



**Question** What is the purpose of the waveform display?

**Answer** A perfect square wave indicates that the circuit **impedance** is acceptable. A non-square wave indicates that the circuit impedance is too high.

**Explanation** A perfectly square waveform indicates to the user that the nerve stimulator accommodates sufficiently for the **impedance** of the closed circuit path. This includes the connection between the ECG pad and the patient, as well as the probe or needle and patient. If the shape of the waveform does not resemble a perfect **square wave**, it means that the impedance of the circuit is higher than what the nerve stimulator can accommodate for, resulting in less current (**charge**) being delivered than what the current (charge) setting indicates.

**Application** An old or **dry ECG electrode** usually causes circuit impedance that is too high. Make sure that the ECG electrode is in good condition. Ensure that the patient's **skin is not excessively dry** where the ECG electrode is connected. When using the nerve mapping probe, it is possible that the probe - skin connection impedance is too high. Ensure that the skin is moist enough in the area where the nerve mapping is intended.

**Question** Why not just display a value for the **impedance measurement** rather than a graphic display of the waveform shape?

**Answer** An impedance measurement offers a very **inconsistent feedback**, because of the **varied impedance spectra** of different types of tissue. The movement of the needle during regional procedures also adds to the continued variance in impedance.

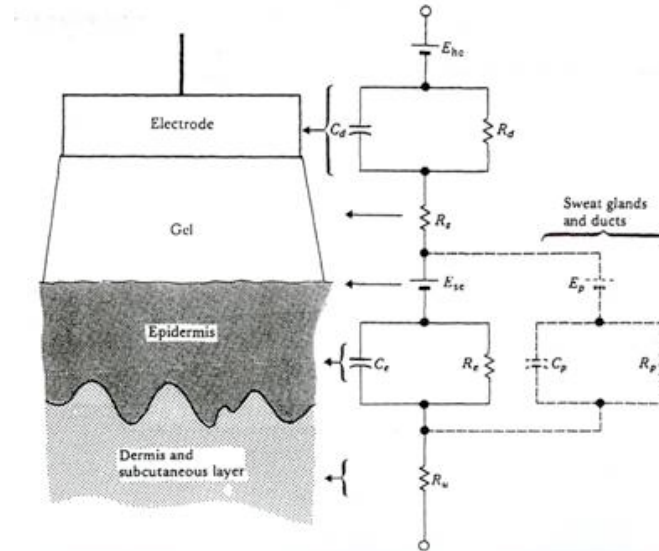
**Explanation** The impedance of a circuit element is defined as the ratio of the phasor voltage across the element to the phasor current through the element:

$$Z_R = \frac{V_r}{I_r}$$

In other words, impedance is the **frequency dependant resistance** as presented by its real and imaginary components. In the human body different tissues have **different impedance spectra** and can be modeled by an equivalent circuit comprising resistive, capacitive and inductive components.

When considering different effects of electrical stimulation, equivalent models of electrode and tissue impedance can help to explain certain stimulation phenomena, which may seem inconsistent to the clinician.

The figure below shows an equivalent model, demonstrating the different impedances to be considered when analyzing the electrode, gel, epidermis, and dermis.



It should become clear that the **total impedance path** through which the electric field, generated between two electrodes, propagates is the **complex result** of the summation of the unique impedance spectra of various types of tissue. Each different stimulating pulse width, as well as its rise and fall times presents **different frequency components** which will result in different unique impedances.

**Application** In contrast to a continually varying impedance feedback, the **waveform shape** offers a **simple and accurate method** to establish whether the circuit impedance is too high.

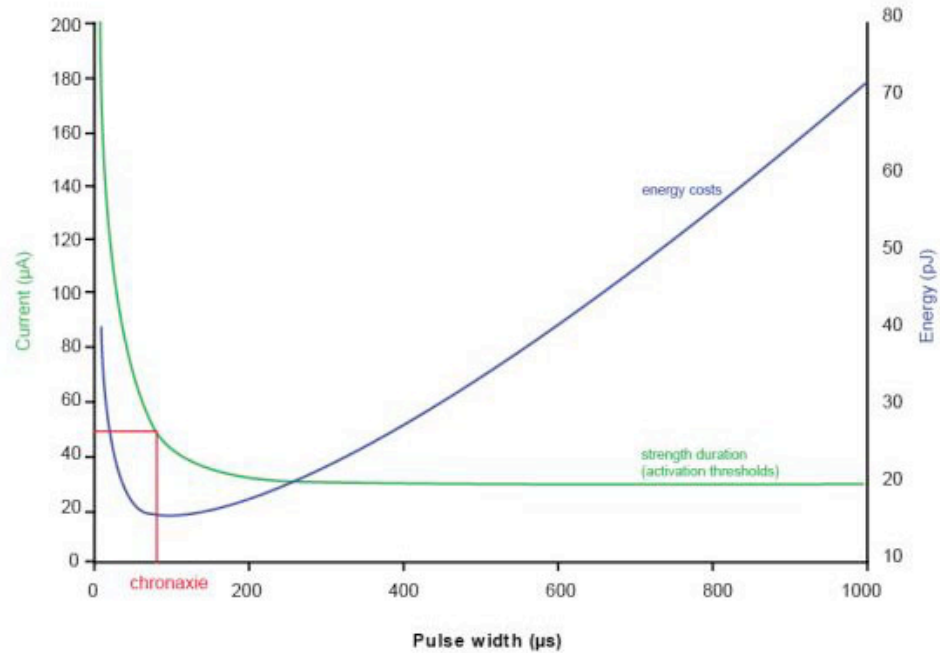
**Question** What is **Chronaxie** and how does it affect the choice of pulse width?

**Answer** **Rheobase** is the lowest current that will elicit a neuromuscular response for an infinitely long-duration stimulus. **Chronaxie**, the excitability constant, is the pulse width, which will elicit a neuromuscular response for a stimulus current of **twice rheobasic** strength.

**Explanation** It should be noted that, although there are many published values for chronaxie for various excitable tissues, the range of variability for a given tissue type is quite large. It is generally assumed, however, that nerves can be classified according to their **chronaxie thresholds** as follows:

Classification	Chronaxie	Sensory Functions
A (Alpha)	40 - 100 $\mu$ s	Predominantly motor neurons. They also have the following sensory functions: Proprioception, hair receptors, vibratory sensors, high discrimination touch
A (Delta)	150 $\mu$ s	Deep pressure and touch, pricking pain, cold
C	400 $\mu$ s	Crude touch and pressure, tickle, aching pain, cold warmth

From the above table it would seem reasonable to deduce that the ideal pulse width to facilitate a motor nerve response (A alpha) would be around 100 $\mu$ s. If one sets the nerve stimulator at 100 $\mu$ s and increase the amplitude to 5mA giving a total charge of 500nC one would not get the same muscle response as if the setting is at 500ms and 1mA, also giving a total Charge of 500nC. In the second case even though the total charge transferred to the nerve is the same, because of the **chronaxie threshold** of 100 $\mu$ s for the nerve, much of the energy transferred to the nerve after the 100 $\mu$ s is wasted on the nerve.



This is clearly shown by the graph above. The **strength duration curve** (green) indicates the current necessary at the different pulse widths to facilitate a contraction. The **energy cost** or total charge is shown by the blue curve. It can be seen that the stimulation is most energy efficient at the **chronaxie pulse** of  $\pm 80\mu$ s width as would be expected. It should be noted how the energy cost increases when pulse width increases.

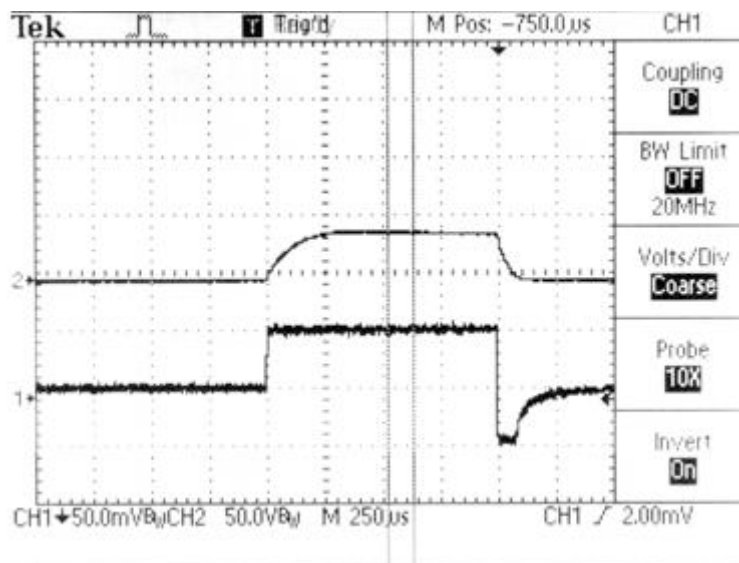
### Application

As a preference, keep the nerve stimulator at a 100 $\mu$ s pulse width and adjust the current. If the nerve stimulator is already set at 5mA and the stimulating needle does not elicit any neuromuscular response, increasing the pulse width to 300 $\mu$ s will offer 3 x more charge, however bear in mind that the net effect on the nerve will not constitute a contraction which is 3 times more powerful.

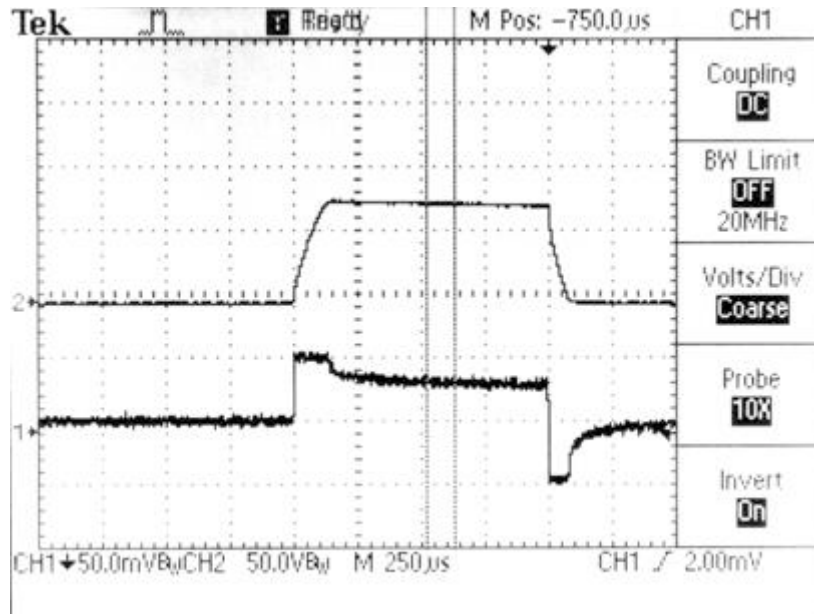
**Question** What does it mean if the waveform is only partially square and how does it relate to the stimulated muscle response?

**Answer** It means that the maximum **Voltage** that the nerve stimulator can deliver is not enough to accommodate for the higher **impedance** encountered by the circuit. Depending on the **pulse width** of the square section of the waveform, the contraction from the stimulated muscle may or may not represent an artifact.

**Explanation** When one stimulates with a good **current source**, the shape and amplitude of your stimulus pulse will always be as selected, as long as the nerve stimulator can deliver the **voltage** required to accommodate for the varying **circuit impedance**. All brands of nerve stimulators are limited in the way they can accommodate varying impedances by their maximum voltage.



The figure above shows a typical current and voltage stimulation response. V (Voltage - channel 2) is measured across the two electrodes connected to a subject's body. I (Current - channel 1) is measured over a 10Ω resistor connected in series with one of the electrodes. The maximum current as displayed in this picture is 5mA. The maximum voltage necessary to facilitate this is approximately 40V. Even though stimulation was done with a 5mA, 1ms square wave stimulus, the approximately 80µs negative current component is indicative of the reactive impedance of the combined electrode, tissue impedance.



The figure above shows the nerve stimulator at the same settings, however the **impedance** of the electrode/ epidermis interface was increased to a level where the nerve stimulator cannot supply enough voltage to facilitate the increased impedance.

It is clear that after approximately 140µs the nerve stimulator could not deliver the required **voltage**. The current immediately dropped to around 4mA.

According to the discussion on **chronaxie thresholds**, though, it is quite likely that the second waveform will elicit a very similar response to the first waveform. This is due to the fact that the second waveform is 'square' for the first 140µs while the chronaxie of the nerve is 100µs. This means that the drop in current (**charge**) supplied after 140µs would have a limited effect on the nerve due to the fact that it would've been 'wasted' in any case.

### Application

One approach to offering the user an indication of the expected net stimulus effect would be to average out the total current delivered. This would give the user the impression that the observed response was equivalent to a perfect square wave of 1ms pulse width and 3.7mA amplitude. However due to the discussion in the paragraph above, it should be noted that most of the neuromuscular stimulating response was most likely facilitated in the first 100µs of the stimulus at 5mA. It could then be misleading to simply look at the average stimulating amplitude. In other words it could be argued that the stimulation as indicated in the first figure and the one in the second figure could elicit a similar neuromuscular stimulating response (contraction) with the electrodes positioned at exactly the same distance from the target nerve. If one then relied on the information presented of an actual average current transferred, one would have the erroneous impression that the cathode in eliciting a response in the case of the second figure would be closer to the nerve than the cathode that elicited the same response in the case of the first figure.

## References

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