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NRL Memorandum Report 522

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VLF SIGNAL RECEPTION CAPABILITY OF THREE EXPERIMENTAL CROSSED-LOOP ANTENNAS

S. V. Fratianni

RADIO DIVISION

19 September 1955

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NAVAL RESEARCH LABORATORY
Washington, D.C.

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NRL MEMORANDUM REPORT
NO. 522

VLF SIGNAL RECEPTION CAPABILITY OF THREE EXPERIMENTAL CROSSED-LOOP ANTENNAS

by

S. V. Fratianni

19 September 1955

Radio Division
Radio Techniques Branch

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ABSTRACT

Laboratory studies were made to determine the very low frequency (VLF) signal pickup efficiency in air of three experimental iron-cored crossed-loop antennas submitted by W. J. Polydoroff to the Bureau of Ships. Submarines generally require that auxiliary equipment be made physically small for the conservation of space, reduction of external drag and weight, and facilitation of installation. This, and the additional fact that radio frequency (r-f) signals are so seriously affected by the attenuation of sea water require that every effort be made in loop design to improve loop pick-up efficiency with the imposed volume limitations. The antennas were compared to each other and to the Model AT-317 submarine antenna, which is the current type employed for submerged VLF reception. The three experimental antennas, which were not alike in design, provided somewhat greater signal pickup than the AT-317 antenna in all cases. However, the small improvement in each case appeared to be due to a larger loop-winding area and length of iron core relative to the AT-317 structure. Incorporation of such designs in proper form for underwater use would result in larger and heavier antennas than the AT-317, thus offering no advantage over a larger-size version of the AT-317.

Studies of one of these loop antennas fitted with a Faraday shield indicated that the interference effects of undesired radio signals were not changed by the presence of the shield.

PROBLEM STATUS

This is an interim report; work on other phases of the problem is continuing.

AUTHORIZATION

NRL Problem No. 54R01-09
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INTRODUCTION

The Bureau of Ships and Naval Research Laboratory are vitally interested in improving, if possible, the pickup efficiency of loop antennas employed for the submerged reception of VLF radio signals. In order to achieve greater loop antenna pickup efficiency at no increase in physical size, and possibly weight, as compared to the Model AT-317 antenna (the latest type of crossed-loop antenna presently employed on submarines), it was felt that new fabrication techniques and core materials might have to be devised and employed, respectively. The new core materials currently available provide greater permeability, and with some core rearrangement and consequently new core shape factors it should be possible to achieve greater field flux distortion in the vicinity of the loop antenna windings. Also, individual changes in the winding area should result in an internal structure more amenable to the desired overall tear-drop shape of the antenna. It is necessary that the increased pickup be achieved without affecting, to any great extent, the loop-antenna Q values when submerged in sea water.

The Bureau of Ships contracted with Mr. W. J. Polydoroff and Associates to provide the U. S. Navy with three crossed-loop antenna structures based on the above requirements. The major requirements of the contract stipulated, (1) a desired design objective of at least two-to-one greater signal pickup in each loop winding relative to the windings of the Model AT-317 loop antenna, (2) the inductance of each loop winding to be equivalent to that of the AT-317 antenna so that these experimental antennas could be employed with the Model CU-352(XN-1) BRR antenna coupler, (3) the overall volume dimensions of these antennas are not to exceed those of the AT-317 antenna, (4) to supply two crossed-loop antennas which provide equal signal pickup between each pair of crossed windings and are similar in all major physical respects except for one antenna being shielded for purposes of making comparison noise studies, and (5) to design a third, unshielded crossed-loop antenna which provides the maximum signal pickup possible from each winding regardless of inequality of loop terminal voltages. This latter requirement permits large departures from a circular antenna response pattern when the antenna is employed with associated circuitry suitable for omnidirectional loop reception. It was not required that the three experimental antennas be insulated from the sea water for laboratory tests.

The three different models of crossed-loop, iron-cored antennas resulting from the above contract were examined and evaluated at NRL to determine their individual superiority, if any, relative to each other and to the Model AT-317 loop antenna. This program was undertaken at the request of the Bureau of Ships [1,2]. An additional study of the influence of a Faraday shield placed around one of the experimental loop antennas was undertaken to determine possible system sensitivity improvements by attenuation of undesired noise and/or other interfering signals.

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[1] BUSHIPS ltr S67/9-12(838) Ser 838-168 of 6 Aug 1954 to Director, NRL

[2] NRL ltr 4010-170/54 sce (102860) of 17 Sept 1954 to Chief, Bureau of Ships

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EXPERIMENTAL LOOP ANTENNA FUNCTIONS AND COMPONENT PARTS

The subject experimental iron-cored loop antennas were designed with the specific objective of serving as prototypes for replacement of the Model AT-317 loop antenna, if study and evaluation of their electrical and mechanical characteristics indicated them to be superior. The subject antennas incorporate two loop windings at right angle to each other in azimuth with an inductance of approximately 500 microhenries in each separate winding. The "in air" Q's of the new antennas were designed to be equal to or better than those for the Model AT-317 antenna. As in the case of the Model AT-317 antenna coupler system, circular antenna response patterns (omnidirectional antenna responses) are obtained when the terminal voltages of the two 90 degrees physically orientated loop windings are equal and are electrically phased 90 degrees from each other before summation. Departure from a circular antenna response pattern will occur if (1) the pickup capabilities of the loop windings are unequal due to unequal winding areas, or if the core effectiveness varies as a result of differences in core shapes and amounts of iron for each separate winding of the antenna structure, (2) the input circuit Q's are unequal due to either unequal loop winding Q's or other unbalanced input circuit components in the omnidirectional coupler, (3) there is an improper degree of coupling between the respective input circuits, and (4) there is misalignment between the resonant input loop winding circuits. A circular antenna response pattern might be maintained if any one of the above named elements is improperly adjusted, but compensated by manipulation of one or more of the other elements. In this case, however, the system sensitivity will suffer to an extent increasing with greater values of compensation.

PHYSICAL DESCRIPTION OF THE EXPERIMENTAL LOOP ANTENNAS

The three experimental loop antennas are identified by the numbers 1, 2 and 3 in Figures 1, 2 and 3, respectively. Although the antennas were received at NRL without metal base pedestals, each is shown mounted to a pedestal, of the type with which they were designed to be used. (The close proximity of the pedestal to the loop antenna windings will affect the measurements to some extent in each case.) As shown, the antennas were received without the external covering of polyethylene and neoprene which serves in the Model AT-317 antenna to insulate and separate the loop windings from the sea water and gives the antennas its "teardrop" shape. When, and if, this insulation is molded around the subject experimental antennas, they should physically resemble the Model AT-317 loop antenna shown in Figure 4. 40/30 "Litz" wire is used in all three experimental antenna windings, and the windings were adjusted to provide a nominal inductance value of approximately 500 microhenries in each case.

Antenna No. 1 of Figure 1 consists of two closely wound (small lateral spacing between turns) windings which are physically oriented 90 degrees to each other on a rectangular ferrite core. The core consists of individual rectangular plates (approximately 13/16 inches thick), comprised

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of Stackpole's Ceramag 5n (permeability equal to 475), which are attached to an inner solid, rectangularly shaped Bakelite bar with nickel-plated screws. The completed assembly forms a rectangular core with approximate dimensions of 13" x 5-5/8" x 4". As shown in Figure 1, the core with its crossed loop windings is supported by four screws on each end which pass through specially shaped phenolic-impregnated cloth end-pieces. The two end-pieces are attached, in turn, to an oval-shaped base of the same material containing nickel-plated metal inserts (as used for the Model AT-317 antenna), permitting attachment of the entire assembly to the metal base pedestal. One lead of each loop winding is attached to a connector plug which mates with a cable fitting that passes up through the center of the pedestal. The two remaining winding leads are soldered to two metal inserts in the oval "Bakelite" base. These last two end leads are effectively connected together and grounded when the antenna is attached to the pedestal.

Antenna No. 2, which is shown in Figure 2, is physically similar to antenna No. 1 in all major respects except for the use of a Faraday or capacity shield. This shield completely surrounds both loop windings of the No. 2 antenna. The shield has openings or gaps appropriately placed for each loop winding to prevent inductive shielding of the antennas from the desired radio signals. The shield is held in place around the core with a baked-on, glass Melamine tape.

In the construction of antenna No. 3, shown in Figure 3, the core was lengthened to permit more effective use of the available volume without consideration to the resultant effect on the winding pickup efficiencies. The middle or center section of the core was constructed of ferrite plates and an inner phenolic core as with antennas No's. 1 and 2. The end pieces consist of hollow, semi-circular ferrite sections which also connect to the inner phenolic core. The complete core assembly, as shown in Figure 3, measures 16-1/2" x 5-5/8" x 4". As in the other two experimental antennas, two loop windings are arranged 90 degrees to each other around the core. In this case, the "Fore-Aft" loop winding (plane of winding parallel to the long axis of the core) is closely wound to just fit on the core, whereas the "Athwart" loop winding is widely spaced along the core to provide the maximum number of turns possible and still maintain the desired nominal value of inductance. The core and its loop windings are attached to an oval-shaped phenolic base by means of four stainless steel straps. The two shorter forward straps are connected to metal inserts in the oval base, while the two longer straps are connected to the oval base directly on the phenolic. The loop winding connections to the antenna cable are made in a manner similar to those previously outlined for antennas No's. 1 and 2. However, in this case, the core is directly grounded to the pedestal.

ANTENNA CONSTRUCTIONAL ANALYSIS

The subject experimental antennas appear to be structurally weak, particularly at the phenolic core supports and in the oval base. For example, in the case of loop antennas No's. 1 and 2, the "Fore-Aft"

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winding is pressed directly against the phenolic end supports (winding sandwiched between core and supports). The weight of the core in combination with antenna operational vibration may cause the individual strands of "Litz" wire of the sandwiched "Fore-Aft" winding to roll on the core, and they may actually be crushed. This, of course, would result in short-circuited strands and/or possibly short-circuited turns. The latter effect, in particular, will seriously degrade the electrical performance of the loop antenna winding. For example, antenna No. 2 gave evidence of this fault in design. In this instance, for radio frequency (r-f) measurements the "Fore-Aft" loop winding was inoperative. Operation was restored by removing some of the screws holding the core to the "Bakelite" end supports. It is believed that some of the crushed loop winding turns shorted-over to the Faraday shield via these screws. If the core were to be elevated slightly, to prevent this wire-crushing effect, the strength of the present phenolic mount assembly would be inadequate to support the weight of the core (see Figures 1 and 2).

The supporting mounts for loop antenna No. 3 are even more prone to establish short-circuited turns and/or inadvertent grounding of the loop windings. As shown in Figure 3, the "Athwart" winding turns of antenna No. 3 may experience wire crushing, as previously. In addition, excessive vibration or rough handling of the assembly could conceivably result in cutting of wire strands and/or turns by the stainless steel brackets which support the core. Also, complete sections of the loop winding may be grounded to the metal pedestal by possible cutting action of the stainless steel straps.

PRELIMINARY MODEL CONSTRUCTION

In order to study the effects of pickup of, or the degree of sensitivity improvement resulting from, the ferrite iron-cores in the experimental antennas, additional antennas containing wooden or air-cores were constructed such that all parameters (e.g., size, geometry, inductance, and Q) were approximately identical to those of the iron-core antennas being investigated. A wooden or "air-core" loop antenna of approximately the same physical shape and size as each experimental iron-core antenna (including the Model AT-317) was constructed. Each individual winding length, physical bulk, and value of inductance was adjusted to be approximately equal to that of the iron-core counterpart. The wire chosen was either "Litz" or solid copper, depending on availability and the type of wire which provided the highest winding Q without permitting the winding bulk to differ greatly from the pertinent winding of the iron-core counterpart.

On the right-hand side of Figures 1, 2, 3 and 4 are shown the comparison wooden-core antennas designated with No's. 4, 4, 5 and 6, respectively. The wooden pedestal height for each antenna shown was constructed to provide the same height for all the loop antenna centers above

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the base plate (i.e., at a fixed distance below a horizontal transmission line employed in the tests). This arrangement permitted a direct comparison between all antennas and obviated the necessity of making relative room-constant corrections for the transmission-line type measurements.

As shown in Figure 1, the wood-core loop antenna No. 4 was compared to the iron-core antenna No. 1. Since antennas No's. 1 and 2 are similar, except for a Faraday shield, antenna No. 2 was also compared to antenna No. 4 (see Figure 2). Figure 3 shows that the wood-core antenna No. 5 was compared to the iron-core antenna No. 3. The physical dimensions of the Model AT-317 antenna were obtained from contractor's drawings. The design of the wood-core antenna No. 6 was based on these dimensions, and the winding structure, shown in Figure 4, represents a facsimile of the Model AT-317 iron-core loop antenna.

METHODS OF TEST

Q measurements of all pertinent components and circuits were made with a "Freed" low-frequency Q meter, Type 1030.

A "General Radio Company" impedance bridge, Type 650-A, was used to make all inductance measurements.

Standard laboratory shielded-room transmission-line techniques were used to make all comparative sensitivity tests [3]. Each antenna investigated was centrally mounted in a shielded room and situated at a standard distance under a properly terminated transmission line which was energized by a signal generator located outside of the shielded room. The same room, line, and generator was used in each case. The signal generator was accurately set to each measurement frequency with a crystal-controlled frequency counter. The loop antenna cable entered an adjacent shielded room which contained the loop antenna coupler, Model R-21X. This coupler resonated the loop antenna windings and was successively connected to Models AN/BRR-1 (XN-1) and AN/SRR-11 VLF radio receiving equipments and tuned to the desired radio frequencies. For making the tests, the Model AN/BRR-1 (XN-1) receiver's loop-antenna input circuits were disabled and the signal from the coupler was connected directly into the grid circuit of the receiver's first r-f amplifier. This receiver was used to determine the performance of the experimental antennas in the 10 to 15 kilocycle frequency range. For antenna performance measurements between frequencies of 15 and 27 kilocycles, the Model AN/SRR-11 receiver was employed. In this case, the coupler output was connected to the antenna input jack of the receiver (adjusted for high impedance antenna input). As each loop antenna winding was orientated for maximum signal pickup, the coupler was adjusted for single-plane operation, so that the loop windings could be individually tuned to compensate for small differences in loop-winding inductances and thus improve the accuracy of measurement.

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[3] NRL Memorandum Report No. 188 (Confidential) of July 1953, "VLF Omni-directional Loop Receiving Adapter", by S. V. Fratianni

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Procedures and the arrangement of test equipments for investigation of noise interference effects on the No. 2 loop antenna (which contains the Faraday shield) were performed in a manner similar to the above sensitivity tests. Pulse and "white" noise type signals were produced with a "General Radio Company Strobotac" and a noise generator, respectively. Experiments were performed with the No. 2 antenna Faraday shield (Figure 2) both connected to and disconnected from the ground circuit of the antenna system. Also, the No. 1 antenna (Figure 1) was placed under the transmission line alongside of the No. 2 antenna, so that a simultaneous comparison between the two antennas could be made.

Antenna azimuth response patterns were obtained by rotating each subject antenna horizontally through 360 degrees in a radio field of constant strength. This constant field was produced by the transmission line in the shielded room. Output responses were measured with a high impedance vacuum-tube voltmeter across the high impedance output jack of the Model R-21X coupler. Each antenna winding was individually resonated with the coupler adjusted to single-plane loop operation, and the output response was measured at every 10 degrees of antenna rotation.

RESULTS OF INVESTIGATION

Antenna Weight Measurements

Loop antennas No's. 1, 2 and 3 weigh approximately 67-1/2, 68-1/2, and 68 pounds, respectively. These antenna weights include the core, supports, windings, and pedestal. The Model AT-317 antenna weighs approximately 71 pounds and includes all of the above items, plus a tear-drop shaped polyethylene and neoprene shell which serves to isolate the loop windings from the sea water. If the same quantity of insulation (exact weight unknown) were molded to each of the experimental antennas, the total individual antenna weights would probably considerably exceed that for the Model AT-317 antenna.

Antenna Inductance Measurements

The inductance of each separate antenna winding was measured at 1000 cycles per second (cps) without the antenna cable connected, and with the metal pedestal attached, so that a direct comparison could be made with comparable windings of the Model AT-317 antenna. The measurements showed that none of the experimental antenna loop inductances were exactly equal to those of the Model AT-317 antenna windings. The "Fore-Aft" windings measured approximately 505, 480, and 493 microhenries and the "Athwart" windings measured approximately 498, 486, and 502 microhenries for experimental loop antennas No's. 1, 2 and 3, respectively. This represents an inductance difference between the crossed-loop winding pair of each experimental antenna of approximately 1.4, 1.25, and 1.8 percent, respectively. The inductance of each winding of the Model AT-317 antenna is 484 microhenries (without a cable attached), for comparison.

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Q Measurements and Analysis

The variation of Q as a function of frequency for both the "Fore-Aft" and "Athwart" windings of loop antenna No. 1 without the antenna cable attached is shown in Figure 5. Also shown are the effects on the winding Q's when the metal pedestal is attached to the core (see Figure 1). The graph shows that between 5 and 10 kilocycles the Q's of both windings (with or without the pedestal) are approximately equal and increase at about the same rate. For frequencies above 10 kilocycles and with the pedestal removed from the antenna, the Q of the "Athwart" winding increases quite rapidly until it levels off at a peak value of approximately 245 at 50 kilocycles, while the "Fore-Aft" winding attains a maximum Q of 200 at about 40 kilocycles which it maintains for higher frequencies. The graph shows that the Q of both windings will be reduced in value when the pedestal is attached to the antenna. This reduction in winding Q (approximately 7 percent at 20 kilocycles) results from the close proximity or coupling between the pedestal and the antenna windings.

Figure 6 shows the variation of Q with frequency for loop antenna No. 2. In this case the "Fore-Aft" winding without the pedestal attains a maximum Q of approximately 158 at a frequency of about 22 kilocycles, while the "Athwart" winding without the pedestal attains a maximum Q of 240 at about 50 kilocycles. As previously discussed, and shown again in Figure 6, the close proximity of the pedestal to the antenna core results in a reduction of Q for both antenna windings. At 20 kilocycles this reduction is approximately 8 and 19 percent for the "Athwart" and "Fore-Aft" windings, respectively. In addition, for frequencies between 15 and 60 kilocycles, all magnitudes of Q for antenna No. 2 are less than those for antenna No. 1. Antennas 1 and 2 are similar in all major respects except for the use of a Faraday shield on antenna No. 2; the differences between Figures 5 and 6 with regard to Q are attributed primarily to this shield. However, some part of the difference may be attributed to slight variations in size and effective permeability of the loop cores.

As is evident in Figure 3, antenna No. 3 is structurally dissimilar to antennas No's. 1 and 2. As shown in Figure 7, the Q's of the No. 3 antenna windings are more nearly equal to each other in the 5 to 60 kilocycle frequency range and do not increase with frequency to as high an absolute value as for antennas No's. 1 and 2. Both the near equality and the lower absolute values of Q are probably due to the very close proximity between the two windings and the presence of the stainless steel straps which help support the core (see Figure 3). In addition, the effect of the pedestal on the loop Q is less pronounced here since the pedestal losses are relatively small compared to the losses introduced by the coupling of the steel straps to the No. 3 antenna winding. These steel straps are coupled more tightly to the "Athwart" winding, so that the "Fore-Aft" winding Q's are greater than those of the "Athwart" winding (the reverse results of the two previous experimental antennas). As

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shown in Figure 7, this is particularly the case for frequencies above 45 kilocycles. Without the pedestal attached to the antenna the Q of the "Fore-Aft" winding is approximately 40 at 5 kilocycles, and steadily increases to about 110 at 25 kilocycles. Between 25 and 60 kilocycles, the Q gradually increases to about 120. The Q of the "Athwart" winding changes from approximately 40 to 95 between 5 and 28 kilocycles, respectively. From 28 to 60 kilocycles the increase in the Q of this winding is more gradual, reaching 104 at the upper frequency limit. In this case, the pedestal loading effect at 20 kilocycles reduces the Q's by approximately 8 and 4.7 percent for the "Fore-Aft" and "Athwart" windings respectively.

Figures 8, 9, 10 and 11 show the variation in overall effective Q of the experimental loop antennas and the Model AT-317 antenna with the pedestal and 75 feet of Type RG-160/U interconnecting cable in the frequency range from 5 to 55 kilocycles. Each of these graphs also shows the resultant effective Q of an experimental iron-core antenna compared to the resultant Q of a comparable wooden-core antenna with the same cable attached. For example, Figure 8 shows a comparison of effective Q between loop antennas 1 and 4. The Q's of the "Fore-Aft" and "Athwart" windings of antenna No. 4 are equal and their absolute magnitudes and rates of increase with increasing frequency are not materially different from those obtained with the windings of antenna No. 1. This is approximately the identical result obtained in a comparison of antenna No. 2 with No. 4, except the "Fore-Aft" winding of the No. 2 antenna departs from the general trend or slope of the other curves at approximately 30 kilocycles (see Figure 9). The difference in Q between the "Athwart" and "Fore-Aft" windings of both the antennas No's. 3 and 5 is greater than shown for the antennas in Figures 8 and 9. For example, Figure 10 shows that at 20 kilocycles the "Fore-Aft" and "Athwart" windings of the No. 3 antenna have Q values of 60 and 68 respectively, while the respective Q values of the No. 5 antenna windings are 42 and 45. This compares to no change in Q for the No's. 1, 2 and 4 antenna windings at 20 kilocycles. This difference in Q between crossed-loop windings increases slightly with frequency above 20 kilocycles for all the antennas of Figures 8, 9, and 10 except antenna No. 4, which maintains equality of winding Q at all frequencies. Figure 11 shows that the Model AT-317 antenna has a Q of 73 at 20 kilocycles for either winding as compared to Q values of 40 and 36 for the "Fore-Aft" and "Athwart" windings respectively of the No. 6 antenna. At 40 kilocycles, the <u>ratio</u> of the Q's between the windings of the AT-317 and No. 6 antenna increases slightly relative to the lower frequencies, becoming greater than two to one.

Since it is desirable to make a direct comparison between the experimental antennas No's. 1, 2, 3, and the Model AT-317 antenna, the winding Q's of these antennas were not separately altered or adjusted in an attempt to match them to the Q's of the comparison wooden-core antennas (No's. 4, 5, and 6). The experimental antennas are about equal to each other in effective overall Q, which permits a direct circuit comparison. However, to correct for the difference in Q between each iron-core and wood-core

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antenna winding compared, the curves of Figure 12 were computed to permit corrections in overall input circuit sensitivity to be made for different winding Q's.

Figure 12 shows the theoretical variation in effective overall loop system signal-to-noise ratio and, consequently, sensitivity, as a function of the overall antenna Q change, for different initial Q values of the loop antenna windings. These curves are based on equations given in NRL Report R-3464, and on the employment of a specific type of input transformer such as was used in the input circuit of each of the loop antennas in these tests [4]. The coefficient of coupling of this transformer is 95 percent, the primary and secondary transformer Q's are 100 and 150 respectively, and the ratio of the transformer primary-to-loop winding inductances is 0.7. The use of this graph involves knowledge of Q_o (which is the Q of the antenna system to which a comparison is desired) and of Q_o' (the Q under any other condition, lower in value than Q_o).

Figure 11 shows that at 20 kilocycles, Q equals 73 for the windings of the Model AT-317 antenna while Q equals about 38 for the windings of the No. 6 antenna, providing a ratio of Q_o to Q_o' of 73/38 or about 1.9. Figure 12 shows that the input circuit sensitivity should decrease by approximately one decibel as a result of this Q difference. Similarly, at 40 kilocycles, Q_o equals 96 and Q_o' equals approximately 45 for the windings of the Model AT-317 and No. 6 antennas, respectively, providing a ratio of Q_o to Q_o' of approximately 2.1. In this case, the input circuit sensitivity should change approximately 0.9 decibels (see Figure 12).

The curves of Figure 12 are also useful in determining the decrease in sensitivity that results from loop antenna Q-changes due to submergence of the antenna in sea water. However, the graph is applicable only for the particular transformer constants given above. Loop-antenna input transformers, should, in general, be designed with constants very similar to those used in the transformer employed in this investigation. Thus the graph of Figure 12 will be generally useful and applicable in most cases.

Figure 13 shows the effects of the addition of 75 feet of Type RG-160/U cable on the loop winding Q's of the Model AT-317 antenna in the 5 to 55 kilocycle frequency range. This information, along with that given in Figure 12, will allow determination of the overall degradation of the loop cable on the antenna input-circuit sensitivity. For instance, at 20 kilocycles the cable causes the loop circuit Q to change from 110 to 73, providing a Q ratio of approximately 1.5. Figure 12 shows that for this value of Q ratio (Q_o/Q_o' and a Q_o of 110) the sensitivity of the input circuit will be reduced by less than 0.2 decibels. Since the Q ratio remains approximately constant at 1.5 in the frequency range of 5 to 30 kilocycles, while Q_o is changing from approximately 35 to 133, the limits

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4 NRL Report R-3464 of May 1949, "The Equivalent Selectivity of Transformer-Coupled Loop-Antenna Input Circuits", by S. V. Fratianni

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of input circuit sensitivity loss due to the cable will vary between approximately 0.85 and 0.35 decibels over this frequency range.

Sensitivity Measurements

Figure 14 shows the direct improvement obtained in overall circuit sensitivity for the "Fore-Aft" and "Athwart" windings of experimental antennas No's. 1, 2, and 3 as compared to similar windings of the Model AT-317 antenna in the frequency range from 12 to 27 kilocycles. As previously indicated, no correction for differences in winding Q's have been made, since Figure 12 shows that small Q changes do not substantially affect the sensitivity. The results shown in Figure 14 indicate that the "Athwart" windings of antennas No's. 1 and 2 are equally superior to the corresponding winding of the Model AT-317 antenna by approximately 2.5 decibels in the 12 to 27 kilocycle frequency range, while the "Fore-Aft" windings of these same antennas are only about 1.2 decibels superior to the corresponding winding of the Model AT-317 antenna. As previously indicated in this report, the two crossed-loop windings of antenna No. 3 are unequal but designed for maximization of signal pickup. As a result, Figure 14 shows a greater spread of sensitivity relative to the Model AT-317 between the "Fore-Aft" and "Athwart" windings for this antenna. Specifically, the "Athwart" winding of antenna No. 3 is uniformly superior to the corresponding winding of the Model AT-317 antenna by about 4.5 decibels, while the superiority of the "Fore-Aft" winding of antenna No. 3 varies from approximately 2.3 decibels at 12 kilocycles to 1.3 decibels at 27 kilocycles. For comparison purposes, the measured results at 20 kilocycles are given in Table 1.

A direct comparison between corresponding windings of the experimental antennas can also be obtained from Figure 14. For example, at 20 kilocycles the No's. 1 and 2 antenna "Athwart" windings are 1.6 decibels superior to their own "Fore-Aft" windings, 1.9 decibels superior to the "Fore-Aft" winding of the No. 3 antenna, and 2 decibels inferior to the "Athwart" winding of the No. 3 antenna.

Figures 15, 16, and 17 show the improvement in loop antenna pickup due to the iron cores of the experimental antennas in the 12 to 27 kilocycle frequency range. Each curve is a comparison between identical loop windings of related iron-core and wood-core antennas (as depicted in the photographs of Figures 1 through 4). As previously shown in Figures 8, 9, 10, and 11, the effective Q's of the related antenna windings around the iron and wood cores differ. However, in no instance (between frequencies of 12 and 27 kilocycles) does this Q difference exceed 2-to-1. Therefore, as mentioned before (Figure 12), the correction for differences in Q is relatively minor and if applied to the curves of Figures 15, 16, and 17 would not exceed 1.5 decibels under any circumstance, this value being obtained for the extreme Q differences between related loop antenna windings. Figures 15, 16, and 17 show that the improvement in pickup due

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to the field distortion effect of iron cores of each experimental winding are approximately constant in the 12 to 27 kilocycles frequency range. For comparison purposes, the 20 kilocycle iron-core pickup improvement values are also shown in Table 1. In each case, if the Q correction factor discussed above were applied, these improvements would be slightly less, since all of the experimental iron-core loop antenna windings exhibit higher Q than the wooden-core antenna windings to which they were compared.

Significance of the Pickup Superiority of the Experimental Antennas

As the above sensitivity measurements indicate, the windings of the experimental antennas provide for greater system sensitivity and pickup relative to similarly oriented windings of the Model AT-317 antenna in all instances. Since the Q's and loop inductances of the related experimental antenna windings are approximately equal, the resulting improvements are attributed primarily to, (1) the improved core materials employed, (2) increased turns-spacing of the windings, (3) increased core lengths, (4) more favorable coil-to-core form factors, and (5) increased winding cross-section areas (major factor).

Some of the physical dimensions which determine or establish the pickup variations (shown in Table 1) occurring between the antenna windings are given in Table 2. As shown here (and in Figures 1, 2, and 4), the "Fore-Aft" windings of the No's. 1, 2, and Model AT-317 antennas are approximately rectangular in crossection. However, the "Fore-Aft" winding areas of the No's. 1 and 2 antennas are greater than for the Model AT-317 antenna by approximately 21 percent, while their ratios of core length to coil length are smaller by approximately 12.5 percent, so that the roughly 1 db improvement in sensitivity that resulted (at 20 kilocycles, see Figure 14) for the experimental antennas was due to the greater winding areas involved. For the "Athwart" windings of the No's. 1, 2 and AT-317 antennas the different crossectional shapes are approximately equal in area, but the ratios $\left(\frac{\text{core-length}}{\text{coil-length}}\right)$ and core lengths are greater for the No's. 1 and 2 antennas (an increase of approximately 125 and 62.5 percent, respectively), which accounts for the 2.6 decibels sensitivity superiority of these windings (at 20 kilocycles) relative to the "Athwart" winding of the Model AT-317 antenna.

The "Fore-Aft" winding of the No. 3 antenna is approximately elliptical in shape and has an area which is about 2-to-1 greater than that of the corresponding winding of the Model AT-317 antenna. However, the coil and core length of this winding are almost equal (ratio of 1.1 as compared to 1.6 for the Model AT-317 antenna) which could result in a cancellation of some of the beneficial effects on pickup developed by the core. The net improvement relative to the Model AT-317 antenna is about 0.7 decibels at 20 kilocycles, and appears due mainly to the larger winding area involved. Although the "Athwart" windings of the No. 3 and Model AT-317 antennas are of different shape, their areas are almost equal (AT-317 larger by 15%).

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The core-to-coil length ratio of the No. 3 "Athwart" antenna is smaller than the corresponding Model AT-317 antenna winding by approximately 30 percent (as shown in Table 2), but both its core and coil lengths are greater (2-to-1 for the core and 3-to-1 for the coil), accounting for the 4.6 decibels better pickup of this winding relative to the "Athwart" winding of the Model AT-317 antenna.

"Faraday" Shield Effects on Antenna Noise Pickup

The "Faraday" shield, which is a part of antenna No. 2, had no noticeable effect on the background noise level or output signal-to-noise ratio of the antenna system with the shield connected either to the metal pedestal or left "floating", for any of the various noise generating sources employed (in combination with each other, or together with a desired signal). When the shield of the No. 2 antenna was connected to its pedestal and simultaneously compared with the unshielded No. 1 antenna, there was no improvement shown for any of the types of externally introduced noise to the system. Various noise output levels and polarizations of the noise sources were employed in these tests.

Antenna Response Patterns

Figures 18, 19, 20, and 21 show the individual antenna patterns of the "Fore-Aft" and "Athwart" windings for the No's. 1, 2, 3, and Model AT-317 antennas respectively, at 20 kilocycles. The graphs indicate that the output responses of the "Athwart" windings are, in each case, greater than those of the "Fore-Aft" windings. These graphs permit a direct comparison of antenna pickup between the various windings, since all the auxiliary circuit components used with the antennas were identical and the magnitude of the radio field was maintained constant. Due to the small inductance differences existing between the individual antenna windings, slight individual antenna input circuit retuning was necessary. Also, the results do not include corrections for slight differences in individual antenna Q's.

The antenna patterns of each winding in Figures 18 through 21, in general, follow a cosine law and display figure-of-eight patterns. The exception appears to be the response pattern of the No. 3 antenna "Athwart" winding, where the measured response is shown by the lightly-dashed curve and the heavy-dashed curve is the estimated true response of this winding (see Figure 20). The measured "flattening" effect evident near maximum output response was due to saturation of the amplifier, which was maintained at constant gain setting so that a direct comparison could be made between all the response patterns of the windings of the various antennas.

As is shown, the "Fore-Aft" and "Athwart" response maximums or minimums of each experimental antenna winding are displaced from each other by 90 ± 2 degrees (i.e., the two crossed-loop windings of each antenna are correctly orientated at right angles to each other to within ± 2 degrees). Antennas

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No's. 1 and 2 are very similar, and are both slightly superior in pickup capabilities to the Model AT-317 antenna (Figs. 18, 19 compared to Fig. 21). A comparison of Figure 20 with Figure 21 shows that the "Fore-Aft" winding of the No. 3 antenna has a slightly better response, while the "Athwart" winding has much greater pickup capability (about 4.5 decibels) relative to comparable windings of the Model AT-317 antenna. These results closely substantiate those obtained in the sensitivity measurements.

Omnidirectional reception with antenna patterns which do not deviate from a circle by more than a total of two decibels are obtainable from antennas No's. 1 and 2, since the maximum response magnitudes from each antenna's "Fore-Aft" and "Athwart" winding for the same field intensity differ by only 0.4 and 1.3 decibels respectively (reference Figs. 18 and 19). On the other hand, the signal pickups of the No. 3 antenna windings differ by 4.3 decibels (reference Figure 20), and will provide, therefore, omnidirectional antenna patterns which depart from a circular response by a total of more than four decibels. In this case, the antenna omnidirectional response will be essentially elliptical rather than circular. However, as indicated above, this No. 3 antenna will provide relatively superior pickup when orientated for minimum omnidirectional response compared to the other experimental antennas (No's. 1 and 2) or Model 317 antenna.

Measurements of Antenna Volumes

To be operationally useful, these experimental iron-core antennas will have to be modified so that they are cased in polyethylene or a suitable substitute. The applicable specifications require a tear-drop form of structure with the same physical dimensions as the Model AT-317 antenna. Measurements of clearances between the experimental antennas and the required casing were made by placing each antenna in the neoprene jacket stripped from a damaged Model AT-317 antenna. Under these conditions, the clearances between the antenna proper and the outside surface of the casing at the "Fore" and "Aft" corners of the No's. 1 and 2 antennas were found to be approximately 1/2 and 1/16 inch, respectively. If the antenna base were redesigned to effectively move each antenna forward by about 1/4 to 1/2 inch relative to the base mount, the above specified clearances would be changed to approximately 3/8 and 1/8 inch, respectively. In either of the above instances, some few end-turns of the crossed-loop windings would be approximately one inch from the outside surface of the polyethylene casing.

The placement of the No. 3 antenna in the test neoprene jacket showed that the "Fore" and "Aft" corner edges of the core would all clear the outside surface of casing material by approximately 1/8 inch. Also, some few turns of the "Fore-Aft" winding would likewise be only 1/8 inch from the casing surface. Additionally, examination of this antenna showed that the phenolic base, which contains the metal screw-inserts, should be ro-

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tated 180 degrees from its present position for proper orientation of the antenna with respect to the pedestal and casing.

The above results indicate that the three experimental antennas would fit the present AT-317 casing, but the clearances at each antenna "Fore-Aft" corner will be very small and thus questionable. Since the thickness of polyethylene casing separating the antenna proper from the sea water at these points will be small, the antennas appear to be of insufficient mechanical strength at these points. In particular, the "Fore-Aft" winding of the No. 3 experimental antenna would be insufficiently separated from the sea water. Therefore, it appears necessary to consider larger casings for the experimental antennas before they can be employed operationally.

CONCLUSIONS

It is concluded that:

(1) Both windings of the experimental crossed-loop antennas No's. 1, 2, and 3 are superior in pickup efficiency to those of the Model AT-317 antenna. This superiority is attributed to the greater winding areas and greater core lengths of the experimental antennas. However, compared to the Model AT-317 antenna, the small pickup superiority of the No's. 1 and 2 antennas (approximately 1.5 or 2.5 decibels, depending upon winding compared, reference Figure 14) is not considered sufficient to justify, on this ground alone, a change from the presently employed Model AT-317 antenna. The No. 3 antenna provided a pickup improvement of approximately 1 and 4.5 decibels for the "Fore-Aft" and "Athwart" windings, respectively, over the Model AT-317. The inequality of pickup between loop windings would result in a seriously eccentric (elliptical) antenna pattern when the antenna is employed for omnidirectional reception.

(2) The experimental antennas will fit the same casing as presently employed for the Model AT-317 antenna. However, this can be accomplished only by reducing the thickness of the polyethylene at the "Fore" and "Aft" corners of each antenna. In order to incorporate sufficient strength into each experimental antenna structure, the Model AT-317 antenna mold would have to be enlarged somewhat to permit sufficient insulation to be built up around these new antennas, such that any loop winding turn will be insured a separation of at least 3/4 inch to sea water.

(3) The use of a Faraday shield enveloping the No. 2 loop antenna did not reduce the magnitude of external interference (particularly noise) induced into the loop antenna. The shield provided adversely effects the loop antenna winding Q's and values of inductance.

(4) The design of the experimental antenna core supports was inadequate to prevent crushing or short-circuiting of the winding turns in operational use.

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RECOMMENDATIONS

It is recommended that:

(1) Experimental antennas No's. 1 and 2 not be considered as replacements for the Model AT-317 antenna for use in omnidirectional systems, since the improvement in radio signal pickup obtained from these antennas in their present form is insufficient to warrant new mechanical redesign in addition to an increase in the resultant overall antenna weight which is operationally undesirable.

(2) Although elliptical response patterns are obtained from experimental antenna No. 3, consideration be given this antenna since the pickup improvements relative to the AT-317 antenna were substantial. However, the mechanical aspects require redesign.

(3) Development of various experimental crossed-loop, iron-core antennas be continued with the intent of providing designs with appreciable improvement in sensitivity, while avoiding the mechanical shortcomings of the antennas examined here, particularly with regard to the danger of crushing, short-circuiting or grounding the winding turns under service operating conditions.

(4) Studies involving the use of "Faraday" shields be continued since this evaluation was limited to one antenna and type of shield.

(5) New single-plane loop-antenna designs be investigated with long core and coil lengths (about 3 feet long) and small crossections (about 2 or 3 inches in diameter). If the pickup capabilities of long antenna designs such as this are satisfactory, a pair might be mounted at right angles in azimuth to each other at the highest point on the submarine's super-structure, to provide for omnidirectional reception. This type of design might eliminate the need for a separate retractable mast and minimize antenna installation and maintenance problems.

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TABLE 1

MEASURED PICKUP VARIATIONS OF LOOP ANTENNAS AT 20 KILOCYCLES

Antenna	No. 1 or No. 2		No. 3		Model AT-317	
Winding	"FORE-AFT"	"ATHWART"	"FORE-AFT"	"ATHWART"	"FORE-AFT"	"ATHWART"
Superiority above AT-317 DECIBELS	1	2.6	0.7	4.6	- -	- -
Iron-Core Improvement DECIBELS	6.1	11.8	4.5	11.5	5.8	8.5

TABLE 2

MEASURED PHYSICAL DIMENSIONS OF LOOP ANTENNAS

Antenna	No. 1 or No. 2		No. 3		Model AT-317	
Winding	"FORE-AFT"	"ATHWART"	"FORE-AFT"	"ATHWART"	"FORE-AFT"	"ATHWART"
Coil length	4"	2-1/2"	3-1/2"	10-1/4"	3-3/4"	3-1/2"
Coil height or diameter	4-1/8"	4-3/4"	5-3/4"	6"	5-1/2"	6"
Core length	5-5/8"	13"	4"	16-1/2"	6"	8"
Shape of Crossection	RECTANGULAR	RECTANGULAR	ELLIPTICAL*	RECTANGULAR	RECTANGULAR**	CIRCULAR
Area of Winding (sq. in.)	53.5	28.5	93	24	44	28.3
Ratio, core-length / coil length	1.4	5.2	1.1	1.61	1.6	2.3

* Approximately elliptical (See Figure 3)
** Each turn of different rectangular area (See Figure 4)

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ILLUSTRATIONS

FOR

NRL MEMORANDUM REPORT NO. 522

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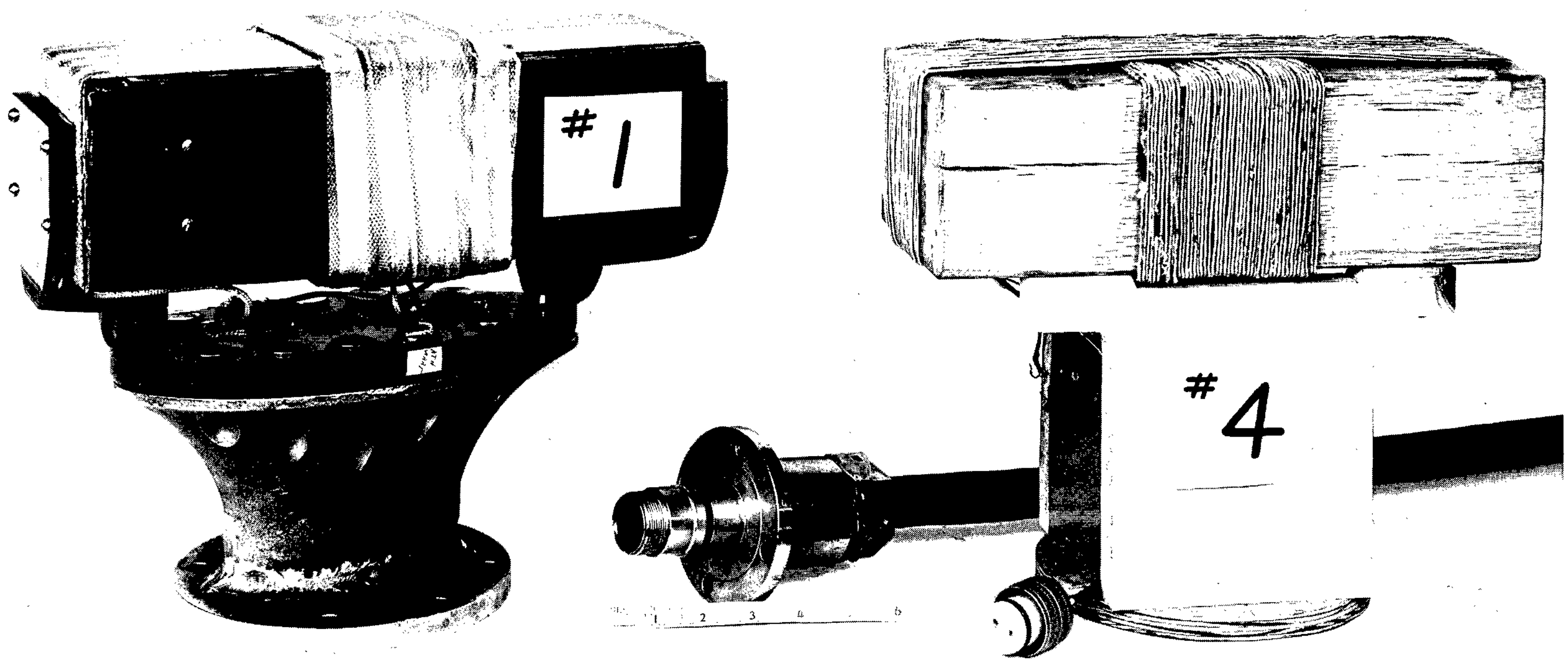

Figure 1 - Experimental Iron-Core Loop Antenna No. 1 and "Equivalent" Air-Core Loop Antenna No. 4 of Same Size,Q, and Inductance

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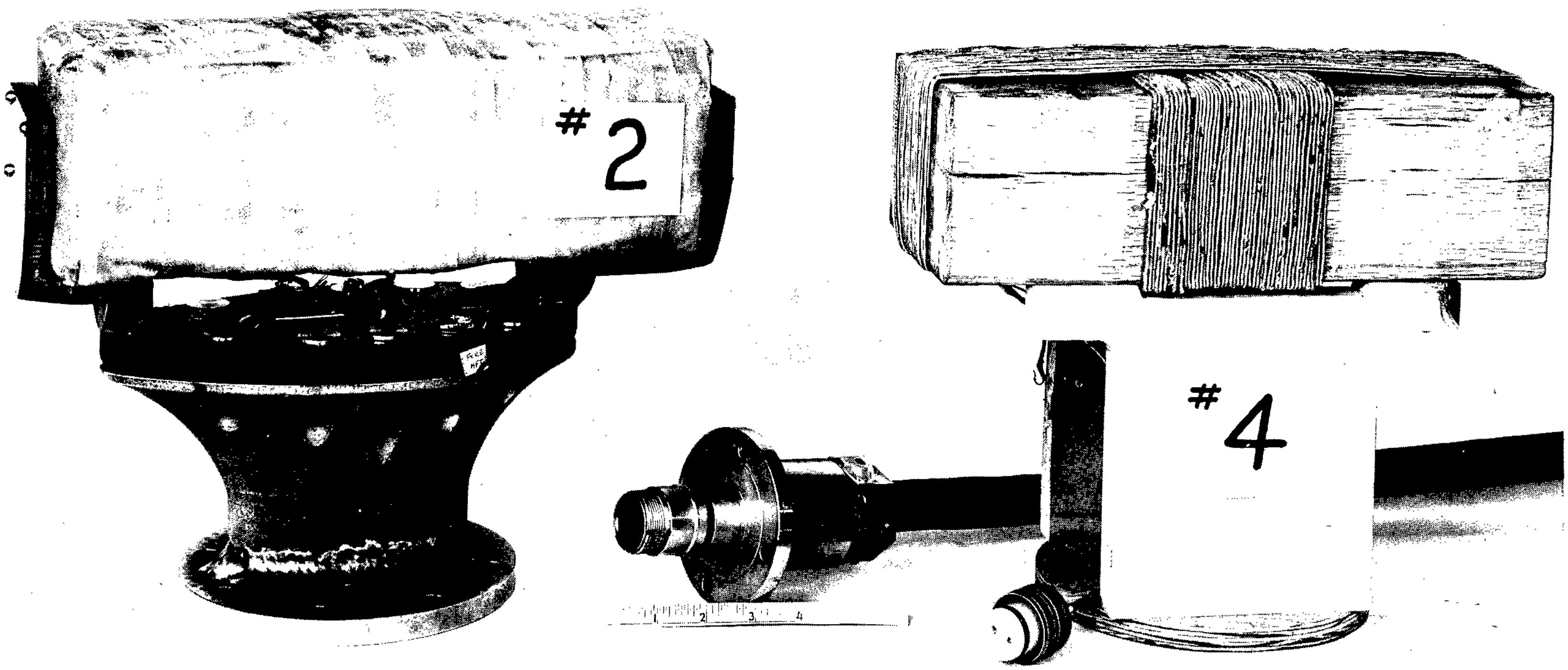

Figure 2 - Experimental Iron-Core Loop Antenna No. 2 and "Equivalent" Air-Core Loop Antenna No. 4 of Same Size, Q, and Inductance

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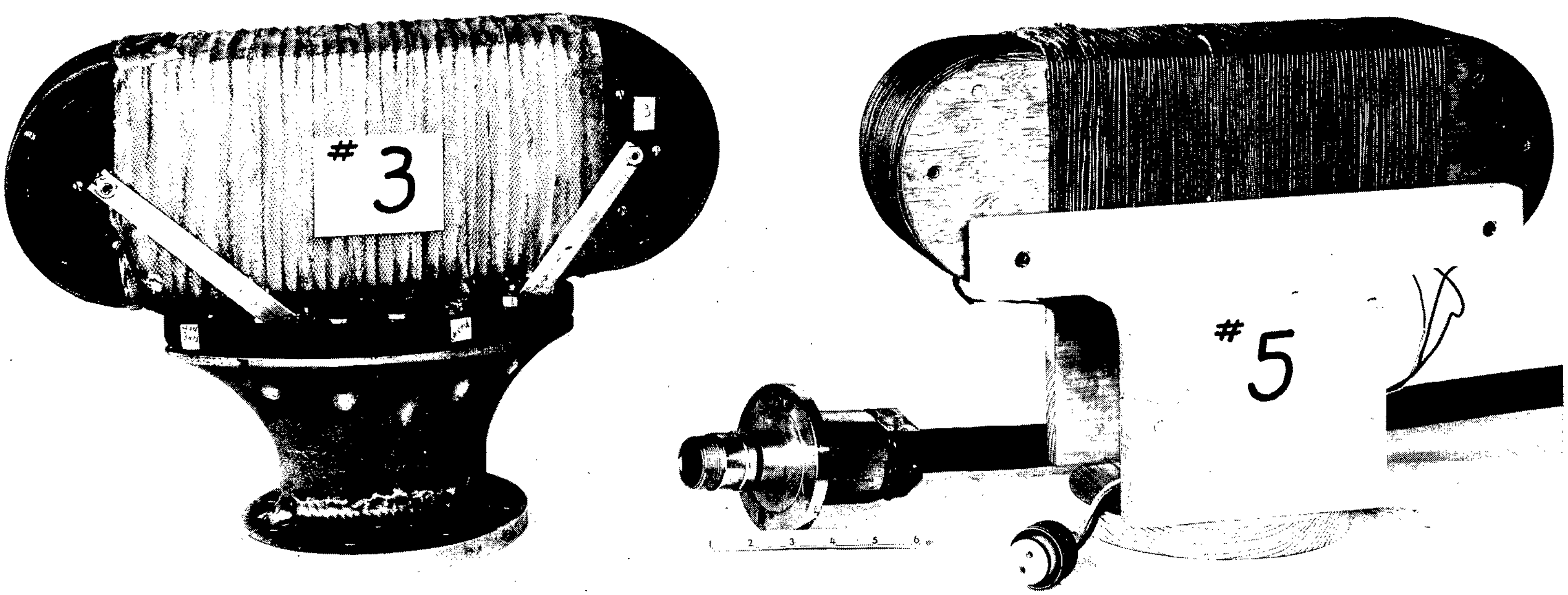

Figure 3 - Experimental Iron-Core Loop Antenna No. 3 and "Equivalent" Air-Core Loop Antenna No. 5 of Same Size,Q, and Inductance

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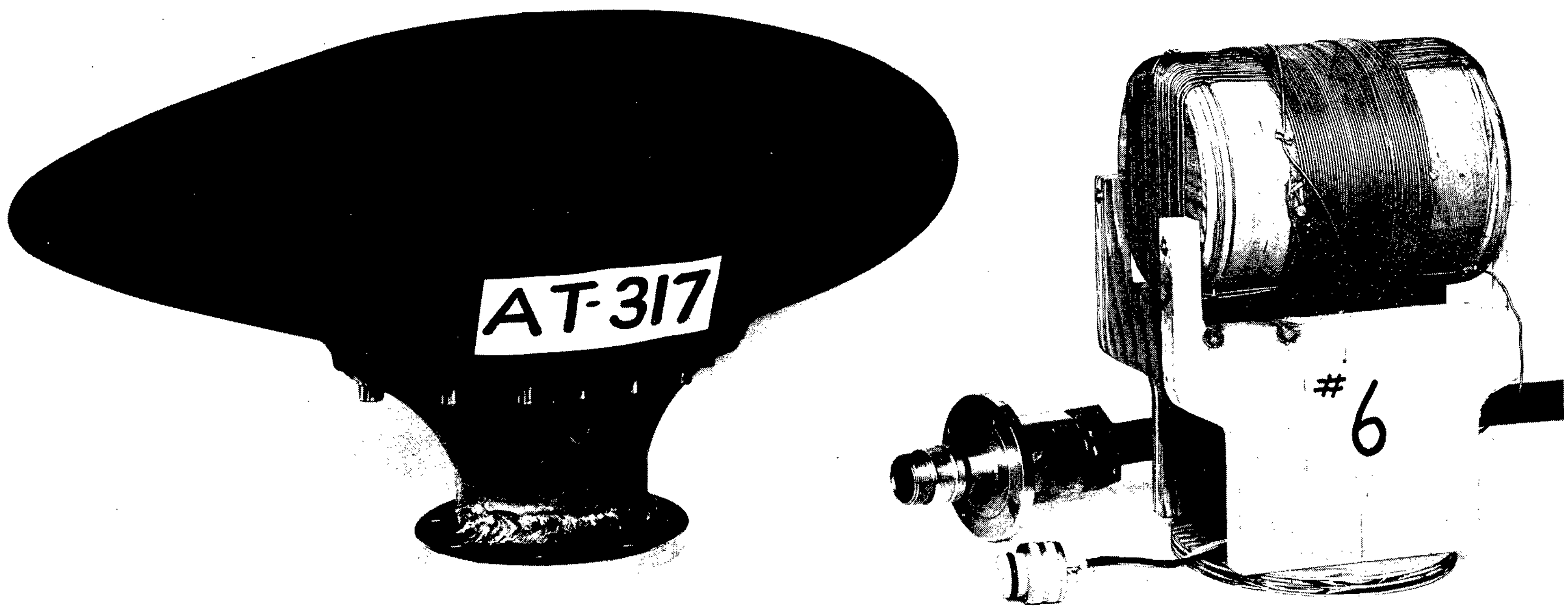

Figure 4 - Iron-Core Model AT-317 Loop Antenna and "Equivalent" Air-Core Loop Antenna No. 6 of Same Size, Q, and Inductance

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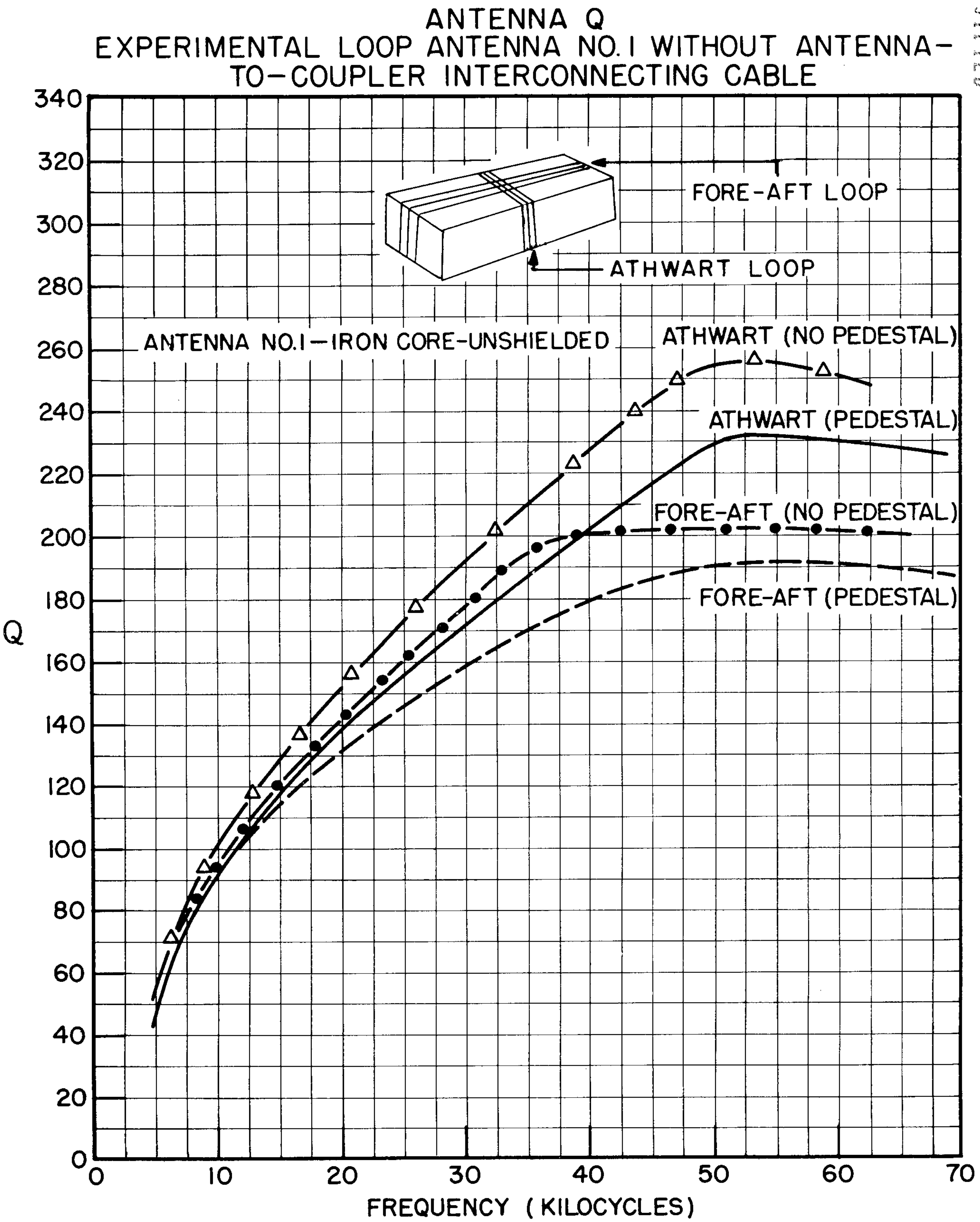

FIG. 5

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ANTENNA Q
EXPERIMENTAL LOOP ANTENNA NO. 2 WITHOUT ANTENNA-TO-COUPLER INTERCONNECTING CABLE

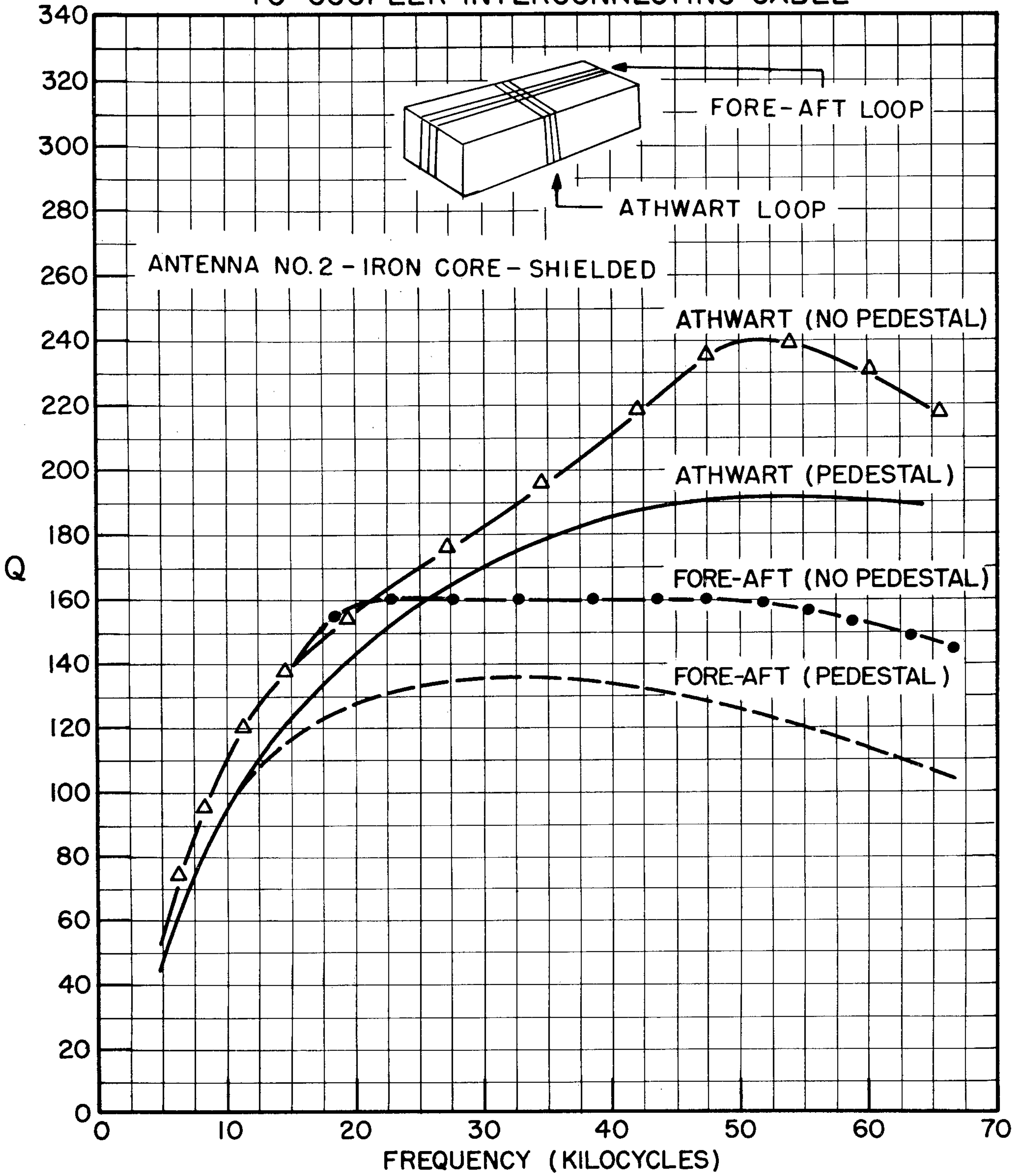

FIG. 6

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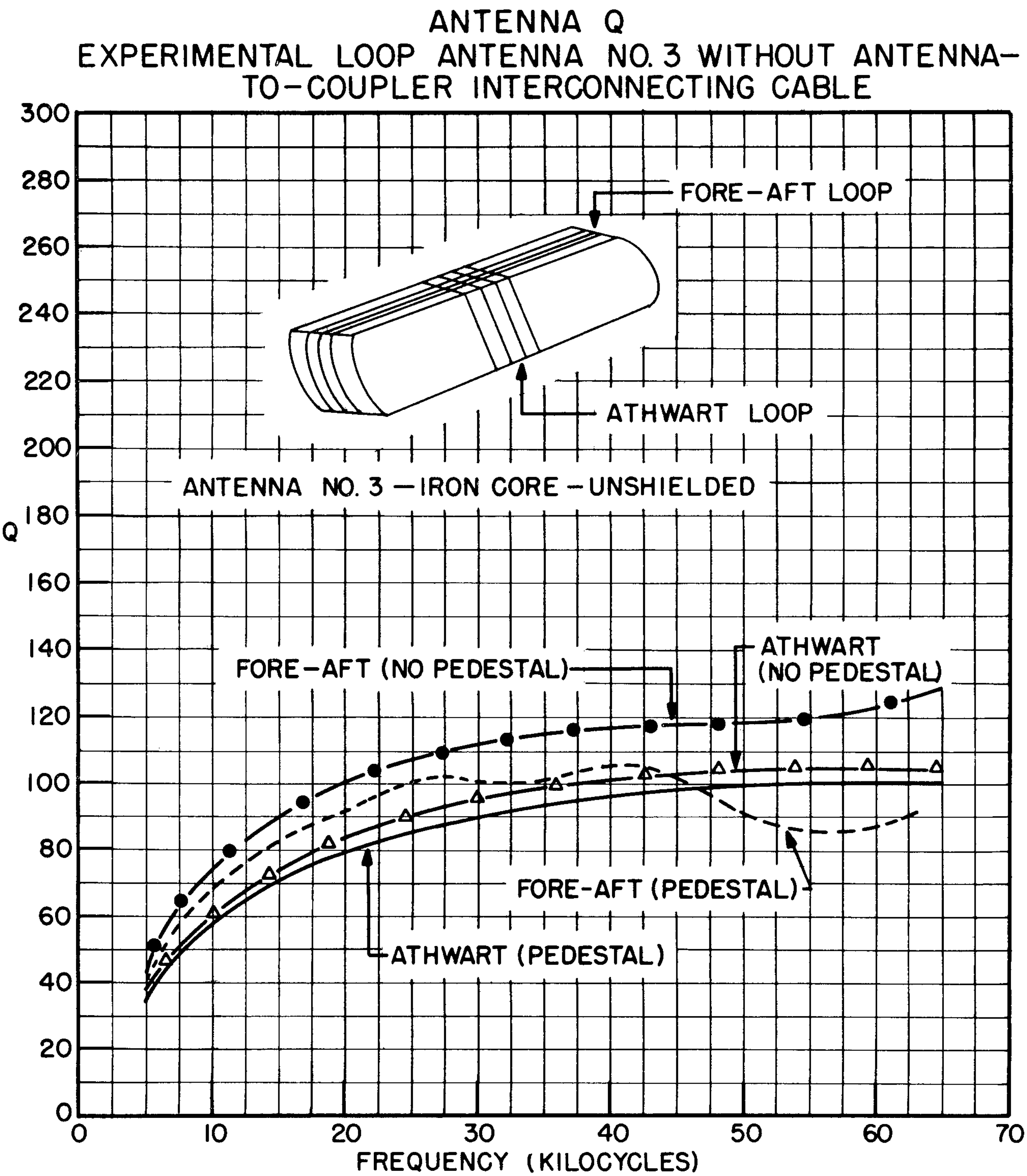

FIG. 7

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EFFECTIVE OVERALL ANTENNA Q
(ANTENNA + PEDESTAL + 75 FOOT INTERCONNECTING CABLE)

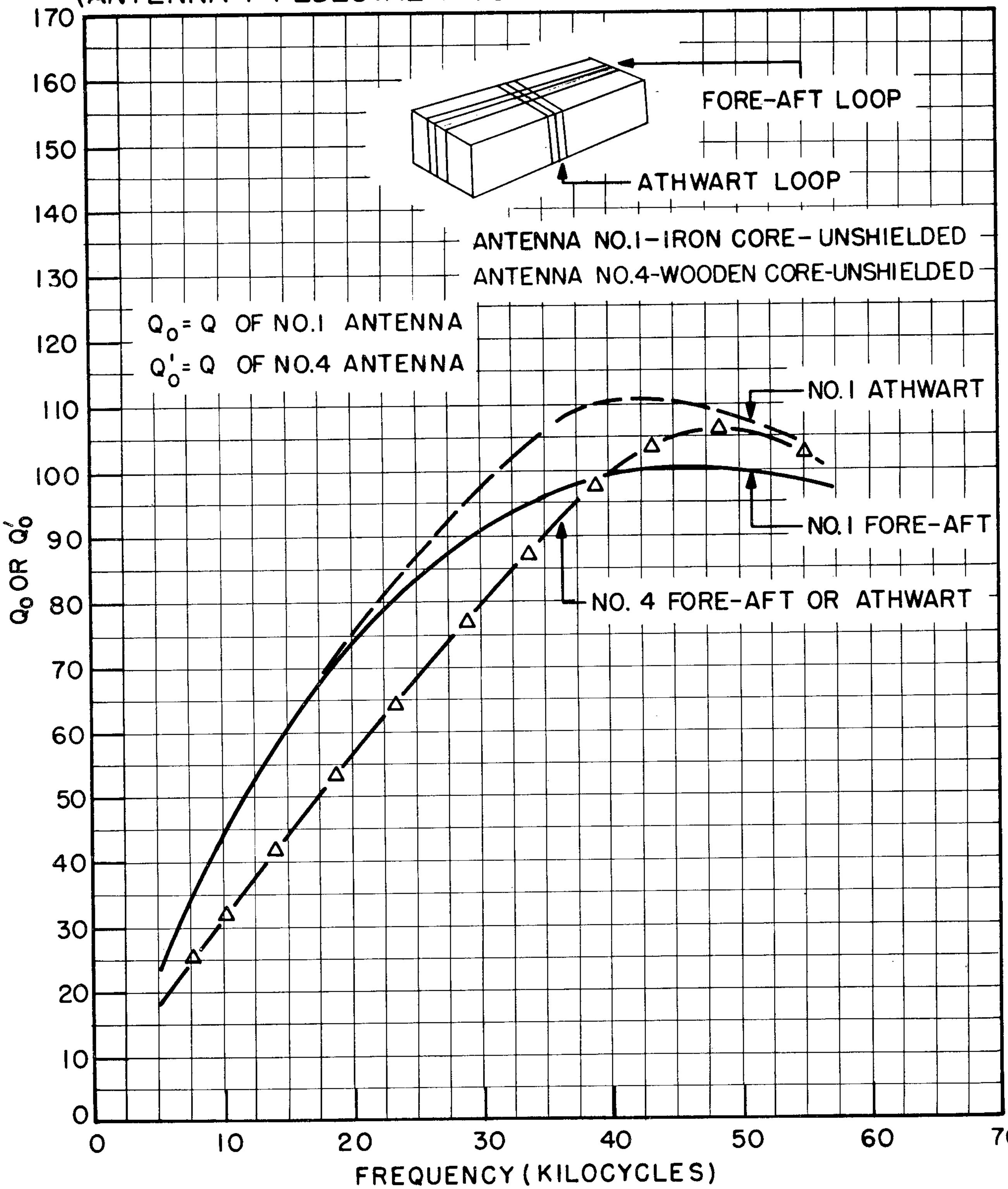

FIG. 8

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EFFECTIVE OVERALL ANTENNA Q
(ANTENNA + PEDESTAL + 75 FOOT INTERCONNECTING CABLE)

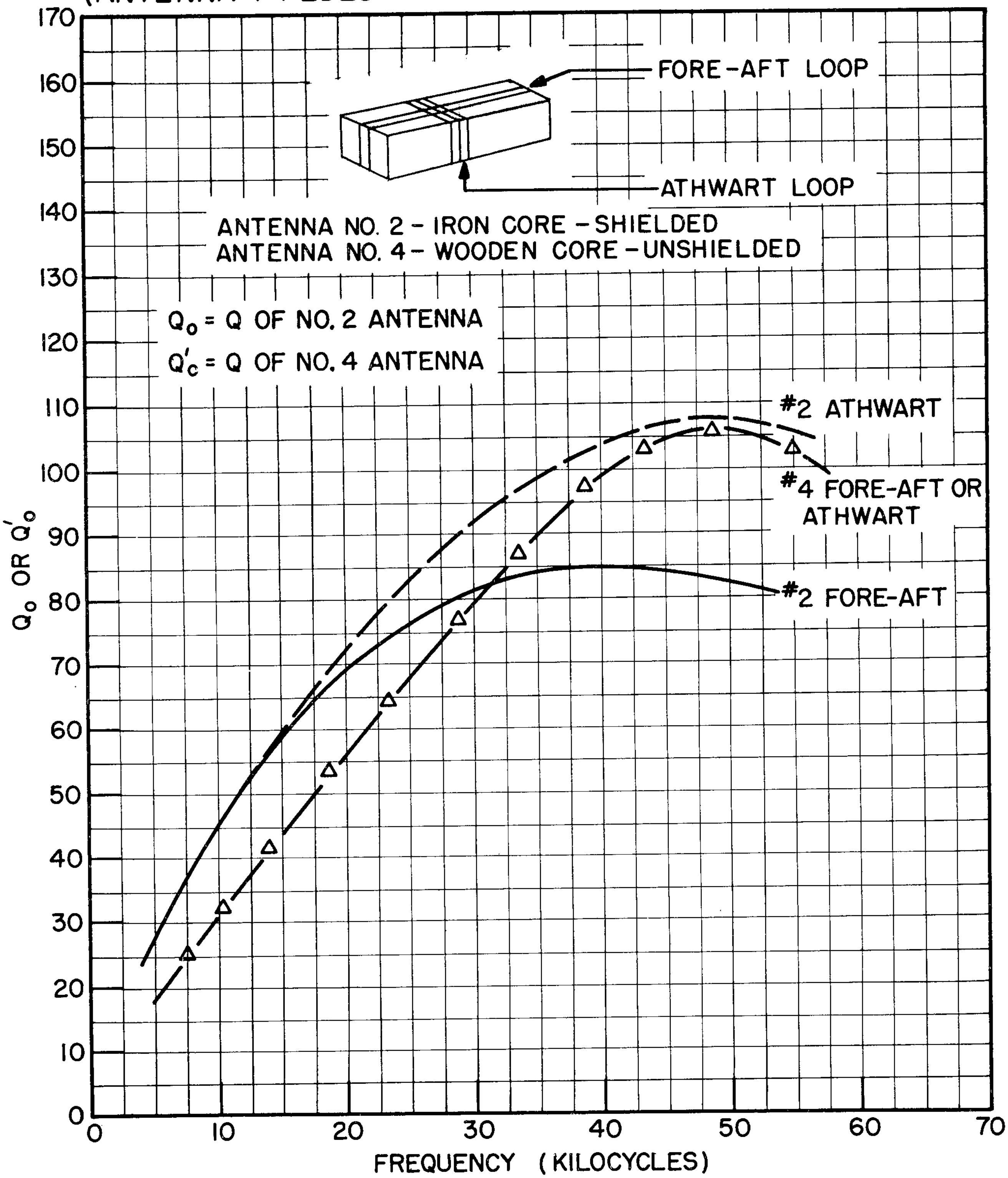

FIG. 9

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EFFECTIVE OVERALL ANTENNA Q
(ANTENNA + PEDESTAL + 75 FOOT INTERCONNECTING CABLE)

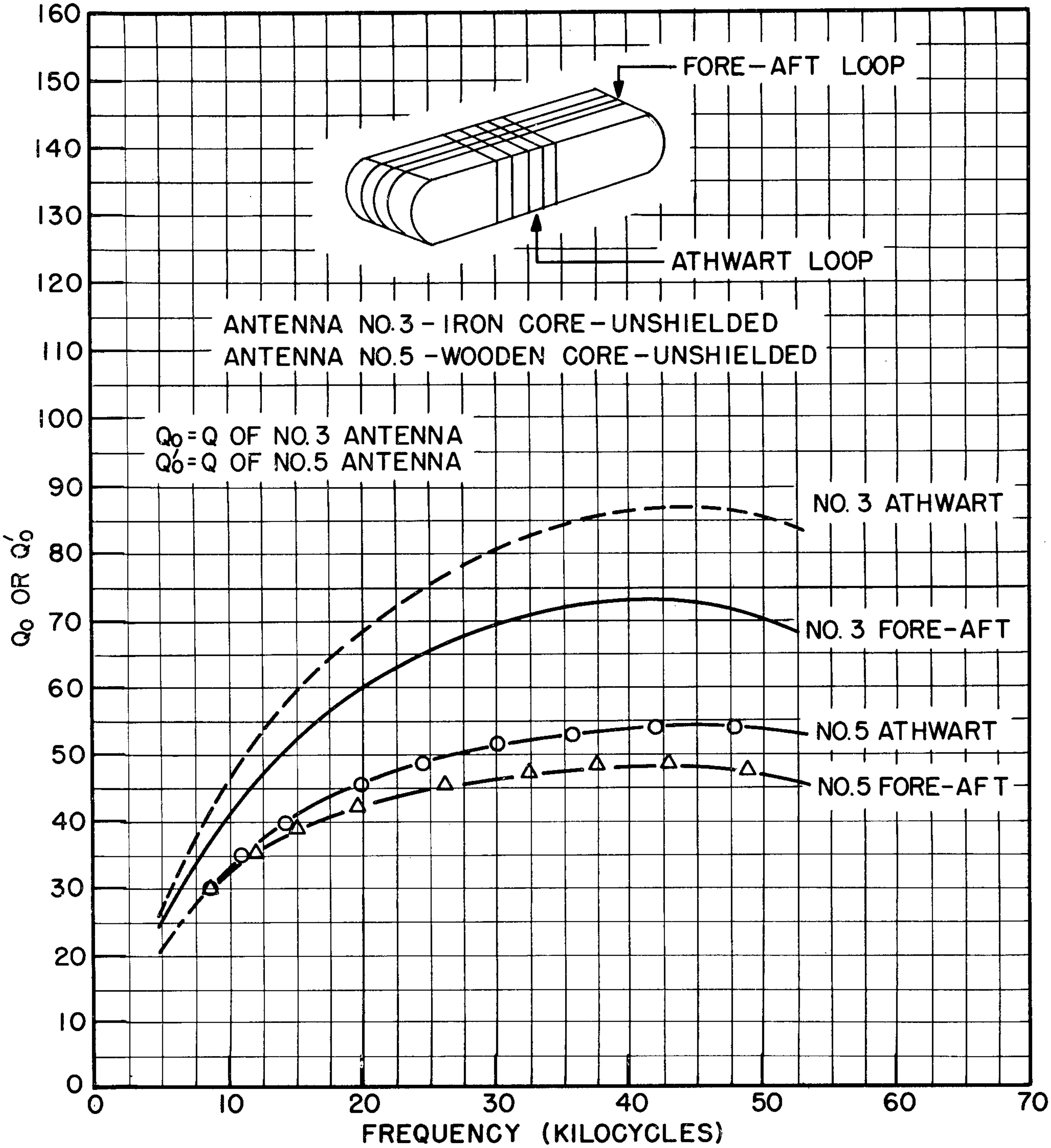

FIG. 10

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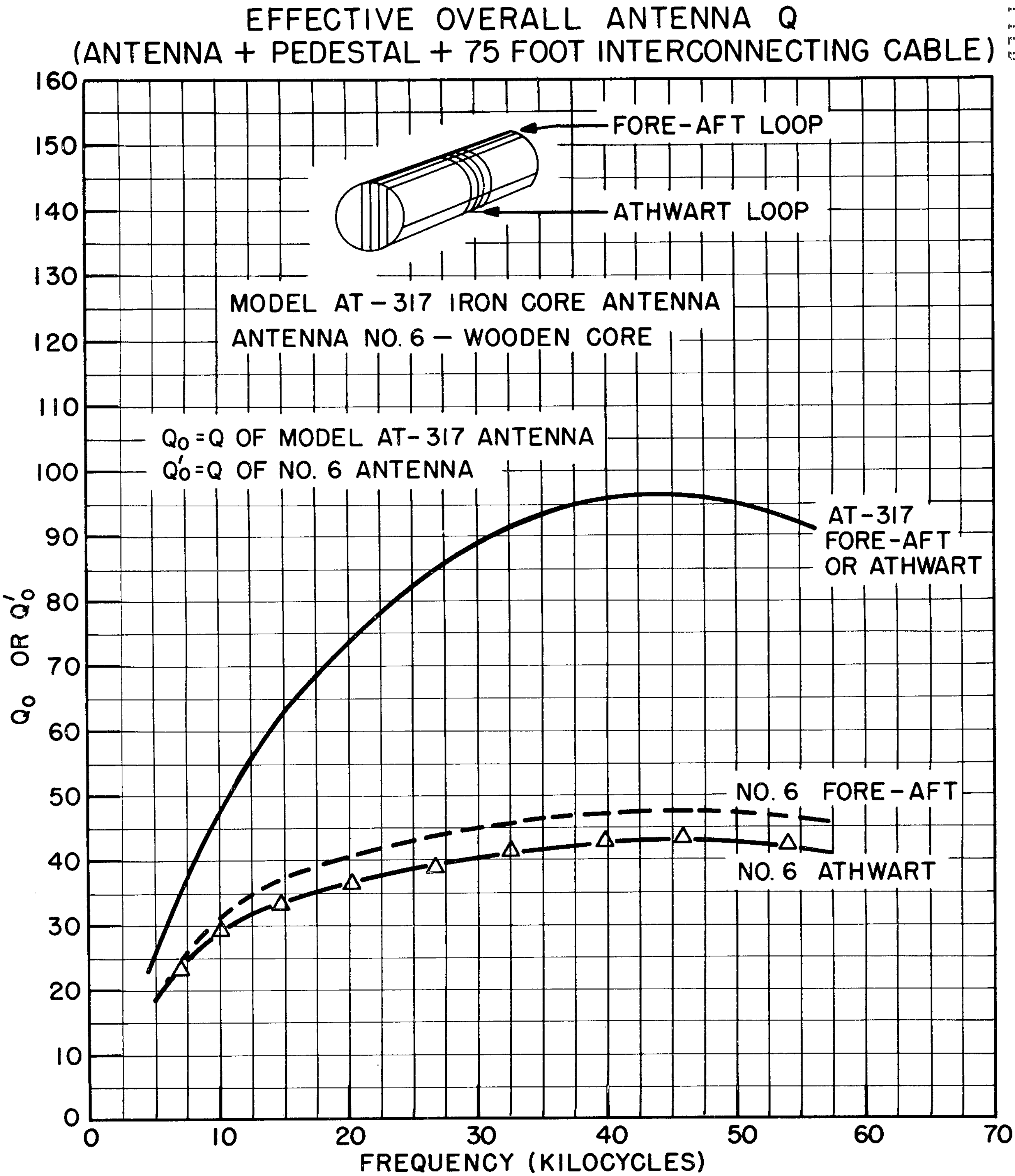

FIG. 11

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VARIATION OF EFFECTIVE OVERALL LOOP ANTENNA INPUT CIRCUIT S/N RATIO AS A FUNCTION OF LOOP ANTENNA Q RATIO CHANGE FOR DIFFERENT INITIAL Q VALUES OF LOOP ANTENNA (COMPUTED)

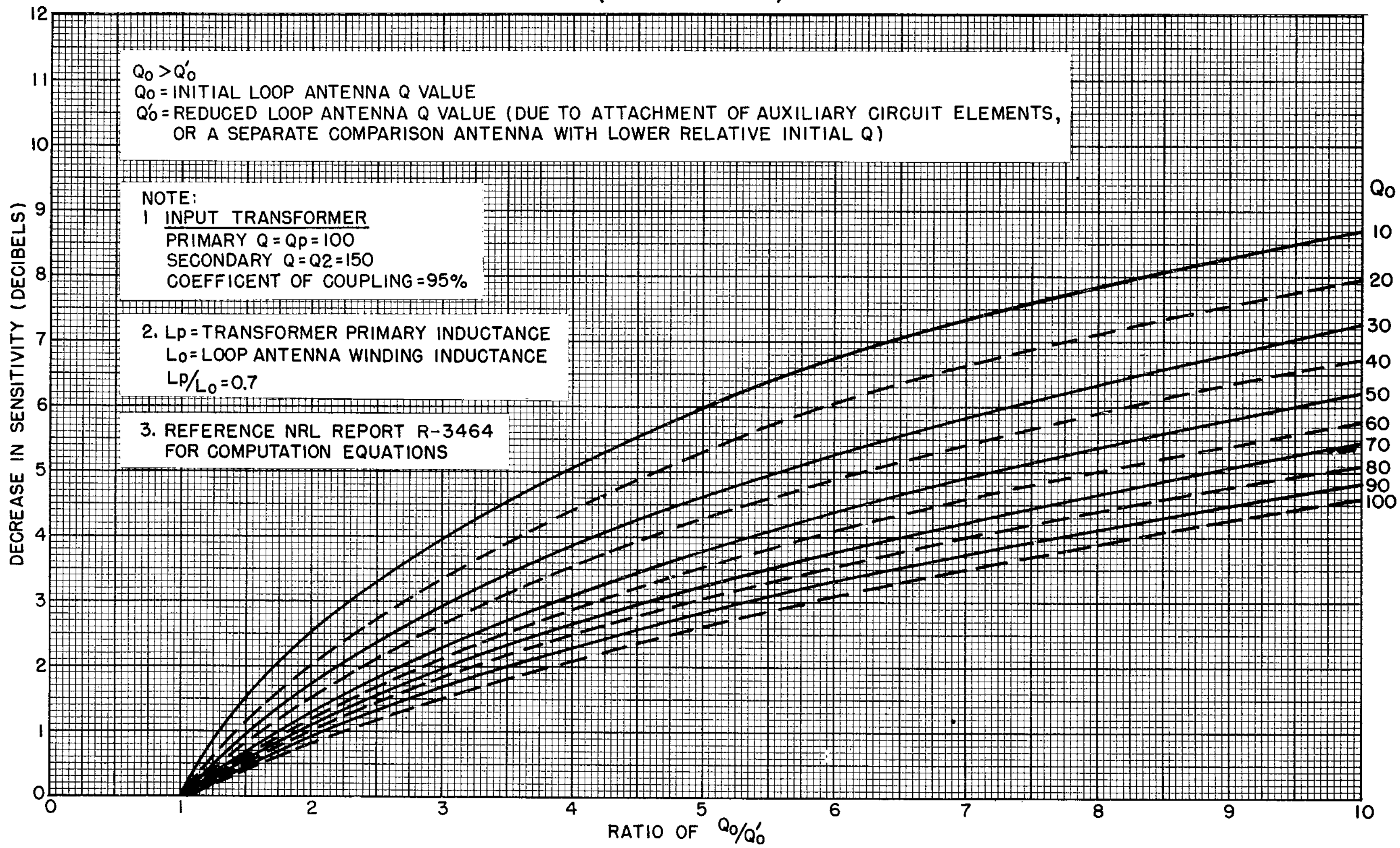

FIG. 12

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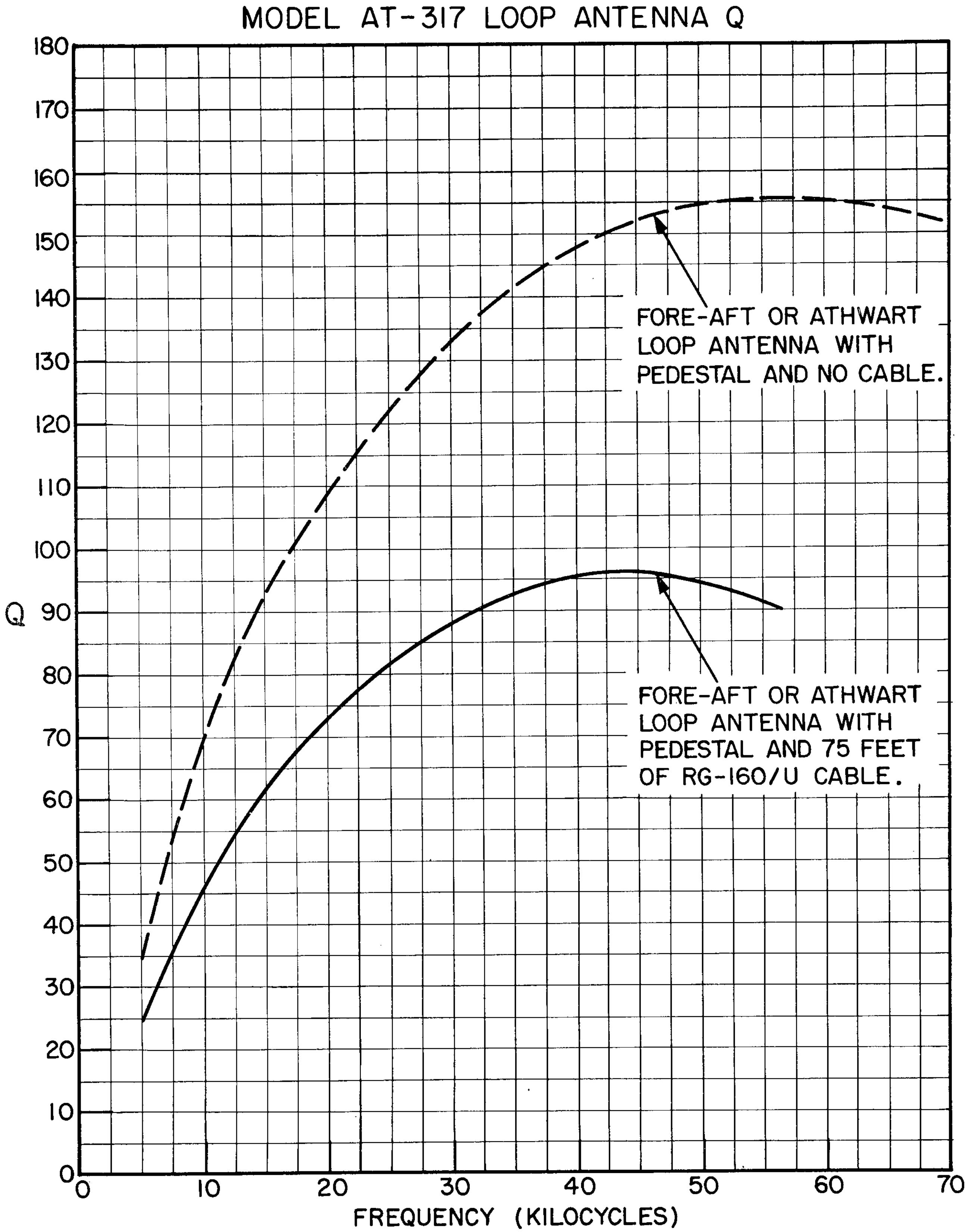

FIG. 13

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PICKUP SUPERIORITY OF EXPERIMENTAL LOOP ANTENNAS RELATIVE TO MODEL AT-317 LOOP ANTENNA

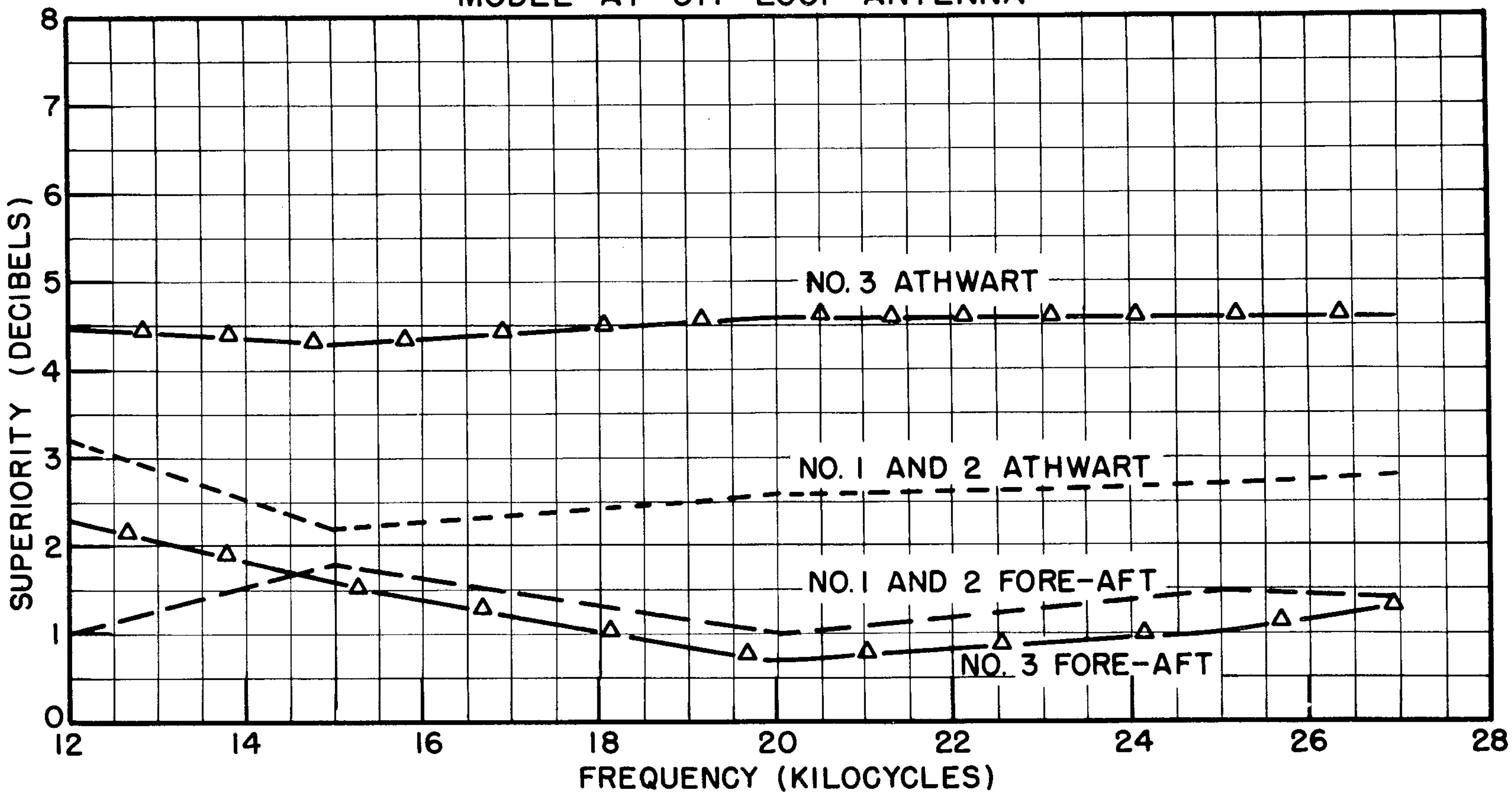

FIG. 14

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LOOP ANTENNA PICKUP IMPROVEMENT DUE TO IRON CORE
LOOP ANTENNAS NOS. 1 AND 2

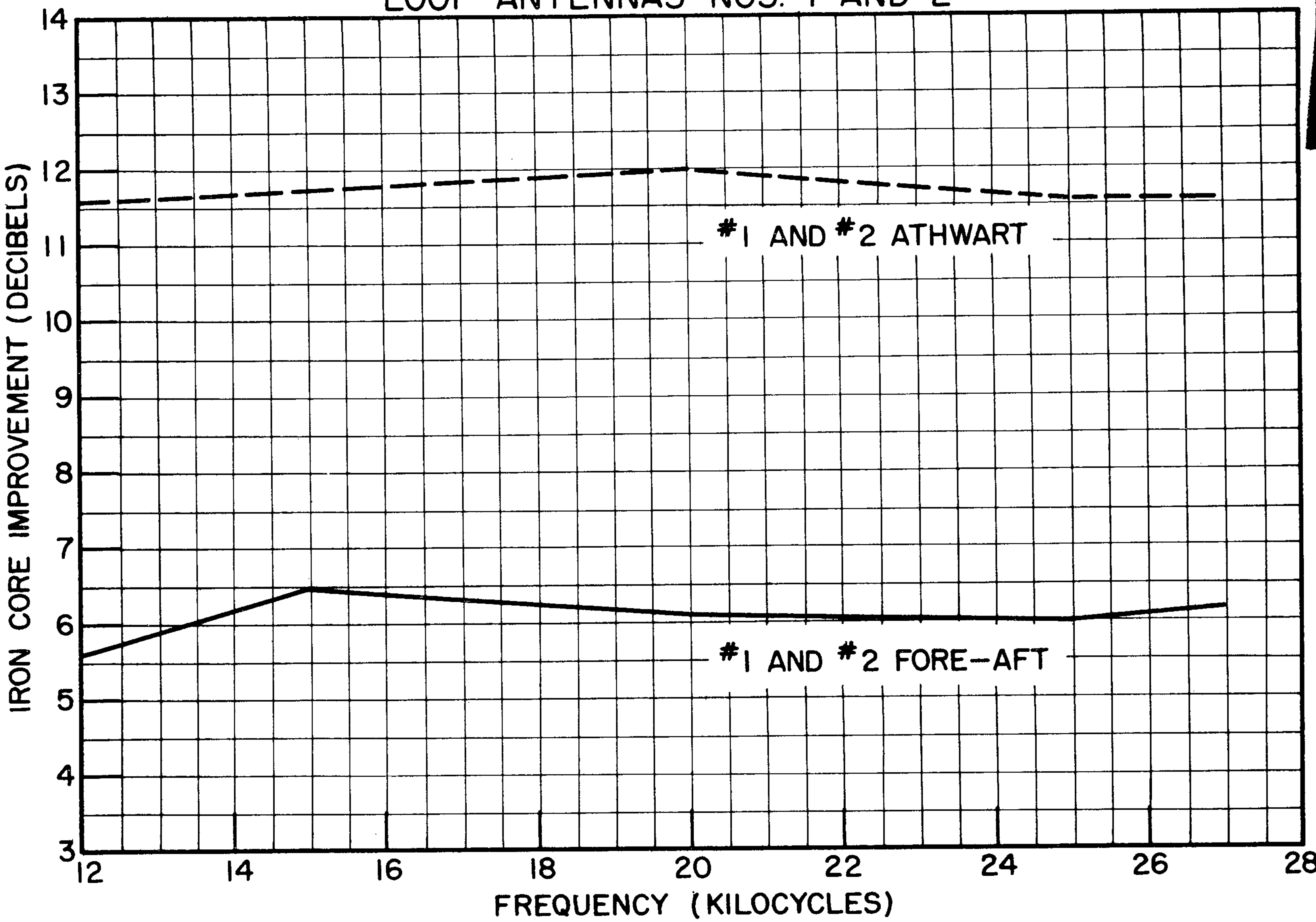

FIG. 15

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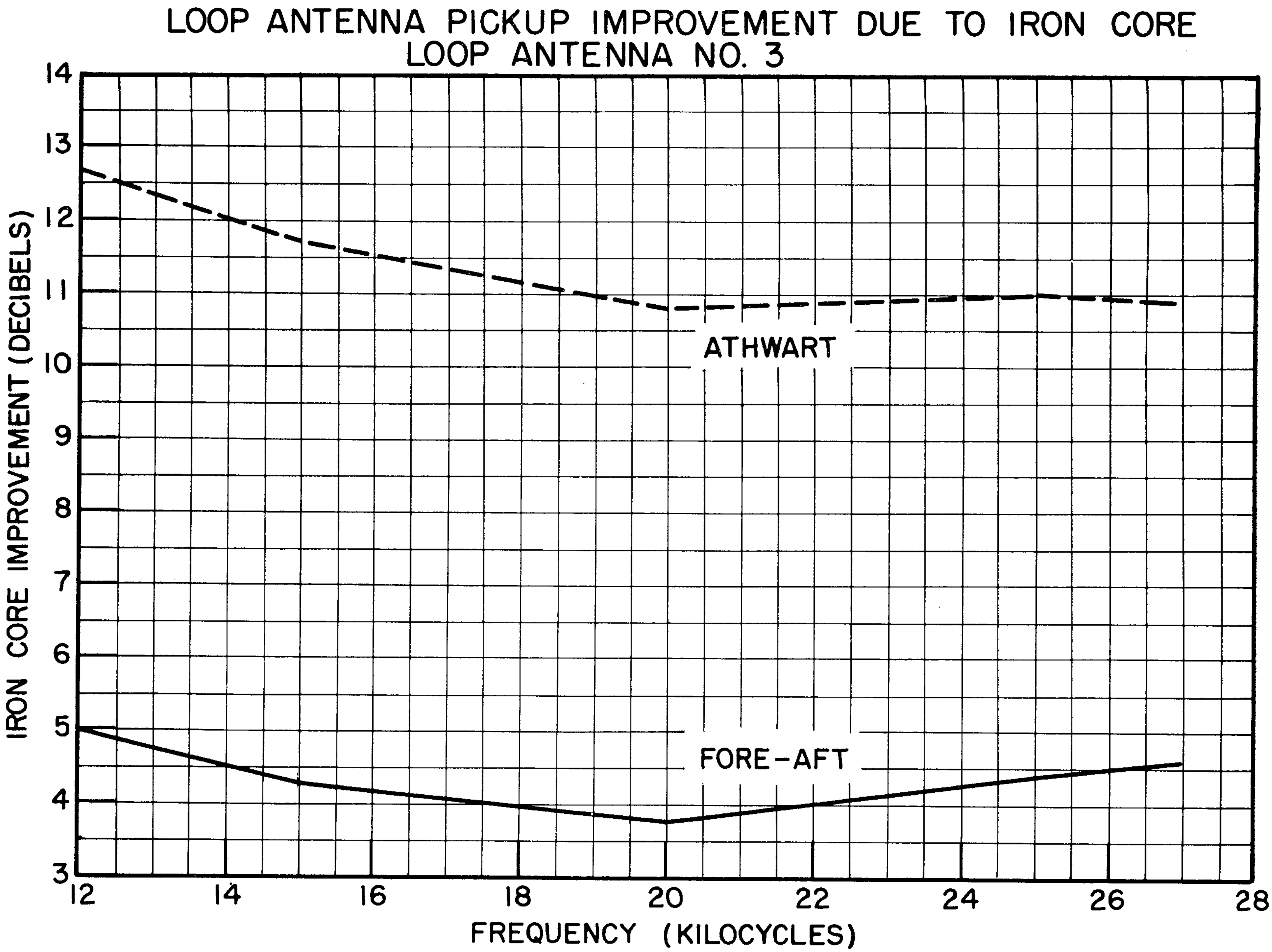

FIG. 16

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LOOP ANTENNA PICKUP IMPROVEMENT DUE TO IRON CORE
MODEL AT-317 ANTENNA

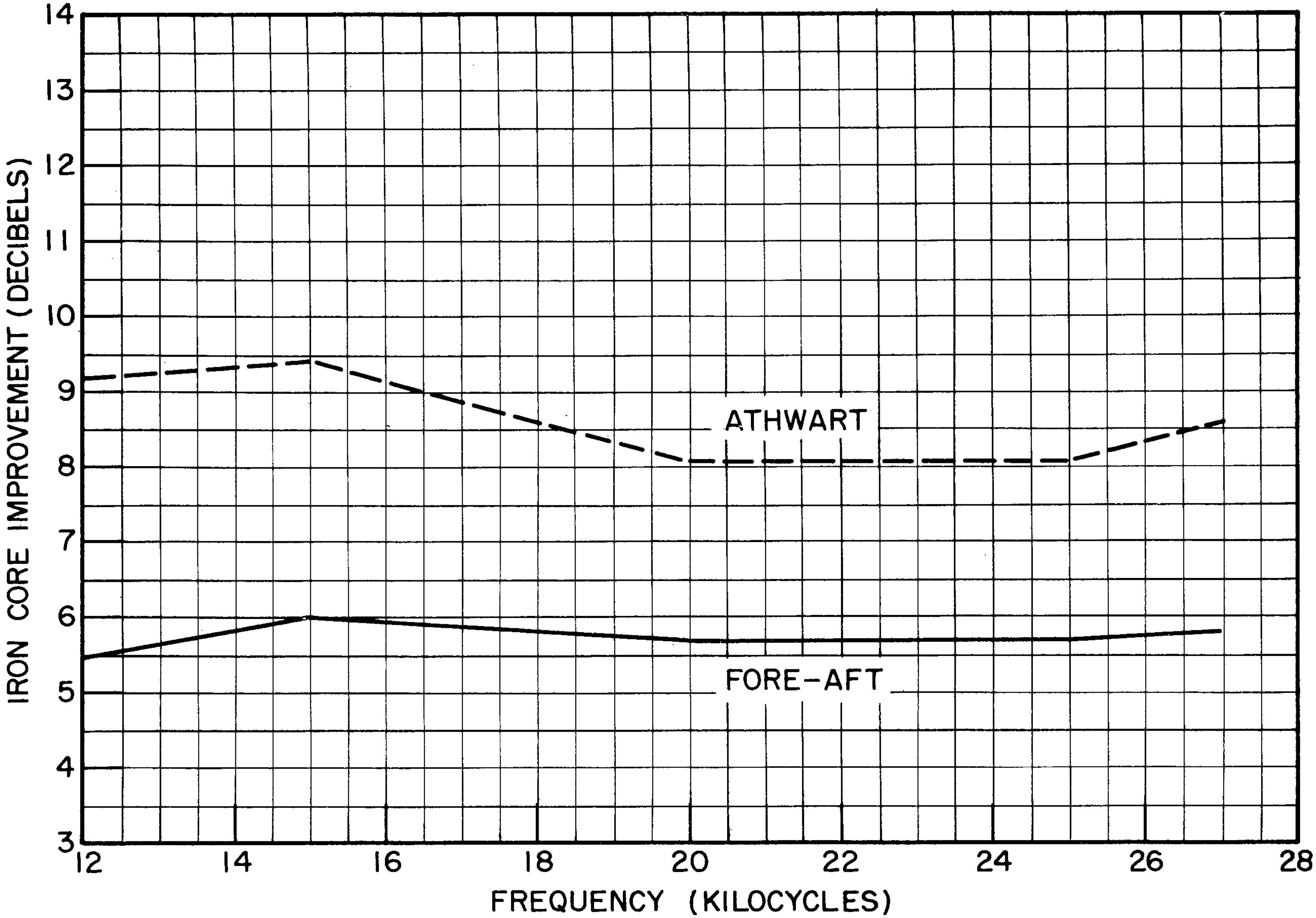

FIG. 17

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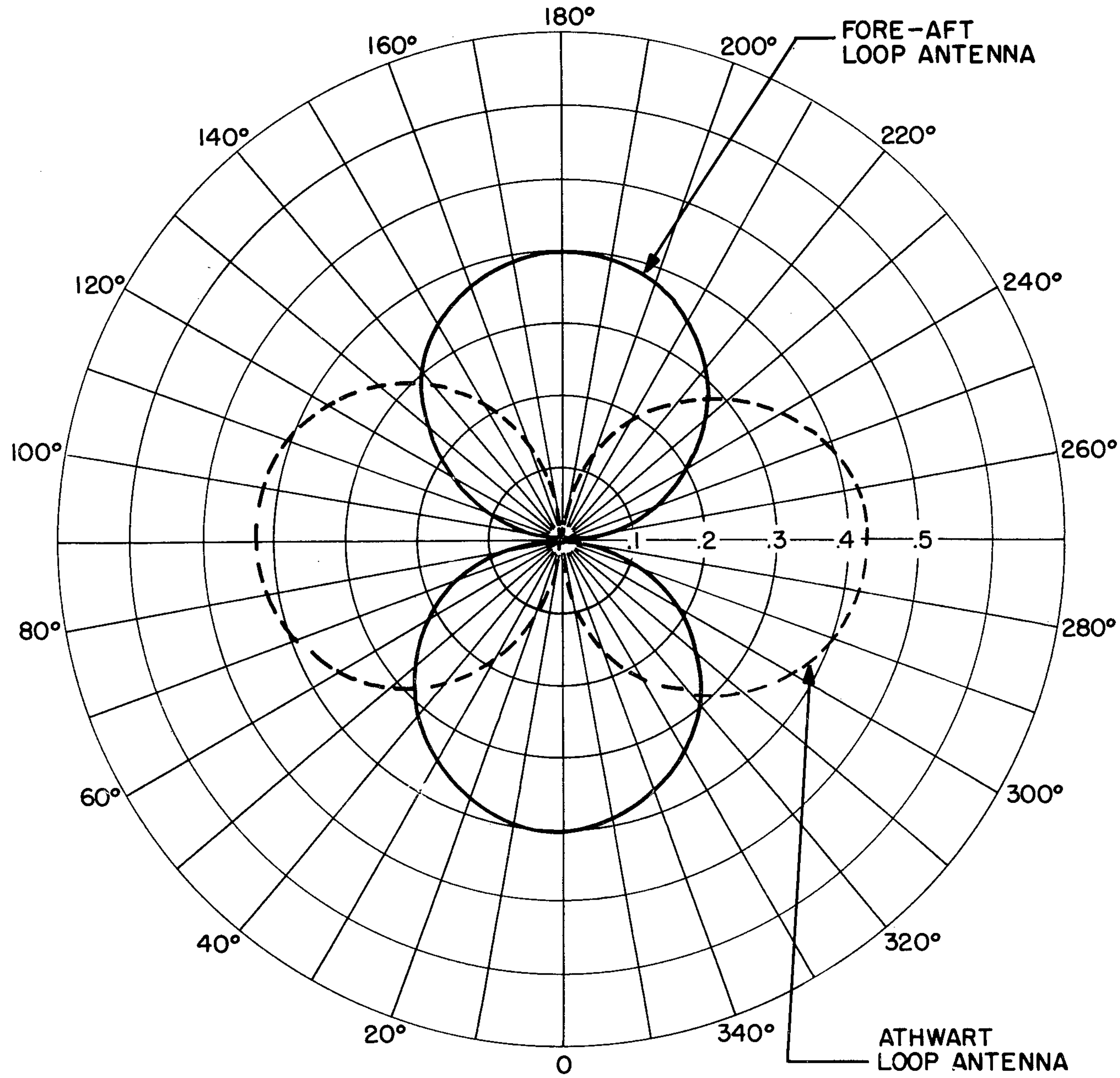
ANTENNA PATTERNS OF LOOP ANTENNA NO. 1 (20 KILOCYCLES)



NOTE: MAXIMUM AMPLITUDES BETWEEN WINDINGS DIFFER BY 0.4 DECIBELS.

FIG. 18

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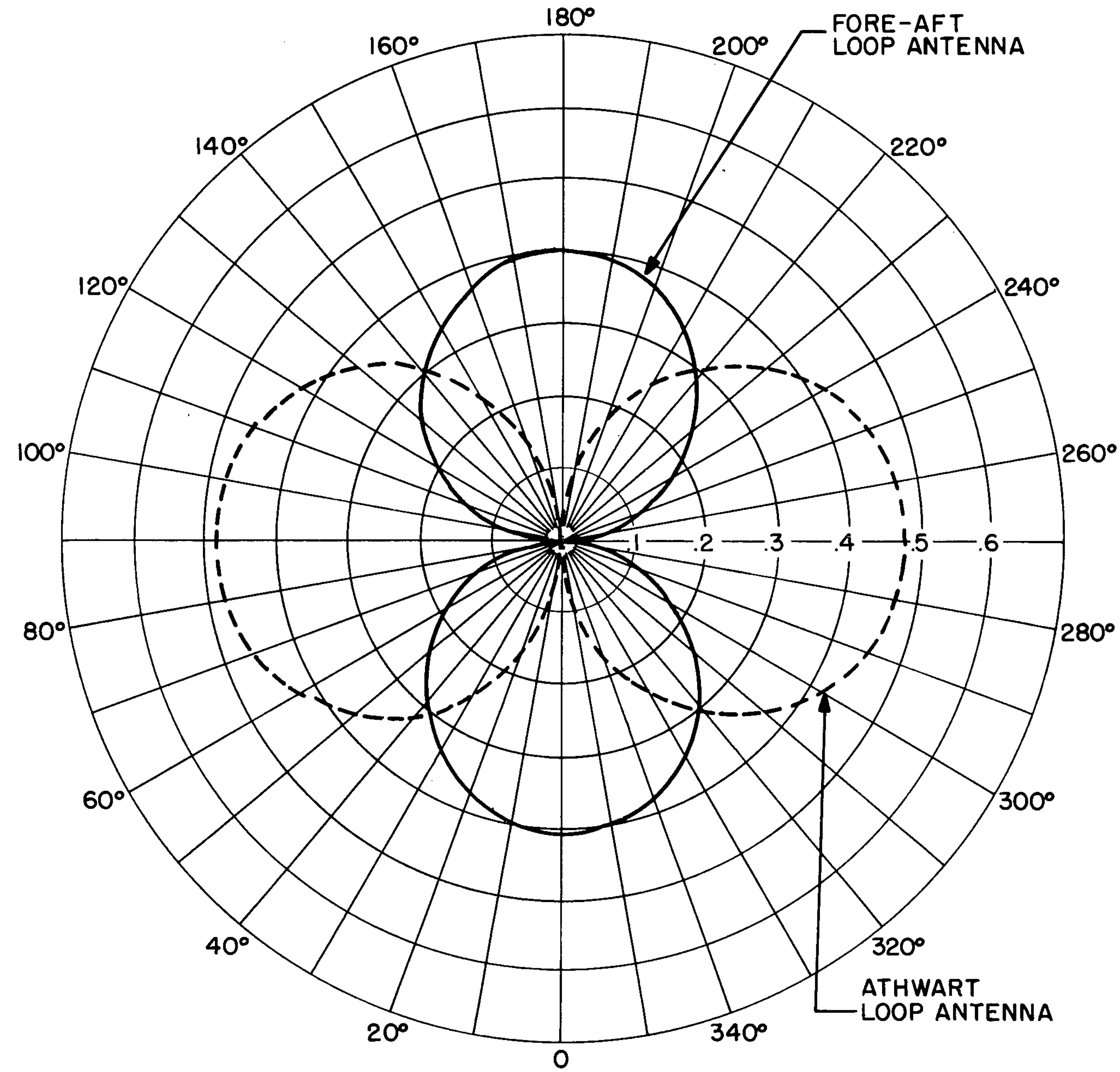
ANTENNA PATTERNS OF LOOP ANTENNA NO. 2
(20 KILOCYCLES)



NOTE: MAXIMUM AMPLITUDES BETWEEN WINDINGS DIFFER BY 1.3 DECIBELS.

FIG. 19

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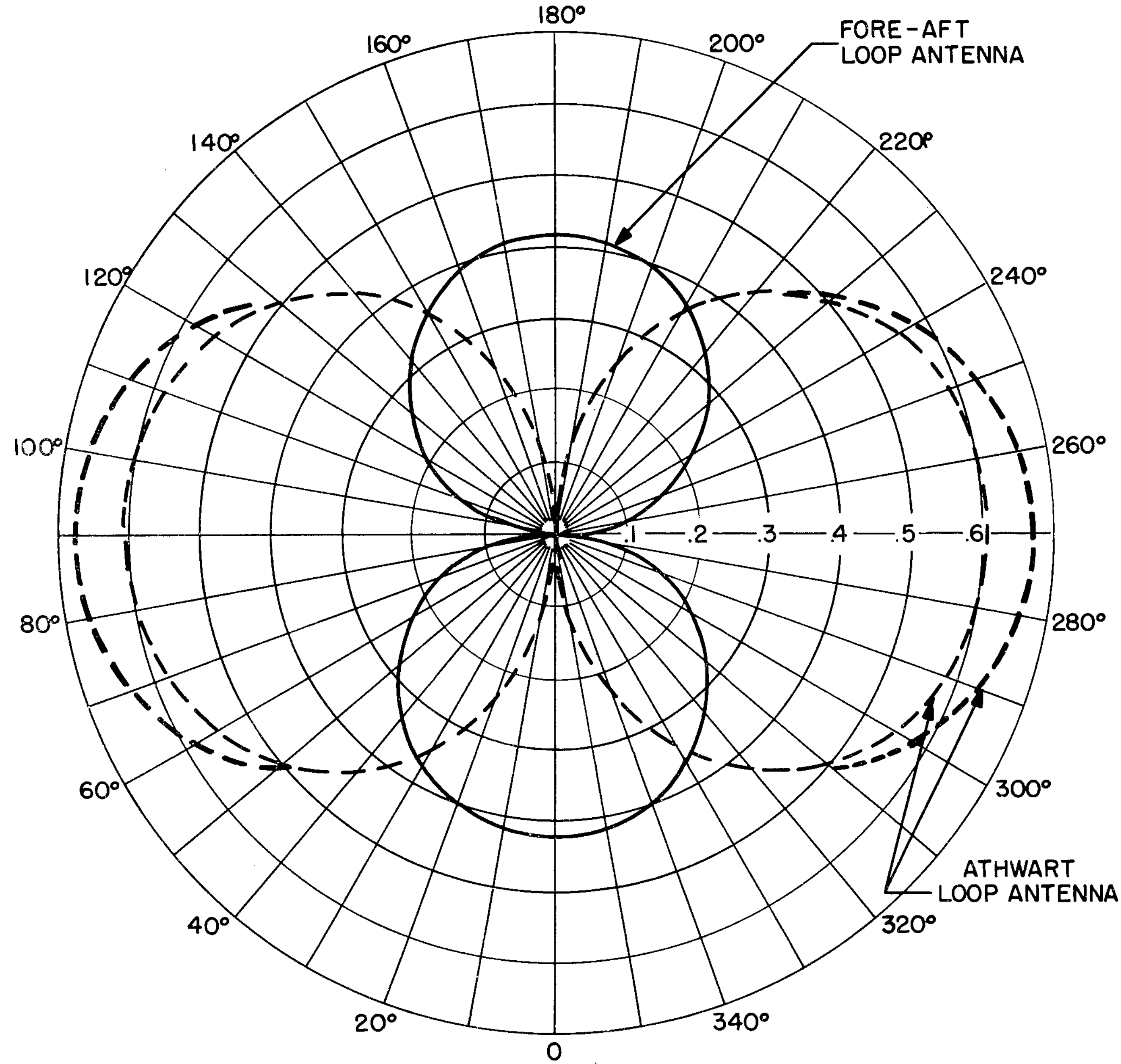
ANTENNA PATTERNS OF LOOP ANTENNA NO. 3
(20 KILOCYCLES)



NOTE: MAXIMUM AMPLITUDES BETWEEN WINDINGS DIFFER BY 4.3 DECIBELS.

– – – MEASURED

━ ━ ━ EXTRAPOLATED (ALLOWING FOR AMPLIFIER SATURATION)

FIG. 20

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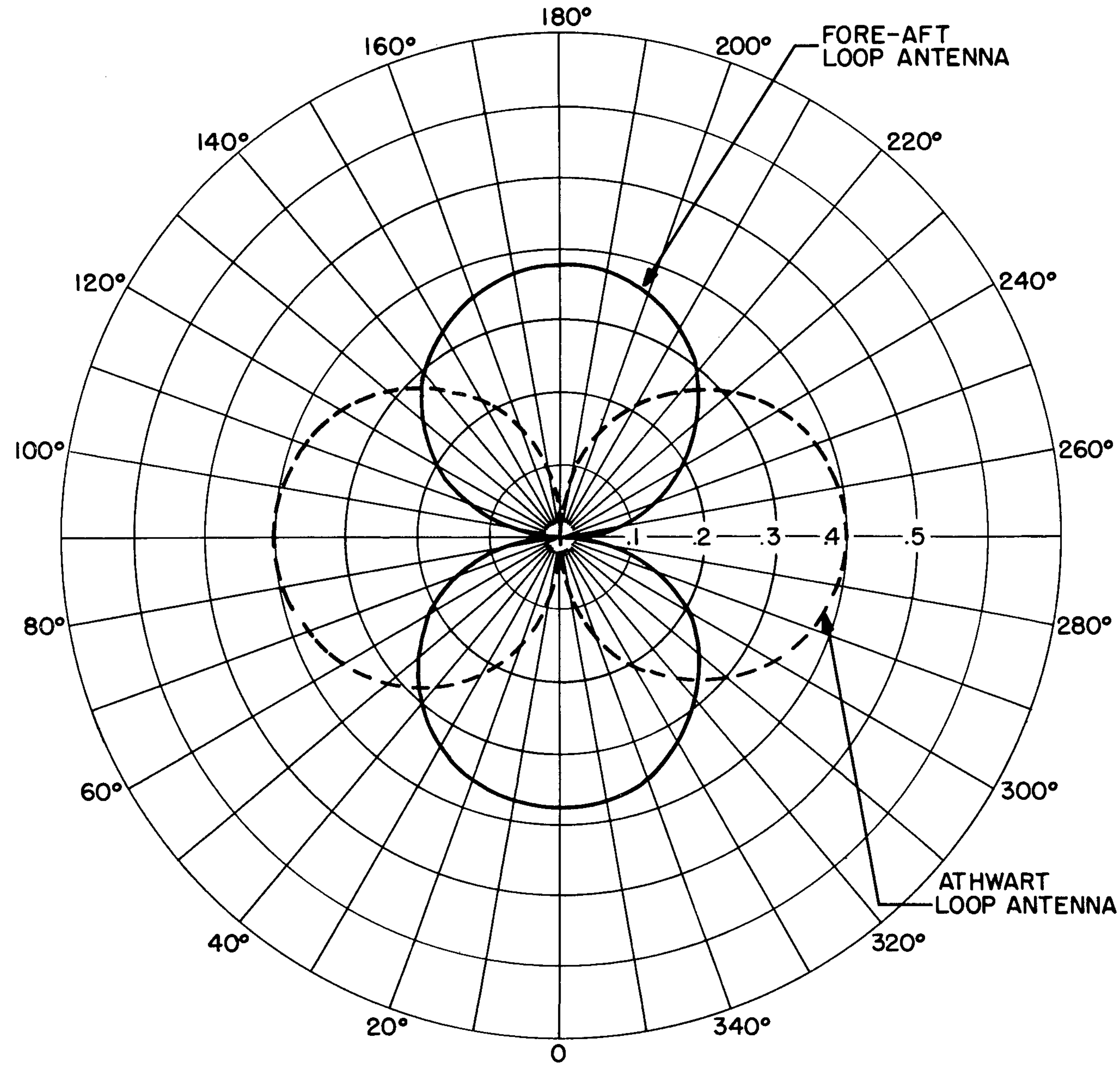
ANTENNA PATTERNS OF MODEL AT-317 LOOP ANTENNA
(20 KILOCYCLES)



NOTE: MAXIMUM AMPLITUDES BETWEEN WINDINGS DIFFER BY 0.4 DECIBELS

FIG. 21

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