100
1-3-66

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS, NEW MEXICO

Electrical Characteristics of Coaxial Cable

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report expresses the opinions of the author or authors and does not necessarily reflect the opinions or views of the Los Alamos Scientific Laboratory.

Printed in USA. Price \$1.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, United States Department of Commerce, Springfield, Virginia.

LA-3318
UC-37, INSTRUMENTS
TID-4500 (45th Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY of the University of California

Report written: April 15, 1965

Report distributed: November 15, 1965

Electrical Characteristics of Coaxial Cable

by
Grenfell P. Boicourt

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

ABSTRACT

A pulsed ringing method was used to measure the inductance and resistance of several special coaxial cables used at the Los Alamos Scientific Laboratory as transmission lines in banks for controlled thermonuclear research. The cables are described, the method of measurement is outlined, and the properties of the cables are given.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the help and criticisms of E. L. Kemp, M. J. Hollen, and J. A. Mcyor.

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

INTRODUCTION

In designing a capacitor bank for controlled thermonuclear research experiments, it is of critical importance that the electrical characteristics of the components be known in order to meet certain rise time and energy transfer requirements.

This report presents the results of measurements of inductance, resistance, and capacitance for several coaxial cables commonly used as transmission lines in energy storage capacitor banks.

It is difficult to get good design numbers for coaxial cable at the frequency of interest. Often the manufacturer's values published for their commercial cables do not agree with the actual values displayed by the cables when used at frequencies different from the frequency of measurement. In many cases even these values are not available, since the cable is of special design.

This report gives the results of direct measurements of cable inductance and resistance made in a ringing capacitor discharge circuit, that is, in a circuit which closely approximates the actual use.

In general, the current range over which the measurements were made was 10,000 to 50,000 A and the frequency range was 10 to 65 kc/sec. The exact range is given for each cable type.

The designation of the cable type is given as it is commonly known at the Los Alamos Scientific Laboratory. If other designations are known, these are also listed.

Fig. 1. Sectioned Piece of RG 17/14 Cable.

Cable designations of the form α/β indicate its construction. A cable designated α/β would have its outer conductor made according to the specifications for the outer conductor of RG α/U and its inner conductor made according to the specifications for the outer conductor of RG β/U . For example, 17/14 has the same outer conductor as RG 17/U (RG 218/U) and its inner conductor is the same as the outer conductor of RG 14/U (RG 217/U). Figure 1 shows a sectioned piece of RG 17/14. Because some standard cables have a double outer braid, some of the cables thus made may also have double braid as an outer or inner conductor.

The graded cables are made with a thin layer of conducting polyethylene just outside the center conductor and just inside the outer conductor.

THEORETICAL CONSIDERATIONS

The capacitor discharge circuit of Fig. 2 may be represented by the equivalent circuit shown in Fig. 3, where R_s is the resistance of the source, L_s is the inductance of the source, R_c is the resistance of the cable and L_c the inductance of the cable. Let $R_t = R_s + R_c$ and $L_t = L_s + L_c$.

The source is understood to include the capacitor, the switching ignitron, and whatever amount of cable is necessary for connections.

Fig. 2. Capacitor Discharge Circuit.

Fig. 3. Equivalent Circuit.

The current in this circuit is given by the equations

$$I = I_0 e^{-\left(R_t/L_t\right)t/2} \sin \omega t$$

$$\dot{I} = Ae^{-\left(R_t/L_t\right)t/2} \cos(\omega t + \varphi)$$

where A and φ are constants depending on ω and R_t/L_t . These values are not important to the following.

The period of I is equal to

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{1}{L_t C} - \frac{R_t^2}{4L_t^2}}}$$

For the circuits under consideration (minimum damping - high reversal)

$$\frac{1}{L_t C} \gg \frac{R_t^2}{4L_t^2}$$

and

$$\tau = 2\pi \sqrt{L_t C}$$

or

$$L_t = \frac{\tau^2}{4\pi^2 C}$$

Let λ_c be the inductance per unit length of the cable. Then the total inductance, $L_t = L_s + L_c$, can be written $L_t = L_s + \lambda_c x$, and $dL_t/dx = \lambda_c$, where x is the length of the cable. Hence λ_c can be determined from the slope of the plot of L_t versus the length of the cable.

For the determination of $R_t = R_s + R_c$, consider the ratio of two successive peaks of $\dot{I}$

$$\frac{\dot{I}_{t_1}}{\dot{I}_{t_1 + \tau/2}} = \frac{Ae^{-\left(R_t/2L_t\right)t_1} \cos(\omega t_1 + \varphi)}{Ae^{-\left(R_t/2L_t\right)(t_1 + \tau/2)} \cos(\omega t_1 + \omega\tau/2 + \varphi)}$$

but

$$\cos(\omega t_1 + \varphi) = -\cos(\omega t_1 + \omega\tau/2 + \varphi)$$

and, therefore

$$\frac{\dot{I}_{t_1}}{\dot{I}_{t_1 + \tau/2}} = -e^{\left(R_t/L_t\right)\tau/4}$$

Thus

$$\frac{R_t}{L_t} \tau/4 = \ln \left| \frac{\dot{I}_{t_1}}{\dot{I}_{t_1 + \tau/2}} \right|$$

or

$$R_t = \frac{4L_t}{\tau} \ln \frac{A_1}{A_2}$$

where A_1/A_2 is the ratio of two successive extrema of $\dot{I}$. As in the case of the inductance, we can write

$$R_t = R_s + r_c x$$

$$\frac{dR_t}{dx} = r_c$$

where r_c is the resistance per unit length of the cable, and we determine r_c from the slope of a plot of R_t versus the length of the cable.

MEASUREMENTS

A 101-ft length of test cable was connected to a 15- μ F capacitor with an ignitron used as a switch. One end of the cable was shorted to complete the circuit. A Rogovski loop placed around the anode stud of the ignitron was used as a signal pickup.

The capacitor was discharged through the cable, and the integrated signal from the Rogovski loop was recorded by photographing an oscilloscope trace. Then the cable was shortened by 20 ft and another discharge recorded. This procedure was repeated, removing 20 ft of cable each time, until the cable was used up.

The total system inductance was calculated from the known capacity of the capacitor and the ringing frequency. The inductance was then plotted as a function of cable length. The slope of the graph gives the inductance per foot of the cable and is independent of the pulsing source. Figure 4 shows such a plot for 8/59 cable.

Fig. 4. System Inductance vs Nominal Cable Length (8/59 Cable).

A similar procedure was followed to determine the resistance per unit length. The total system resistance was calculated from the total inductance and the decrement as determined from the oscilloscope trace. The slope of the plot of resistance versus cable length then gave the resistance per unit length of the cable. A typical plot (8/59 cable) is shown in Fig. 5.

The capacity of the cable was measured on a G. R. 1650 impedance bridge.

Fig. 5. System Resistance vs Nominal Cable Length (8/59 Cable).

It was tacitly assumed in the procedure outlined above that the inductance and resistance were essentially independent of frequency over the range of the measurement. This will be true if the skin depth is equal to, or greater than, one-half the thickness of the conductor. This condition is met by all the braided cables except those which have a conductor made according to the specification for the outer conductor of RG 217, i.e., types 17/14, 17/14 HV Graded, 19/14, 19/14 HV Graded. For these cables, the total braid thickness is somewhat greater than two skin depths at the high-frequency end of the measurement. It is not clear how this should affect the measurement, since the braided conductor allows field penetration to the center of the conducting region without requiring that the field pass through the conductor. At any rate, the change in inductance is small. The resistance could be affected somewhat more. Care should be taken in applying the results for these cables when frequencies higher than 35 kc are expected.

Five cables have solid or larger twisted center conductors: RG 8/U, 20-P2 BICC, RG 217/U, RG 218/U, and RG 19/U. For RG 8/U, the radius of the center conductor is 0.014 in.; the highest test frequency for this cable was 28 kc at which the skin depth is 0.15 in., and thus the inductance and resistance should be unaffected by the frequency change.

An estimate of the inductance change for 20-P2 BICC, RG 217/U, and RG 19/U indicates that the inductance variation should be less than 4% over the test frequency range. However, the

resistance variation for these cables is large enough to make the resistance measurement by this method invalid. Thus, the values of R given for these cables represent average values over the frequency range.

RESULTS

Table I gives the measured values of R/ft, L/ft, and C/ft for the braided cables, and Table II

gives the results for the solid center conductor cables. The tables also give the thickness of the interconductor insulation. In each case the dielectric is polyethylene. The indicated errors in Table I are due mainly to reading errors, while the errors given in Table II reflect mainly the effect of skin depth changes. Unfortunately, it is true that almost all the cables are used at voltages far higher than the manufacturers recommend. It is hoped that the insulation thickness data will aid in selecting the proper cable for a given voltage.

TABLE I
Measured Values for Braided Cables

Type	Inductance per ft (nH)	Resistance per ft (mohms)	Frequency Range of Measurement (kc)	Capacitance per ft ($\mu\mu\text{F}$)	Average Insulation Thickness (in.)
8/59 (14/13)	50 $\pm$ 1.5%	4.8 $\pm$ 1.5%	18 - 39	65.0	0.067
8/142	55 $\pm$ 1.1%	3.9 $\pm$ 1.6%	17 - 38	40.0	0.070
Type 4 (P14-4)	26 $\pm$ 2.0%	3.1 $\pm$ 1.4%	24 - 50	120.0	0.036
17/14	36 $\pm$ 1.6%	1.1 $\pm$ 1.4%	21 - 47	78.2	0.110
17/14 HV Graded	40 $\pm$ 1.5%	1.1 $\pm$ 1.1%	20 - 41	75.5	0.140
19/14	49 $\pm$ 1.1%	—	18 - 40	51.7	0.225
19/14 HV Graded	54 $\pm$ 1.1%	0.97 $\pm$ 1.8%	17 - 36	53.5	0.225
19/17	17 $\pm$ 1.8%	0.71 $\pm$ 2.0%	31 - 64	136.0	0.100
YK 198 (Belden)	28 $\pm$ 1.5%	2.3 $\pm$ 1.3%	23 - 50	110.5	0.048

TABLE II
Measured Values for Solid Center Conductor Cables

Type	Inductance per ft (nH)	Resistance per ft (mohms)	Frequency Range of Measurement (kc)	Capacitance per ft ($\mu\mu\text{F}$)	Average Insulation Thickness (in.)
RG 8/U	104 $\pm$ 1.5%	3.7 $\pm$ 2.5%	12 - 28	29.8	0.104
RG 19/U	86 $\pm$ 2.5%	0.97 $\pm$?	14 - 40	29.5	0.330
20-P2 BICC	35 $\pm$ 3.8%	1.9 $\pm$?	21 - 45	129.0	0.050
RG 217/U (RG 14/U)	95 $\pm$ 2.7%	2.0 $\pm$?	13 - 28	30.0	0.121
RG 218/U (RG 17/U)	86 $\pm$ 3.8%	1.1 $\pm$?	14 - 42	29.5	0.242