Superluminal Tunneling Devices

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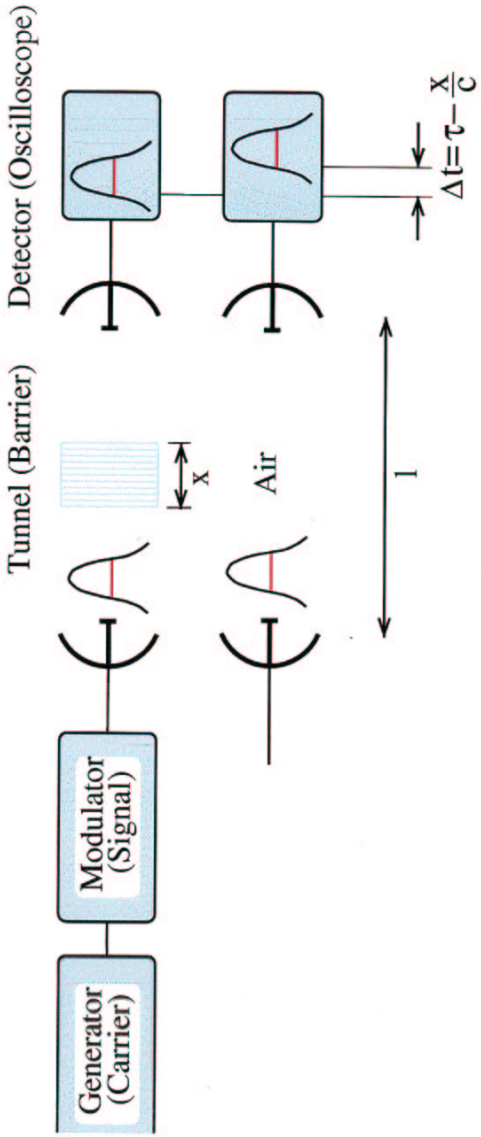
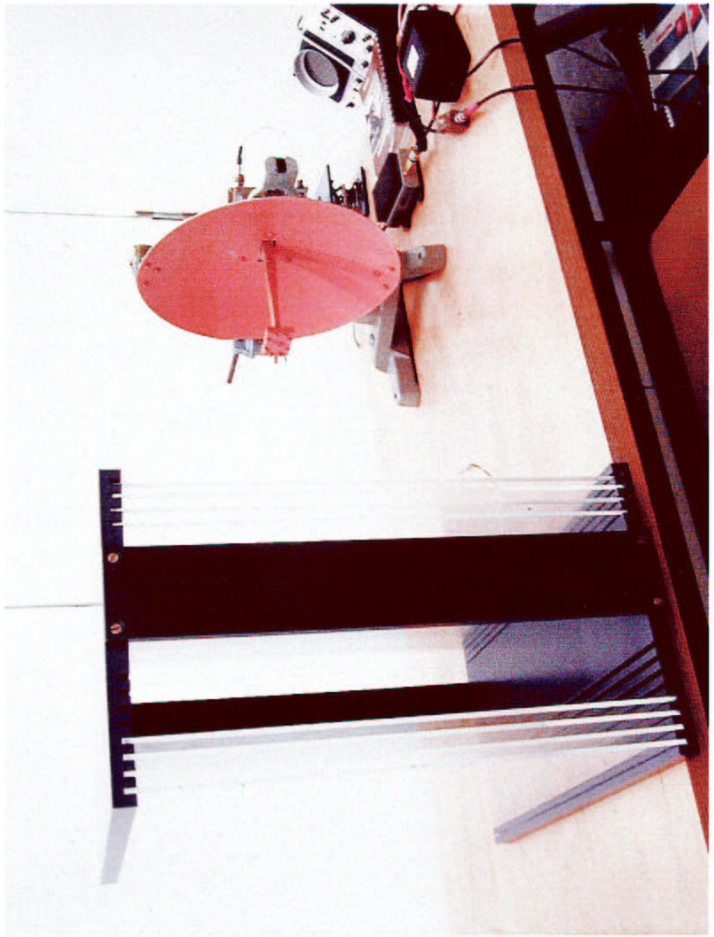
5. Superluminal Electronic Tunneling
   a) Electronic Lattice Structure
   b) pn-Junction
6. Summing-Up

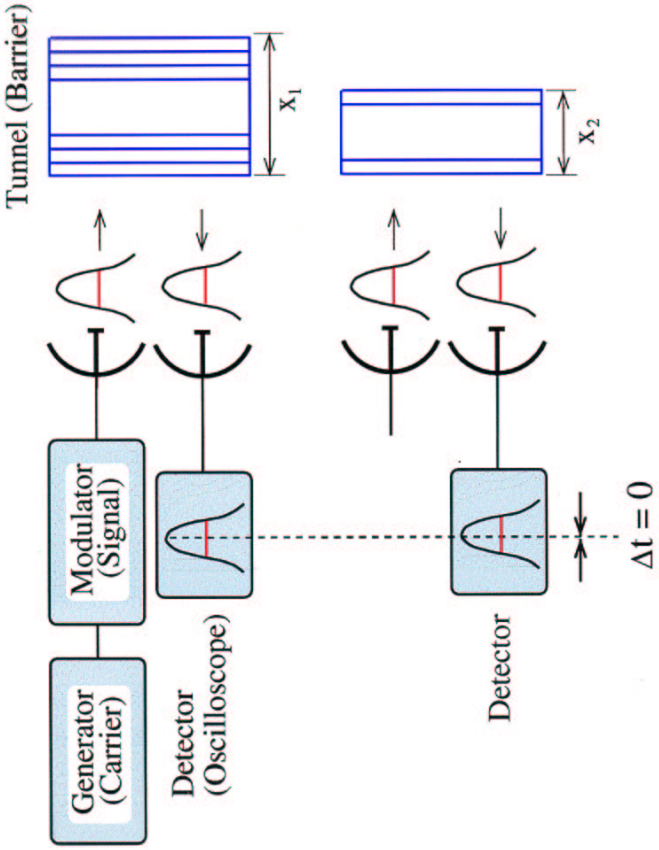
Experiment: Signalvelocity

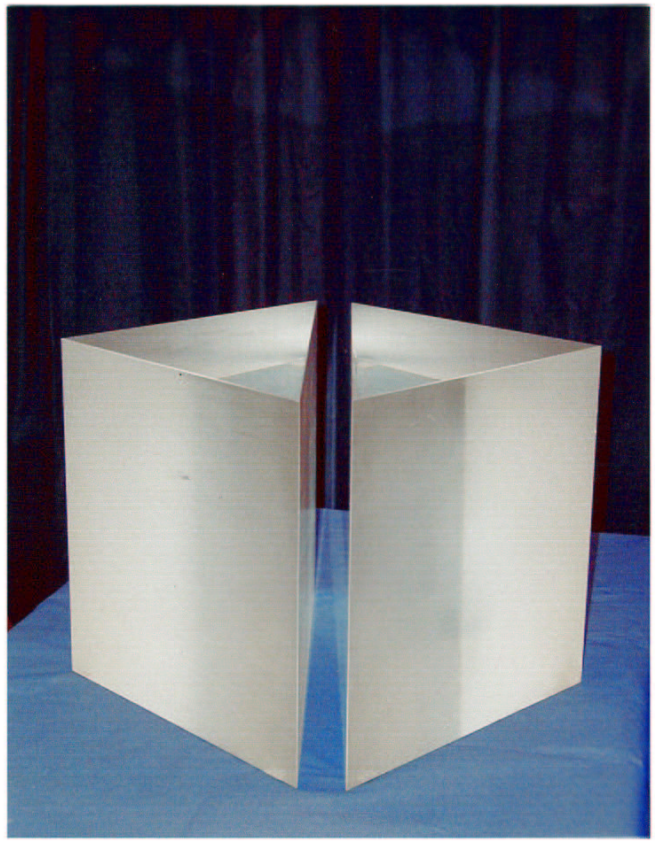


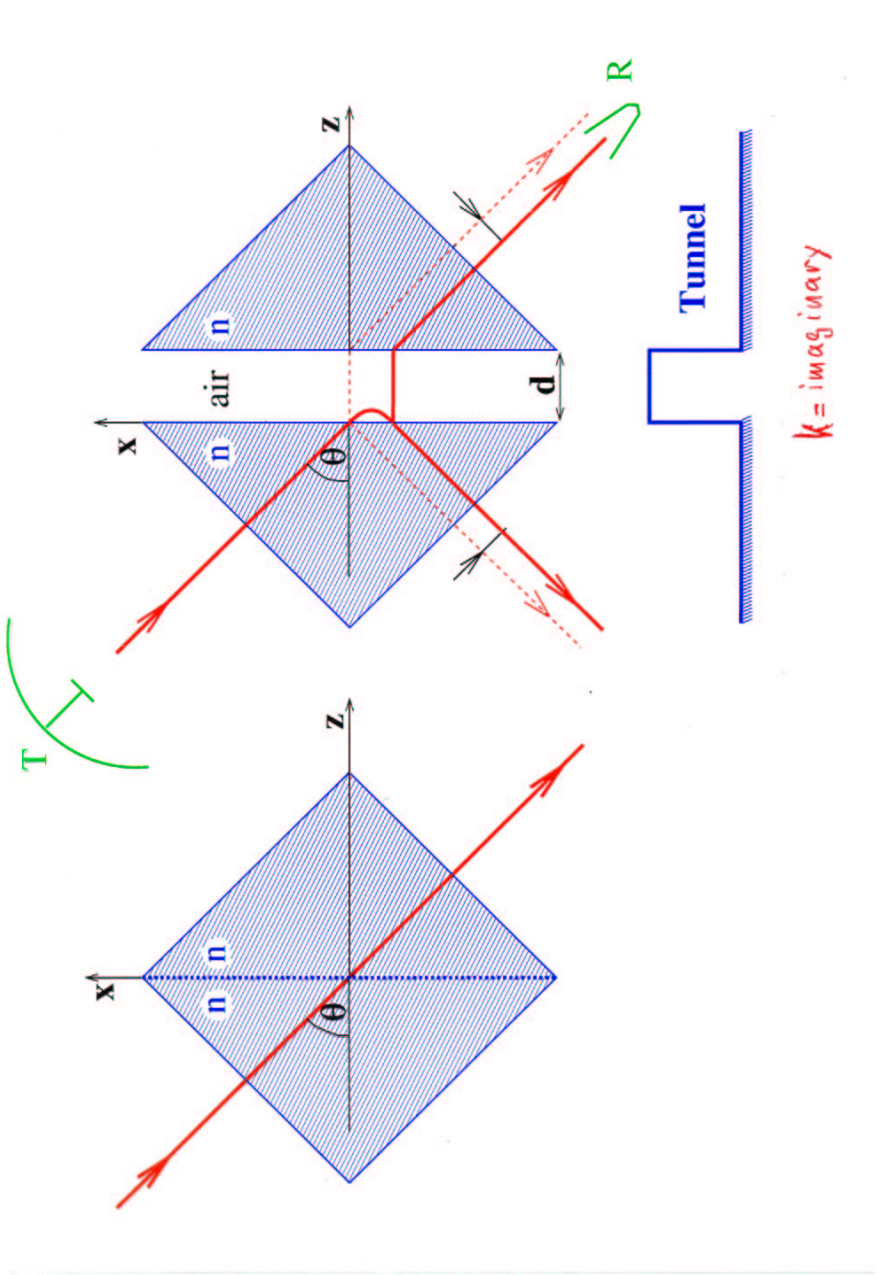
$$V = \frac{x}{\tau} = \frac{0.3\,\mathrm{m}}{125\,\mathrm{ps}} = 8c$$

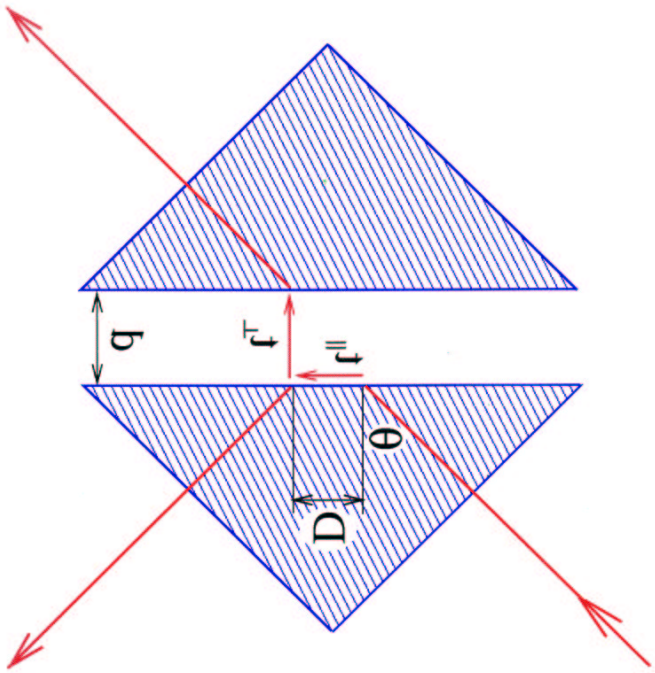


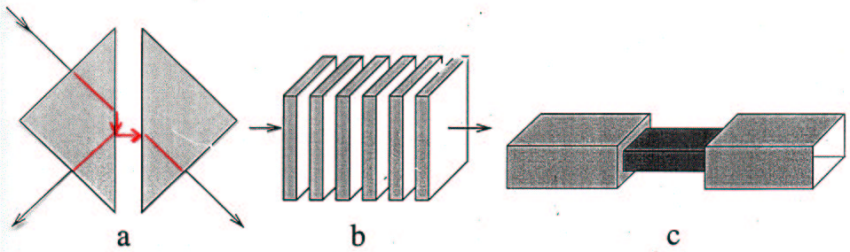
Partial Reflection






x
n
n
θ
z
x
n
air
n
θ
d
z
T
R
Tunnel
k_z = imaginary





a) Double Prism -
Frustrated Total Internal Reflection

b) Photonic Lattice

c) Undersized Waveguide

All these tunnelling systems are characterized by an imaginary wavenumber:

$k \rightarrow i\kappa$

$E(t,x) = E_0 \, e^{-i(\omega t - k x)}$

Universal Relationship of Tunnelling Time and Frequency

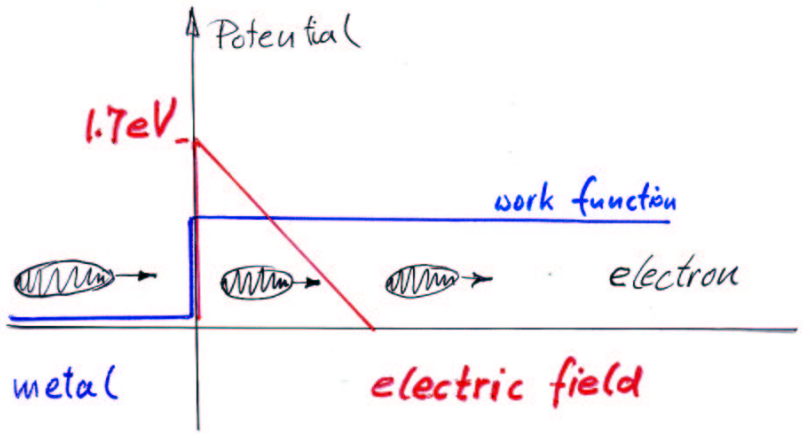
$$\tau \approx T = 1/f$$

Photonic Barrier	Reference	Tunnelling Time τ	Reciprocal Frequency $T = 1/f$
FTIR at the Double–Prism	Haibel/Nimtz	117 ps	120 ps
	Carey et al.	$\approx$ 1 ps	3 ps
	Balcou/Dutriaux	40 fs	11.3 fs
	Mugnai et al.	134 ps	100 ps
Photonic Lattice	Steinberg et al.	2.13 fs	2.34 fs
	Spielmann et al.	2.7 fs	2.7 fs
	Nimtz et al.	81 ps	115 ps
Undersized Waveguide	Enders/Nimtz	130 ps	115 ps
FEM	Sekatskii/Letokhov	6–8 fs	>2.43 fs

Electron Tunneling Time

Sekatskii & Letokhov, PRB 64 (2001) 233311

Field emission, τ = 6 - 8 fs
e.g. $W_{electron} \approx 0.6$ eV $\rightarrow$ h/W = 7 fs



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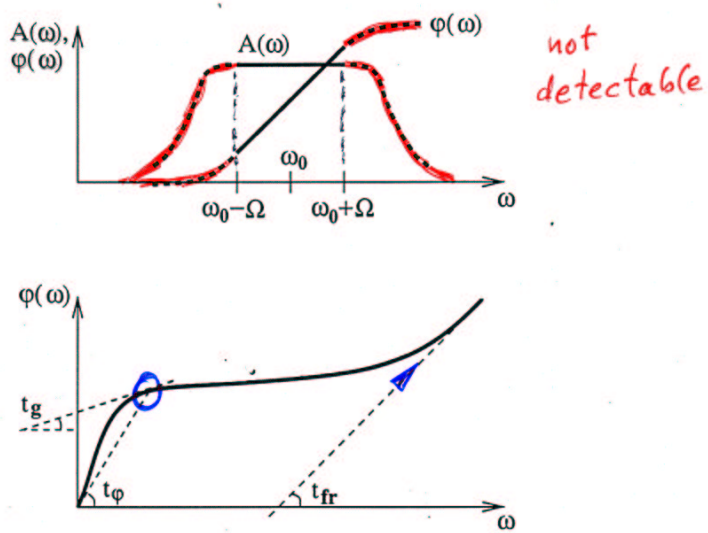


not detectable

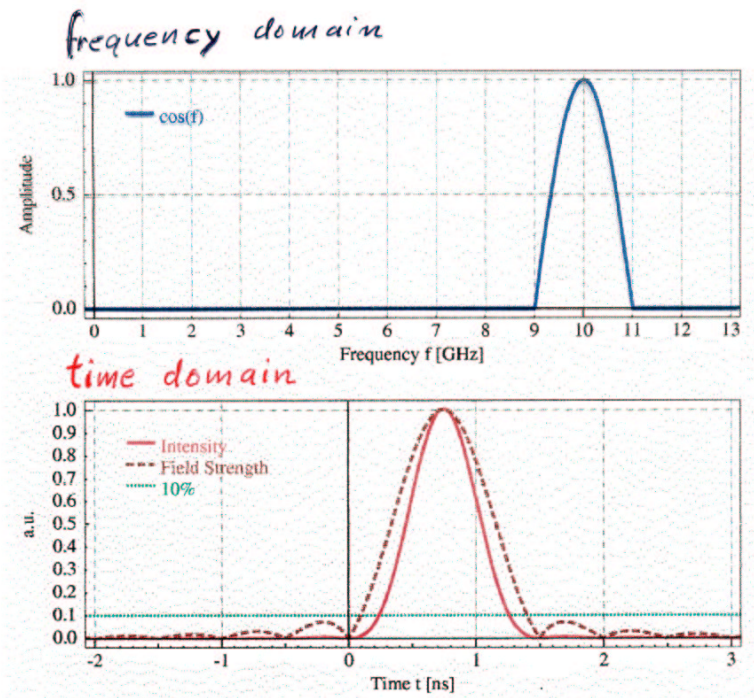
Fig. 4 A sketch of a frequency band limited signal with amplitude $A(\omega)$ vs frequency ω, of phase angle $\varphi(\omega)$, and of various delay times as defined e.g. in Eqn.(4) - (6) Ref. [21]. $\omega_0 \pm \Omega$ is the frequency-band width around the center frequency ω_0.

Phase time delay $t_\varphi(\omega) = \varphi(\omega)/\omega = xk/\omega$ (4)

Group time delay $t_g(\omega) = d\varphi(\omega)/d\omega = x\,dk/d\omega = x/v_g \equiv \tau$ (5)

Front time delay $t_{fr}(\omega) = \lim_{\omega\to\infty} \varphi(\omega)/\omega$ = not defined (6)

$E(x) \sim e^{+ikx} \to e^{-\kappa x}$ $\quad k = i\kappa$

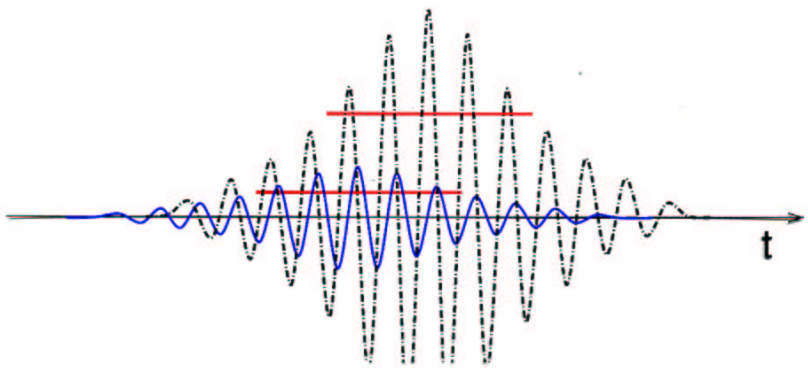


Frequency band limited microwave signal. Field strength and Energy Intensity. Planck (1900): The minimum of any field energy is h · f.

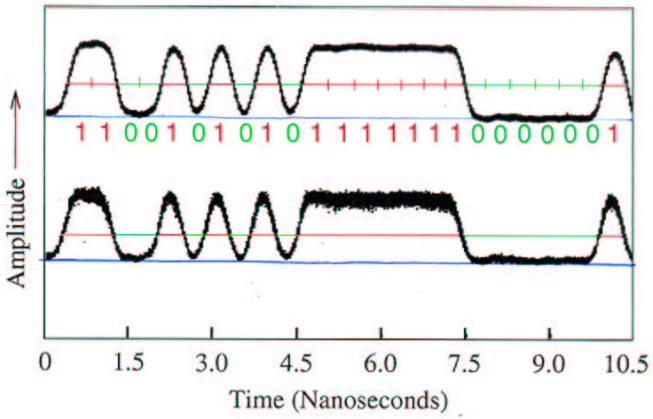
Front delay time:

$$t_{Front} = \lim_{\omega\to\infty} \varphi(\omega)/\omega$$

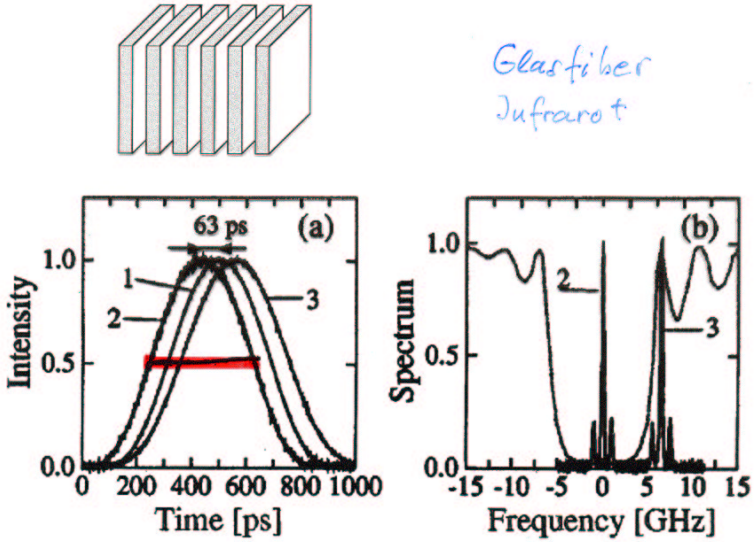
not defined in signals

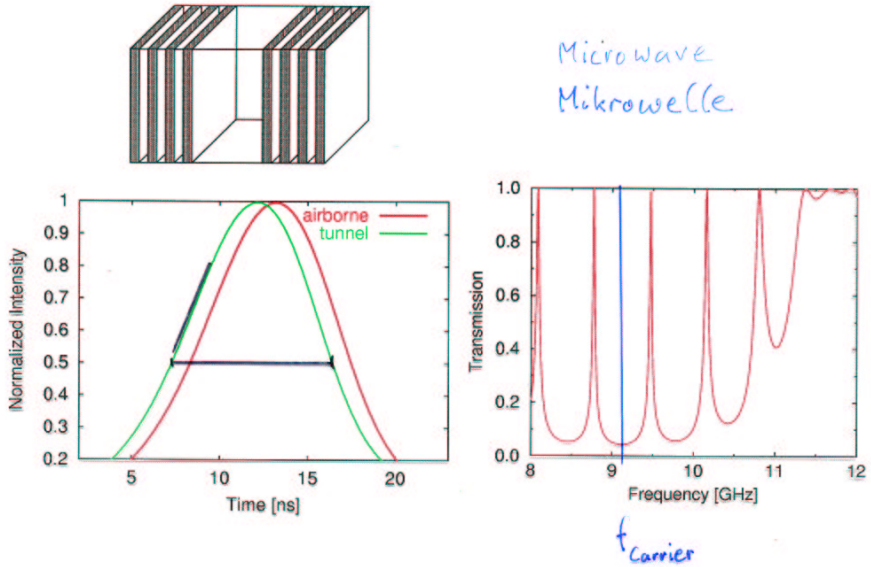


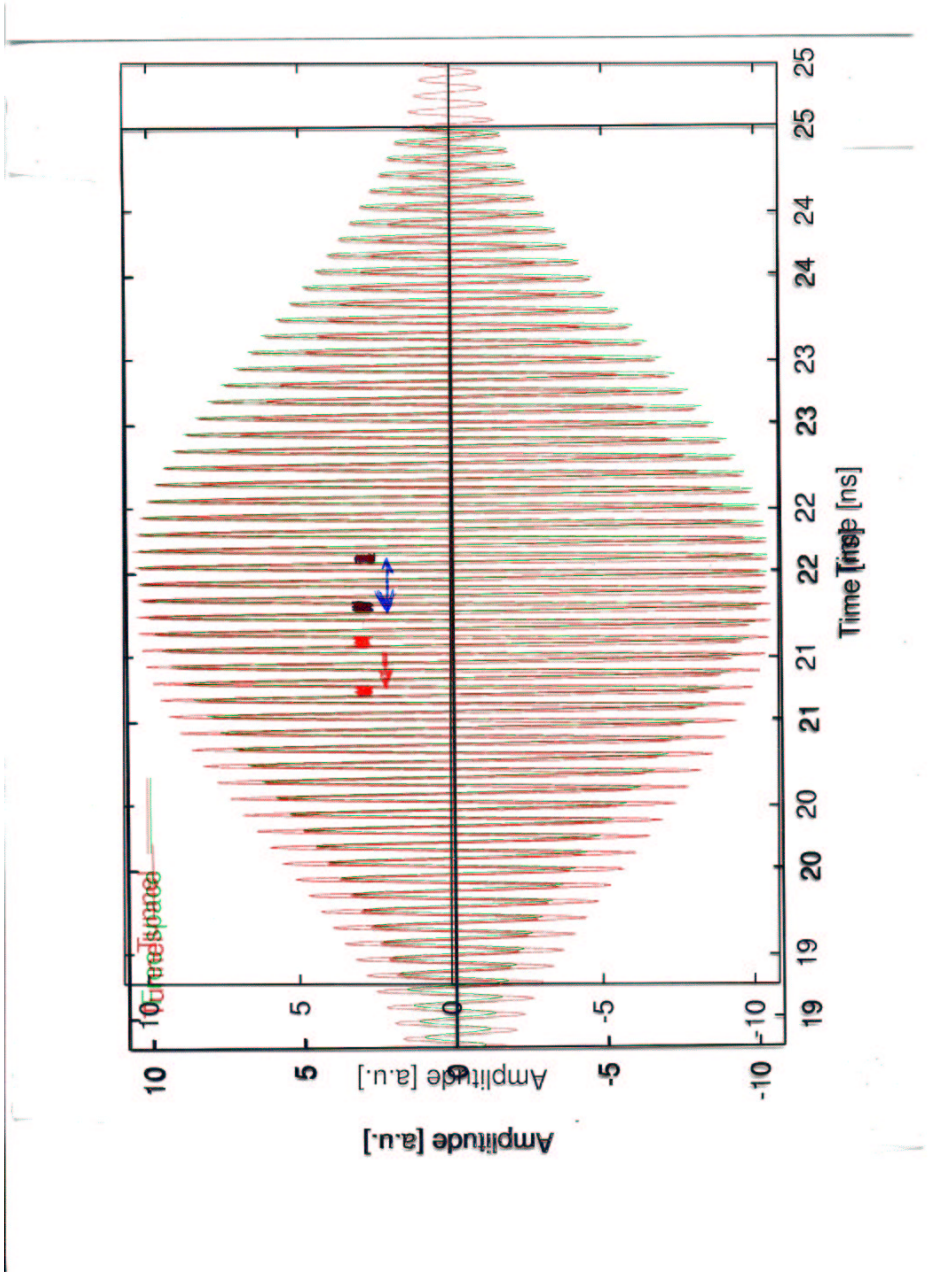
Digital fiber signals

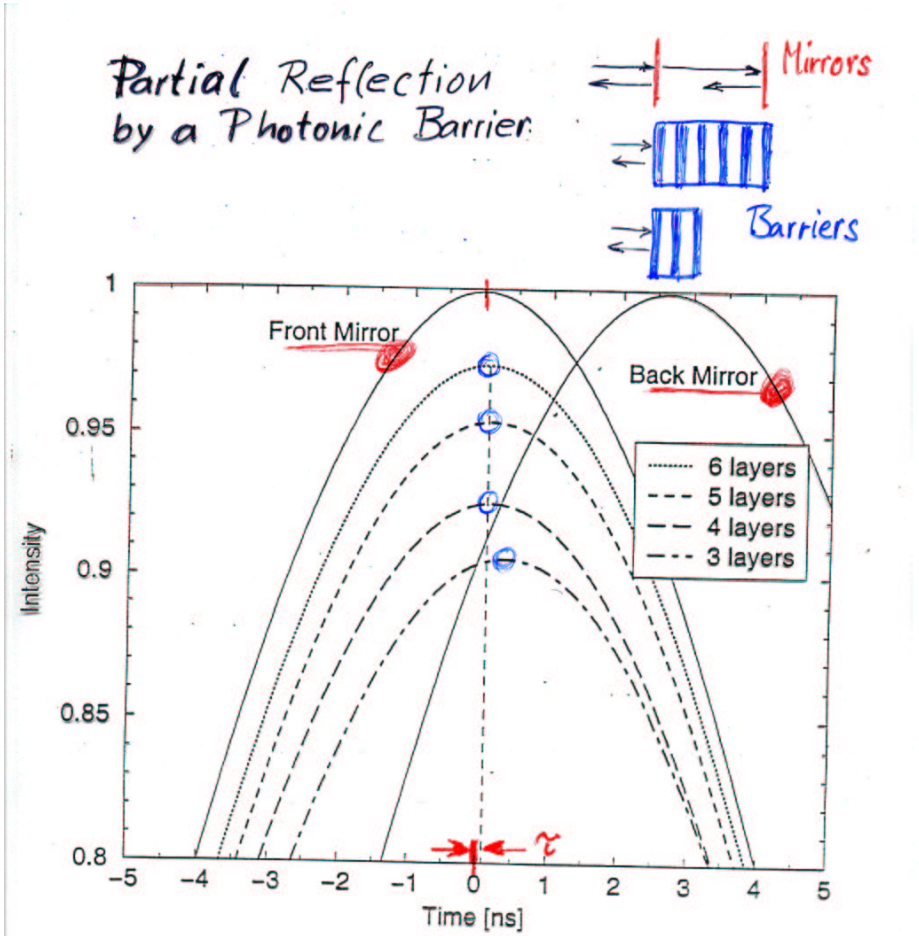


AM–Carrier: $2 \cdot 10^{14}$Hz $\triangleq$ 1.5 μm Wavelength


Glasfiber
Infrarot
63 ps
(a)
(b)
Intensity
Spectrum
Time [ps]
Frequency [GHz]


Microwave
Mikrowelle
airborne
tunnel
Normalized Intensity
Time [ns]
Transmission
Frequency [GHz]
f Carrier

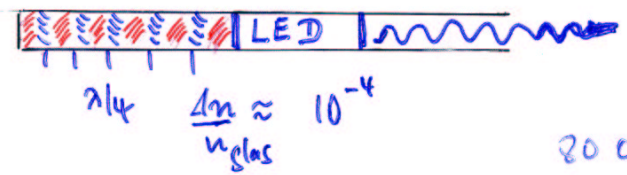

Amplitude [a.u.]
Time [ns]



Application of Superluminal Tunneling

Fiber Optics:

1. Mirrors for LEDs photonic lattice



20 000 layers
n = 1.400
n = 1.401

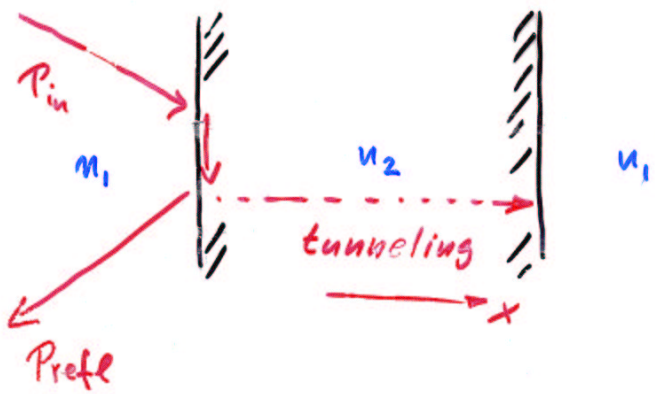
2. Superluminal Signal Transmission & Modulator

$v_{signal} \approx 2 \cdot c$

$\lambda = 1.5\ \mu m$

barrier = 200 mm

Measuring fast a distance x by FTIR: within τ!



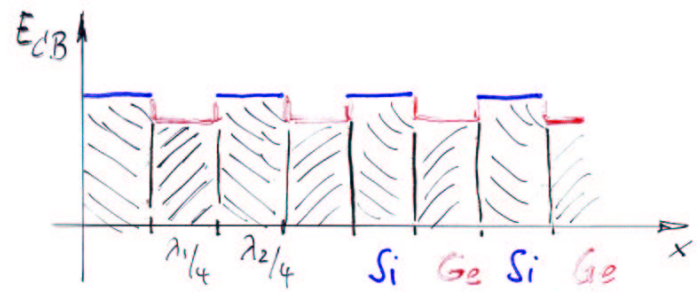
$$R = 1 - T = 1 - e^{\kappa x}$$

$$= f(x)$$

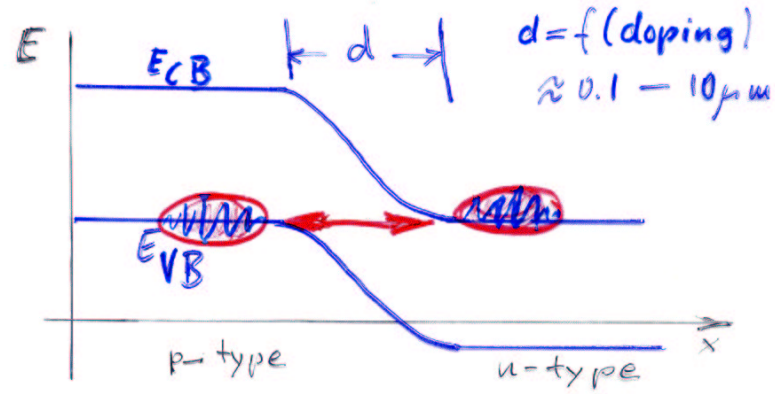
Electronics

1. 1D-electronic lattice

E_{CB} = conduction band,
periodic modulation Si/Ge



2. Interband tunneling, interconnections



SUMMING-UP

1. The tunneling proces allows energy and signal velocities to exceed:
   $v > c$.

2. Photonic and electronic tunneling time is universal:
   $\tau \approx T = 1/f$.

3. Tunneling is a nonloçal process.
   All informations on barrier hight and length are known within the tunneling time τ.

4. Superluminal tunneling has been observed in photonic and electronic barriers.

5. Superluminal velocities shorten the time span between cause and effect,
   however, they cannot be exchanged.
   No TIME MACHINE.

H. Aichmann, A. Haibel, P. Mittelstaedt, A. Stahlhofen, R.-M. Vetter

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