1 Introduction

It is often difficult to measure blood flow in laboratory animals using electromagnetic flow probes when electrical stimulation of a nearby organ is occurring simultaneously with flow measurements. Electrically pacing the dog's heart in our laboratory during aortic flow measurements resulted in the pacing artefact substantially interfering with aortic flow measurements. The unwanted artefact is averaged along with the pulsatile flow to produce an erroneous mean flow measurement. The amount of error produced is unacceptably large for most physiological studies. The error cannot be predicted or compensated for because it often exhibits an irregular or random frequency of oscillation relative to the pulsatile flow signal as well as varying amplitudes.

Montgomery and Scher (1974) describe a method of removing the stimulating artefact from the flow signal by electronically synchronising the pacing stimulus with the flowprobe excitation frequency. This scheme draws upon the fact that during each flowprobe excitation cycle there is a point where the flow signal is least susceptible to noise. If the pacing stimulus can be electronically delayed until that specific point in the flowprobe excitation cycle, then the resultant artefact will be minimised to an acceptable level. Their circuit may be broken down into three subcircuits:

(a) pacing signal generator

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Correspondence should be addressed to Dr Robinson
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Although this arrangement was shown to be successful, its use required special electronic equipment not normally present in the laboratory. We found that their system could be greatly simplified by using physiological stimulators that are already present in most laboratories. Physiological stimulators usually contain the first and third components of the circuit described by Montgomery and Scher (1974); the remaining circuit, the signal synchronisation circuit, can be easily and cheaply built. This paper describes the building of the circuit and its use with the electromagnetic flowmeter and the physiological stimulator.

2 Methods and circuit description

For our system, we used a Grass model S88 multifunction solid-state square-wave stimulator and Zepeda Instrument model SWF-4 electromagnetic square-wave flowmeter. The synchronising circuit, or pacing artefact filter as it has been named, is illustrated in Fig. 1. The circuit accepts inputs from both the stimulator and the flowmeter. Both inputs require conditioning before synchronisation. The train sync. output pulse from the stimulator is 30 V in magnitude and must be passed through a two-resistor voltage divider to bring it down to a CMOS-compatible level. The probe current monitor output of the flowmeter is picked off the 500 mA current driver bridge of the flowmeter and is only 340 mV in amplitude. This signal is fed into three-fourths of an LM324 quad operational amplifier. The three amplifiers are arranged in a high-impedance differential amplifier configuration with an overall gain of 50. The output is driven rail-to-rail at the flowprobe frequency.

Synchronisation is accomplished by a 4013 CMOS dual type D flip-flop. The two flip-flops are arranged in series with the output of the first connected to the data input of the second. The train sync. input sets the first flip-flop high. The flowprobe pulse train clocks the second flip-flop and transfers the data input to the output on the leading edge of the next flowprobe pulse. This output is fed to the

(b) signal synchronisation circuit
(c) pacing signal delay circuit.

Chart recording of pulsatile and mean aortic flow signal during atrial pacing in a conscious dog. The dog was instrumented with an electromagnetic flow probe positioned on the ascending aorta and bipolar electrodes, for pacing, were attached to the epicardial surface of the left atrium. (a), (b), (c) and (d) are sequential tracings of aortic flow during atrial pacing at 120 pulses min⁻¹. In (a) the pacing artefact filter is not on and the tracing illustrates its typical random effect on the flow signal. Arrows point to the pacing artefact in the pulsatile flow signal. In (b), (c) and (d) the pacing artefact filter is on. In (b), the pacing artefacts are always positive and they occur at the same time relative to each pulsatile flow event; the delay is too short. In (c), the pacing artefacts are all negative; the delay is too long. In (d) the delay has been correctly adjusted and the pacing artefact is eliminated from the flow signal. The mean flow signal is superimposed on the pulsatile trace; it is recorded at twice the sensitivity of the pulsatile signal (i.e.full scale is 80 ml s⁻¹) to heighten the illustration of the effect of the pacing artefact on mean flow values. When the pacing artefact is positive mean flow values are in excess of actual values and when it is negative they are below actual values.