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MEASUREMENT OF CHARACTERISTIC IMPEDANCE AND ATTENUATION OF TWISTED PAIR TRANSMISSION LINES.

By
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NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
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BUREAU OF ENGINEERING

Report on

Measurement of Characteristic Impedance and Attenuation of Twisted Pair Transmission Lines.

NAVAL RESEARCH LABORATORY
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ABSTRACT

This work was done in an effort to develop a method for accurately determining the characteristic impedance and attenuation of flexible twisted type transmission lines having other than air dielectric, at high frequencies.

As flexible transmission lines are being used in the higher frequency bands, and thus may be of value in the Naval Service, it is important that the electrical values of these lines be known before being employed as part of any communication installation.

The two values to be determined are the characteristic impedance and attenuation, as the efficiency of the energy transfer depends upon the impedance matching, and the lines attenuation or losses particularly if the lines length is in the order of several hundred feet.

As no existing data are obtainable at the present time, this work becomes of a pioneer attempt to develop a method for determining the electrical values of this type transmission line.

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AUTHORIZATION

1. This work was authorized by the Bureau of Engineering letter NP14 (5-6-W8) of 12 July 1935.

STATEMENT OF PROBLEM

2. The problem is to establish a method for accurately determining the characteristic impedance and attenuation of transmission lines of the twisted pair type, having other than air dielectric, at high frequencies.

KNOWN FACTS BEARING ON THE PROBLEM

3. At the present time there are few known facts concerning this work and no existing publications of any importance.

THEORETICAL CONSIDERATIONS

4. The theoretical operation and application of transmission lines is well known; however, this established knowledge concerns only transmission lines of which the perameters are known.

5. In the case of lines having various dielectric materials there is little, if any, definite data upon the changes in dielectric constant and losses at very high frequencies.

6. It is to be expected that the capacity, dielectric constant and leakage losses change with variation in frequency; to what extent would be guess-work to say at the present time.

7. In order to calculate the impedance of these type lines it would be necessary to measure the dielectric constant and losses at the high frequencies at which they are to be used. This in itself is as great an undertaking as the measurement of the direct impedance, so it is obvious that to measure the impedance direct is the shortest and most plausible method of solving the problem.

NARRATIVE OF ORIGINAL WORK DONE AT THIS LABORATORY ON THE PROBLEM

8. Several methods were employed, the simplest being the so-called Z method; that is, by measuring the surge impedance with the line open and closed. The line impedance is then equal to $\sqrt{ZoZs}$.

9. This method is believed to be fairly accurate at the higher frequencies provided that all radio frequency current indicating meters have been calibrated in the higher frequency bands.

10. A method for calibrating the commercial type radio frequency current meter at frequencies above 5 mcs. is being developed at this Laboratory at the present time. A report of this work will be forwarded at a leter date.

11. A Cathode Ray Wattmeter was employed to make these measurements, the voltage and current legs being carefully calibrated with a known

resistance load. The line was then connected in place of the resistance and the current and voltage measured with the line open and closed, and the impedance then calculated.

12. The length of the line with respect to frequency is a deciding factor upon the accuracy of the result; that is, if the line length is an exact half-wavelength, its impedance for a zero loss line would be zero, and an infinite impedance for a quarter wavelength. Thus for lines having high attenuation the impedance for a length one-half wavelength would be something more than zero and for one-quarter wavelength would be something less than infinite.

13. It is necessary then, for accurate results, to first cut the line to a length terminating between one-quarter and one-half wavelength or between one-half and three-quarter wavelength.

14. It should be noted that in the case of twisted pair lines the electrical length does not agree with the physical length due to the degree of "twist" of the conductors and the degree of attenuation.

15. Probably the best method of determining the exact electrical length is to explore the length of line with a resonance indicating device and thus locate the current loops which will of course occur at intervals of one-half wavelength.

16. The ratio of the driving frequency to the measured electrical length in the cable will give the per cent propagation.

17. The Cathode Ray Wattmeter method being developed at this Laboratory presents an ideal method for determining the impedance and attenuation with one operation.

18. The current and voltage legs of the cathode tube are first corrected for phase, then a load of known non-inductive resistance is shunted across the tube and accurate readings taken. From the watts load and the corresponding area of the cathode tube figure a calibrated or reference is thus obtained.

19. The line is then connected through the cathode ray wattmeter and terminated with a known non-inductive resistance in series with an accurately calibrated current meter. The ratio of watts input to output is thus the line attenuation.

20. For a number of terminating resistances a curve of the output-input ratio is drawn with the output-input plotted against the terminating resistances.

21. For lines of fairly low attenuation a smooth curve with well defined peak of lowest attenuation will result; for lines of high attenuation the curve will be less peaked at the lowest attenuation but of such character that the terminating resistance giving the lowest attenuation is readily observed.

22. The accuracy of this method will depend upon the reactive component of the terminating resistances at the frequency used, the calibration of the current indicating meters and the symmetry of circuit

arrangement.

23. An approximate symmetrical circuit was used; a more precise set-up is now under construction which, when completed, will present a quick and accurate method for measuring twisted pair lines.

24. With this method, by terminating the line, the length of the line is not a factor in the accuracy except that for a line one-quarter wavelength long or multiples of odd quarters, the attenuation rises rapidly with termination mismatch. This results in a sharply defined curve. For a line length of one-half wavelength or multiples of even quarters the attenuation rises slowly with termination mismatch and results in a somewhat flat curve. The minimum attenuation will occur with proper termination however with any length of line.

25. The method employed to measure the impedance at 45 mcs. is that as described by Hund, (High Frequency Measurements). This method was used on lines of air dielectric whose impedance was readily calculated by existing formulae. Modifications were necessary in order to produce results within ±10% of calculated values. These modifications consisted mainly of making the line input symmetrical.

26. The procedure is to first determine the electrical length of the line and tune to resonance a length of line one-half wavelength or multiples of even quarter wavelengths long, then cut off the open end a length of one-eight wavelength, substitute a variable air condenser for the cut off piece and retune line to resonance. At resonance the reactance of the resonating capacity is equal to the lines impedance.

27. The disadvantage of this method is apparent. The use of a resonating capacity practically limits the measurements to lines whose impedance is lower than 100 ohms, as a capacity whose reactance at 45 mcs is 100 ohms is so small that the accuracy of measurement is severly reduced, as for 100 ohms at 45 mcs the capacity value is 35 uuf; thus a 10% error in measured impedance is only a capacity variation of 3.5 uuf.

28. The cathode ray wattmeter method is considered the most reliable system of obtaining the impedance of high attenuation lines at the higher frequencies. By this method practically all types of lines may be measured and the correct terminating impedance value determined with such accuracy as to eliminate any serious loss in efficiency due to mismatching.

29. The value of attenuation of any line is also an important factor in the efficiency of the line transfer of energy.

30. By perfect impedance matching with a zero loss line a transfer of energy of 100% could be achieved; however, even with perfect matching transfer efficiency may be reduced to a low value with high attenuation lines, particularly if the lines length is in the order of several hundred feet or more as may be necessary.

31. Thus, in the case of twisted pair lines it is as necessary to determine the attenuation as the impedance. Referring to the commercial type lamp cord we find that at 30 mcs. the correct matching impedance is

67 ohms and the attenuation is .097 db per foot. A loss of 50% in power or 29% in voltage is effected in this line for a length of only 30 feet.

32. If this particular line were employed to couple an antenna to a receiver and a length of 100 feet was used, then the voltage at the receiver input would be down 9 decibels with respect to the voltage at the antenna, and the receiver would necessarily have to be used at higher gain with subsequent increase in local noise level.

METHODS

33. The use of any radio frequency current indicating meter at frequencies above 5 mcs. necessitates the careful calibration of such meters at these frequencies before their use in measuring circuits or apperatus. It has been determined that at frequencies above 5 mcs. these meters read in error as great as fifty percent.

34. The non-inductive resistors employed shall have a reactive component of zero if possible. Their physical length must be small compared with the frequency used.

35. The circuit conditions should be such as to insure symmetry and thus eliminate stray capacity and leakage.

DATA OBTAINED

36. Several lines of varying constructional details have been measured. Measurements were made on commercial lamp cord, several shielded cables and the products of A.H. Lynch, Inc., which concern features the "Giant Killer" line on the commercial market.

37. The results of these tests are tabulated below. All of these cables are non-metallic covering.

Cable	Characteristic Impedance (Ohms) 4.6 Mcs	15 Mcs	30 Mcs	45 Mcs	$\sqrt{Z_o Z_c}$	$\frac{L}{C}$
Lynch Giant Killer	98	92	85	77	84	88
Lynch Super Giant Killer	97	94	90	81	88	95
Lynch Standard	84	72	60	52	54	69
Commercial Lamp Cord	95	84	72	60	72	109

Cable	Attenuation (decibels per foot) 4.6 mcs	15 mcs	30 mcs	45 mcs
Lynch Giant Killer	.0082	.019	.041	.091
Lynch Super Giant Killer	.0066	.023	.044	.097
Lynch Standard	.014	.064	.097	.127
Commercial Lamp Cord	.015	.054	.097	.128

38. Following are tabulated values obtained on metallic covered or shielded lines of the twisted pair type having other than air dielectric.

Cable	Impedance (ohms) 4.6 mcs	14 mcs	L/C	Attenuation (db per foot) 4.6 mcs	14 mcs
Lynch Heavy Duty	125	110	133	.022	.127
Lynch Extra Duty	120	100	125	.028	.124
High Voltage Cable (BX)	100	90	84	.014	.040
High Voltage Cable (ignition)	84	76	72	.020	.060
Triple Armor	100	90	34	.047	.094

39. Following are tabulated values obtained on metallic covered single conductor lines of other than air dielectric.

Cable	Impedance (ohms) 5 mcs	30 mcs	45 mcs
Western Electric (700)	72	68	61
High Voltage Cable	120	108	95
High Voltage Cable (oiled)	109	97	84
			Attenuation (db per ft)
Western Electric (700)	.008	.034	.046
High Voltage Cable	.024	.050	.130
High Voltage Cable (oiled)	.016	.052	.065

40. As a point of reference to the above values of attenuation for these lines it should be noted that the attenuation of a well designed concentric line of air dielectric has an attenuation at 1 mc of less than .001 db per foot.

41. The degree of error in measurements of the above values is considered to be in the order of ±10% for impedance values and ±10% for attenuation.

CONCLUSIONS AND RECOMMENDATIONS

42. From the results of the work done as described on this problem it is evident that impedance measurements can be accomplished with a fair degree of accuracy at frequencies above 45 mcs. It is possible that measurements may be made up to 100 mcs. and higher.

43. That this should be done is evident from the results obtained up to 45 mcs. as the results show that the impedance of these type lines have a negative change with respect to frequency. Consequently, a line having a known impedance at, say, 30 mcs. when used at 100 mcs. may have an impedance variation of large proportions. It is shown in the above tabulated values that the Lynch "Giant Killer" line has an impedance of 98 ohms at 4.6 mcs. and 77 ohms at 45 mcs. This is a 21% decrease of impedance. If the same ratio was applicable to a higher frequency, then at 100 mcs. the impedance would be in the order of 26% less than at 4.6 mcs. or about 71 ohms.

44. Thus, considerable loss in efficiency is evident if we use

these type lines at the higher frequencies and simply assume the impedance to be in the order as known at a lower frequency as in the case of air dielectric lines. The efficiency, of course, will not only be affected by the impedance mismatching at the higher frequencies but also, and probably to a larger extent, by the increase in attenuation. It is evident, then, that data should be obtained on lines having other than air dielectric at the higher frequencies universally used today.

45. In consideration of the impedance characteristics and the high attenuation of these type lines, it is recommended that wherever possible transmission lines of air dielectric be employed at the higher frequencies.