Cardiac pacemakers

Introduction:

Electrical stimulators are widely used: physiotherapists use them in order to exercise muscles; anesthetists test for muscular relaxation during surgery by observing the response to stimulation of a peripheral nerve. A growing use of peripheral nerve stimulators is for the relief of pain. Cardiac pacemakers and defibrillators are used to stimulate cardiac muscle directly.The pacemaker corrects for abnormalities in heart rate, whereas cardiac defibrillators are used to restore a fibrillating heart to normal sinus rhythm.

Rhythmic contraction of the heart is maintained by action potentials which originate at a natural cardiac pacemaker. There are actually two pacemaker areas in the heart, the sinoatrial (SA) node and the atrioventricular (AV) node, but the SA node normally dominates because it has the higher natural frequency. The normal course of events is that an impulse from the SA node is propagated through the myocardium, spreading over the atria to the AV node where there is a small delay before the impulse is conducted over the ventricles causing depolarization of the musculature. The normal cardiac rhythm is called sinus rhythm.Any defects in conduction of the cardiac impulse can cause a change in the normal sinus rhythm and this is called an arrhythmia. Heart block occurs when the conduction system between atria and ventricles fails. This will not usually stop the heart because other pacemaking areas of the ventricles will take over or, if the blockage is not complete, some impulses may get through from the atria, but the heart rate will fall. This is called bradycardia (slow heart rate) and it may mean that the heart cannot supply the body’s demands and so dizziness or loss of consciousness may occur.

There are three types of heart block:

- In first-degree block the delay at the AV junction is increased from the normal 0.1 to 0.2 s.

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- In second-degree block some impulses fail to pass at all but a few get through to the ventricles.
- In complete block no impulses get through and so the ventricles pace themselves, but at a very much reduced heart rate of typically 40 beats per minute.

In all these cases an artificial pacemaker can be used to increase the heart rate to a level where the cardiac output is adequate to meet the body's needs.

Types of pacemaker:

The classification of pacemakers into different types is based on the mode of application of the stimulating pulses to the heart. External pacemakers are used when the heart block presents as an emergency and when it is expected to be present for a short time. Internal pacemakers are used in cases requiring long-term pacing because of permanent damage that prevents normal self-triggering of the heart. In the latter case, the pacemaker itself may be implanted in the body. The patient is able to move about freely and is not tied to any external apparatus.

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External Pacemaker:

External pacemaker are employed to restart the normal rhythm of the heart in cases of cardiac standstill, in situations where short-term pacing is considered adequate, while the patient is in the intensive care unit or is awaiting implantation of a permanent pacemaker. Frequently, External pacemakers are used for patients recovering from cardiac surgery to correct temporary conduction disturbances result in for the surgery. As the patient recovers, normal conduction returns and the use of pacemakers are discontinued. The pacing impulse is applied through metal electrodes placed on the surface of the body. Electrode jelly is used for better contact and to avoid burning of the skin underneath. An external pacemaker may apply up to 80 mA pulses through 50cm^2 electrode on the chest. This procedure is painful and therefore is used only in an emergency of a temporary situation.

The pulses may be delivered:

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1. Continuously: when it is felt that the heart rate is below the pre-set value. The impulses frequency is independent of the electrical activity of the heart.
2. On demand R-wave synchronous pacing: normally the pacemaker is inoperative but is activated when the heart rate falls below the normal or pr-set value. In such a situation, beat to beat examination of the time interval between two R-waves is done. When this interval exceeds the pre-set value, the pacemaker comes into operation. This technique eliminate any competition between the hearts own pacemaker and externally applied pacemaker pulses. In the R-wave synchronous mode of the operation, the external pacemaker can be used to support an implanted unit shortly before re-implantation or shortly after initial impanation to secure pacing.

Pacing with external pacemakers through the chest requires a maximum of 150V pulses across an impedance of the order1kΩ. However, external pacing has the disadvantage that the electrodes tend to burn the skin and the electrical pulses become painful. Also, each impulse causes an uncomfortable contraction of the thoracic muscles around the area of the electrodes. The stimulation pulses can be applied to a heart through pacing catheter passing through a vein and connected to the heart. This is called internal pacing. The pacing current required is much less than when is applied through the chest. The voltage output of internal pacemakers is about 0-15 V and the available output current ranges form 1-20 mA, and the pulse width is around 2ms with a rate of 30-180 pulse per minute.

The electronic circuit of a pacemaker consists of two parts, namely the impulse-generating circuit and the output circuit. The impulse-forming circuit determines the frequency and duration of the impulses. This is usually a multi-vibrator circuit with adjustable rate and fixed pulse width. The output circuit determines the shape and amplitude of the impulse.

Implantable Pacemaker:

The implantable pacemaker, along with its electrodes, is designed to be entirely implanted beneath the skin. Their output leads are connected directly to the heart muscle. The PM is a miniaturized pulse generator and is powered by small batteries. The circuit is so designed that the batteries supply sufficient power for a long period.

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Since the PM is located just beneath the skin, the replacement of the pacemaker unit involving relatively minor surgery.

For any implantable circuit, the basic requirements are:

- The components used in the circuit should be highly reliable.
- The power source should be in a position to supply sufficenet power to the circuit over prolonged periods of time.
- The circuit should be covered with a biological inert material so that the implant is not rejected by the body.
- The unit should be covered in such a way that body fluids do not find a way inside the circuit and thus short- circuit the batteries or result in other malfunctioning of the circuit.

Internal pacemakers are implanted, with the pulse generator put in a surgical pouch often below the left or right clavicle (figure 1). The internal leads may then pass into the heart through the cephalic vein.

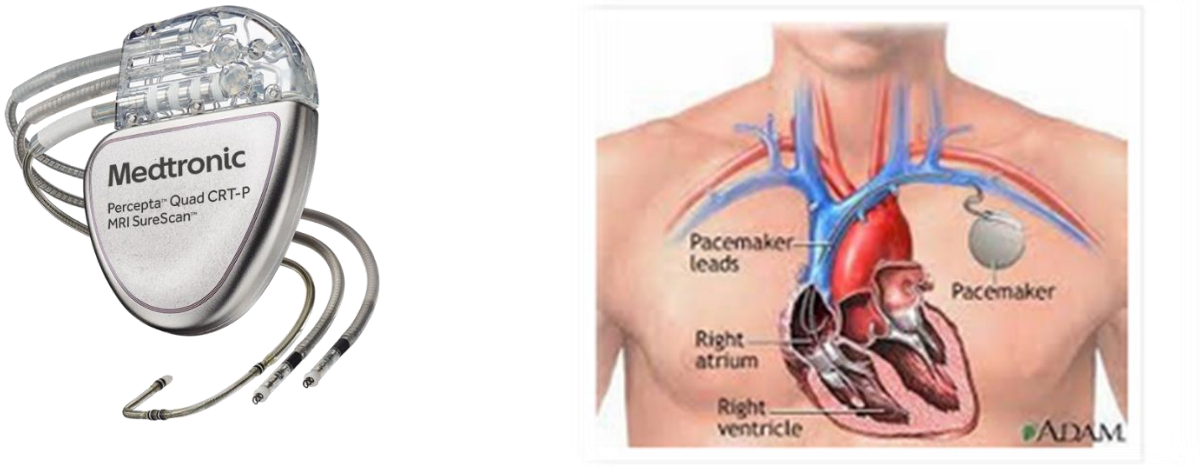

Figure 1. The transvenous lead from the pacemaker enters the subclavian vein and is guided under x-ray control into the heart. The pacemaker is installed in a subcutaneous pouch.

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The simplest type of pacemaker produces a continuous stream of output pulses at about 60-70 bpm like circuit in figure 2. The circuit is self-starting and its output wave shape (pulse width and interval between pulses) remains almost constant despite drops in battery voltage. The circuit consumes almost no power between pulses. The output was a 2-ms pulse of about 5 V in amplitude every 1 s. This early circuit powered from a single 2.8-V cell. In the circuit, the output of the oscillator drives a voltage doubler, making the pacing pulses delivered to the heart achieve sufficiently high amplitudes (approximately 5V) for the pacing electrodes of the time to "capture" the heart.

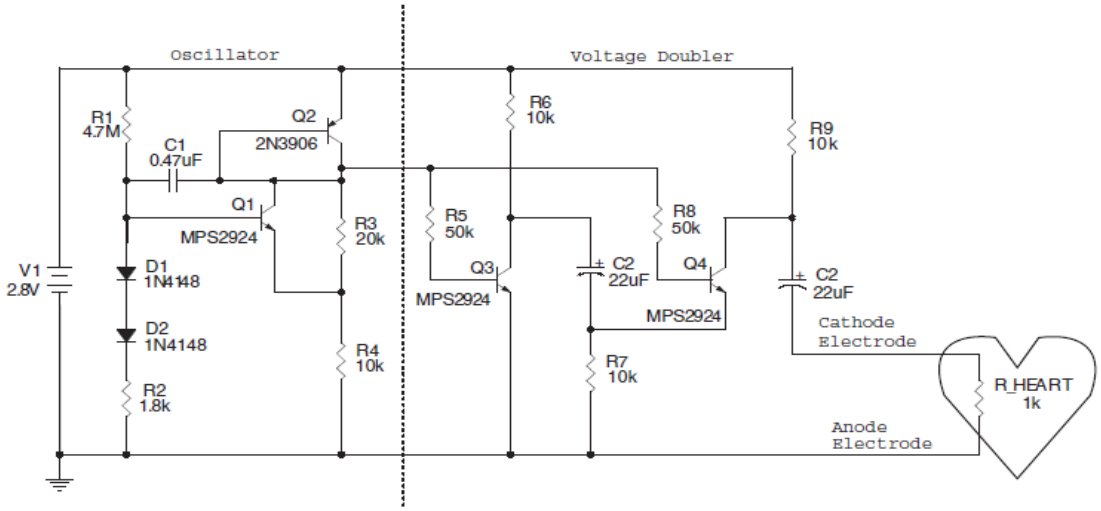

Figure 8.3 Early pacemakers had a period and pacing pulse characteristics (amplitude, wave shape, and duration) that were solely a function of their circuit.

There are many disadvantages to this simple approach, one being that the heart rate will not vary in response to what the patient is doing. Another disadvantage is that power may be wasted if heart block is not complete because some beats could occur naturally without the pacemaker. In addition this competition between naturally occurring beats and the pacemaker output may not lead to the most effective cardiac performance. These disadvantages to fixed-rate pacing (often referred to as competitive or asynchronous pacing) have led to the development of a range of more complex devices. These are illustrated in figure 3.

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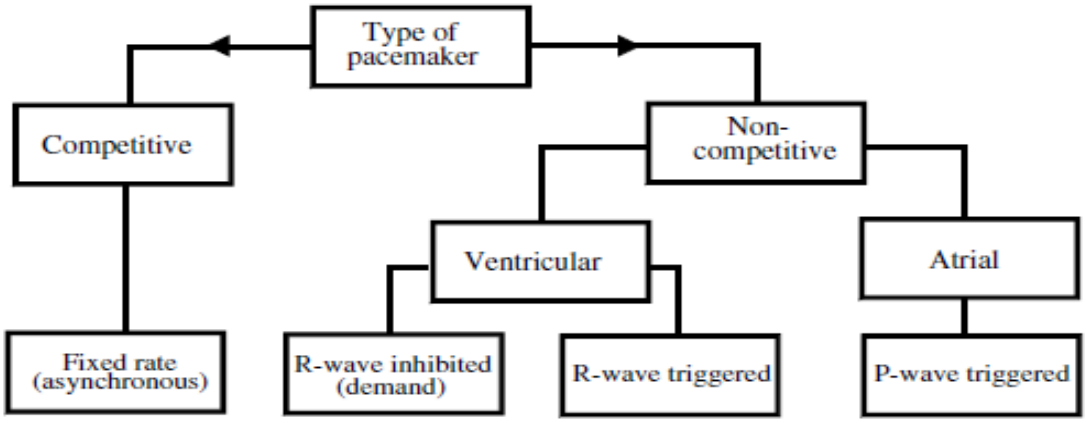

Figure 3 Categories of pacemaker.

The alternative to fixed-rate or competitive pacing is non-competitive pacing. In this case the pacemaker records the ECG produced by the heart and produces an output in response to this signal. Non-competitive types can be subdivided into ventricular and atrial-triggered devices.

Atrial-triggered devices produce an output triggered by the *P-wave* of the ECG which is generated by the atria and will not be affected by the heart block. Ventricular-triggered devices use the *R-wave* of the ECG in one of two ways. In a demand-type pacemaker an output pulse is only produced in the absence of a naturally occurring R-wave, i.e. the R-wave is used to inhibit the output of the pacemaker. If the pulse rate falls below the pre-set rate of the pacemaker then output pulses will again be produced. However, in a standby R-wave triggered device an output pulse is produced in response to every R-wave and if one does not occur when expected then the pacemaker will generate one.

Demand triggered PM:

Ventricular demand-type pacemakers are the most commonly used. This delivers a fixed rate pacing stimulus only when the normal QRS waves fail to follow the natural P-wave stimulus. It can therefore never trigger ventricular fibrillation by delivering a stimulus to relaxing heart muscle. This relaxing period is known as the “vulnerable period”. See figure below.

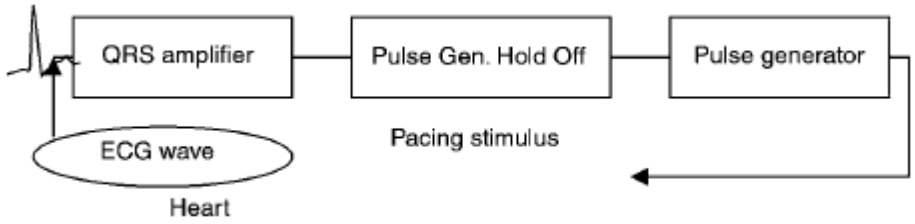

Fig. 12.8a. Demand Triggered pacemaker-Block diagram.

Atrialy triggered PM:

Atrial-triggered devices are used in complete heart block. In order to record the P-wave, electrodes have to be placed in the atria in addition to the pacing electrodes in the ventricles. Natural excitation P-wave from atrium is somehow prevented from reaching the ventricles. Pacemaker amplifies this wave, delays it for an appropriate interval, and then fires a pulse into the ventricular muscle, as in figure below.

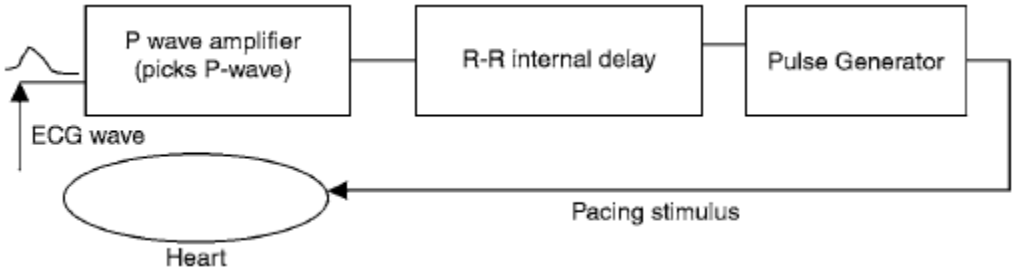

Fig. 12.8b. Shows the block diagram for the artificially triggered Pacemaker unit.

Principle of Sensing and Controlled Stimulation

The failure of excitation generating and spreading may be permanent or temporary. In case of temporary failure, the pacemaker must be able not only to stimulate, but also to recognize whether a spontaneous action takes place or not. This task of recognition is called ‘‘sensing.’’ The signal that is recorded by sensing is actually the electrocardiogram (ECG). If this potential is recorded directly from the heart, the signal is called an intramyocardial electrogram (IEGM).

Sensing is achieved by electrodes comparable with those that are used for stimulation, and frequently the same electrode is employed for sensing and stimulating.

If the failure is permanent, sensing is not required at the site where stimulation is applied. Atrial sensing is not required for permanent SA node failure, but for temporal failure that must be detected in order to apply atrial stimulation. Ventricular sensing is not required for permanent AV conduction failure, but for temporary failure that must be detected in order to apply ventricular stimulation.

In case of temporary and permanent failure, the atrial signal is used to achieve synchronization of the ventricular with the atrial contraction. For such IPMs, the term ‘‘synchronous’’ or even ‘‘rate responsive’’ devices has been introduced because the ventricular heart rate is synchronized with and also determined by the spontaneous SA node rate. In case of temporary failure, the atrial signal can additionally be employed to start the interval during which the arrival of the excitation in the ventricles inhibits the ventricular stimulation. In both cases, atrial sensing renders possible matching of the AV delay with the actual sinus rate because the AV delay becomes shorter with higher heart rate.

The most essential units of a PM are (Fig. 3):

– One or more sensing channels (i.e., signal amplifiers with appropriate transmission characteristics);

– One or more stimulating channels (i.e., pulse shapers with output amplifiers);

– A microprocessor for signal processing and timing control together with a clock, usually quartz-controlled, and memories (RAM, ROM);

– A power unit (i.e., a battery with voltage converter, together with an ‘‘end-of-life’’ indicator); a bidirectional telemetry unit for the communication with an external (i.e., extracorporeal) transmitter-receiver unit in order to check the actual operational parameters and to use the flexible programming capability; and

– One or more electrodes [i.e., leads that connect the PM directly or, in case of external PM, indirectly] with the heart for sensing and stimulation.

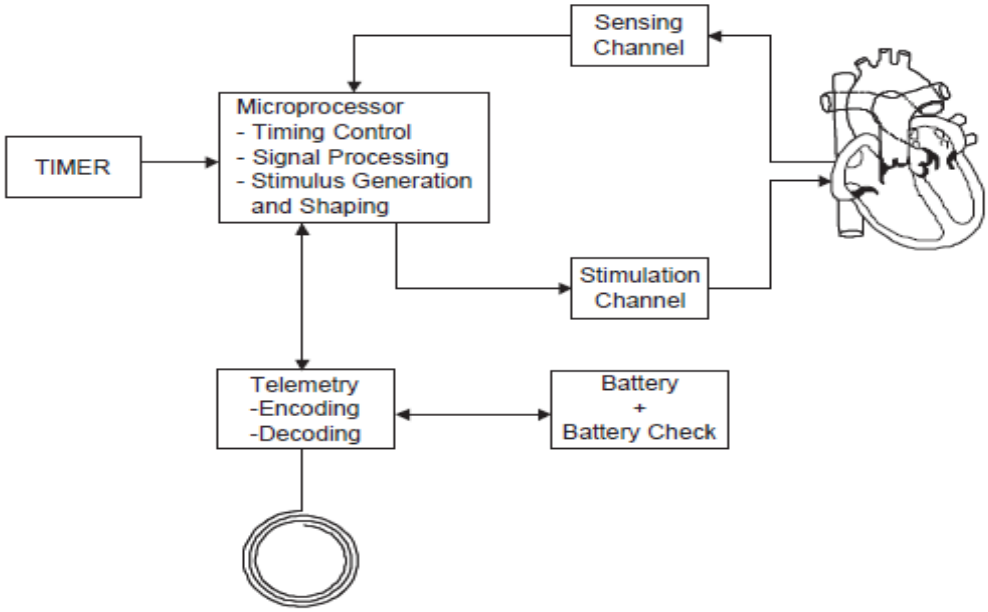

Figure 3. Simplified schematic diagram with the basic functional units of a remotely programmable PM.

Computer Algorithms

Pulse generators usually can be seen as small microprocessor devices. As such they contain computer code or computer algorithms to control their function, delivering advantages to the patient and clinician, as the pacemaker's mode of operation can be changed.

Telemetry Circuit

Today's pulse generators are capable of both transmitting information from an RF antenna and receiving information with an RF decoder. This two-way communication occurs between the pulse generator and the programmer at approximately 300 Hz. Real-time telemetry is the term used to describe the ability of the pulse generator to provide information such as pulse amplitude, pulse duration, lead impedance, battery impedance, lead current, charge, and energy. The programmer, in turn, delivers coded messages to the pulse generator to alter any of the programmable features and to retrieve diagnostic data. Coding requirements reduce the likelihood of inappropriate programming alterations by environmental sources of radiofrequency and magnetic fields. It is also prevents the improper use of programmers from other manufacturers.

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Power sources

It is essential that the pacemaker has a reliable power source which will last as long as possible. It is possible to replace an exhausted pacemaker but surgery is necessary and battery failure if it is not detected at an early stage can give rise to a life-threatening situation. The ideal power source should be very small, have a long life, i.e. a high capacity, be unaffected by body temperature, be easy to test so that exhaustion can be predicted, be cheap, be unaffected by autoclaving and give an output of at least 5 V. No gases must be produced. Types which have been used include mercury cells, nuclear-powered thermoelectric generators and lithium cells.

The battery check has two functions. One is to detect a low battery voltage and use this to reduce the fixed-rate output as a means of signaling a low battery. The other is to increase the output pulse width when the battery voltage falls so that the output pulse energy remains constant.

Leads:

Implantable pacing leads must be designed not only for consistent performance within the hostile environment of the body but also for easy handling by the implanting physician. Every lead has four major components (Fig. 77.6): the electrode, the conductor, the insulation, and the connector pin(s).The electrode is located at the tip of the lead and is in direct contact with the myocardium. Bipolar leads have a tip electrode and a ring electrode (located about 2 cm proximal to the tip); unipolar leads have tip electrodes only. A small-radius electrode provides increased current density resulting in lower stimulation thresholds. The electrode also increases resistance at the electrode-myocardial interface, thus lowering the current drain further and improving battery longevity. The radius of most electrodes is 6–8 mm^2.

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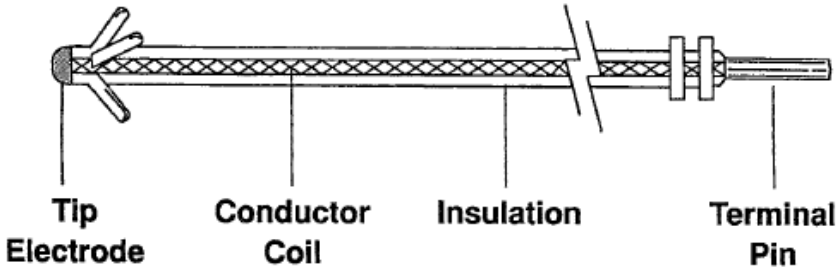

FIGURE 77.6 The four major lead components.

Classification codes for pacemaker:

To make it easier to understand the gross-level system operation of modern pacemakers, a five-letter code has been developed by the North American Society of Pacing and Electrophysiology and the British Pacing and Electrophysiology Group. The first letter indicates the chamber (or chambers) that are paced. The second letter reveals those chambers in which sensing takes place, and the third letter describes how the pacemaker will respond to a sensed event. The pacemaker will "inhibit" the pacing output when intrinsic activity is sensed or will "trigger" a pacing output based on a specific previously sensed event. For example, in DDD mode:

D: Pacing takes place in the atrium and the ventricle.

D: Sensing takes place in the atrium and the ventricle.

D: Both inhibition and triggering are the response to a sensed event.

An atrial output is inhibited with an atrial-sensed event, whereas a ventricular output is inhibited with a ventricular-sensed event; a ventricular pacing output is triggered by an atrial-sensed event (assuming no ventricular event occurs during the A-V interval).The fourth letter in the code is intended to reflect the degree of programmability of the pacemaker but is typically used to indicate that the device can provide rate response. For example, a DDDR device is one that is programmed to pace and sense in both chambers and is capable of sensor-driven rate variability. The fifth letter is reserved specifically for antitachycardia functions (as in the Table).

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TABLE1 The NASPE/NPEG Code

Position	I	II	III	IV	V
Category	Chamber(s) paced O = None A = Atrium V = Ventricle D = Dual (A+V)	Chamber(s) sensed O = None A = Atrium V = Ventricle D = Dual (A+V)	Response to sensing O = None T = Triggered I = Inhibited D = Dual (T+I)	Programmability rate modulation O = None P = Simple programmable M = Multiprogrammable C = Communicating R = Rate modulation	Antitachyarrhythmia function(s) O = None P = Packing S = Shock D = Dual (P+S)
Manufacturers' designation only	S = Single (A or V)	S = Single (A or V)			

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