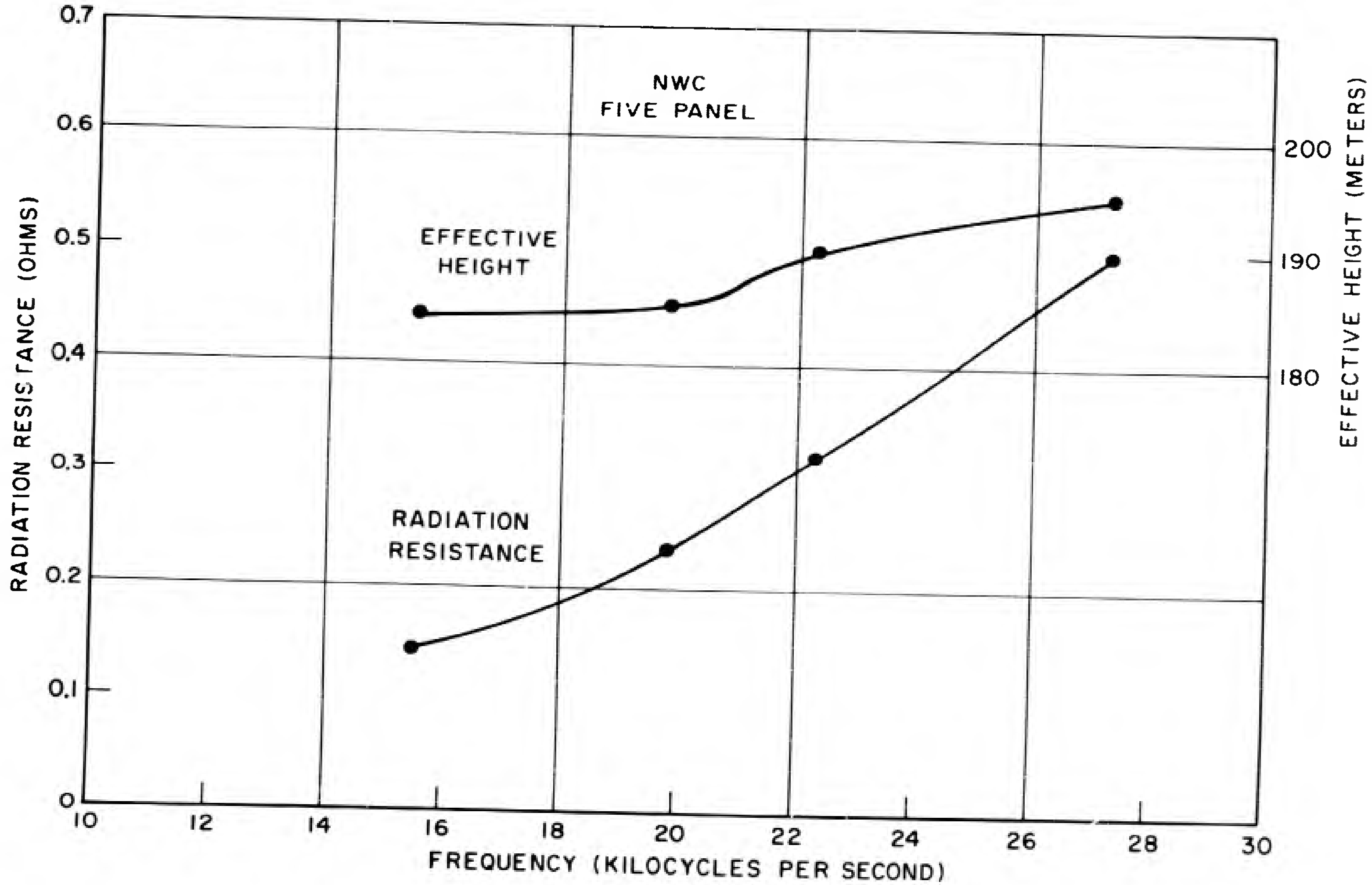

Figure 14 - Radiation resistance and effective height of the NWC antenna system operating with five panels as a function of frequency

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Research Laboratory Washington, D. C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

RADIATION PARAMETERS OF THE VLF TRANSMITTING STATION NWC, NORTH WEST CAPE, AUSTRALIA

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final report on the problem.

5. AUTHOR(S) (First name, middle initial, last name)

W. E. Garner, J. E. Raudenbush, and C. B. Brookes, Jr.

6. REPORT DATE June 21, 1967	7a. TOTAL NO. OF PAGES 38	7b. NO. OF REFS 1

8a. CONTRACT OR GRANT NO. NRL Problem R01-39A b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Memorandum Report 1783 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distribution of this report is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Facilities Engineering Command Washington, D. C.

13. ABSTRACT

The U.S. Naval Research Laboratory experimentally determined the radiation parameters, radiation resistance and effective height, of the very low frequency (VLF) transmitting station NWC at the U.S. Naval Communication Station, North West Cape, Australia. The work was carried out in January and February 1967 as part of the Proof of Performance evaluation of this new transmitting station.

The radiation parameters were determined for five operating frequencies; 14.2, 15.5, 19.8, 22.3, and 27.3 kc/s, with transmitting antenna operating with all six of its top-loading panels. The parameters were also determined for the antenna operating with five panels but at only four frequencies; 15.5, 19.8, 22.3, and 27.3 kc/s.

The values for the radiation parameters of the NWC transmitting system are reported and discussed along with a detailed discussion of the experimental techniques and data reduction processes.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radiation parameters VLF Transmitting Station NWC, North West Cape, Australia						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Security Classification