Coherence and Interference

Introduction

Coherence and interference are two ideal wave features that complement each other. The wave interference does occur but for it to be considered constructive interference, it needs the coherence of some of the physical quantities of the waves involved; the wavelength, amplitude, and phase of the constituent wave forms must be identical. The most distinct concept of coherence in waves requires that the waves are in phase, their peaks are aligned with each other.

Interference

Wave interference is the phenomenon that occurs when two waves meet while traveling along the same medium. The interference of waves causes the medium to take on a shape that results from the net effect of the two individual waves upon the particles of the medium.

Consider two pulses of the same amplitude traveling in different directions along the same medium. Let's suppose that each displaced upward 1 unit at its crest and has the shape of a sine wave. As the sine pulses move towards each other, there will eventually be a moment in time when they are completely overlapped. At that moment, the resulting shape of the medium would be an upward displaced sine pulse with an amplitude of 2 units. The diagrams below depict the before and during interference snapshots of the medium for two such pulses. The individual sine pulses are drawn in red and blue and the resulting displacement of the medium is drawn in green.

This type of interference is sometimes called constructive interference.

Constructive interference

Constructive interference is a type of interference that occurs at any location along the medium where the two interfering waves have a displacement in the same direction. In this case, both waves have an upward displacement; consequently, the medium has an upward displacement that is greater than the displacement of the two interfering pulses. Constructive interference is observed at any location where the two interfering waves are displaced upward. But it is also observed when both interfering waves are displaced downward. This is shown in the diagram below for two downward displaced pulses.
Fig 1. Constructive interference of waves traveling in opposite direction

In this case, a sine pulse with a maximum displacement of -1 unit (negative means a downward displacement) interferes with a sine pulse with a maximum displacement of -1 unit. These two pulses are drawn in red and blue. The resulting shape of the medium is a sine pulse with a maximum displacement of -2 units.

**Destructive interference**

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Destructive interference is a type of interference that occurs at any location along the medium where the two interfering waves have a displacement in the opposite direction.

For instance, when a sine pulse with a maximum displacement of +1 unit meets a sine pulse with a maximum displacement of -1 unit, destructive interference occurs. This is depicted in the diagram below.

Fig 2. Destructive interference

In the diagram above, the interfering pulses have the same maximum displacement but in opposite directions. The result is that the two pulses completely destroy each other when they are completely overlapped. At the instant of complete overlap, there is no resulting displacement of the particles of the medium. This "destruction" is not a permanent condition. In fact, to say that the two waves destroy each other can be partially misleading. When it is said that the two pulses destroy each other, what is meant is that when overlapped, the effect of one of the pulses on the displacement of a given particle of the medium is destroyed or canceled by the effect of the other pulse.

The two interfering waves do not need to have equal amplitudes in opposite directions for destructive interference to occur. For example, a pulse with a maximum displacement of +1 unit could meet a pulse with a maximum displacement of -2 units. The resulting displacement of the medium during complete overlap is -1 unit.
This is still destructive interference since the two interfering pulses have opposite displacements. In this case, the destructive nature of the interference does not lead to complete cancellation.

**Principle of superposition**

The principle of superposition is sometimes stated as follows:

> When two waves interfere, the resulting displacement of the medium at any location is the algebraic sum of the displacements of the individual waves at that same location.

Assume, that we have this situation:

In the cases above, the summing the individual displacements for locations of complete overlap was made out to be an easy task - as easy as simple arithmetic:

<table>
<thead>
<tr>
<th>Displacement of Pulse 1</th>
<th>Displacement of Pulse 2</th>
<th>Resulting Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1</td>
<td>+1</td>
<td>= +2</td>
</tr>
<tr>
<td>-1</td>
<td>-1</td>
<td>= -2</td>
</tr>
<tr>
<td>+1</td>
<td>-1</td>
<td>= 0</td>
</tr>
<tr>
<td>+1</td>
<td>-2</td>
<td>= -1</td>
</tr>
</tbody>
</table>

Ø Coherence
This is a property holding for two or more waves with logical and consistent ability of sticking together, it is a wave feature marked with an orderly correlation between waves having identical physical quantities. “Coherence describes all properties of the correlation between physical quantities of a single wave, or between several waves or wave packets”[1].

This physical phenomena can be observed in practical lab experiment carried out to study characteristics of wave properties, the concept of wave coherence can be clearly visible when individual waves exhibit a constructive interference; a state at which the waves sum up and produce a compound sinusoidal wave form with an amplified crest as shown in Pic 1. The wave in blue color is the resultant wave of the two lime waves.

Pic1.Constructive interference. Modified screen shot from an online source [2].

While constructive interference amplifies the output signal, the destructive interference does the opposite hence causing the input signals to cancel each other and a result weakens the output or destroy it producing a non-aligned wave form, Pic 2.
Pic2. Destructive interference. Modified screen shot from an online source [2].

Ø Spatial and Temporal coherence >>