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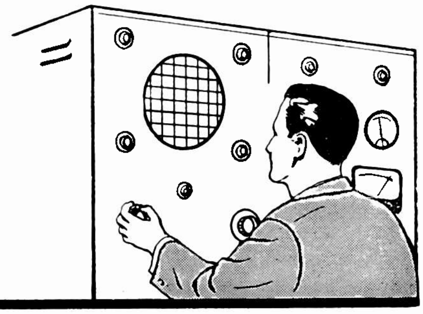

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RC Timing Circuit Considerations

By the Engineering Department, Aerovox Corporation

AFTER many years of use, modification, and improvisation, the relatively simple resistance-capacitance and resistance-inductance circuits still remain the basis of electronic timing systems. In such circuits, it is convenient to make the resistive element adjustable to provide continuously variable control of the timing interval. This article presents various observations on the operation of the resistance-capacitance (RC) circuit. Theory is reviewed only briefly.

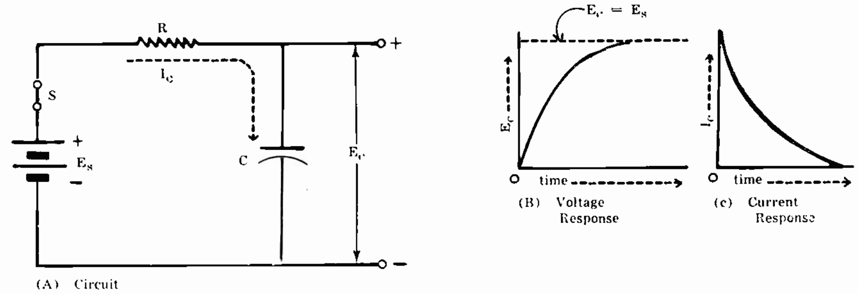


Figure 1. Charge-Type RC Timing Circuit.

Operating Principle

In the first type of RC timing circuit (Figure 1-A), a capacitor is charged through a resistor when the switch is closed; in the second type (Figure 2-A), a capacitor is discharged through a resistor when the switch is opened. The charge or discharge current varies exponentially with time, and at any instant is equal to:

1) $I = (E/R)e^{-t/RC}$

Where I is the instantaneous current (amperes)

E, the steady d-c supply voltage (volts)

t, the time interval of interest reckoned from the start of charge or discharge (seconds)

R, the resistance (ohms)

C, the capacitance (farads)

e = 2.71828

Charge and discharge rates are illustrated by Figure 1 (B and C) and Figure 2 (B and C).

The **time constant** of the RC circuit is expressed in the following manner: (1) when the capacitor is discharging, the time (t) required for the voltage across the capacitor, or the discharge current, to decrease to e^{-1} of its initial full-charge value. ($e^{-1} = 0.3679$.) (2) When the capacitor is charging, the time (t) required for the voltage across the capacitor to increase to $(1 - e^{-1})$ of its full-charge value. ($(1 - e^{-1}) = 0.6321$.) Each of these conditions is expressed by the equation:

2) t = RC

Where t = time (seconds) required to reach $0.6321E_{MAX}$ for charge, or $0.3679E_{MAX}$ for discharge, where E_{MAX} is the final or initial capacitor voltage, respectively.

R = resistance (ohms)

C = capacitance (farads)

From Equation (2), R = t/C, and C = t/R. In an RC circuit, the capacitor is, for all practical purposes, fully charged to voltage E, or **completely** discharged to zero volts in approximately 5RC seconds. (See Figure 3.) The table in Figure 4 shows relationships between various common resistance, capacitance, and time units used to determine time constant.

Generally, the timing voltage developed across the capacitor or resistor is presented to the high-resistance input circuit of a d-c amplifier or a control tube and a relay, or other device to be controlled, is operated from the amplifier or control tube output. The input resistance of the tube-type circuit is much greater than that of the timing resistor in the RC circuit and therefore has negligible effect on the timing voltage. Occasionally, a sensitive d-c relay coil is connected directly in series with the resistor-capacitor timing circuit and operated, without amplification, by the charge or discharge current directly.

Use of Ultra-High Capacitance

Capacitors offering ultra-high capacitance in small space recently have become commercially available (example: ½ farad at 1½ volt). These high capacitances allow the design of timing circuits having very low resistance components. Thus, a 10-second timing circuit now is possible with C = 0.5 farad and R = 20 ohms. Sometimes, these low resistances may be maintained with high accuracy.

Such low resistance levels are compatible with the low input resistance of such devices as transistorized amplifiers, galvanometer elements in oscillographic recorders, recorder pen motors, etc.

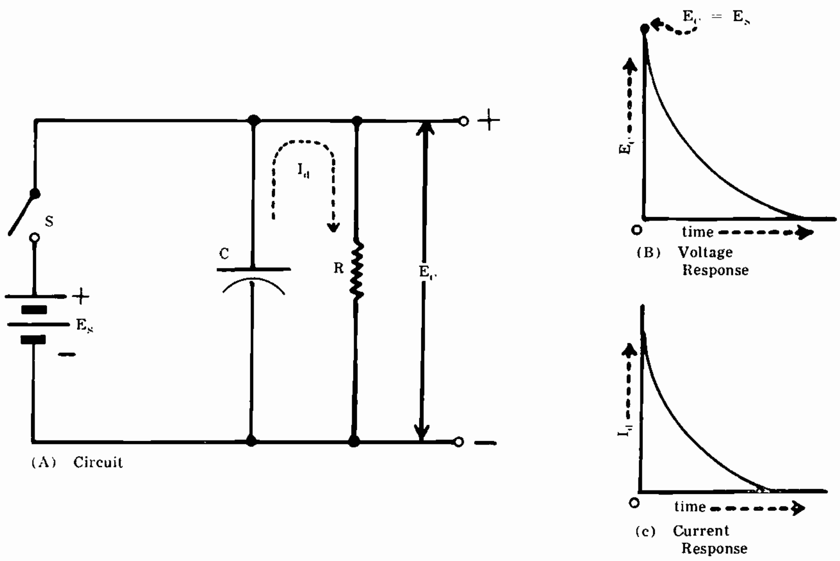


Figure 2. Discharge-Type RC Timing Circuit.

Special Charge and Discharge Curves

For special applications, the classic charge and discharge curves of the RC circuit may be distorted in various ways. The simplest expedient is to employ a nonlinear resistance as the shaping element. By this means, the charge or discharge rate may be slowed or speeded over desired portions of the operating range.

Various devices will function satisfactorily as nonlinear resistors. (See "Nonlinear Resistors," **Aerovox Research Worker,** October-November 1953.) These include semiconductor diodes, thermistors, Thyrite resistors, tungsten-filament lamps, and milliampere-type fuses. Each of these devices has a nonlinear voltampere characteristic. Their salient features are discussed briefly below.

Conventional Semiconductor Diode, Forward-biased. The E-I characteristic follows approximately a square law up to about 10 ma. Forward resistance of a Type 1N34 germanium diode is of the order of 10,000 ohms at 50 mv and decreases to about 100 ohms at 1 v. Below a critical forward voltage, the slope of the conduction curve of the semiconductor diode is less than linear; above this value, greater than linear.

Conventional Semiconductor Diode, Reverse-biased. The slope of the E-I curve is considerably less than linear. The reverse resistance of the diode is of the order of 0.5 megohm or so near zero voltage and increases to a peak of several megohms at a critical reverse voltage and current value; thereafter decreasing to a low value (several kilohms or less) at the maximum allowable reverse operating voltage and current.

Zener Diode, Reverse-biased. The resistance is very high (of the order of megohms) until a critical "breakdown" or "Zener Voltage" is reached, whereupon the resistance suddenly drops to a very low value (100 ohms or so) and the current increases to a high value. This breakdown is nondestructive.

Thermistor. This device is available in many nominal resistance values. The voltage drop across the thermistor increases very rapidly with current (considerably steeper than a linear slope) until a peak is reached, whereupon voltage decreases with further current increase. Thus, the thermistor not only exhibits the same resistance at two different voltages but shows a negative resistance characteristic as well. It is temperature-sensitive, being affected by both internal and ambient heating. This temperature sensitivity also gives rise to a time delay effect.

Thyrite Resistor. Like the thermistor, it is available in many nominal resistance values. The slope of the conduction curve is very steep (considerably higher than a linear slope): a change in voltage over a single order of magnitude can produce a change in current over several orders of magnitude.

Tungsten Filaments and Small Fuses. The conduction characteristic is somewhat similar in small incandescent lamps and low-current miniature fuses (e. g., Type 8AG 1/100 ampere). The slope of the E-I curve is slightly less than linear between zero and the illumination point (lamp) or the burnout point (fuse).

Effect of Extraneous Series Resistance

Extraneous series resistance (R_S) in capacitors and resistors is due to the resistance of leads, terminals, contacts, and electrodes. At radio frequencies, this resistance often is high and sometimes is difficult to take into account completely in circuit design. With the steady direct currents at which RC timing circuits are operated, however, R_S ordinarily is only a few thousandths or hundredths of an ohm, and its effect on operation is negligible. A significant value of R_S at d-c levels generally indicates a defect in the capacitor or resistor.

An exception is the timing circuit employing ultra-high capacitance and

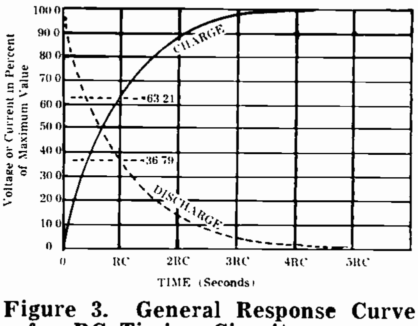


Figure 3. General Response Curve for RC Timing Circuits.

low resistance. For example, a ½ farad capacitor will give a 5-second time constant with only 10 ohms of timing resistance. In such a circuit, even 1/10 ohm of extraneous series resistance must be taken into account.

Effect of Leakage Resistance

External leakage resistance (i. e., along the outside surface of the capacitor) is so high in a clean, dry capacitor as to be of no consequence. Internal leakage resistance is due to current flow between plates, through the dielectric, and may be represented by the equivalent parallel resistance, R_P in Figure 5. In a nonelectrolytic capacitor in good condition, R_P is several thousand megohms in value and need not be considered; in an electrolytic capacitor, on the other hand, R_P normally may be so low as to affect timing circuit design. Thus, R_P must be taken into consideration in the design of timing circuits employing most types of electrolytic capacitors, and also becomes important in nonelectrolytic types which have developed high leakage in service. (Where it can possibly be avoided, electrolytic capacitors are not normally recommended for timing circuit applications).

Leakage resistance can give rise to two malfunction effects. (1) It provides a hidden discharge path in a circuit such as that of Figure 5(A), where the capacitor C is to be discharged through external resistive circuitry connected at terminals X,

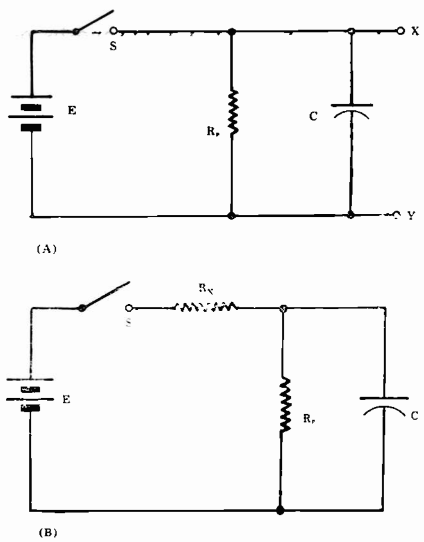


Figure 5. Effect of Parallel (Leakage) Resistance.

TIME (t)	RESISTANCE (R)	CAPACITANCE (C)
seconds	ohms	farads
seconds	megohms	microfarads
microseconds	ohms	microfarads
microseconds	megohms	picofarads
milliseconds	kilohms	microfarads

Figure 4. Corresponding t, R, C Units

Y. Closing and then opening switch S charges the capacitor which then proceeds to discharge not only through the desired external timing resistance but also through leakage resistance R_P. The time constant due to this component alone is $t = CR_P$. Thus, the timing rate is determined by the combination of R_P and the external resistance (R_{XY}) in parallel, that is by the reciprocal of $(1/R_{XY} + 1/R_P)$.

(2) In a circuit such as that of Figure 5(B) in which the capacitor is to be charged through a timing resistor, R_X, the leakage resistance, R_P, acts with R_X to form a voltage divider. This reduces the charging voltage to $ER_P/(R_X + R_P)$. Additionally, as in the previous case, R_P provides an unintended discharge path.

Internal leakage resistance must sometimes be taken into account in timing circuit design. Since many RC timing circuits exploit the high capacitance to size ratio of electrolytic capacitors, the normal value of the leakage resistance of this type of capacitor must be allowed for in circuit design.

Effect of Parameter Shift

Resistance and/or capacitance may shift in magnitude, temporarily or permanently, as a result of such factors as temperature and aging. Any variation in either R or C directly affects the time constant of a circuit. When one of these constants changes by some multiple **n**, the time constant changes by the same multiple. Thus, doubling C while R remains constant, doubles t. When both components change by the same multiple, n, the time constant changes by the multiple n^2. Similarly, when the R multiple is m, and the C multiple n, the t multiple will be mn.

The new time constant (t + dt) resulting from small changes in resistance and capacitance may be calculated simply:

3) $t + dt = (R + dR)\ (C + dC)$

From this, the change (dt) in time constant may be determined:

4) $dt = [(R + dR)\ (C + dC)] - t = [RC + RdC + CdR + dRdC] - t$

(and since $t = RC$)

4A) $dt = [RdC + CdR + dRdC]$

The sign of the change (positive for increase, negative for decrease, in R, C, or t) must be taken into account of course.

The designer must select stable components for both R and C circuit elements. Where a certain amount of variation in one component is unavoidable, the other component may sometimes be obtained with an equal variation of opposite sign. Examples are temperature-compensated capacitors, and positive-temperature-coefficient resistors. By this expedient, the net drift of the circuit may be reduced to zero, and the RC product stabilized.

Effect of Dielectric Absorption

RC calculations show that a capacitor should be fully charged by time 5RC (See Figure 3). Actually, with many capacitors, charging current continues to flow for some time beyond that limit. The additional energy is thought to flow **into** the dielectric (not through the dielectric resistance), and the phenomenon accordingly has been termed **dielectric absorption.**

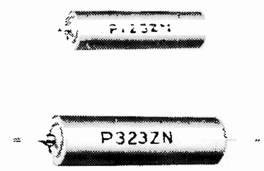
Similarly, when such a capacitor is discharged, its discharge current does not fall to zero in the calculated 5RC seconds, but continues to decrease for some time beyond that instant, indicating that during the added interval a part of the absorbed charge is being released by the dielectric.

The geometric capacitance is charged or discharged in 5RC seconds, but in practical capacitors the charge or discharge interval is lengthened by an amount proportional to the value of the dielectric absorption. In many capacitors, dielectric absorption is negligible and does not degrade timing circuit operation to any noticeable extent; in others, dielectric absorption is high enough to demand attention. Capacitors finally selected for the timing circuit should have low dielectric absorption, or allowance should be made in the circuit design.

Aerovox Metallized Paper Capacitors Meet Critical Operating Requirements to +125°C Without Voltage Derating

PRODUCT NEWS FROM AEROVOX

The reduced size and the variety of case styles make these high-quality capacitors ideal for space-tight applications.



Aerovox High-Temperature Metallized Paper Capacitors are designed and manufactured under the strictest quality controls to meet critical operating conditions and the need for increased reliability. They offer many advantages to the design engineer and manufacturer who require dependable service, long life and small size. Aerolene®* impregnated units are available in a wide range of sizes and case styles in types capable of operation to +125°C without voltage derating. The most widely used types are the metal cased tubular P323ZN, the bathtub type P30ZN, and the rectangular metal cased unit P09ZNR. All types feature low radio frequency impedance.

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Also Available:
P123ZN—Rated at 50 VDC. Full voltage rating to +100°C.
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Hermetically sealed metal cased tubulars are available in both grounded construction and floating case construction. Plastic insulating tubes may be used with either construction. Threaded neck mounting and mounting by soldered tangential brackets are also available.

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Aerovox metallized paper capacitors have proven their reliability and ruggedness in such demanding applications as guided missiles, computers, and airborne receivers, in addition to transistorized radios, color TV receivers, telephone and other equipments. Whatever your particular application requirement may be, you are invited to discuss the selection of the best type with our experienced engineers . . . they are ready at all times to be of service.

Availability

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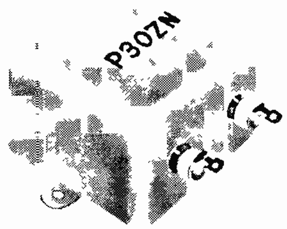
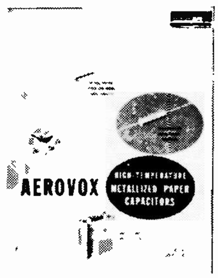


Technical Data

Call your nearest Aerovox field representative or send for a free copy of Catalog Sheets 131B8 and 131B6.



*Aerolene is an Aerovox registered trademark for a specially developed high-temperature, solid dielectric impregnant which provides excellent protection from vibration.

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