An Integrating Circuit for Measurement of the Areas of the Waves in the Electrocardiogram

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An electronic circuit capable of integrating the electrocardiogram is described. The net areas of the QRS complex, the T wave and of the entire ventricular complex, QRS-T, in the standard leads may be estimated by measurement of the length of two vertical lines in each of the integrated records. The manifest areas of QRS, T and the gradient (QRS-T) with the orientation of these vectors are easily calculated from the data. An example of an integrated electrocardiogram is reproduced, and the procedure for estimation of the gradient is presented.

INTRODUCTION

A quick and accurate method for the estimation of areas of certain deflections in the electrocardiogram has been needed since 1931 when Wilson, Macleod, and Barker outlined the concept of the ventricular gradient and pointed out that it may be calculated if the net areas of the QRS complexes and T waves in any two of the standard limb leads are known. Various methods, all time consuming or subject to considerable error, have been used for the measurement of these areas, and we believe that the circuit to be described will be helpful to any physician or investigator who is interested in the ventricular gradient. An electronic integrator has been under investigation in this laboratory for several years, and recent simplifications have placed the outfit on a practical operating basis.

METHOD

The circuit employed for integration of the electrocardiogram is shown in Fig. 1. The integrator itself is diagrammed in detail and a great deal need not be said here concerning its construction or operation. When the push button switch (S) is pressed, the variable contact moves to the integrating position (+), the condenser, C, will charge, and a voltage \( E = \int \frac{dv}{C} \) that is proportional to the integral of the electrocardiogram appears across its terminals. To record this voltage, as we have done, with a string galvanometer, the circuit must be arranged so that no current is drawn from the condenser, and this is the purpose of the double triode, the 6SL7. When the push button is not depressed the condenser, C, is short circuited, and a very small fraction of the output of the preamplifier is supplied to the input of the triode and on to the string. Thus, the string galvanometer records the electrocardiogram except when the integrating switch is depressed. The network of resistances with the battery is a balancing arrangement, and by proper adjustment of the coarse and fine controls the base line of the integrated curve (T-P interval) is made as nearly motionless as possible, before a record is actually taken.

Since vertical displacements in the integrated electrocardiogram are proportional to corresponding areas in the electrocardiogram itself, it is desirable, if possible, to record the two simultaneously. Most two-channel electrocardiographs may be used for this purpose, but we prefer to record the integral curve with the string galvanometer and have used the Cambridge Simplitrol Electrocardiograph with the mirror galvanometer (ordinarily used for sound tracings) to record the accompanying electrocardiogram. Since this galvanometer is rather insensitive, two double triodes, 6SN7, connected in parallel and arranged as indicated in figure 1, are employed to drive it.

The diagrams in figure 2 show in simplified form the type of records that are obtained and illustrate the way to measure the areas of QRS and T waves from the integrated record. In the ideal case shown in figure 2A the T-P intervals are horizontal, and the measurement is very simple. If the T-P intervals slant, as shown in figure 2B, due to imperfect balancing, the areas may be estimated again from the length of vertical lines, drawn in this instance from the slanting lines parallel with the T-P segment. Measurements in either situation will not give an accurate estimate of the areas unless complexes are selected where the inclination of the T-P intervals is essentially constant for several heart beats. We...
have used a transparent ruler with fine graduations (\(\frac{1}{30}\) inch) to measure the vertical displacements in Ashman units by a simple standardization. The obvious way to accomplish this is to introduce into the

![Wiring diagram showing integrator and associated circuits.](image)

**Fig. 1.** Wiring diagram showing integrator and associated circuits. See text. NOTE: The wires should not be electrically connected at the point marked X. The high voltage supply for the 6SL7 should be +200 volts and not 270 volts.

![Schematic diagrams illustrating how net areas of the QRS complex and the T wave may be obtained from integrated electrocardiograms.](image)

**Fig. 2.** Schematic diagrams illustrating how net areas of the QRS complex and the T wave may be obtained from integrated electrocardiograms. See text.

that represent the net areas of the QRS complex and the T wave, but these areas, expressed in arbitrary units, can be converted to microvolt seconds or input of the preamplifier a fraction of a millivolt for a known period of time. This produces in the electrocardiographic record a known area, in microvolt
seconds, and the vertical displacement simultaneously observed in the integrated tracing is thus easily expressed in the desired units of area. It is possible to simplify the standardization procedure further. A constant ratio exists between the sensitivities of the circuit in the integrating (switch S depressed) and non-integrating positions. This ratio can be determined by experiment, and when it is known, the vertical displacements in the integrated curve are easily converted to areas in microvolt seconds. For our integrator the relationship is as follows:

\[ \text{Deflection per microvolt second} \]

\[ = \text{Deflection per millivolt} \]

\[ \text{(Integrated curve)} \]

\[ \text{Deflection per millivolt} \]

\[ \text{(Nonintegrated curve)} \]

This means that areas in microvolt seconds = \( K \) multiplied by the areas measured in arbitrary units, where

\[ K = \text{Deflection per millivolt} \]

\[ \text{(Nonintegrated Curve)} \]

The preamplifier shown in figure 1 must have a voltage gain of approximately 50,000, very good stability, and be designed so it will amplify the electrocardiogram with reasonable fidelity.

Figure 3 illustrates the standard leads and the accompanying integrated records taken on a subject with a normal electrocardiogram. Reference is made to this figure and to table 1 in the description of the procedure, included below, for calculation of the gradient.

The lengths of the vertical lines labelled A and B represent the net areas of QRS and QRS-T in the three leads, and the actual measurements (made in 50ths of an inch) are indicated in the table in columns I, II and III. The figures for the areas of the T waves are gotten by subtracting the areas of QRS from those of QRS-T. Since Einthoven’s law must be true for net areas over a given interval, as it is for instantaneous deflections, the figures representing the areas of QRS, T and QRS-T in Lead II should equal the algebraic sum of those in Leads I and III. Due to errors of measurement (usually caused by un-

certainties regarding the position of the baseline), the calculations do not ordinarily check as they should, and in order to minimize and distribute these errors, the figures are adjusted by a simple calculation. The correction to be applied to each of the areas is very easily gotten, and the adjusted areas may be defined as follows:

\[ I_a = I - 1/3 \Delta \]

\[ II_a = II + 1/3 \Delta \]

\[ III_a = III - 1/3 \Delta \]

where \( \Delta = I + III - II \)

**TABLE 1**

<table>
<thead>
<tr>
<th>COMPLEX</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>( \Delta )</th>
<th>( I_a )</th>
<th>( II_a )</th>
<th>( III_a )</th>
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</thead>
<tbody>
<tr>
<td>QRS</td>
<td>11.7</td>
<td>18.0</td>
<td>8.7</td>
<td>2.4</td>
<td>10.9</td>
<td>18.8</td>
<td>7.9</td>
</tr>
<tr>
<td>QRS-T</td>
<td>26.0</td>
<td>37.0</td>
<td>14.7</td>
<td>3.7</td>
<td>24.8</td>
<td>38.2</td>
<td>13.5</td>
</tr>
<tr>
<td>T</td>
<td>14.3</td>
<td>19.0</td>
<td>6.0</td>
<td>1.3</td>
<td>13.9</td>
<td>19.4</td>
<td>5.6</td>
</tr>
</tbody>
</table>

**TABLE 2**

<table>
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<th>COMPLEX</th>
<th>( 2H + V )</th>
<th>( V )</th>
<th>( H )</th>
<th>( 2H + V )</th>
<th>( V )</th>
<th>( H )</th>
<th>( 2H + V )</th>
<th>( V )</th>
<th>( H )</th>
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<tbody>
<tr>
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<td>15.4</td>
<td>10.9</td>
<td>18.9</td>
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<td>34.6</td>
<td>8.7</td>
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</tr>
<tr>
<td>QRS-T</td>
<td>51.6</td>
<td>29.8</td>
<td>24.8</td>
<td>38.8</td>
<td>50.1</td>
<td>71.0</td>
<td>17.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>24.9</td>
<td>14.4</td>
<td>13.9</td>
<td>20.0</td>
<td>46.0</td>
<td>36.6</td>
<td>9.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 3.** An illustration of integrated electrocardiograms taken with the arrangement described.

The standardization record is mounted to the right of the limb leads. See text.
Direction (angle $\alpha$) = $\arctan \frac{V}{H}$

where $H = I_a$ and $V = \frac{II_a + III_a}{\sqrt{3}} = \frac{2II_a - I_a}{\sqrt{3}}$

These quantities have been calculated and are shown in the table. The values for the angle $\alpha$ are independent of units used in measurement of the areas and need no adjustment. To express the magnitude of the vectors in microvolt-seconds instead of arbitrary units of area, the method outlined in an earlier paragraph is employed. The factor, $K$, by which the areas must be multiplied to convert them to microvolt-seconds is here $43/23.5 = 1.83$, where 43 is a constant of the integrating circuit determined by experiment and 23.5 is the deflection of the string shadow when 1 millivolt is introduced into the input circuit of the pre-amplifier and the integrating button is in the neutral (non-integrating) position. This standardization is shown in figure 3 with the limb leads. The magnitudes of the vectors QRS, QRS-T and T expressed in microvolt-seconds and also in Ashman units $(\text{microvolt-seconds} \times \frac{4}{4})$ will be found in the table. These vectors are shown graphically in figure 4. They are plotted with reference to a horizontal line (angle $\alpha = 0^\circ$) and their size is proportional to the dotted horizontal line which represents 40 microvolt-seconds (10 Ashman units).

**DISCUSSION**

The circuit and technic described above for estimation of the gradient have been employed with over one hundred patients, and we are satisfied that the method saves enough time and is sufficiently accurate to justify its use in a laboratory where it is desired to determine the gradient for a large number of electrocardiograms.

The most troublesome problem that arises, irrespective of the method one may use to estimate the net areas of QRS and T, is to decide where the baseline should be located. Careful inspection of many electrocardiograms reveals that the baseline (T-P interval) is not a straight horizontal line, and in the integrated records these difficulties are multiplied. We have no ready solution for this problem but think some generally accepted arbitrary method for placing the baseline may be necessary. Another situation that often complicates the use of the integrator arises from slow fluctuations of the "skin potentials." It is usually easy, with the integrating circuit we have described, to adjust the balancing resistances so that the T-P intervals of the integrated record are represented by horizontal or nearly horizontal segments for a few cycles but rarely does this baseline retain a horizontal or other constant position for more than a few seconds at a time.

The foregoing difficulty might be minimized by the use of a preamplifier with a time constant sufficiently long to pass the low frequency components of the electrocardiogram without significant attenuation and short enough to block out very low frequency drifts that may lead to fluctuations of the baseline. There are objections, however, to the use of a resistance-condenser coupled pre-amplifier, particularly one with a relatively short time constant, and at the moment we are using a differential amplifier capable of direct current amplification designed by one of the authors (Richard McFee). Incidentally, after the apparatus has been turned on for a sufficient period (fifteen to thirty minutes), there is great stability, and drift due to the pre-amplifier and associated circuits is negligible.

Because of the chance that part, at least, of the variable "skin currents" that have proved so troublesome to us are not due to variable electromotive forces arising beneath the surface of the skin but are due to slight differences between the electrodes, we are planning to investigate this possibility.* Should the use of

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* An electrical engineer who has designed a cathode-ray electrocardiograph with a D.C. differential amplifier has been able to practically eliminate low frequency drifts by the use of special electrodes. The
special electrodes eliminate all or most of the low frequency drift, the value of the integrator we have described will be considerably enhanced.

**Conclusions**

1. A circuit for integration of the electrocardiogram is described, and the method by authors, unfortunately, cannot remember the name and address of this individual but wish to give him credit for the idea.

which the gradient may be estimated is outlined in detail.

2. Low frequency shifts of the baseline which are not constant for any great period of time are the most troublesome problem encountered in the use of the apparatus. Special electrodes may aid in the elimination of this difficulty.

**Reference**

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