AD NUMBER:	AD0130461

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 4 Jan 1957. Other requests shall be referred to Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, CA.

AUTHORITY

USNCBC ltr dtd 14 Oct 1974

Project NY 411 002
Technical Memorandum M-117

Interim Report

STUDIES LEADING TO THE DEVELOPMENT OF A RADIO INTERFERENCE FILTER FOR OVERHEAD POWER LINES

4 January 1957

u. s.
naval
civil
engineering
research
and
evaluation
laboratory

port hueneme,
california

OBJECT OF PROJECT

The continual demand for increased instrument sensitivity and the overcrowding of communication channels has made it necessary that the maximum utilization of the radio frequency energy spectra be utilized. A limiting factor has been the spurious electromagnetic energy emanating from various devices. The object of the radio interference reduction project is to study methods whereby these spurious emanations may be controlled or eliminated.

OBJECT OF SUBPROJECT

One of the primary sources of difficulty in eliminating radio-interference is the delivering of interference-free power to a test area or military establishment. The object of this subproject is to conduct investigations leading to the control or elimination of interference associated with the power system.

OBJECT OF THIS REPORT

This report presents the initial studies conducted in connection with the development of a radio interference filter suitable for high voltage power line applications.

RESULTS

A unique distributed loss filter is proposed and some experimental data are presented. A program for continued investigation is recommended.

U. S. Naval Civil Engineering Research and Evaluation Laboratory
Port Hueneme, California

Project NY 411 002
Technical Memorandum M-117

Interim Report

STUDIES LEADING TO THE DEVELOPMENT OF A RADIO INTERFERENCE FILTER FOR OVERHEAD POWER LINES

4 January 1957

J. C. Senn

SUMMARY

This report presents the initial studies conducted to develop a radio interference filter suitable for high voltage power line applications. A unique distributed loss filter is proposed and experimental data are presented.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

A previous study of power line radio interference[1] by NAVCERELAB led to the conclusion that a distributed-loss type of filter is needed for successful isolation of overhead power lines from uncontrolled sources of interference. This report covers work which has been completed to date toward the development of a distributed-loss filter, and proposes additional work necessary for successful completion of the power line isolation filter development.

Background

Electric power for a Navy Shore Station is normally transmitted at high voltage over public utility lines to a substation on Navy property. At this point, Navy-owned distribution lines conduct the power at a lower voltage to the individual load transformers. All of these lines are capable of transmitting radio interference intercepted by them and, in addition, generating their own interference.

Interference originating on the portions of the system owned by the Navy can be controlled. Control methods are relatively simple, as explained in the "Practical Handbook"[2] published recently by the Laboratory. Local control is of little effect, however, if interference can be transmitted to the controlled lines from the utility-owned lines outside the Navy activity.

It has been proven many times that interference energy can indeed be transmitted from outside lines over long distances into areas sensitive to radio interference. The worst condition for propagation of interference, and the condition which most often occurs, is brought about when interference currents are in phase in all the conductors and return through the earth. Figure 1 illustrates this type of propagation. Although the resistivity of the earth is rather high, the effective conducting volume is large, and the interference currents in the earth can be thought of as mirror images of the line currents. The total earth current is the vector sum of the line currents; therefore, the largest value of earth current

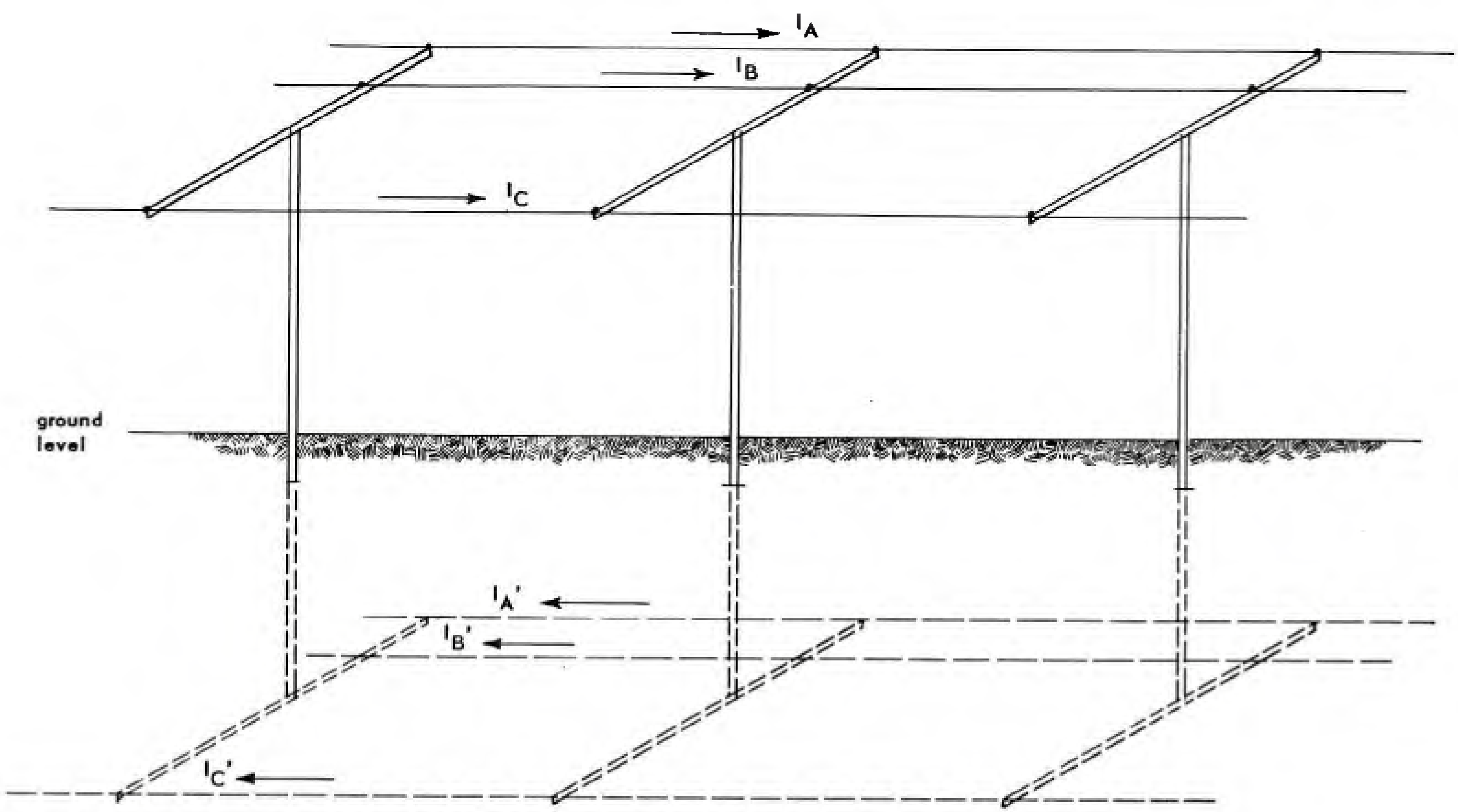


Figure 1. Interference current propagation.

results when the line currents are in phase. The presence of the image currents (and charges) causes an electromagnetic field to exist in the space between the conductors and the image currents. Because the earth acts as a large volume conductor, very little power is absorbed from the electromagnetic interference field as it travels along the line. This means that the interference energy can travel for a long distance before it is finally dissipated.

It is quite simple to suppress interference to any practical level when interference is present on the leads of a small motor, business machine, or other device where the leads are physically near each other and near to ground. It is only necessary to enclose the interference source within a metal shield and insert LC filter sections in the leads as needed. The source of transmitted power line interference is a long line with large dimensions that make enclosure in a shield completely impractical. The use of an LC network would be theoretically applicable except for the necessity of having excessively long leads on the capacitor elements. The distributed impedance of such a lead, perhaps 40 feet long, becomes very high at radio frequencies, so that the capacitors can not effectively be connected to ground. A series inductance in the power conductor will cause some radio frequency voltage drop, but this will be limited to a relatively narrow frequency band because of stray capacitive coupling in parallel with the coil and lack of sufficient shielding of the output lead from the input lead. These inadequacies of conventional suppression techniques have led to consideration of a filter having a relatively large length and distributed losses.

Figure 2 illustrates use of a distributed-loss filter to protect a sensitive area from interference transmitted to its boundaries by "noisy" lines from the outside. The length of the filter provides the necessary decoupling of input and output and the filter itself gradually absorbs the traveling interference energy.

Figure 3 illustrates the details of construction of the lossy filter. The insulation must be designed for the full line voltage because of the ground connection made at every pole along the filter's length. The conductive rubber sheath is applied by the cable manufacturer in place of the standard neoprene sheath ordinarily used. The principle of operation of the filter can be seen more easily by reference to Figure 4, which shows a quarter-section of a small length of the filter fitted into the three-dimensional cylindrical coordinate system. The

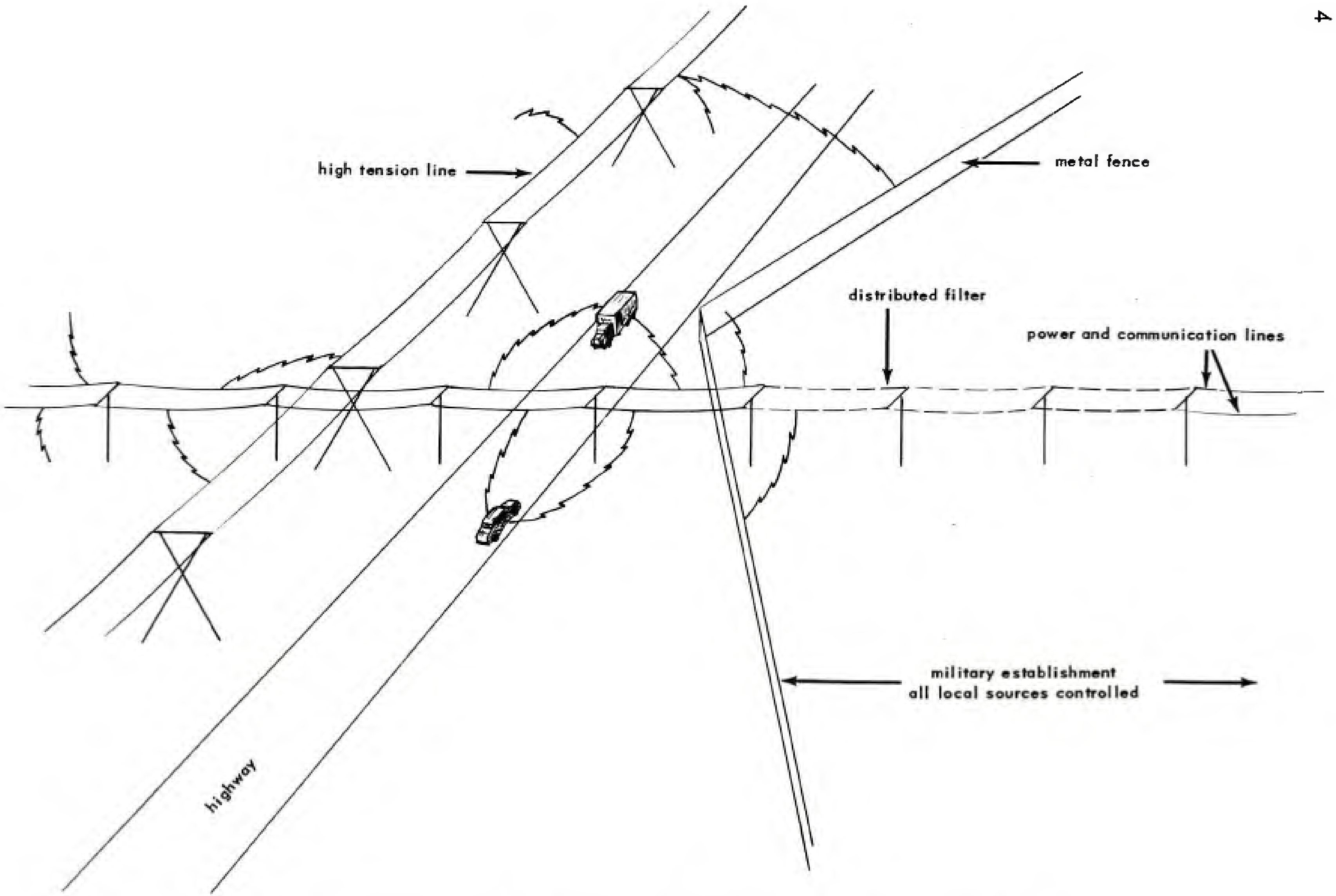


Figure 2. Isolation of area of uncontrolled interference from controlled area.

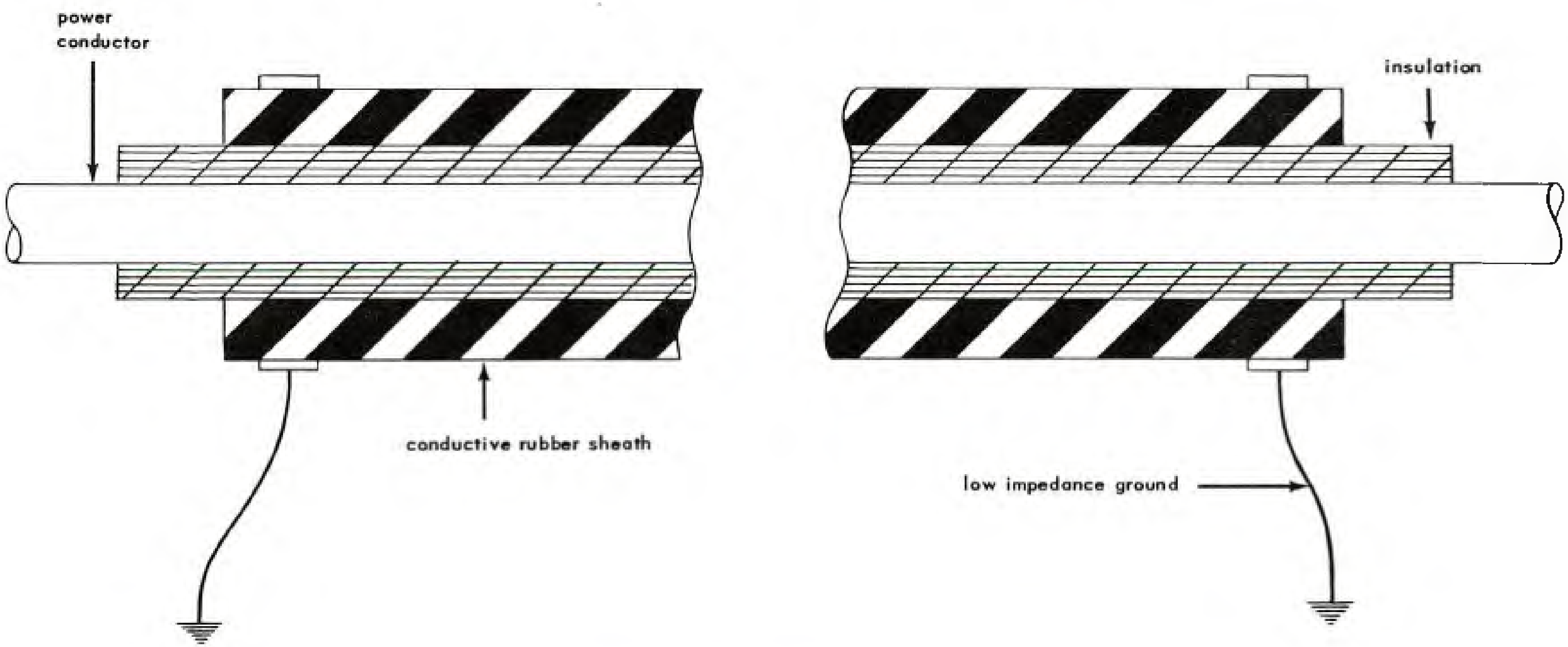


Figure 3. Distributed loss filter characteristics.

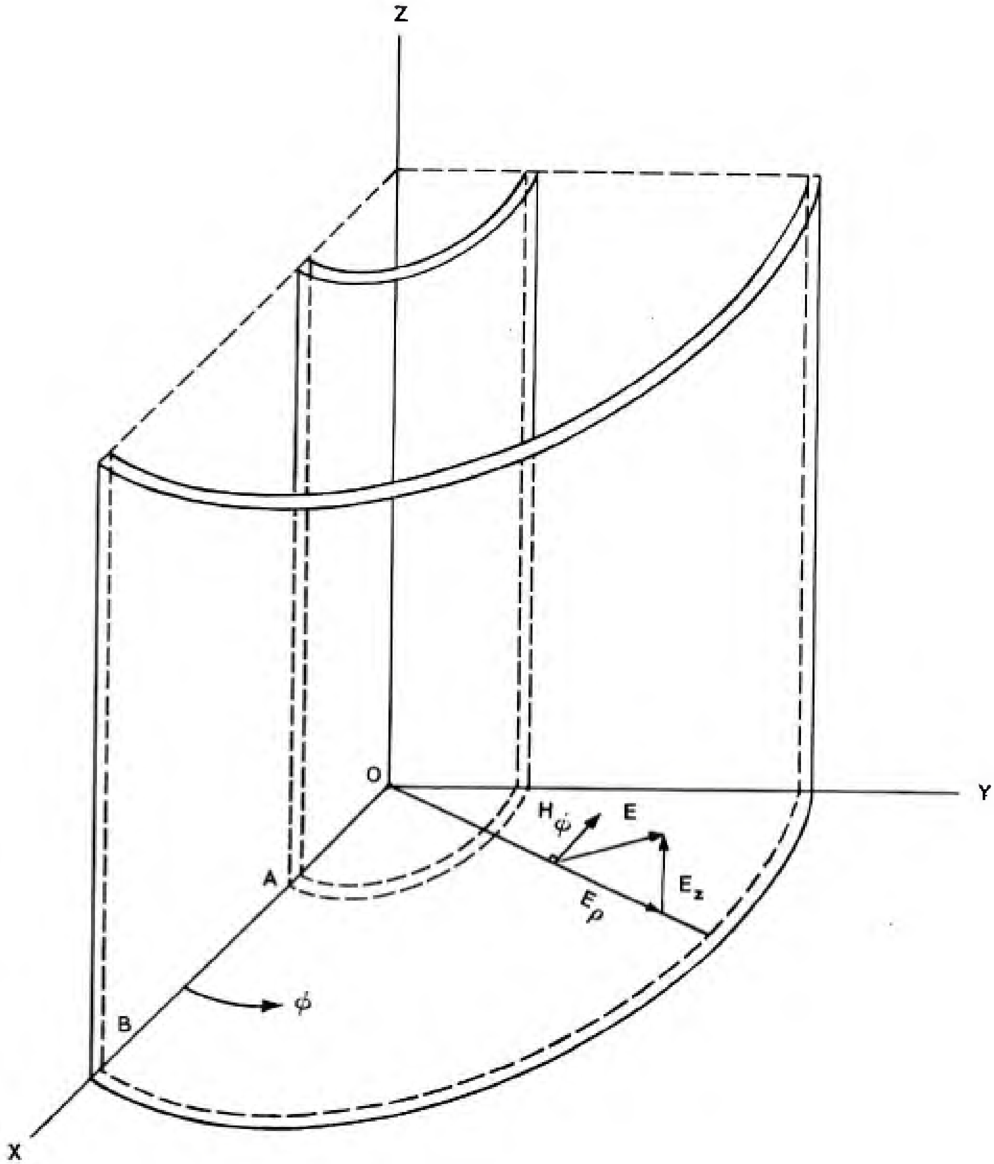


Figure 4. Electromagnetic field in a coaxial system.

cylinder OA represents the center conductor, and the concentric cylinder AB represents the insulation (dielectric). The outermost shell is the conductive sheath. The lines of magnetic flux, represented by H_ϕ, form concentric cylinders between the conductor and sheath. The electric field is made up of two components. The component E_ρ is radial and perpendicular to the axis of the conductor. This component is the electric gradient $\frac{V}{AB}$, where V is the total voltage rise from conducting sheath to conductor. The remaining component, E_z, is parallel to the Z axis and perpendicular to the radius. This component is the voltage drop per unit distance caused by current flow through the sheath resistance. The total current in the sheath is the sum of the differential currents caused to flow by the gradient E_ρ and therefore E_z depends directly upon the voltage difference between sheath and conductor. Since the power absorbed by the sheath is $\frac{(E_z)^2}{R}$ where R is the unit sheath resistance, it is obviously necessary to maintain a reasonably large potential difference between sheath and conductor. This is the purpose of the ground wire, which places the sheath at a potential near ground potential. If the ground wire has zero impedance, then the sheath-to-conductor voltage will be the full value of the interference voltage. Any ground lead impedance, however, creates a series voltage drop which moves the potential of the sheath nearer to that of the center conductor and reduces the effectiveness of the filter.

The distributed filter theoretically has a large radio frequency attenuation factor. Figure 5, taken from a recent technical paper,[3] shows the attenuation theoretically possible with a perfectly-grounded sheath having a resistance of 47.2 ohms per centimeter. Presently available sheath materials with suitable physical characteristics and of practical thickness will have somewhat larger values of resistance.

TESTS

Description of Tests

A survey was made of the electrical characteristics of a large number of materials for possible use as the filter sheath. It was hoped that a material of high permeability, or a low-resistance nonmetallic flexible material could be found. Samples of many materials were tested and their electrical characteristics measured. At the time of the survey, no low-cost magnetic material with

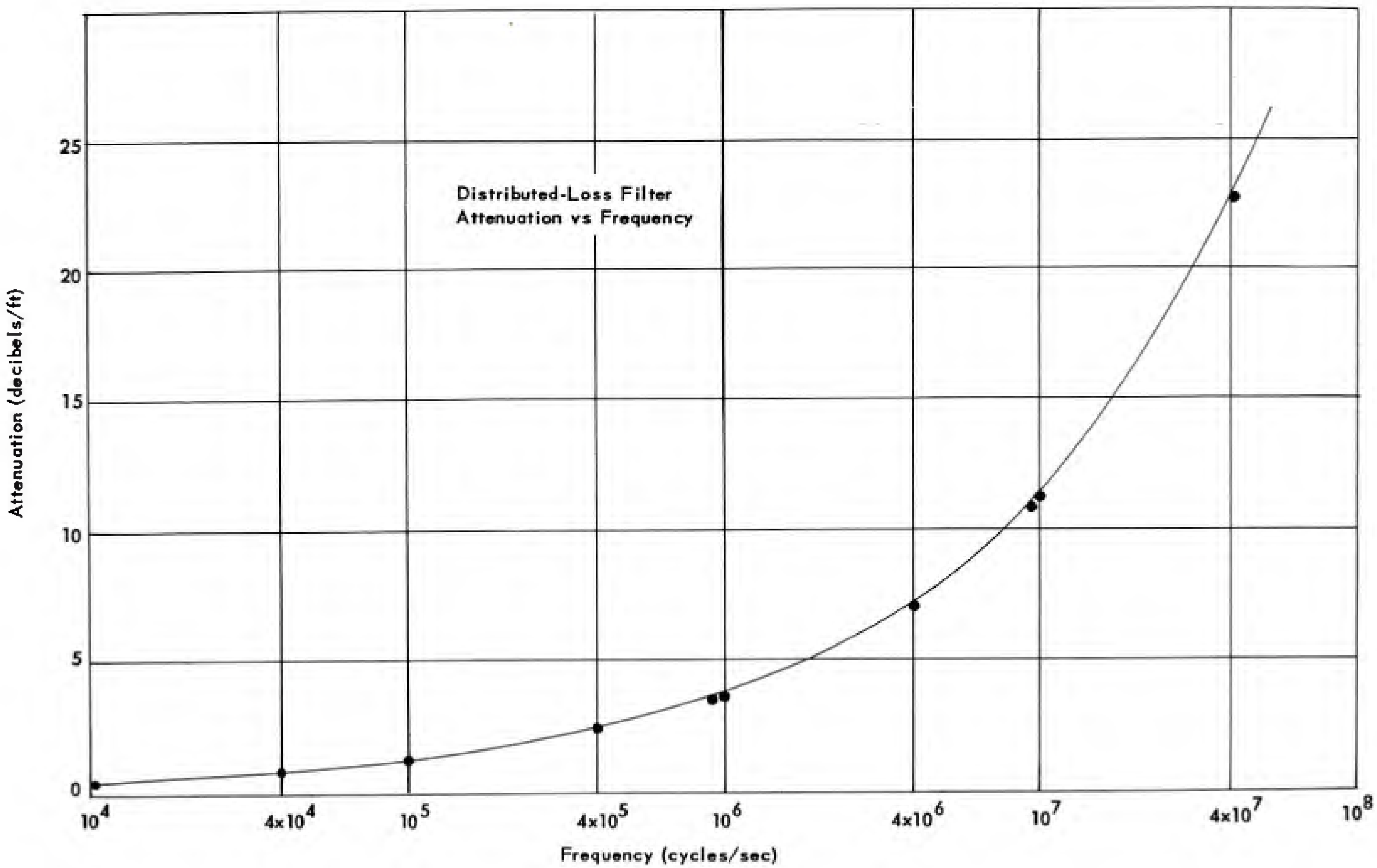


Figure 5. Calculated attenuation.

suitable mechanical properties was available. In an attempt to find a conductive, flexible, nonmetallic material, a large number of rubber and plastic compounds were mixed with varying proportions of carbon to improve their conductivity. One compound with particularly good electrical properties was found to be a plastic conductive cement, but this material is brittle and expensive. It was finally concluded that the best compromise between electrical characteristics, physical properties, and cost could be obtained by using a thick sheath of carbon-loaded neoprene or rubber similar to the conductive sheath used on some aerial cable. Since such a cable would have to be custom made, it was decided to simulate the sheath characteristics by using a readily available conductive tape wrapped on the test cable. This tape, having a resistance of approximately 377 ohms per square, was wrapped in one-inch widths on a 5000-volt insulated cable (see Figures 6 and 7). Each turn of tape overlapped the previous turn by 1/4 inch, and succeeding layers were spiralled in opposite directions. Several turns of soft copper wire were used to secure the tape at the ends and to make electrical contact from the tape to the ground leads. Each time a new layer of tape was added, reducing the sheath resistance, an insertion loss measurement was made. The filter cable, which was 80 feet long, was suspended on wooden hangers inside a shielded building. An identical cable, which had no conductive sheath, was suspended on the same hangers at the opposite ends of the arms. Figure 8 shows this installation which is inside a 40 x 100 ft sheet steel shielded building. Insertion loss was determined by sending a signal through the filter, to get a fixed reference reading on a receiver, then sending the same signal through the unfiltered line and an attenuator. The attenuator was set to give the same receiver reference reading as previously, thus the attenuator reading was the insertion loss of the filter.

Results of the tests in the shielded room indicated that the lossy sheath construction might be successfully applied if the optimum sheath resistance were used and if the problem of grounding at certain critical frequencies could be worked out. A design was drawn up for a cable that could be used on an actual outdoor installation, and a contract for the manufacture of this cable was let. In order to study the grounding problem and check the variation of loss with sheath resistance under conditions of actual use, conductive tape was used to simulate the sheath on a 250-foot filter in an actual power line. Because of long delays in procurement of the specially-designed cable, all data to date have been obtained from the simulated section.

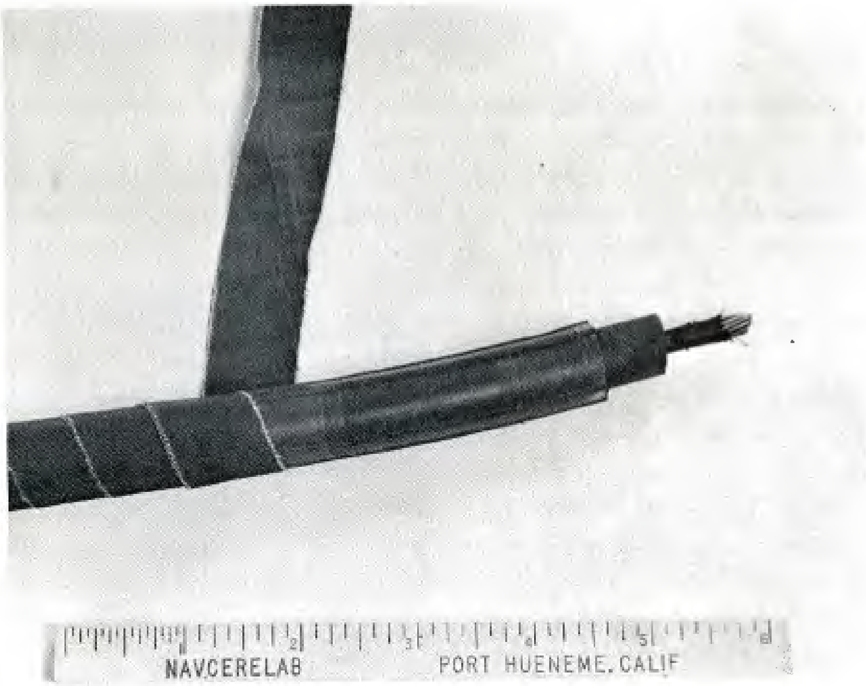


Figure 6. First layer of conductive tape being wound on insulated cable.

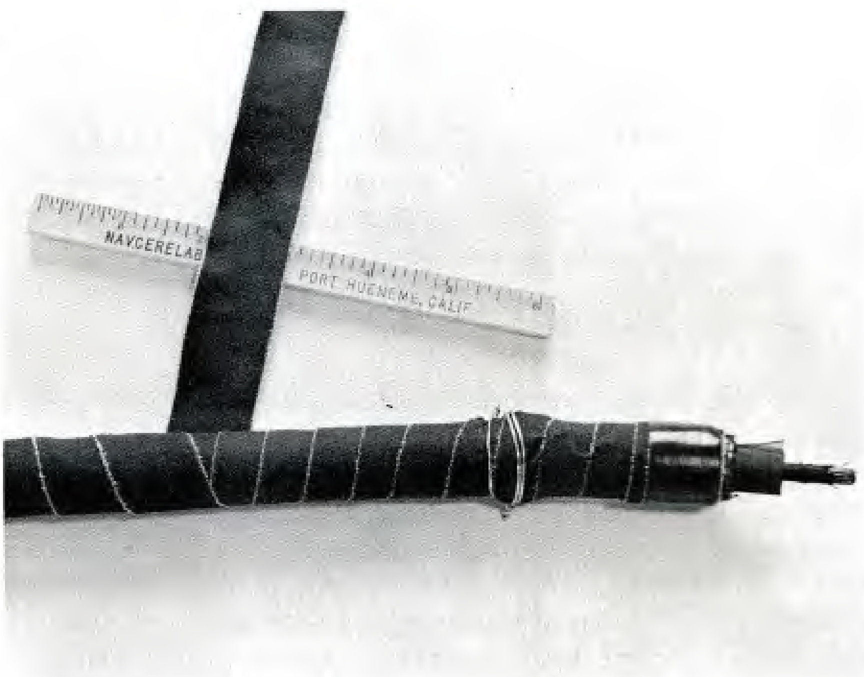


Figure 7. Final layer of conductive tape being wound on insulated cable.

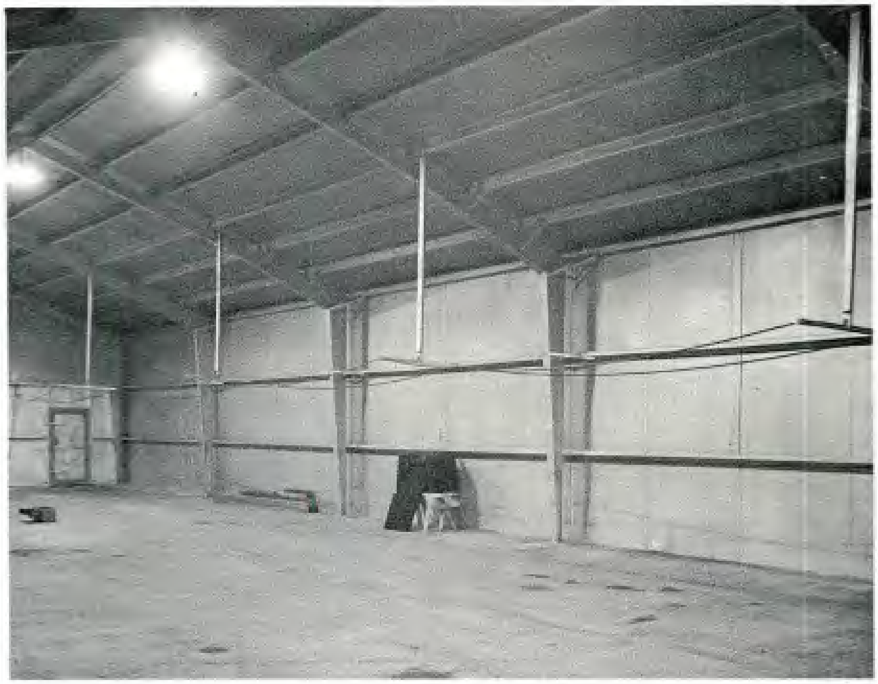


Figure 8. Cables suspended in shielded room for insertion loss tests.

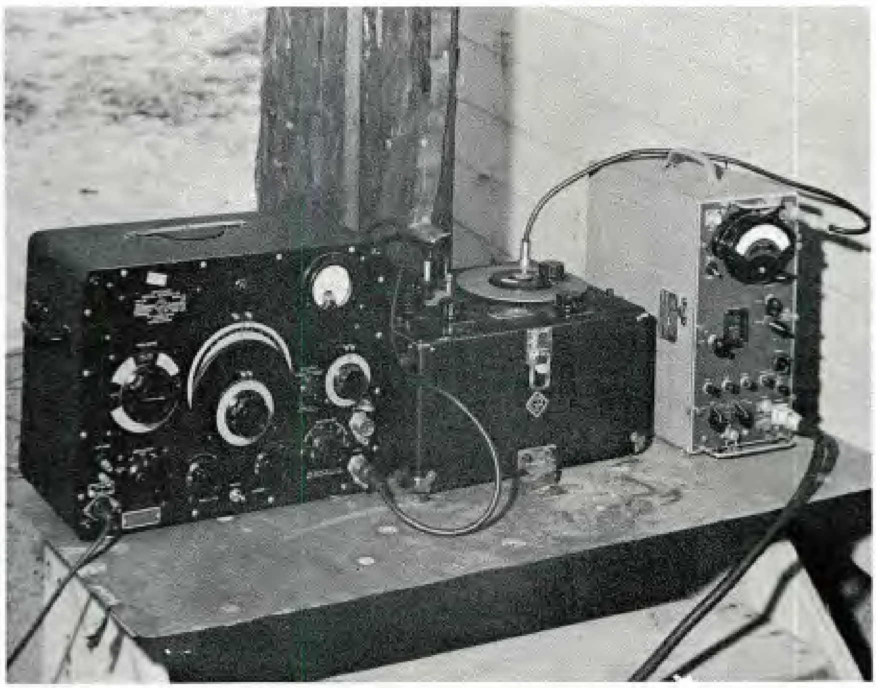


Figure 9. Instrumentation for input impedance measurements.

The facility for this test is a 1000-foot power line on 50-foot poles spaced 125 feet apart. The conductors are two #6 AWG hard-drawn solid copper wires on pin-type insulators at the outer pin positions. The line is insulated for a nominal 5000 volts. Since interference conditions are worst when the line currents are in phase, the conductors, for all tests, were strapped together at each end.

To study the filter characteristics, it was necessary to know the electrical characteristics of the line. These characteristics can be determined completely by measurements of input impedance over a sufficiently large frequency range, with the far end of the line open, and with the far end directly grounded. A General Radio Company radio frequency impedance bridge was used to make these measurements (see Figure 9). Radio frequency signals were supplied from the General Radio standard signal generator. The null detector was a PRM-1 radio noise and field intensity meter. It was determined from these tests that the characteristic impedance of the line fluctuated about a value of 400 ohms, so a 400-ohm termination was used at both ends of the line for the insertion loss tests which followed.

The insertion loss test setup is shown schematically in Figure 10. A set of output readings was taken, before inserting the filter in the circuit, with a known signal generator reference output. The filter, which was 250 feet long, was then placed in the circuit and a new set of readings taken. Comparison of the two sets of readings gave the reduction of signal through the filter. Figure 11 shows the two-span filter section in the power line during tests.

The filter was constructed exactly as it was for the tests in the shielded building, except that flexible silver paint was used at the ground connections to the conductive tape for more positive electrical contact. For most of the tests, four layers of tape were used, but two layers were used for the last test. The purpose of the change in number of layers was to check the effects on insertion loss resulting from a known change in sheath resistance.

Provision was made in the ground leads for connection of various impedance elements so that an attempt could be made to compensate for the ground lead impedance. Figure 12 shows a coil of wire inserted in the ground lead for one of the tests.

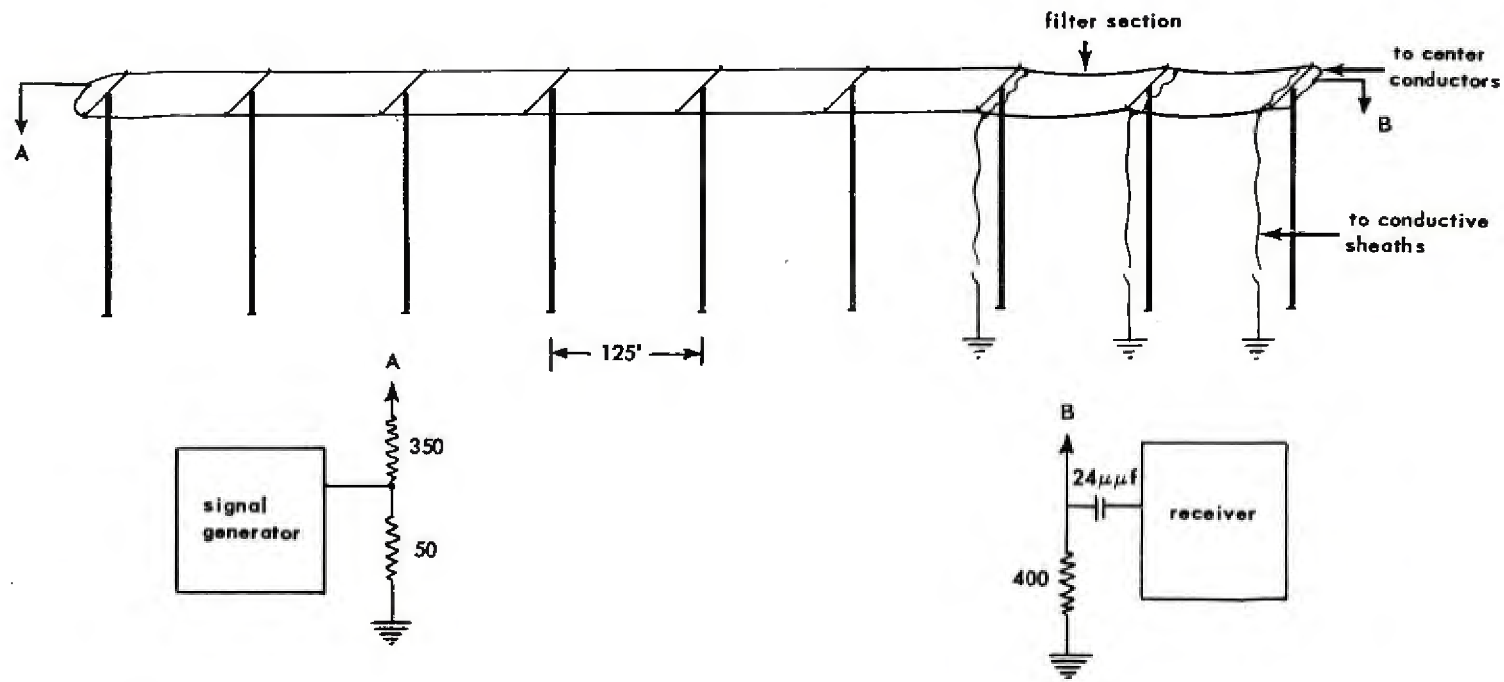


Figure 10. Filter insertion loss test setup.

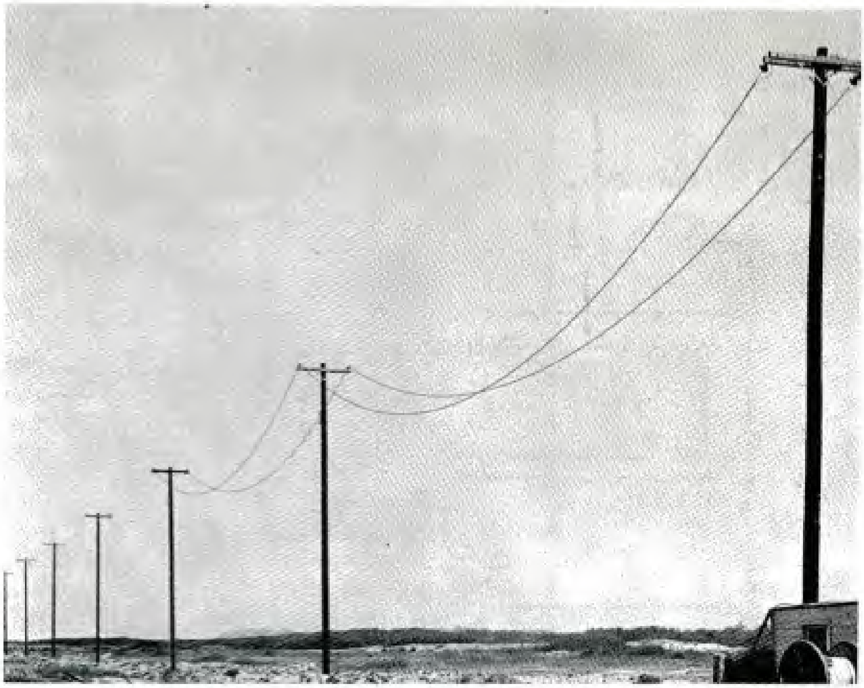


Figure 11. Two-span (250-ft) filter section under test in power line.

Figure 12. Wire loop inserted in ground lead for impedance correction.

The resistivity of the conductive tape is plotted for varying numbers of layers in Figure 13. For two layers of tape, the resistance is 672 ohms per foot, and for four layers it is 256 ohms per foot.

Test Results

Figure 14 shows graphically the insertion loss of an eighty-foot section of the filter as tested in the shielded building. Each curve is for a different number of layers of conductive tape, representing different sheath resistance values. For each construction, there is an approximately exponential increase in loss with increasing frequency, as predicted by theory. In each instance, there is a peak in the curve between 4 and 5 mc, and all the curves show a deep minimum at 14 mc. The configuration of the filters required a ground lead 17.5 feet long. Since this length corresponds to a quarter-wave resonant frequency of 14 mc, the ground lead is effectively an infinite, or "open circuit," impedance at that frequency. Other fluctuations are the results of impedance discontinuities on the line. The curves here show a general increase in insertion loss as the sheath resistance is reduced, with the maximum occurring for 5 layers of conductive tape. It was found that the addition of more layers had no significant effect on the loss characteristics.

The input impedance of the 1000-foot power line under open-circuit and short-circuit load terminal conditions is shown in Figure 15. The short circuit characteristic is a damped tangent curve, while the open circuit characteristic is a damped cotangent curve. These curves are precisely what would be expected for a low-loss transmission line. The short-circuit curve has a very slightly different period from that of the open circuit curve. This difference corresponds exactly to the increased effective line length introduced by the 43-foot grounding strap. The added resistance of the grounding strap also introduces some resistance loss which shows up as a slightly larger damping effect on the short-circuit characteristic. At frequencies considerably higher than those shown on the graph, the effective length of the ground lead became a larger part of a wave length and tended to bring the two characteristics in phase. The approximate value of the characteristic impedance of the line can be found by drawing a curve through the points of intersection of the two impedance curves. Actual calculation of the characteristic impedance corresponds to these points

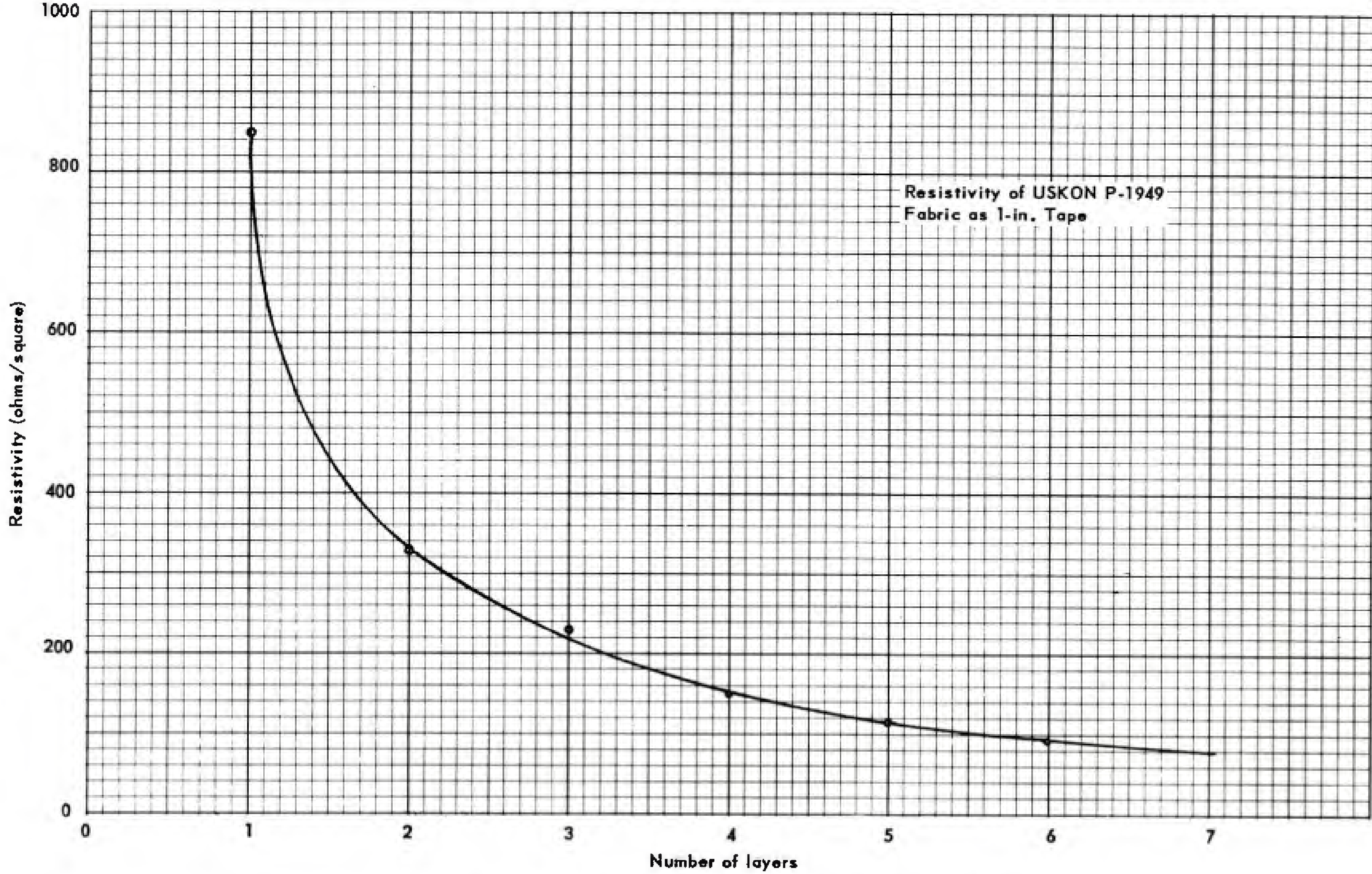


Figure 13. Resistivity of conductive tape cable sheath.

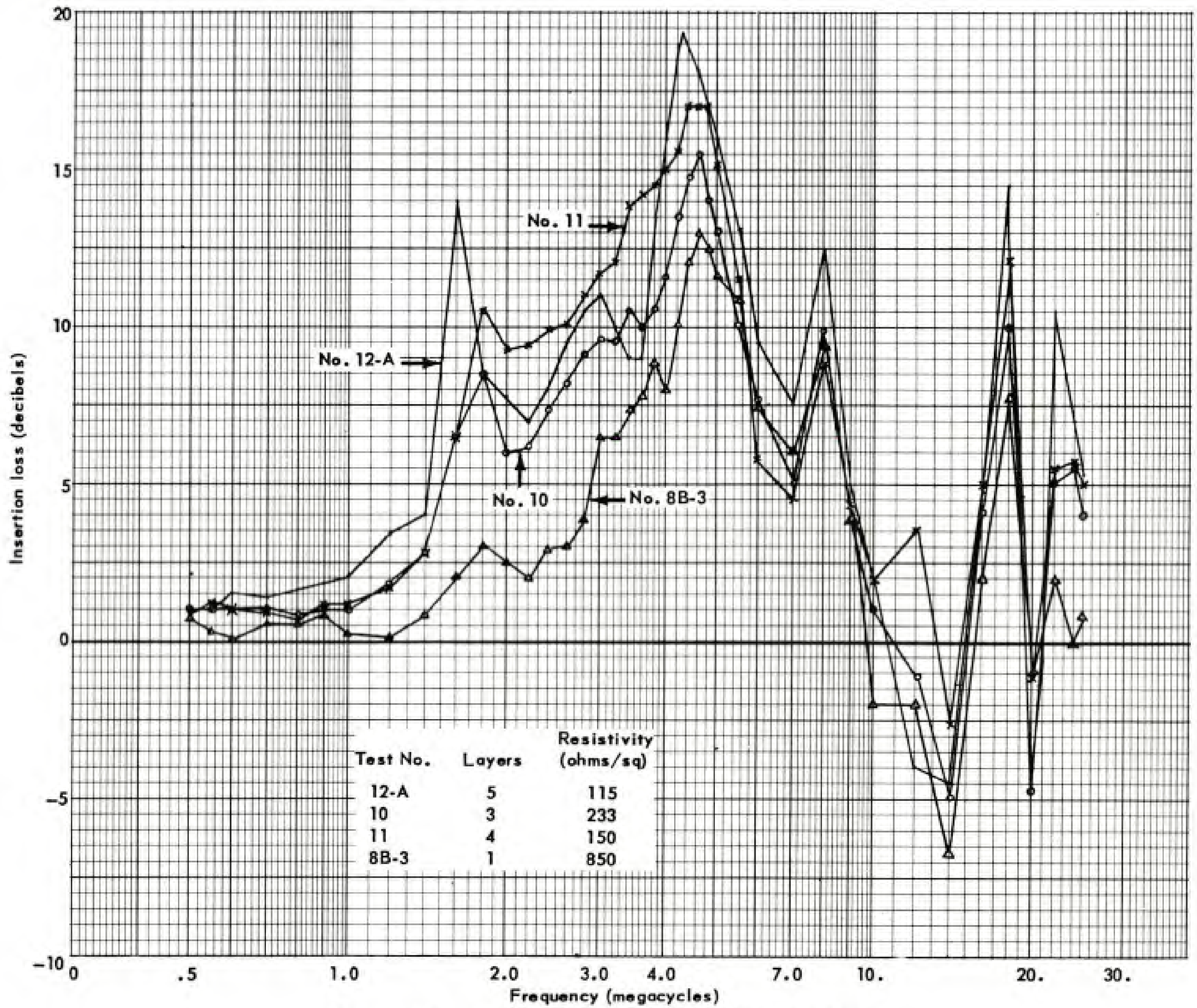


Figure 14. Insertion loss of 80-ft filter sections.

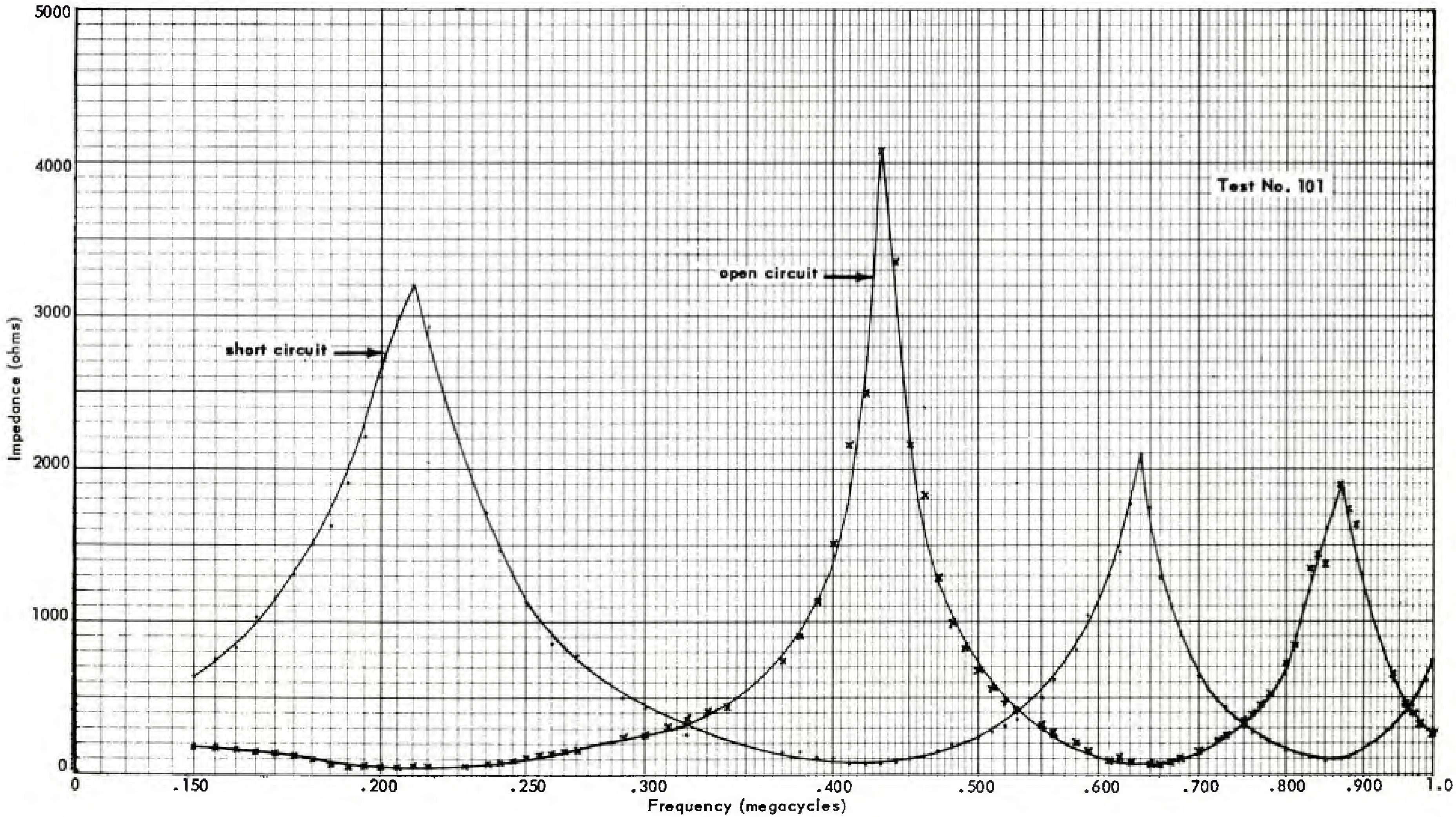


Figure 15. Power line input impedance.

and fluctuates about a value of 400 ohms. This value was also checked by calculations based on the conductor size and spacing from the earth.

The damping, or attenuation, on the power line is found from the input impedance characteristics. The propagation constant is

$$B = \frac{1}{x} \tan^{-1} \sqrt{\frac{Zsc}{-Zoc}}$$

where x = line length
Zsc = short circuit input impedance
Zoc = open circuit input impedance

The quantity B is complex, and expresses the time relation or phase shift constant and the attenuation constant. The quadrature, or imaginary, component of B is the attenuation constant. Values of attenuation, expressed in decibels per 1000 feet, are plotted in Figure 16. These values were calculated from the measured impedance values. Note that this curve shows an exponential rise with increasing frequency. Because of the increasing phase shift caused by the ground strap, it is not practical to compute attenuation from impedance measurements at frequencies much above those shown in Figure 15. The exponential trend is clearly shown, however.

The most significant results of the tests of the filter on a 1000-foot line are plotted in Figures 17 and 18. In Figure 17, Test 301 is on a 250-foot filter section having four layers of conductive tape, and having ground leads at each end and at the middle of its length. Since these data and the shielded building data showed that effective grounding cannot be obtained when the ground lead approaches quarter-wave resonance, it was postulated that if one of the ground leads were doubled in length the losses would be increased, for when the short ground lead becomes 1/4 wave length, the long ground lead becomes 1/2 wave length. The impedance of the 1/2 wave lead is then reduced to its ac resistance value. Test 309 shows the results of using one double-length ground lead, along with two straight leads at the other two poles. The losses were improved considerably and the minimum was not as low as previously. Test 344 was the same as 301, except that only two conductive layers were used for the sheath. As expected, the losses were lower for this construction.

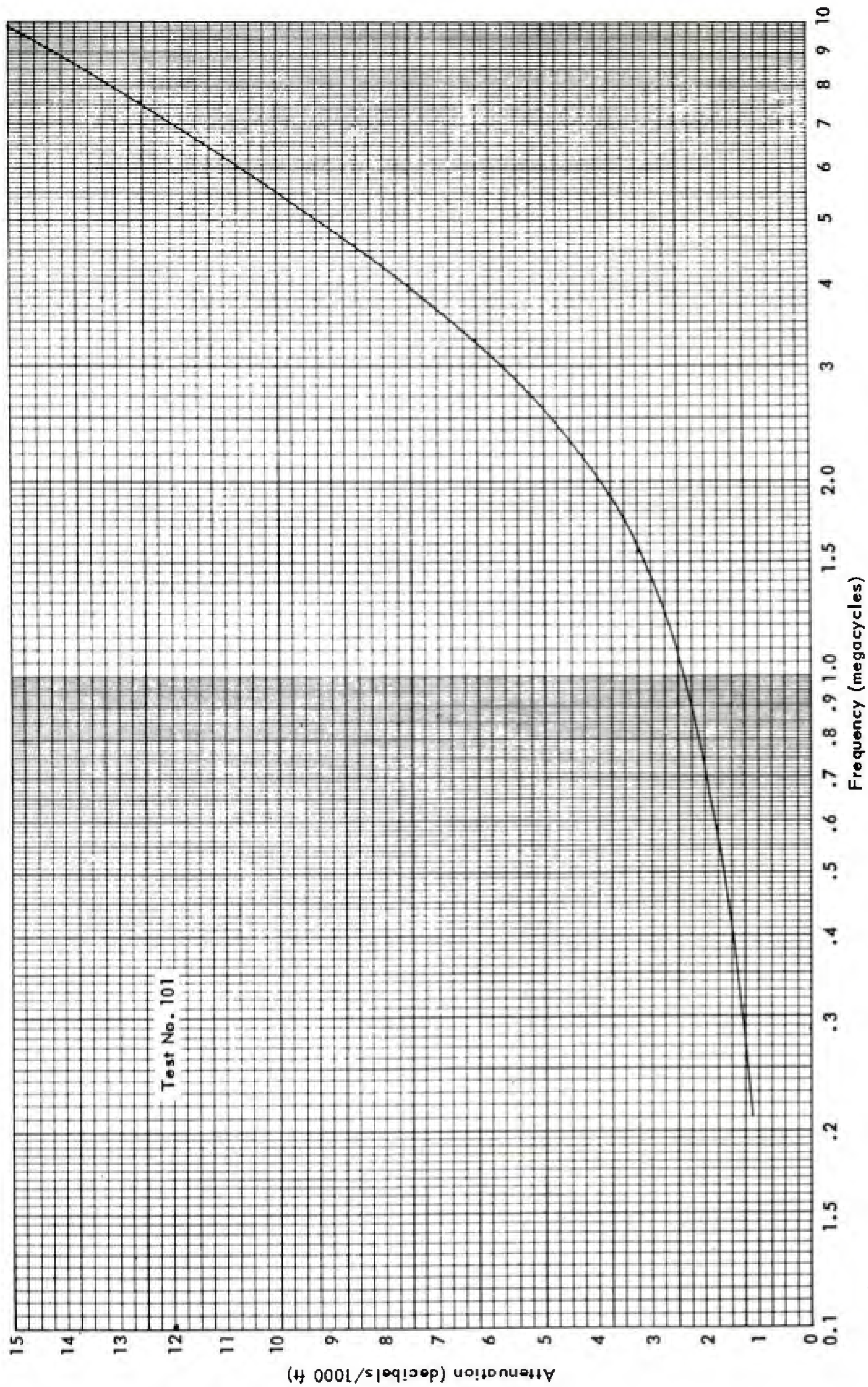


Figure 16. Power line attenuation.

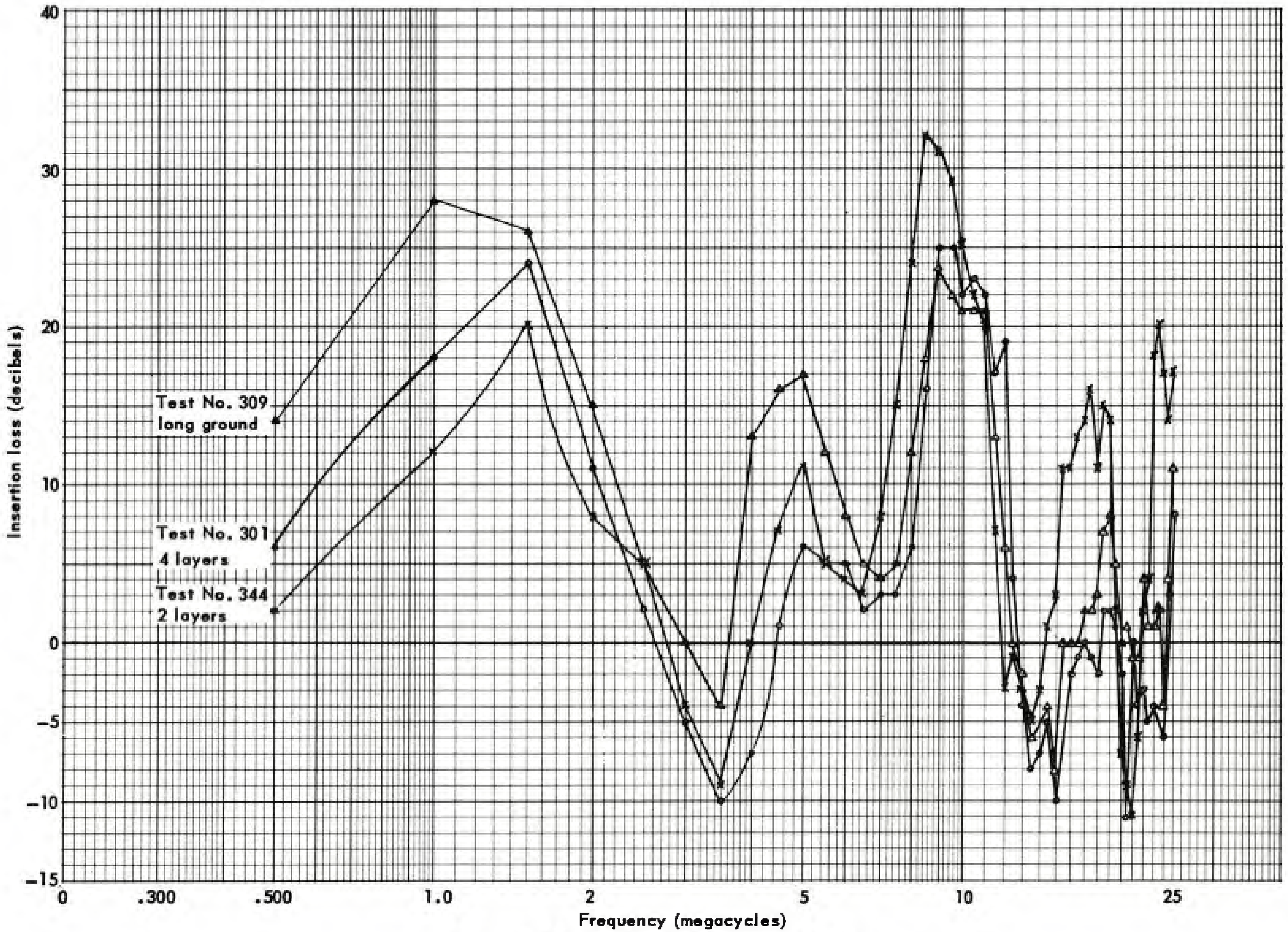


Figure 17. Lossy filter insertion loss.

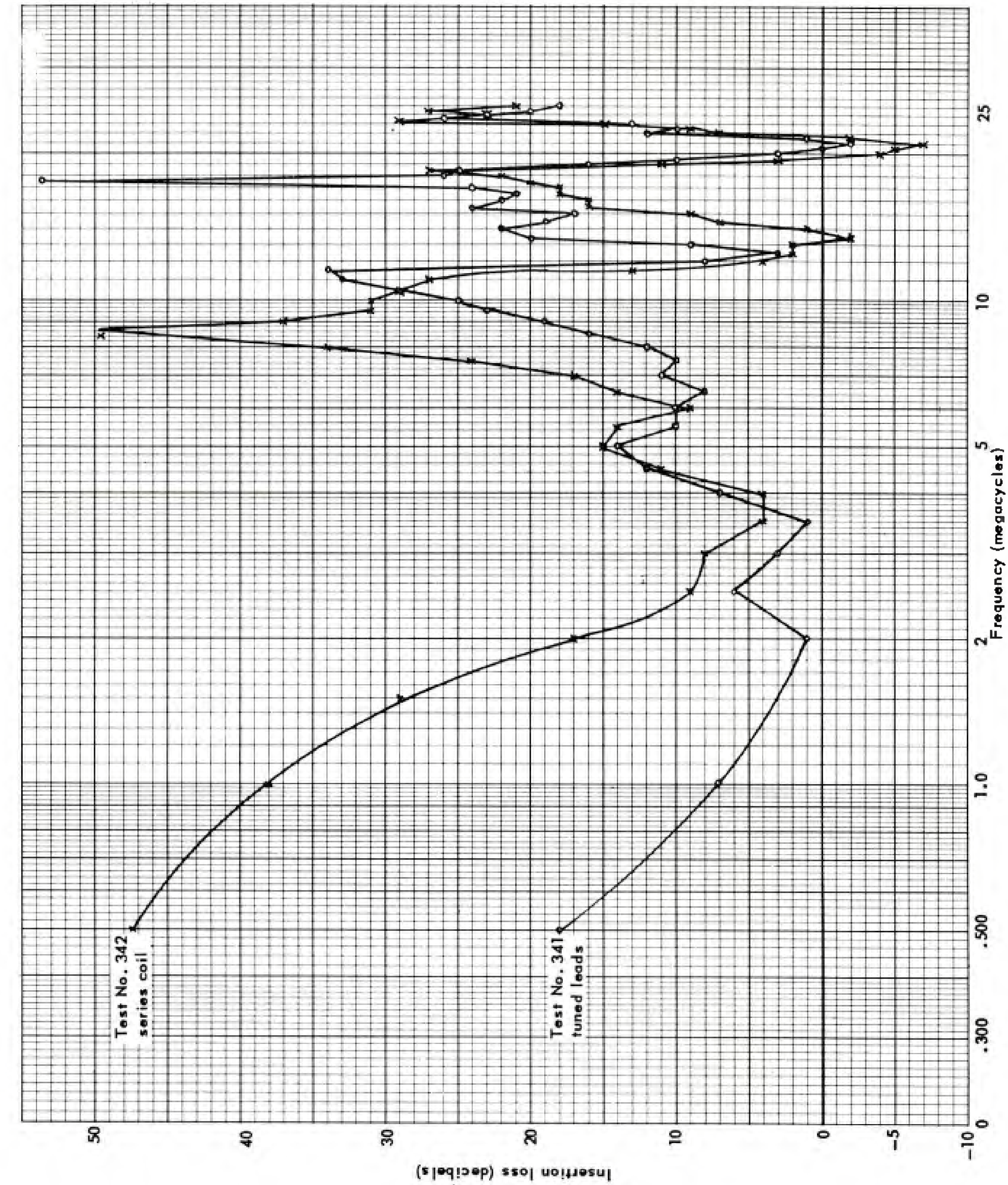


Figure 18. Lossy filter insertion loss.

A further attempt to correct for the dip in the loss characteristic at resonant frequencies resulted in the data of Test 341 (see Figure 18). It was thought that a tuned parallel RLC circuit inserted in the ground lead might be used to improve the losses at the resonant frequencies, at some expense to the low frequency response. Parallel RLC circuits were connected in each of the three ground leads and tuned individually for best response at .5, 3.5, and 13.5 mc. Thus it was possible to have only one ground lead in effect at each of these frequencies, with intermediate effect at other frequencies. Appreciable improvement in the loss characteristic at the resonant frequencies resulted, even though this was effectively a reduction in the number of ground connections.

For Test 342, the four-layer sheath filter was connected in series with a commercial power line interference coil in each conductor. Except for the presence of the coils, this test was the same as Test 341. This particular coil has a resonant frequency of approximately 500 kc because of inter-turn capacitance. The insertion loss characteristic was improved by the coil, but a serious dip remained at the resonant frequencies.

Discussion

The impedance and attenuation characteristics of the power line show conclusively the high efficiency of propagation of radio interference along a power line. The current must follow the conductors, essentially in phase, and return through the earth. At low frequencies, it is clear that the earth is a good conductor because of the deep penetration of earth currents. The occurrence of 1/4 wave resonance at 3.5 mc for a 45-foot ground lead indicates that the effective depth of penetration at that frequency is about 35 feet. The next resonance, for 3/4 wave length, occurs at 13.5 mc, and shows that the penetration has been reduced to about 8.5 feet. The earth volume available for conduction is then seen to become much smaller as the frequency is raised. This clearly shows why low-frequency interference may be propagated for miles, while frequencies of 50 mc or more are insignificant at more than two or three spans away from the source. This result is also clearly supported by the exponentially rising attenuation characteristic of Figure 16.

Tests 301 and 344, which are typical of many similar runs, support the results of the shielded building tests of the filter. The increase in sheath conductivity to an optimum value results in improved loss characteristics. The problem of quarter-wave ground lead resonance is painfully obvious in all the tests. The use of tuned circuits in ground leads does not appear too promising because of the complexity of proper tuning in the field by untrained personnel. Complexity is also a problem in determining the physical length of an electrically double-length ground lead. It was found during the tests that only a few inches error in this lead length cancelled the effects of using it.

A less obvious practical solution of the grounding problem is indicated by the results of Test 342. The coils used for this test were used only because they were readily available. They were shown in a previous study[4] to exhibit parallel resonance at 500 kc. Above this frequency their impedance is approximately inversely proportional to frequency. It would be a simple matter to raise the resonant frequency of the coil by using fewer turns, so that the parallel resonance of the coil would occur at or near the quarter-wave resonant frequency of the ground lead. When this is done, a large insertion loss will be introduced by the coil, to be added to the small filter loss. The addition of a second small coil of suitable design in series with the line at the other end of the filter would have a similar effect at the 3/4 wave length resonant frequency. The proper combination of lossy filter and coils should give a good broad band insertion loss characteristic.

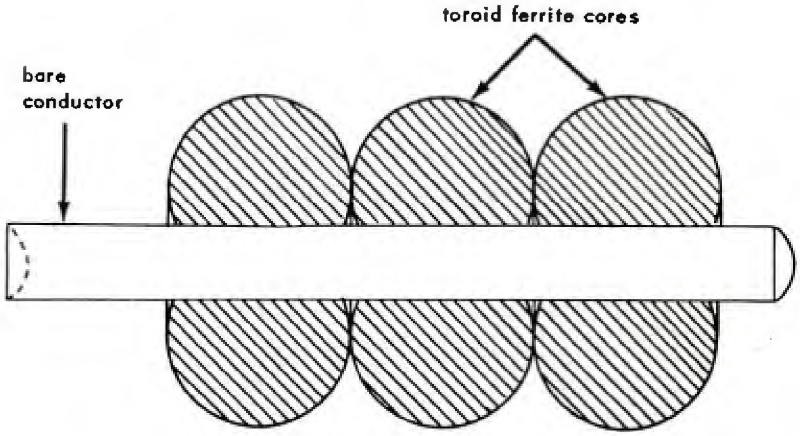
RECOMMENDATIONS

The following studies outline the recommended program for continued progress toward the development of a practical interference filter for overhead power lines.

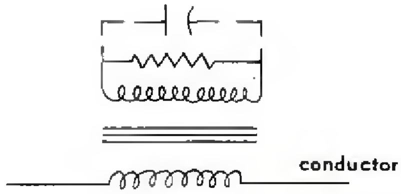
1. Make insertion loss tests on a 1000-foot length of conductive rubber-sheathed cable which is scheduled for early delivery to the Laboratory.

2. Design suitable inductance coils for series connection in a filtered line as described under the heading Discussion.

3. Study possible use of ferrite materials as a filter element. Since the original investigation of these materials, some new ferrites have become available at low cost. Some of these materials have high permeability, along with relatively high conductivity. A suggested application and the equivalent electrical circuit are illustrated in Figure 19. The ferrite could be purchased in the form of toroids or beads with all edges rounded to prevent corona discharge. Since it would not be necessary to ground the cores, they could be fitted directly on the conductor, thus allowing very close coupling and requiring little or no insulation. The use of toroids or beads would avoid the necessity for a flexible material. Radio frequency currents in the conductor would induce eddy current, hysteresis, and residual losses in the conductive magnetic material. The equivalent circuit is represented by a transformer with a low-resistance secondary load. The secondary resistance is reflected into the primary (the power conductor) as a series resistance and causes power to be absorbed. The proportion of power absorbed depends on the frequency, so the 60-cycle loss will be negligible, while the radio frequency loss may be large. A preliminary study indicates that the core material should have a Q factor of between 1.0 and 1.3 for optimum results. It will be necessary to select a material with the proper permeability-Q product and to determine the optimum geometry for the core, as well as to determine the necessary cross section to avoid magnetic saturation by the 60-cycle current.



A. Cores on Conductor



B. Equivalent Circuit

Figure 19. A proposed distributed-absorption filter.

REFERENCES

1. NAVCERELAB Technical Memorandum M-095, Interim Report Reduction of Power Line Radio Interference, by J. C. Senn and A. W. Gosley, 1 February 1955.

2. NAVCERELAB Technical Memorandum M-116, A Practical Handbook on Location and Prevention of Radio Interference from Overhead Power Lines, by J. C. Senn and D. B. Wright, 21 November 1956.

3. Senn, J. C., "Reduction of Power Line Radio Interference," Proceedings of the Second Annual Conference on Radio Interference Reduction, Armour Research Foundation, 4 March 1956.

4. NAVCERELAB Technical Note N-282, Laboratory and Field Tests on Risco Radio Interference Choke Coils for Overhead Power Lines, by J. C. Senn, 26 December 1956.

DISTRIBUTION LIST

No. of Copies	
15	Chief of Civil Engineers
1	Chief, Bureau of Ships, Research Division, Attn: L. W. Thomas (Code 837)
1	Navy Liaison Officer, Air Proving Ground Command
1	Navy Liaison Officer, Detroit Arsenal
1	Commander, U. S. Naval Air Missile Test Center
1	Commanding Officer and Director, U. S. Navy Electronics Laboratory
1	Commanding Officer and Director, U. S. Naval Engineering Experiment Station
1	Commander, U. S. Ordnance Test Station, Inyokern
1	Commander, U. S. Naval Ordnance Test Station, Pasadena
1	Commander, U. S. Naval Ordnance Laboratory, Silver Spring
2	Director, Pacific and Alaskan Division, Bureau of Yards and Docks
2	Deputy Director, Pacific Division, Bureau of Yards and Docks
1	Director, Atlantic Division, Bureau of Yards and Docks
1	Yards and Docks Supply Officer, Port Hueneme, California
1	U. S. Naval School, CEC Officers School, Port Hueneme
1	Commandant, 1st Naval District
1	Commandant, 3rd Naval District
1	Commandant, 4th Naval District
1	Commandant, 5th Naval District
1	Commandant, 6th Naval District
1	Commandant, 8th Naval District
1	Commandant, 9th Naval District
1	Commandant, 10th Naval District
1	Commandant, 11th Naval District
1	Commandant, 12th Naval District
1	Commandant, 13th Naval District
1	Commandant, 14th Naval District
1	Commandant, 15th Naval District
1	Commandant, 17th Naval District
1	Commandant, Potomac River Naval Command
1	Commandant, Severn River Naval Command
1	Commanding Officer, Headquarters Command, COMNAV, Marianas
1	District Public Works Office, 1st Naval District

1	District Public Works Office, 3rd Naval District
1	District Public Works Office, 4th Naval District
1	District Public Works Office, 5th Naval District
1	District Public Works Office, 6th Naval District
1	District Public Works Office, 8th Naval District
1	District Public Works Office, 9th Naval District
1	District Public Works Office, 10th Naval District
1	District Public Works Office, 11th Naval District
1	District Public Works Office, 12th Naval District
1	District Public Works Office, 13th Naval District
1	District Public Works Office, 14th Naval District
1	District Public Works Office, 15th Naval District
1	District Public Works Office, 17th Naval District
1	District Public Works Office, Potomac River Naval Command
1	District Public Works Office, Severn River Naval Command
1	President, Signal Corps Board, U. S. Army
1	Office of the Quartermaster General, Department of the Army
1	Commanding Officer, Signal Corps Engineering Laboratories
1	Commanding Officer, Engineer Research and Development Laboratories
1	Commanding General, Air Research and Development Command
1	Chief of Engineers, U. S. Army
1	U. S. Army Corps of Engineers, Office of the District Engineer, St. Paul District
1	Commanding General, Air Proving Ground
1	Commanding General, Air Materiel Command, Air Installation Division
1	Commanding General, Wright Air Development Center, Standards Division
1	Director, Bureau of Reclamation, Department of Interior
1	Director, National Bureau of Standards
1	Director, Office of Technical Services
1	Library of Congress
1	Library, Engineering Department, University of California, Berkeley
1	Library, Engineering Department, University of California, Los Angeles
1	Library, University of Southern California, Los Angeles
1	Commanding Officer, U. S. Naval Air Development Center
1	Commander, U. S. Naval Air Test Center
1	Technical Library, Office of Assistant Secretary of Defense
1	Commanding Officer, Rome Air Development Center

1	Commander, Mare Island Naval Shipyard
1	Radio Interference Group, Dept. 6, Building 51, Convair, San Diego, Attn: Mr. R. B. Withrow
1	Radio Interference Section, Hughes Aircraft Co., Culver City, California Attn: Mr. Don Nevin
1	California-Pacific Utilities Company, La Grande, Oregon, Attn: Mr. J. K. Moore
1	Liaison Engineering 7-L, Westinghouse Electric Corp., East Pittsburgh, Pennsylvania, Attn: Mr. W. E. Pakala
1	Armour Research Foundation, Chicago, Illinois, Attn: Mr. Arnold L. Albin
1	Pacific Gas and Electric Company, San Luis Obispo, California, Attn: Mr. M. A. Wood
1	Interference Testing and Research Laboratory, Boston, Massachusetts, Attn: Mr. Paul B. Wilson
1	Rensselaer Polytechnic Institute, Troy, New York, Attn: Dr. K. E. Mortensen
1	Commander, San Francisco Naval Shipyard
1	Commander, Naval Ordnance Laboratory, Corona, California
1	Technical Library, U. S. Naval Postgraduate School, Monterey, California
1	Naval Liaison Officer, Signal Corp Engineering Laboratories
1	Navy Material Laboratory, New York Naval Shipyard, Attn: R. W. Fairweather
1	Commanding Officer, Naval Research Laboratory, Washington, D.C.
10	Armed Services Technical Information Agency

Naval Civil Engineering Research and Evaluation Laboratory. Technical Memorandum M-117.
STUDIES LEADING TO THE DEVELOPMENT OF A RADIO INTERFERENCE FILTER FOR OVERHEAD POWER LINES, by J. C. Senn. 4 January 1957.
31 p. illus. UNCLASSIFIED

This interim report presents the initial studies conducted to develop a radio interference filter suitable for high voltage power line applications. A unique distributed loss filter is proposed and experimental data are presented.

1. Radio interference - Countermeasures
I. Senn, J. C.
II. NY 411 002

Naval Civil Engineering Research and Evaluation Laboratory. Technical Memorandum M-117.
STUDIES LEADING TO THE DEVELOPMENT OF A RADIO INTERFERENCE FILTER FOR OVERHEAD POWER LINES, by J. C. Senn. 4 January 1957.
31 p. illus. UNCLASSIFIED

This interim report presents the initial studies conducted to develop a radio interference filter suitable for high voltage power line applications. A unique distributed loss filter is proposed and experimental data are presented.

1. Radio interference - Countermeasures
I. Senn, J. C.
II. NY 411 002

Naval Civil Engineering Research and Evaluation Laboratory. Technical Memorandum M-117.
STUDIES LEADING TO THE DEVELOPMENT OF A RADIO INTERFERENCE FILTER FOR OVERHEAD POWER LINES, by J. C. Senn. 4 January 1957.
31 p. illus. UNCLASSIFIED

This interim report presents the initial studies conducted to develop a radio interference filter suitable for high voltage power line applications. A unique distributed loss filter is proposed and experimental data are presented.

1. Radio interference - Countermeasures
I. Senn, J. C.
II. NY 411 002

Naval Civil Engineering Research and Evaluation Laboratory. Technical Memorandum M-117.
STUDIES LEADING TO THE DEVELOPMENT OF A RADIO INTERFERENCE FILTER FOR OVERHEAD POWER LINES, by J. C. Senn. 4 January 1957.
31 p. illus. UNCLASSIFIED

This interim report presents the initial studies conducted to develop a radio interference filter suitable for high voltage power line applications. A unique distributed loss filter is proposed and experimental data are presented.

1. Radio interference - Countermeasures
I. Senn, J. C.
II. NY 411 002