# Physics of Ultrasound

## Fifth lecture

# Intensity of Ultrasound

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## 1. *Introduction*

- To understand the meaning of intensity, we recall that an oscillating source of ultrasound in contact with tissue transfers its mechanical energy to the particles of the tissue medium, causing them to vibrate. The medium particles then possess energy by virtue of their motion.
- Intensity is a measure of this energy. It represents the vigor of mechanical vibrations of the medium particles.
- Different physical parameters may be used to express this vigor. These include particle displacement, particle velocity, particle acceleration, and particle pressure.
- Each of these parameters varies in time and in space within the medium, and so does the intensity.
- Intensity may be expressed either as an absolute measurement, or using a relative scale.

## 2. *Absolute measure of intensity*

- On the absolute scale, intensity is expressed as the rate of flow or energy per unit area.
- Definition: The intensity of a beam of ultrasound at a point is the amount of energy passing through unit cross-sectional area perpendicularly to the beam per unit time at that point
- Units: The following units are commonly used to specify absolute intensities in clinical ultrasound.

  ***Joule (J) for energy***

  ***Seconds (s) for time***

  ***Square centimeter ($cm^2$) for area.***

  Using these units, ***intensity*** is expressed in ***joules/second/square centimeter***.

***Joule/second*** represents the rate of flow of energy and is given the special name ***watt*.**

1 watt (W) = 1 J/s

Therefore intensity can be specified as ***watts/square centimeter (W /cm²)***

- The power in a beam of ultrasound is the *total energy passing over the whole cross sectional area of the beam per unit time*. If the intensity is uniform over the plane of interest, then

Power = intensity (W /$cm^2$) x area ($cm^2$)

The units of power are ***joules/second***, or ***watts***.

- Knowledge of the absolute intensity of ultrasound is required for two reasons.
  - ✓ First, the output intensity of an ultrasound instrument affects its sensitivity, and hence signals sizes.
  - ✓ Secondly, when we wish to assess the potential biological consequences of exposure to ultrasonic energy, we must have knowledge of the amounts of energy actually dissipated in tissue.

## 3. *Relative intensity*

- ✓ On the relative scale, the intensity at a point of interest is compared to that at some defined reference point, and expressed in units called ***decibels (dB).***
- ✓ Definition: *The intensity, I, relative to a reference intensity $I_0$*, is defined as:

$$\text{Relative intensity (dB)} = 10 \log_{10} (I/I_0)$$

- ✓ The dB values will be positive if the intensity of interest, I, is larger than the reference intensity, $I_0$, and negative if I is less than $I_0$.
- ✓ The choice of the reference intensity is arbitrary, but must be defined.

- For example, I could be the intensity at some point of interest in tissue, and $I_0$ the intensity on the skin surface.
- The logarithmic scale used in the definition has the inherent mathematical characteristic of compressing the intensity scale such that a very wide range of intensities on the absolute scale can be accommodated on a much smaller range on the dB scale.
- The dB notation is useful practically because the levels of intensity used in diagnostic imaging are very low and therefore difficult to measure absolutely. The determination of the ratio of one intensity relative to another is easier, since neither of the two has to be measured absolutely.

## 5. *The 3 dB change*

- A change of relative intensity by 3 dB is of special significance. For every 3 dB change, there is a change in absolute intensity by a factor of two.
- By definition Relative intensity (dB) = $10 \log_{10} (I/I_0)$

  - Special case 1: Intensity at point of interest equals the reference intensity.

    When $I = I_0$

    decibel level = $10 \log_{10} (1) = 10 \times 0$ dB = 0 dB

The decibel level at the reference point is equal to zero.

  - Special case 2: Intensity at point of interest equals half the reference intensity.

    When $I = 1/2 I_0$

    decibel level = $10 \log_{10} (0.5) = 10 \times (-0.301)$ dB = -3.01 dB

Reducing the intensity to a half corresponds to a 3 dB reduction in relative intensity.

- Special case 3: Intensity at point of interest equals twice the reference intensity.

  When $I = 2 I_0$

  decibel level = $10 \log_{10}(2) = 10 \times (+3.01)$ dB = + 3.01dB

Doubling the intensity corresponds to a 3 dB increase in relative intensity.

- These calculations illustrate that a change in intensity by a factor of 2, be it an increase or a decrease, results in a corresponding change of 3 dB on the relative scale.
- It can now be inferred that every HVT in a medium reduces the relative intensity by 3 dB.
- Table presents data which show relation between half value thickness, decibels, and absolute intensity.

| No. of HVTs | Relative intensity (dB) | Absolute intensity $mW/cm^2$ |
|---|---|---|
| 0 | -0 | 1,600 (Reference) |
| 1 | -3 | 800 |
| 2 | -6 | 400 |
| 3 | -9 | 200 |
| 4 | -12 | 100 |
| 5 | -15 | 50 |
| 6 | -18 | 25 |
| 7 | -21 | 12.5 |
| 8 | -24 | 6.2 |
| 9 | -27 | 3.1 |
| 10 | -30 | 1.6 |

- The reference level in these data has been arbitrarily assigned the absolute intensity value of 1,600 $mW/cm^2$.

- Note the compressing effect of the logarithmic dB scale, a thousand-fold reduction in absolute intensity from 1,600 mW/cm2 to 1.6 $mW/cm^2$ corresponds to a dynamic range of only 30 dB on the relative scale.
- Any other choice of reference intensity, in place of the 1,600 $mW/cm^2$ would give the same result.