1980

Evaluation of the operating internal resistance and capacitance of intact trapezoidal waveform defibrillators

Charles F. Babbs
Purdue University, babbs@purdue.edu

SJ Whistler

LA Geddes

Clinical Device Note

Evaluation of the operating internal resistance and capacitance of intact trapezoidal waveform defibrillators

C. F. Babbs, M.D., Ph.D.

S. J. Whistler, B. S.

L.A. Geddes, M. E., Ph.D.

Biomedical Engineering Center, Purdue University, West Lafayette, Indiana, USA.

(MEDICAL INSTRUMENTATION, Vol.14, No.1, 1980, pp. 67-68)

The technique described permits determining values that may be useful in preventive maintenance programs. ***Key words:*** *defibrillation, ventricular fibrillation, waveform.*

We have previously described a simple method for determining the values of internal resistance, inductance, and capacitance of a damped sine wave defibrillator solely from measurements of the output waveform using two or more power resistors and a storage oscilloscope (Babbs et al. 1978). Measurement of these values may be useful in preventive maintenance, since a change might indicate equipment aging or impending failure. This clinical device note presents a similar method applicable to trapezoidal waveform defibrillators.

The output circuit of a trapezoidal waveform defibrillator can be represented by a capacitor C, a series internal resistance R_s, a parallel internal resistance R_p, the subject or load resistance R_L, and switching elements S_1, and S_2 (Fig. 1). The parallel internal resistance R_p is large with respect to the load and is included to ensure proper operation of the switching elements. To initiate the defibrillating current pulse, the charged capacitor is switched so that it discharges through the internal resistances and the load. After a predetermined duration, d, the exponential discharge is arrested by a short-circuiting switch S_2, in parallel with the subject.

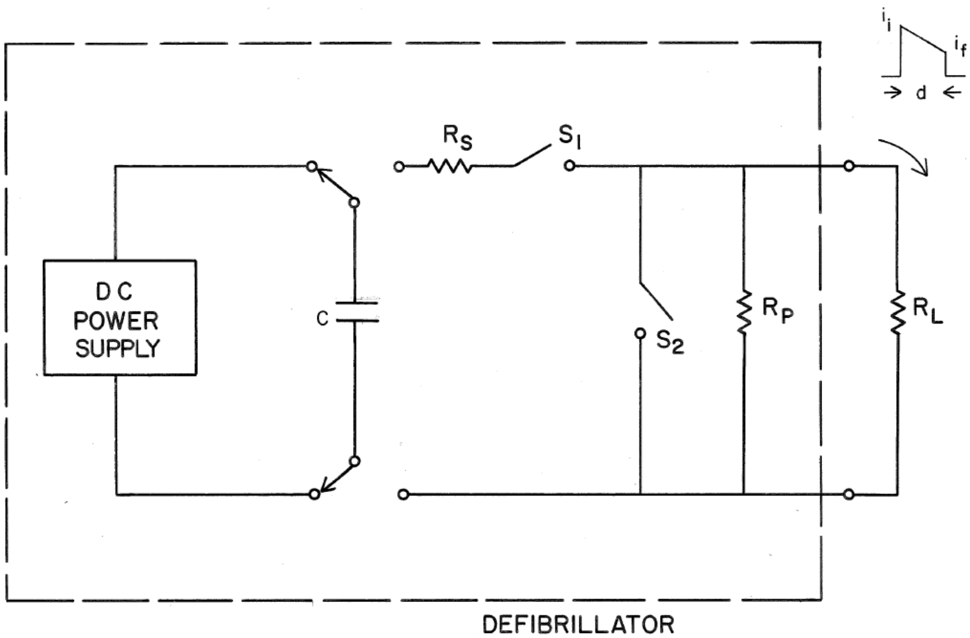


Fig.1. Trapezoidal waveform defibrillator output circuit.

If the initial current value is i_i and the final nonzero current value is i_f, then

$$i_f = i_i \exp\left(-\frac{d}{R_{eq}C}\right);$$

where

equivalent resistance = $R_{eq} = R_s + \dfrac{R_p R_L}{R_p + R_L}$.

Rearrangement of this expression gives the time constant, τ , of the circuit:

$$\tau = R_{eq}C = \frac{d}{\ln(i_i / i_f)}.$$

This expression indicates that if the ratio of initial to final current and the pulse duration are measured on a storage oscilloscope, then a plot of the calculated variable $d/\ln(i_i/i_f)$ as a function of R_{eq} will yield a straight line with slope equal to the capacitance, C, in the defibrillator. For any resistive load, the ratio of initial to final current is equal to the ratio of the initial to final output voltage and is easily determined from the recorded waveform.

It is necessary, however, to know the values of the internal series and parallel resistances, R_s, and R_p, to calculate R_{eq} . These may be determined by investigating the relationship of the calculated time constant of the pulse for the open-circuit condition (τ_∞ for $R_L = \infty$) to the calculated time constant of the pulse for various measured loads. In particular,

$$\frac{\tau_\infty}{\tau} = \frac{R_s + R_p}{R_{eq}} = \frac{R_s + R_p}{R_s + \dfrac{R_p R_L}{R_p + R_L}} .$$

Simplifying and rearranging, one obtains the expression

$$\frac{\tau}{\tau_\infty - \tau} = \frac{R_s}{R_p} + \frac{R_s + R_p}{R_p^2} \cdot R_L ,$$

which is a linear function of the load resistance, R_L.

Therefore, if the defibrillator is first discharged into the open air to obtain τ_∞ and then discharged into differing known resistive loads, a plot of the calculated value $\tau / (\tau_\infty - \tau)$ as a function of R_L will be a straight line with slope $(R_s + R_p)/(R_p)^2$ and intercept R_s/R_p. Then, solving for R_s, and R_p in terms of the slope and intercept, one may obtain

R_s = intercept(1 + intercept)/ slope,

and

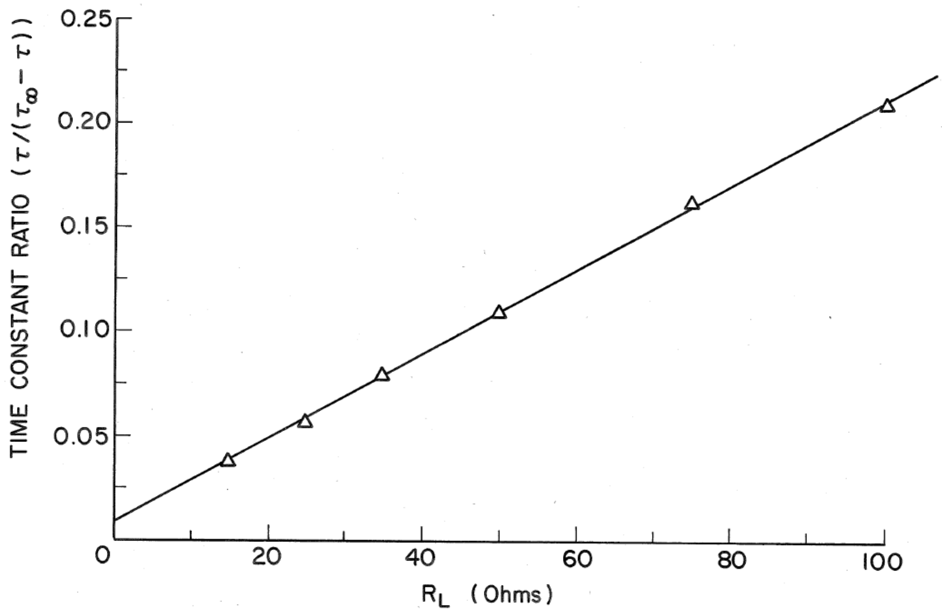
R_p = (1 + intercept)/slope.

These are the values of series and parallel internal resistances of the defibrillator shown in Fig. 1.

To find the capacitance, it is merely necessary to calculate the equivalent resistance,

$$R_{eq} = R_s + \frac{R_p R_L}{R_p + R_L} ,$$

for each load and determine the capacitance as $C = \tau \cdot R_{eq}$, the best estimate of C being given as the slope of the τ vs. R_{eq} graph for several values of load resistance.



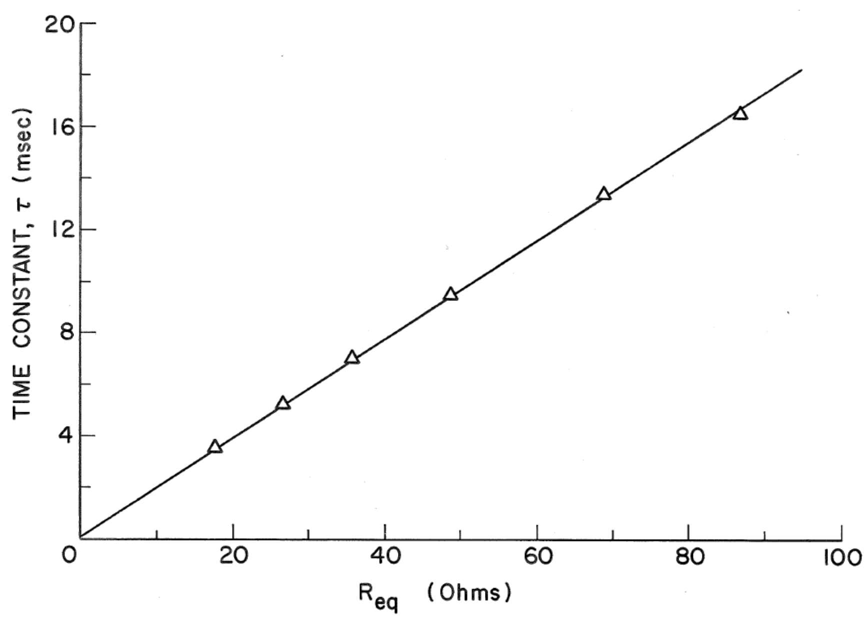


Fig. 2. Top: Plot of time constant ratio vs. load resistance. Intercept = 7 x 10^{-3} ; slope= 2.02 x 10^{-3} Ω^{-1}. Bottom: Plot of time constant vs. equivalent resistance. Slope= 19.2 msec/100 Ω.

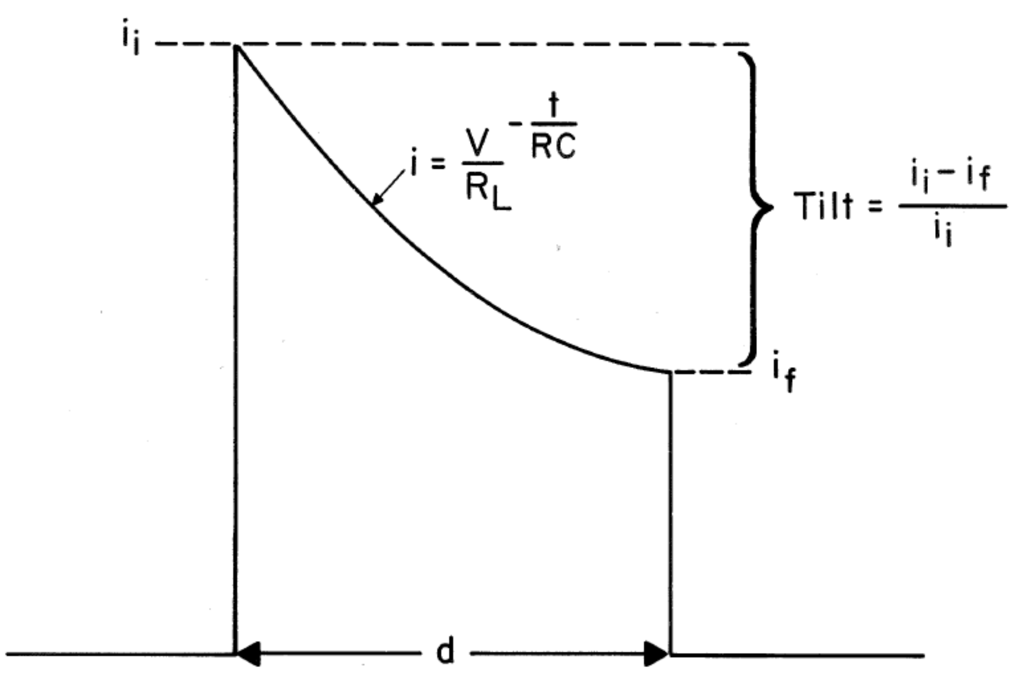
We applied this analysis to a low-energy trapezoidal waveform defibrillator in our laboratory. The defibrillator was discharged in the open-circuit mode and into known resistive loads from 15 to 100 Ω, while the initial amplitude, final amplitude, and duration of each pulse were recorded using a storage oscilloscope. The slopes and intercepts of the time constant plots (Fig. 2) were determined by least-squares linear regression. Using the conversion factor, 1 sec = 1 Farad x 1 Ω, the calculated values of capacitance and parallel internal resistance were 192 F and 498 Ω. Corresponding rated values for these components were 200 F and 500 Ω. The calculated series internal resistance was 3.5 Ω.

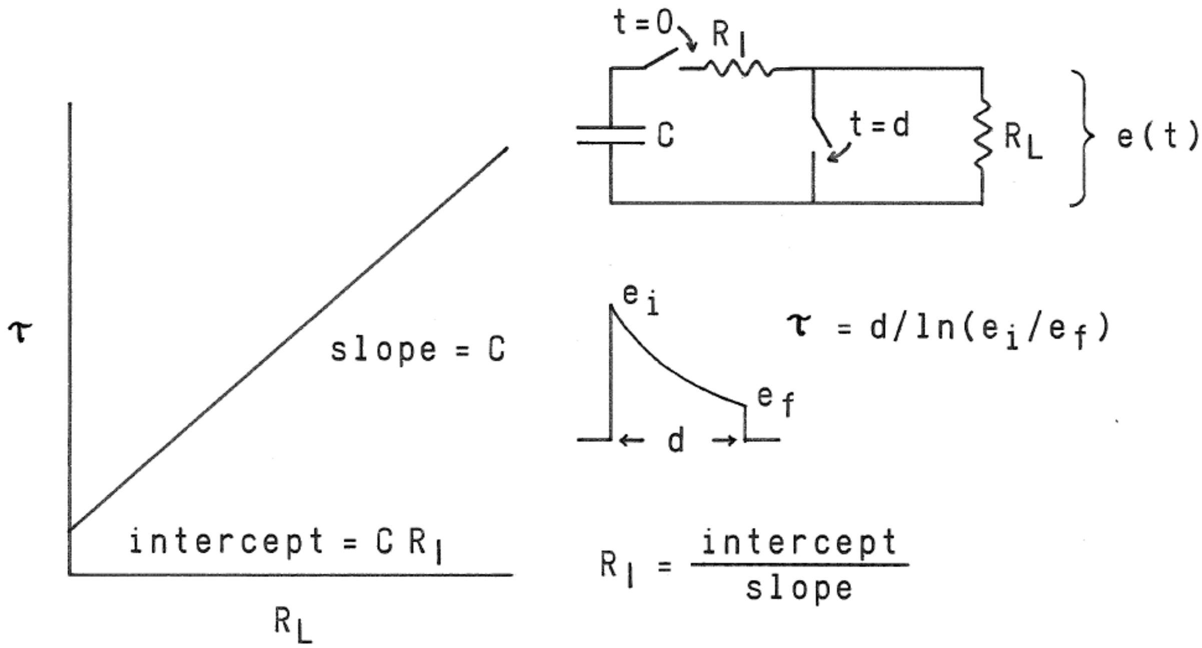
As the use of trapezoidal waveform defibrillators becomes more widespread, this technique may become increasingly useful to clinical engineers in establishing preventive maintenance programs.

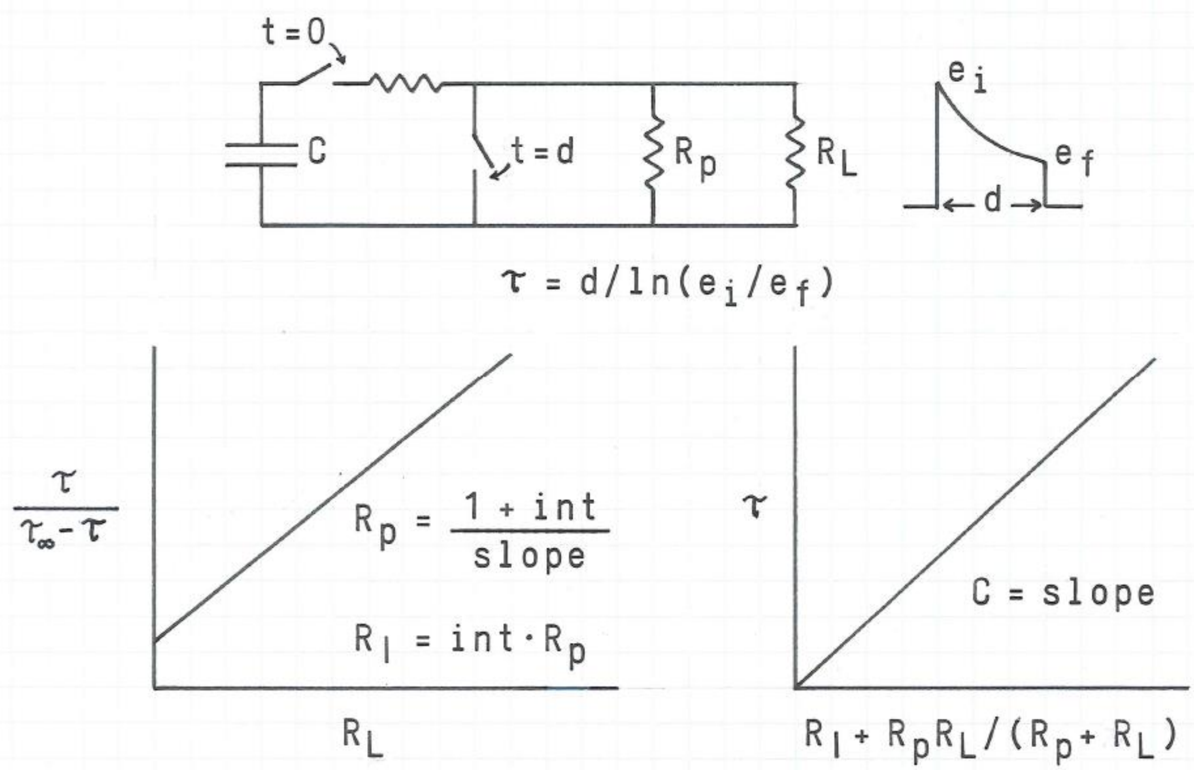
Reference

Babbs, C. F., and S. J. Whistler, 1978. Evaluation of the operating internal resistance, inductance, and capacitance of intact damped sine wave defibrillators. Med. Instrum. 12: 34-37.

Graphical Summary




t = 0
R l
C
t = d
R L
e(t)
e i
τ = d/ln(e i /e f)
e f
d
τ
slope = C
intercept = C R l
R L
R l = intercept / slope


t = 0
C
t = d
R p
R L
e i
e f
d
τ = d/ln(e i /e f)
τ / (τ∞ - τ)
R p = (1 + int) / slope
R l = int · R p
R L
τ
C = slope
R l + R p R L /(R p + R L)