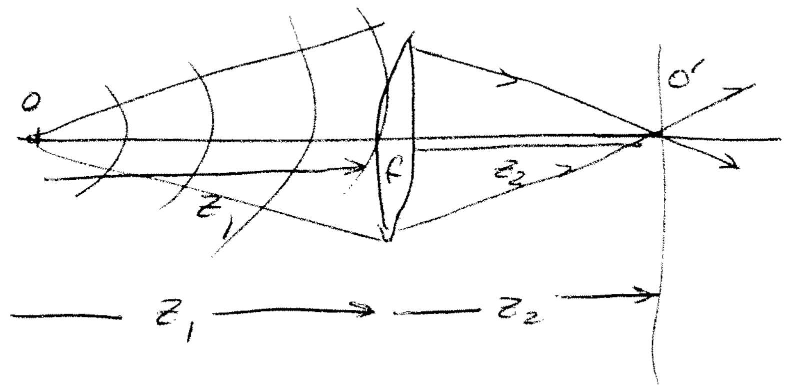
30 NOVEMBER 2009 OPTICS

www.cis.rit.edu/class/simg733

$$\left(+\frac{1}{z_1}\right) + \left(+\frac{1}{z_2}\right) = \frac{1}{f}$$

$$\cancel{\frac{1}{o} + \frac{1}{i} = \frac{1}{f}}$$



REAL IMAGE

VIRTUAL IMAGE

$$n = \frac{c}{v}$$

psf

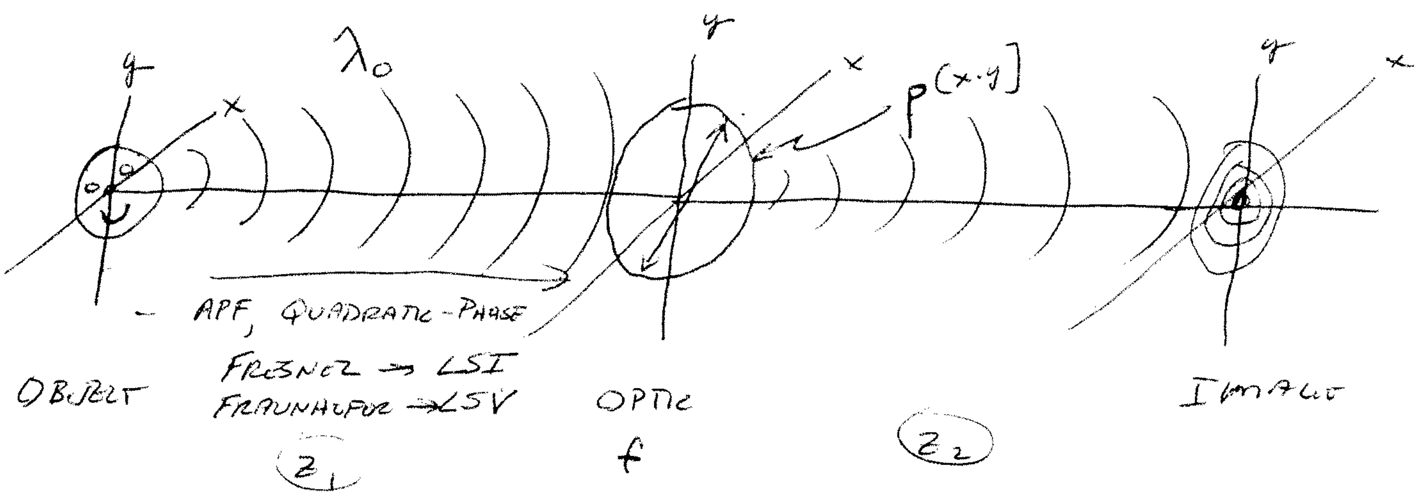
$$\left[\begin{array}{l} f[x,y] * h[x,y] = g(x,y) \\ F[\xi,\eta] \cdot H(\xi,\eta) = G(\xi,\eta) \end{array}\right]$$

OTF

LSI → "QUALITY" OF LIGHT

→ MONOCHROMATIC → COHERENT

→ INCOHERENT



C-M-C

IF $\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$

$H[\xi,\eta] \propto p[-\lambda_0 f \xi, -\lambda_0 f \eta]$; $\mathcal{H}[\xi,\eta] \propto p[-\lambda f \xi, -\lambda f \eta] \star p[-\lambda_0 f \xi, -\lambda_0 f \eta]$

$h[x,y] \propto P\left[\frac{x}{\lambda_0 f}, \frac{y}{\lambda_0 f}\right]$; $\mathscr{h}[x,y] = \left|P\left[\frac{x}{\lambda_0 f}, \frac{y}{\lambda_0 f}\right]\right|^2$

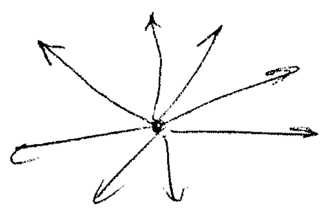
$f[x,y] * h(x,y) = g(x,y) \Rightarrow$ LPF

OPTICS → "MODEL" OF LIGHT TO DO USEFUL STUFF

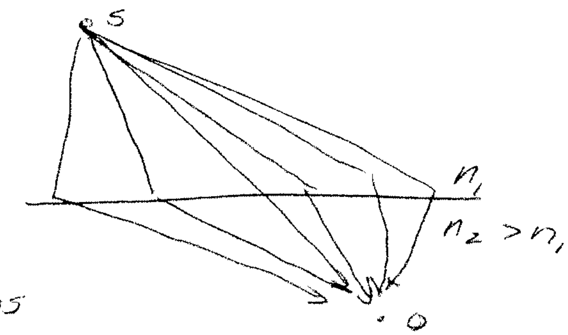
3 MODELS

(1) GEOMETRICAL OPTICS – RAY OPTICS – MACROSCOPIC DESCRIPTION

LIGHT AS RAYS



FERMAT'S PRINCIPLE OF LEAST TIME



DESIGN OPTICAL SYSTEMS

OSLO, CODE V, ZMAX

$\lambda \to 0$; CHROMATICITY

IMAGE "QUALITY" → RESOLVE CLOSELY SPACED POINT SOURCES

2 PHYSICAL OPTICS - WAVE OPTICS - MICROSCOPIC INTERACTIONS OF LIGHT & MATTER

LIGHT AS WAVES - TRAVELLING OSCILLATION

SINUSOIDAL TRAVELING WAVE

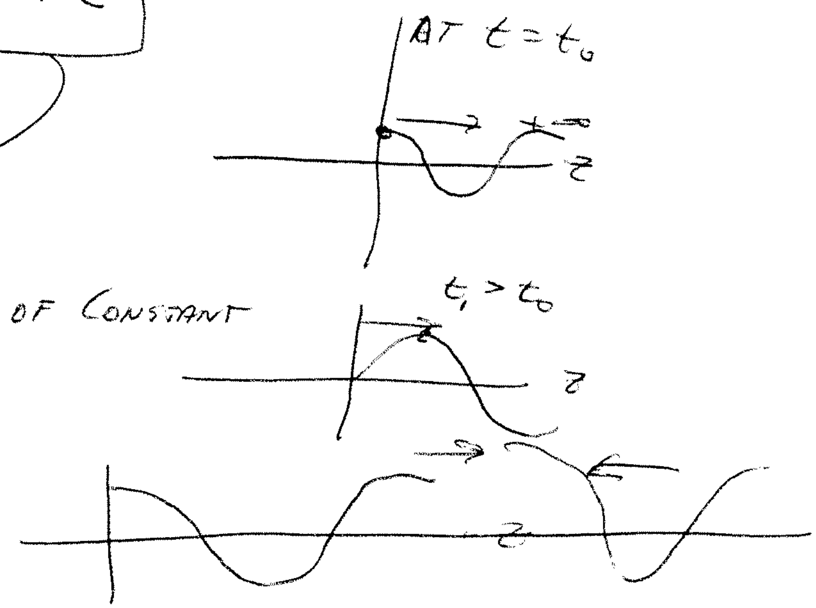
DIRECTION

$$\cos\left(2\pi\left(\frac{z}{\lambda_0} \pm \nu_0 t\right) + \varphi_0\right)$$

$$\boxed{\lambda_0 \nu_0 = V_0 \to c}$$

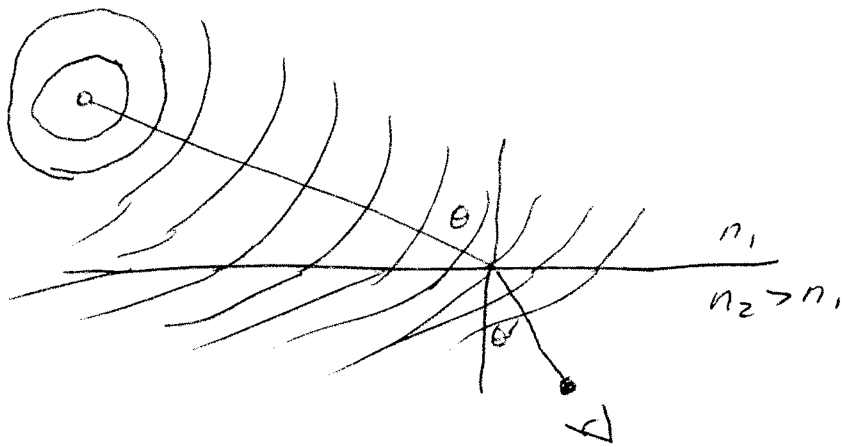
$$2\pi\left(\frac{z}{\lambda_0} - \nu_0 t\right)$$

VELOCITY OF POINT OF CONSTANT PHASE



MAXWELL'S EQUATIONS → WAVE

INTERFERENCE EFFECTS → WAVES



$n_1 \sin\theta_1 = n_2 \sin\theta_2$

INTERFERENCE (FEW SOURCES) ⟶ DIFFRACTION (MANY SOURCES)

INTERFERENCE ⟷ DIFFRACTION

QUALITY METRICS ⟶ RESOLUTION
DEPTH OF FIELD / FOCUS

3 LIGHT AS PHOTONS - QUANTUM OPTICS - SENSORS

"PACKETS" OF ENERGY $\qquad \underline{\underline{E_0 = h\nu_0}} = h \frac{c}{\lambda_0}$

PLANCK'S CONSTANT $\simeq 6.626 \cdot 10^{-34}$ J·sec

A

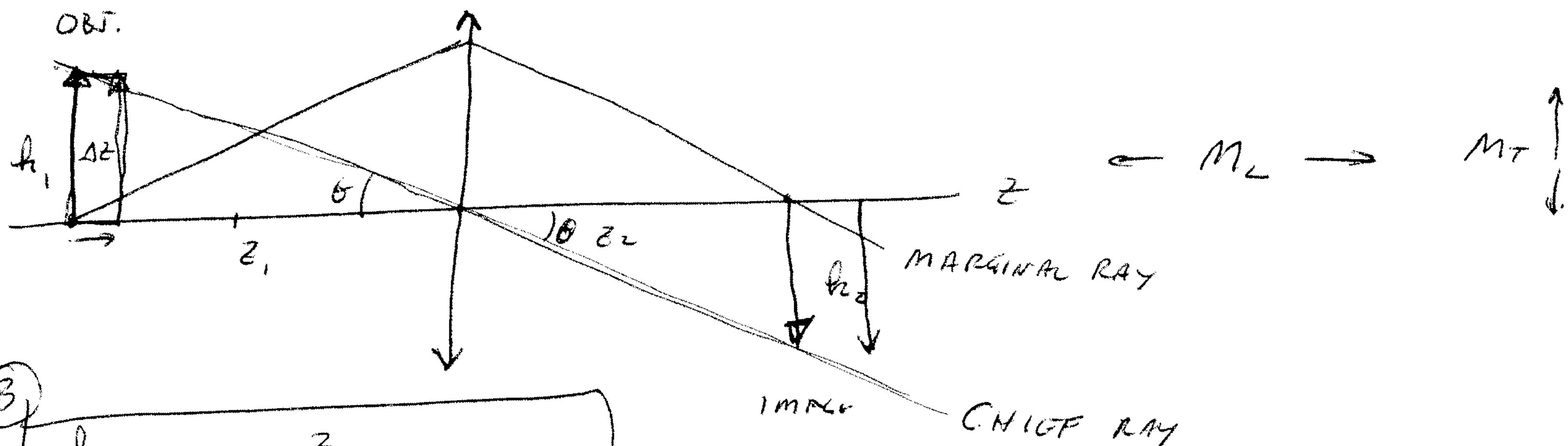
$$\boxed{\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}}$$

INPUT (z_1) OUTPUT (z_2) SYSTEM (f)

DIRECT (1) $z_2 = \left(\frac{1}{f} - \frac{1}{z_1} \right)^{-1}$

INVERSE (2) $z_1 = \left(\frac{1}{f} - \frac{1}{z_2} \right)^{-1}$

ANALYSIS (3) $f = \left(\frac{1}{z_1} + \frac{1}{z_2} \right)^{-1}$



B

$$\boxed{\frac{h_2}{h_1} = -\frac{z_2}{z_1} = M_T}$$

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

$$d\left(\frac{1}{z_1} + \frac{1}{z_2}\right) = d\left(\frac{1}{f}\right) = -\frac{1}{f^2}\cancelto{0}{df} = 0$$

$$-\frac{dz_1}{z_1^2} - \frac{dz_2}{z_2^2} = 0 \implies -\frac{dz_1}{z_1^2} = \frac{dz_2}{z_2^2}$$

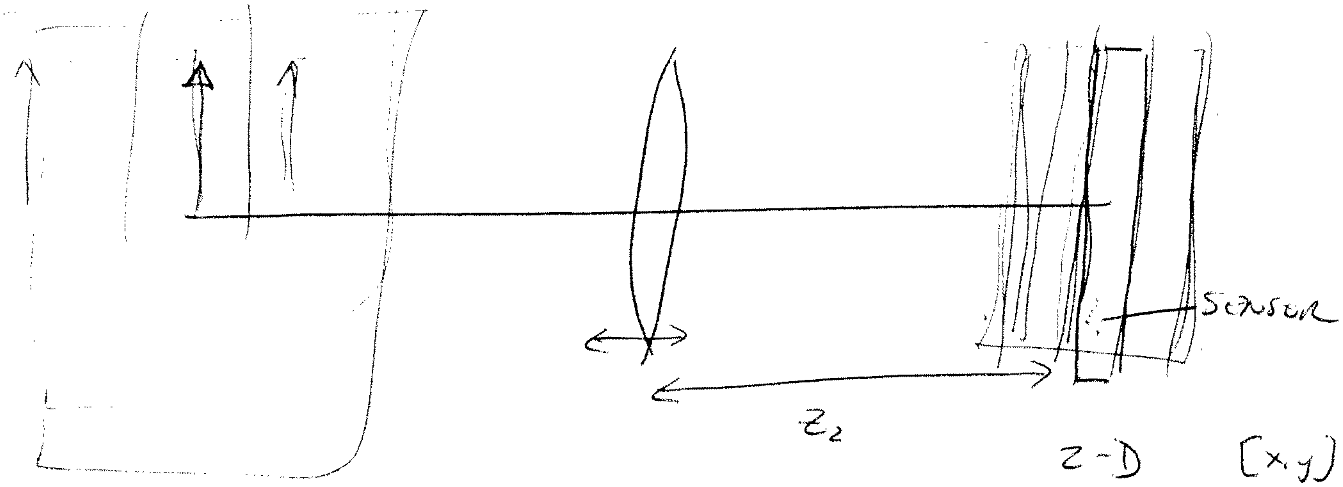
$$= \frac{dz_2}{dz_1} = -\frac{z_2^2}{z_1^2} = M_L$$

LONGITUDINAL MAGNIFICATION

$$= -\left(-\frac{z_2}{z_1}\right)^2 = \boxed{-\left(M_T\right)^2 = M_L}$$

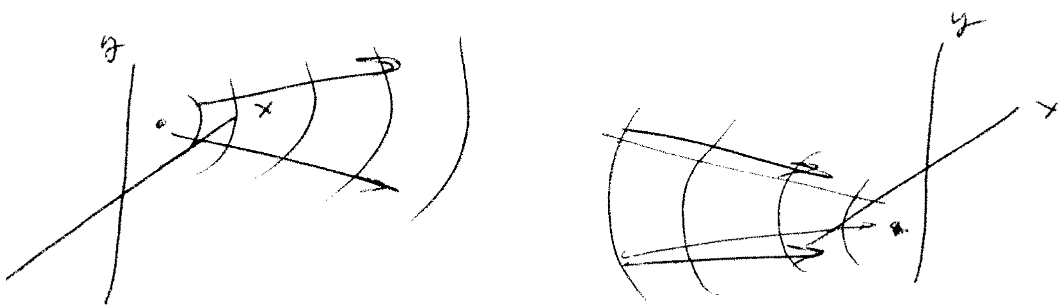
$$M_T \equiv \left(-\frac{z_2}{z_1}\right)$$

DEPTH OF FIELD



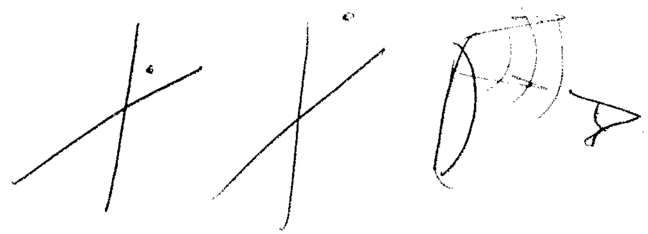
REAL IMAGES → MEASURE WITH A SENSOR – ACCESSIBLE

$z_2 > 0$



VIRTUAL IMAGE – NOT ACCESSIBLE

$z_2 < 0$

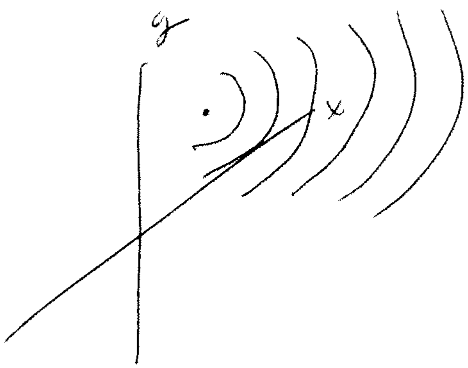


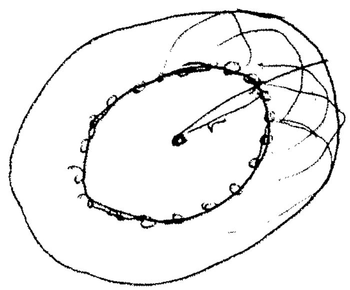
WAVE OPTICS AND IMAGING

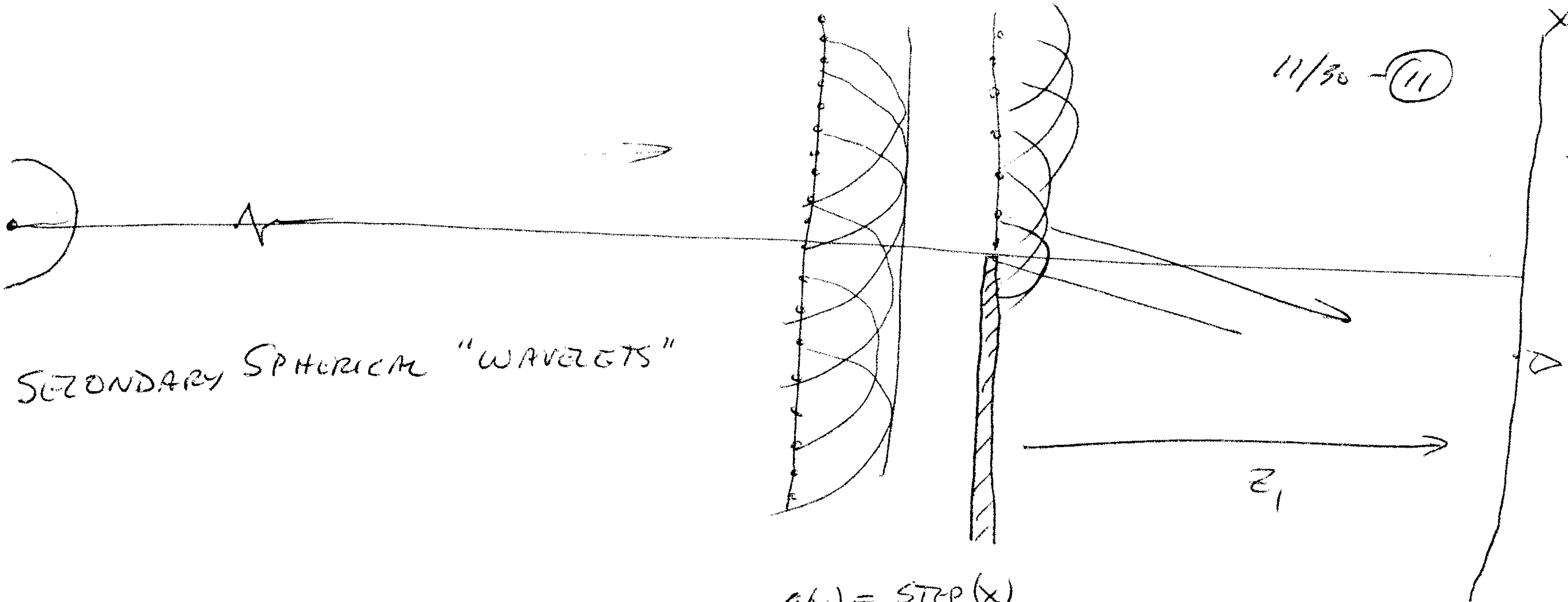
$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

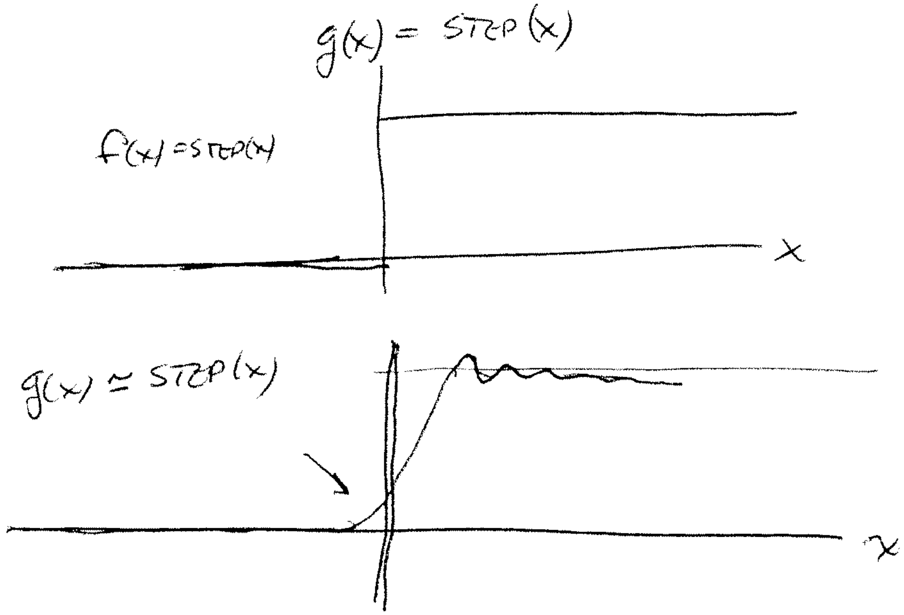
DESCRIBE PROPAGATION OF LIGHT

CHRISTIANNE HUYGENS → HUYGENS' PRINCIPLE



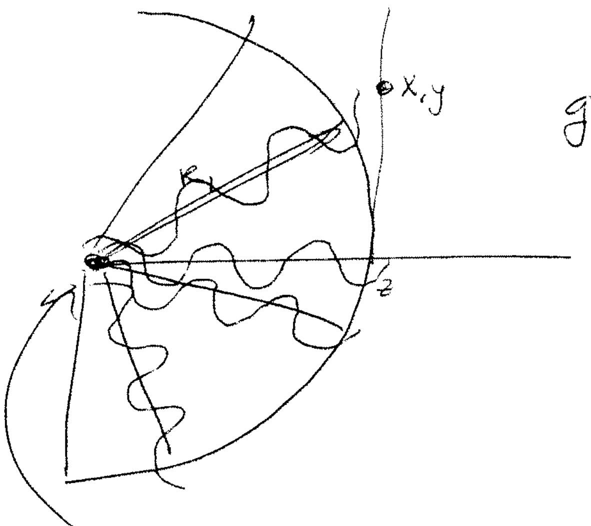



SECONDARY SPHERICAL "WAVELETS"
z_1


$g(x) = \text{STEP}(x)$
$f(x) = \text{STEP}(x)$
x
$g(x) \simeq \text{STEP}(x)$
x

$f[x,y] * \underbrace{h[x,y;z_1]} = g(x,y;z) \longrightarrow$ FRESNEL DIFFRACTION

$(\ ) e^{+i\pi \frac{x^2+y^2}{\alpha^2}}$



$\delta(x,y)\,\delta(z)$

$$g[x,y;z] = \frac{1}{R_1} \underbrace{\cos\left(\frac{2\pi}{\lambda_0} R_1 - \nu_0 t + \varphi_0\right)}_{\text{SINUSOID}}$$

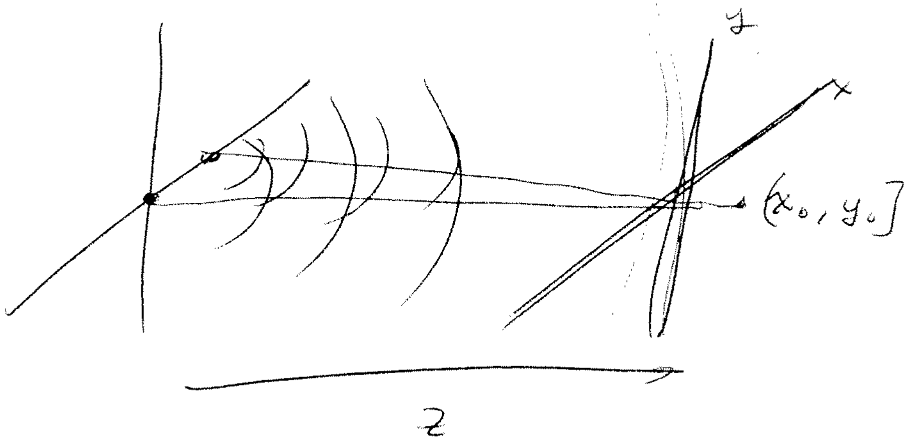
INVERSE SQUARE LAW

$R_1 = \sqrt{x^2+y^2+z^2}$ — DISTANCE FROM SOURCE

SPHERICAL WAVES

$\left| g[x,y;z] \right|^2 \rightarrow$ ENERGY

$$g[x,y;z] = \underline{\frac{1}{\sqrt{x^2+y^2+z^2}}} \cos\left[2\pi\left(\underbrace{\frac{\cancel{z}\sqrt{x^2+y^2+z^2}}{\lambda_0}}_{} - \nu_0 t\right) + \varphi_0\right]$$



LSV → NO CONVOLUTION

$$\sqrt{z^2\left(1+\frac{x^2+y^2}{z^2}\right)}$$

FRESNEL APPROXIMATION TO HUYGENS' PROPAGATION → LSI

$$\frac{1}{z} \cos\left(2\pi\underbrace{\left(\frac{x^2+y^2}{\lambda_0} \mp \nu_0 t\right)}_{}\right) \cos\left(2\pi \frac{z}{\lambda}\right) \quad \text{LSI}$$

↑ INVERSE SQUARE

QUADRATIC-PHASE FILTER