An Introduction to Radio Interferometry

3-1 Interference pattern of a double slit

You can find relevant material
on my personal webpage

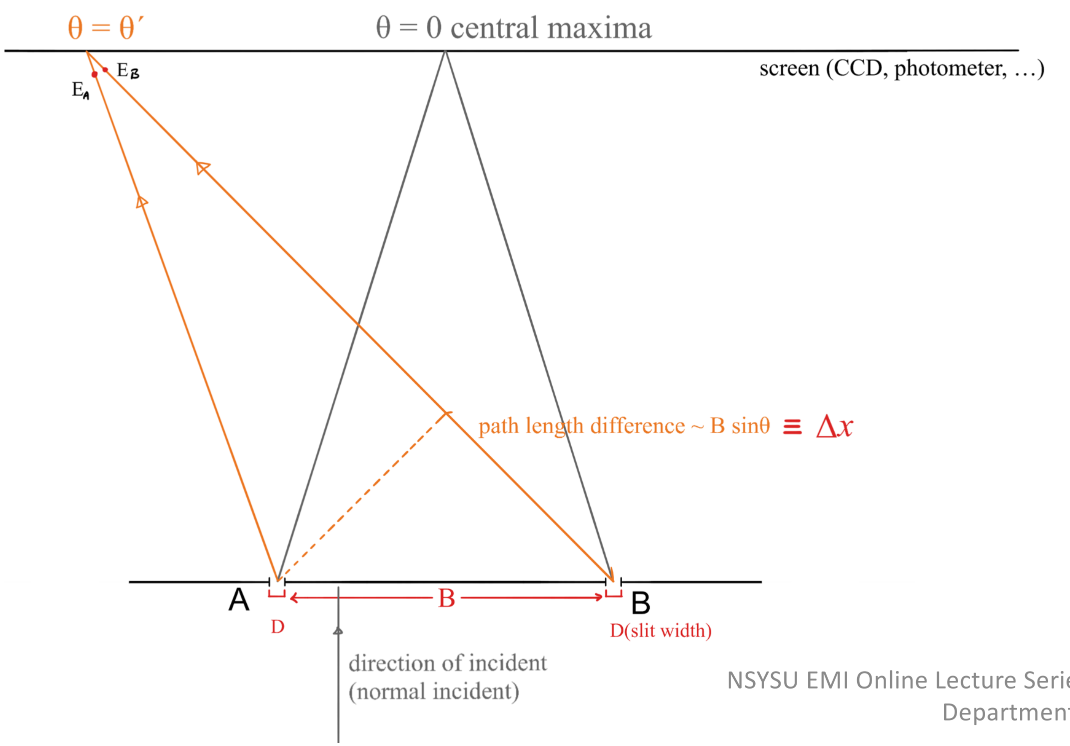
1. <u>EM-wave at long-distance limit: plane wave $E = E_0 \cos(kx - wt + \phi_0)$</u>
2. Energy flux density $\propto E_0^2$

Lecture Unit 1-2

Single slit field $= -\dfrac{\sin\left(\frac{1}{2}kD\sin\theta'\right)}{\frac{1}{2}k\sin\theta'}\cos\left(kx - \omega t + \frac{1}{2}kD\sin\theta'\right)$

$$\equiv \underbrace{\sqrt{\tilde{P}(\theta)}}_{\text{Amplitude modulation}}\cos(kx - \omega t + \underbrace{\phi_s}_{\text{Phase modulation}})$$

Lecture Unit 2-2



Number of incoming photons in a unit of time and a unit area (at the angle of emergence $\theta = \theta'$)

$$\propto [E_A + E_B]^2$$
$$= \tilde{P}(\theta)[\cos(kx - \omega t + \phi_0) + \cos(k(x + \Delta x) - \omega t + \phi_0)]^2$$
$$= \tilde{P}(\theta)\{[\cos(kx - \omega t + \phi_0)]^2 + [\cos(k(x + \Delta x) - \omega t + \phi_0)]^2 + 2\cos(kx - \omega t + \phi_0)\cos(k(x + \Delta x) - \omega t + \phi_0)\}$$

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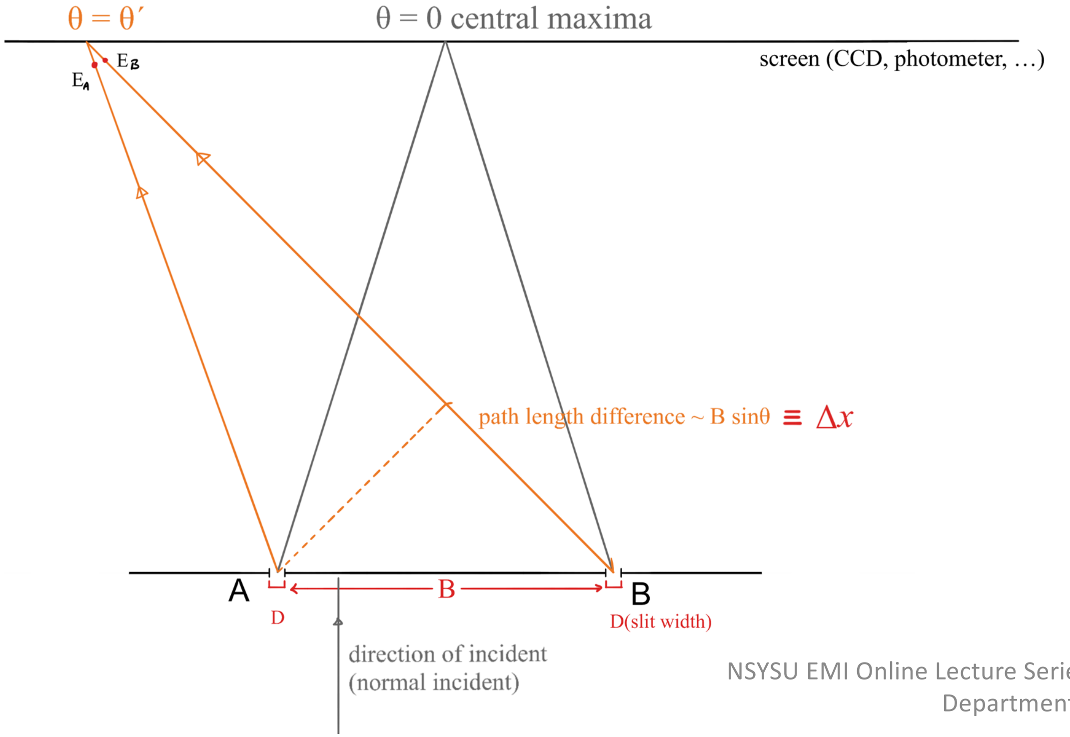

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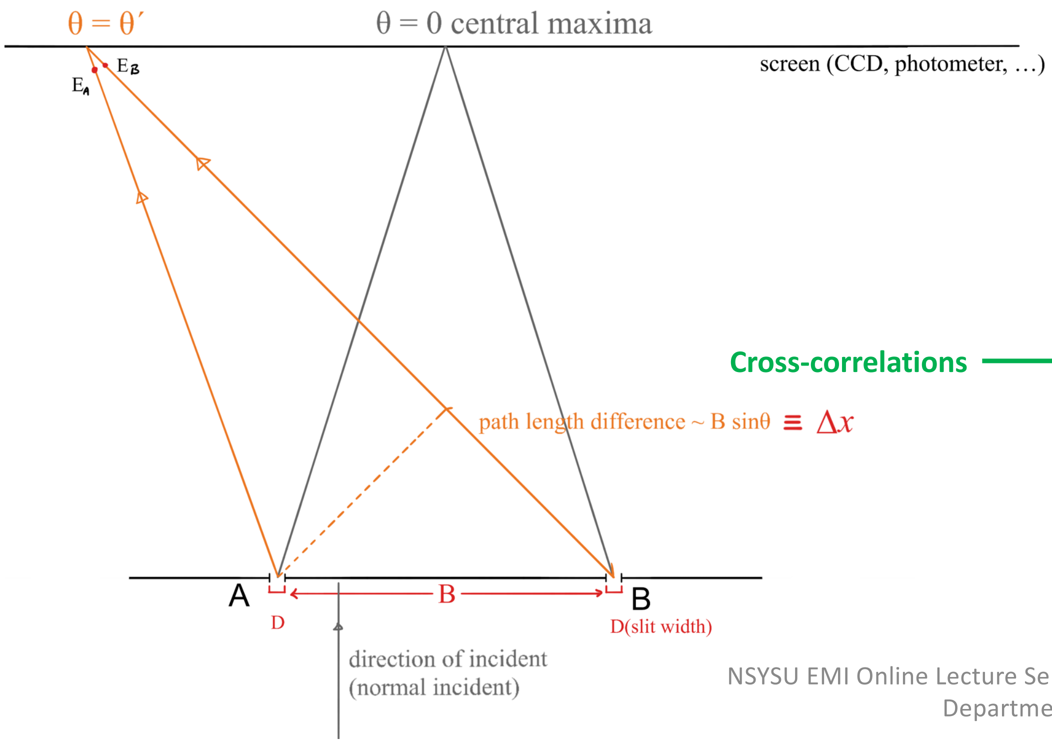
Lecture Unit 2-2



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$$= \left.\begin{aligned} &< [\cos(kx - \omega t + \phi_0)]^2 > \\ &+ < [\cos(k(x + \Delta x) - \omega t + \phi_0)]^2 > \end{aligned}\right\} \text{Auto-correlations}$$

Cross-correlations $\rightarrow$ $+ < 2\cos(kx - \omega t + \phi_0)\cos(k(x + \Delta x) - \omega t + \phi_0) >$

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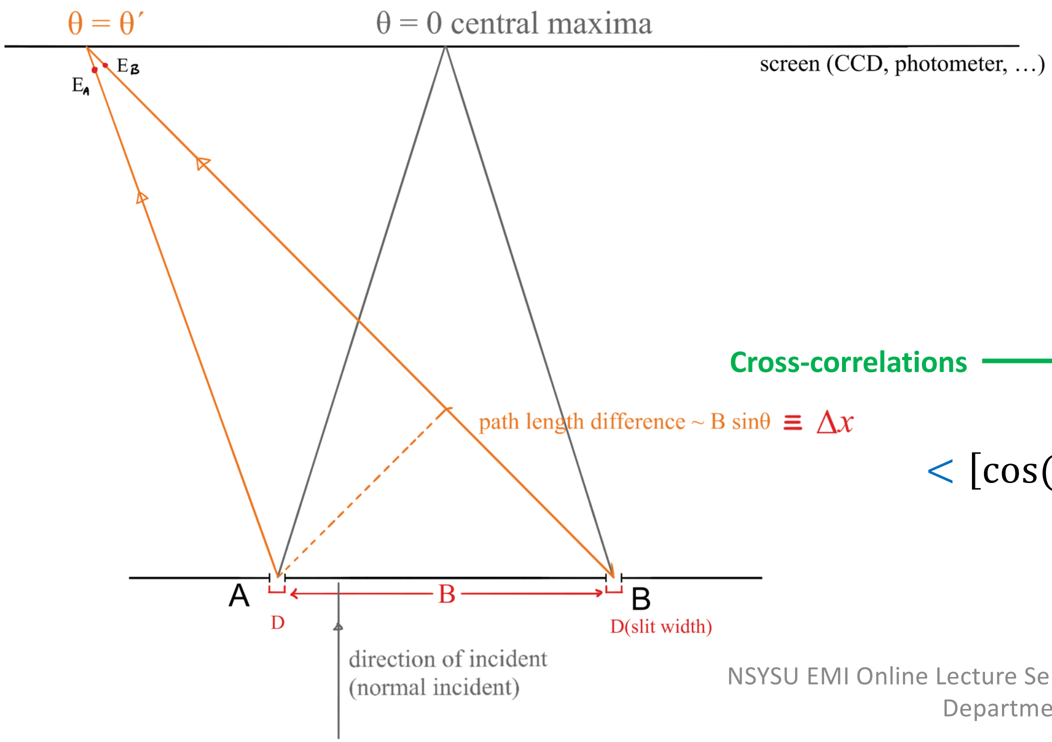

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Auto-correlations

Cross-correlations $\rightarrow$ $+ \langle 2\cos(kx - \omega t + \phi_0) \cos(k(x + \Delta x) - \omega t + \phi_0) \rangle$

$$\langle [\cos(kx - \omega t + \phi_0)]^2 \rangle \equiv \lim_{\Delta t \to \infty} \frac{1}{\Delta t} \int_{-\frac{1}{2}\Delta t}^{\frac{1}{2}\Delta t} [\cos(\underbrace{kx - \omega t + \phi_0}_{\beta})]^2 dt$$

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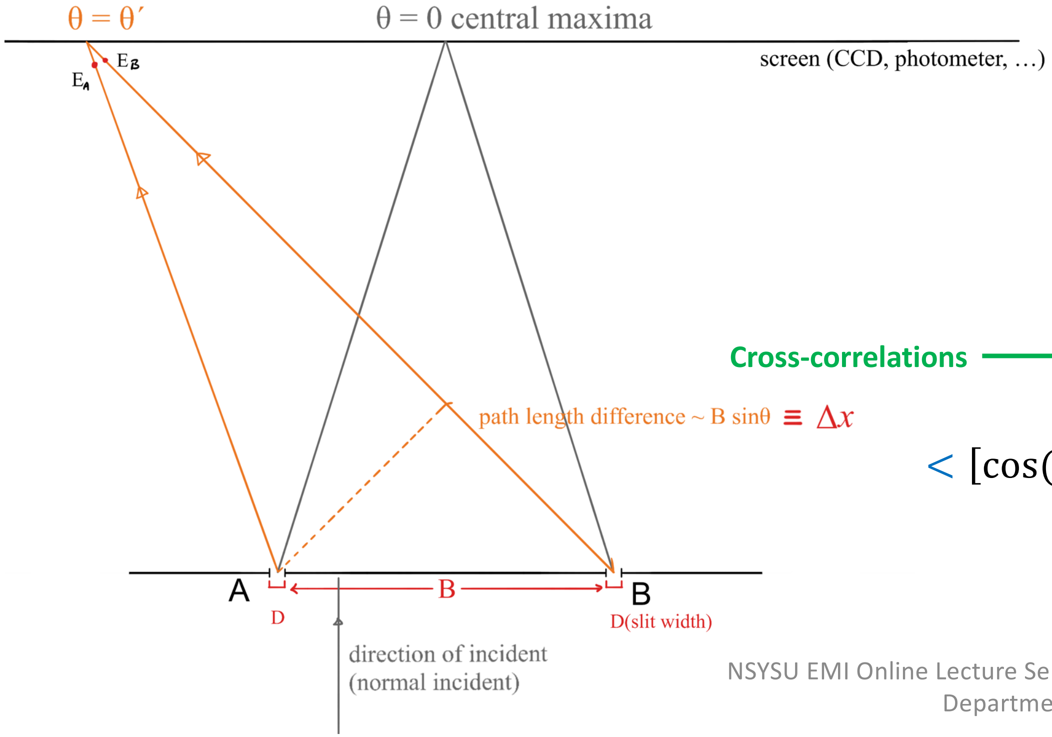
Lecture Unit 2-2



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Auto-correlations

Cross-correlations

$$+ < 2\cos(kx - \omega t + \phi_0) \cos(k(x + \Delta x) - \omega t + \phi_0) >$$

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1. **EM-wave at long-distance limit: plane wave $E = E_0 \cos(kx - wt + \phi_0)$**
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Lecture Unit 2-2

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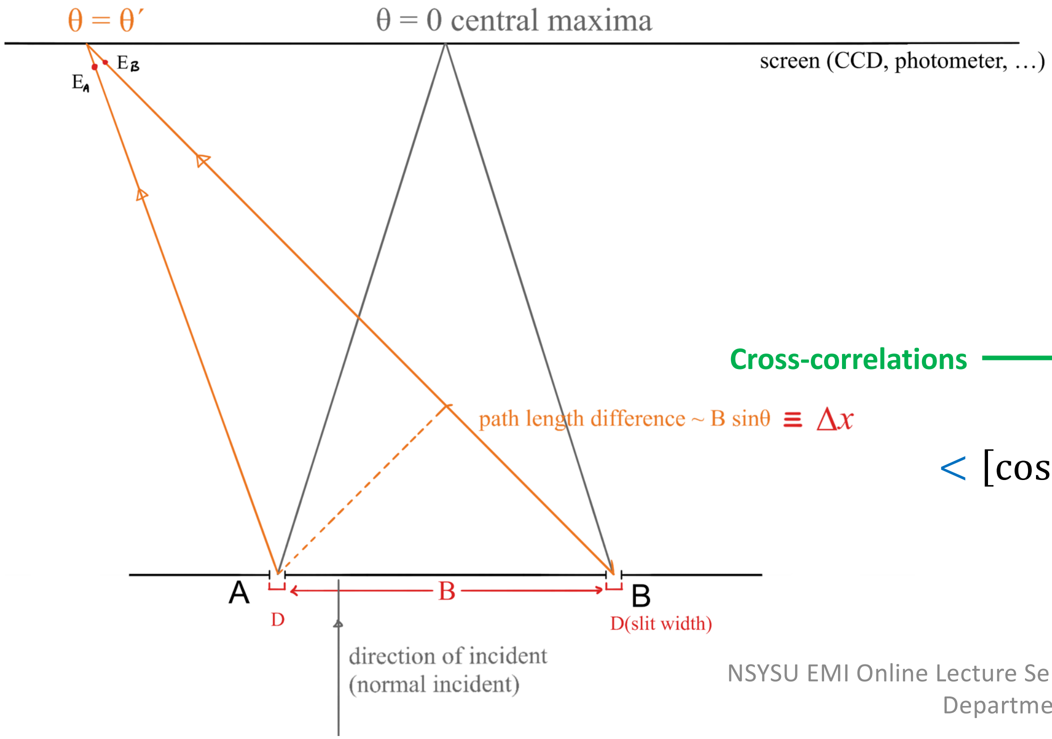

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Cross-correlations $\rightarrow$ $+ \left\langle 2\cos(kx - \omega t + \phi_0)\cos(k(x + \Delta x) - \omega t + \phi_0) \right\rangle$

$$\left\langle [\cos(kx - \omega t + \phi_0)]^2 \right\rangle \equiv \lim_{\Delta t \to \infty} \frac{1}{\Delta t}\int_{-\frac{1}{2}\Delta t}^{\frac{1}{2}\Delta t} [\cos(\underbrace{kx - \omega t + \phi_0}_{\beta})]^2 dt$$

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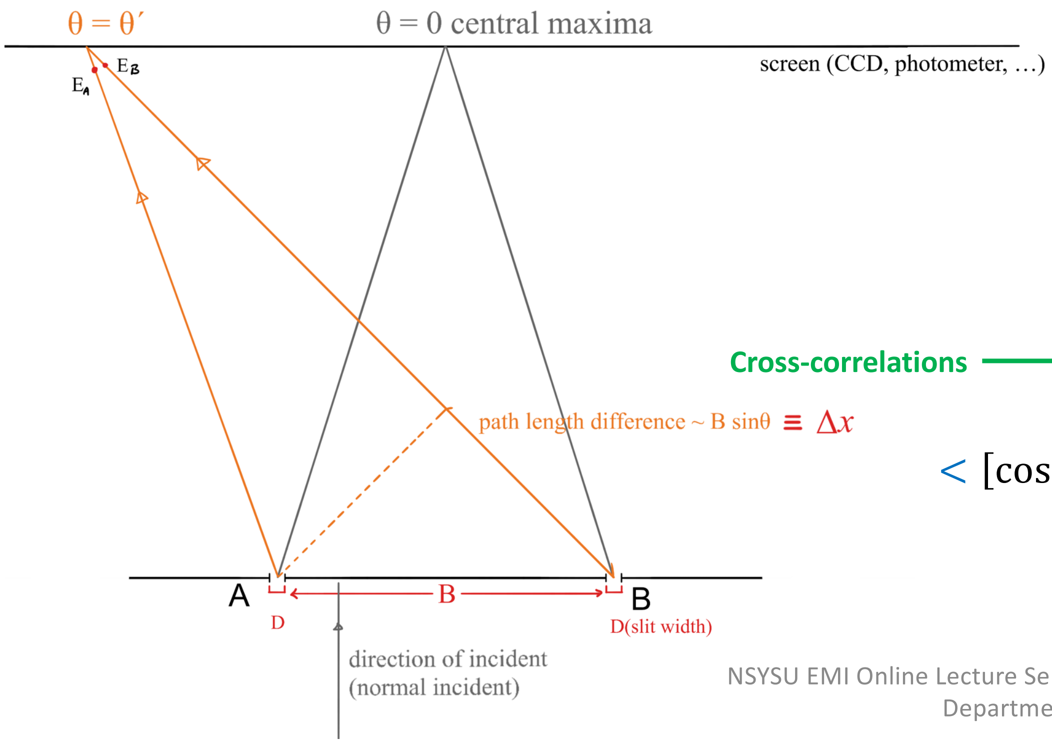

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$= {}^1/_2$
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Cross-correlations $\rightarrow + \langle 2\cos(kx - \omega t + \phi_0)\cos(k(x + \Delta x) - \omega t + \phi_0) \rangle$

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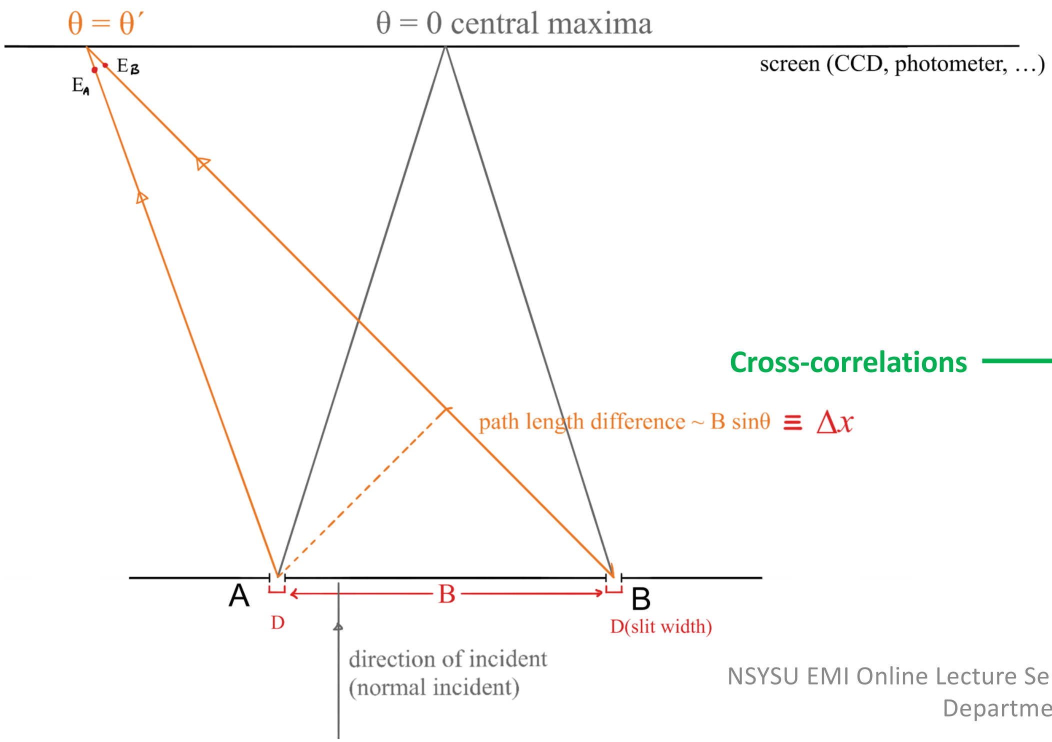

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Lecture Unit 2-2

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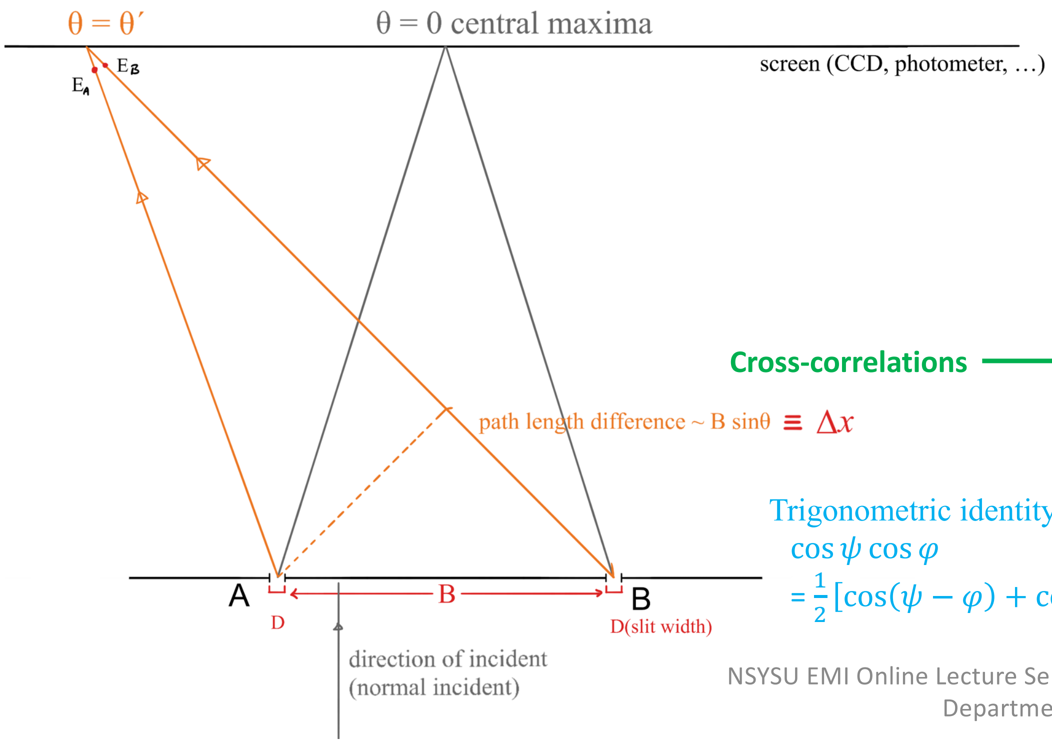

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Cross-correlations $\longrightarrow$ $+ < \boxed{2\underbrace{\cos(kx - \omega t + \phi_0)}_{\psi}\,\underbrace{\cos(k(x + \Delta x) - \omega t + \phi_0)}_{\varphi}} >$

Trigonometric identity:

$\cos\psi\cos\varphi$

$= \frac{1}{2}[\cos(\psi - \varphi) + \cos(\psi + \varphi)]$

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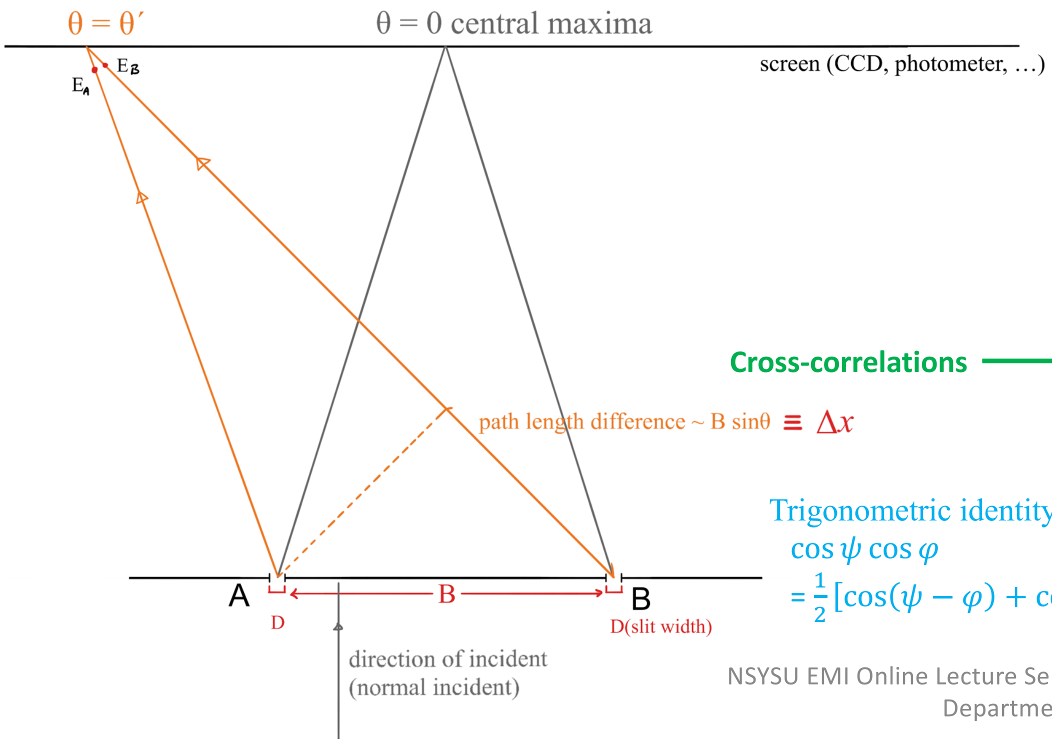

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Cross-correlations ⟶

$$+ \langle \underbrace{\boxed{2\cos(\underbrace{kx - \omega t + \phi_0}_{\varphi}) \cos(\underbrace{k(x + \Delta x) - \omega t + \phi_0}_{\psi})}}_{\cos(k\Delta x) + \cos(2kx - 2\omega t + 2\phi_0 + k\Delta x)} \rangle$$

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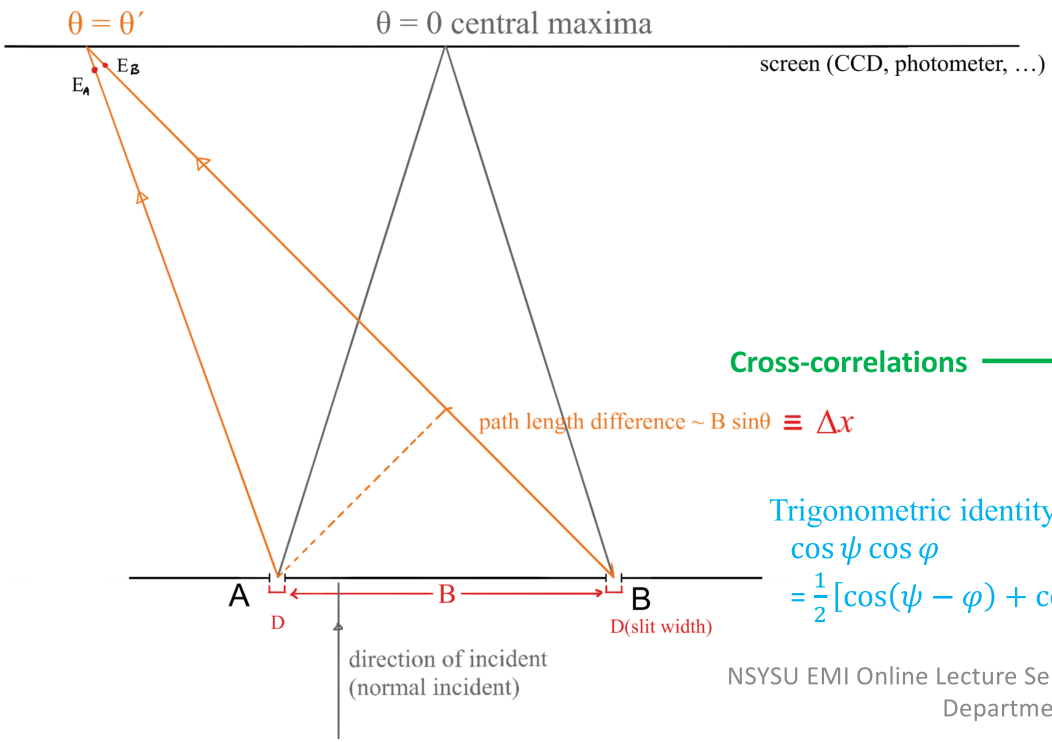

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$$\cos(k\Delta x) + \cancel{\cos(2kx - 2\omega t + 2\phi_0 + k\Delta x)}$$

Trigonometric identity:
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$= \frac{1}{2}[\cos(\psi - \varphi) + \cos(\psi + \varphi)]$

Minima: $\cos(k\Delta x) = -1$
$\Rightarrow k\Delta x = \frac{2\pi}{\lambda} B\sin\theta = m\pi,\ m = \pm 1,3,5,\cdots$

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Lecture Unit 2-2

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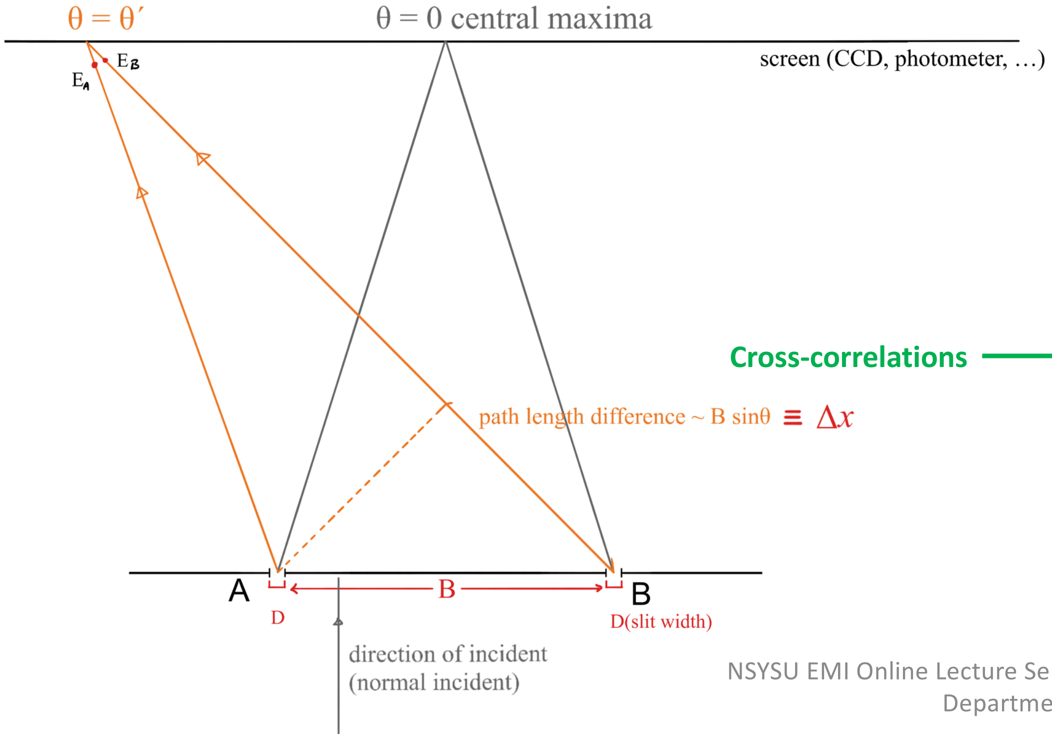

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Cross-correlations $\longrightarrow$ $+ \langle \boxed{2\underbrace{\cos(kx - \omega t + \phi_0)}_{\varphi}\underbrace{\cos(k(x + \Delta x) - \omega t + \phi_0)}_{\psi}} \rangle$

$$\langle [E_A + E_B]^2 \rangle = \tilde{P}(\theta)\left[1 + \cos\left(\frac{2\pi}{\lambda}B\sin\theta\right)\right]$$

$$\sim \tilde{P}(\theta)\left[1 + \cos\left(2\pi\frac{B}{\lambda}\theta\right)\right]$$

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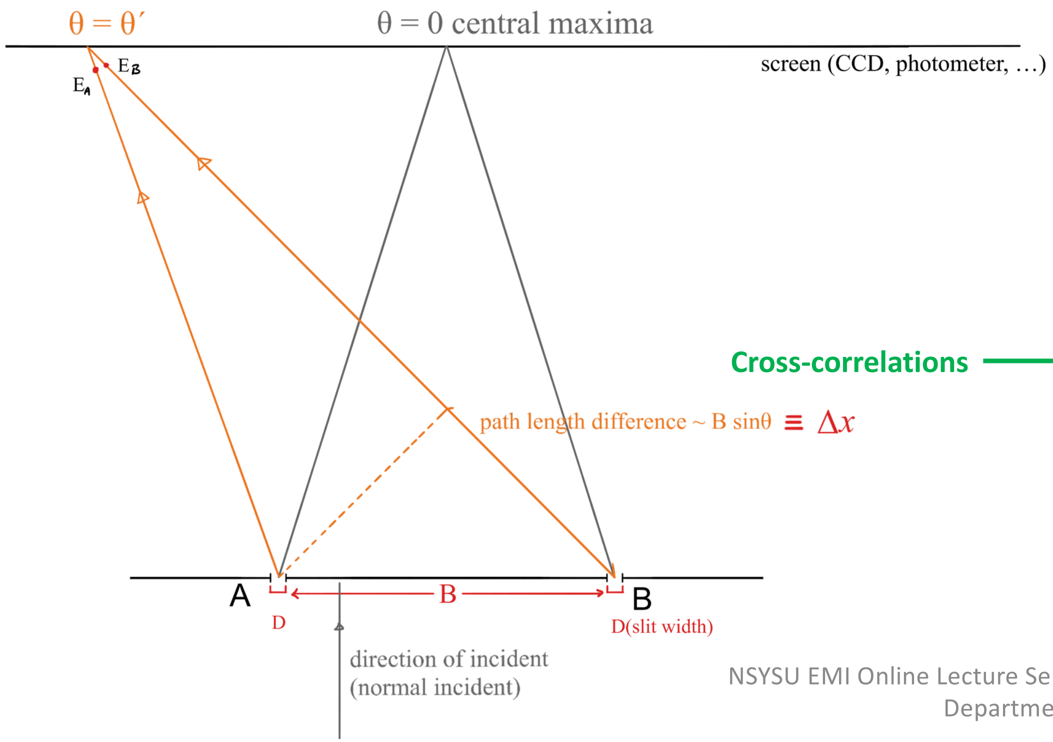
Amplitude modulation

Phase modulation

Lecture Unit 2-2



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$$\langle [E_A + E_B]^2 \rangle = \tilde{P}(\theta)\left[1 + \cos\left(\frac{2\pi}{\lambda} B \sin\theta\right)\right]$$
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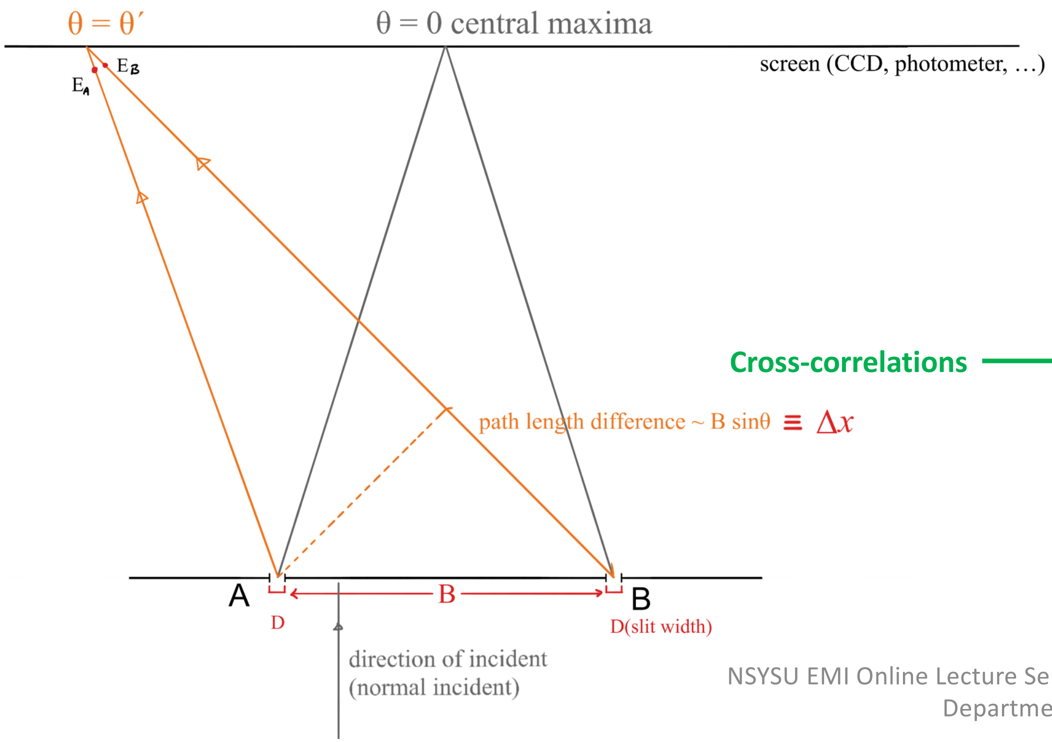

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$$= \left.\begin{matrix} 1/2 \\ + 1/2 \end{matrix}\right] \text{Auto-correlations}$$

Cross-correlations $\longrightarrow + \langle \boxed{2\underbrace{\cos(kx - \omega t + \phi_0)}_{\varphi}\underbrace{\cos(k(x + \Delta x) - \omega t + \phi_0)}_{\psi}} \rangle$

$$\langle [E_A + E_B]^2 \rangle = \tilde{P}(\theta)\left[1 + \cos\left(\frac{2\pi}{\lambda}B\sin\theta\right)\right]$$
$$\sim \tilde{P}(\theta)\left[1 + \cos\left(2\pi\frac{B}{\lambda}\theta\right)\right] \sim \tilde{P}(\theta)[1 + \cos(2\pi u\theta)]$$

1. Interference pattern of a double-slit:

$\tilde{P}(\theta)\left[1+\cos\left(2\pi\frac{B}{\lambda}\theta\right)\right] \sim \tilde{P}(\theta)[1+\cos(2\pi u\theta)]$, where B is the separation of the two slits, and $\tilde{P}(\theta)$ is the diffraction pattern of a single-slit.