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TEST RESULTS FOR THE MOORING LINE DATA LINE

Doyle A. Ellerbruch

Electromagnetics Division
Institute for Basic Standards
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Final Report

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U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W Roberts, Director

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TEST RESULTS FOR THE MOORING LINE DATA LINE

Results obtained from the Mooring-Line-Data-Line (MLDL) measurements program are presented. Frequency and time domain measurements were made to determine characteristic impedance, input impedance, current, and propagation parameters. Most of the measurements were made with an MLDL deployed specifically for this program, however some were made on an MLDL used to moor a buoy.

Keywords: Characteristic impedance; coupler; current; impedance; input impedance; mooring line data line; propagation characteristics; transmission line.

1.0 INTRODUCTION

The measurement program developed to determine the electrical parameters of the Mooring-Line-Data-Line (MLDL) has been completed. The work was performed by the Electromagnetics Division of the National Bureau of Standards during 1972, under NOAA sponsorship.

The MLDL is an eight-conductor woven harness, where each conductor is encased in a polyethylene jacket and imbedded in a synthetic fiber rope. The MLDL is approximately 550 meters long.

Three separate series of experiments were conducted. The first series was conducted aboard the US Coast Guard Cutter Acushnet at Gulfport, Mississippi, April 10-11, 1972. The objective was to check out test procedures that were being incorporated into the MLDL test plan [1], and to obtain data on electrical ground planes planned for use on the deployed buoys. Very short lengths (30 meters or less) of RG-8/U coaxial cable, having its braided outer conductor stripped away, were used to simulate the MLDL.

The second series was conducted aboard an Environmental Buoy (EB-10), June 23, 1972, one week after the buoy was deployed in the Gulf of Mexico. The objective was to obtain data on the MLDL in its deployed operational state. A special test plan was developed for these experiments [2].

The third series was conducted at the U.S. Navy's Atlantic Undersea Test and Evaluation Center (AUTEC), Andros Island, Bahamas, September 8-14, 1972, where an eight-conductor MLDL was deployed specifically for the measurements program defined in the test plan [1].

The results obtained from the experiments are summarized here. The measurement objectives, procedures, resources, theory, and data reduction methods are discussed in detail in the test plan previously reported. Equations and computer programs for calculating the propagation properties of the MLDL have been reported separately [3].

Section 1 is the introduction, and section 2 describes the MLDL deployment configurations.

Section 3 summarizes results obtained with the Time Domain Reflectometer in evaluating the ground planes, in measuring the characteristic impedance and the velocity of propagation, and in locating line discontinuities such as couplers.

Section 4 summarizes results obtained at discrete frequencies in determining the propagation parameters, the current standing wave pattern, and the wire-to-wire coupling.

2.0 DEPLOYMENT CONFIGURATIONS

2.1 USCGC Acushnet Experiments

These experiments were conducted from the fantail of the Acushnet. RG-8/U coaxial cables with their outer shields removed were used as a single strand MLDL. Lengths of approximately 8, 16, and 32 meters were placed approximately horizontal in sea water such that both the input and termination ends were accessible at the surface.

2.2 Environmental Buoy Experiments

These experiments were conducted on the deck of EB-10 after it had been moored. The MLDL extended approximately vertically into the sea and was under considerable tension due to the anchoring function of the MLDL. The manufactured length was approximately 525 meters. The actual length when placed under tension is unknown.

2.3 AUTEC Experiments

The experiments were conducted from a U.S. Navy barge. The MLDL had a "dry" length of 547 meters (1795 feet). It was deployed first in a horizontal position and finally in a vertical position for testing at sea.

2.3.1 Horizontal Deployment

The barge was anchored in water that was at least 18 meters (60 feet) deep. A small buoy was anchored approximately 600 meters away. The deployed MLDL extended from the deck of the barge to the buoy. Approximately 535 meters (1750 feet) of the MLDL was under water. The MLDL was supported horizontally 9 meters (30 feet) below the surface by a series of synthetic fiber guylines attached to floats. A guyline was attached every 6 meters (20 feet) along the entire length of the MLDL.

The input end of the MLDL extended through approximately 18 meters (60 feet) of 7.6 cm (3 inches) diameter flexible metallic tubing. The tubing had two purposes. First, it formed a coaxial outer conductor for the portion of the MLDL that extended from the water surface up to the instrumentation on the deck of the barge. Second, approximately 6 meters (20 feet) of the flexible tubing extended below the waters surface and was used as the electrical ground plane at the input end.

The termination end was underwater but could be retrieved, when required, from the anchored buoy.

The electrical conductor in each strand was individually connected to terminal blocks at both the input and the termination ends. A shorting bus was used to connect all the electrical conductors together at the termination end. The bused terminations were connected coaxially to a cylindrical galvanized metal ground plane that was 20 cm (8 inches) in diameter and 2.25 (7 feet) long.

No Ocean Sensor Housings were attached to the MLDL when it was deployed horizontally.

2.3.2 Vertical Deployment

The barge was towed into water that was at least 600 meters (2000 feet) deep. The barge was held in a "zero-drift" position with a powered craft.

The deployed MLDL extended vertically into the water from the deck of the barge. The flexible metallic tubing arrangement at the input to the MLDL used in the horizontal deployment was also used in the vertical deployment.

The cylindrical ground plane at the termination end was loaded with anchor chain to keep the MLDL in a nearly vertical position while deployed.

Two Ocean Sensor Housings were attached to the MLDL. One contained a split-core coupler and was attached 305 meters (1000 feet) from the input end. The other contained a solid-core coupler and was attached 518 meters (1700 feet) from the input end. Both Ocean Sensor Housings were attached during all the measurements with the vertically deployed MLDL.

3.0 TIME DOMAIN DATA

A Time Domain Reflectometer (TDR) was used to accomplish several objectives in this measurement program. The performance of the TDR and the data obtained with it were, to a large extent, as anticipated.

TDR measurements are especially useful in non-dispersive networks which have single mode propagation. Unfortunately, seawater is a dispersive electromagnetic medium in that its attenuation constant is a function of frequency and its phase constant is not proportional to frequency. However, it was learned from the Acushnet measurements that the electrical characteristics of seawater would not seriously degrade the usefulness of the TDR in evaluating MLDL termination ground planes, uniformity of parameters, and continuity checks.

EB-10 and AUTEC data were collected as a function of the number of strands driven in parallel. Those strands not in use were individually terminated in their characteristic impedance at the input end.

3.1 Evaluation of the Ground Planes

The objectives of these measurements were to characterize the ground planes in terms of size, geometry, and resistance at the metallic conductor-seawater interface.

The termination resistance values were obtained by analyzing the responses of the TDR with respect to selected termination resistances. An open-circuit termination was accomplished by lifting the ground plane out of the water.

Ground planes of various geometries, sizes and materials were measured. A summary of the results is given on Figure 1.

3.2 Characteristic Impedance

The objective of these measurements was to determine the characteristic impedance of the MLDL. Impedance magnitude values were obtained by analyzing the responses of the TDR with respect to the responses obtained with selected termination resistances.

A summary of results are given in Figure 2. The measured values obtained on EB-10 are significantly higher, probably because the MLDL was under tension. It is probable that the cross-section dimensions of the line changes under tension by an amount necessary to produce the measured differences. For example, the helically wound center conductor will tend to straighten under tension, resulting in a smaller effective inner conductor diameter. Further, the synthetic fibers may not be water saturated under tension, resulting in a larger effective outer conductor diameter. Either of these effects would tend to produce a higher characteristic impedance when the MLDL is placed under tension.

Not shown on Figure 2 is the characteristic impedance of the single strand RG-8/U lines. Their measured value, Z_o = 95.2 ohms, is significantly different than that obtained with the MLDL because materials and cross-sectional dimensions are different.

3.3 Velocity of Propagation

The objective was to determine the velocity of propagation of a signal on the MLDL. The results were obtained as the ratio of twice the MLDL "dry" length to the total propagation time measured with the TDR.

A summary of the results are tabulated on Figure 3. The measured value obtained on EB-10 is higher than that obtained with the vertically deployed MLDL at AUTEC. Changes in the physical dimensions as discussed in section 3.2 would be directly applicable here also. It should be noted, however, that the actual length of the EB-10 MLDL is not known. Further, it was assumed that the length of the AUTEC MLDL remained at 547 meters when deployed vertically.

3.4 Discontinuity and Coupler Locations

The objectives of these measurements was to determine if the TDR has sufficient sensitivity to detect a discontinuity in the electrical parameters of the MLDL. During the horizontal deployment experiments at AUTEC the MLDL was lifted out of the water at a point 250 meters from the input end to form a discontinuity. During the vertical deployment the Ocean Sensor Housings with couplers installed were considered as discontinuities. Even though these discontinuities were not detected with the TDR, it is believed that discontinuities as gross as a metallic conductor break would be detectable because large changes in the characteristic impedance will occur when the number of conductors in parallel changes as shown on Figures 1 and 2.

4.0 FREQUENCY DOMAIN DATA

4.1 Results at Test Frequency 7200 Hz

4.1.1 MLDL Parameters and Transmission Characteristics

The objectives in these measurements was to determine values for the four fundamental line parameters; self-inductance L, wire-to-seawater capacitance C, series resistance R, and shunt conductance G, and to determine the characteristic impedance Z_o, the complex propagation constant, and the input impedance when the MLDL is terminated in a short circuit.

Test data consisted of complex input impedance measurements when the MLDL was terminated first in a short-circuit and later in an open-circuit. The physical "dry" length of the MLDL was used in data reduction by assuming that its "wet" and "dry" lengths were identical.

Results derived from the test data are given in Figures 4 to 8. Figure 5 is a comparison of the resistance data obtained at dc and 7200 Hz. The dc values were obtained by measuring the resistance of the metallic conductors only and does not, therefore, include the resistance of the seawater.

4.1.2 Current Standing Wave Pattern

The objective of these measurements was to determine the current standing wave pattern with the MLDL operated at its anticipated operational current input (1 ampere) and terminated in a short circuit.

Current data were obtained for both horizontal and vertical deployments. In the horizontal deployment a coupler was moved from the termination end to the input end of the MLDL in increments of 15 meters. An ac voltage was measured at the terminals of a 12-turn secondary transformer in the coupler. A coupler rectified current output was also measured by connecting a full wave bridge rectifier, having a 144 ohm load resistance, to the secondary terminals.

In the vertical deployment the couplers mounted with Ocean Sensor Housings were used. Each Ocean Sensor Housing contained a full wave bridge rectifier having a 144-ohm load resistor, and a battery-powered strip chart recorder.

The Sensor Deck Unit (SDU) power amplifier used to supply current to the input to the MLDL was evaluated. Data on SDU performance were obtained for both deployments. The objective was to determine how the SDU should be adjusted so that it would deliver 1 ampere at the input of the MLDL during subsequent current standing wave measurements. Variables in these experiments were the number of MLDL strands driven, the position of a coupler on the MLDL, and the SDU output tap number. Results are given in Figures 9 through 12. The apparent input current steps observed in Figure 11 resulted from the resolution of the current meter used in the experiments.

Figures 13 and 14 are the current standing wave patterns obtained with the split core and the solid core couplers used in these experiments. A single current value obtained with eight strands in parallel in the vertical deployment is also shown on Figures 13 and 14.

Figures 15 and 16 are the coupler secondary rms voltage values.

Data obtained with the MLDL deployed vertically are given in Figures 17 and 18.

Two experiments were tried to determine if the seawater within the coupler forms a short circuited secondary turn. In one experiment the split core coupler was installed 305 meters from the input end. Eight strands were driven in parallel which, for a 1.10 ampere input current, resulted in 17 vac rms across the secondary terminals, and 108 ma rectified current. The diameter of the MLDL at that point was then built up to the inner diameter of the coupler with 15 cm wide synthetic fiber tape in an attempt to keep the seawater from entering the volume between the MLDL and the coupler. Eight strands were again driven in parallel. The input current and secondary voltage remained the same, however the rectified current increased to 109 ma. It was the general consensus of those present that this attempt to keep seawater out of the coupler was not entirely successful.

The second experiment was done with the split core coupler 153 meters from the input. With the seawater in the coupler and eight strands connected in parallel the input current was 1.06 amperes, 14.0 vac rms was measured across the secondary and the rectified current output was 86 ma. The coupler was then lifted above the water surface. The input current remained constant while the secondary voltage dropped to 13.5 vac and the rectified current dropped to 82 ma.

4.2 Results as a Function of Frequency

4.2.1 MLDL Parameters and Transmission Characteristics

The objectives in these measurements was to determine values for line parameters, the characteristic impedance, the propagation constant, and the input impedance as a function of frequency when the MLDL is terminated in a short circuit.

Results derived from the test data are given in Figures 19 through 28. The parameters are calculated for frequencies from 5 kHz to 20 kHz.

4.2.2 Voltage Characteristics at the Input to the MLDL

The objective was to measure the magnitude of the voltage at the input of the MLDL as a function of frequency to determine the frequency at which it is one-quarter wavelength long. Data obtained from these measurements is shown in Figure 29. The peak of the curve occurs at the frequency where the line is one-quarter wavelength long, which is 27.6 kHz.

4.3.3 Wire-to-Wire Coupling

The objective of this measurement was to determine the wire-to-wire coupling between the center conductors of the MLDL. The power coupled from the driven to the undriven strands was measured. The coupling data derived from those measurements is given in Figure 30.

5.0 CONCLUSIONS

The objectives for the testing program were:

Task 1. Develop test plans and procedures for in situ testing of the Engineering Evaluation Platform Mooring-Line-Data-Line.

Task 2. Perform the in situ testing in accordance with the developed test plan.

Task 3. Perform auxiliary tests in situ or in the laboratory as required to meet the requirements of the test program.

The test plan and procedures were completed in May 1972. Measurements conducted aboard the US Coast Guard Cutter Acushnet and in the laboratory at Boulder, Colorado, were conducted prior to finalizing the test plans and procedures.

In situ testing of the eight-conductor MLDL was accomplished aboard the Environmental Buoy (EB-10), June 1972, and at the Atlantic Undersea Test and Evaluation Center (AUTEC), September 1972.

Data were obtained with measuring systems in the time domain and in the frequency domain.

The material and shape of the ground planes were found to be non-critical to the performance of the MLDL. A galvanized steel-seawater contact area of one square meter or larger is sufficient to provide a termination impedance less than one ohm.

The current standing-wave pattern was measured at the NOAA proposed operational frequency 7200 Hz. The pattern was determined to be a very smooth function along the MLDL, but sensitive to the number of strands driven in parallel.

The electrical characteristics of the MLDL were determined to be a function of the number of conductors driven in parallel. The characteristics become increasingly difficult to measure as the number of driven strands is increased, and as the frequency is increased.

6.0 ACKNOWLEDGMENTS

Many individuals are responsible for the success of this measurements program. Particular acknowledgments are made to Mr. Richard P. Mueller, Sperry Rand, Mr. William Rehman, General Electric, and the range staff at AUTEC.

7.0 REFERENCES

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[3] Single Strand Model Computer Programs for the Transmission Line Properties of the Mooring Line Data Line, by D.R. Holt and N.S. Nahman, April, 1973 (unpublished).

[4] MLDL Measurements on the Acushnet in April, by D.A. Ellerbruch, letter report submitted to the National Data Buoy Office, April 27, 1972 (unpublished).

[5] MLDL Measurements on EB-10, by D.A. Ellerbruch, letter report submitted to the National Data Buoy Office, July 25, 1972 (unpublished).

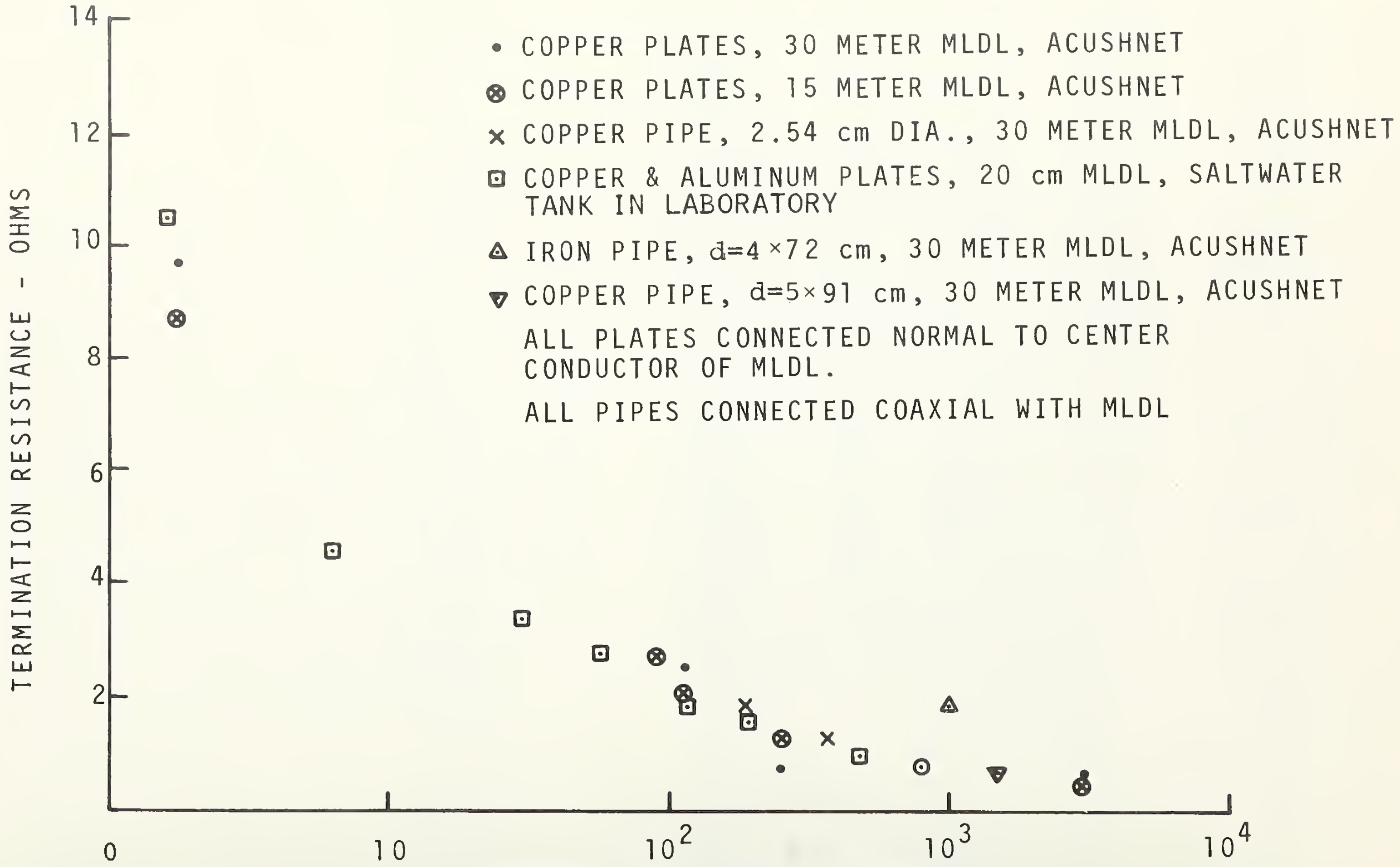

Figure 1. Ground Plane Resistance

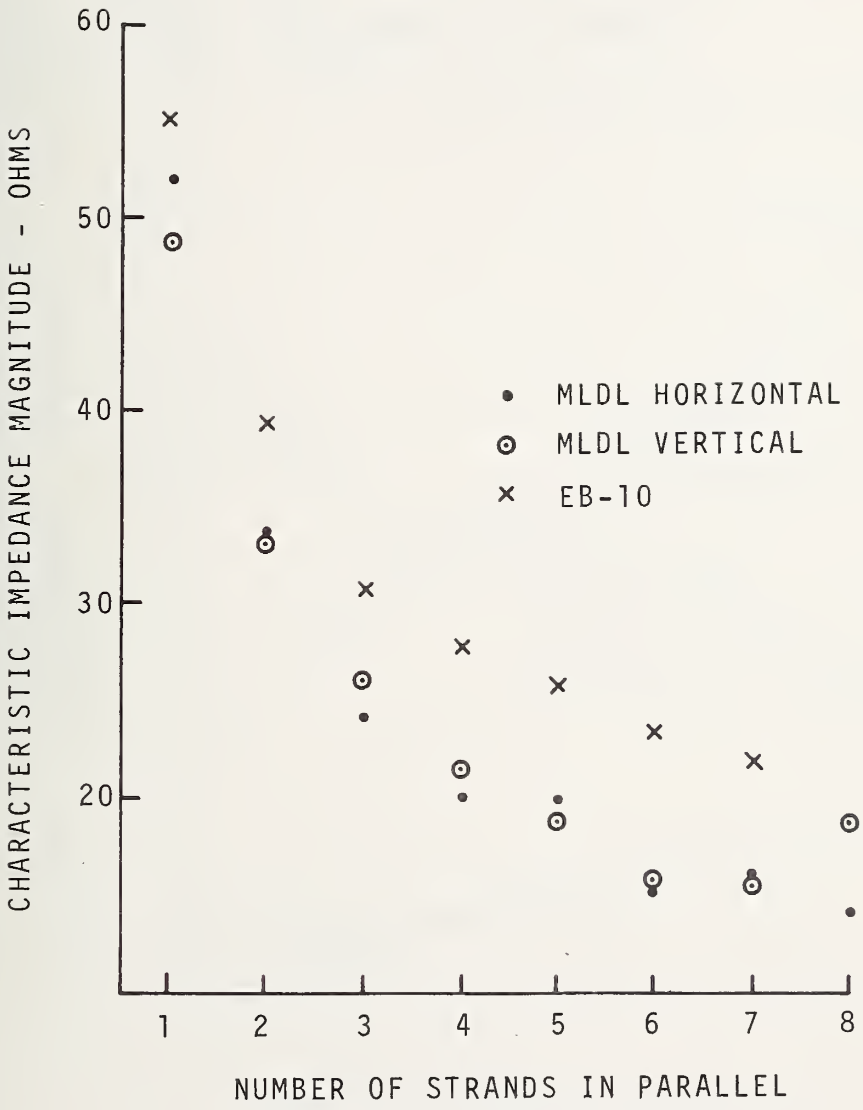

Figure 2. Characteristic Impedance Magnitude

	Velocity of Propagation (meters/second)
Acushnet - RG-8/U	10.9×10^7
EB-10 - 8 strand MLDL	7.1×10^7 *
AUTEC - 8 strand MLDL	
Horizontal Deployment	7.3×10^7 **
Vertical Deployment	6.9×10^7 **

*based on a length of 525 meters.

**based on a length of 547 meters.

Figure 3. Velocities of Propagation

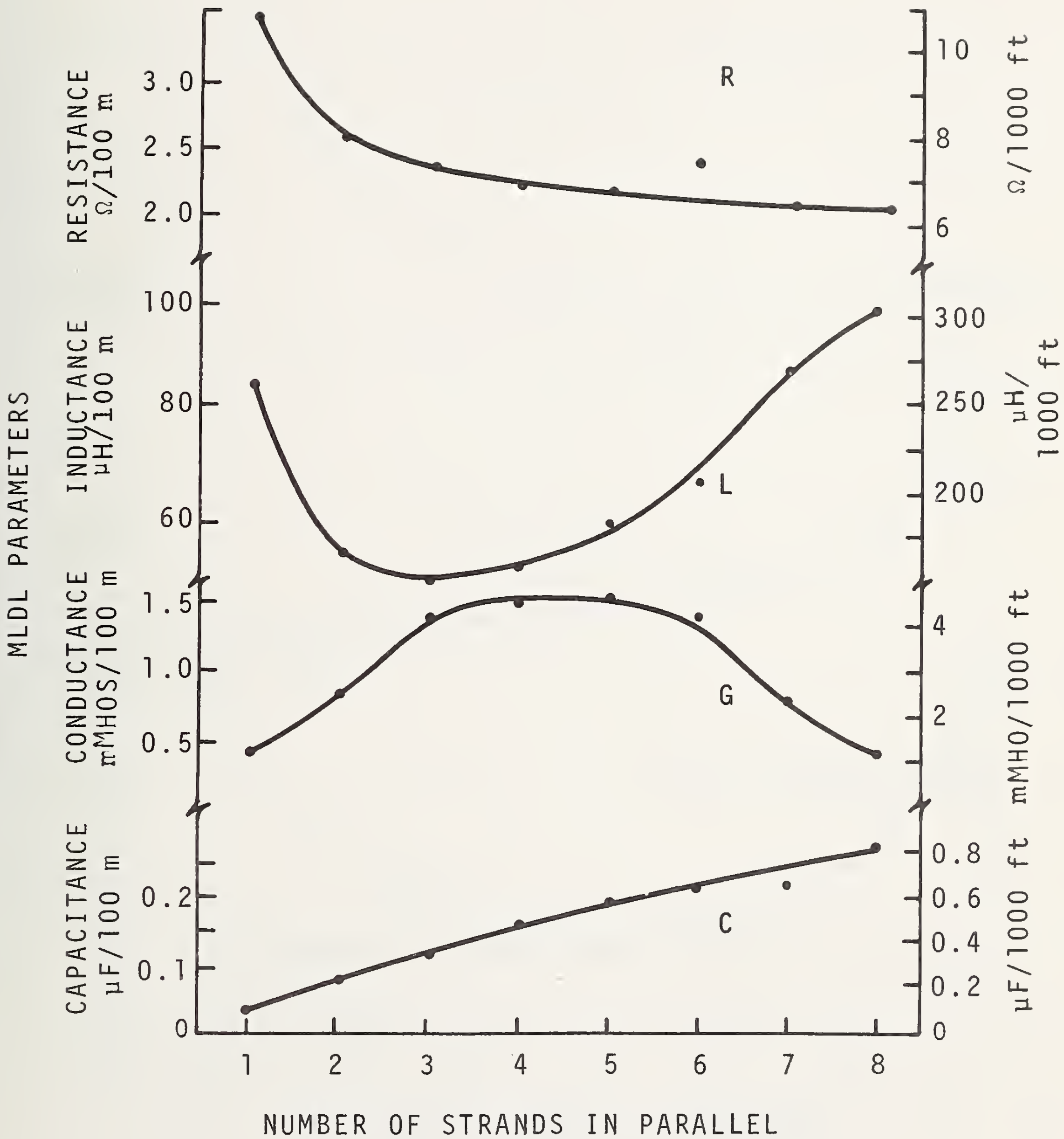

Figure 4. MLDL Parameters

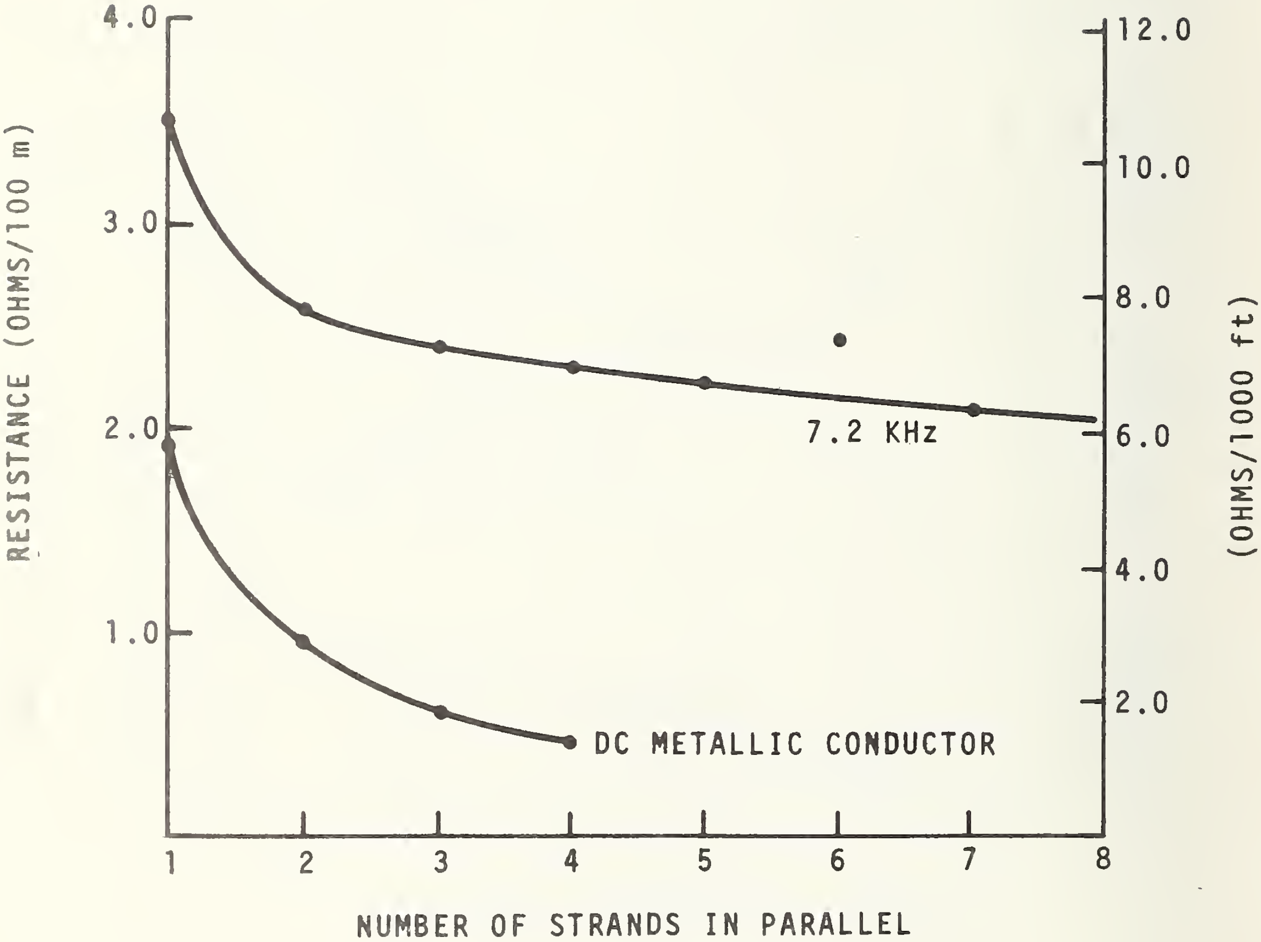

Figure 5. MLDL DC and AC Resistance

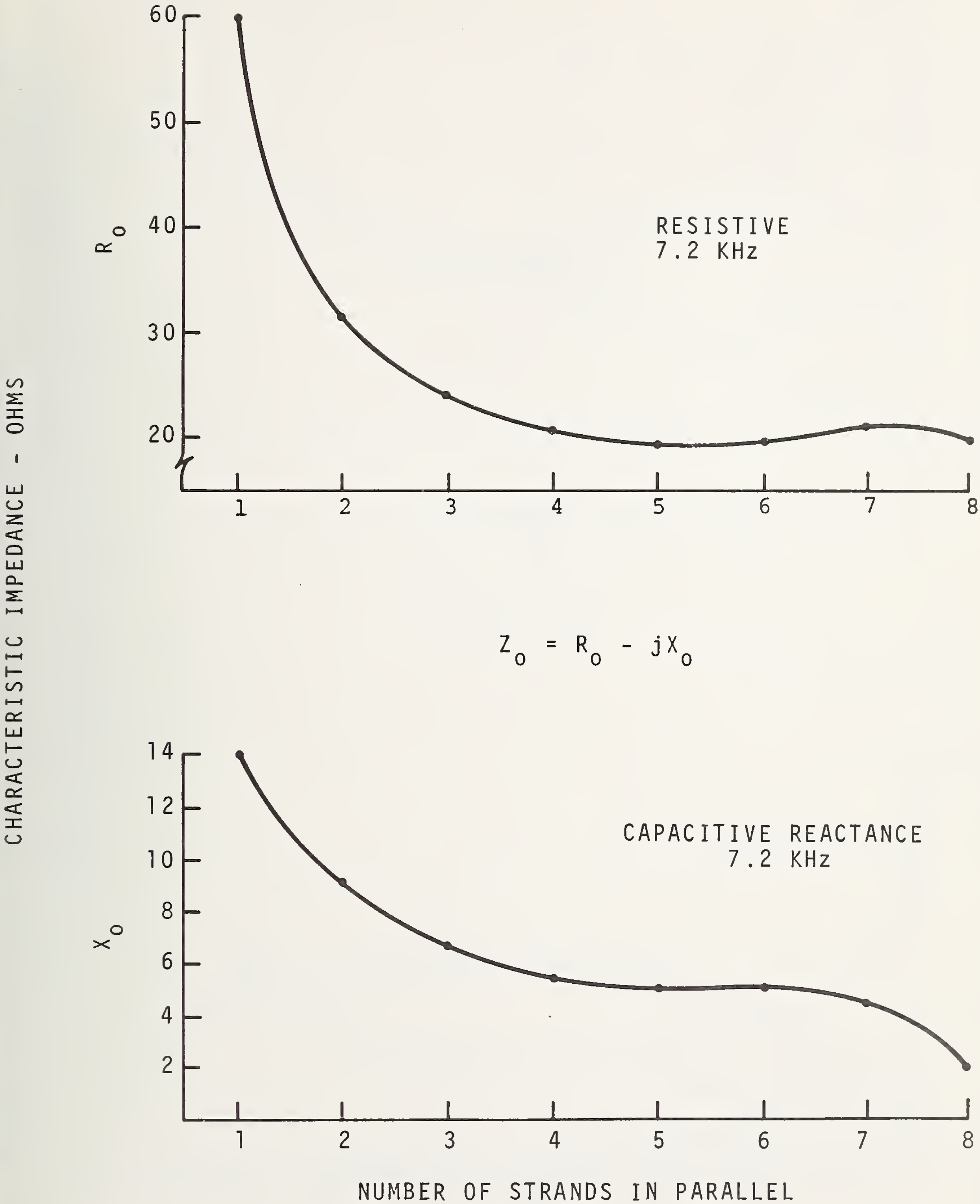

Figure 6. Complex Characteristic Impedance

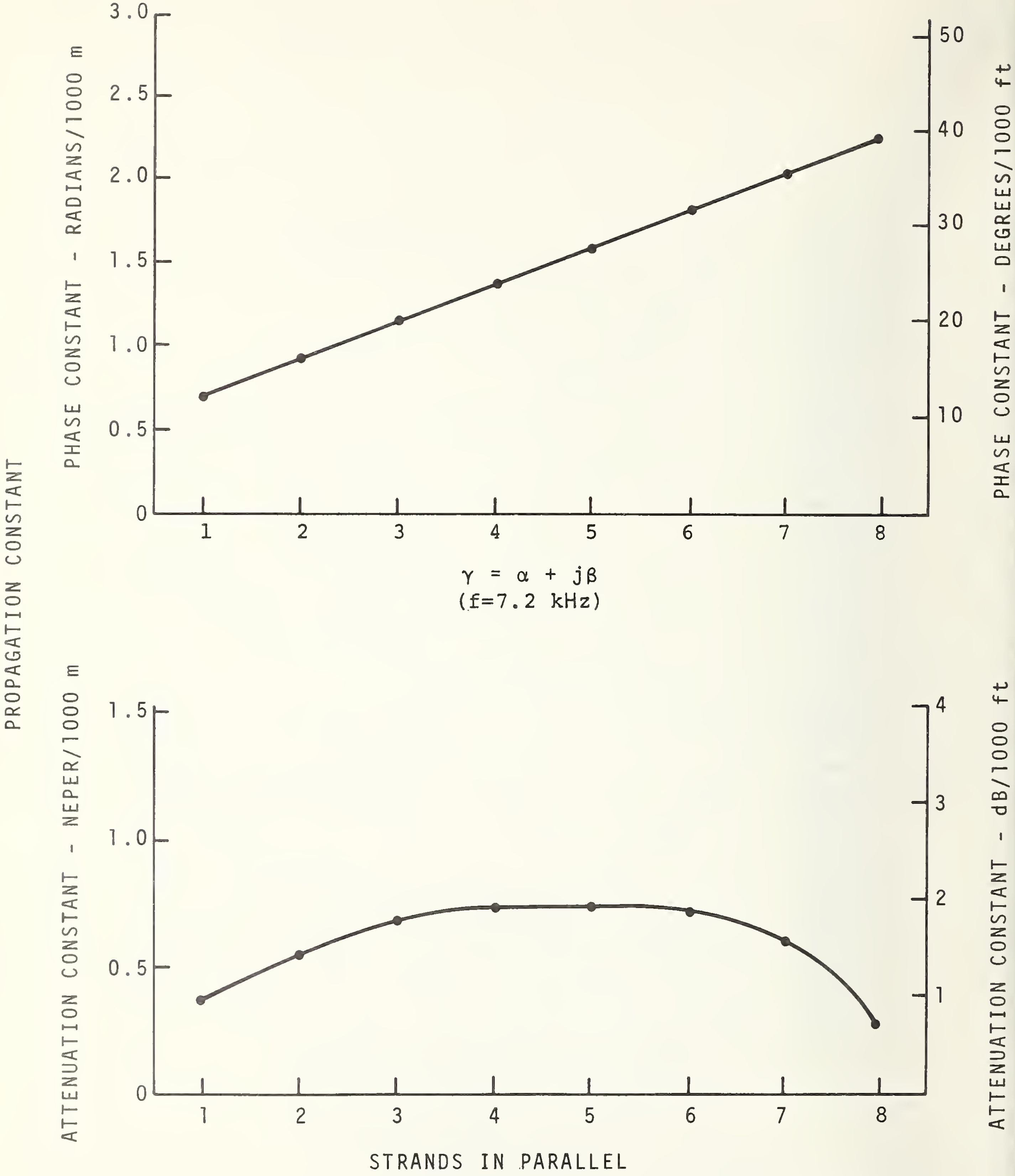

Figure 7. Complex Propagation Constant

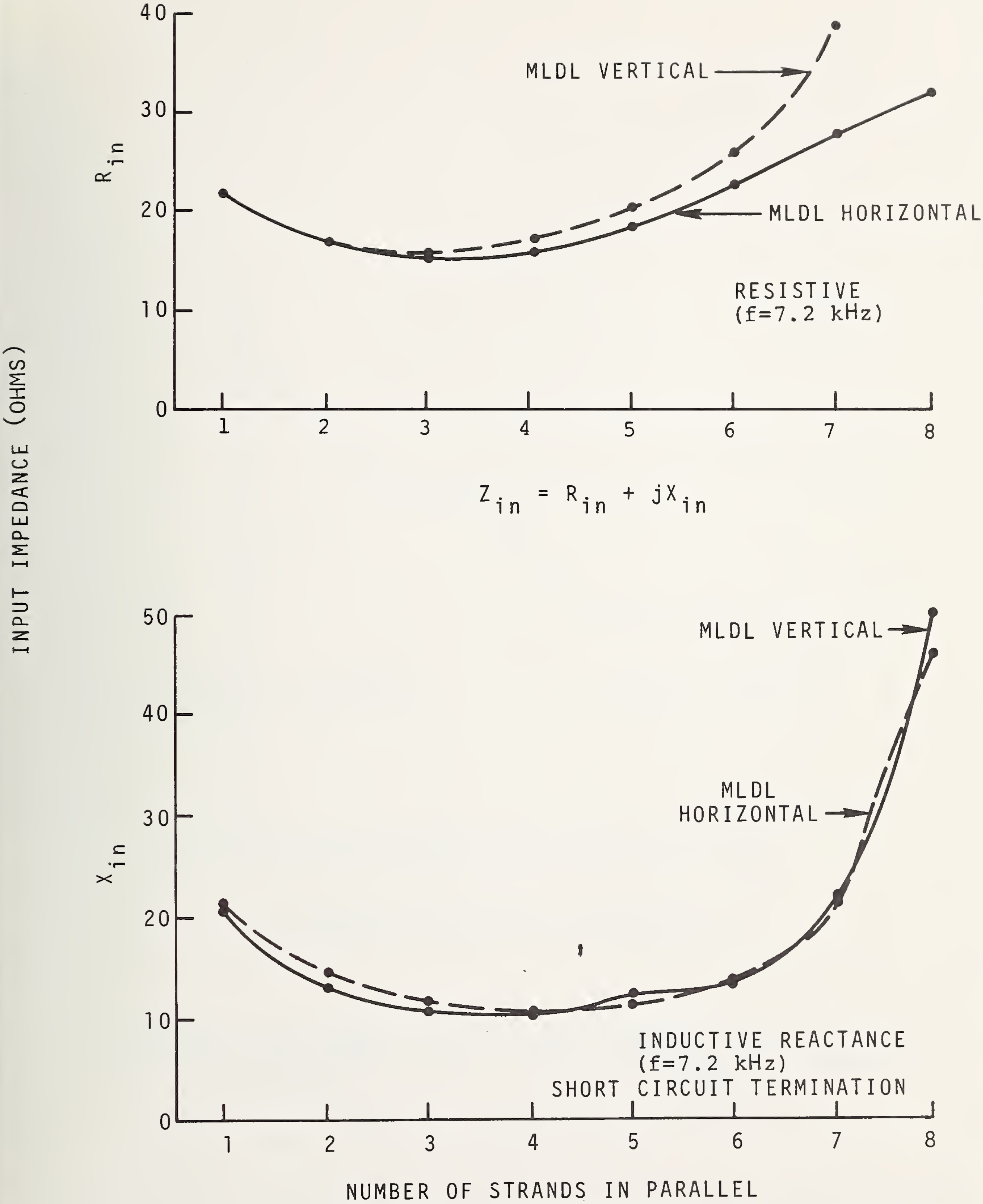

Figure 8. Input Impedance with Short Circuit Termination

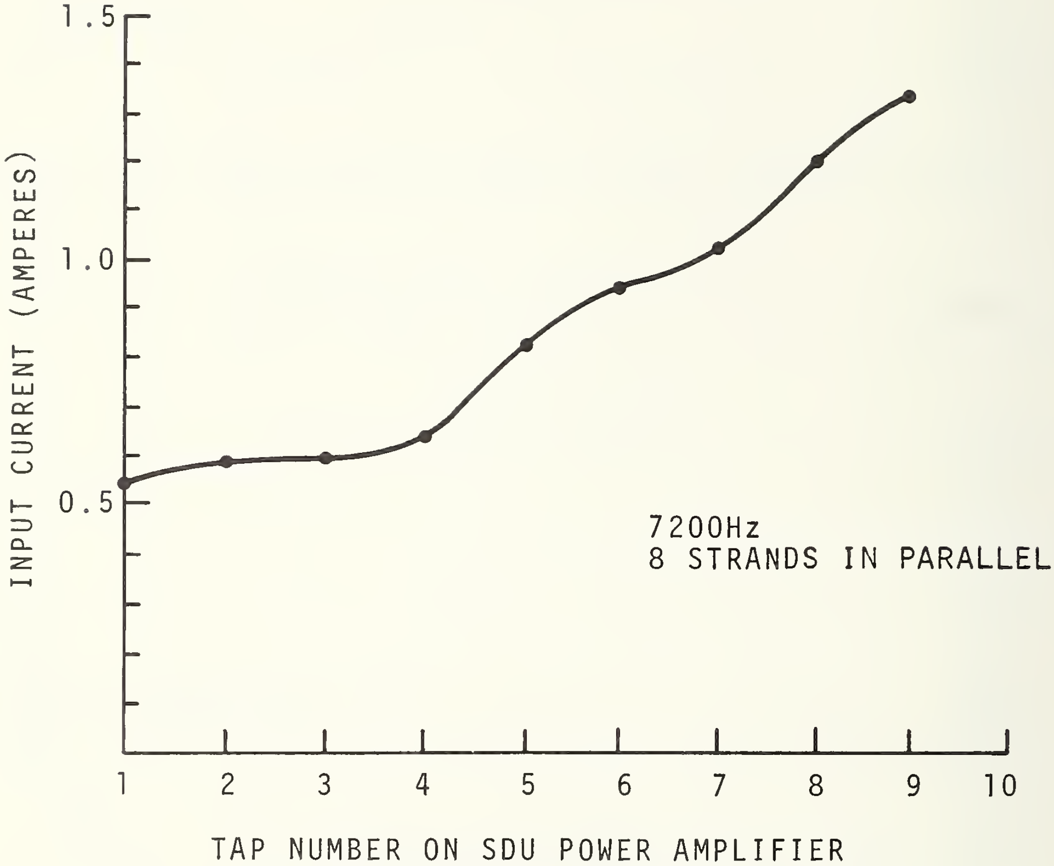

Figure 9. MLDL Input Current versus Sensor Deck Unit Tap Number

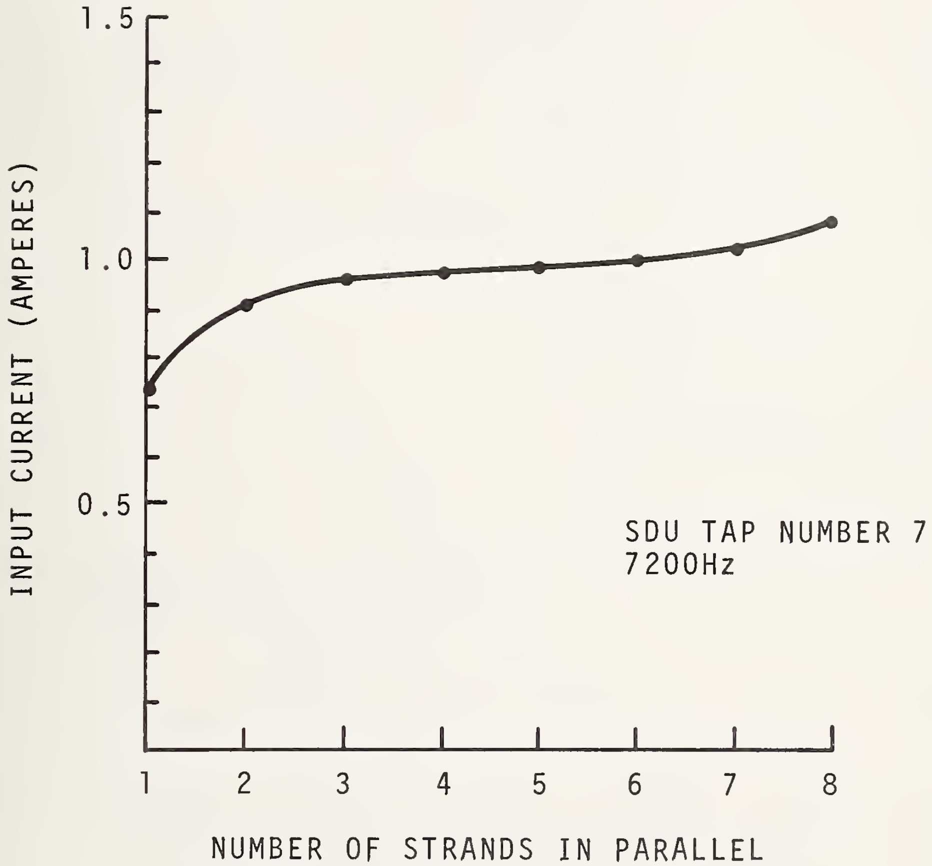

Figure 10. MLDL Input Current versus Number of Strands in Parallel

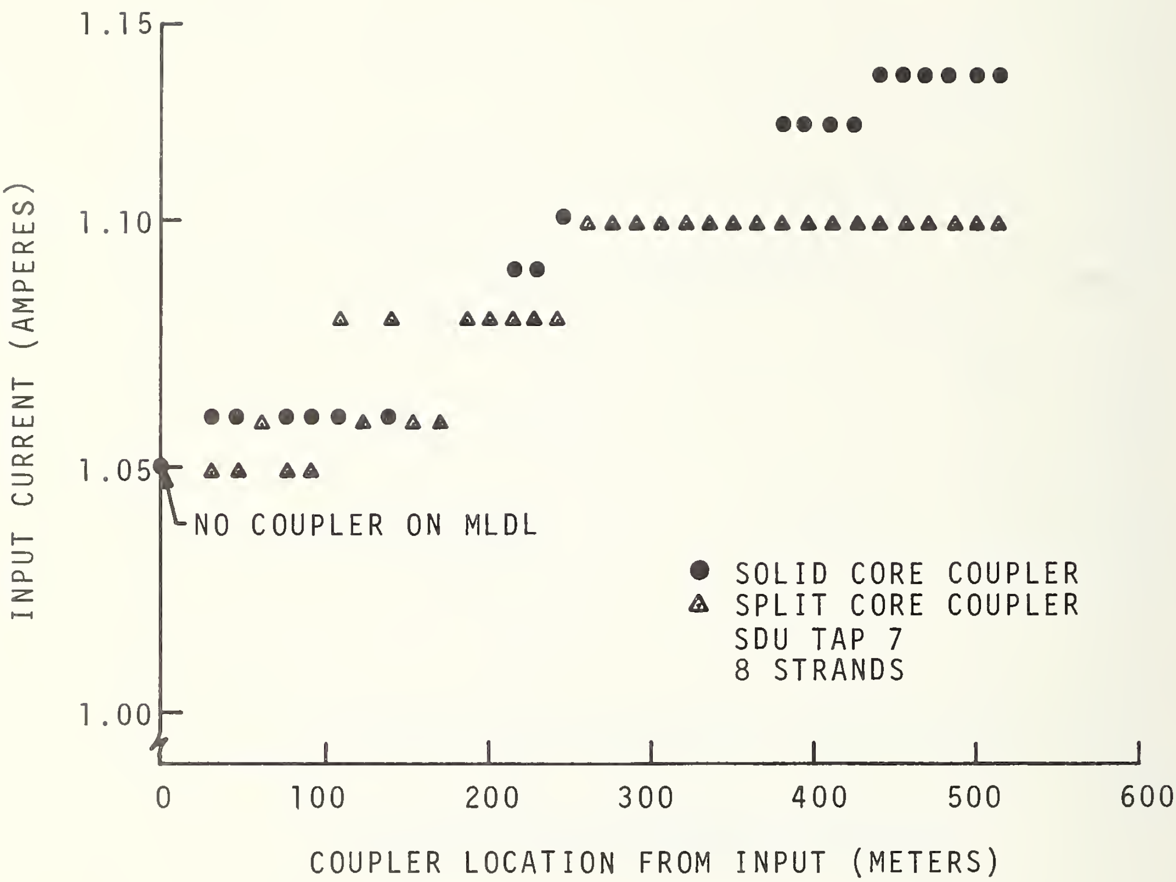

Figure 11. MLDL Input Current versus Coupler Locations

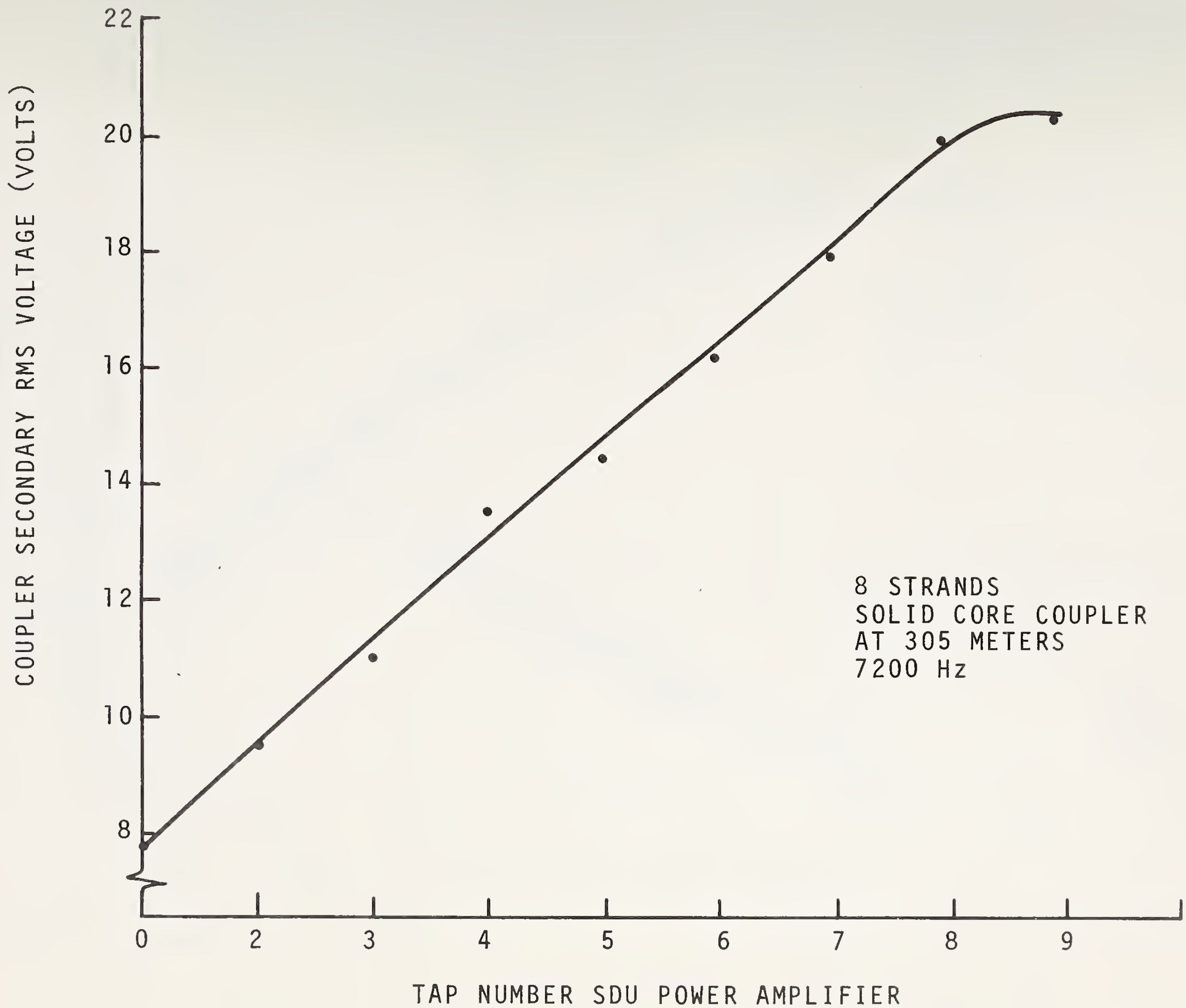

Figure 12. Coupler Voltage versus Sensor Deck Unit Tap Number

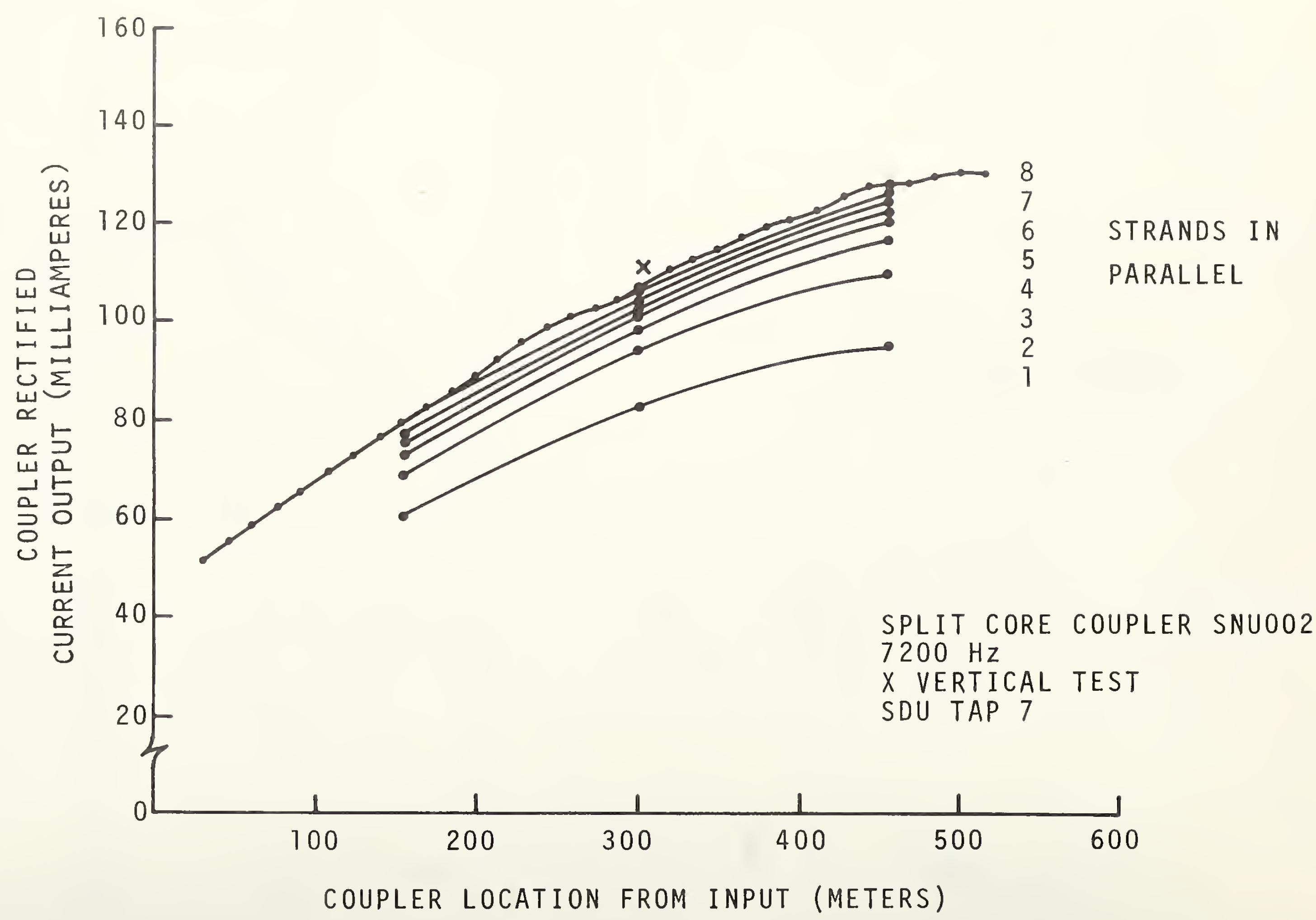

Figure 13. Current Measured with Split Core Coupler

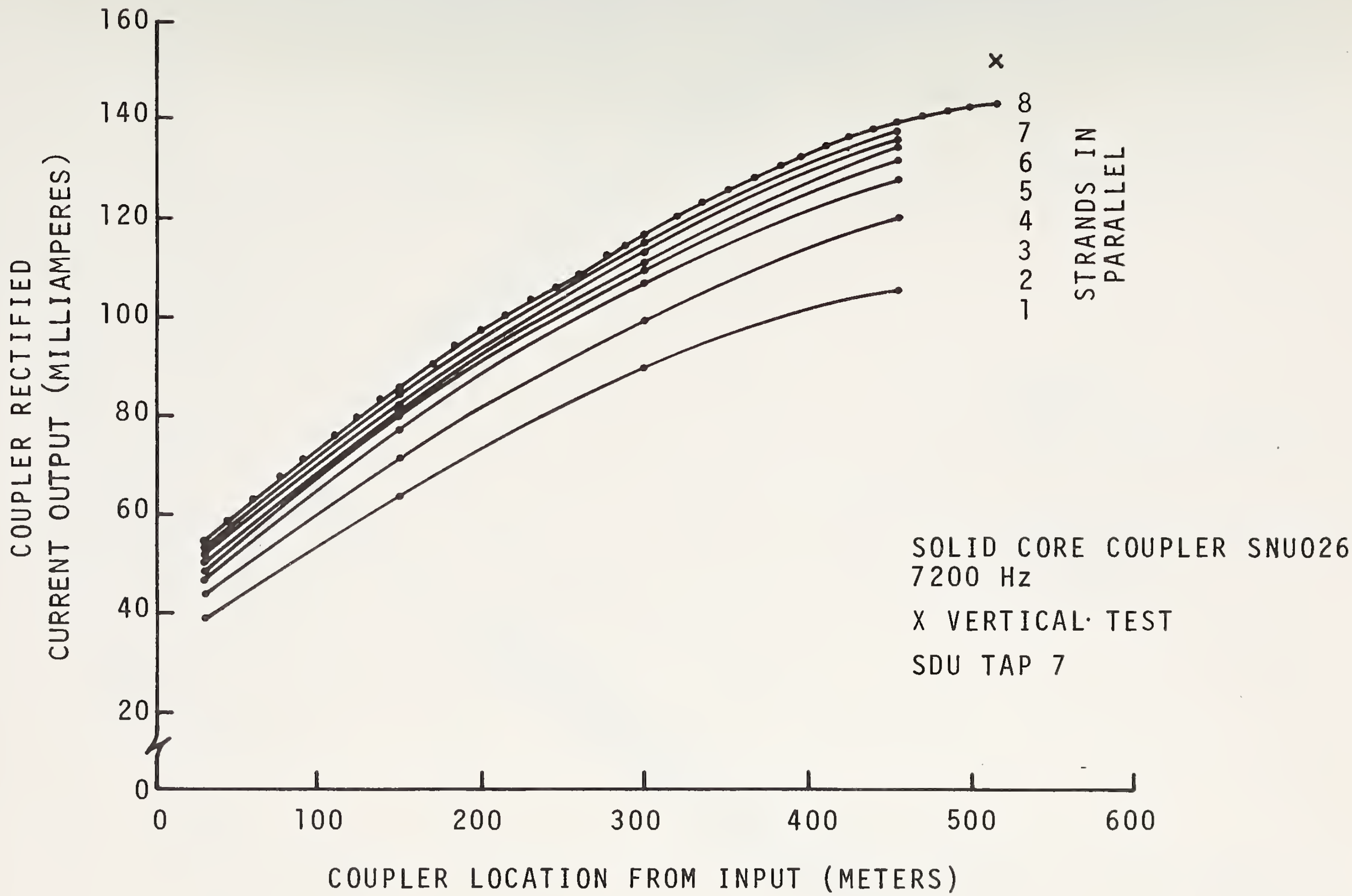

Figure 14. Current Measured with Solid Core Coupler

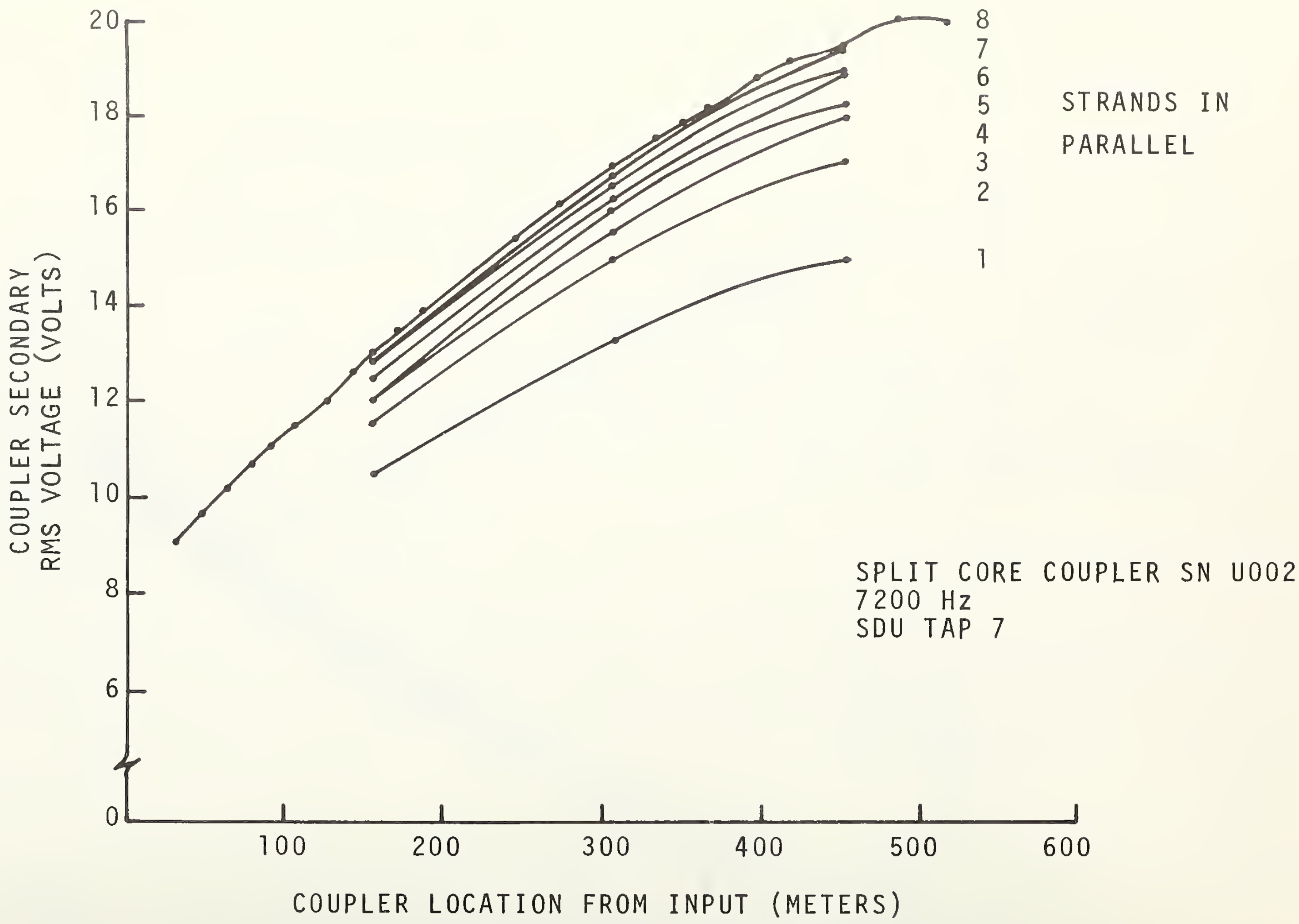

Figure 15. Coupler Voltage Measured with Split Core Coupler

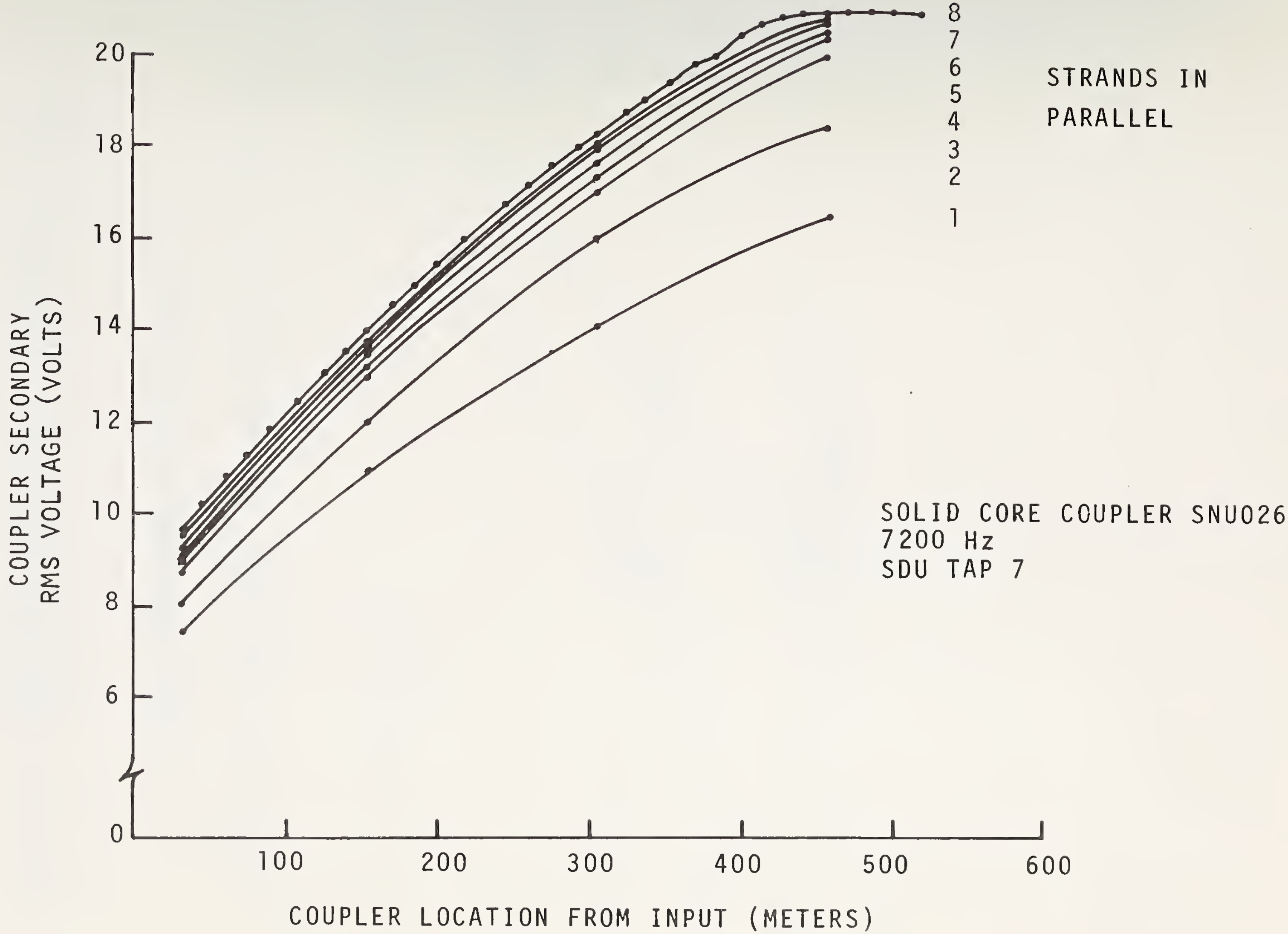

Figure 16. Coupler Voltage Measured with Solid Core Coupler

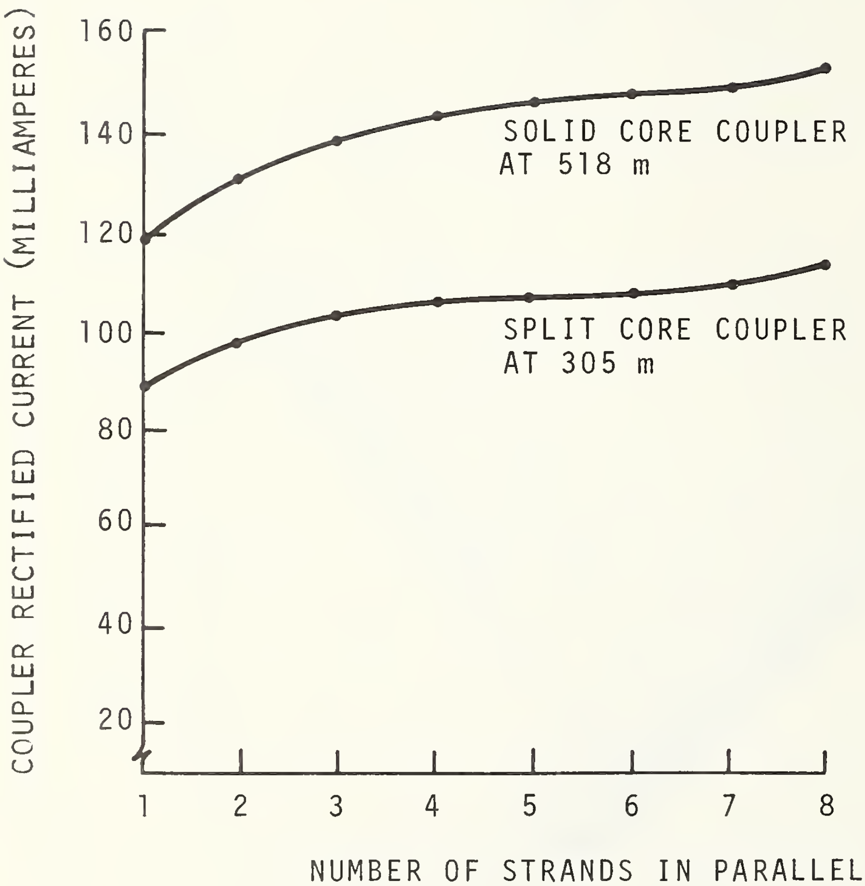

Figure 17. Current versus Number of Strands in Vertical Deployment

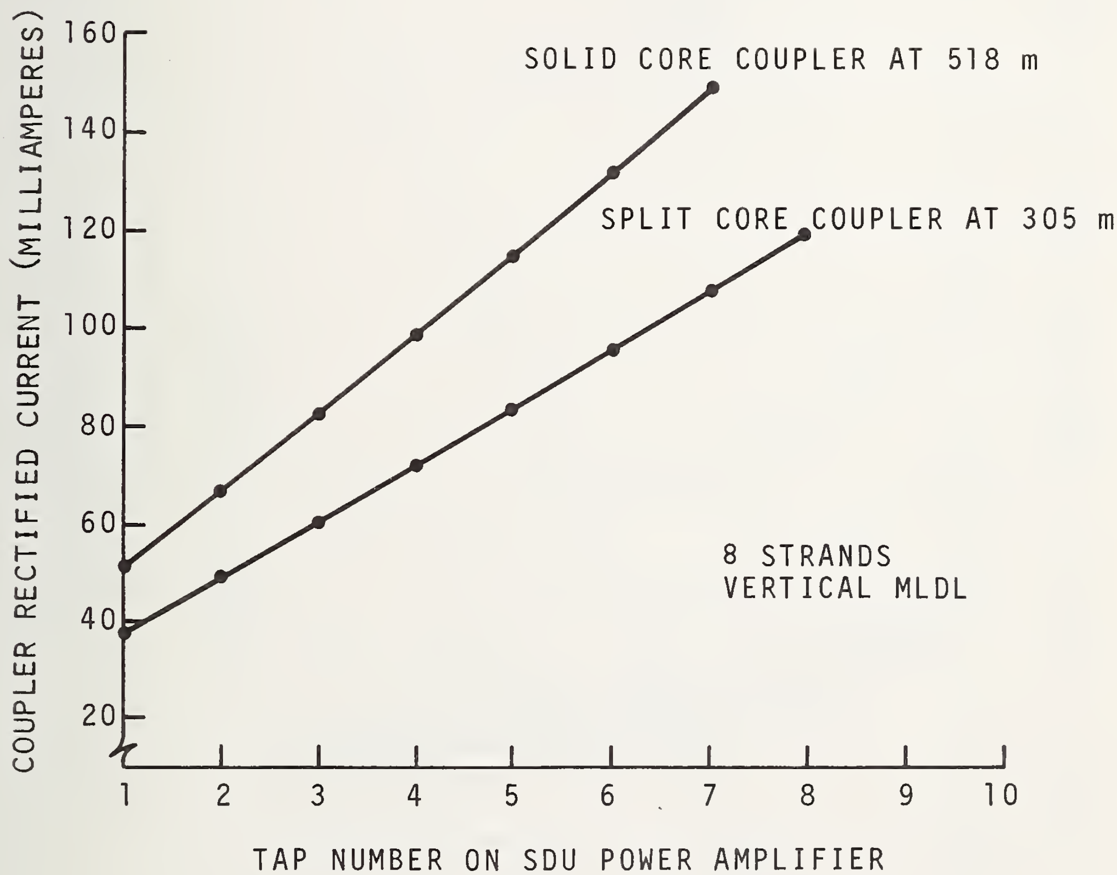

Figure 18. Current versus Sensor Deck Unit Tap Number in Vertical Deployment

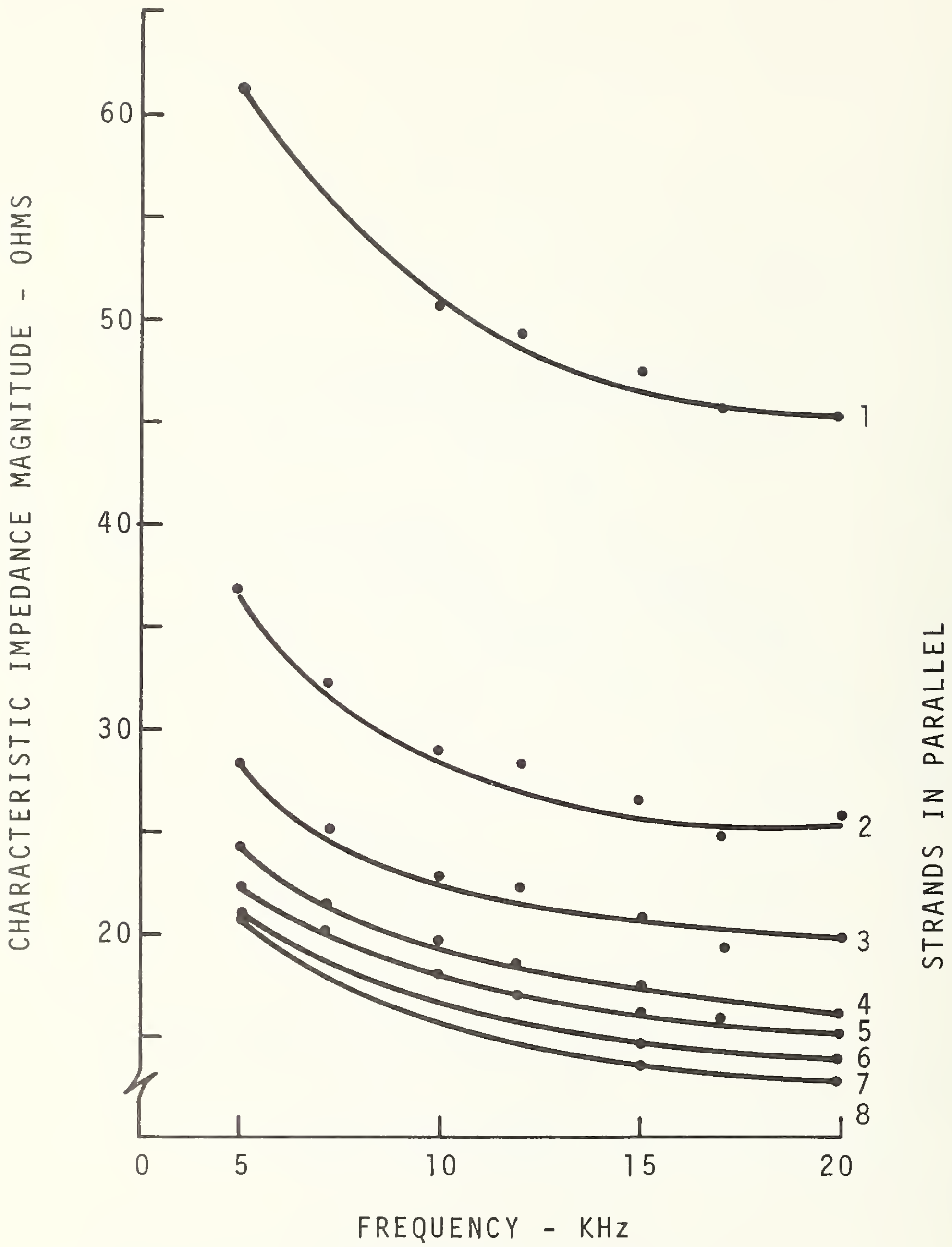

Figure 19. Characteristic Impedance Magnitude versus Frequency

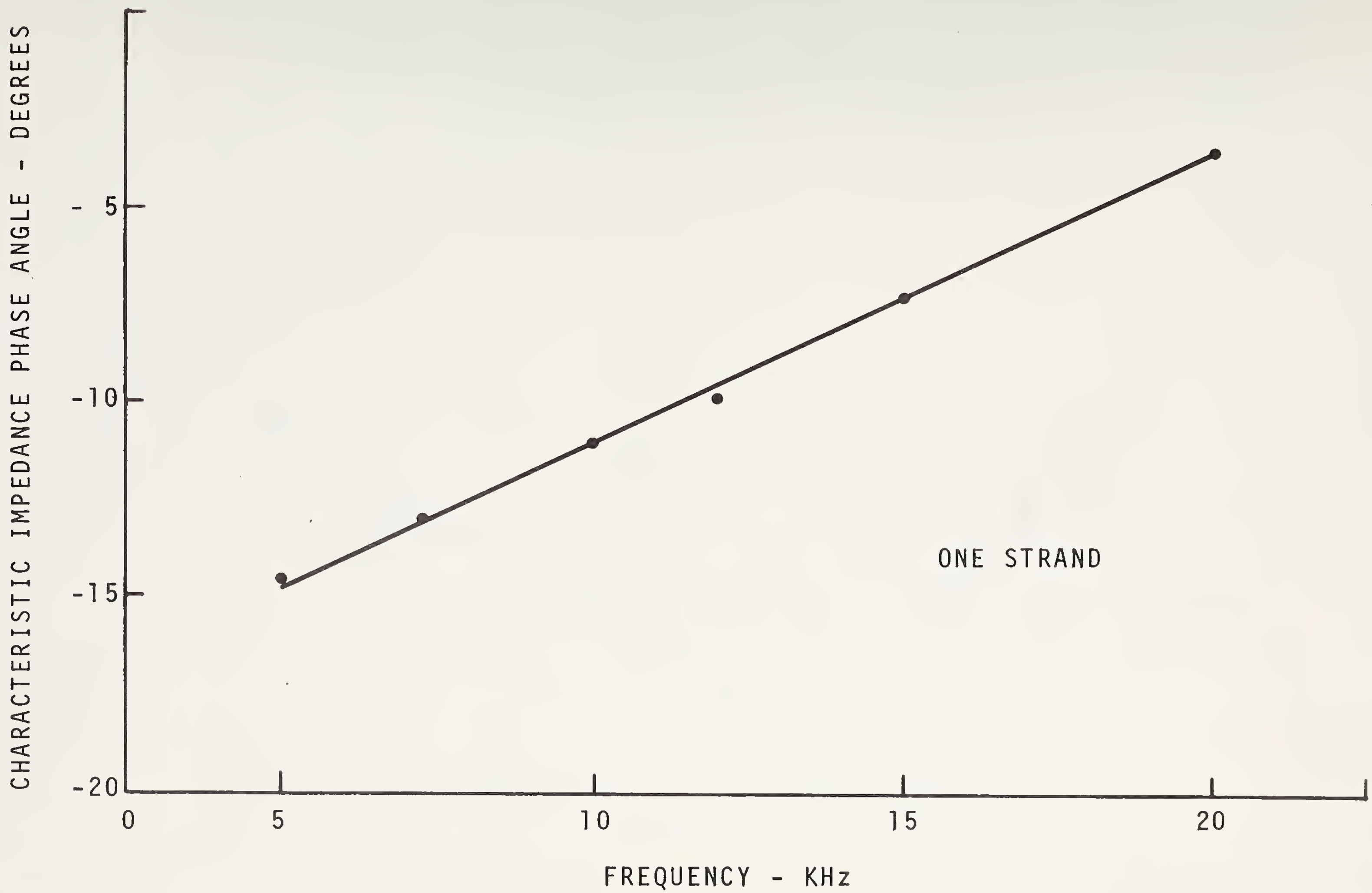

Figure 20. Characteristic Impedance Phase Angle versus Frequency

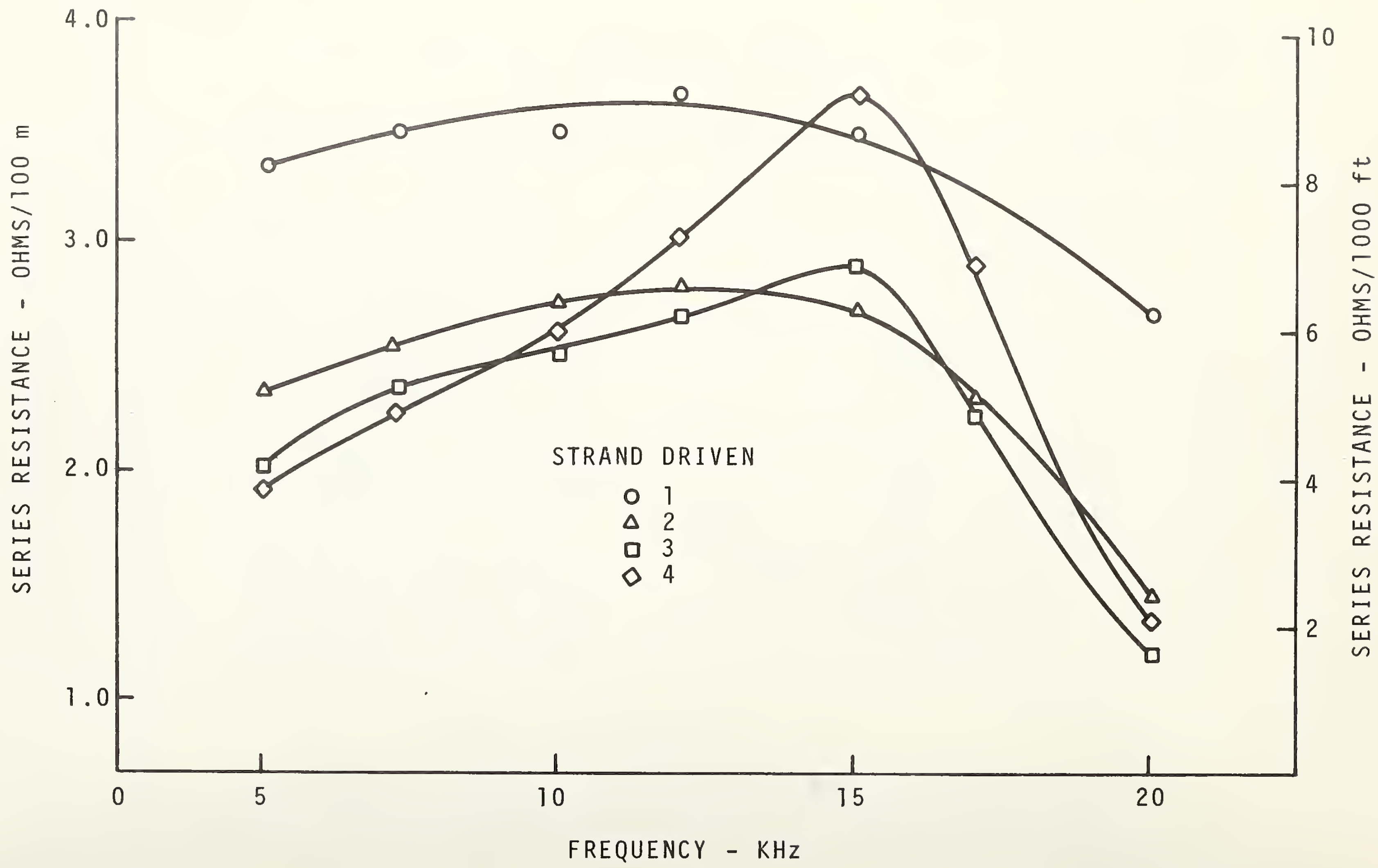

Figure 21. Series Resistance versus Frequency for 1-4 Strands

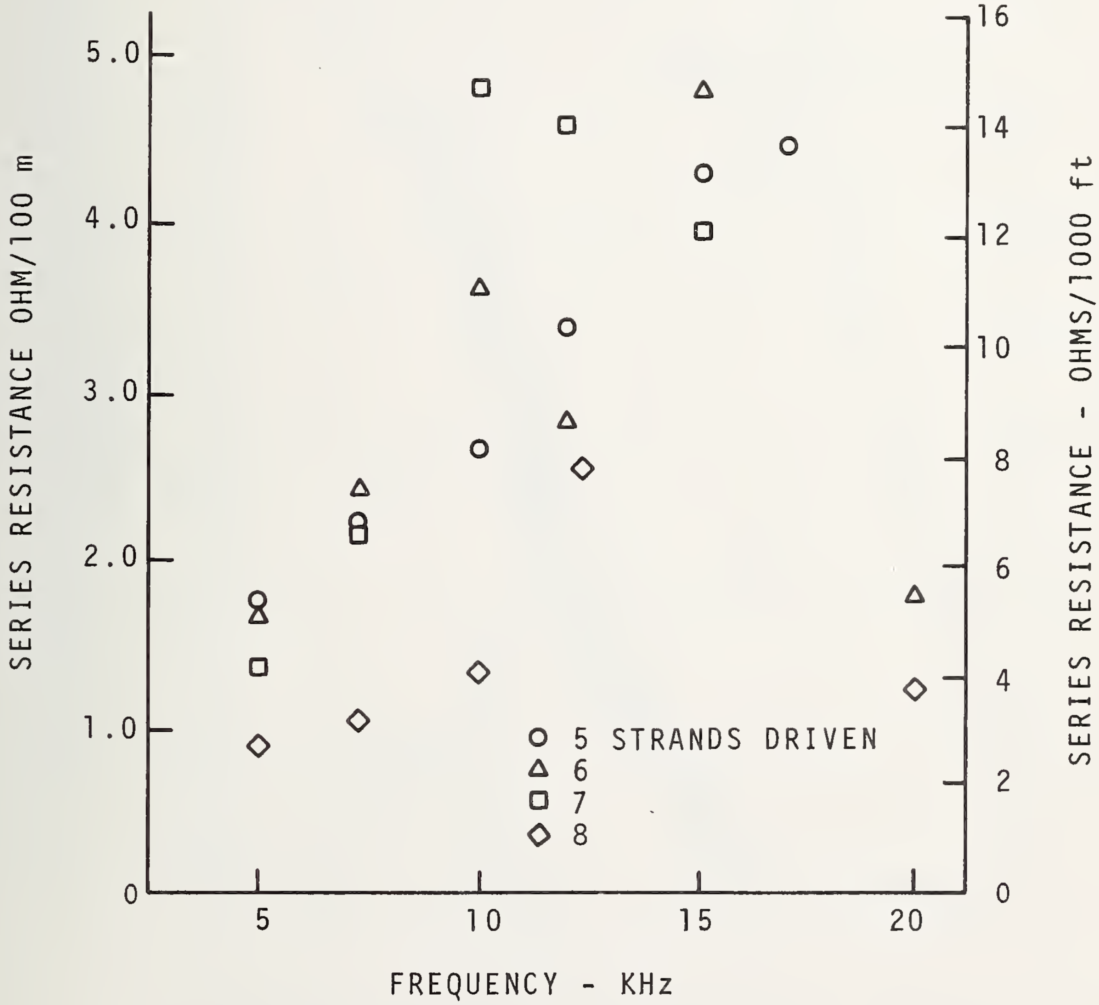

Figure 22. Series Resistance versus Frequency for 5-8 Strands

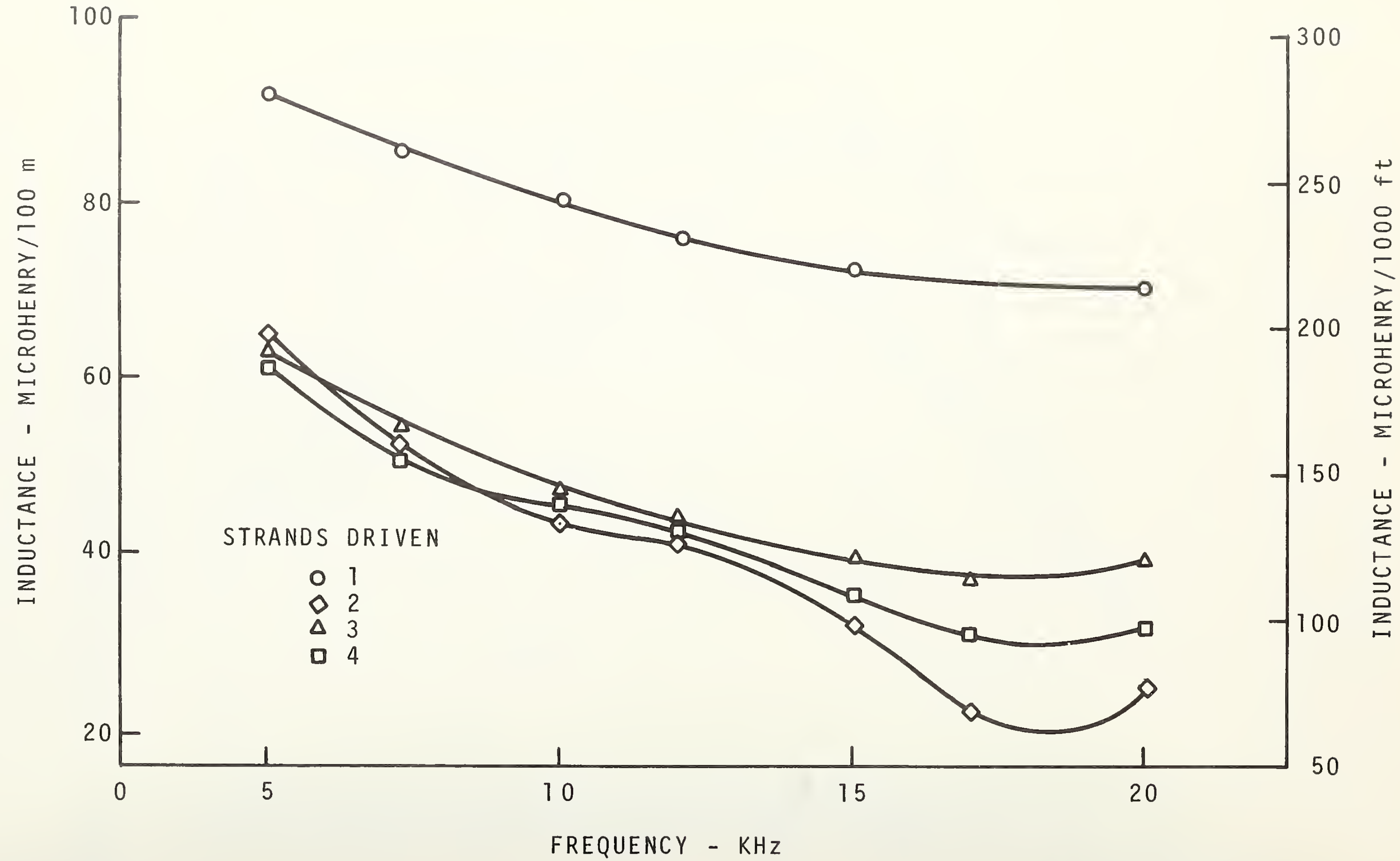

Figure 23. Inductance versus Frequency for 1-4 Strands

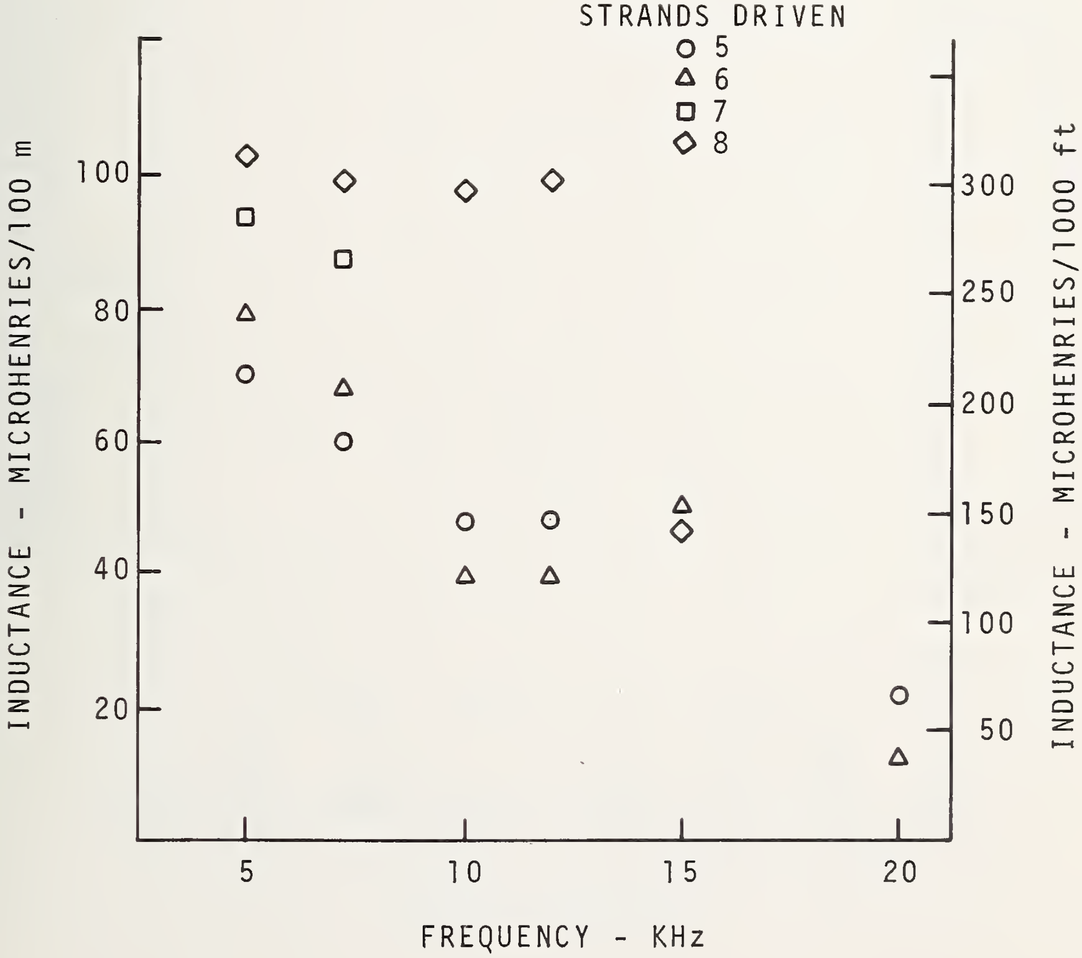

Figure 24. Inductance versus Frequency for 5-8 Strands

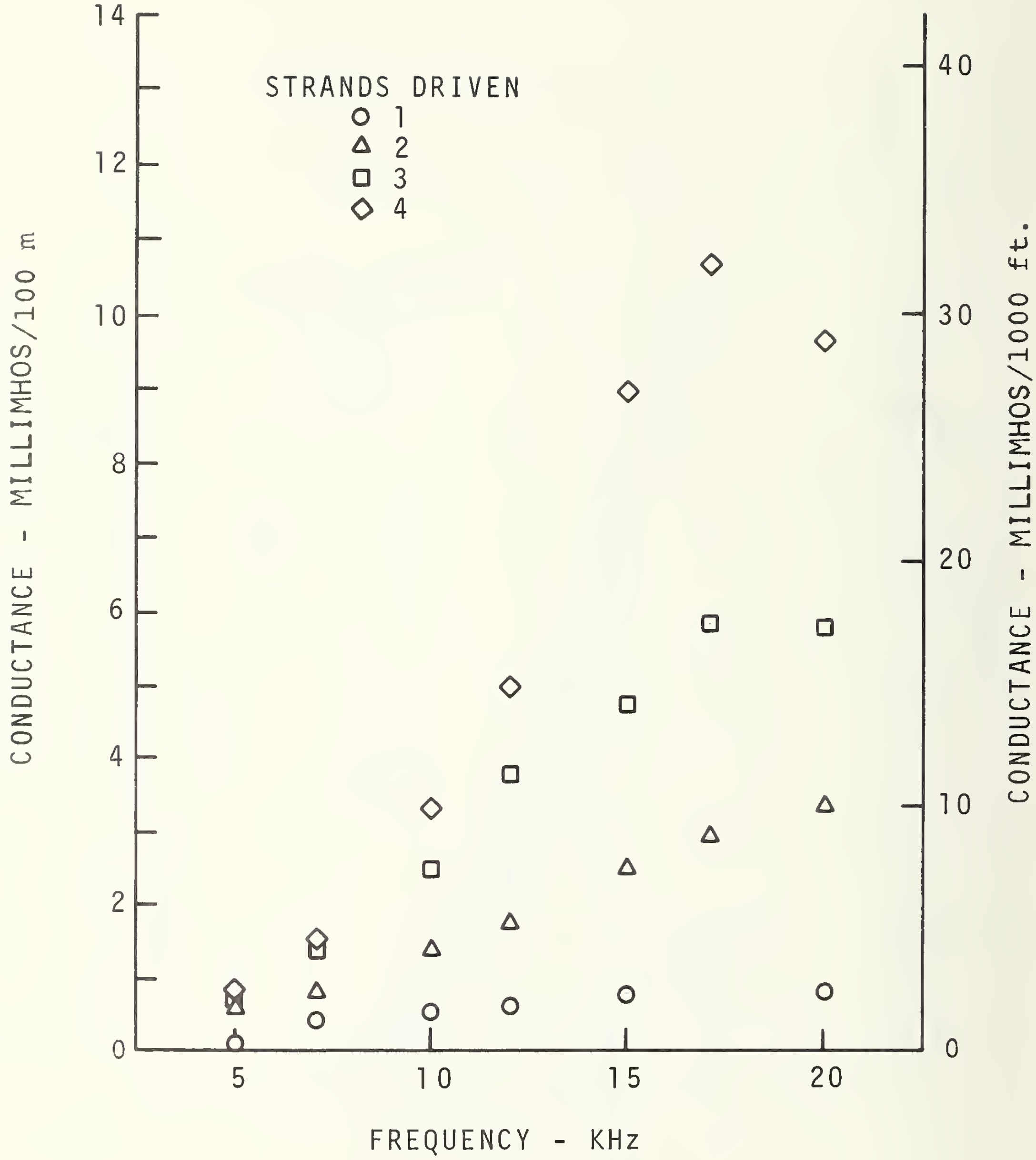

Figure 25. Conductance versus Frequency for 1-4 Strands

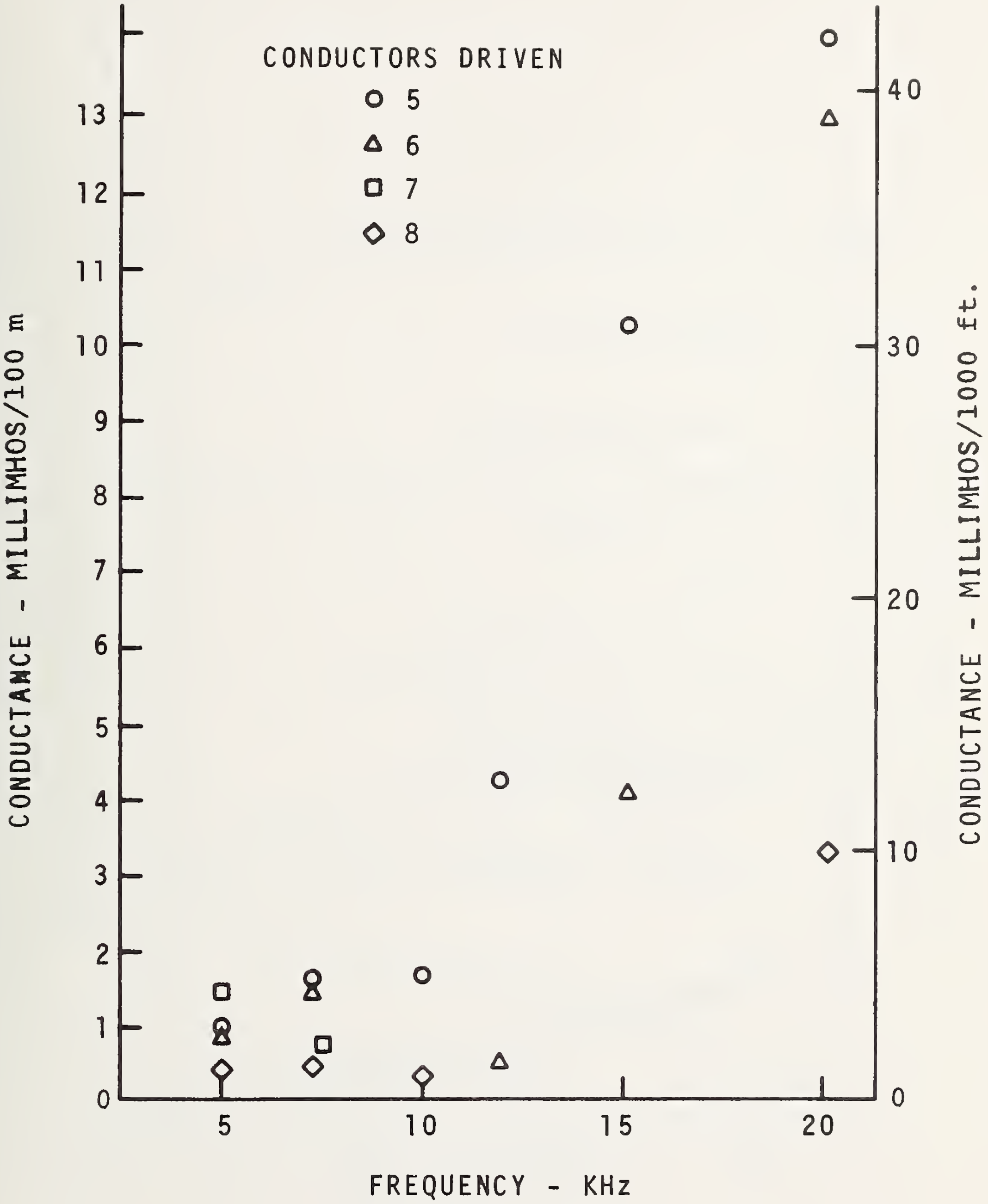

Figure 26. Conductance versus Frequency for 5-8 Strands

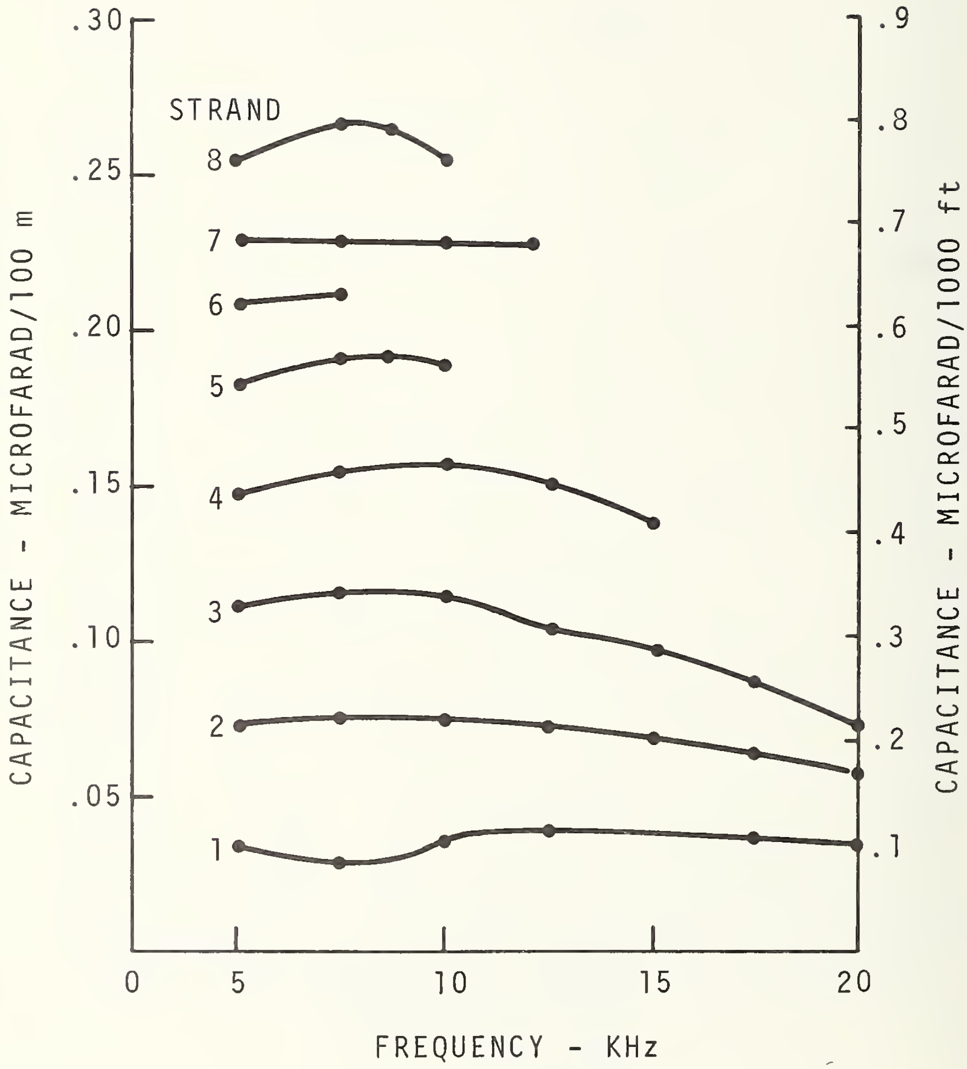

Figure 27. Capacitance versus Frequency

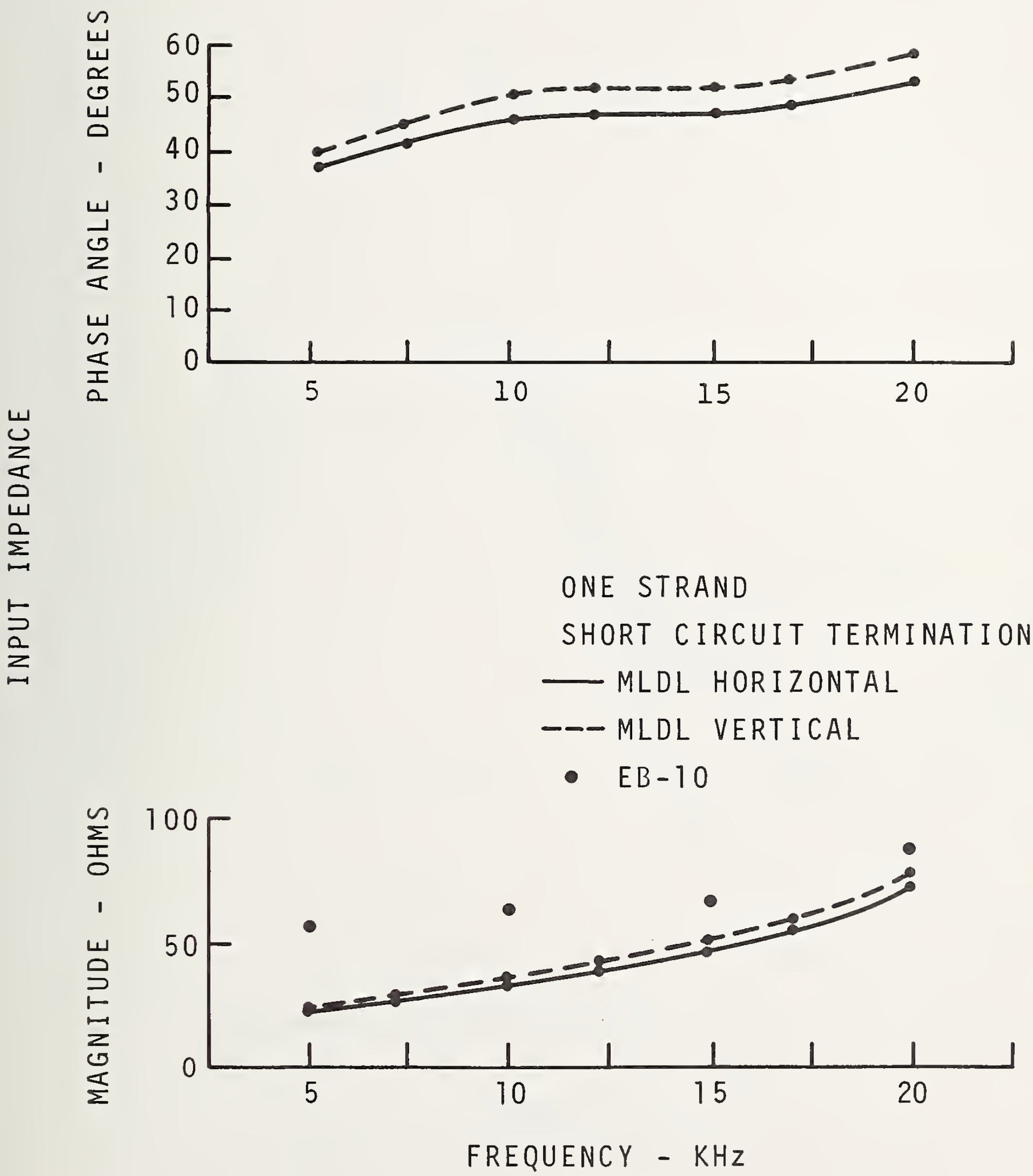

Figure 28. Input Impedance versus Frequency

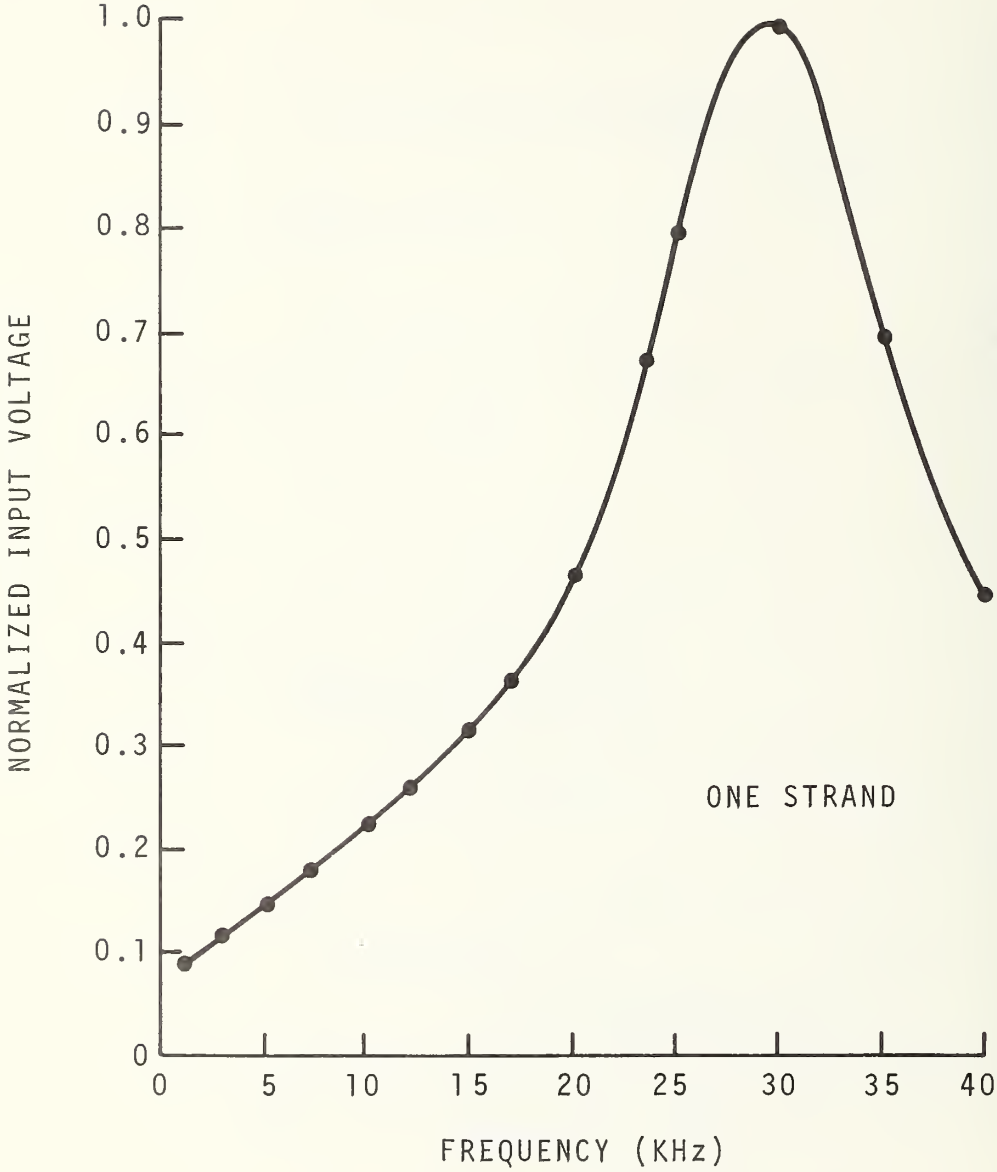

Figure 29. Voltage at the Input

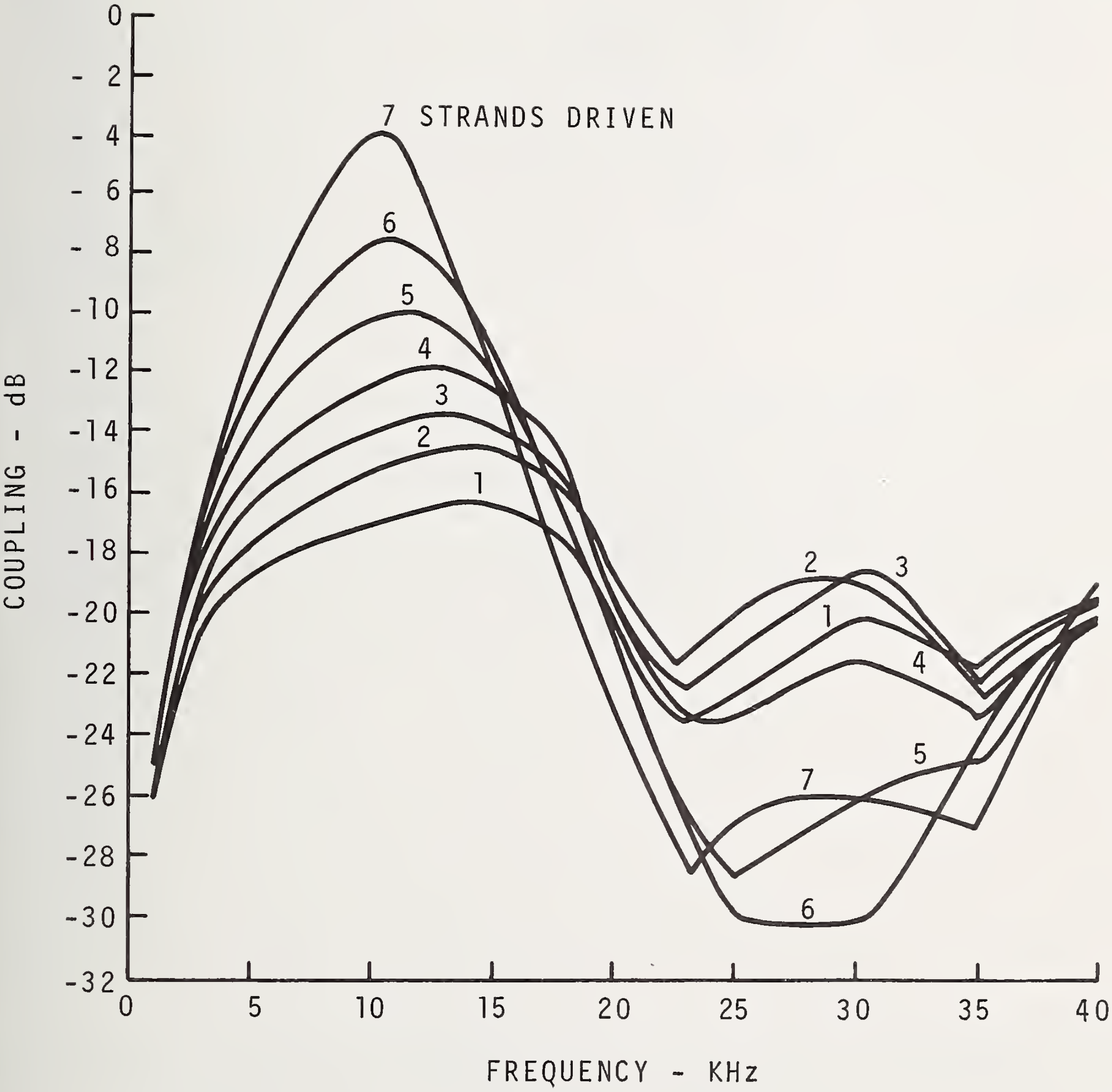

Figure 30. Wire-to-Wire Coupling

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Results obtained from the Mooring-Line-Data-Line (MLDL) measurements program are presented. Frequency and time domain measurements are made to determine characteristics impedance, input impedance, current, and propagation parameters. Most of the measurements were made with an MLDL deployed specifically for this program, however, some were made on an MLDL deployed buoy.

17. KEY WORDS (Alphabetical order, separated by semicolons) Characteristic impedance; coupler; current; impedance, input impedance; mooring line data line; propagation characteristics; transmission line.

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