

THE ELECTRICAL ENGINEERING HANDBOOK SECOND EDITION

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CRC PRESS



IEEE PRESS

A CRC Handbook Published in Cooperation
with IEEE Press

Publisher: *Ron Powers*
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PrePress: *Kevin Luong, Carlos Esser, Greg Cuciak, Walt Cerny*

Library of Congress Cataloging-in-Publication Data

Catalog record is available from the Library of Congress.

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International Standard Book Number 0-8493-8574-1

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

Printed on acid-free paper

Related Topics

22.1 Physical Properties • 25.1 Integrated Circuit Technology • 51.1 Introduction

References

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1.2 Capacitors and Inductors

Glen Ballou

Capacitors

If a potential difference is found between two points, an electric **field** exists that is the result of the separation of unlike charges. The strength of the field will depend on the amount the charges have been separated.

Capacitance is the concept of energy storage in an electric field and is restricted to the area, shape, and spacing of the **capacitor** plates and the property of the material separating them.

When electrical current flows into a capacitor, a force is established between two parallel plates separated by a **dielectric**. This energy is stored and remains even after the input is removed. By connecting a **conductor** (a resistor, hard wire, or even air) across the capacitor, the charged capacitor can regain electron balance, that is, discharge its stored energy.

The value of a parallel-plate capacitor can be found with the equation

$$C = \frac{x\epsilon[(N - 1)A]}{d} \times 10^{-13} \quad (1.21)$$

where C = capacitance, F; ϵ = dielectric constant of insulation; d = spacing between plates; N = number of plates; A = area of plates; and x = 0.0885 when A and d are in centimeters, and x = 0.225 when A and d are in inches.

The work necessary to transport a unit charge from one plate to the other is

$$e = kg \quad (1.22)$$

where e = volts expressing energy per unit charge, g = coulombs of charge already transported, and k = proportionality factor between work necessary to carry a unit charge between the two plates and charge already transported. It is equal to $1/C$, where C is the capacitance, F.

The value of a capacitor can now be calculated from the equation

$$C = \frac{q}{e} \quad (1.23)$$

where q = charge (C) and e is found with Eq. (1.22).

The energy stored in a capacitor is

$$W = \frac{CV^2}{2} \quad (1.24)$$

where W = energy, J; C = capacitance, F; and V = applied voltage, V.

The **dielectric constant** of a material determines the electrostatic energy which may be stored in that material per unit volume for a given voltage. The value of the dielectric constant expresses the ratio of a capacitor in a vacuum to one using a given dielectric. The dielectric of air is 1, the reference unit employed for expressing the dielectric constant. As the dielectric constant is increased or decreased, the capacitance will increase or decrease, respectively. Table 1.4 lists the dielectric constants of various materials.

The dielectric constant of most materials is affected by both temperature and frequency, except for quartz, Styrofoam, and Teflon, whose dielectric constants remain essentially constant.

The equation for calculating the *force of attraction* between two plates is

$$F = \frac{AV^2}{k(1504S)^2} \quad (1.25)$$

where F = attraction force, dyn; A = area of one plate, cm²; V = potential energy difference, V; k = dielectric coefficient; and S = separation between plates, cm.

The Q for a capacitor when the resistance and capacitance is in series is

$$Q = \frac{1}{2\pi fRC} \quad (1.26)$$

where Q = ratio expressing the factor of merit; f = frequency, Hz; R = resistance, Ω ; and C = capacitance, F.

When capacitors are connected in *series*, the total capacitance is

$$C_T = \frac{1}{1/C_1 + 1/C_2 + \cdots + 1/C_n} \quad (1.27)$$

and is always less than the value of the smallest capacitor.

When capacitors are connected in *parallel*, the total capacitance is

$$C_T = C_1 + C_2 + \cdots + C_n \quad (1.28)$$

and is always larger than the largest capacitor.

When a voltage is applied across a group of capacitors connected in series, the voltage drop across the combination is equal to the applied voltage. The drop across each individual capacitor is inversely proportional to its capacitance.

$$V_C = \frac{V_A C_X}{C_T} \quad (1.29)$$

TABLE 1.4 Comparison of Capacitor Dielectric Constants

Dielectric	K (Dielectric Constant)
Air or vacuum	1.0
Paper	2.0-6.0
Plastic	2.1-6.0
Mineral oil	2.2-2.3
Silicone oil	2.7-2.8
Quartz	3.8-4.4
Glass	4.8-8.0
Porcelain	5.1-5.9
Mica	5.4-8.7
Aluminum oxide	8.4
Tantalum pentoxide	26
Ceramic	12-400,000

Source: G. Ballou, *Handbook for Sound Engineers, The New Audio Cyclopedia*, Carmel, Ind.: Macmillan Computer Publishing Company, 1991. With permission.