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BIBLIOGRAPHY
ON
CABLE CHARACTERISTICS FOR DATA COMMUNICATION

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BIBLIOGRAPHY ON THE CHARACTERISTICS OF CABLES FOR DATA COMMUNICATION

General References

There is no single reference which includes all the data and formulas or curves needed to calculate from the physical dimensions and electromagnetic constants of the materials the channel capacity of a cable. These general references come the closest to covering large sections of the material needed for such computations. Each of these references is oriented toward some particular frequency range, type of cable, type of dielectric, or particular phase of the more general problem. In listing books, the chapters or sections relevant to the problem are listed. In the following sections classified by topic, the specific page references are listed.

A. Communications Networks (book), vol. II. The Classical Theory of Long Lines, Filters and Related Networks, Ernst A. Guillemin. John Wiley and Sons, New York, N.Y., 1935, 587 pp. See Chap I-III.

B. Communication Networks and Lines (book), W. J. Creamer. Harper and Bros., New York, N.Y., 1951, 509 pp. See Chapters 12-15, 17-18.

C. Electric Transmission Lines -- Distributed Constants, Theory and Applications (book), H. H. Skilling. McGraw-Hill Book Co., New York, N.Y., 1951. 438 pp. Chap. 1, 5-7, 9, 12.

D. Electrical Communications Systems Engineering, Radio (book). U. S. Department of the Army, Washington, 25, D. C., Technical Manual No. 11-486-6, Aug. 23, 1956. 545 pp. Chaps. 10-11.

E. Electrical Communications Systems Engineering Handbook (book). U. S. Department of the Army, Washington 25, D. C., Technical Manual No. 11-486-10, Sept. 13, 1956. 346 pp. Secs. 6-9, 17, 19; 8-2.

F. Principles of Electricity Applied to Telephone and Telegraph Work, 1953 Edition (green book), American Telegraph and Telegraph Co., New York, N.Y., 354 pp., Chap. 13-14, 18-21, 30, 34.

G. Theoretical Fundamentals of Pulse Transmission, E. D. Sunde. Bell System Technical Journal, vol 33, 1954. Part I, pp. 721-788, Part II, pp. 987-1010.

H. Transmission Line Theory (book), Ronald W. P. King. McGraw-Hill Book Co., New York, N.Y., 1953, 509 pp. Chaps. I-III.

I. Transmission Properties of Polyethylene Insulated Telephone Cable at Voice and Carrier Frequencies, G. S. Eager, Jr., L. Jachimowicz, I. Kolodny, and D. E. Robinson. Communications and Electronics, No. 45, Nov. 1959, pp. 618-640 (AIEE Paper 57-778).

Primary and Secondary Parameters, Crosstalk, Shield Parameters.

REFERENCES CLASSIFIED BY TOPIC

1. Lumped Constant Analysis

1.1 Ref A (Guillemin), pp. 12-30.

The historical development of the theoretical analysis is given with a derivation of a formula for the accuracy of the lumped constant analysis at high frequencies.

1.2 General Microwave Circuit Theorems, R. H. Dicke, in Principles of Microwave Circuits (book), C. G. Montgomery, editor, M.I.T. Radiation Laboratory Series, vol. 8, pp. 130-161, McGraw-Hill Book Co., New York, N.Y., 1948, 486 pp.

Clarifies the equivalence between the two approaches to transmission lines: (1) the Maxwellian approach using the field description, and (2) the electrical-engineering approach using Kirchoff's laws extended from d-c to a-c by use of complex numbers.

2. Skin Effect and Proximity Effect

2.1 American Institute of Physics Handbook (book). McGraw-Hill Book Co., New York, N.Y., 1951, 1624 pp. pp. 5-5, 5-85, 5-90/95.

2.2 Fields and Waves in Modern Radio (book), S. Ramo and John R. Whinnery, John Wiley and Sons, Incl., New York, N.Y., First Edition, 1944, 502 pp.; Second Edition, 1953. Chap. 6 (1st ed.) Skin Effect and Circuit Impedance.

2.3 Proximity Effect in Wires and Thin Tubes, H. B. Dwight. Transactions AIEE, vol. 22, 1923, pp. 850-859.

This paper is useful for understanding the basic physical and mathematical concepts.

2.4 Table of Integrals and Other Mathematical Data (book) , H. B. Dwight, MacMillan Co., New York, N.Y., Revised Edition, 1947, 250 pp. Table 1050 (Ber and bei functions).

2.5 Ref A (Guillemin), pp. 24-29. Frequency Variation of Primary. Constants.

2.6 Ref. B (Creamer), pp. 197-201, 287.

2.7 Ref. I (General Cable Co.) based upon the methods of Arnold, Carson, and Hebbert which are easier to calculate than the basic forumulas of Dwight.

2.8 Inductance Calculations (book), F. W. Grover. Van Nostrand Co., New York, N.Y., 1946, 286 pp. pp. 261-282.
Includes the extension of inductance formulas for short wires to the case of long pairs of wire forming long lines.

2.9 Smithsonian Physical Tables (book), William G. Forsythe. Smithsonian Institution, City of Washington, Ninth Revised Edition, 1954, 827 pp. Table 426.

2.10 New H. F. Proximity-Effect Formula, A. C. Sim. Wireless Engineer, vol. 30, 1953, pp. 204-207.
Alternative solution for high frequencies.

2.11 Static and Dynamic Electricity (book), William R. Smuthe. McGraw-Hill Book Co., New York, N.Y., Second Edition, 1950. 616 pp. p. 463, eq. 8, 9: Derivation of the High Frequency Asymptotic Formula for the Proximity Effect.

2.12 Radio Engineers Handbook (book), R. E. Terman. McGraw-Hill Book Co., New York, N.Y., First Edition, 1943, 1019 pp.
pp. 30-36. Skin Effect Formulas and Curves.
pp. 36-37. Sample Curves for Proximity Effect at Very High Frequencies.

3. Primary Constants: R, L. C, and G.

3.1 Ref A (Guillemin) pp. 12-29.
Derivation of L and C for telephone line. Constant values of R and G are used in most of the examples in this book which limits the formulas to voice frequencies.

3.2 Ref B (Creamer)
pp. 198-201 Curves of R up to 50 kc./s., formulas for L and C.
pp. 289 Variation of C up to 100 kc./s.
p. 290 General formula for G from one to 100 kc./s. paper insulation.

3.3 Ref E (Army TM 11-486-10)
p. 6-24. Measured and computed values of R vs. f up to 150 kc./s.
P. 6-28. R, L, C, and G of No. 19 ga. Cable Pair at 1.0 kc./s.

3.4 Ref F (A.T.and T. Co.)
Table X (fol. p. 180) R, L, C, and G for twisted pair at 1.0 kc./s.

3.5 Ref H (R. W. P. King)
High frequency formulas are derived for external L, G, and C; and for internal L and R. References are given for exact formulas for lower frequencies.

3.6 Ref I (General Cable Co.) Polyethylene Twisted Pair Cables.
Measured and computed values of R for 19 AWG-O.083 and 22 AWG-0.083 cables of 1.0 to 1000 kc./s.
Total inductance (L) for 19 AWG-0.066 and 0.083; an d 22 AWG-0.083 from 1.0 to 1000 kc./s.
Formulas for capacitance (C).
Conductance for dry, moist, and wet conditions, 19 AWG-0.083 from 1.0 to 1000 kc./s.
Formulas for the increase in effective R due to eddy current losses in the surrounding wires.

3.7 The A. C. Resistance of Solid Magnetic Wires, M. Kamal Gohar. AIEE Paper 59-1086, Oct. 1959
The analytical techniques of this paper would be useful in obtaining an upper bound for the low frequency R of a copper-clad steel conductor.

3.8 Design of Polyethylene-Insulated Multipair Telephone Cable, A. S. Windeler. Electrical Engineering, vol. 78, No. 10, Oct. 1959, pp. 1030-1033. (AIEE Paper 59-783)
This analysis is for voice frequencies, i.e., d-c values of R are used. Refinements in the calculation of C are introduced to account for the fact that the polyethylene sheaths of the two wires of a pair do not make pe̸rfect contact, but have an average air gap getween them. The shielding effect of the surrounding wires is also included.

3.9 Dielectric Materials and Applications (book), A. R. von Hippel. John Wiley and Sons, New York, N.Y., 1954.
The dielectric constant and loss tangent of many dielectric materials, including paper insulation and polyethylene are tabulated over a frequency range of d-c up to 10^9 c./s.

3.10 Interaxial Spacing and Dielectric Constants of Pairs in Multipaired Cables, J. T. Maupin. Bell System Technical Journal, vol. 30, July 1951, pp. 652-667.

The shielding effect of other wires in the cable is investigated. The effect of the air gap between the insulating sheaths of pairs, the air left between edges of the strip paper windings, and the air bubbles in extruded paper pulp insulation in reducing the effective dielectric constant is studied.

3.11 Rome Cable Manual of Technical Information (book). Rome Cable Corp., Rome, N.Y., Second Edition, 1957, 393 pp.
pp. 184-188. R. L, and C up to 100 kc./s.

3.12 The Simplex Manual (book). Simplex Wire and Cable Co., Cambridge 39, Mass., 1953, pp. 75-76. Effect of pigment on dielectric constant of polyethylene; pp. 193-194, Power factor of dielectric; pp. 195-197, Calculation of C and L; and p. 240, G.

3.13 Specifications for Fully Color-Coded Polyethylene Insulated, Polyethylene-Jacketed Telephone Cables, Rural Electrification Administration, U. S. Department of Agriculture, Spec. PE-22, Jan., 1958.
Includes specifications on capacitance, capacitance unbalance, resistance, and other details.

3.14 Reference Data for Radio Engineers (book). International Telephone and Telegraph Corp., New York, N. Y., Fourth Edition, 1956, 1121 pp.
p. 821. R, L, C, and G up to 150 kc./s. for 13, 16 and 19 AWG quadded toll cables.
p. 823. Primary constants at 1.0 kc./s. of various cables.
p. 824. Primary constants of 16 ga. spiral-four disk-insulated toll-entrance cable up to 200 kc./s.
p. 825. Primary constants for coaxial-cable 0.270" diam. (1936 N. Y.-Phila. Type) up to 1000 kc./s.

4. Characteristic Impedance

Most of the references listed in Section 3 which give formulas or curves for the primary constants as functions of frequency, also include formulas or curves for the characteristic impedance for the same cables and conditions. Therefore no detailed listing is made, except for special references which include information not generally discussed.

4.1 Ref A (Guillemin), pp. 107-111.
The nature of the characteristic impedance when plotted on the frequency axis of the frequency-time plane indicates a resonance phenomena at zero frequency with a very high impedance at resonance. This would be a pole, if the dielectric was a perfect insulator.

5. Secondary Constants: Attenuation and Phase

The general formulas for the secondary constants in terms of the primary constants are included in most handbooks. Therefore this listing will be limited to references which contribute some supplementary information or provide tables and curves for specific wire sizes and cable types.

5.1 Ref A (Guillemin), pp. 83-99.
  Analysis of the accuracy of the approximate formulas for the secondary constants.

5.2 Ref B (Creamer)
  - pp. 242-3. Attenuation of 13, 16, 19 ga. cables for 100 to 10,000 c./s.
  - p. 254. Phase of 19 ga. cable up to 10 kc./s.
  - p. 291-2. Attenuation and phase of 19ga. cable pairs up to 100 kc./s
  - p. 299. Attenuation of coaxial cables up to 10 mc./s.

5.3 Ref C (Skilling), p. 204
  Attenuation of 19 ga. cable up to 3 kc./s.

5.4 Ref D (Army TM 11-486-6)
  - pp. 10-4/5. Attenuation of rf transmission lines and cables up to 5000 mc./s.
  - p. 11-5. Sample attenuation data for surface-wave transmission lines at 2000 mc/s.

5.5 Ref E (Army TM 11-486-10)
  - p. 6-20. Attenuation up to 30kc./s. for field wire and cable.
  - p. 6-22. Attenuation up to 700 kc./s. for 19 ga. cable pair.
  - p. 6-26. Attenuation up to 60 kc./s. for non-loaded cable circuits and up to 150 kc./s. on disk insulated toll entrance cable.
  - p. 6-30. Attenuation of toll-entrance cable up to 200 kc./s.

5.6 Ref F (A. T. and T. Co.), p. 183
  Attenuation of non-loaded cable circuit up to 60 kc./s.; disc-insulated toll entrance cable up to 150 kc./s.; and 0.375" coaxial cable up to 6000 kc./s.

5.7 Ref H (R. W. P. King), pp. 91-93.
  Different format for the formulas for attenuation and phase for different frequency ranges. Formulas use tables of $f(h)=\cosh[(1/2)\sinh^{-1}h]$ and $g(h) = [(1/2)\sinh^{-1}h]$ from Ref. 5.8.

5.8 Electromagnetic Engineering, Vol. I. Fundamentals (book), R. W. P. King. McGraw-Hill Book Co., New York, N. Y., 1945. 580 pp.
  pp. 510-518. Tables of the Functions f(h) and g(h).

5.9 Ref I (General Cable Co.)
Comparison of computed and measured α and β for polyethylene cable pairs from 1 to 1000 kc./s. Also effect of moisture and temperature.

5.10 Rome Cable Manual (book, same as Ref 3.12), p. 192.
Attenuation of polyethylene cables and paper insulated cables for various carrier frequency ranges.

5.11 Reference data for Radio Engineers (book, same as Ref 3.16).
p. 821. Attenuation and phase of quadded toll cables.
p. 824. Attenuation and phase of 16-ga. spiral four toll entrance cable up to 200 kc./s.
p. 825. Attenuation of various coaxial cables up to 10 mc./s.

5.12 Carrier Transmission for Closed-Circuit Television, L. G. Schimpf. Electronics, vol. 32, June 12, 1959, pp. 66-68.
Includes attenuation for 3/16" diameter coaxial cable with partially blown-up polystyere dielectric for 5 to 15 mc./s.

5.13 Experiments in Television over Telephone Cable Facilities, C. R. Kraus. Journal of the Franklin Institute, vol. 265, No. 1, Jan, 1958, pp. 1-12.
Includes curves of attenuation of 22, 24, and 26 ga. paper insulated cables up to 1000 kc./s.

5.14 A Transistorized Pulse Code Repeater, Gordon R. Partridge. AIEE Paper 59-944, June, 1959.
Includes the attenuation for spiral-four cable up to 4 mc./s.

6. Bandwidth

Since Shannon's basic formula for the channel capacity of a communication channel requires knowledge of the bandwidth, and the frequency transfer characteristic of a non-loaded cable dies off exponentially without a distinct cutoff frequency, the alternative definitions of bandwidth must be reviewed.

6.1 Vacuum Tube Circuits (book), L. B. Arguimbau. John Wiley and Sons, New York, N.Y., 1948. 668 pp.
p. 191. Bandwidth and Q of series and parallel circuits. These are the classical definitions of bandwidth for lumped constant resonant circuits corresponding to the 3 db points.
p. 105. Equivalent bandwidth integral for single stage amplifier used in computing thermal-agitation noise. The amplitude-squared curve here is similar to the amplitude curve of a cable.

6. 2 Theory of Communication, D. Gabor. Journal of Inst. of Elec. Engrs. (London), vol. 93, pt. III, 1946, pp. 429-456.

The relation between time and frequency is expressed by defining the minimum ideal quantum of information by $\Delta t \Delta f \geq 0.500$. For an ideal band pass filter $\Delta t \Delta f \geqq 0.571$.

6. 3 Synthesis of Lumped Parameter Precision Delay Line, E. S. Kuh. Proc. I. R. E., vol. 45, No. 12, pp. 1632-42, Dec., 1957.

An equivalent bandwidth for a transmission line is defined by the integral of the area enclosed by the amplitude vs. frequency plot.

6. 4 Cross-Talk Consideration in Time-Division Multiplex Systems. S. Moskowitz, L. Diven, and L. Feit. Proc. I. R. E., vol. 38, Nov. 1950, pp. 1330-1336. Here f_c is defined as the 3db down point for a series R, parallel C circuit.

7. Crosstalk and Noise Limitations

7. 1 Dr. Campbell's Memoranda of 1907 and 1912. Bell System Technical Journal, vol. 14, Oct., 1935, pp. 558-72.

Basic equivalent circuit and analytical treatment of crosstalk in telephone cables.

7. 2 Ref I (General Cable Co.)

Typical calculations and curves for crosstalk in polyethylene insulated cable. Includes both near-end and far-end crosstalk.

7. 3 Vacuum Tube Circuits (book, same as Ref 6. 1)

pp. 98-105. Thermal Agitation Noise.
pp. 106-110. Random Noise of Vacuum Tubes.
pp. 142-144 Differentiating Circuit (Low frequency approximation to crosstalk)

7. 4 Cross-Pulse Pickup in Twisted Pair Cables, J. Gregg Stephenson. Electronics, Feb., 1956, pp. 170-172.

Distribution of induced voltage in 24 pairs due to square pulse on one pair of cable (experimental).

7. 5 Ref H (R. W. P. King), pp.

Radiation resistance of a pair of wires. This can be used to obtain a qualitative estimate of the near-end crosstalk variation with frequency and length.

7. 6 The Simplex Manual (book, same as Ref 3. 13)

p. 242. Maximum lengths of cable between repeaters, for different carrier and voice systems on different gauge cables.

8. Channel Capacity

These references provide the techniques for three alternate approaches to obtain bounds on the channel capacity of a cable: (1) Determination of bits per second by use of a Fourier transformation of the signal and the transfer function of the cable to determine the highest bit rate for a given tolerance on inter-bit interference; (2) Determination of channel capacity by an equivalent decrease in signal-to-noise ratio due to delay distortion of particular signal waveform; and (3) Use of the equivalent bandwidth directly in the channel capacity formula.

8.1 Ref G (E.D. Sunde)

Method of using the spectrum of the signal waveform in the convolution integral with the transform of filter or transmission line, to obtain the output waveform. This approach leads to a correction in the channel capacity formula to account for delay distortions.

8.2 A Mathematical Theory of Communication (book), C. E. Shannon and Warren Weaver, University of Illinois Press, Urbana, Ill., 1949. (Reprint of Bell Syst. Tech. Journal articles July-Oct. 1948).

This gives the basic formulas of channel capacity in terms of the bandwidth of the system.

8.3 Reference Data for Radio Engineers (book), Fourth Edition, International Telephone and Telegraph Corp., New York, N. Y., 1956, pp. 973-980.

A short abstract of the basic theorems and formulas of information theory.

8.4 The Optimal Distribution of Signal Power in a Transmission Link whose Attenuation is a Function of Frequency (correspondence), Gordon Raisbeck, I. R. E. Transactions on Information Theory, vol. IT-4, no. 3, Sept., 1958, pp. 129-130.

This analysis gives the channel capacity as a function of signal-to-noise power ratio for high frequencies where the skin effect controls the attenuation.

8.5 Transformation Calculus and Electrical Transients (book), Stanford Goldman. Prentice-Hall Co., New York, N. Y., 1949. 439 pp.

Basic formulas for Fourier Transforms and related Green's Functions, Convolution Integral, etc.

8.6 Information Theory (book), Stanford Goldman. Prentice-Hall, Inc., New York, N. Y., 1953. 385 pp.

Channel capacity formulas and Fourier and related transforms.