ICD Electronics - Building Blocks

- Ohm’s Law
- ICD Shocking / Pacing Outputs
- Sensing
- Battery Technology
Ohm’s Law

Voltage = Current x Resistance

\[ V \text{ (Volts)} = I \text{ (Amps)} \times R \text{ (ohms)} \]

Voltage is the “pressure” that pushes the current through the circuit. It is also called electromotive force (emf).

Current is the flow of charge through the circuit.

Resistance is a measure of the amount of current you will get based on a certain Voltage (pressure). Resistance is basically the availability of charge carriers – the fewer charge carriers, the higher the resistance.
Ohm’s Law

1 Amp = 1,000 milliAmps = 1,000,000 microAmps

1 milliAmp = 1,000 microAmps

Sensing currents are typically  5 – 20 microamps

Pacing currents are typically 1 – 20 milliamps

Defibrillation currents are typically 1 – 20 Amps
Power and Energy

Power = Voltage x Current

\[ P(\text{watts}) = V(\text{Volts}) \times I(\text{Amps}) \]

Energy = Power x Time (sec)

\[ E(\text{watt-sec}) = V \times I \times \text{Time} \]

\[ E(\text{joules}) = V \times I \times \text{Time} \]
Power and Energy

Energy is the ability to do work.

1 Joule = 1 Volt x 1 Amp x 1 sec
1 Joule = 1 Watt x 1 sec

If the ball has a mass of 1 kilogram (2.2 pounds) and it was dropped 1 meter, its kinetic energy would be approximately 10 joules.
Capacitance

Although capacitance does not come into full play until it is applied to alternating-current circuits, it does effect dc circuits. This chapter is groundwork for further electrical studies.

The Property of Capacitance

In direct-current circuits voltages are steady and unchanging. However, if a switch is closed or opened, drastic voltage changes can be encountered.

Capacitance opposes any change in voltage. Figure 8-1 illustrates this principle.

Everything exhibits some capacitance. The amount of a capacitance in circuit depends on the physical construction of the circuit and on the electrical devices used. In most cases this capacitance is so small that its effect on voltage is negligible.

Electrical devices that add capacitance to a circuit are called capacitors (or condensers, although this term is incorrectly used). The circuit symbols for capacitors are shown in Fig. 8-2.

The basic unit of capacitance is the farad (F). A capacitor has a capacity of one farad when applied emf of one volt causes the capacitor to take a charge of one coulomb. (One coulomb equals $6.28 \times 10^{18}$ electrons.) In practical circuits a farad is too large a unit to work with. The microfarad ($1\mu F = 10^{-6}$ F) and the
Fig. 8-1. Capacitance opposes any change in voltage.

*picofarad* (1 pF = $10^{-12}$ F) are the units usually used. See Chapter 3 if you have forgotten how to work with these prefixes.

**THEORY OF CAPACITANCE**

Capacitance exists because certain parts of a circuit are able to store an electrical charge. Figure 8-3 shows two parallel flat metal plates directly facing each other but not touching. From the principles of static electricity, you can see why these plates can be charged either negatively or positively, depending on the charge.

![Fixed capacitors and variable capacitors](image)

Fig. 8-2. Capacitor symbols.
Fig. 8-3. Ability of a capacitor to store an electrical charge.

transferred to them. The positively charged plate will be forced to give up some of its electrons, and the negatively charged plate will have an excess of electrons pumped into it.

To charge the plates, we need an emf. For the plate to have
Ohm’s Law - Pacing

During pacing, the current flow will be between the cathodal tip and the anode ring or shocking electrode. Typical impedance is 400 - 1200 ohms.
Ohm’s Law – Defibrillation

In an active can ICD system, current flow will be between the ICD metal can and the shocking electrode(s) in the heart. Typical impedance is 20 – 80 ohms.

When the shock is delivered, sufficient current density must be achieved to depolarize a critical mass of cardiac cells.
Ohm’s Law – Series Circuit

Series Circuit – when the pacing switch closes, current flows from the pacing capacitor through the resistance of the lead and through the resistance at the tip of the lead. All of the current goes through the same path, so the resistances ADD.
Ohm’s Law - Series Circuit

**NUMBERS** – If the resistance in the lead is 50 ohms and the resistance at the tip / tissue interface is 550 ohms, the series resistance is the summation of the resistances or 550 + 50 = 600 ohms. Since the current must go through each resistance in series, the current or flow “sees” the total of all the individual resistances.
Parallel Circuit – when the pacing switch closes, current flows from the pacing capacitor through the resistance of the first lead and through the resistance at the tip of the lead. Also, current goes through the second lead that is in parallel to the first lead. This is an example of BiV pacing the RV and LV with a tied output device.
Ohm’s Law - Parallel Circuit

**NUMBERS** – If the resistance in the first lead is 50 ohms and the resistance of its tip / tissue interface is 550 ohms, the series resistance is the summation of the resistances or 550 + 50 = 600 ohms. If the resistance of the second lead is 100 ohms and the resistance of the tip / tissue interface is 900 ohms, the series resistance is the summation of the resistances or 100 + 900 = 1000 ohms.

So we now have 600 ohms in parallel with 1000 ohms.
Ohm’s Law - Parallel Circuit

**NUMBERS** – So we now have 600 ohms in parallel with 1000 ohms. The current will travel down both the 600 ohm path and down the parallel path of 1000 ohms. The total resistance would then be the parallel path of 1000 ohms and 600 ohms. Mathematically, the resulting total resistance of both paths in parallel will always be LOWER than either path single path. Sort of like pouring water down two long tubes in parallel to each other – you get more total water flow (the resistance to water flow has gone down).

Here is the math to calculate the total resistance when you have two parallel paths . . .

Total Resistance = \( \frac{600 \text{ ohms} \times 1000 \text{ ohms}}{600 \text{ ohms} + 1000 \text{ ohms}} = 375 \text{ ohms} \)
Shock Outputs

*Programmable Stored Energy* - The energy stored in the output capacitors is programmable. The pulsewidth of the output may also be programmable. Typically 10–15% of the stored energy is lost due to circuitry in the ICD and losses in the waveform.

*Programmable Delivered Energy* - The energy that will be delivered to the shocking lead system is programmable and the AICD stores sufficient energy to ensure the delivered output.
Shocking Outputs

During ICD charging, the battery generates low Voltage and high current which is transformed to a high Voltage and a low current and this current then charges up the capacitors to specific voltage levels depending on programmed energy.

During energy delivery, current flows from the output capacitors similar to how water empties from a column. Initially, the current flow is high, but it decreases as the voltage decreases – the capacitor empties.
Shock Outputs

Voltage and current start high and then decrease as energy in the capacitors flows out.

Once a specific Voltage is reached, energy delivery is stopped.

Monophasic pulse
Shocking Outputs

Typically, biphasic DFTs are 30 – 40% lower than monophasic DFTs

Biphasic pulse – Polarity of waveform is reversed during the shock delivery
Sensing and Detection

Amplitude is Typically > 5 mV in the ventricle

Slew Rate = Amplitude / Time = dV/dT

NOTE: “Far-field potentials arise from electrical activity distant from the electrode and include contralateral ventricular activation, skeletal muscle potentials, and external electromagnetic interference (EMI). “
Sensing and Detection

Pacemakers typically use programmable fixed sensitivity circuits for detecting intrinsic activity.

2.5 mV

Blanking

Programmable Refractory
Sensing and Detection

ICDs use auto-adjusting sensitivities or auto-adjusting amplification for detecting intrinsic activity.

2.5 mV

Blanking

Refractory
Sensing and Detection

NSR Lead Signal

AICD Filtered Signal

Refractory
Sensing and Detection

NSR Lead Signal
2 mV R-wave and
4 mV T-wave

AICD Filtered Signal

Refractory
Sensing and Detection

Rate Sensing Electrogram Showing Sensing Post-Pacing

Rate Sensing EGM
Markers

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Battery Technology

Since 1972, lithium batteries have been the primary power source for pacemakers. Today, Lithium-Iodine batteries are used in virtually all pacemakers.

Other chemistries that have been used include Lithium cupric sulfide, Lithium thionyl chloride, Lithium lead and Lithium silver chromate. The type of chemistry determines the battery’s voltage and discharge characteristics.

• 1958 - Rechargeable batteries
• 1958 through 1960 - zinc-mercury batteries. Pacemaker longevity of about 2 years.
• Nuclear Batteries - half-life of 87 years.
Battery Technology - Li-Ion

- BOL = 2.8 V
- Voltage curve
- ERT Impedance is typically 5K to 10K ohms
- Impedance curve

ERT
QUESTION: What typically happens to the charge time for a high energy shock as an AICD approaches ERT?
Highly Accelerated Test Time - 2 Years

Charge Cycles Every TWO months (4 charge cycles per test)

- Charge Time: 18 seconds
- V-drop

Graph showing battery capacity vs. volts/charge time with key:
- V(MONITORING)
- V(CHARGING)
- Charge Time / 10 seconds
Accelerated Test Time - 3 Years

Charge Cycles Every THREE months (4 charge cycles per test)

- Charge Time 18 seconds

- 3 times V (MON)
- per year V (CHRG)
- per year Charge T

Battery Capacity

Volts / Charge time

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“Non-Accelerated” Test Time - 5 Years

Charge Cycles Every SIX months (4 charge cycles per test)

Charge Time 30 seconds

V-drop

Battery Capacity

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