Spring 2020

CSEN 1099 – Introduction to Biomedical Engineering

Cardiac Pacemakers

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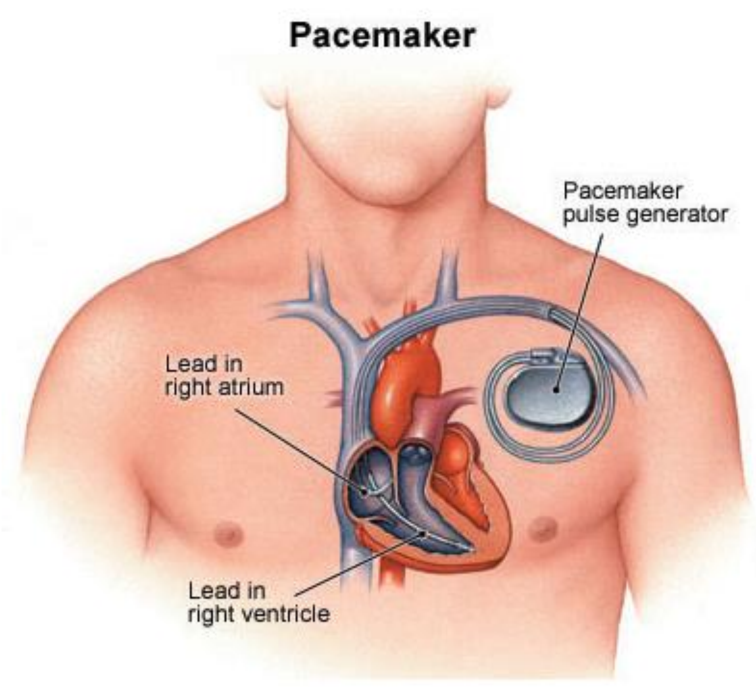
Cardiac Pacemakers

- Reference for this lecture is:
  - J. G. Webster, "Medical Instrumentation Application and Design", Wiley, 4th edition (Chapter 13: Section 13.1)
- The cardiac pacemaker is an electric stimulator that produces periodic electric pulses that are conducted to electrodes normally located within the lining of the heart



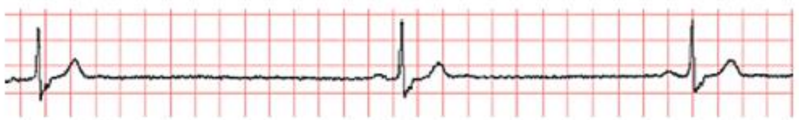
Cardiac Pacemakers

- The stimulus conducted to the heart causes it to contract; this effect can be used prosthetically in disease states in which the heart is not stimulated at a proper rate on its own

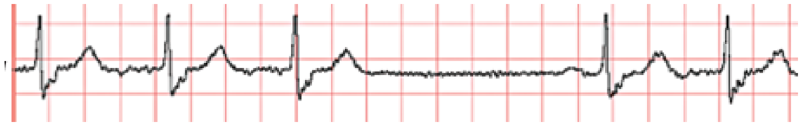
- The principal pathologic conditions in which cardiac pacemakers are applied are known collectively as heart block referring to problems with the electric system of the heart

- Can fix problems covered in the previous lecture including different types of Arrhythmias

Sinus Bradycardia



Sinus Arrest



Cardiac Pacemakers

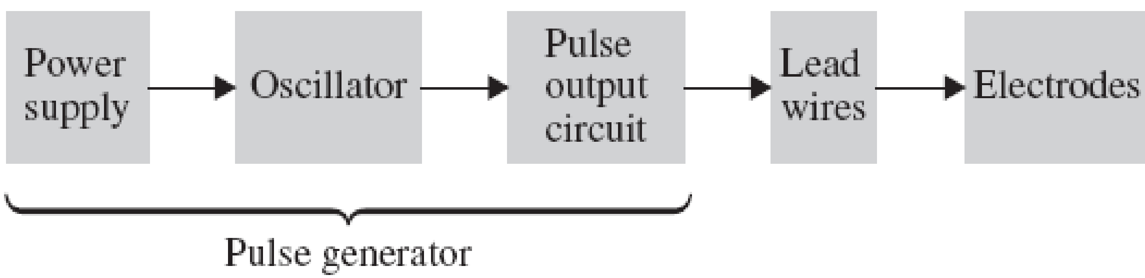
- In this lecture, we will cover three types of Cardiac Pacemakers:
    - Asynchronous Pacemakers
    - Synchronous Pacemakers
    - Rate-Responsive Pacemakers

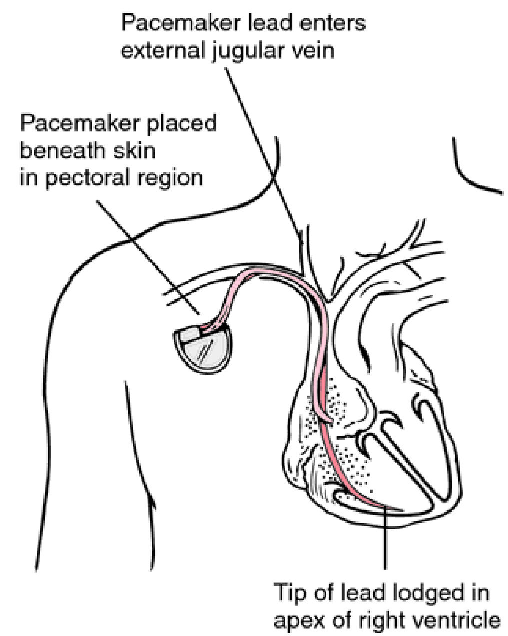
I. Asynchronous Pacemakers

- An asynchronous pacemaker is one that is free running. Its electric stimulus appears at a uniform rate regardless of what is going on in the heart or the rest of the body

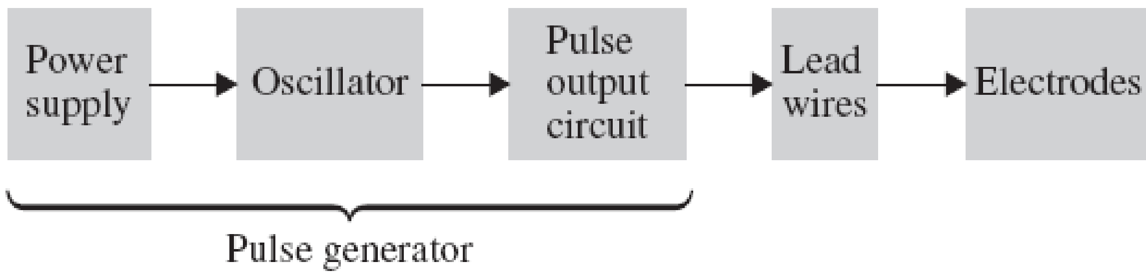
- It was the first type of pacemakers that was developed in the mid-twentieth century giving a fixed heart rate

- System Block Diagram:





Asynchronous Pacemakers: Power Supply

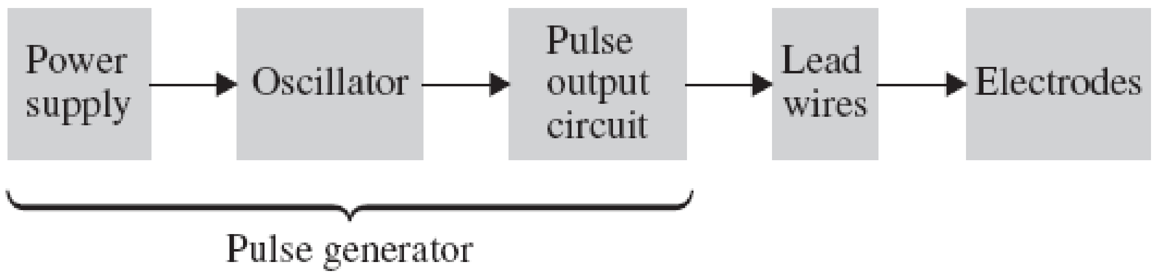


- The power supply is necessary to supply energy to the pacemaker circuit. Primary battery sources are used

- Customary practice in the early 1970s was to change the pacemaker generator every two years due to limitations of the batteries used at that time

- Current Pacemakers use Lithium batteries which are much more reliable than the batteries that had been used before

Asynchronous Pacemakers: Oscillator

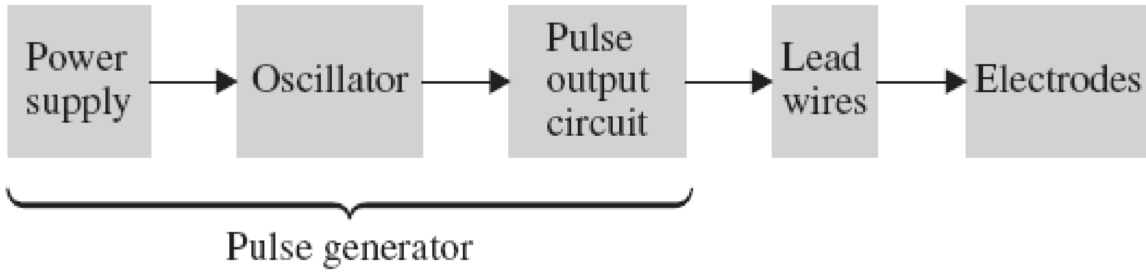


- The oscillator establishes the pulse rate for the pacemaker which controls the pulse output circuit that provides the stimulating pulse to the heart

- A free-running oscillator is all that is required for the timing pulse in such a system since it produces pulses at a fixed rate

- Rates for asynchronous pacemakers range from 70 to 90 beats/min

Asynchronous Pacemakers: Output Circuit



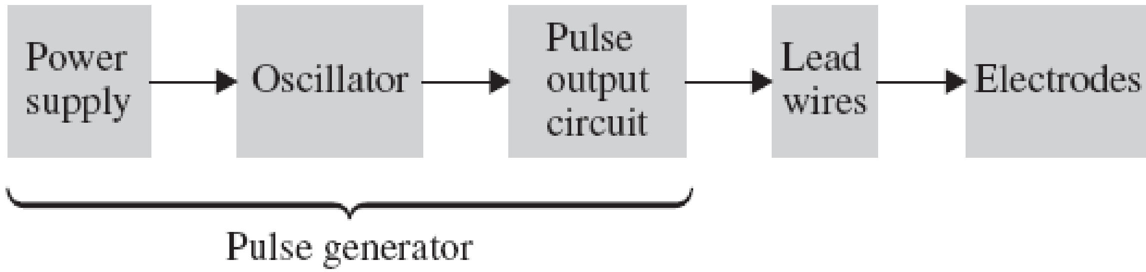
- The pulse output circuit of the pacemaker generator produces the actual electric stimulus that is applied to the heart

- At each trigger from the timing circuit, the output circuit generates an electric stimulus pulse that has been optimized for stimulating the heart through the electrode system that is being applied with the generator

- Constant-voltage or constant-current amplitude pulses are the two usual types of stimuli used:

  - Constant-voltage amplitude pulses are in the range of 5.0 to 5.5 V with a duration of 500 to 600 μs
  - Constant-current amplitude pulses are in the range of 8 to 10mA with pulse durations ranging from 1.0 to 1.2 ms

Asynchronous Pacemakers: Lead Wires

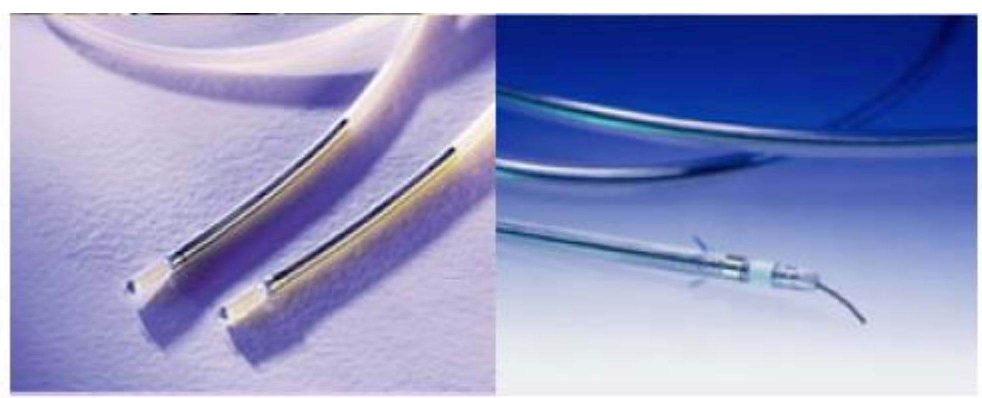


- Lead wires carry electrical pulses from the generator to the electrodes

- The lead wires must be:

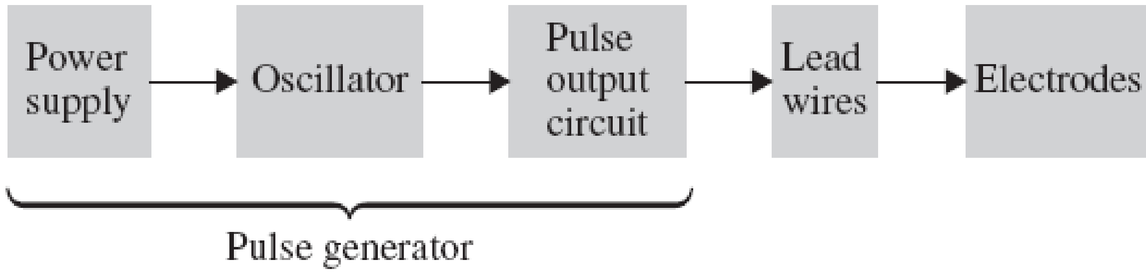
  - Mechanically strong to withstand the constant motion of the beating heart

  - Well insulated



Examples of Lead Wires

Asynchronous Pacemakers: Electrodes



- Cardiac pacemakers are either of the unipolar or the bipolar type

- In a unipolar device, a single electrode is in contact with the heart. A large indifferent electrode is located somewhere else in the body, usually mounted on the generator, to complete the circuit

- In the bipolar system, two electrodes are placed within the heart, and the stimulus is applied across these electrodes

- The electrodes must be able to stand up to the repeated stress they may encounter as a result of the mechanical activity of the heart, and they must remain in place to provide effective pacing

II. Synchronous Pacemakers

- Often patients require cardiac pacing only temporarily, because they can establish a normal cardiac rhythm between periods of block

- For these patients, it is not necessary to stimulate the ventricles continuously

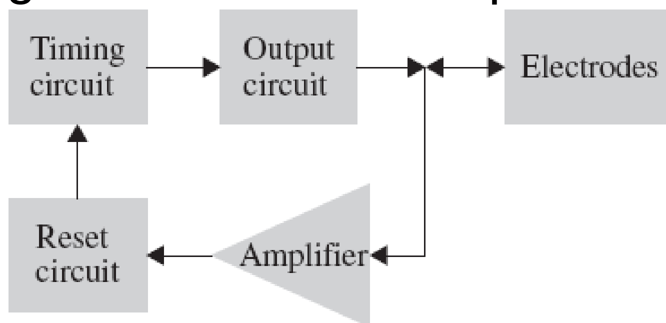
- There are two general forms of synchronous pacemakers:

  - Demand pacemakers

  - Atrial-synchronous pacemakers

Demand Pacemakers

- Similar to asynchronous pacemakers but with a feedback loop. The main idea is to generate an electric pulse only when needed



- The timing circuit is set to run at a fixed rate, usually 60 to 80 beats/min

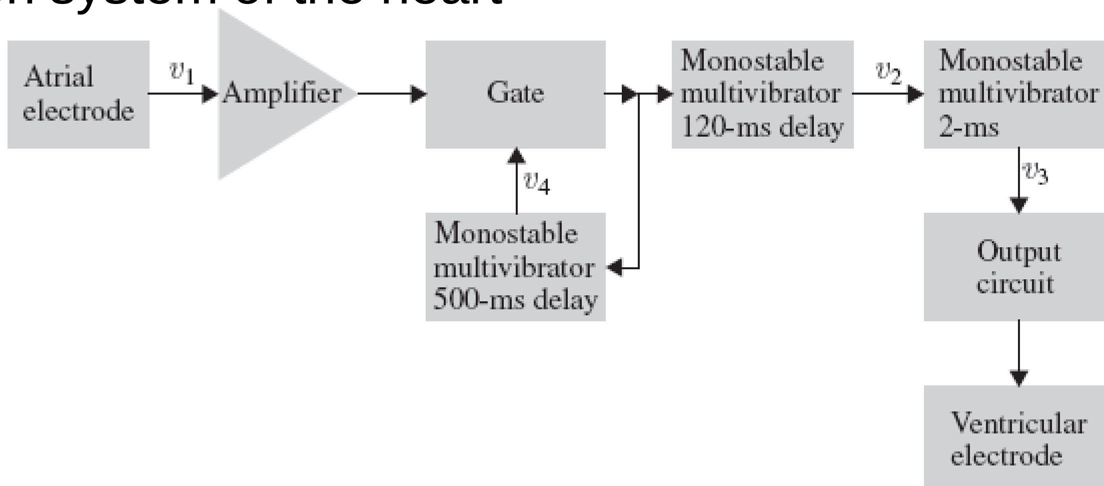
- After each stimulus, the timing circuit resets itself, waits the appropriate interval to provide the next stimulus, and then generates the next pulse

- If during this interval a natural beat occurs, the feedback circuit detects the QRS complex from the ventricle electrodes and amplifies it

- This signal is then used to reset the timing circuit and prevent generating a pulse

Atrial-synchronous Pacemakers

- In this case, the pacemaker is designed to replace the blocked conduction system of the heart



- If the SA node is able to stimulate the atria, the electric signal corresponding to atrial contraction (the P wave of the ECG) can be detected by an electrode implanted in the atrium (v_1)

- This voltage is a pulse that corresponds to each beat

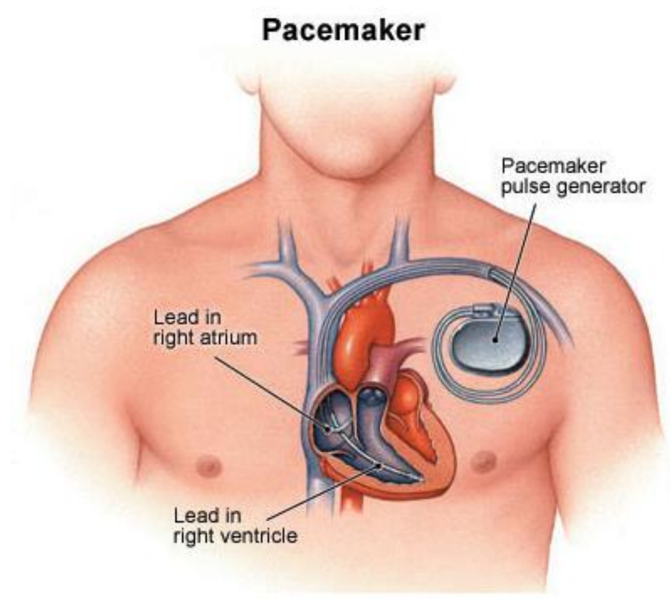
- The atrial signal is then amplified and passed through a gate to a monostable multivibrator giving a pulse v_2 of 120 ms duration, the approximate delay between the atria and ventricles

Atrial-synchronous Pacemakers

- Another monostable multivibrator giving a pulse duration of 500 ms is also triggered by the atrial pulse

- It produces v_4, which causes the gate to block any signals from the atrial electrodes for a period of 500 ms following contraction

- This eliminates any artifact caused by the ventricular contraction from stimulating additional ventricular contractions



III. Rate-Responsive Pacemakers

- The demands of the body during stressful activities such as exercise cannot be fully met by asynchronous or synchronous pacemakers

- A sensor is used to convert a physiological variable in the patient to an electric signal that serves as an input to the controller circuit

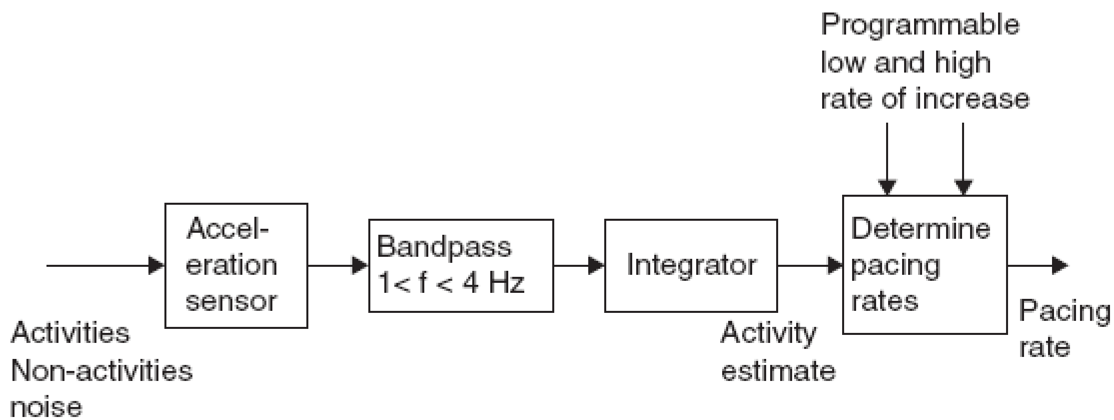
- This block of the pacemaker is programmed to control the heart rate on the basis of the physiological variable that is sensed

- This controller can determine whether any artificial pacing is required and can keep the pacemaker in a dormant state when the patient’s natural pacing system is functional

- The remainder of the system is the same as described before

Rate-Responsive Pacemakers

- Example of a Rate-Responsive Pacemaker that adjusts heart rate based on body acceleration



- In case of high acceleration (such as during playing sports), the system will automatically increase the pacing rate. Otherwise, it will use normal pacing rates

Rate-Responsive Pacemakers

- Many other physiological variables have been used to control rate-responsive pacemakers

Table 13.1 Physiological Variables That Have Been Sensed by Rate-Responsive Pacemakers

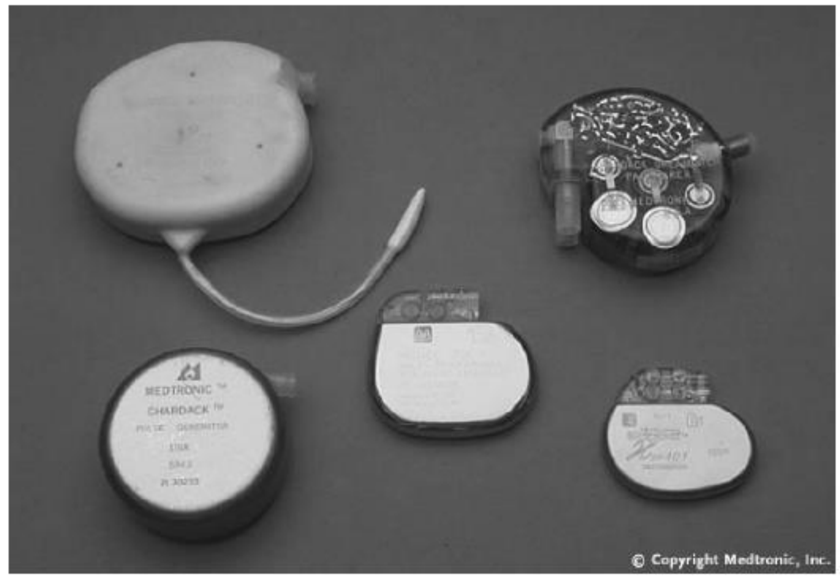
Physiological Variable	Sensor
Right-ventricle blood temperature	Thermistor
ECG stimulus-to-T-wave interval	ECG electrodes
ECG R-wave area	ECG electrodes
Blood pH*	Electrochemical pH electrode
Rate of change of right ventricular pressure* $\left(\frac{dp}{dt}\right)$	Semiconductor strain-gage pressure sensor
Venous blood oxygen saturation*	Optical oximeter
Intracardiac volume changes	Electric-impedance plethysmography (intracardiac)
Respiratory rate and/or volume	Thoracic electric-impedance plethysmography
Body vibration	Accelerometer

Commercially Available Pacemakers

- A typical modern pacemaker is quite small compared to earlier versions. The complete package is about the size of a pocket watch and has a special connector to attach the lead-wire-electrode system

Early Pacemakers

Modern Pacemakers



Commercially Available Pacemakers

- Example:

  A cardiac pacemaker delivers 5 V pulses of 2 ms duration to bipolar electrodes, that can be approximated as being a 2 kΩ-resistive load. The mean pulse rate of the pacemaker is 70 per min. The pulses represent 25% of the energy consumed by the pacemaker. The pacemaker is powered by two lithium cells connected in series to give a voltage of 5.6 V. As the designer of this circuit, you are called upon to specify a battery capable of operating the pacemaker for 10 years. What is the minimal acceptable capacity for each cell?

  Solution:

  The energy per stimulus pulse will be $E_p = \frac{v^2}{R}T = \frac{(5\,\text{V})^2}{2\,\text{k}\Omega} \times 2\,\text{ms} = 25\,\mu\text{J}$

  The number of pulses in 10 years will be

$$N = 70\,\text{min}^{-1} \times 60\,\text{min/h} \times 24\,\text{h/day} \times 365.25\,\text{day/year} \times 10\,\text{year}$$
$$= 3.68 \times 10^8\,\text{pulses}$$

Commercially Available Pacemakers

- Thus the total energy will be

$$E_t = NE_p = 3.68 \times 10^8 \times 25\ \mu\text{J} = 9.2\ \text{kJ}$$

- The energy supplied by the battery must be four times as great

$$E_b = 4E_t = 36.8\ \text{kJ}$$

- If we assume drawing a current of 1 A from the battery, it would be supplying a power of 5.6 W per stimulus ($P = V$ x I). The period of time over which this power would have to be supplied to give an energy E_b would then be ($E_b = P$ x t)

$$t = \frac{E_b}{5.6\ \text{W}} = 6.57\ \text{ks} = 1.83\ \text{h}$$

- Thus, the battery capacity must be at least 1.83 A.h, or rounding off, 2 A.h to operate this pacemaker