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BASIS OF SELECTION OF VLF ANTENNA CONFIGURATION

U. S. NAVY

VLF COMMFACPAC

NBy 37636

April 1963

HNCD

A JOINT VENTURE

Los Angeles, California

Holmes & Narver, Inc.
Continental Electronics Manufacturing Company
DECO Electronics, Inc.

Encl (1) to BUSHIPS Ser 694E-370

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1. INTRODUCTION

This report presents the background and studies leading to HNCD's recommendation for the basic configuration of the high-power, very-low-frequency antenna system on which final design was developed for the VLF antenna to be constructed at the U. S. Navy's VLF Communication Facility at North West Cape, Western Australia. The recommendation, subsequently accepted by the Navy, was based on work accomplished under a preliminary engineering phase and continued under the final design contract.

Under Bureau of Yards and Docks Contract NBy-37598, a Feasibility Study and Preliminary Engineering Report for the VLF Communication Facilities, Pacific (Ref. 1) was developed by the Joint Venture firm of Developmental Engineering Corporation (later, DECO Electronics, Inc.) and Holmes & Narver, Inc. The final design effort based on these preliminary studies was carried out under Contract NBy-37636 between the Bureau of Yards and Docks and the augmented Joint Venture firm, HNCD, comprised of Holmes & Narver, Inc., Continental Electronics Manufacturing Company and DECO Electronics, Inc.

Four basic approaches were considered under the preliminary engineering phase: a complete Cutler-type antenna scaled down to about nine-tenths size, a single 3000-foot vertical radiator, a pair of 2200-foot vertical radiators operated simultaneously and a single modified Cutler-type antenna. The latter, a single section of the Cutler antenna scaled upward by a factor of 1.28 was selected as the most economical of the designs examined and formed the basis for further work in the Preliminary Engineering Report (PER) and the initial base for the final design effort.

The electrical parameters for the basic antenna, as estimated in Supplement 1 (Ref. 2) to the PER, were subjected to scale model studies (Refs. 3, 4) under Change Order F to the same contract. In the course of the model studies, information was developed with regard to electrical performance under various structural configurations as outlined later under Section 3, Basis for Electronic Analysis. It was left, however, to the final design contract to analyze this data in more detail and to develop costs corresponding to the various electronic parameters so that an optimum design could be pursued under the detailed final design effort. It is the purpose of this report to document those further electronic analyses and structural cost studies and their composites which were analyzed to develop the configuration selected for final design.

Navy-Joint Venture conferences were held in early January and early February to review developments toward the antenna selection and to resolve problems which developed. The final recommendation of the Joint Venture was forwarded to the Navy by letter of 7 February 1962 (Ref. 5) and the selected basic configuration concurred in by reply letter of 20 February 1962, Serial 238 (Ref. 6).

This report is aimed basically at showing the development of the design to the point of recommendation in the HNCD letter of 7 February 1962. Since an appreciable time has elapsed since the recommendation was made and basic selection approved, it should be borne in mind that the report reflects the thinking and conditions at a time before final decisions relating to all major features of the towers and top hat system had been made. Consequently, it is to be expected that some of the details contained in the report will not reflect conditions as finally evolved. Any such differences have stemmed from later developments in the course of the final design process.

One item of particular note which occurred subsequent to the basic configuration selection is discussed since it is a major feature in the finally developed system. This is the non-counterweighted, or fixed-halyard, system used in lieu of the original counterweighted system which forms the basis for this report. While the modification would have had no major influence on the selection of the optimum combination of antenna height and top hat span, there is an economic importance associated with the use of fixed halyards which justifies inclusion of the study in this report for completeness.

2. SCOPE OF STUDY

2.1 Electronic Considerations

In the electronics portion of the antenna selection study, several items were considered. These included the critical item of developing means of increasing the resonant frequency of the system, the effect of coupling circuitry on maximum operating frequency, and the further analysis of data gathered under the Change Order F tests. This information was combined with cost information developed for various combinations of top hat heights and spans to arrive at a practical optimum for maximum bandwidth for no more than the antenna system cost developed in the PER.

During the course of the study, approximate ground system cost variations with top hat heights and spans were also developed as were the main string insulator requirements as a function of top hat voltage. Results of final model studies are contained in the report "Model Studies of the VLF PAC Antenna" (Ref. 7).

2.2 Structural Considerations

This investigation consisted of two phases. The first phase considered optimization of the structural system with respect to electronic performance. For this, preliminary structural designs were developed for 18 cases involving various tower heights and top hat spans chosen to cover the range considered in the electronic performance determinations. Costs were developed for each of the 18 cases, in all of which sloping counterweighted halyards were assumed. Figure 2-1 shows the layout of the tower and antenna system, and Fig. 2-2 summarizes the principal dimensions for the various cases.

A second phase considered the effect of varying certain structural parameters. The intent of this phase was to study the effect and develop the costs of changing the length of the cantilever at the top of the tower for both sloping and vertical halyard systems. Again, these costs were evaluated in terms of the electronic performance under corresponding structural conditions. These tower systems also utilized counterweighted halyards.

An additional investigation conducted after the basic antenna configuration was selected studied a fixed (non-counterweighted) sloping halyard system in lieu of the counterweighted system. It is reported here for completeness.

The structural criteria used was consistent with that previously used in the Preliminary Engineering Report phase (Ref. 1). The analysis approach, however, was necessarily less refined than that of Ref. 2 because of time limitations.

A reasonably accurate structural analysis of the top hat for the single modified Cutler antenna was available. This analysis served as a basis for estimating pulloffs, conductor tensions and counterweight masses for the various configurations.

Figures 2-3, 2-4 and 2-5 show the makeup of the tower and guying system for the shortest towers, the single modified Cutler antenna towers (aspect ratio* = 1.0; similitude ratio* = 1.0) from the PER, and the tallest towers, respectively. The figures represent the extremes and the approximate average of guy sizes and tower heights.

* For definitions of "aspect ratio" and "similitude ratio", see Paragraph 3.

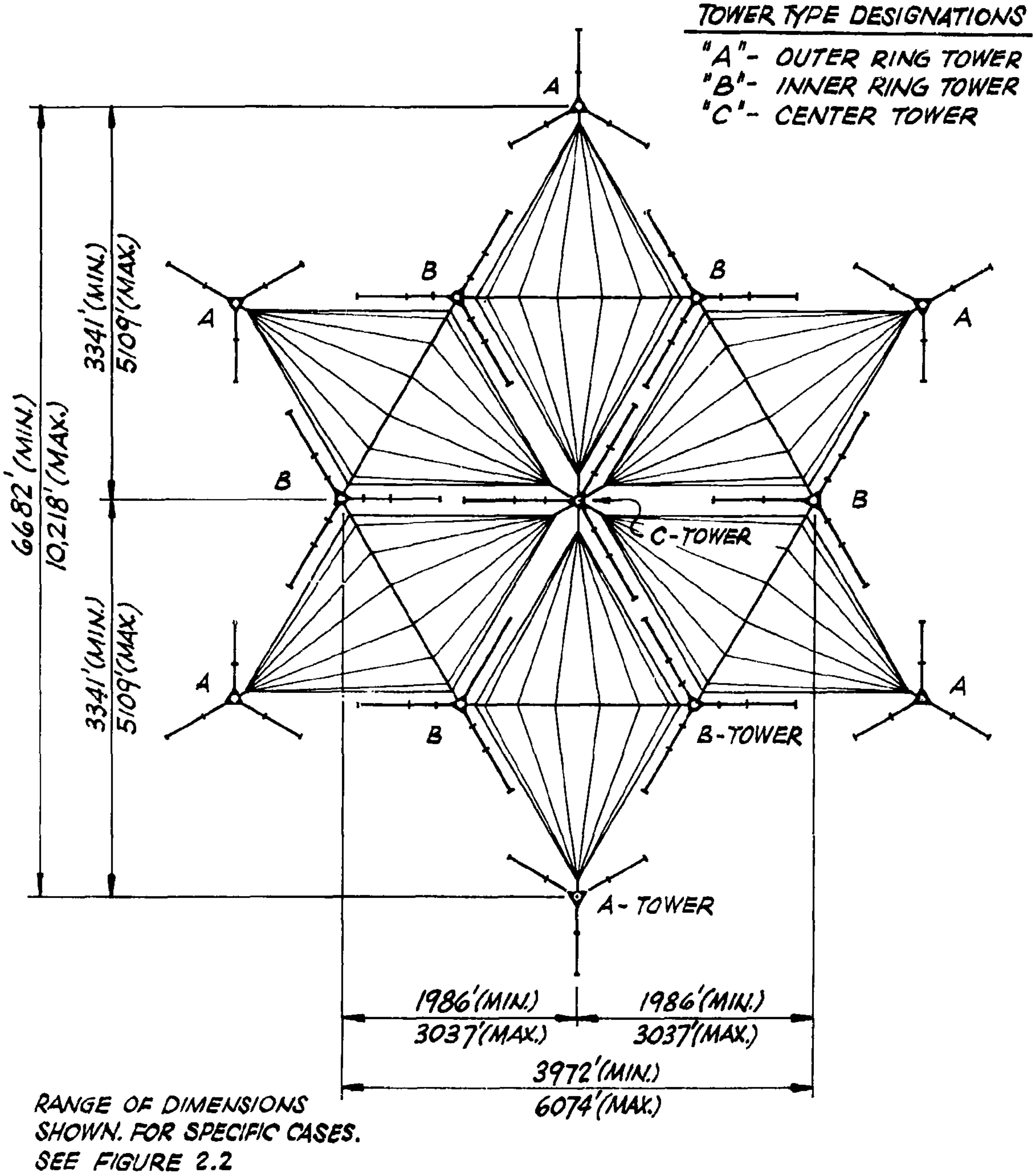
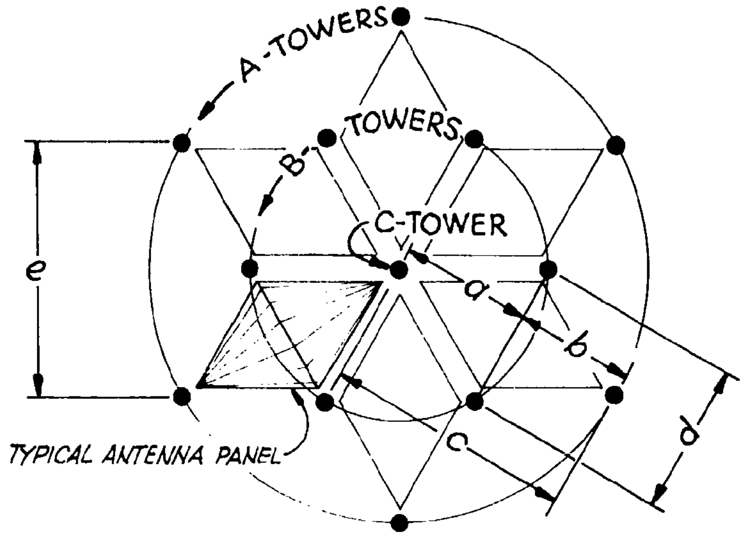


FIG. 2-1 LAYOUT OF ANTENNA ARRAY



ASPECT RATIO	SIMILITUDE RATIO	DIAMETER OF B TOWER (feet)	TOWER HEIGHTS (feet)			DISTANCES BETWEEN TOWERS (feet)				
			A	B	C	a	b	c	d	e
0.70	1.10	6.5	788	957	1042	2225	2098	4323	2570	4323
0.70	1.20	6.5	859	1044	1137	2428	2288	4716	2803	4716
0.70	1.30	7.0	931	1131	1231	2630	2479	5109	3037	5109
0.85	1.00	6.5	870	1024	1101	2023	1907	3930	2336	3930
0.85	1.05	6.5	913	1074	1155	2124	2003	4127	2453	4127
0.85	1.10	7.0	957	1126	1211	2225	2098	4323	2570	4323
0.85	1.20	7.5	1043	1228	1321	2428	2288	4716	2803	4716
1.00	0.95	7.0	972	1118	1191	1922	1812	3734	2219	3734
1.00	1.00	7.0	1023	1177	1254	2023	1907	3930	2336	3930
1.00	1.05	7.5	1074	1236	1317	2124	2003	4127	2453	4127
1.00	1.10	8.0	1125	1295	1379	2225	2098	4323	2570	4323
1.20	0.90	7.5	1105	1243	1313	1821	1716	3537	2102	3537
1.20	0.95	8.0	1166	1313	1386	1922	1812	3734	2219	3734
1.20	1.00	8.0	1228	1382	1459	2023	1907	3930	2336	3930
1.40	0.85	8.0	1217	1348	1414	1720	1621	3341	1986	3341
1.40	0.90	8.5	1289	1428	1497	1821	1716	3537	2102	3537
1.40	0.95	8.5	1361	1507	1580	1922	1812	3734	2219	3734
1.40	1.00	9.0	1432	1586	1663	2023	1907	3930	2336	3930

FIG. 2-2 SUMMARY OF DIMENSIONS

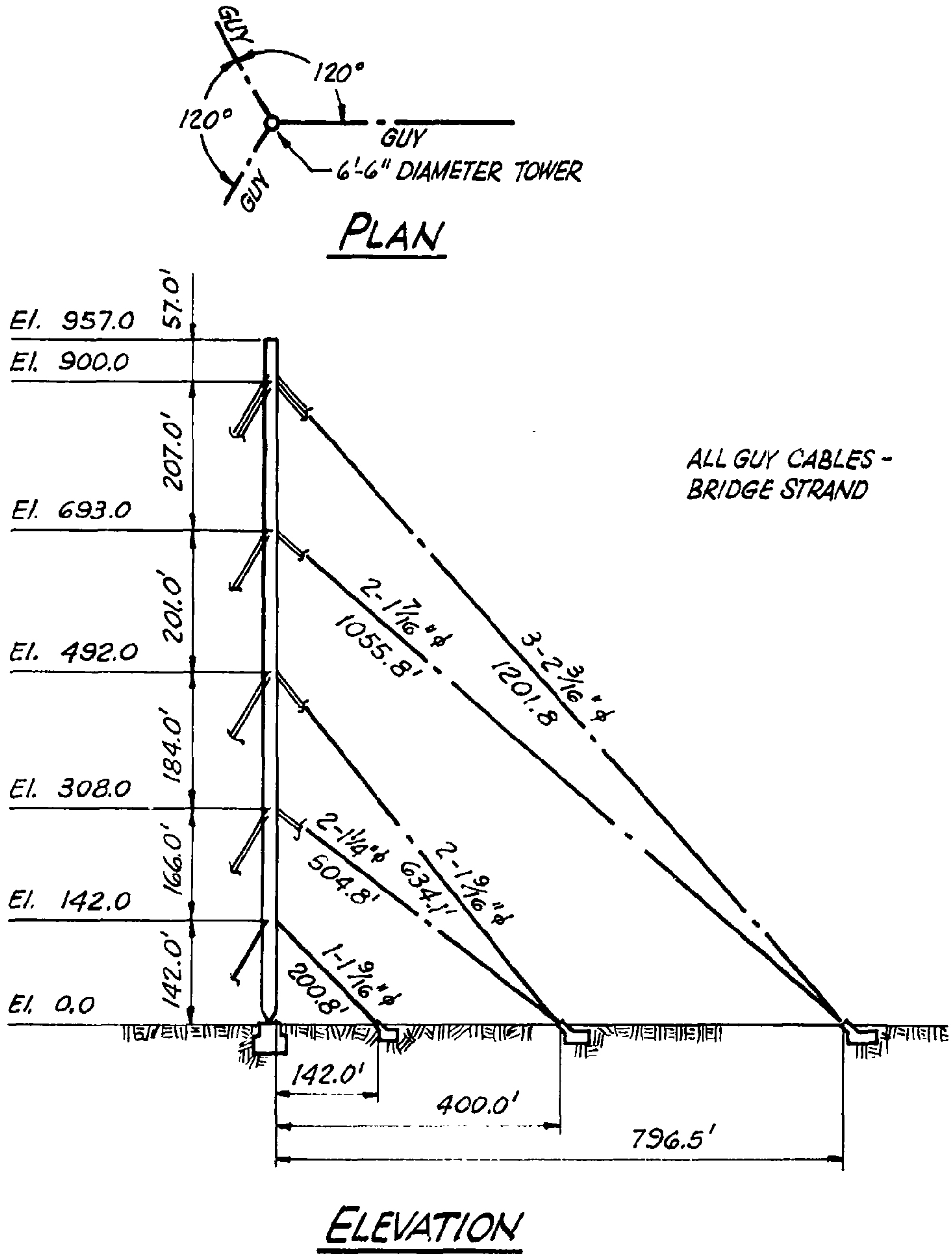


FIG. 2-3 "B" TOWER (ASPECT RATIO = 0.70: SIMILITUDE RATIO = 1.10)

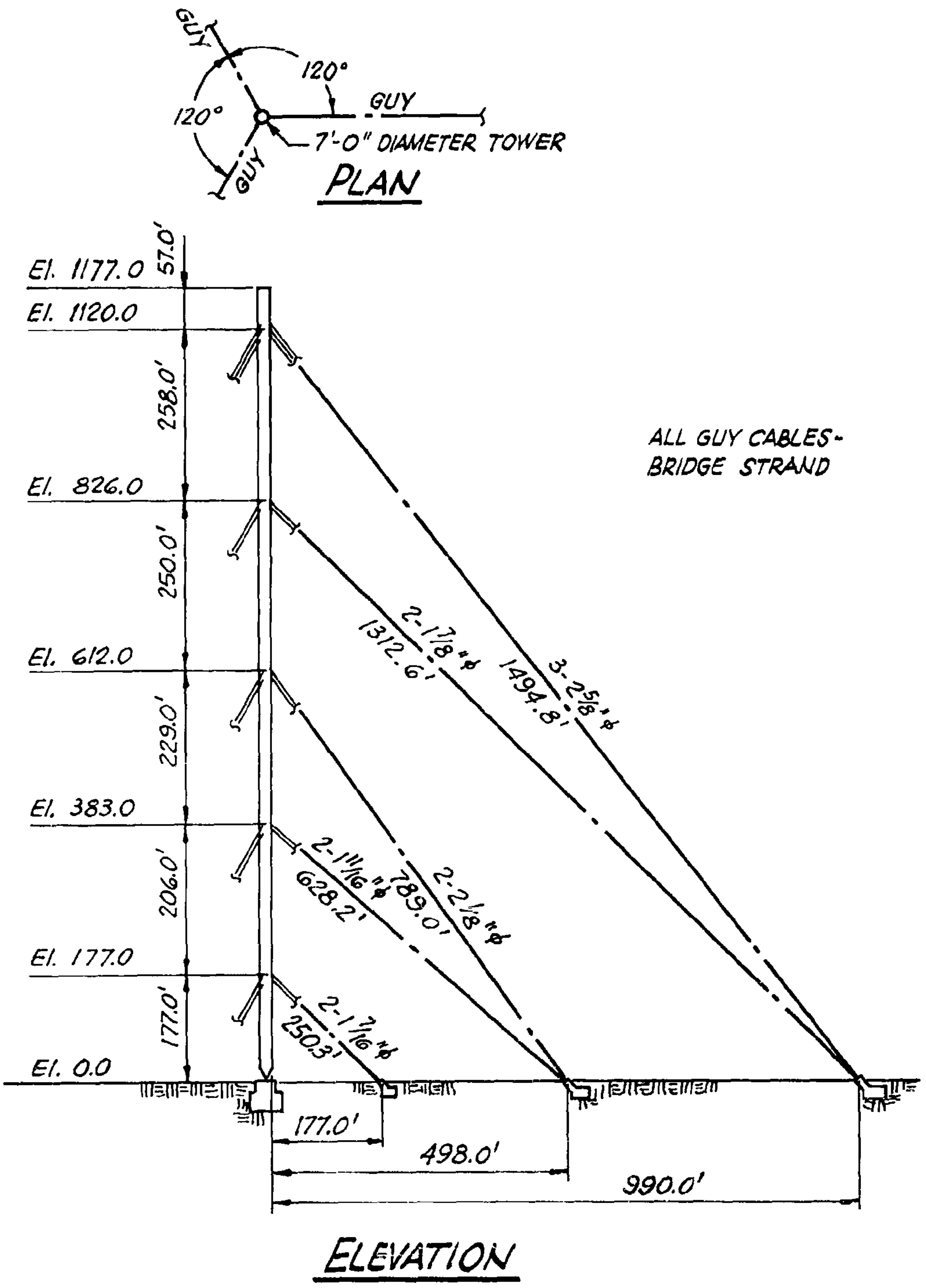


FIG. 2-4 "B" TOWER (ASPECT RATIO = 1.00: SIMILITUDE RATIO = 1.00)

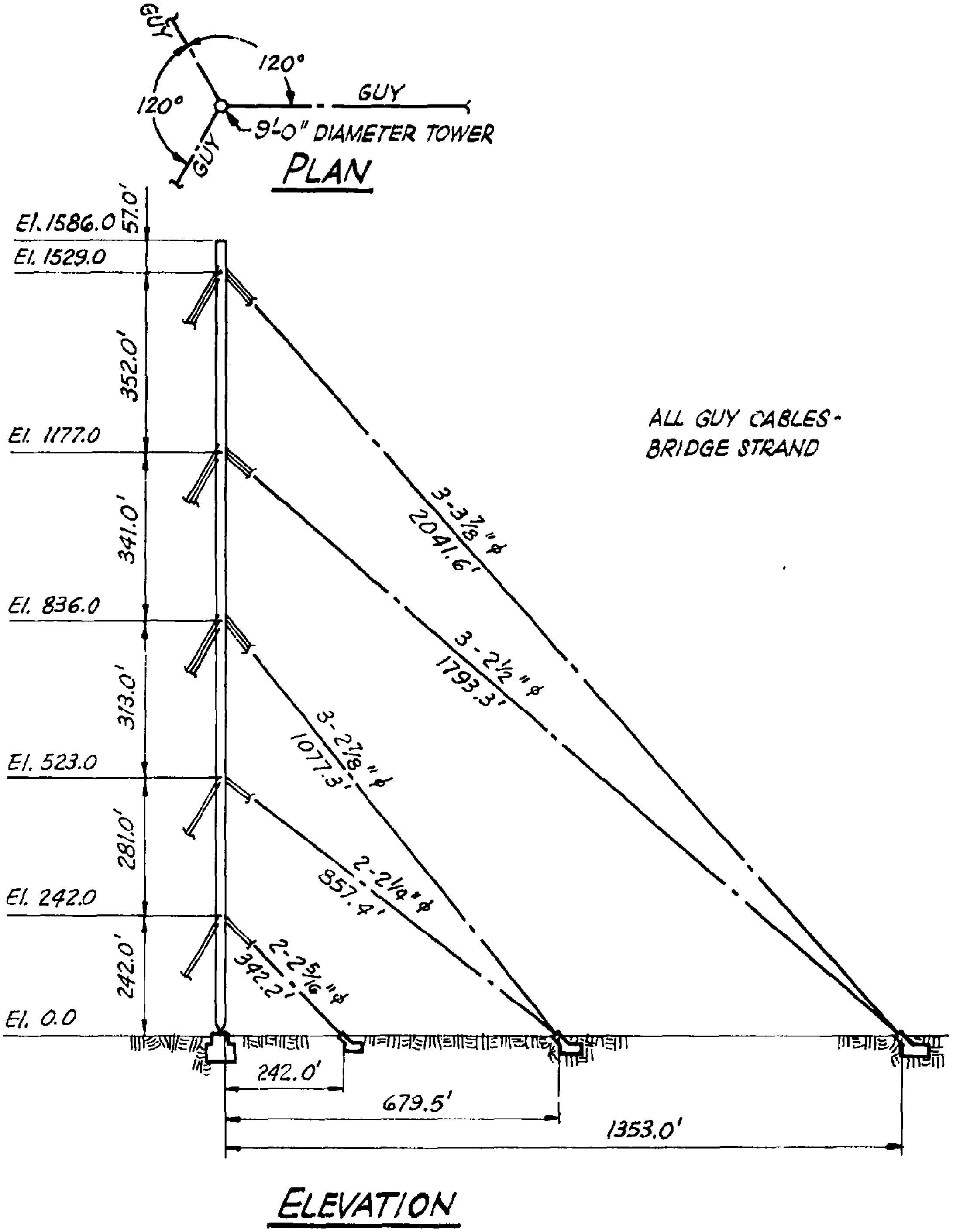


FIG. 2-5 "B" TOWER (ASPECT RATIO = 1.40; SIMILITUDE RATIO = 1.00)

3. BASIS FOR ELECTRONIC ANALYSIS

3.1 General

The electronic analysis was an extension of the work undertaken in the PER phase in which the single modified (1.28) Cutler antenna was selected for first design. Since the results of this earlier work formed the basis for the final design development, pertinent aspects are briefly reviewed.

The electronic effects of the number of guy levels, the top hat halyard pulloff system (vertical vs sloping), the amount of tower cantilever, compensation for these effects by change of the B tower height, and selected locations of the transmitter building were determined under Change Order F. Analysis of the resultant data indicated no significant effect of the number of guys used (4, 5 or 6) nor of the location of the transmitter building relative to the helix house. A preliminary optimum compromise of halyard type, cantilever, and B-tower compensation, based on approximate cost trends, was used for the succeeding model studies conducted under Change Order F.

The compromise solution of vertical halyard, 10-foot cantilever lengths and 45-foot B-tower compensations (relative to a strictly scaled 1.28 Cutler-size) was applied to the model used in developing the aspect ratio* data. This electrical data was one of the prime factors involved in gaining increased bandwidth without increasing antenna system

* Throughout this report the terms "aspect ratio" and "scale factor" or "similitude ratio" are used repeatedly. Definitions developed in earlier reports are summarized here for convenience: "Aspect ratio" $\underline{a}$ is defined as the ratio of outer tower height to maximum top hat span, normalized to the 1.28-Cutler dimension. "Scale factor" or "similitude ratio" $\underline{s}$ relates all linear dimensions to the 1.28 Cutler design for unity aspect ratio.

cost over that of the PER configuration. The aspect ratio study developed the basic electrical performance data for a Cutler-type antenna whose height, in relation to horizontal dimension, was varied above and below that of the PER configuration (1.28 times a single Cutler section). For the same plan configuration and size, the 1.28 Cutler antenna was varied in height. Increases of 20 and 40 per cent above, and decreases of 15 and 30 per cent below the PER size were investigated.

The characteristics of the antenna at the five specific aspect ratios were determined by model techniques. Intermediate points may then be determined from curves developed from the measured data. By further analysis, expansion of the "measured" curves, either upward or downward, is possible by similitude scaling. Table 3-1 summarizes the basic data resulting from the aspect ratio studies; Figure 3-1 is a plot of these basic parameters in the region of primary interest. In developing further information in the study, data taken from the smooth curves of Figure 3-1 was used as a base.

3.2 Resonant Frequency Studies

The resonant frequency characteristics of the single modified Cutler antenna, scaled upward to 1.28 times the size of one of the Cutler sections, was recognized as a critical item in Supplement 1 to the PER. Under strict upward scaling of the Cutler configuration the resonant frequency, and consequently the upper limit of operating frequency, was predicted to require series capacitance to tune to 30 kc, the desired upper limit of operating frequency. Inclusion of such tuning element required not only the capacitor, but also added such other components as switches and a static drain inductor, and required expansion of the helix house volume to accommodate the added components. Recognizing the significant additional cost, one of the first steps in planning the final model effort was a study of selected means of increasing the antenna resonant frequency in an effort to achieve the desired upper operating frequency of 30 kc.

3.3 Performance Requirements

A Navy-Joint Venture meeting early in January 1962, discussed the preliminary results of the aspect ratio versus cost study, and the resonant frequency studies to that date. The results available indicated that, at no additional cost for the basic antenna system, some gain could be made in bandwidth by adjusting the aspect ratio downward and similitude scale factor upward. Simultaneously, however, using an estimated effect of the coupling circuitry on the antenna resonant frequency, it appeared that the desired maximum operating frequency of 30 kc could not be achieved simultaneously with the gain in bandwidth without the use of a capacitive tuning element. Consequently, certain criteria for the antenna to be selected were modified by the Navy to the following:

1. Antenna bandwidth (100 per cent efficiency) - 37.5 cycles at 15.5 kc.
2. Upper limit of system operating frequency - not less than 28.5 kc.
3. No tuning capacitors to be required to meet (2) above.

Other basic requirements remained unchanged, including:

1. Estimated cost - not to exceed estimated cost of the single modified (1.28) Cutler antenna.
2. 1 megawatt radiated at 15.5 kc.
3. Operation down to 14 kc, at relaxed performance, if necessary.

3.4 Tolerances

In complying with the electronic requirements outlined above, it was necessary to recognize, as in any measurement program, that the results have some degree of tolerance. Therefore, an estimate of this degree of accuracy of the data was required to give a reasonable assurance that the desired results would be achieved. In the performance-cost evaluation, it was readily apparent that such an estimate was needed to intelligently select the optimum antenna configuration.

Throughout the collection of model data, continued improvement was made in measurement techniques, analysis procedures, and consequently, in the accuracy of the resulting information. Considering the various factors involved, the probable errors for the various basic measurements were regarded as within the following tolerances:

Effective height	plus or minus 2%
Static capacitance	plus or minus 1%
Resonant frequency	plus or minus 1%

It was necessary, therefore, that these tolerances be applied to the basic curves in order to provide a sufficient margin of safety to assure the probability that the end results would meet the requirements.

In addition to the above parameters predicted directly from measurements, the resulting effect on the pertinent parameter of bandwidth was also evaluated. Since bandwidth is proportional to the square of the effective height and the first power of capacitance, it follows that the tolerance for the predicted bandwidth is approximately plus or minus 5 per cent.

Departures from measurements or derived information, in accordance with the tolerances above, must be recognized. Throughout the study, the conservative approach with regard to tolerances was obviously followed in order to assure the greatest probability of compliance with the specified operation.

TABLE 3-1

BASIC ANTENNA PARAMETERS

SINGLE MODIFIED CUTLER ANTENNA

From model measurements-converted to full scale values
4-wire cage downleads

Aspect Ratio	Effective Height ft.	Static Capacitance (microfarads)	Resonant Frequency kc
0.7	483	.1609	34.6
0.85	551	.1541	32.9
1.00	632	.1486	31.5
1.20	694	.1455	29.7
1.40	751	.1451	28.5

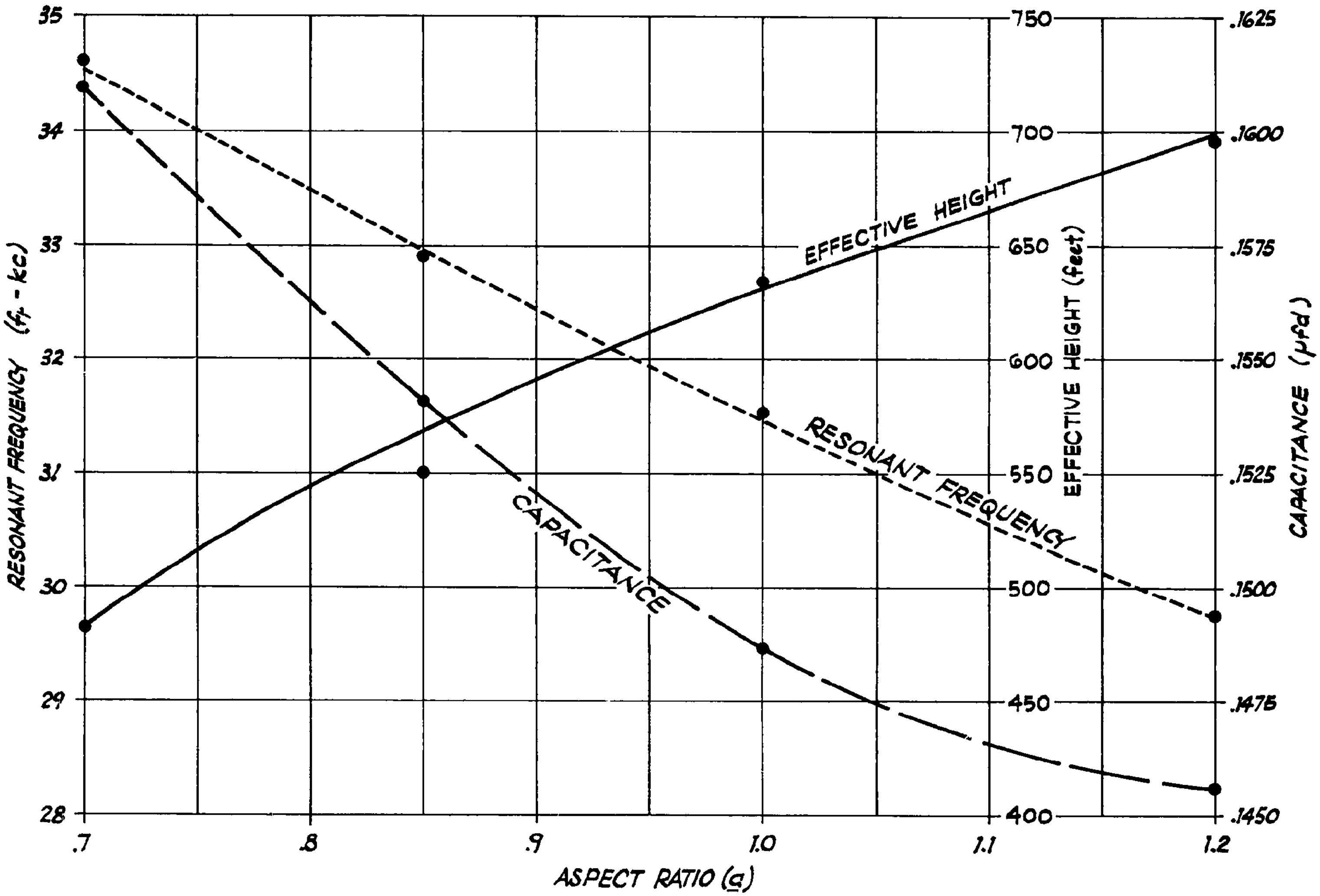


FIG. 3-1 ANTENNA PARAMETERS - FROM MODEL MEASUREMENTS
4 WIRE CAGE DOWNLEADS

4. BASIS FOR STRUCTURAL ANALYSIS

4.1 General

This preliminary design effort was confined to the inner row of towers (B towers). To estimate cost of the A and C towers and counter-weight towers, it was assumed that the relationship between the costs of these various towers was in accordance with those previously derived from cost estimates set forth in Ref. 1. The previous studies of Ref. 1 demonstrated that tubular towers for supporting the top hat system are essentially identical in cost to their framed counter-parts; consequently, the further studies of Ref. 2 and this investigation also, considered tubular towers to take advantage of a large saving in design time. The material considered was A-7 steel throughout.

4.2 Towers

4.2.1 Aspect Ratio Study

The compressed time scale available for the preliminary design of 18 towers completely eliminated the possibility of any computation refinement, computer based or otherwise, and dictated the use of numerous simplifications. These simplifications were chosen so to provide, as far as possible, uniformity in the degree of optimization for each tower-top hat system. One such simplification was to make all height increments between guy levels proportional to those of the B tower of Ref. 2, (hereafter designated as the reference tower). In addition, the deflection pattern for each tower design was assumed to be proportional to that of the reference tower, and the tower shaft diameters were varied from 6.5 feet to 9.0 feet depending on height.

Tower loading conditions assumed for each study were as outlined in Appendix H of Ref. 1. Pulloff loads from the top hat were obtained by extrapolations of previous data.

The approximate method of tower analysis utilized the assumed deflection curve previously described and consisted of the following steps:

(a) Fixed-end moments derived from the wind, top hat pulloffs, and assumed deflected shape, were distributed in the conventional manner to obtain end moments.

(b) Cross-sectional areas of the guys at any level relative to those of the reference tower, were assumed to be proportional to the simple beam wind reaction.

(c) Axial thrust increments due to guy tension at each guy level were assumed to include the vertical component of initial tension plus the vertical component induced by the simple beam reaction. These were combined with the vertical component of the top hat pulloff and the tower dead load to give the total axial thrust at any given level.

(d) Wall thicknesses, based on the assumed use of A-7 steel, were selected according to the criteria of Ref. 1.

Tower anchor blocks were sized on the basis of the simple beam reactions at each guy level relative to those of the reference tower. The size of the footing under each tower was proportioned on the basis of axial thrust at the base relative to that of the reference tower.

4.2.2 Effect of Varying Cantilever Projection and Halyard Type

This portion of the investigation studied the effect of varying the height of the cantilever sections above the top guy level on towers having a similitude ratio of 1.0 and an aspect ratio nominally equal to unity, and using both sloping and vertical halyard systems. For both halyard systems, cantilever projections of 10, 30, and 57 feet were investigated, 10 feet being considered an approximation of a practical minimum, and 57 feet being the projection used in Ref. 2. The influence of cantilever projection and the effect of type of halyard (sloping vs. vertical), on the electronic characteristics, required different total heights for each tower. For this reason, the towers with 10 foot cantilevers were higher than those having 30 or 57 foot cantilevers, and towers with sloping halyards were higher than those with vertical halyards. The analysis procedure, as in the case of the aspect ratio study, was based on maintaing a tower deflection pattern proportional to that of the reference tower. However, the method of analysis of each tower was somewhat more refined than that used in the aspect ratio study in that it was possible in this instance to utilize guy data made available from the computer program (GLAD) in all calculations. After assuming a deflection curve for the tower under wind, guy sizes were selected so as to result in a deflection consistent with the deflection pattern assumed. End moments were then computed by the method of balancing angle changes described in Ref. 1, in a simplified version which neglected the somewhat minor influences of guy couples and axial thrust. Thereafter, reactions and deflections were computed at each guy level and the computed deflections were then compared against those assumed, for purposes of detecting significant variations from the assumed shape of the deflection curve. The remaining analysis paralleled that of the aspect ratio study, except that tower axial thrust and footing and anchor block design utilized the computer-derived data previously mentioned.

4.2.3 Fixed Halyard Study

The effect of using fixed (non-counterweighted) halyards was studied for the case of a similitude ratio of 1.0 and a nominal aspect having a similitude ratio of 1.0 and an aspect ratio nominally equal to unity, and using both sloping and vertical halyard systems. For both halyard systems, cantilever projections of 10, 30, and 57 feet were investigated, 10 feet being considered an approximation of a practical minimum, and 57 feet being the projection used in Ref. 2. The influence of cantilever projection and the effect of type of halyard (sloping vs. vertical), on the electronic characteristics, required different total heights for each tower. For this reason, the towers with 10 foot cantilevers were higher than those having 30 or 57 foot cantilevers, and towers with sloping halyards were higher than those with vertical halyards. The analysis procedure, as in the case of the aspect ratio study, was based on maintaing a tower deflection pattern proportional to that of the reference tower. However, the method of analysis of each tower was somewhat more refined than that used in the aspect ratio study in that it was possible in this instance to utilize guy data made available from the computer program (GLAD) in all calculations. After assuming a deflection curve for the tower under wind, guy sizes were selected so as to result in a deflection consistent with the deflection pattern assumed. End moments were then computed by the method of balancing angle changes described in Ref. 1, in a simplified version which neglected the somewhat minor influences of guy couples and axial thrust. Thereafter, reactions and deflections were computed at each guy level and the computed deflections were then compared against those assumed, for purposes of detecting significant variations from the assumed shape of the deflection curve. The remaining analysis paralleled that of the aspect ratio study, except that tower axial thrust and footing and anchor block design utilized the computer-derived data previously mentioned.

4.2.3 Fixed Halyard Study

The effect of using fixed (non-counterweighted) halyards was studied for the case of a similitude ratio of 1.0 and a nominal aspect ratio of 1.0, adjusted electronically to compensate for the increased top hat sag required for a non-counterweighted system. The approach used was identical to that described in the preceding section.

4.3 Top Hat

4.3.1 Aspect Ratio Study

The load case selected for the top hat study was wind parallel to the catenary. The conductor size (1-1/8" Alumoweld) selected for the study of the single modified Cutler antenna system, (Ref. 2), was used throughout this investigation. A constant proportion of sag to span was maintained for all similitude ratios. Pulloffs, conductor tensions, and counterweight requirements were assumed to be proportional to the total wind load acting on the top hat. To determine the variation of counterweight tower and counterweight cost with changes in aspect and similitude ratios, a rough trial design was made based on the combination of these two parameters which yielded an extreme maximum. The change in cost from that of the counterweight and counterweight tower of Ref. 2 was not a large percentage of the total cost of the antenna system; consequently, the interpolation used to determine cost for other aspect and similitude ratios involved only minor error.

4.3.2 Effect of Halyard Type

Halyards and top hat conductor tensions for a given tower height and spacing are essentially independent of the type of halyard system used (sloping or vertical). This fact enabled determination of tower pulloffs for either system based on this assumption.

4.3.3 Fixed Halyard Study

The possibility of eliminating counterweights had been explored previously (Ref. 8), (based on a similitude ratio of 1.0 and a nominal aspect ratio of 1.0), with results tending to indicate reasonable pulloffs and potential savings in cost. A subsequent study by the Joint Venture substantiated the approach used and the results obtained.

An important consideration, in the case of the fixed halyard system, is whether there is a detrimental redistribution of wind shear between the various towers under overload wind conditions. To resolve this question the top hat of Ref. 8 was further studied on the premise of a wind velocity about 30% greater than that used in the study of Ref. 8.

In adapting the fixed halyard concept of Ref. 8 to the requirements of the antenna configuration study, the plan dimensions of the panels were maintained; however, certain alterations became necessary to provide consistency, from an electronic standpoint. These adjustments consisted of increasing the tower heights to provide the necessary average top hat elevation, and changing of wires sizes from the 1-inch diameter assumed in Ref. 8 to the 1-1/8-inch diameter assumed throughout the antenna configuration study. This latter change required an estimate of the resulting increased pulloff.

5. SUMMARY OF RESULTS

5.1 General

The results of the several studies conducted in arriving at the antenna configuration selected for recommendation are presented and discussed below. The results include those of the resonant frequency studies made on the scale model and the effect of the coupling circuitry in deriving the system operating frequency from the antenna resonance. Results also include the electronic, structural and cost considerations related to the selection of aspect ratio and similitude scale factor and also the considerations related to the recommended halyard-cantilever-compensation combination. Information concerned with the fixed halyard system, which was actually developed after the basic antenna configuration was selected, is also included for completeness.

5.2 Resonant Frequency Studies

In pursuing means of increasing the resonant frequency of the antenna, studies were made of this and other pertinent electrical characteristics of the 1.28 Cutler antenna with several variations of downlead configuration. Basically, the variations were in the shape of the downlead from the standpoints of the location of the hinge point, the location of the point of attachment to the top hat, and the configuration of the vertical portion of the downlead (i.e., the cage or fan version). The results of some twelve tests, plus two supplemental measurements, are given in Table 5-1. Figures 5-1, 5-2, 5-3 and 5-4 illustrate the various configurations studied, and show pertinent dimensions and downlead arrangements. While shown on Table 5-1, test results are also included on the figures for ready reference.

Tests 1 and 9 (Figure 5-1) of the test series represent the "1.28" version of the antenna system (with vertical halyards, 10-foot cantilever, 45-foot B-tower compensation) and yield an antenna resonant frequency of approximately 31.5 kc. Test 2 (also Figure 5-1) maintained the same attachment point at the antenna top hat, but reduced the length of the 4-wire cage downlead by virtually eliminating the hinge point. While this reduced the downlead length, it also resulted in a smaller average diameter for the "cage" composed of the six vertical downleads around the C tower. The increased inductance resulting from the reduced overall downlead diameter apparently overrides the reduced inductance of the shortened length and effects a reduction in resonant frequency.

Tests 3, 4 and 5 (Figure 5-2) were made with the attachment point at the top hat moved out by some 200 feet beyond the original radius. For Test 5, a 4-wire cage downlead, essentially vertical from the top hat attachment point to the hinge point, and a more or less horizontal run to the helix house, a gain of approximately 0.7 kc was achieved. Again, however, the virtual elimination of the hinge point by routing the downlead directly from the top hat attachment point to the helix house attachment point (Test 3) reduced the resonant frequency as it did in the case of the original top hat attachment point radius. In Test 4, with a hinge point intermediate between those of Tests 3 and 5, a slightly higher resonant frequency was achieved, but at a lesser bandwidth than for Test 3.

A third basic approach to the problem of increasing the resonant frequency was made by substituting a fan arrangement for the 4-wire cage on the vertical portion of the downlead (Tests 6-8, 10-12; Figures 5-1, 5-3, 5-4). Both 4- and 8-wire versions of the fan were studied, not only for the normal point of attachment to the top hat but also for one at an additional 200 feet from the C tower. Depending on the radius of the point of attachment to the top hat, gains from about 1.8 to 2.7 kc were made with the 8-wire fan configurations, as compared to otherwise similar 4-wire cage versions.

Test 12 was similar to the basic PER configuration with the 4-wire cage, except that a 4-wire fan was used and the hinge point was slightly farther from the C tower than the attachment point of the top hat, rather than slightly nearer the C tower as in Test 11. This arrangement yielded a slight increase in resonant frequency over Test 11, but not quite as great as Test 10 where an 8-wire fan was used. Considering that the resonant frequency for the Test 12 configuration would have been increased slightly if an 8-wire fan had been used, it is estimated that such modified Test 12 configuration would have characteristics quite similar to those of Test 10. Test 10 also had a very slight advantage in bandwidth characteristics.

Tests 11a and 11b were supplemental checks made using the same basic configuration as Test 11. Test 11a added the strain insulator and pulloff halyard at each of the six hinge points, but showed essentially no different result from corresponding Test 11, where the hinge points were positioned by non-conductors.

Test 11b showed the effects of a significant capacitive shunt at the helix house. As anticipated, the measured static capacitance at the base was increased and the apparent effective height decreased. The bandwidth, as derived from equations based on simple equivalent circuits, actually showed a slight increase with the added capacitance. A more rigorous representation of the equivalent circuit, however, would probably show a slight loss, rather than a gain, in bandwidth. Of particular significance here, however, is the fact that there was no indicated change in resonant frequency of the system.

For structural reasons, it was considered undesirable to increase the radius to the attachment point on the top hat. Therefore, for the additional studies, and as the basis for selection, the results of Test 10 were adopted for the further analysis. At some time after the selection, further structural considerations gave preference to the Test 12 configuration modified to an 8-wire fan. This change, however, introduced no significant differences in predicted performance from that of the originally selected configuration.

5.3 Coupling Circuitry Effects

In a very simple form (Figure 5-5), a VLF antenna may be represented as a simple series circuit composed of inductance, capacitance and resistance, where the inductance is that of the top hat and downleads, the capacitance is the static capacitance of the system, and the resistance is composed of radiation resistance and loss resistances representing those of the ground system, antenna conductors, dielectrics and other losses reflected into the system from towers, guys, and other structures in the surrounding area. As frequency is increased, a point is reached at which the reactance of the apparent inductance in the system is equal to the reactance of the static capacitance. This is the frequency which has been termed "antenna resonant frequency."

The resistance in the system is relatively low, even at the higher end of the nominal operating frequency range. The output impedance of the transmitter is, by comparison, relatively high. To efficiently couple the transmitter to the antenna, a relatively low-loss impedance-matching circuit (Figure 5-5) composed of a coupling inductor and a tuning inductor, which allows the complete system to be resonated at various frequencies throughout the desired operating range, is employed.

As indicated in Appendix A showing a sample calculation of coupling circuitry design, a certain reactance is required in the coupling inductor to properly match between the generator and load resistances. For a given frequency, this value is fixed for a given combination of generator and load resistances. The inclusion of this added inductance in the circuit results in an overall resonant frequency below that of the antenna system itself. In practice the minimum normal inductance adjustment of the tuning inductor must be somewhat greater than zero, even at the highest frequency of operation, so that some variation is possible for tuning the antenna to a particular frequency and for following required inductance variations as the antenna characteristics vary slightly with temperature, wind, etc. In addition, the inductance of connecting busses must be included in the maximum operating frequency determination.

In estimating the extent of the change from antenna resonant frequency to maximum operating frequency, the coupling inductance as required by the generator and load resistances, was used as a base. The total of the other inductances in the circuit, including the tuning inductor and the various busses, was assumed to equal that of the coupling inductance. On the basis of several calculations following the simplified antenna circuit concept and the coupling circuit element philosophy outlined above, it was shown that the upper operating frequency before requiring a capacitive element, was approximately 10 per cent lower than the antenna resonant frequency.

5.4 Aspect Ratio Studies

5.4.1 General

Results of the aspect ratio studies were developed in the areas of electronic performance and structural costs. These elements were then combined into a performance-cost display which was used in selecting the recommended antenna configuration.

5.4.2 Electronic Performance Factors

As pointed out above, the basic experimental data of the aspect ratio studies was developed in the PER phase and is summarized in Table 3-1 and Fig. 3-1 of this report. Figure 3-1 is an expanded plot of the predicted antenna parameters as a function of aspect ratio in the area of primary interest and for a similitude scale factor of 1.0. In developing the further information for use in performance evaluation, data taken from the smooth curves of Figure 3-1 was used as a base. Similitude scaling was then applied to this data to cover a broad range of antenna sizes, resulting in Figs. 5-6, 5-7 and 5-8 which show, respectively, the primary parameters of bandwidth, resonant frequency and top hat voltage, each as a function of scale factor and for the selected values of aspect ratio of 0.7, .85, 1.0, 1.2 and 1.4.

The bandwidth figures were based on the effective height and capacitance data from Fig. 3-1 and are the predicted characteristics at 15.5 kc. The basic effective height and capacitance data from Fig. 3-1, along with the required radiation of 1 megawatt at 15.5 kc, resulted in the required top hat voltage values shown in Fig. 5-8. The several values were derived for particular aspect ratios and were scaled, by similitude, to cover other sizes in accordance with the following laws:

Parameter	Power Law
Bandwidth (at a given frequency)	s^3
Resonant frequency	s^{-1}
Top hat voltage (at a given frequency and radiated power)	s^{-2}

It will be noted from the three figures that, as indicated by the laws above, the resulting curves are straight lines as plotted on the log-log paper. Included on each of the three figures are the values of the particular parameters as predicted from the PER.

Since the primary consideration in the aspect ratio study was the determination of combinations of aspect ratio and scale factor yielding an increase in antenna bandwidth (at 100 percent antenna efficiency and 15.5 kc) for a given cost, data from the several curves above was combined into a composite, Fig. 5-9, in which bandwidth is plotted as a function of aspect ratio for various values of scale factor. Superimposed on these curves are the resonant frequencies corresponding to various combinations of scale factor and aspect ratio, and a constant cost line as developed in a later section and corresponding to the PER cost estimate for the antenna system.

The performance information is based on the measured model data and interpolation from the derived curves with similitude scaling adjustments. No measurement tolerances were considered in the preparation of Fig. 5-9. The reference antenna configuration, as denoted by the point a = 1, s = 1, is that of the PER, except for the use of vertical halyards and a 10-foot cantilever with 45-foot B tower compensation. Five guy levels were used and the PER 4-wire cage downlead configuration was followed.

If the antenna were to be considered alone and no tolerances applied to the measurements, it may, for example, be seen from Fig. 5-9 that a bandwidth of approximately 40 cycles could be achieved with a resonant frequency of 30 kc for the same cost as the PER estimate. This configuration would have an aspect ratio of approximately 0.90 and a scale factor of 1.08. However, in practically evaluating antenna performance, the effect of the coupling circuitry on the upper limit of operating frequency of the system (without resorting to the use of series tuning capacitors) must be considered as well as the measurement tolerances. Over the range of a and s values of interest, it was estimated, as discussed above, that inclusion of the effects of the required coupling circuitry would result in an operating frequency approximately 10 per cent less than that of the antenna resonant frequency.

It is obvious, then, that application of the coupling circuitry effect alone will require that an antenna resonant frequency of some 33 kc be achieved to permit system operation up to 30 kc. From Fig. 5-9, it may be noted that such an increase in required antenna resonant frequency results in a sizeable decrease in the antenna bandwidth to well below the desired value of 37.5 cycles if the PER cost estimate is not to be exceeded.

Under the revised maximum operating frequency of 28.5 kc permitted by the Navy, and the assumption that there will be a 10 per cent effect from the coupling circuitry, it may be seen that a minimum antenna resonant frequency of 31.67 kc (28.5/.90) is required, without regard for bandwidth or antenna resonant frequency tolerances. From Fig. 5-9 it is obvious that there is no combination of a and s values which, for this resonant frequency of 31.67 kc, will yield a bandwidth capability of 37.5 cycles, particularly within the PER cost estimate.

This serious problem of resonant frequency was, of course, recognized in the PER studies and, as reported in earlier sections, steps were taken under the final design model effort to find means of increasing the antenna resonant frequency. As discussed above, the configuration which offered the greatest promise electronically, and was considered structurally reasonable was Test 10 (or later, Test 12, modified to an 8-wire fan) of the resonant frequency study series. This configuration substituted a fan of eight wires for the vertical portion of each of the six 4-wire cage downleads from the antenna. The hinge point location and the attachment point to the top hat were virtually the same as those proposed in the PER. The measured resonant frequency with the fan configuration at an aspect ratio of 1.0 was 33.27 kc, which may be compared to the value of 31.43 kc for the 4-wire cage as derived from the resonant frequency curve on Fig. 3-1 at unity aspect ratio.

Considering this gain, percentage-wise, from the change to the fan-type downlead, the estimated 10 per cent coupling circuit effect, and the one per cent resonant frequency tolerance, it was computed (Appendix B) that an antenna resonant frequency of 30.5 kc at an aspect ratio of unity on the basic coordinate system of Fig. 5-9 would yield a maximum system operating frequency of 28.5 kc for the 8-wire fan configuration. Correspondingly, an antenna resonant frequency of 30.2 kc on the basic coordinate system is required if the coupling circuit effect is 9 per cent.

At other than unity aspect ratio the required antenna resonant frequency on the basic coordinate system would follow the 30.5 kc (or 30.2 kc) line if the variation of this parameter for the 8-wire fan were assumed to follow that for the 4-wire cage. However, since no model measurements of this variation with aspect ratio were made for the 8-wire fan, the validity of such an assumption could not be assured.

An alternate estimate of resonant frequency variation with aspect ratio for the 8-wire fan assumed that the total inductance in the antenna circuit was composed of a fixed and a variable inductance with the variable portion assumed proportional to the length of the vertical section of the downlead. Following this premise, a reasonable correlation with measured data was obtained for the 4-wire cage downlead for which model measurements had been made at several aspect ratios. Extending the concept to the fan-type downleads and extrapolating from the single measured point at unity aspect ratio, it was found that the gain in resonant frequency for the fan relative to the cage-type downleads was not as great at the lower aspect ratios as it was at unity. It was apparent, however, that there would always be some gain regardless of aspect ratio.

In applying the above principle to the 8-wire fan configuration, it was assumed that the increase in resonant frequency at an aspect ratio of 0.7 was only one-half the increase at unity aspect ratio. Based on this assumed aspect ratio function for the 8-wire fan, the estimated one per cent resonant frequency measurement tolerance and the 10 per cent coupling circuitry effect, the limiting antenna resonant frequency to achieve a 28.5 kc system operating frequency over a range of aspect ratios is shown on Fig. 5-10. The curve is superimposed on the basic coordinate system and bandwidth performance curves of Fig. 5-9.

5.4.3 Cost Factors and Other Considerations

To evaluate the relative costs of the basic VLF antenna configuration at various aspect ratios and scale factors, some 18 combinations of these factors were considered in accordance with the analysis bases outlined in Paragraph 4. These estimates considered the costs of the towers, top hat, counterweight system, hoists and certain other principal items of the facility for each of the combinations. The cost estimates include only those items of the facility which have a significant effect on cost differences and do not include items whose costs remain essentially constant regardless of the tower heights and antenna spans. Consequently, the total cost figures, which are summarized in Appendix C, do not reflect the total costs of the facility.

Of primary importance in the aspect ratio study are the cost differences between the several total costs developed in Table C-1 of Appendix C and the cost of comparable portions of the PER single modified (1.28) Cutler antenna. The cost difference information from Table C-1 and Fig. C-1 of Appendix C is presented in several forms. Figure 5-11 shows combinations of aspect ratios and scale factors for several selected antenna cost differences. Figures 5-12, and 5-13 plot cost differences as functions of scale factor and aspect ratios, respectively. The zero cost difference line shown on the performance-cost curves, Figs. 5-9 and 5-10, was derived from the basic information developed above.

The cost differences incurred in achieving certain electronic performance characteristics have been developed for various combinations of aspect ratio and scale factor. These relationships are presented in the form of several curves, Figs. 5-14 through 5-16.

Figure 5-14 shows the cost difference as a function of bandwidth, with cost increasing with bandwidth for any given aspect ratio or scale factor. This trend is to be expected since increase of either factor tends to increase the overall size of the antenna.

Figure 5-15 relates cost difference to resonant frequency. Since higher resonant frequencies are associated with smaller antennas, either by reduced aspect ratio or scale factors, costs decrease with increasing resonant frequencies, as shown by the curves.

Figure 5-16 indicates decreasing costs with increasing top hat voltage for constant values of either aspect ratio or scale factor. This again follows the expected trend as smaller antennas tend to require higher top hat voltages for a given radiated power at a given frequency.

To show the variation of top hat insulator loads for various combinations of aspect ratio and scale factor, Fig. 5-17 was developed. This information was used primarily to show practical limits of loads rather than cost differences which were not developed since the insulator tension was a result of various aspect ratios and scale factors rather than a cause.

5.5 Halyard-Cantilever-Compensation Studies

5.5.1 Electronic Performance Factors

The basic electronic data and background information of the halyard-cantilever-compensation studies were developed under Change Order F to the PER contract and were reported in the model study data report of 22 November 1961 (Ref. 3). The study showed that a series of equivalent parameters can be determined for comparable antenna performance.

The B tower height compensations relative to pure 1.28 scaling of the Cutler configuration and based on an effective height of 633 feet and a bandwidth of 35.4 cycles are shown in Table 5-2 for both vertical and sloping halyards. For example, it may be seen from the table that for sloping halyards, a 56-foot cantilever with a 55-foot B-tower compensation yields the same performance by either the effective height or bandwidth criteria as the vertical halyard arrangement with a 10-foot cantilever and a 45-foot compensation. To be on the conservative side, the greater required compensation for each condition, as shown by the underlining in Table 5-2, was used in the cost comparison of the several combinations.

5.5.2 Cost Factors and Other Considerations

The cost aspects of the halyard-cantilever-compensation studies are summarized in Table 5-3. All the results apply to a scale factor of 1.0 and a nominal aspect ratio of 1.0, with the height of the B tower compensated to yield essentially equivalent electronic performance with variations in halyard slope and cantilever projection as shown in Table 5-2. The first column of Table 5-3 reproduces cost data for the single modified Cutler tower system which was previously developed in Supplement 1 to the PER (Ref. 2). Some of the implications from the data shown are as follows:

a. A combination of sloping halyards and cantilever projection creates favorable bending moments at the top of the tower. The minimum cost shown, which corresponds to the 30-foot cantilever projection, indicates that for the sloping halyard combination, there is an optimum projection between 10 and 57 feet which is probably in the range of 30 feet.

b. The main towers of the sloping halyard system are less costly than those of the vertical halyard system because of the smaller pulloff, but the counterweight towers for the sloping halyard system are more expensive because of the less favorable structural conditions created by the sloping halyard.

c. The increased amount of grounding and roads required when sloping halyards are used, creates a small but significant cost penalty against this type of system.

d. The cheapest counterweighted combination uses sloping halyards and a 30-foot cantilever. However, the vertical halyard combination with a 10-foot cantilever is only slightly more expensive (0.4%). It is not possible to estimate cost to within a fraction of a per cent; consequently, it must be assumed that for all practical purposes, the costs of these two tower configurations are essentially identical. Under these circumstances, the greater mechanical simplicity of the vertical halyard system is a point in its favor.

e. Column 7 shows the results of the analysis of the tower using a sloping halyard without counterweights (fixed halyard). This tower has a cantilever overhang of 57 feet. It is to be noted that the total cost of the A, B and C towers in this case is somewhat greater than that of the reference towers shown in Column 1. This is attributable largely to a somewhat greater pulloff and to the slightly greater tower height required to compensate for increased sag. However, this cost trend is reversed by the elimination of counterweight towers, resulting in an estimating saving of over one and a half million dollars (about 10.8% below the cost of the tower system of Column 1), assuming that features performing the function of the deleted counterweights do not have to be added. Using this assumption, it is apparent that the two cheapest configurations would be (1) a system utilizing sloping, fixed halyards and a cantilever projection of about

30 feet, and (2) a system utilizing vertical, fixed halyards and a cantilever projection of 10 feet.

5.6 Fixed Halyard System

Figure 5-18 shows results of the top hat analysis by the Joint Venture for the case of fixed halyards under service wind conditions. These results agree closely with those of Ref. 8. Figure 5-19 shows results for the overload wind.

Similar information, and additional data, are presented in Table 5-4. Relative wind shears, R_y, and relative horizontal components, H, of halyard tension, are shown for the counterweighted system of Ref. 2 under service wind, and for the fixed halyard system of Ref. 8 under both service and overload wind. It is apparent that the windward B tower carries a considerably greater portion of the wind shear in the case of the fixed halyard system. Comparison of H values shows that the relative pulloff distribution is not greatly different between the counterweighted and fixed halyard systems. The maximum variation occurs at the C tower.

A comparison of the data in Columns 3 through 6 shows that the windward B tower carries about 12% more of the total wind shear under the overload condition, (Columns 3 and 5), whereas the distribution at the other towers is relatively unchanged.

Fairly large changes in pulloff are evident at the A tower and leeward B tower, relative to the pulloff at the windward B tower, when comparing service and overload conditions (Columns 4 and 6). However, this is only significant at the A tower, amounting about an 11% increase.

These conditions can be modified within certain limits by adjusting the sags in the catenary and conductor to achieve a more optimum distribution of the loads acting on the towers.

5.7 Assessment of Fixed Halyard System

Important considerations in comparing counterweighted and fixed halyard systems are as follows:

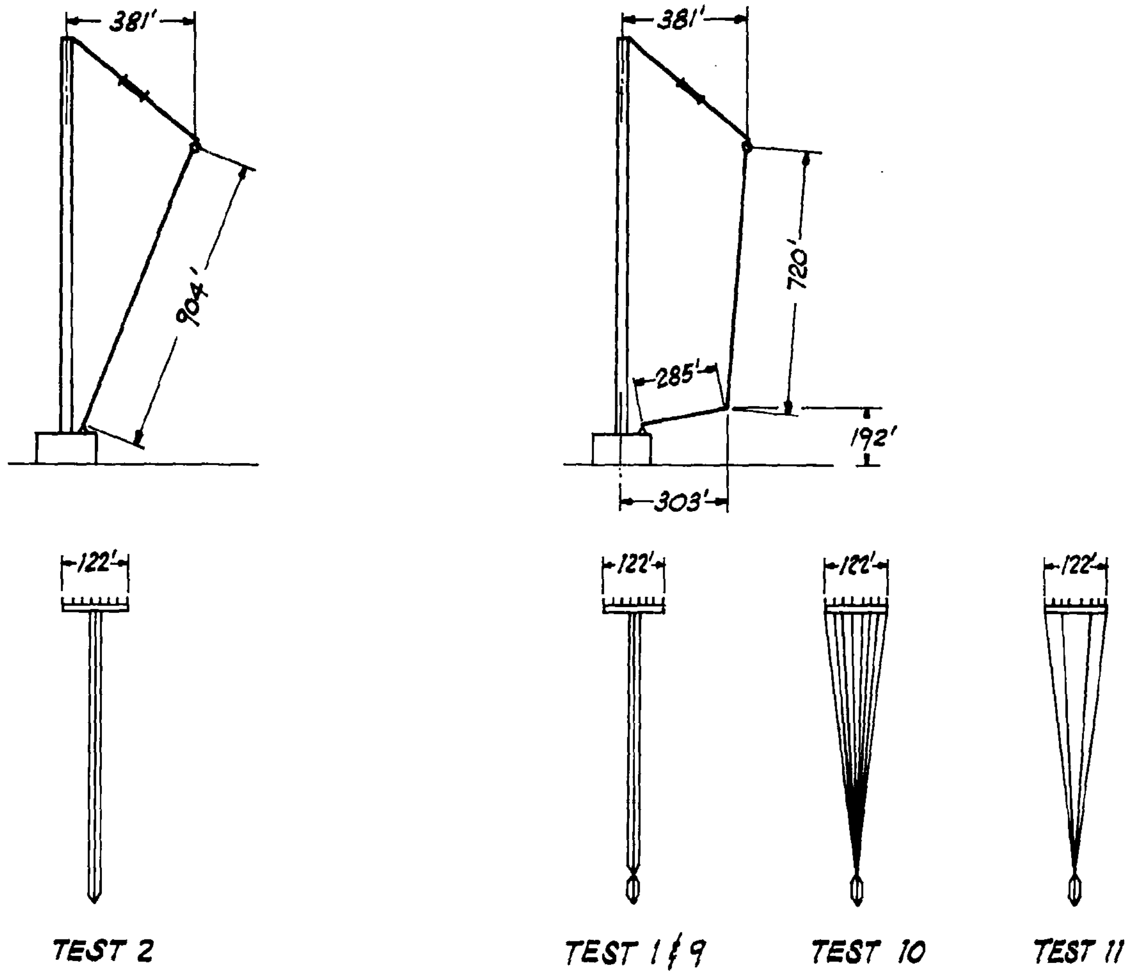
1. To provide a counterweight system with enough travel to bring the top hat to the ground under wind would require counterweights and counterweight towers much larger and costly than those used at Cutler.

2. A counterweight system with a reduced amount of travel can be made to function effectively under the design wind loading (service wind) of VLF PAC. However, overload winds not greatly in excess of the service wind will cause complete payout of the halyard, so that, under overload conditions, it becomes necessary to consider the top hat, at least in part, as a fixed halyard system.

3. Any system with unlimited payout may not necessarily prevent portions of the top hat from draping around the guys or shaft of a leeward tower under hurricane winds. The resulting indeterminate loading condition may or may not be more severe than the loading associated with a fixed halyard system.

4. It may be possible and desirable to incorporate fail-safe features in a fixed halyard system, achieving relief of halyard tension under overload similar to that provided by counterweights and independent of payout. Such features might be devices which jettison the top hat directly by tensile rupture or severing of the halyard, or through a torque release on the winch drum, permitting uncontrolled unwinding. The jettisoning arrangement would detach all four corners of a top hat panel simultaneously.

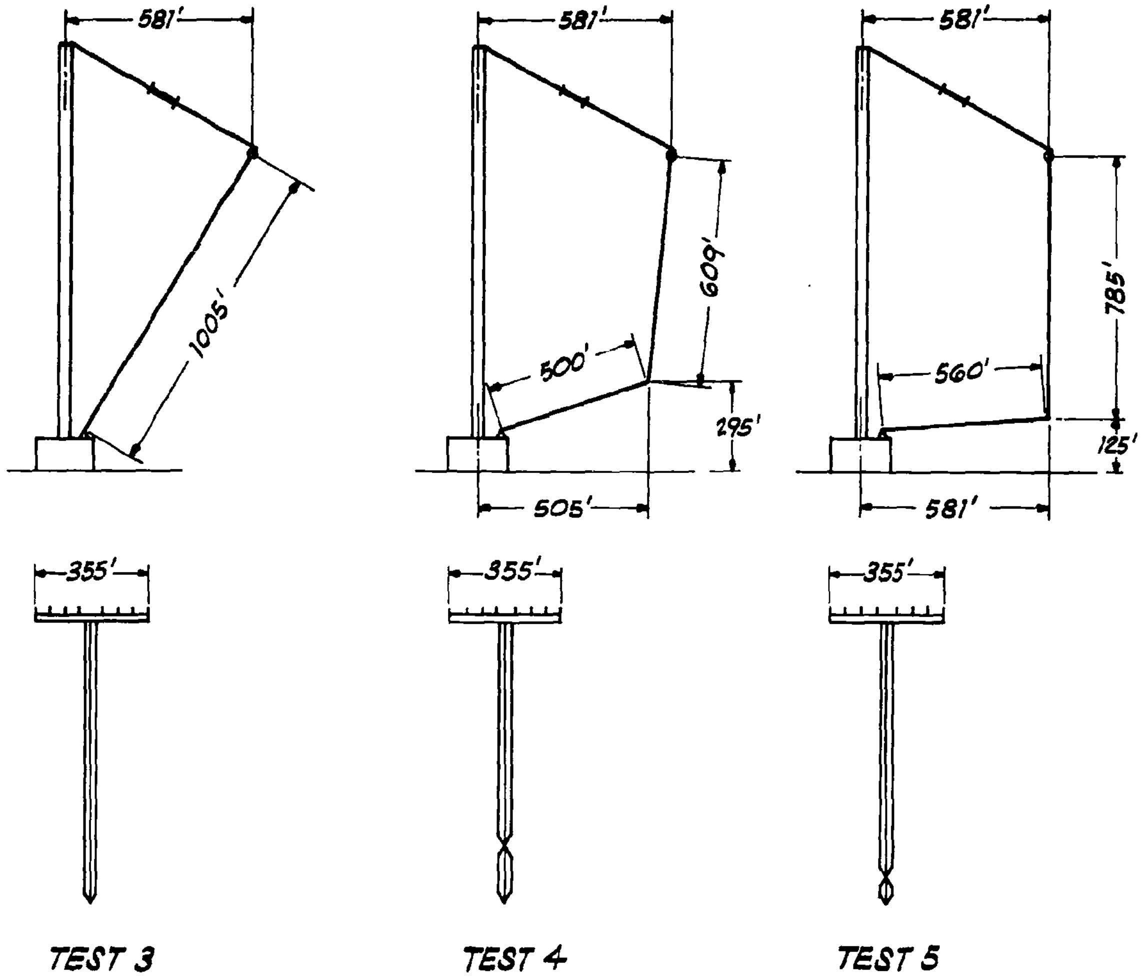
Another possibility is a controlled unwinding scheme that would utilize a dynamic braking system, and would not necessarily require simultaneous release at each supporting tower.



		TEST 2	TEST 1	TEST 9	TEST 10	TEST 11
EFFECTIVE HEIGHT	h_o	640'	638'	642'	635'	634'
STATIC CAPACITANCE	C_o	.1487	.1498	.1497	.1514	.1506
RESONANT FREQUENCY	f_o	30.75	31.50	31.68	33.27	32.87
BASE REACTANCE (15.5 kc)	X_b	-j 50	-j 51	-j 51	-j 51.7	-j 51.6
BANDWIDTH	bw	36.3	36.4	36.8	36.3	36.1

VERTICAL HEIGHT TO PULL OFF POINT TOP HAT-934'
CENTER LINE TRUSS TO TOP HAT-25'

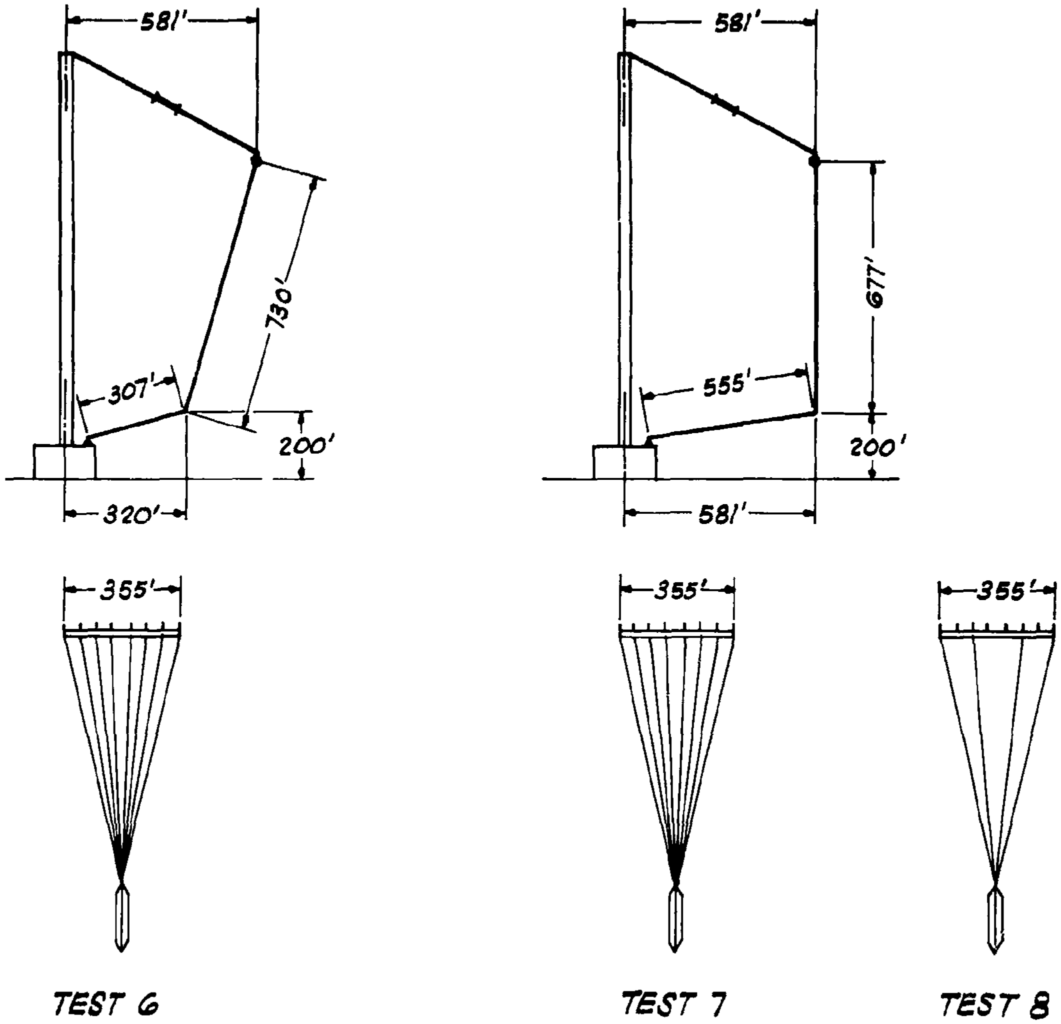
FIG. 5-1 RESONANT FREQUENCY TESTS
CONFIGURATIONS 1, 2, 9, 10 AND 11



	TEST 3	TEST 4	TEST 5
EFFECTIVE HEIGHT h_0	638'	627'	600'
STATIC CAPACITANCE C_0	.1499	.1518	.1561
RESONANT FREQUENCY f_0	32.05	32.30	32.18
BASE REACTANCE (15.5 kc) X_b	-j 51	-j 50	-j 49
BANDWIDTH bw	36.3	35.6	33.5

VERTICAL HEIGHT TO PULL OFF POINT TOP HAT - 914'
CENTER LINE TRUSS TO TOP HAT - 25'

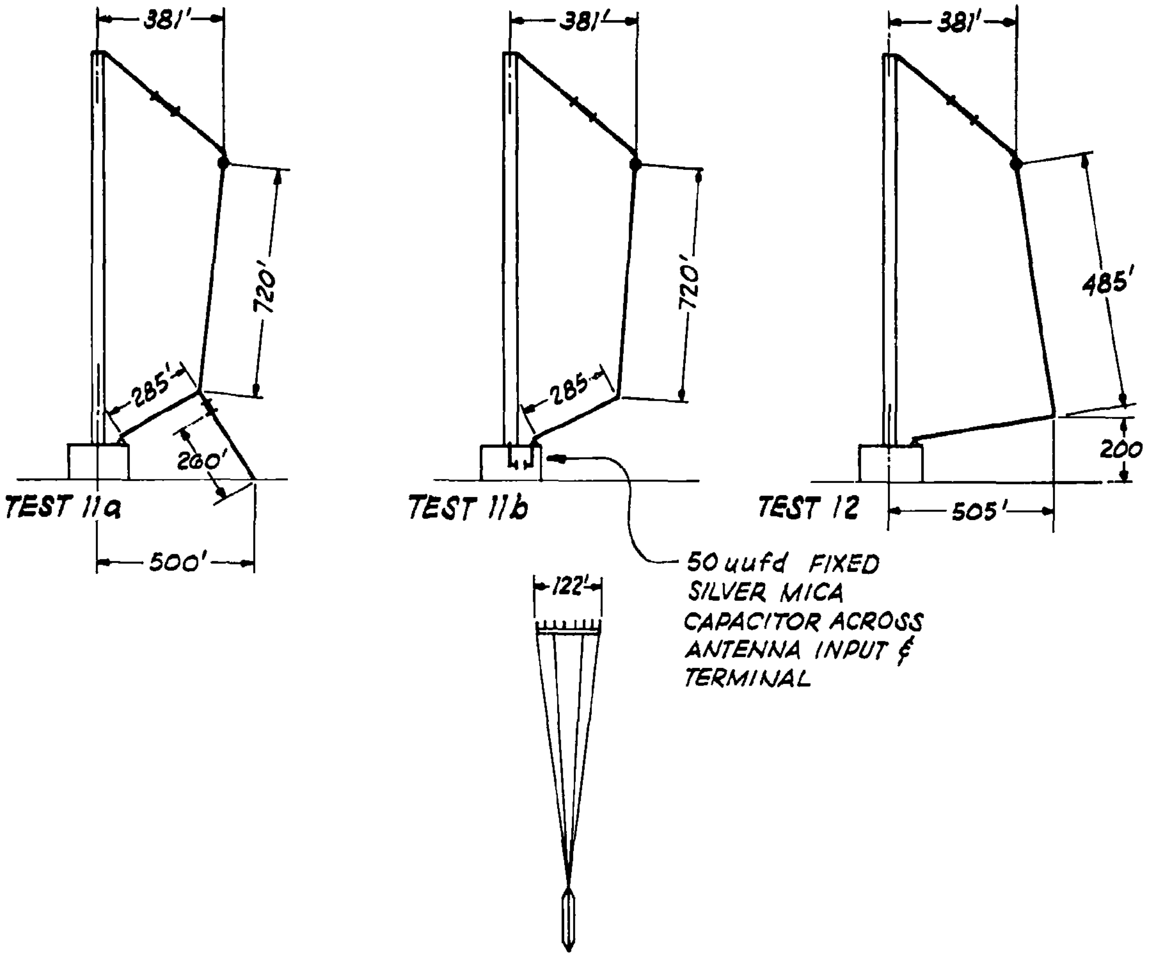
FIG. 5-2 RESONANT FREQUENCY TESTS CONFIGURATIONS 3, 4 AND 5



		TEST 6	TEST 7	TEST 8
EFFECTIVE HEIGHT	h_o	643'	628'	635'
STATIC CAPACITANCE	C_o	.1530	.1543	.1531
RESONANT FREQUENCY	f_o	35.10	34.98	34.47
BASE REACTANCE (15.5 kc)	X_b	-j 54.5	-j 49.7	-j 51.6
BANDWIDTH	bw	37.7	36.3	36.8

VERTICAL HEIGHT TO PULL OFF POINT TOP HAT - 914'
CENTER LINE TRUSS TO TOP HAT - 25'

FIG. 5-3 RESONANT FREQUENCY TESTS
CONFIGURATIONS 6, 7 AND 8



TESTS 11a, 11b, ¢ 12

	TEST 11a	TEST 11b	TEST 12
EFFECTIVE HEIGHT h_o	639'	635'	631'
STATIC CAPACITANCE C_o	.1505	.1554	.1521
RESONANT FREQUENCY f_o	32.87	32.87	33.05
BANDWIDTH bw	36.7	37.3	36.1

VERTICAL HEIGHT TO PULL OFF POINT TOP HAT - 934'
CENTER LINE TRUSS TO TOP HAT - 25'

FIG. 5-4 RESONANT FREQUENCY TESTS CONFIGURATIONS 11a, 11b AND 12

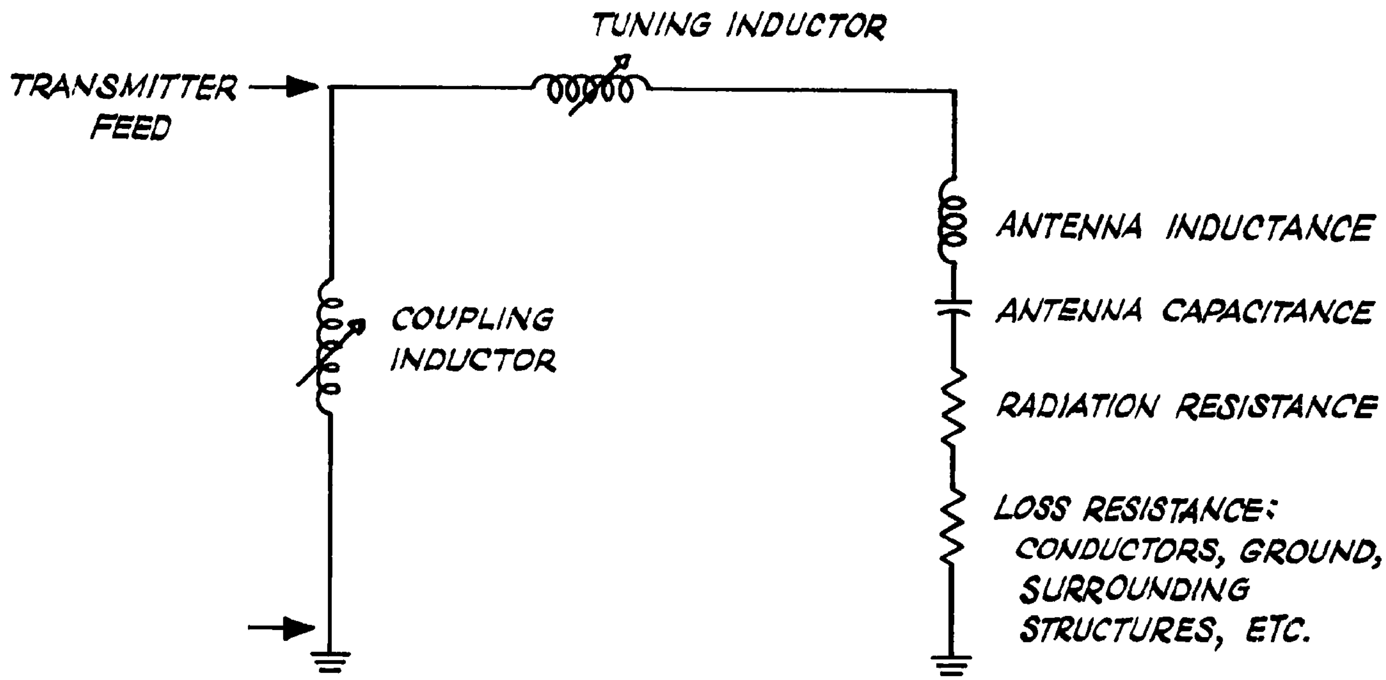


FIG. 5-5 SIMPLIFIED ANTENNA AND COUPLING CIRCUITRY

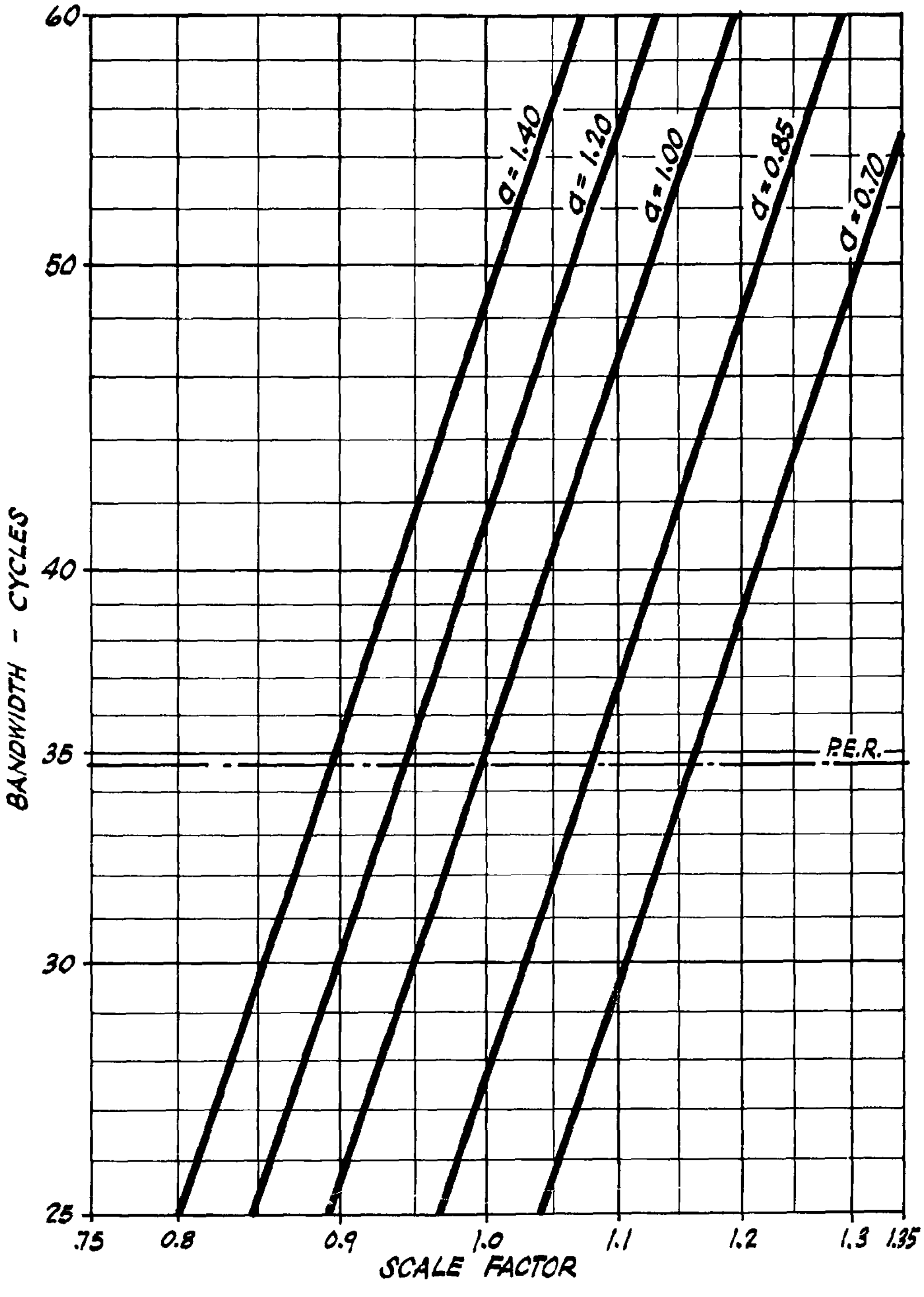


FIG. 5-6 BANDWIDTH AS A FUNCTION OF SCALE FACTOR

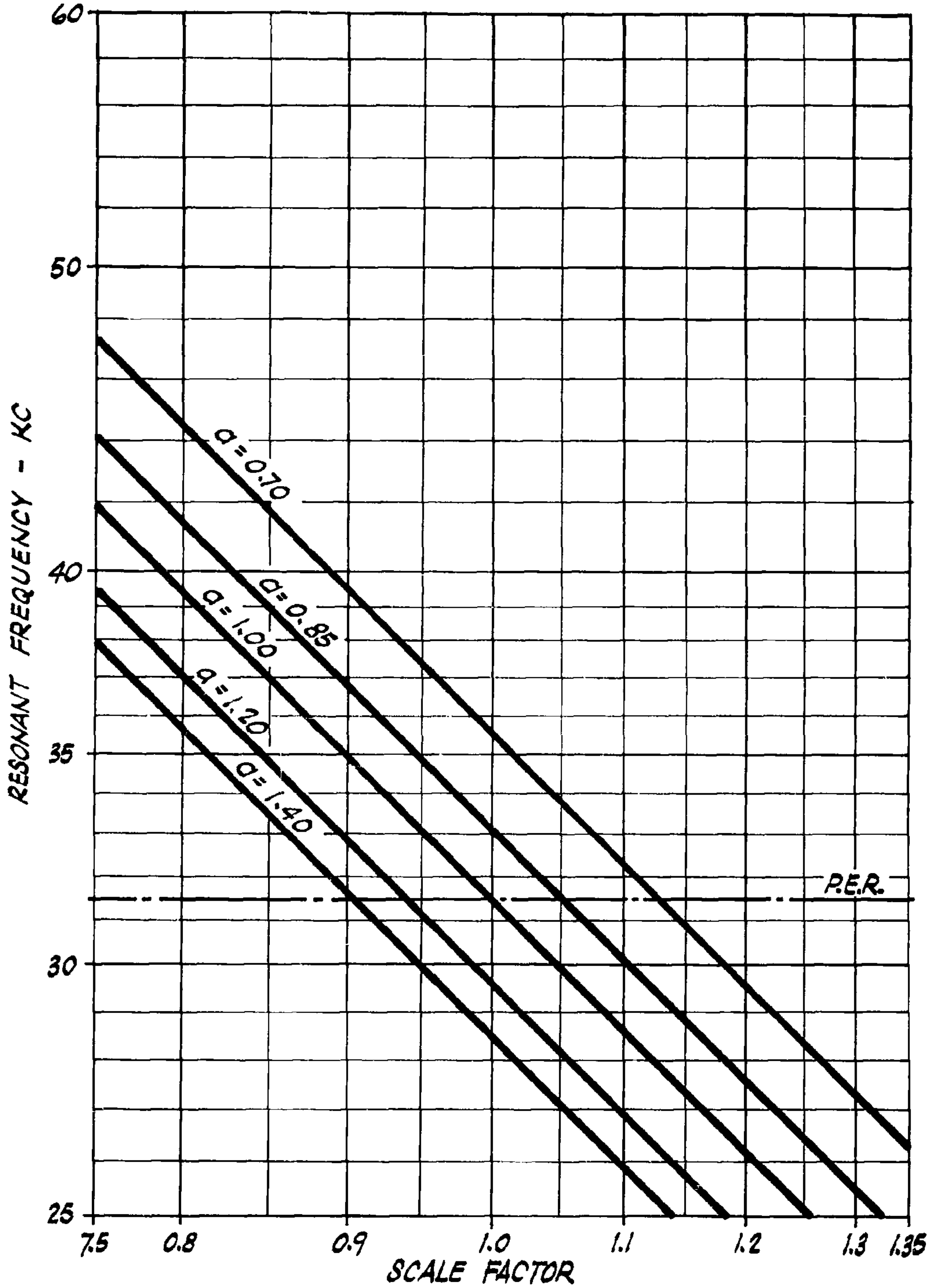


FIG. 5-7 RESONANT FREQUENCY AS A FUNCTION OF SCALE FACTOR

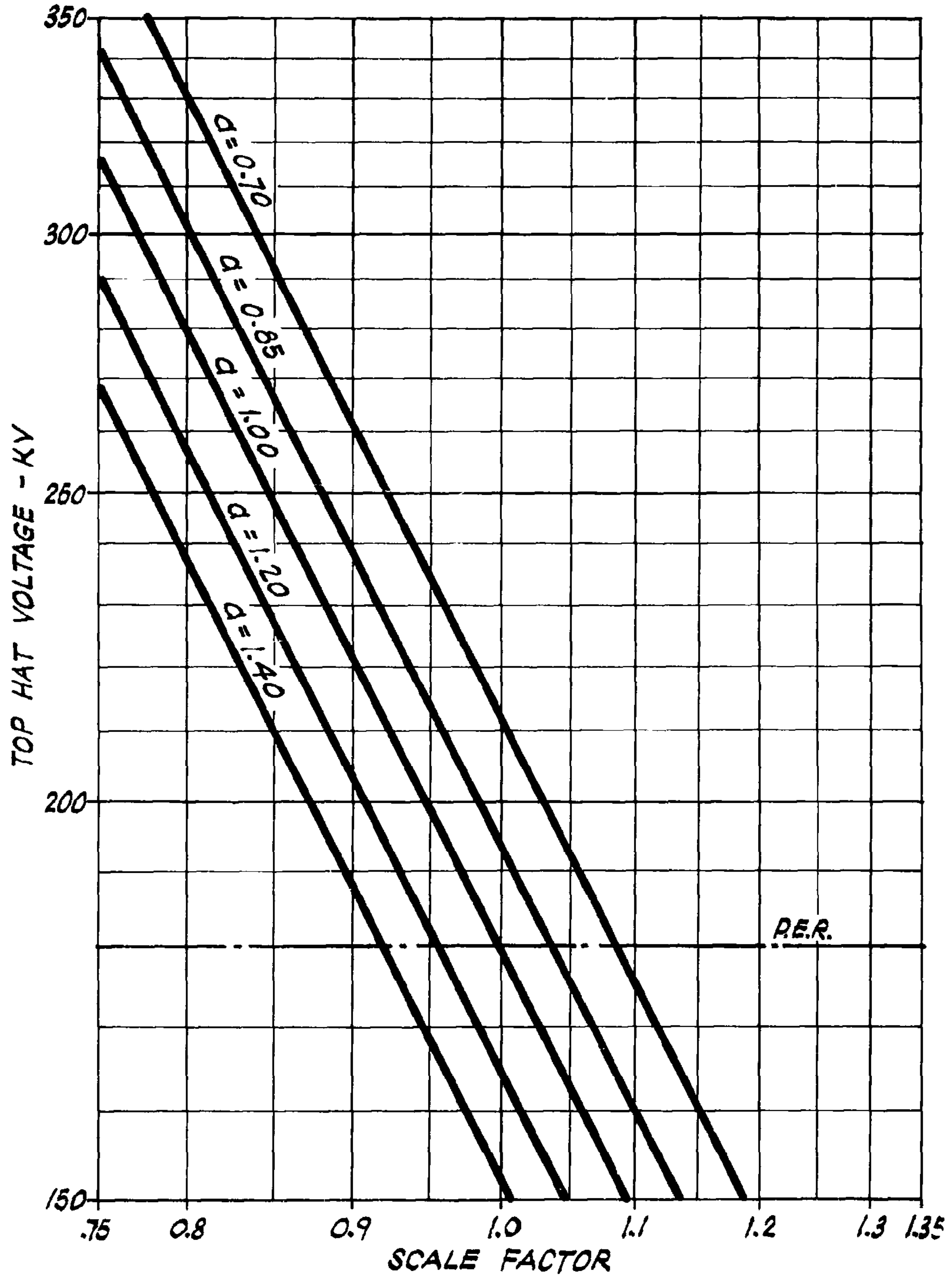


FIG. 5-8 TOP HAT VOLTAGE AS A FUNCTION OF SCALE FACTOR

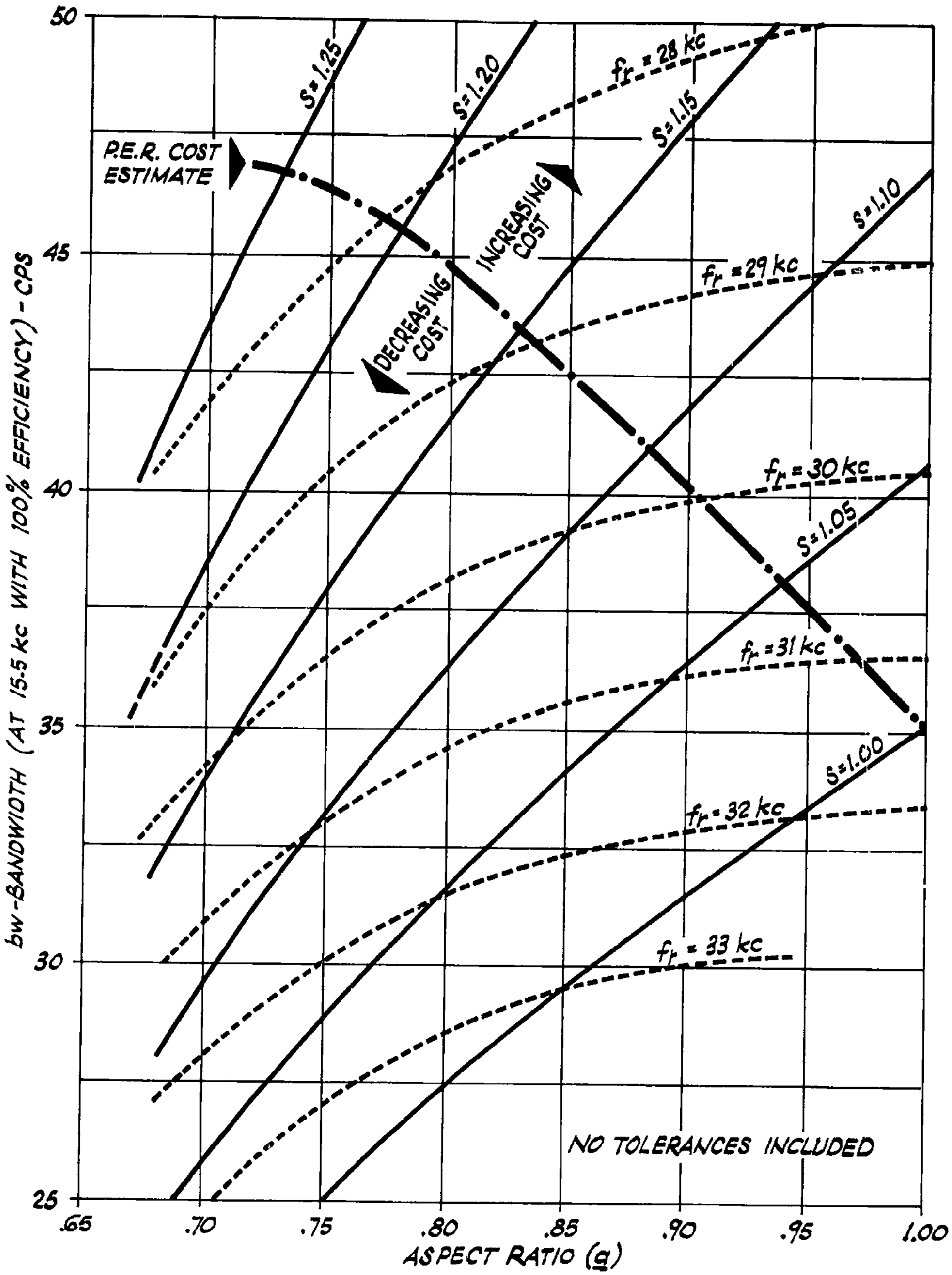


FIG. 5-9 PREDICTED PERFORMANCE OF SINGLE MODIFIED CUTLER ANTENNA FROM MODEL MEASUREMENTS, 4 - WIRE CAGE DOWNLEADS

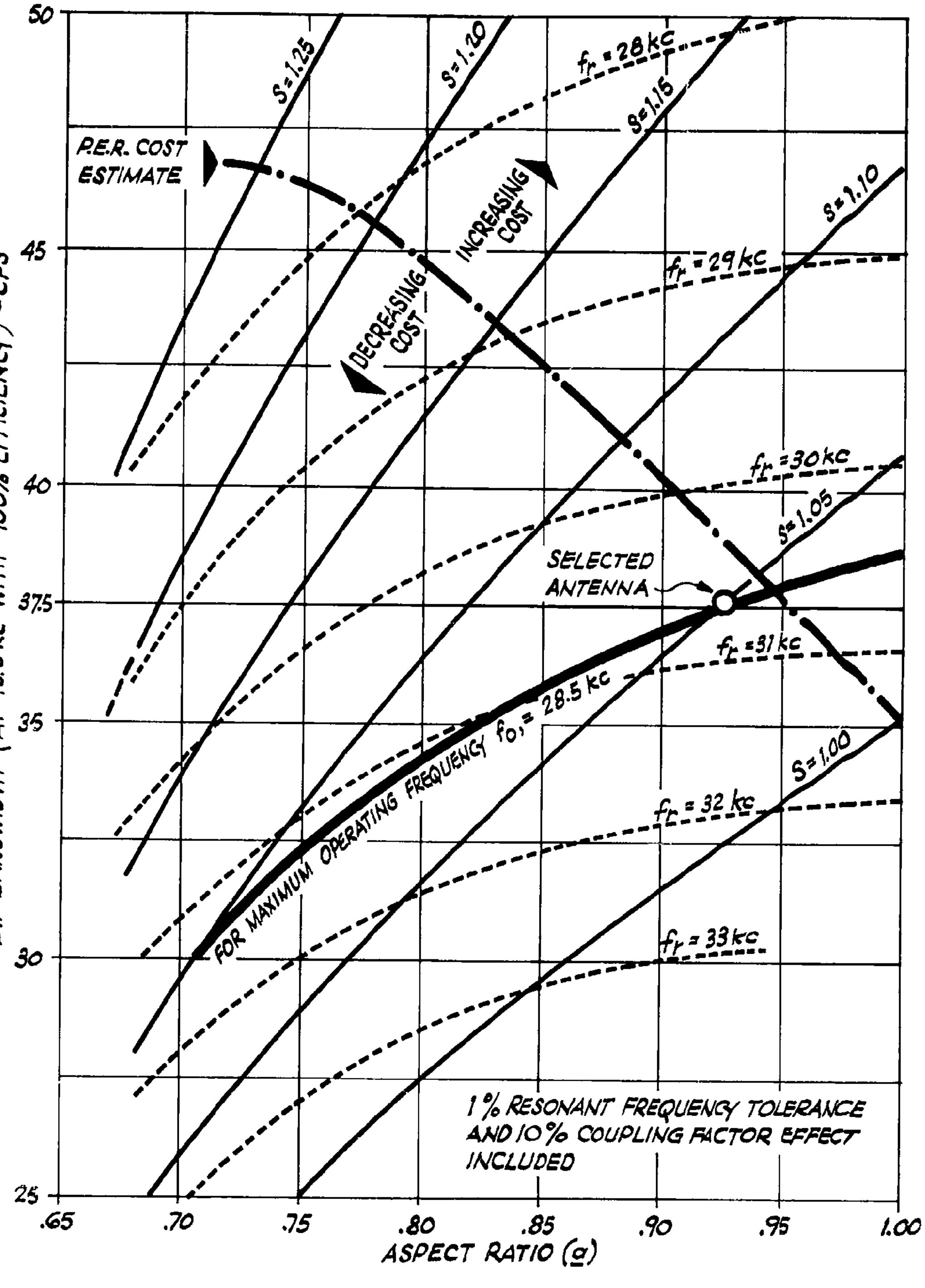


FIG. 5-10 PREDICTED PERFORMANCE OF SINGLE MODIFIED CUTLER ANTENNA FROM MODEL MEASUREMENTS, 8 - WIRE FAN DOWNLEADS

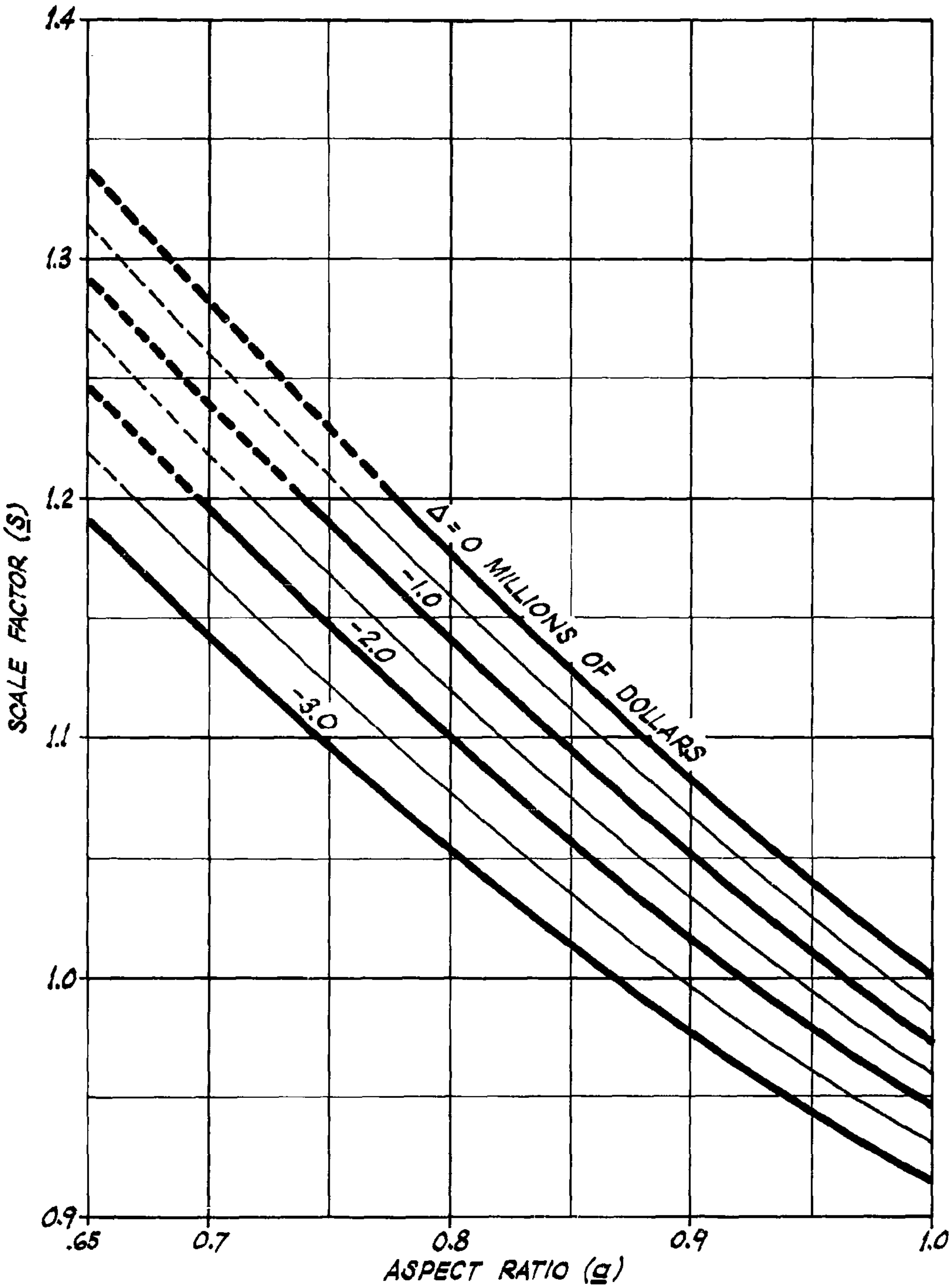


FIG. 5-11 ASPECT RATIO AND SCALE FACTOR COMBINATIONS FOR SPECIFIED ANTENNA COST DIFFERENCES

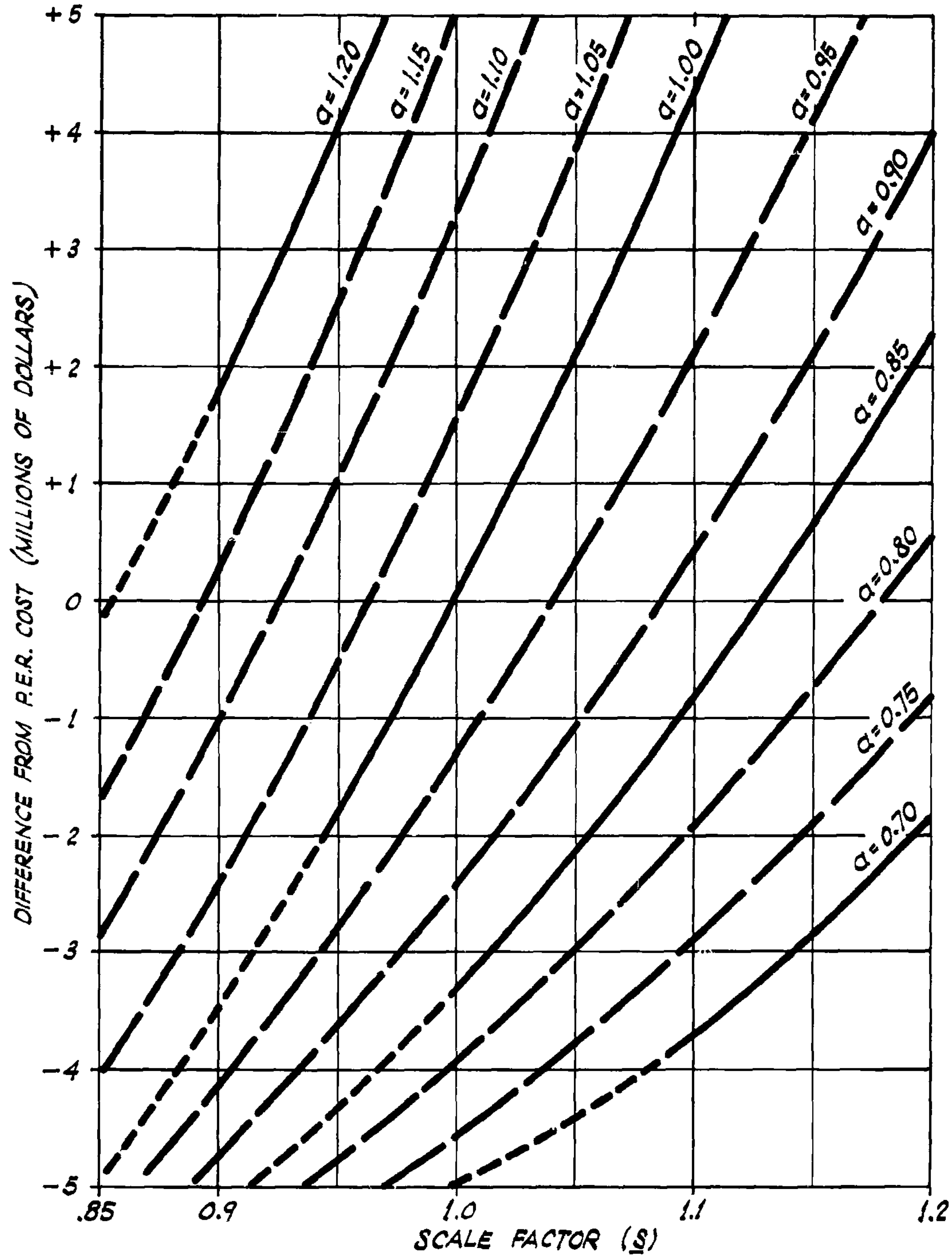


FIG. 5-12 ANTENNA COST DIFFERENCE AS A FUNCTION OF SCALE FACTOR

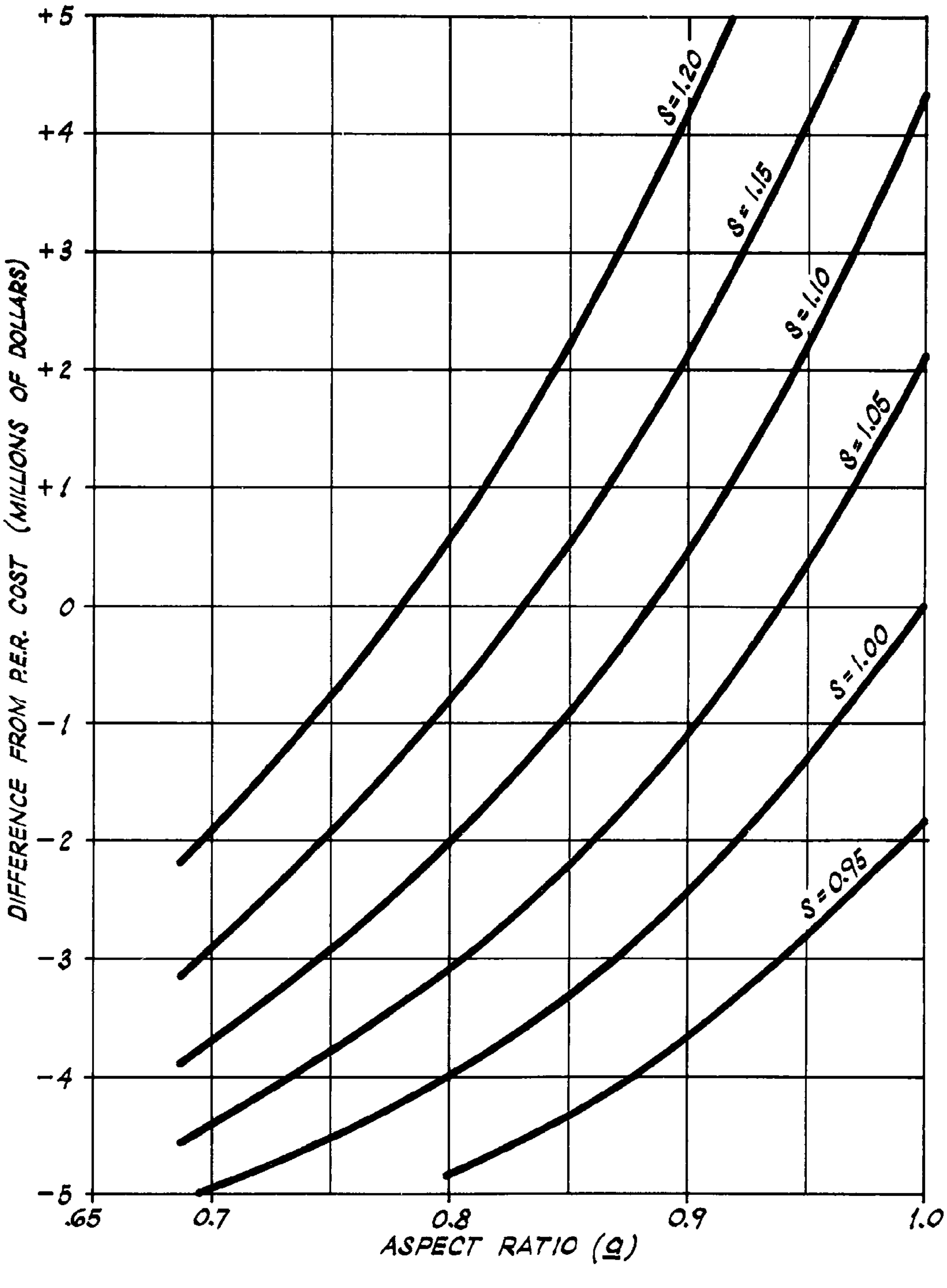


FIG. 5-13 ANTENNA COST DIFFERENCE AS A FUNCTION OF ASPECT RATIO

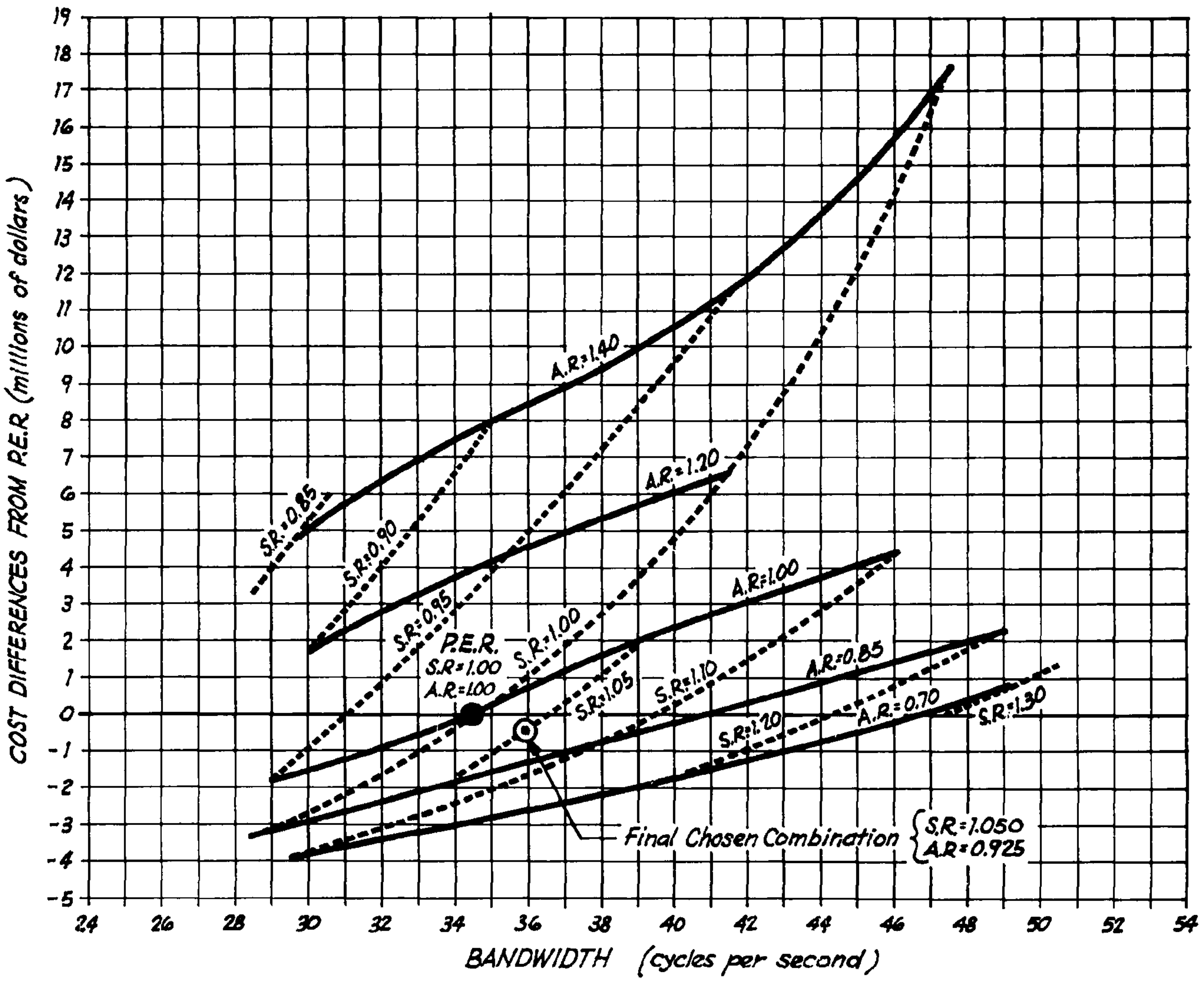


FIG. 5-14 COST DIFFERENCE AS A FUNCTION OF BANDWIDTH

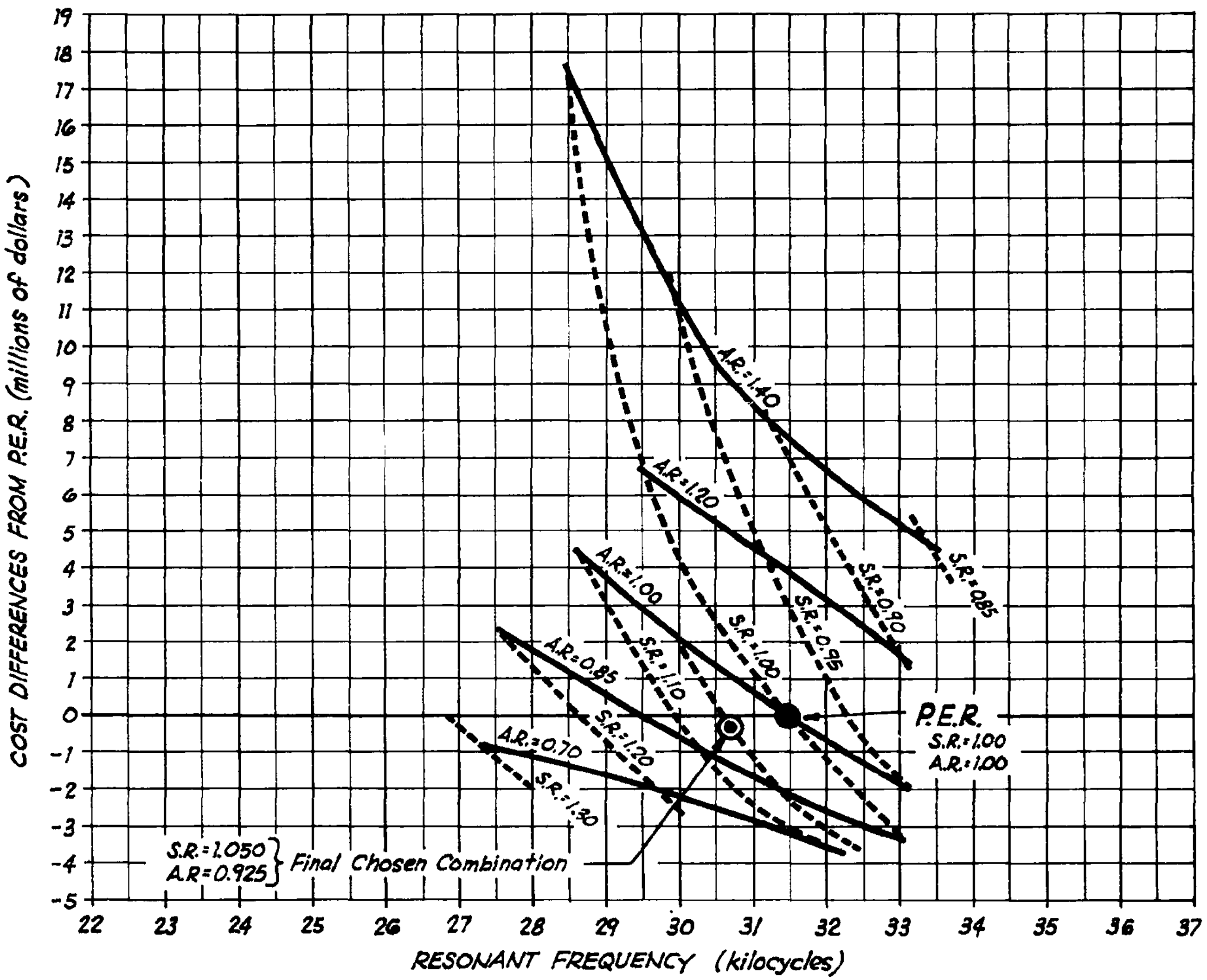


FIG. 5-15 COST DIFFERENCE AS A FUNCTION OF RESONANT FREQUENCY

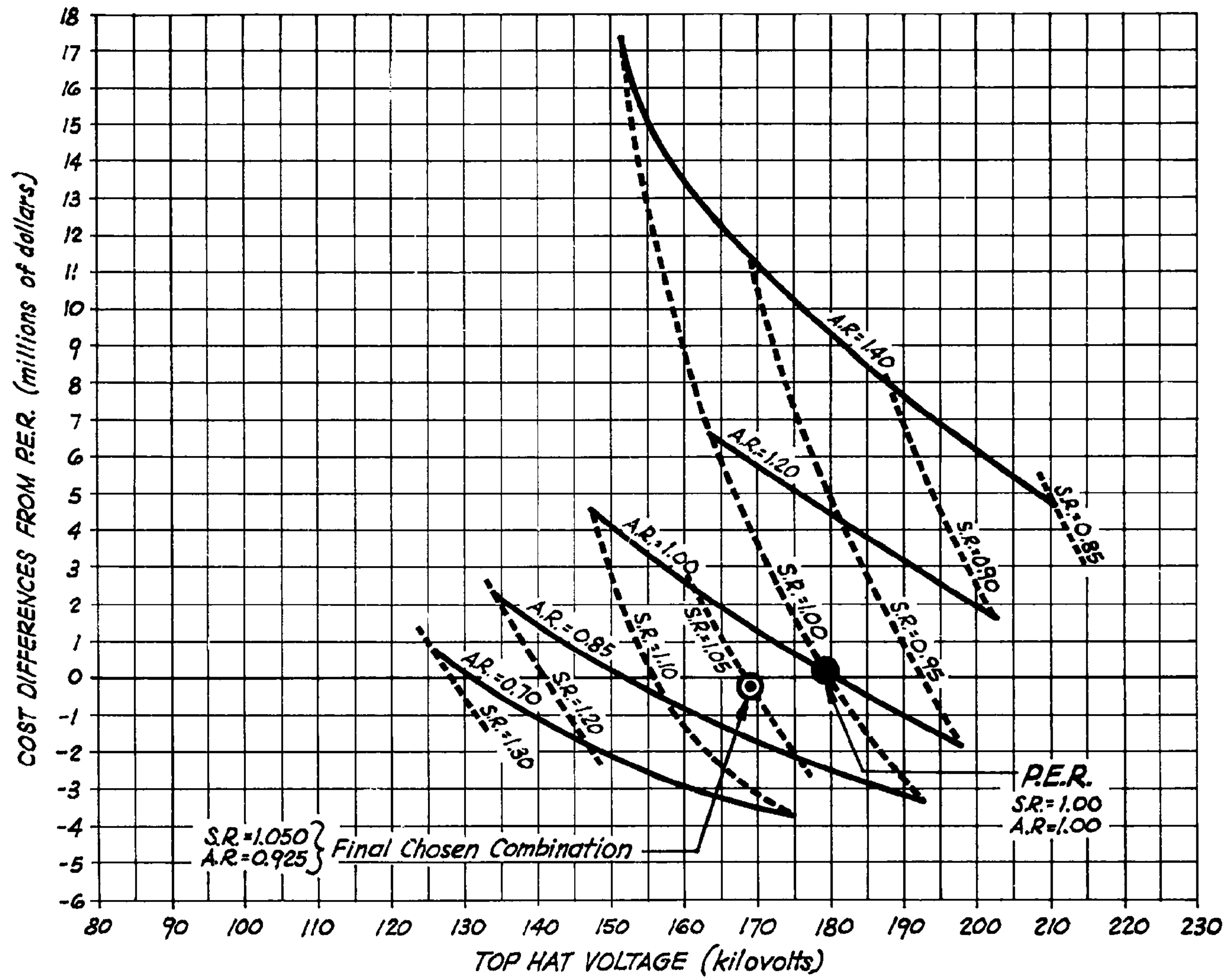


FIG. 5-16 COST DIFFERENCE AS A FUNCTION OF TOP HAT VOLTAGE

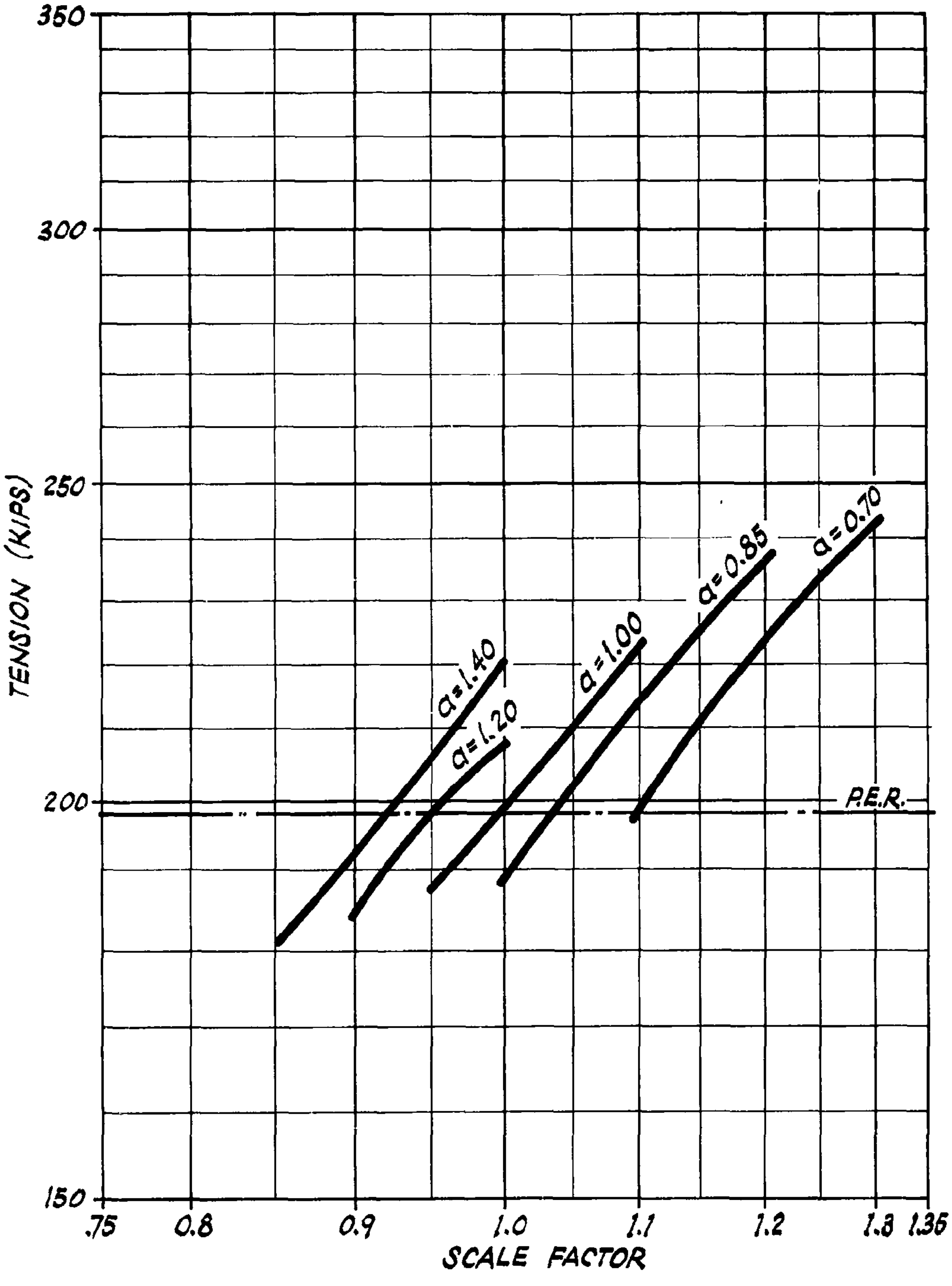


FIG. 5-17 INSULATOR TENSION AS A FUNCTION OF SCALE FACTOR

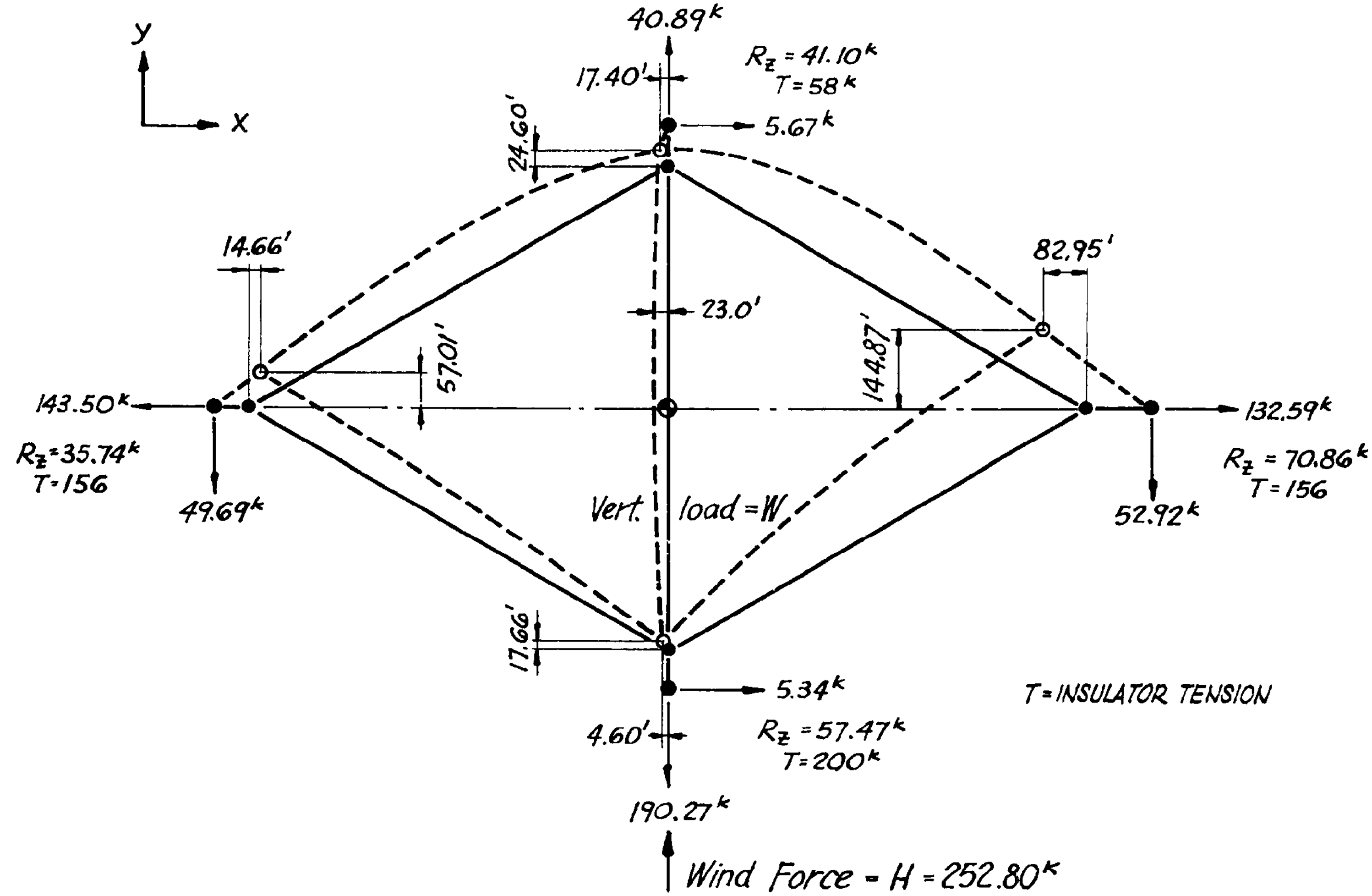


FIG. 5-18 TOP HAT LOADS AND DISPLACEMENTS
FIXED HALYARDS - SERVICE WIND

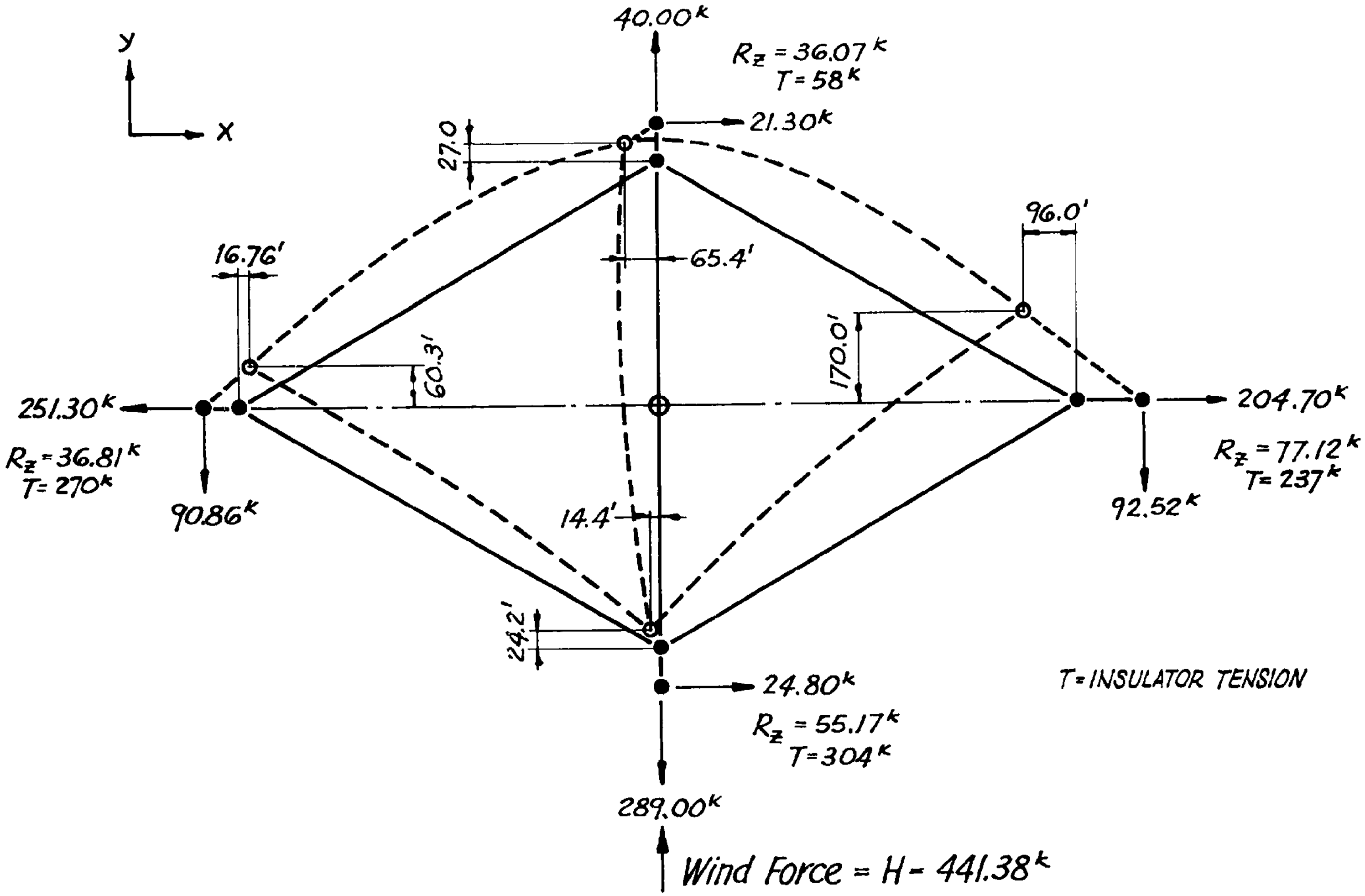


FIG. 5-19 TOP HAT LOADS AND DISPLACEMENTS
FIXED HALYARDS - OVERLOAD WIND

TABLE 5-1

SUMMARY - RESONANT FREQUENCY TEST DATA

MODEL DATA, ADJUSTED TO FULL SCALE

Test No.	Effective Height-Ft.	Capacitance fd	Resonant Freq. -kc	Bandwidth Cycles
1	638	.1498	31.50	36.4
2	640	.1487	30.75	36.3
3	638	.1499	32.05	36.3
4	627	.1519	32.30	35.6
5	600	.1561	32.18	33.5
6	643	.1530	35.10	37.7
7	628	.1543	34.98	36.3
8	635	.1531	34.47	36.8
9	642	.1497	31.68	36.8
10	635	.1514	33.27	36.3
11	634	.1506	32.87	36.1
11a	639	.1505	32.87	36.7
11b	635	.1554	32.87	37.3
12	631	.1521	33.05	36.1

TABLE 5-2

SUMMARY - CANTILEVER - COMPENSATION STUDIES

MODEL DATA, ADJUSTED TO FULL SCALE

		B-Tower Compensation		B-Tower Data	
Halyard	Canti-lever	Bandwidth	Eff. Ht.	Height	Top Guy
Vertical	10 ft.	45 ft.	45 ft.	1165 ft.	1155 ft.
	30	40	38	1160	1130
	56	30	25	1150	1094
Sloping	10 ft.	64 ft.	68 ft.	1188 ft.	1178 ft.
	30	59	62	1182	1152
	56	55	55	1175	1119

Note: Equivalence based on 35.4 cycles bandwidth, or 633 feet effective height. Compensations used in further analysis are those underlined.

TABLE 5-3 COMPARATIVE COSTS OF ANTENNA SYSTEMS

Halyard Type Cantilever length (ft)	(1) Sloping Ctrwtd. 57	(2) Sloping Ctrwtd. 30	(3) Sloping Ctrwtd. 10	(4) Vertical Ctrwtd. 57	(5) Vertical Ctrwtd. 30	(6) Vertical Ctrwtd. 10	(7) Sloping Fixed 57
A - Towers	4,104,800	3,910,300	4,007,100	4,449,800	4,311,100	4,087,200	4,190,800
B - Towers	5,184,200	4,949,800	5,072,300	5,632,600	5,457,100	5,173,700	5,304,800
C - Towers	1,716,900	1,633,400	1,673,900	1,858,800	1,800,800	1,707,300	1,750,600
Counterwt. Towers	1,762,200	1,762,200	1,762,200	1,510,200	1,510,200	1,510,200	0
Single Hoists & Housing	1,442,600	1,444,300	1,446,400	1,341,900	1,340,100	1,340,300	1,381,400
Double Hoists & Housing	419,700	419,700	419,700	419,700	419,700	419,700	419,700
Grounding and Roads	67,300	67,300	67,300	0	0	0	67,300
TOTALS	$14,697,700	$14,187,000	$14,448,900	$15,213,000	$14,839,000	$14,238,400	$13,114,600
Difference from PER	-	-510,700	-248,800	+515,300	+141,300	-459,300	-1,583,100
% Difference	-	-3.5	-1.7	+3.5	+1.0	-3.1	-10.8

TABLE 5-4

WIND SHEAR AND PULLOFF DISTRIBUTIONS

	Service Wind Counterweighted Halyard		Service Wind Fixed Halyard		Overload Wind Fixed Halyard	
	Relative Ry (1)	Relative H (2)	Relative Ry (3)	Relative H (4)	Relative Ry (5)	Relative H (6)
A	0.22	0.82	0.20	0.80	0.20	0.89
B (Windward)	0.31	1.00	0.44	1.00	0.49	1.00
B (Leeward)	0.23	0.21	0.15	0.22	0.09	0.15
C	0.24	0.85	0.21	0.75	0.21	0.75
	1.00		1.00		1.00	

Ry = Component of halyard tension in direction of wind.

H = Horizontal component of halyard tension.

6 OTHER ITEMS INCLUDED

6.1 Ground System Cost

One of the items entering into the overall cost of the radiation system is the cost of the ground system. This cost is expected to vary with both aspect ratio and scale factor. A very preliminary estimate of the variation with these two factors was made for inclusion in the overall cost data for a range of combinations of aspect ratio and scale factor. For a given scale factor, the cost of the ground system may be expected to decrease with increasing aspect ratio and a constant radiation system efficiency since an increasing aspect ratio results in a greater effective height and, consequently, higher radiation resistance. The resistance of the ground system, therefore, may increase without reducing the efficiency of the radiation system.

For a particular aspect ratio, the resistance of the ground system would tend to increase with scale factor for a given efficiency since the height, and consequently the radiation resistance, increases with scale factor, thus reducing the required wire density. This trend over-rides the requirement for increased radial length as a result of top hat size increasing with scale factor.

Based on some preliminary studies accomplished in the PER phase, it was found that the major cost of the ground system was related to the amount, and therefore the cost, of the No. 6 wire installed. Other elements of the cost tended to compensate as aspect ratio and scale factor were varied. Cost variations were, therefore, taken as proportional to the amount of No. 6 copper wire required and all were referenced to the estimated PER cost ($1,262,100) for the ground system (a - 1, s - 1). (See Table I of PER Supplement 1.) The curves derived from this very simple approach are shown in Fig. 6-1.

6.2 Main String Insulators

In arriving at costs for various combinations of aspect ratio and similitude factors, primary insulation is a significant consideration. Structural designs were aimed at maintaining a maximum insulator load of approximately 207,000 pounds, a value which has been achieved in existing insulator designs.

Since the maximum load was to be essentially the same for all variations of the antenna under study, cost differences would be a function of the number of units required to withstand a given top hat voltage. The results of tests by Lapp during the Cutler insulator development provide guidance on the variation in the number of insulators in a graded string as a function of voltage. Figure 6.2 illustrates this variation. This information, combined with the top hat voltage curves of Fig. 5.7 determined the number of insulators estimated for the various configurations studied.

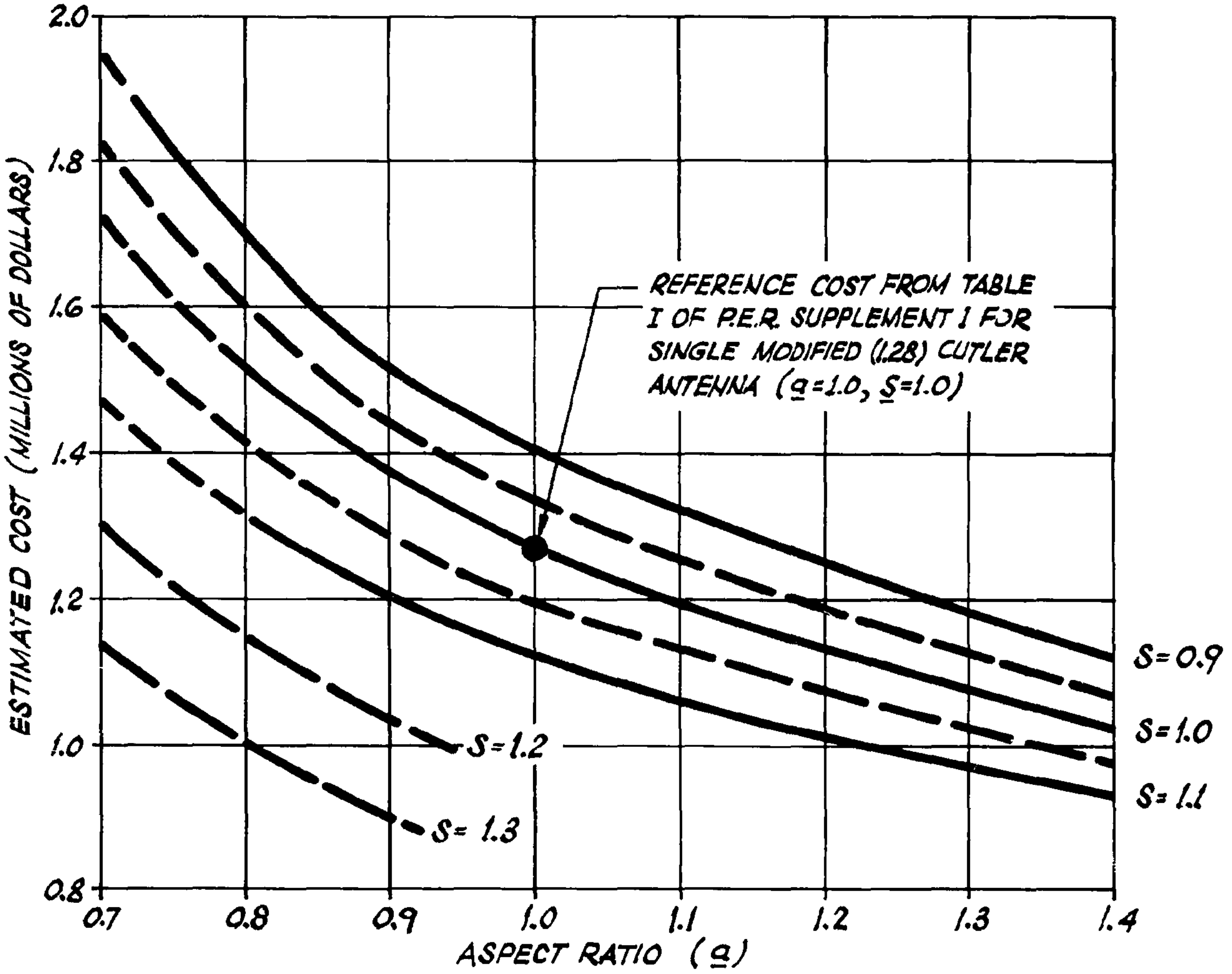


FIG. 6-1 ESTIMATED GROUND SYSTEM COST
AS A FUNCTION OF ASPECT RATIO AND SCALE FACTOR

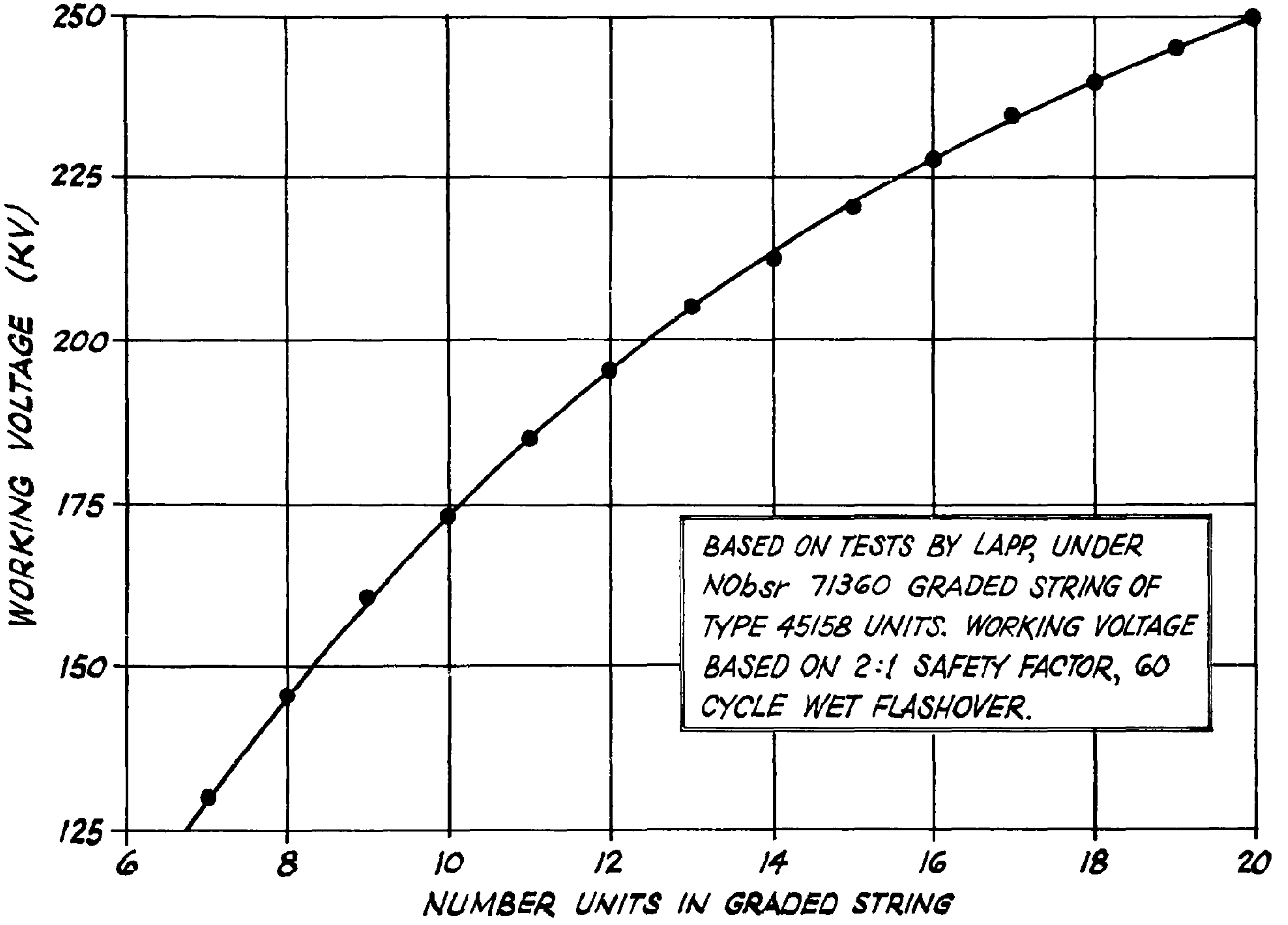


FIG. 6-2 MAIN STRING INSULATOR REQUIREMENTS

7. CONCLUSIONS AND RECOMMENDATIONS

In the development of the recommended VLF PAC antenna system on which to base the final design effort, a number of areas were investigated to assure that the selected configuration would have the greatest potential of meeting the following requirements:

a. Capability of radiating 1 megawatt at 15.5 kc.

b. Capability of operating down to 14 kc, but at reduced output if necessary.

c. Compatible with system operation up to at least 28.5 kc without the requirement for tuning capacitors.

d. An antenna bandwidth (at 100 percent efficiency) of at least 37.5 cycles at 15.5 kc.

e. An estimated cost not to exceed the estimated cost of the single modified (1.28) Cutler antenna.

Each area of investigation led to certain trends or conclusions which were integrated into the configuration recommended as the base for final detailed design development.

From the resonant frequency studies it was concluded that the resonant frequency is increased significantly by increasing the average diameter of the group of downleads, primarily by increasing the radius from the center tower to the attachment point at the top hat and to a lesser degree by increasing the radius from the center tower to the lower hinge point.

The resonant frequency is also increased by using a fan rather than a cage for the vertical portion of the downlead, with an 8-wire fan producing a greater degree of increase than a 4-wire fan.

Structural considerations required a compromise with regard to the downlead attachment position, limiting it to the same relative position as in the Cutler antenna. This corresponds to Test 10 of the resonant frequency series for the 1.28 model with unity aspect ratio. Subsequent to the letter of recommendation (Ref. 5) the configuration of Test 12, modified to an 8-wire fan, was recommended as a substitute to take advantage of structural gains without any significant change in electronic performance. This configuration was adopted in the final design.

Calculations of the effect of the antenna coupling circuitry indicated that the system operating frequency would be reduced by about 10 percent below the antenna resonant frequency. Thus, it was concluded that a 10 percent reduction factor would be used in establishing the required antenna resonant frequency. Since this reduction jeopardized the desired maximum operating frequency for practical antenna system configurations investigated, and in view of the opposing trends of bandwidth and antenna resonant frequency, the Navy was agreeable to accepting a maximum system operating frequency of 28.5 kc in lieu of the originally contemplated 30 kc.

The composite performance curves (Fig. 5-10) developed from the aspect ratio studies and similitude scaling defined a range of configurations permitting compliance with the required performance and cost limitations. This area is defined (Fig. 5-10) by the region above the 37.5 kc bandwidth line, below the PER cost estimate line and below the resonant frequency line "for maximum operating frequency f_o = 28.5 kc." Any point within this area meets performance and cost requirements, recognizing the estimated coupling circuitry factor and the antenna resonant frequency tolerance. With the concurrence of the Navy, however, no bandwidth tolerance was included.

On the basis of the conclusions above and within the permissible area outlined in Fig. 5-10, the selected antenna configuration is defined as one with an aspect ratio of 0.925 and a similitude scale factor of 1.05. These factors are, of course, applied to the basic configuration of a single section of the Cutler type antenna, scaled up by 28 percent from the Cutler size.

In addition to the basic size recommendation, and as a result of the halyard-cantilever-compensation studies, it was recommended that vertical halyards be used, in combination with a 10-foot cantilever projection. With this configuration the "B" series of towers would be increased about 45 feet in height to compensate for degradation of electronic characteristics.

As a result of further analysis, following the establishment of the aspect ratio of 0.925 and the similitude scale factor of 1.05, it was further recommended that counterweighting of top hat halyards be eliminated in favor of fixed halyards. Each fixed halyard should incorporate an overload feature permitting payout when the tension exceeds a predetermined value. The fixed halyard system requires a change in sag-span ratios and tower heights. Therefore, it was recommended that further electronic modeling be performed to insure compliance with Navy performance requirements.

APPENDIX A

EFFECT OF COUPLING CIRCUITRY ON OPERATING FREQUENCY

Sample Calculations

As an example, assume:

$\underline{a}$ = 0.925, $\underline{s}$ = 1.05

8-wire fan downleads

Gain over 4-wire cage downleads at $\underline{a}$ = 0.7 is one-half that at $\underline{a}$ = 1.0

No antenna parameter tolerances considered

Radiation system efficiency = 80%

Operating frequency = 28.5 kc.

For these assumptions, the basic antenna parameters are:

Radiation system resistance	0.663 ohms (at 28.5 kc)
Resonant frequency	32.2 kc
Static capacitance	0.1620 microfarads

Using these antenna parameters, the apparent inductance of the antenna system is 151.4 microhenries.

Assuming a transmitter output impedance of 12.5 ohms and the load resistance of 0.663 ohms, the required coupling impedance is:

$$X_m = \sqrt{R_g \times R_e} = \sqrt{12.5 \times 0.663} = 2.88 \text{ ohms}$$

Where R_g = source resistance

R_e = load resistance

Assuming an operating frequency of 28.5 kc the required coupling inductance is:

$$L_c = \frac{2.88}{2\pi \times 28.5 \times 10^3} = 16.1 \text{ microhenries}$$

In addition to the inductance required in the shunt coupling inductor, it is estimated that an equal inductance is reasonable for inclusion in the series variometer to provide for tuning adjustments under various environmental conditions (e.g., wind) and to provide some tuning tolerance to meet final radiation system parameters.

The total inductance in the system is then:

L_{ant}	=	151.4 Microhenries
L_{cpig}	=	16.1 Microhenries
L_{var}	=	16.1 Microhenries
		183.6 Microhenries

Using the antenna capacitance noted above, the operating frequency is:

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{183.6 \times 10^{-6} \times .1620 \times 10^{-}}}$$

$$f_o = 29.1 \text{ kc}$$

This represents a decrease from resonant frequency to operating frequency of 3.1 kc or 9.63 percent.

APPENDIX B

COMPOSITE PERFORMANCE CURVES AND TOLERANCES

The following are sample calculations showing derivations of the various limit curves for Figures 5-9 and 5-10 based on tolerances outlined in Paragraph 3.4.

Let f_x = Antenna system resonant frequency, with improvements from downlead changes (i.e., 8-wire fan downleads).

f_r = Antenna system resonant frequency from basic aspect ratio tests (i.e., 4-wire cage downleads).

f_o = System operating frequency (28.5 kc specified minimum upper limit).

Define coupling circuit factor, denoting the reduction from antenna resonant frequency due to the effects of the coupling circuitry, as:

$$k_c = \frac{f_c}{f_x}$$

Define downlead factor, denoting the gain in antenna system resonant frequency achieved by change of downleads (e.g., from 4-wire cage to 8-wire fan), as:

$$k_d = \frac{f_x}{f_r}$$

Then, for a measurement tolerance of zero:

$$f_o = k_c f_x$$

$$f_x = k_d f_r$$

Therefore,

$$f_o = k_c k_d f_r$$

or,

$$f_r = \frac{f_c}{k_c k_d}$$

This allows the base curves, Figure 5-9, showing bandwidth versus aspect ratio for various values of scale factor and superimposed by antenna resonant frequency to be used for determining performance characteristics, taking into account the effects of coupling circuitry and different downleads. For example, assume:

Operating frequency,	f_o	=	28.5 kc
Coupling circuit factor,	k_c	=	0.90
Downlead factor,	k_d	=	1.058

The downlead factor above is cited as an example of changing from the 4-wire cage downlead with a resonant frequency of 31.43 kc to the 8-wire fan with a downlead resonant frequency of 33.27 kc. The resonant frequency on the base curves, Figure 5-9, at $\underline{a} = 1$, to meet the 28.5 kc operating frequency is therefore:

$$f_r = \frac{f_o}{k_c k_c} = \frac{28.5}{0.90 \times 1.058} = 29.9 \text{ kc}$$

When data is subject to tolerances, these must also be taken into account in locating the equivalent points and curves on the base coordinate system. In deriving revised locations for Figure 5-10, it was assumed that each piece of resonant frequency data was correct to plus or minus 1 per cent, i.e.:

$$f'_x = f_x \pm 1\%$$

$$f'_r = f_r \pm 1\%$$

Under these conditions, and referenced to the base curves, using tolerances on the conservative side yields:

$$k'_d = \frac{f'_x}{f'_r} = \frac{f_x - 1\%}{f_r + 1\%} = \frac{.99f_x}{1.01f_r} = .98k_d$$

The 28.5 kc operating frequency limit may then be found at $\underline{a} = 1.0$ as follows, assuming a 10 per cent reduction in antenna system operating frequency due to coupling circuitry effect and a one per cent resonant frequency tolerance:

$$f'_r = \frac{f_o}{k_c k'_d} = \frac{28.5}{.90 \times .98 \times 1.058} = 30.5 \text{ kc}$$

Assuming, as above, an aspect ratio function for the fan the same as that for the cage, the 28.5 kc operating frequency limit line would follow the 30.5 kc resonant frequency line on the base coordinate system (or the 30.2 kc line for a 9 per cent coupling circuit effect).

If, however, it is assumed that the gain in resonant frequency of the 8-wire fan over the 4-wire cage decreases linearly to one-half as great at $\underline{a} = 0.7$ as at $\underline{a} = 1.0$, then the equivalent resonant frequency point for the 8-wire fan on the base coordinate of Figure 5-9 is found as follows:

At $\underline{a}$ = 0.7, k_d = 1.058/2 = 1.029

then k'_d = 0.98 k_d = 0.98 x 1.029

As before, k_c = 0.98

The equivalent resonant frequency, f'_r, at $\underline{a}$ = 0.7 is therefore:

$$f'_r = \frac{f_o}{k_c k'_d} = \frac{28.5}{.90 \times .98 \times 1.029} = 31.4 \text{ kc}$$

Points for other values of aspect ratio are found similarly, using a linear relationship for gain between 0.5 and 1.9 as $\underline{a}$ varies from 0.7 to 1.0.

APPENDIX C

COST ESTIMATES

Table C-1 summarizes the cost estimates and cost differences from the single modified Cutler antenna (Ref. 2) for each of the 18 combinations of aspect ratios and scale factors investigated as a part of this study.

The cost estimates summarized in Table C-1 represent only those parts of the facility whose costs vary with changes in tower heights and antenna spans. Other items whose costs are not significantly effected by the tower height-antenna span variations are not included.

The information shown in Table C-1 is depicted graphically in Figure C-1.

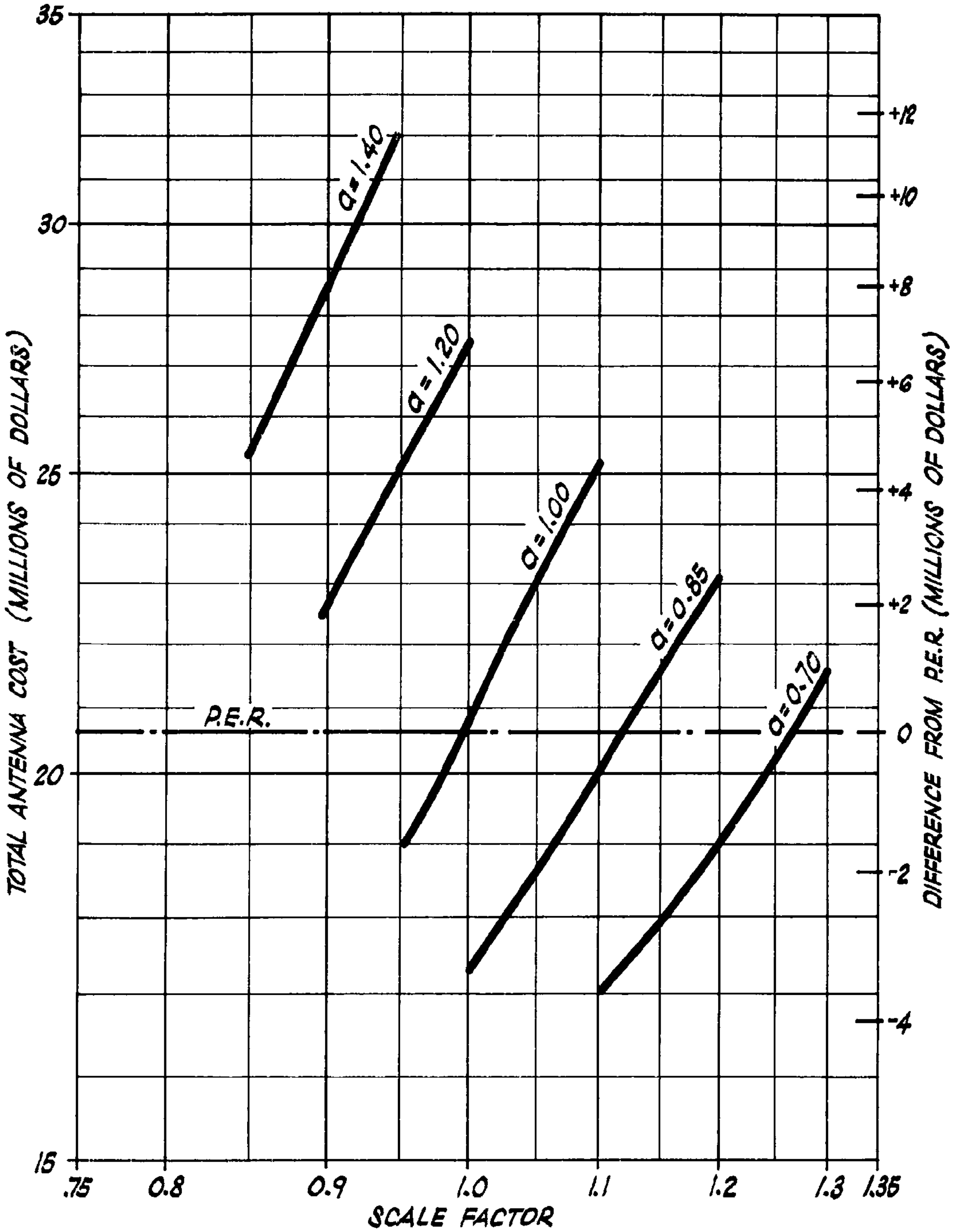


FIG. C-1 ANTENNA COST AS A FUNCTION OF SCALE FACTOR

TABLE C-1 SUMMARY OF ESTIMATED COSTS (1 of 4)

CASE DESCRIPTION	A.R. = 0.70 S.R. = 1.10	A.R. = 0.70 S.R. = 1.20	A.R. = 0.70 S.R. = 1.30	A.R. = 0.85 S.R. = 1.00	A.R. = 0.85 S.R. = 1.05
A - Towers	$ 2,589,200	$ 3,178,600	$ 4,066,800	$ 2,883,100	$ 3,213,500
B - Towers	3,277,500	4,023,500	5,147,800	3,649,500	4,067,700
C - Towers	1,081,600	1,327,800	1,689,800	1,204,300	1,342,300
Counterweight Towers	1,782,400	1,857,500	1,920,000	1,698,000	1,781,300
Downlead Ctrwt. Towers	135,000	135,000	135,000	135,000	135,000
Hoists & Housing - Single	1,297,300	1,352,900	1,406,000	1,298,500	1,361,600
Hoists & Housing - Double	384,900	403,600	425,000	384,000	401,700
Portable Hoist Units	224,000	224,000	224,000	224,000	224,000
Top Hat	2,008,500	2,011,100	1,994,400	1,993,200	1,989,100
Spare Guys	27,700	30,100	32,900	30,100	31,500
Struct. Bon. & Ground.	100,000	100,000	100,000	100,000	100,000
Ground System	1,470,000	1,300,000	1,130,000	1,440,000	1,340,000
Electrical Distribution	693,900	746,200	834,400	586,100	659,400
Communications	263,600	299,100	357,600	232,200	253,400
P.O.L.	41,800	38,700	30,000	49,600	44,400
Cooling System	275,100	277,400	281,900	275,100	275,100
Water Supply	160,800	173,800	187,600	146,900	155,600
Roads	623,800	647,600	688,600	593,300	621,000
Drainage	340,100	404,400	474,500	280,900	309,900
Fencing	75,600	79,200	82,200	73,400	74,500
Site Improvements	184,300	219,100	257,300	152,200	167,900
TOTAL COST	$ 17,037,100	$ 18,825,600	$ 21,466,200	$ 17,429,400	$ 18,548,900
COST DIFFERENCE FROM PER	-$ 3,702,100	-$ 1,909,600	+$ 727,000	-$ 3,309,800	-$ 2,190,300

TABLE C-1 SUMMARY OF ESTIMATED COSTS (2 of 4)

CASE DESCRIPTION	A.R. = 0.85 S.R. = 1.10	A.R. = 0.85 S.R. = 1.20	A.R. = 1.00 S.R. = 0.95	A.R. = 1.00 S.R. = 1.00	A.R. = 1.00 S.R. = 1.05
A - Towers	$ 3,746,300	$ 4,755,400	$ 3,461,600	$ 4,104,800	$ 4,781,500
B - Towers	4,742,200	6,019,500	4,381,800	5,184,600	6,052,500
C - Towers	1,564,900	1,986,400	1,446,000	1,716,900	1,997,300
Counterweight Towers	1,802,800	1,873,100	1,678,900	1,762,200	1,791,400
Downlead Ctrwt. Towers	135,000	135,000	135,000	135,000	135,000
Hoists & Housing - Single	1,405,100	1,502,600	1,364,300	1,442,600	1,733,500
Hoists & Housing - Double	413,700	439,000	398,600	419,700	434,200
Portable Hoist Units	224,000	224,000	224,000	224,000	224,000
Top Hat	1,942,000	1,986,700	2,017,800	1,962,600	1,973,000
Spare Guys	32,900	36,000	32,900	35,000	36,700
Struct. Bond. & Ground.	100,000	100,000	100,000	100,000	100,000
Ground System	1,250,000	1,080,000	1,340,000	1,262,100	1,200,000
Electrical Distribution	693,900	746,200	563,200	586,100	659,400
Communications	263,600	299,100	244,700	232,200	253,400
P.O.L.	41,800	38,700	53,700	49,600	44,400
Cooling System	275,100	277,400	275,900	275,100	275,100
Water Supply	160,800	173,800	140,000	146,900	155,600
Roads	623,800	647,600	580,700	593,300	621,000
Drainage	340,100	404,400	253,800	280,900	309,900
Fencing	75,600	79,200	72,400	73,400	74,500
Site Improvements	184,300	219,100	137,500	152,200	167,900
TOTAL COST	$ 20,017,900	$ 23,023,200	$ 18,902,800	$ 20,739,200	$ 23,020,300
COST DIFFERENCE FROM PER	-$ 721,300	+$ 2,284,000	+$ 1,836,400	$ None	+$ 2,281,100

TABLE C-1 SUMMARY OF ESTIMATED COSTS (3 of 4)

CASE DESCRIPTION	A.R. = 1.00 S.R. = 1.10	A.R. = 1.20 S.R. = 0.90	A.R. = 1.20 S.R. = 0.95	A.R. = 1.20 S.R. = 1.00	A.R. = 1.40 S.R. = 0.85
A - Towers	$ 5,580,100	$ 4,818,400	$ 5,701,200	$ 6,479,800	$ 5,911,700
B - Towers	7,063,400	6,099,300	7,216,700	8,202,200	7,483,200
C - Towers	2,330,900	2,012,800	2,381,500	2,706,700	2,469,400
Counterweight Towers	1,833,600	1,668,700	1,752,000	1,781,300	1,687,900
Downlead Ctrwt. Towers	135,000	135,000	135,000	135,000	135,000
Hoists & Housing - Single	1,595,100	1,490,300	1,651,200	1,708,700	1,561,300
Hoists & Housing - Double	447,200	421,900	445,400	463,700	436,500
Portable Hoist Units	224,000	224,000	224,000	224,000	224,000
Top Hat	1,966,800	1,998,000	1,941,400	1,925,200	2,017,100
Spare Guys	38,100	37,500	39,200	41,300	40,600
Struct. Bond. & Ground.	100,000	100,000	100,000	100,000	100,000
Ground System	1,120,000	1,260,000	1,190,000	1,140,000	1,170,000
Electrical Distribution	693,900	559,200	563,200	586,100	543,000
Communications	263,600	193,000	244,700	232,200	198,500
P.O.L.	41,800	58,400	53,700	49,600	62,500
Cooling System	275,100	288,600	275,900	275,100	277,900
Water Supply	160,800	133,100	140,000	146,900	126,200
Roads	623,800	564,700	580,700	593,300	552,300
Drainage	340,100	227,500	253,800	280,900	203,100
Fencing	75,600	71,400	72,400	73,400	68,500
Site Improvements	184,300	123,300	137,500	152,200	110,100
TOTAL COST	$ 25,093,200	$ 22,485,100	$ 25,099,500	$ 27,297,600	$ 25,468,800
COST DIFFERENCE FROM PER	+$ 4,354,000	+$ 1,745,900	+$ 4,360,300	+$ 6,558,400	+$ 4,639,600

TABLE C-1 SUMMARY OF ESTIMATED COSTS (4 of 4)

CASE / DESCRIPTION	A.R. = 1.40 S.R. = 0.90	A.R. = 1.40 S.R. = 0.95	A.R. = 1.40 S.R. = 1.00
A - Towers	$ 7,087,300	$ 8,286,100	$ 10,487,300
B - Towers	8,971,300	10,488,700	13,275,100
C - Towers	2,960,500	3,461,300	4,380,800
Counterweight Towers	1,678,900	1,762,200	1,791,400
Downlead Ctrwt. Towers	135,000	135,000	135,000
Hoists & Housing - Single	1,739,600	1,888,900	1,956,500
Hoists & Housing - Double	448,900	486,700	502,600
Portable Hoist Units	224,000	224,000	224,000
Top Hat	1,956,400	1,909,900	1,908,000
Spare Guys	42,700	45,100	47,600
Struct. Bond. & Ground.	100,000	100,000	100,000
Ground System	1,120,000	1,070,000	1,020,000
Electrical Distribution	559,200	563,200	586,100
Communications	193,000	244,700	232,200
P.O.L.	58,400	53,700	49,600
Cooling System	288,600	275,900	275,100
Water Supply	133,100	140,000	146,900
Roads	564,700	580,700	593,300
Drainage	227,500	253,800	280,900
Fencing	71,400	72,400	73,400
Site Improvements	123,300	137,500	152,200
TOTAL COST	$ 28,683,800	$ 32,179,800	$ 38,218,000
COST DIFFERENCE FROM PER	+$ 7,944,600	+$ 11,440,600	+$ 17,478,800

REFERENCES

1. Feasibility Study and Preliminary Engineering Report, VLF Communication Facilities, Pacific - Contract No. NBy-37598. May 1961 by Joint Venture, Developmental Engineering Corporation, and Holmes & Narver, Inc., Engineers.

2. Feasibility Study and Preliminary Engineering Report, VLF Communication Facilities, Pacific - Supplement 1 Single Modified Cutler Antenna and VLF Antenna Comparisons, Contract No. NBy-37598. July 1961 by Joint Venture, Deco Electronics, Inc., and Holmes & Narver, Inc., Engineers.

3. Feasibility Study and Preliminary Engineering Report, VLF Communication Facilities, Pacific - Single Modified Cutler Antenna Model Study Data, Contract No. NBy-37598, Change Order F, 22 November 1961 by Joint Venture, Deco Electronics, Inc., and Holmes & Narver, Inc., Engineers.

4. Feasibility Study and Preliminary Engineering Report, VLF Communication Facilities, Pacific - Single Modified Cutler Antenna Aspect Ratio Study, Contract No. NBy-37598, Change Order F, 6 December 1961 by Joint Venture, Deco Electronics, Inc., and Holmes & Narver, Inc., Engineers.

5. Letter, dated 7 February 1962, HNCD to Officer-in-Charge, re VLF Pacific Antenna Selection.

6. Letter, dated 20 February 1962, Serial 238, Officer-in-Charge to HNCD re Contract NBy-37636, Final Plans and Specifications for VLF Pacific; VLF Antenna Final Design.

7. Model Studies of the VLF PAC Antenna - U.S. Navy VLF-COMMFAC-PAC, Contract NBy-37636, 12 April 1963 by HNCD, A Joint Venture, Los Angeles, California, Holmes & Narver, Inc., Continental Electronics Manufacturing Company, Deco Electronics, Inc.

8. Memorandum from E.G. Odley to ROICC VLF Pacific, 11 December 1961. Subject: VLF Communication Facility, Pacific; Feasibility Study Concerning Elimination of Counterweight System.