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Instantaneous cardiac tachometer with extendable range

A. J. Cousin K. C. Smith

University of Toronto, Department of Electrical Engineering, Toronto, Ont. Canada M5S 1A4

Abstract—*There have been various designs presented in the literature which provide heart rate (Roy and Wehnert, 1974; Clark and Meyer, 1969; Cisek, 1972; Czekajewski and Tove, 1965; Caldwell* et al., *1970). Virtually all fall into the following two categories: those that perform an average over several beats and those that measure the time interval between beats and display the reciprocal on a beat-to-beat basis. Although the averaging technique certainly has its area of application, other cases exist where it is desirable to update heart rate with each beat. This communication describes a technique that produces a signal proportional to the instantaneous (beat-to-beat) heart rate with an error of 2 beats/min (b.p.m.) over a 4:1 range of rate. Further, with the addition of a small number of components, the range can be extended to more than five and one half to one with only a small decrease in accuracy. Total component cost including the extendable range feature, but excluding the milliameter, is $6·00.*

Keywords—*Cardiac tachometer*

1 Basic circuit description

THE TACHOMETER circuit is shown in Fig. 1 with its timing diagram. Each time the QRS complex is detected, a pulse is produced (input trigger), which triggers flip-flop IC3A. This device is connected as a one-shot and produces a pulse A of short duration (1·5 ms with the values given). This pulse serves two purposes. First, it samples and stores the value of the discharging *RC* circuit onto capacitor *C*. Secondly, it triggers flip-flop IC3B which produces a reset pulse B of short duration (1·5 ms with the values given) that is used to momentarily short the discharging capacitor. This action resets the *RC* network which then begins discharging again to allow measurement of the next interbeat interval.

The amplifier IC1B and associated circuitry are used as a buffer with R1 allowing adjustment for device to device variations in input bias current of the operational amplifier. The operational amplifier used in this realisation is an LM324 which has a *p–n–p* input. The circuit should work as well for amplifiers with *n–p–n* input circuitry with the equivalent compensation circuit referenced to the positive supply.

Amplifier IC1C is used to buffer the offset adjusting potentiometer, R4. By employing a low-power amplifier buffering a high-impedance voltage divider, one obtains low power dissipation along with the capability to drive a standard analogue meter.

Potentiometer R4 adjusts the meter offset and is used as a control to set up the low end of the rate scale. In the graphs shown subsequently, this potentiometer has been used to adjust the 60 b.p.m. point. Potentiometer R3 controls the total drive to the meter and thus has its major effect at the upper end of the scale. We have used this adjustment to set up the 180 b.p.m. point.

Finally, potentiometer R2 adjusts the exponential curve. This potentiometer is used both to obtain a 'best fit' of the exponential approximation to the $1/T$ requirement and to accommodate small amounts of meter nonlinearity. Although others have not made this resistance adjustable, we feel that this additional degree of freedom allows more explicit control over the conversion accuracy. If it is desired to reduce the adjustable component count, R2 can be replaced by a fixed resistor as described by ROY and WEHNERT (1974).

It should be noted that this circuit provides a constant update based on each beat-to-beat interval. Several circuits that have appeared have a one beat lag when the heart rate is decreasing [e.g. ROY and WEHNERT (1974)]. This constant update feature is a direct result of the cascade connection of capacitor sections—the first providing the *RC* discharge function, the second performing the sample-and-hold operation.

2 Range-extension description

By the addition of only a small a number of components, the basic circuit can be enhanced to provide an extended range that is most needed at low rates. The additional circuitry is shown by dotted lines in Fig. 1. The operation can be described

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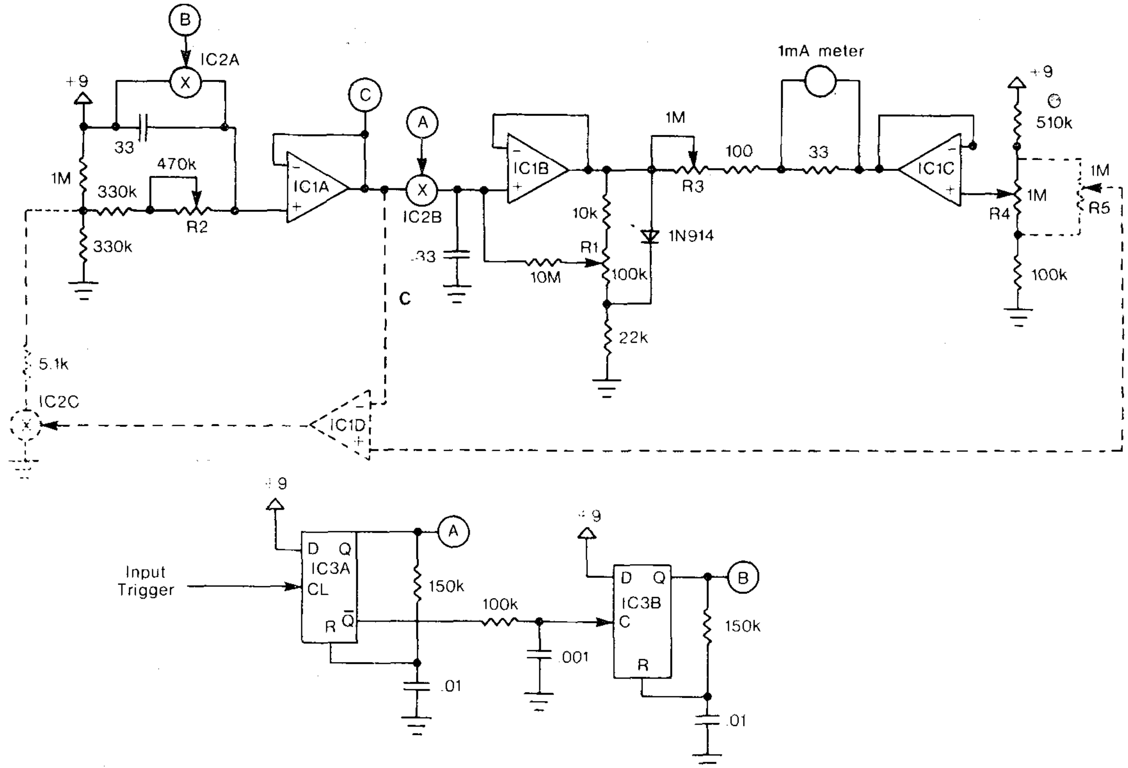
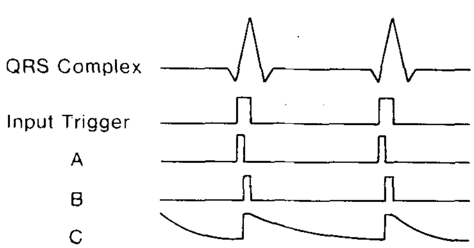
simply as a second exponential time constant that begins after a preselected period has elapsed. The result is illustrated in Fig. 2 which has been exaggerated to bring out this point.





IC1 LM324 Quad Amp
IC2 4066 Transmission Gate
IC3 4013 Flip-Flop
9 Volt Battery

Fig. 1

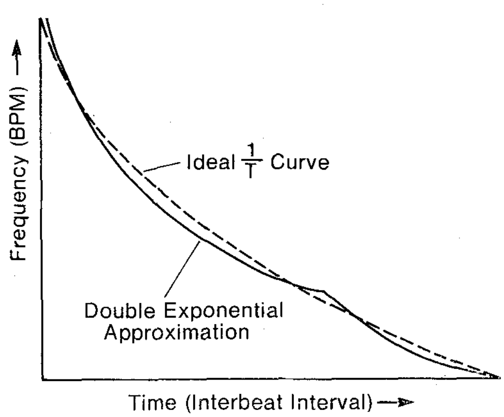


Fig. 2

Specifically, when the discharging exponential at the output of IC1A becomes less than the voltage at the noninverting input of IC1D, transmission gate IC2C is switched on. This action causes both the reference voltage and the resistive component of the *RC* discharging circuit to change or, equivalently, a new exponential discharge to begin as referred to above. By choosing a calibration point roughly midway between the original low rate of the nonexpanded circuit and the desired minimum rate, it is possible to extend the useful range of this circuit.

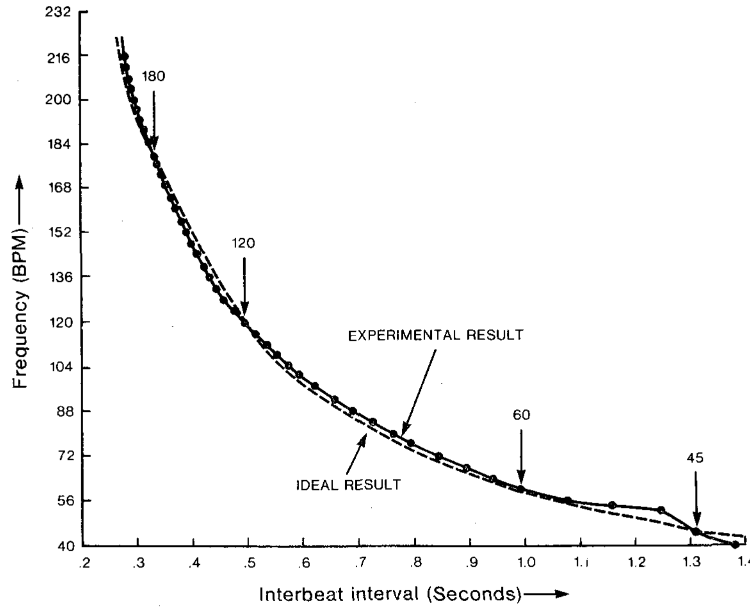


Fig. 3

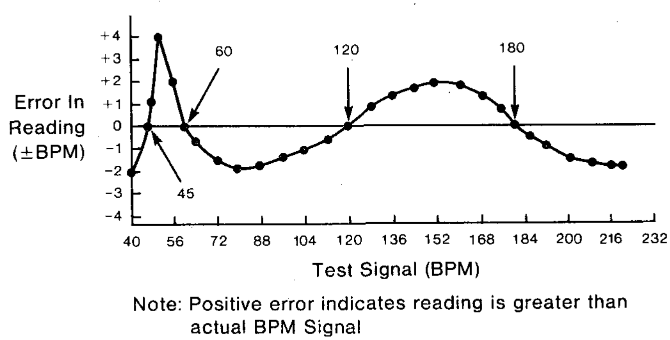


Fig. 4

3 Results

Fig. 3 demonstrates the degree of fit to the required inverse function. The dashed line represents the ideal curve described by

$$\text{b.p.m.} = \frac{1}{T}$$

where T is the interval between beats, in minutes, while the solid line is the experimental result with potentiometer calibration of R5, R4, R2, and R3 at 45, 60, 120, and 180 b.p.m., respectively. The signal generator used is crystal controlled and is described elsewhere (COUSIN, 1977). Fig. 4 is a different view of the same data. It can be seen that the maximum error over the original range of 55–220 b.p.m. is ± 2 b.p.m. while the error in the extended range is held to within 4 b.p.m.

The tachometer described has been in operation under a wide variety of conditions and has performed very reliably. It is currently part of specific instrumentation for the measurement of exercise heart rate. Owing to the exponential nature of the discharge, it is prudent to choose this adjustment point closer to the minimum rate to minimise the overall error in the extended region. For the graphs shown, 45 b.p.m. has been chosen as a calibration point which is set using R5.

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Un tachymètre cardiaque instantané avec gamme extensible

Sommaire—Il existe différentes conceptions sur l'établissement du rythme cardiaque. En fait, elles tombent dans deux catégories: celles qui effectuent une moyenne sur plusieurs battements, et celles qui mesurent l'intervalle entre les battements et affichent la réciproque sur la base de cet intervalle. La technique, établissant la moyenne, a bien sûr son domaine d'application, mais il existe d'autres cas où il est préférable de préciser le rythme cardiaque, à chaque battement. Ce résumé décrit une technique, qui produit un signal proportionnel au rythme cardiaque instantané (intervalle entre deux battements) avec une erreur de deux battements par minute (b/m) sur une gamme de rythme 4:1. De plus en ajoutant quelques composants, la gamme peut être étendue à plus de cinq fois et demie pour une, avec une précision légèrement diminuée. Le prix total des composants, avec toute la gamme extensible, mais sans le milliampèremètre, s'élève à $6.

Ein momentanes Herztachometer mit vergrösserbarem Bereich

Zusammenfassung—In der Literatur wurden verschiedene Modelle zur Feststellung der Herzgeschwindigkeit vorgeführt. Praktisch gesehen, lassen sich alle in zwei Kategorien einteilen: die, die über verschiedene Herzschläge hin einen Durchschnitt erbringen und die, die den Zeitintervall zwischen den Herzschlägen messen und den entsprechenden Wert auf einer Schlag-auf-Schalg-Basis anzeigen. Obwohl die Durchschnitssmessungstechnik bestimmt ihren Anwendungsbereich hat, gibt es andere Fälle, bei denen es wünschenswert ist, die Herzschlagsrate mit jedem Schlag fortzuschreiben. In dieser Kommunikation wird eine Technik beschrieben, die ein zur momentanen (Schlag-auf-Schlag) Herzrate proportionales Signal mit einer Fehlerrate von zwei Schlägen pro Minute (BPM) über einen Geschwindigkeitsbereich von vier zu eines produziert. Weiterhin kann, unter Hinzunahme einer Anzahl von Komponenten, der Bereich auf mehr als fünfeinhalb zu eins mit nur einem geringen Genauigkeitsverlust erweitert werden. Die Gesamtteilkosten enthalten die Bereichsvergrößerungsvorrichtung jedoch nicht das Milliameter und betragen $6.