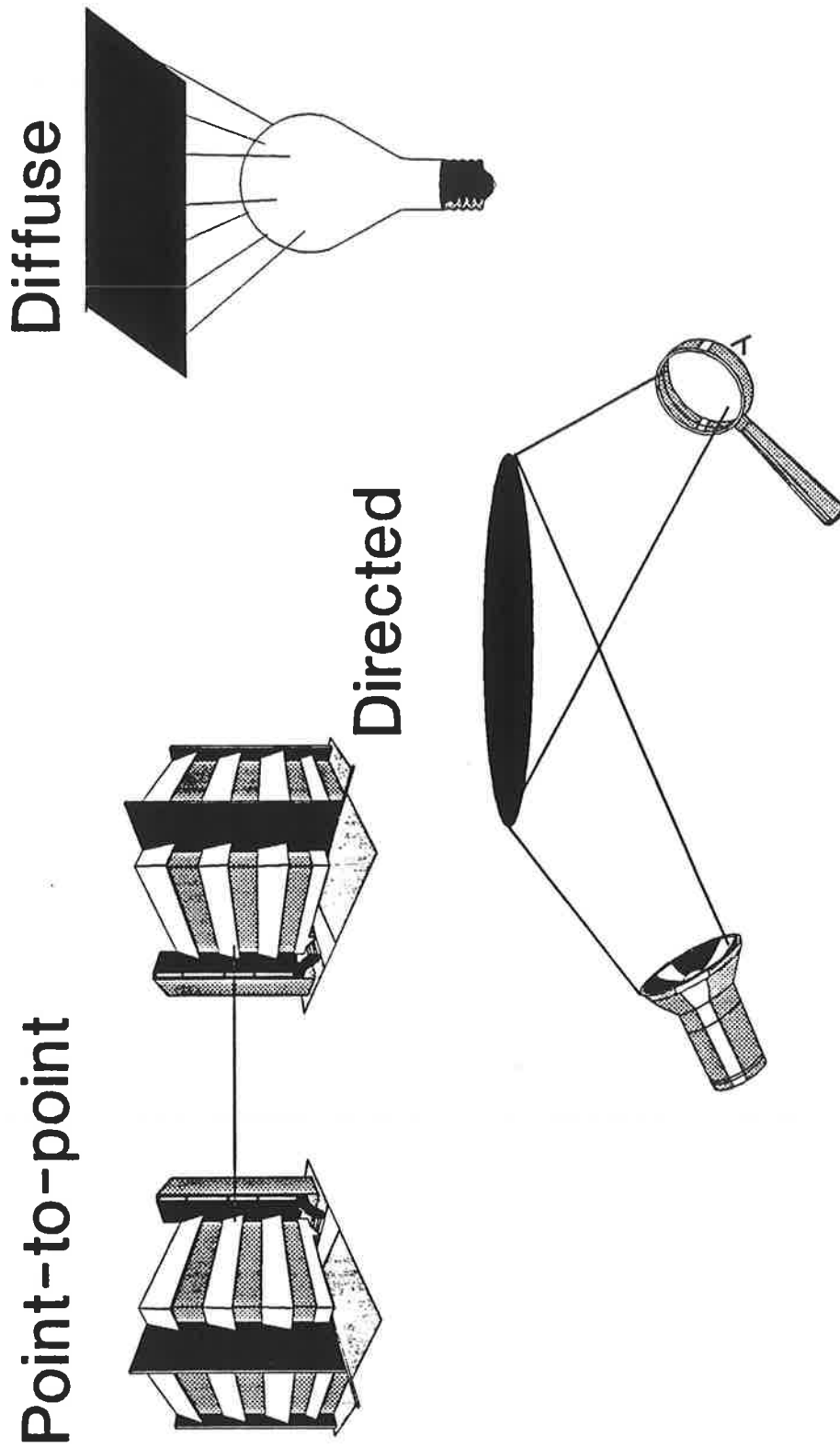


INFRARED WIRELESS NETWORKS

Presentation to IEEE 802.11
Hilton Head, SC
March 11-15, 1991

Richard C. Allen
President
Wireless Research

Infrared Types Description



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Infrared Types

Characteristics

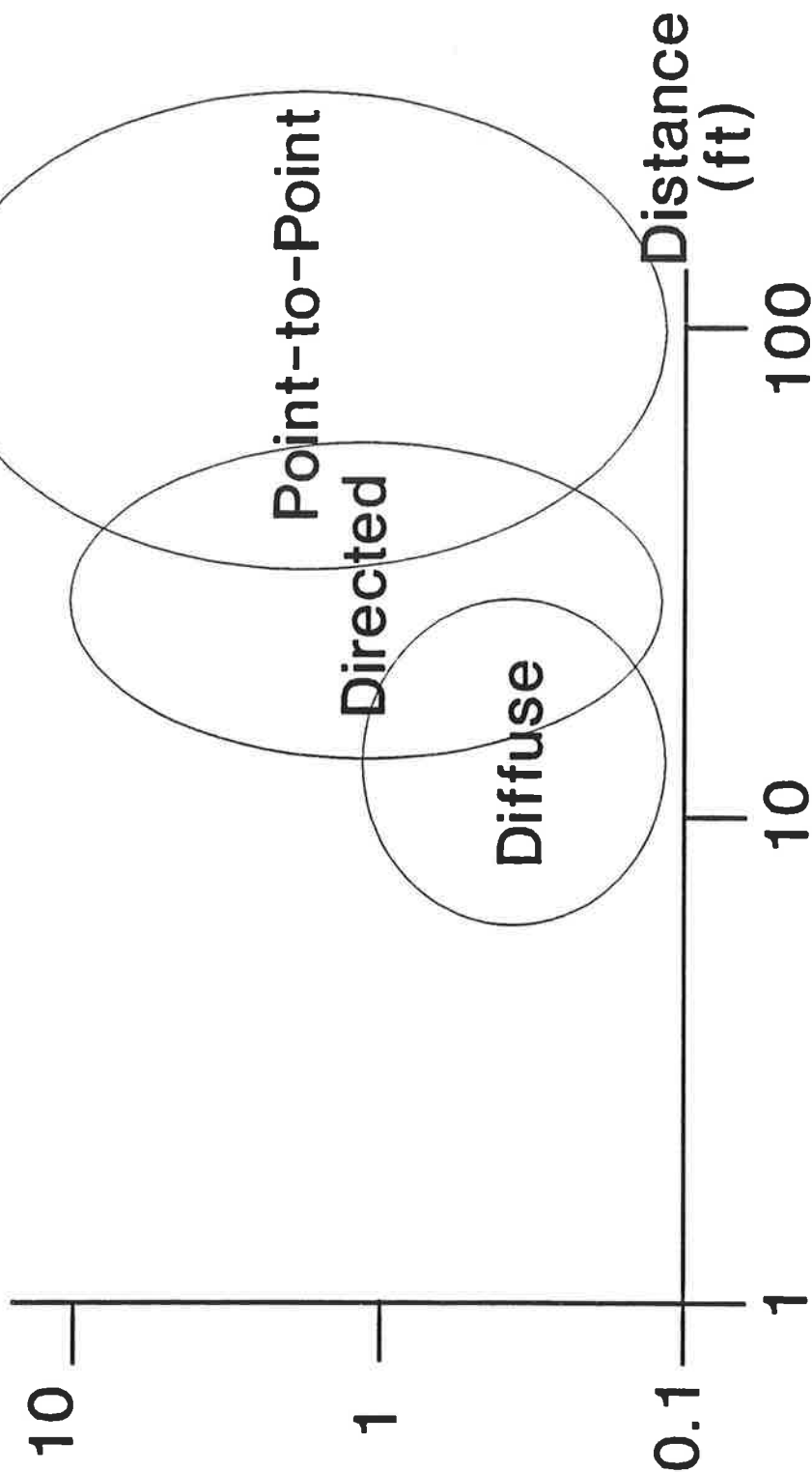
<u>Point-to-Point</u>	<u>Directed</u>	<u>Diffuse</u>
<u>Range:</u> 600ft+	70 ft	30 ft
<u>Speed:</u> >10 Mb/s	10 Mb/s	1-10 Mb/s
<u>Alignment:</u> Precision	Simple	None
<u>SNR/BER:</u> >20 dB; <10 ⁻⁸	>20 dB ; < 10 ⁻⁸	>20 dB ; <10 ⁻⁸
<u>Safety:</u> Safe(LED)	Safe	Safe
<u>Power:</u> 35 W (1)	35 W (1)	50 mW (2) 20 mW/kB (2)
	(1) AC Line Power	(2) DC Power

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Range & Speed

3 Infrared Systems

Speed (Mbit/sec)



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Infrared Types

Advantages

Point-to-Point

Maximum distance
Excludes interference
Power efficient
Secure indoors
Simple alignment

Directed

Efficient vs Diffuse
Many channels
Excludes
 interference
Minimizes shot noise
Secure indoors
Simple alignment
Line-of-sight not
 required

Diffuse

No aiming required

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Infrared Types

Disadvantages

Point-to-Point

Stopped by walls
Stray reflections
can self-interfere
Requires
line-of-sight

Directed

Stopped by walls

Limited range
Not well matched to
ring architecture

Diffuse

Stopped by walls

Very limited range

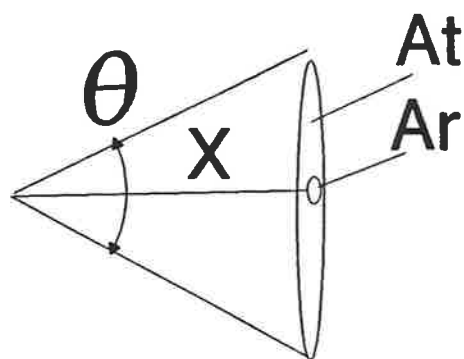
Limited speed
Single channel

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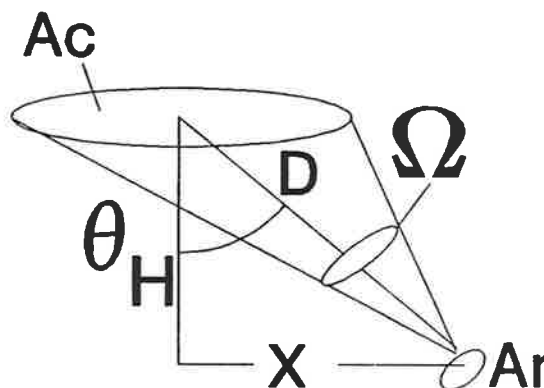
Signal Strength & SNR

Comparison of 3 types

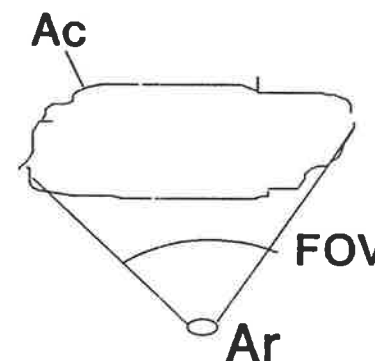
Point-to-point



Directed



Diffuse



Pr:

$$P_t A_r / \pi [X \tan(\theta/2)]^2$$

SNR vs P_t & X :

$$P_t^2 * X^{-4}$$

$$P_t H A_r / \pi X^3$$

$$P_t^2 * X^{-6}$$

$$P_t A_r [\sin(\text{FOV}/2)]^2 / A_c$$

$$P_t^2 \text{ (Independent of } X)$$

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In Wireless -- Small is Beautiful

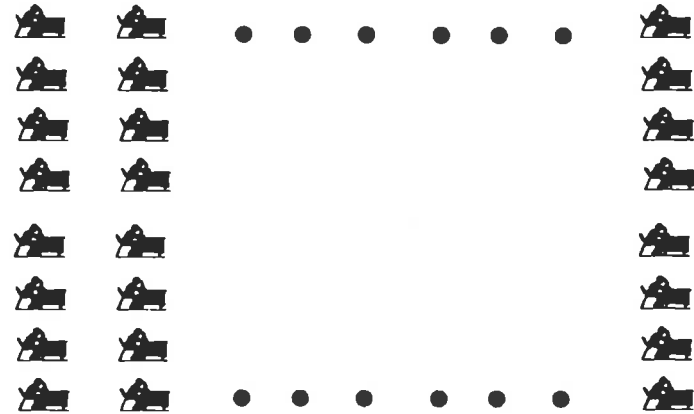
Shorter Range is Better



600 ft (183 M) Range

› 1400 Workers
on a SINGLE network
TOO MANY!

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70 ft (21 M) Range

20 - 40 Workers
on a SINGLE network
JUST RIGHT!
Link zones together
for full connectivity

Small is Beautiful (Cont.)

Shorter Range is Better

- Smaller network zones improve performance
 - Reduced contention
 - More parallelism
- Smaller network zones improve dependability
 - Less subject to system-wide outages
 - Easier fault isolation and repair
- Smaller network zones increase efficiency
 - Greater "frequency" reuse
 - Less interference between networks

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Infrared Doesn't Penetrate Walls

... but that's not all bad

- 2/3 of office workers are in open offices
- Confining IR signals improves security
 - Can't be intercepted by outsiders
- Minimizes interference between network zones
- Other through-the-wall solutions allow links
 - Short range radio
 - Cable

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Directed Multipoint Infrared

- First introduced by Photonics in 1989
- Uses small portion of office ceiling as passive reflector
- Physical layer device
 - Connects like cabling
 - Combines with cabling
 - Standard interfaces
 - Suitable for open offices

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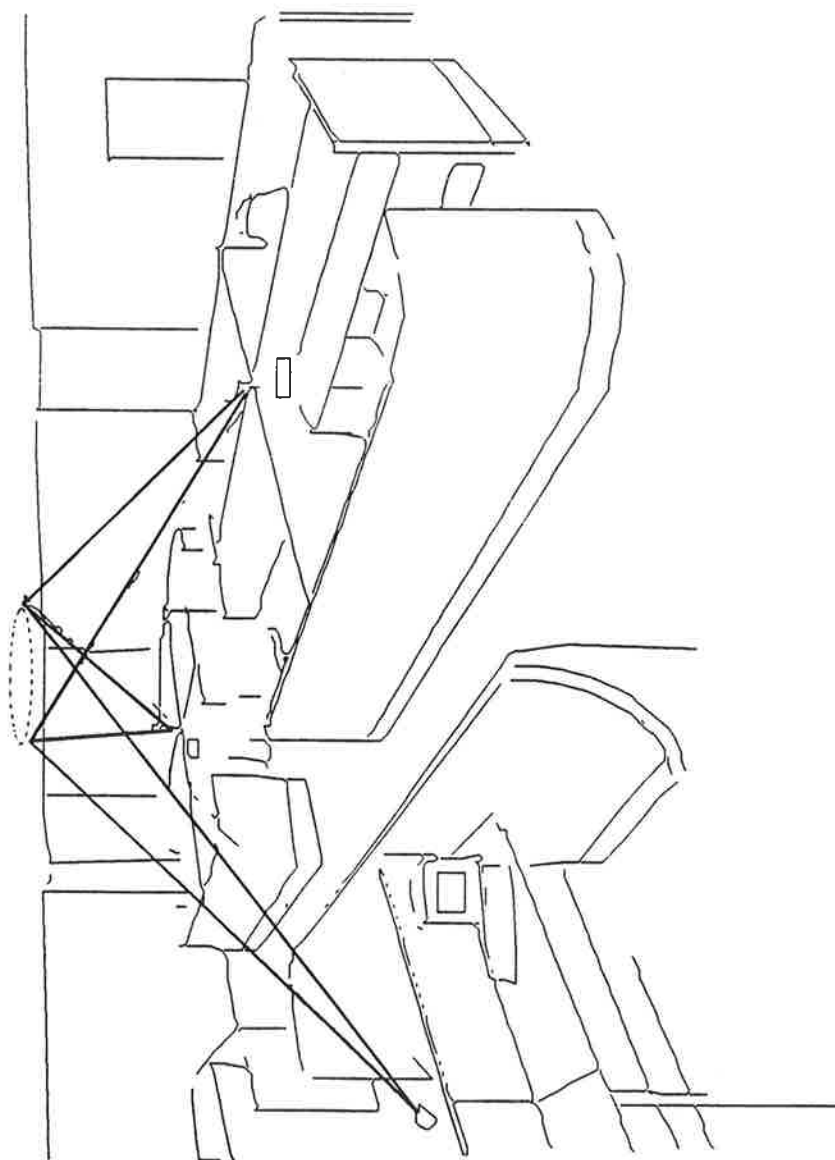
Directed Infrared Characteristics

- Economic < \$300 per node (\$1195 for a 4 port unit)
- User installable
 - No software required
 - No plug-in cards required
 - Simple alignment
- Permits multiple networks to coexist
- Speeds to 10 Mb/s (Ethernet interface)
- Secure
- Safe
- Immune to RF or self-interference

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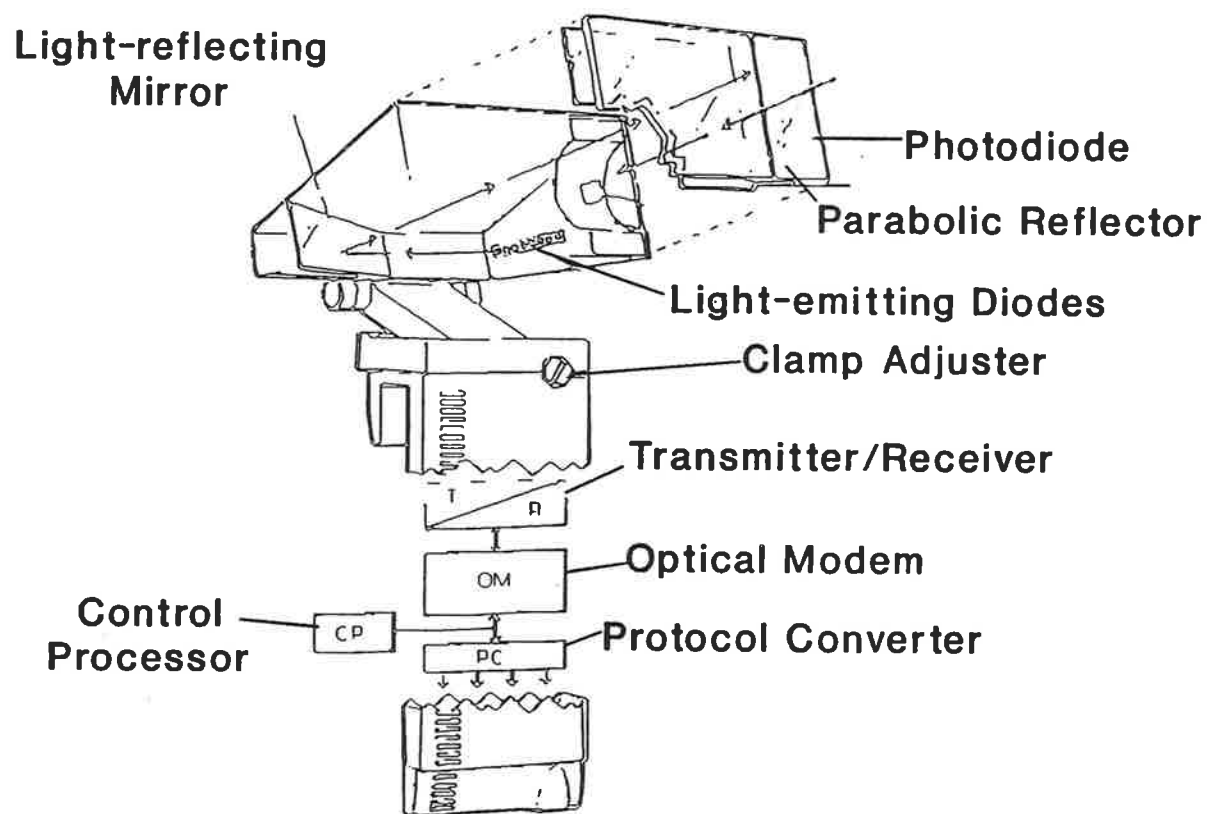
Open-Office Infrared Installation

Nothing on Ceiling 8 - 10 ft Spot



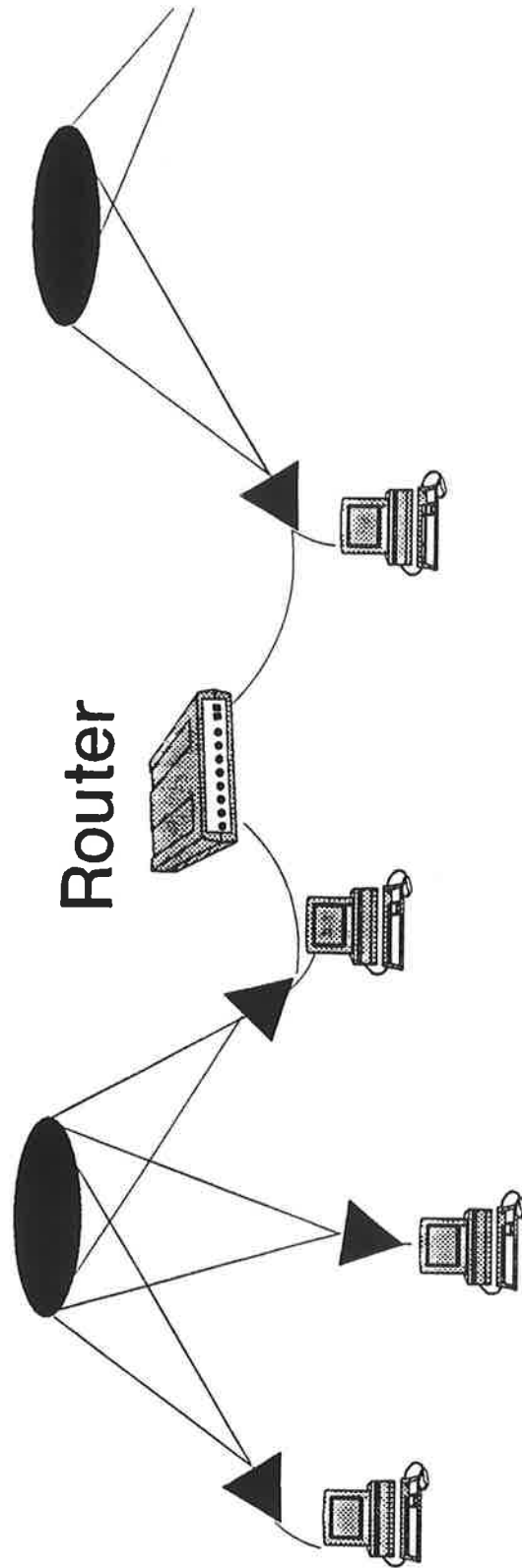
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Inside an Infrared Transceiver



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Infrared Network System Architecture



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Directed Infrared Dependability

How do you make it more dependable than cable?

- Resist blockage
 - Fan-shaped beams
 - Directed overhead
- Built-in error correction
- Indicator lights to aid troubleshooting

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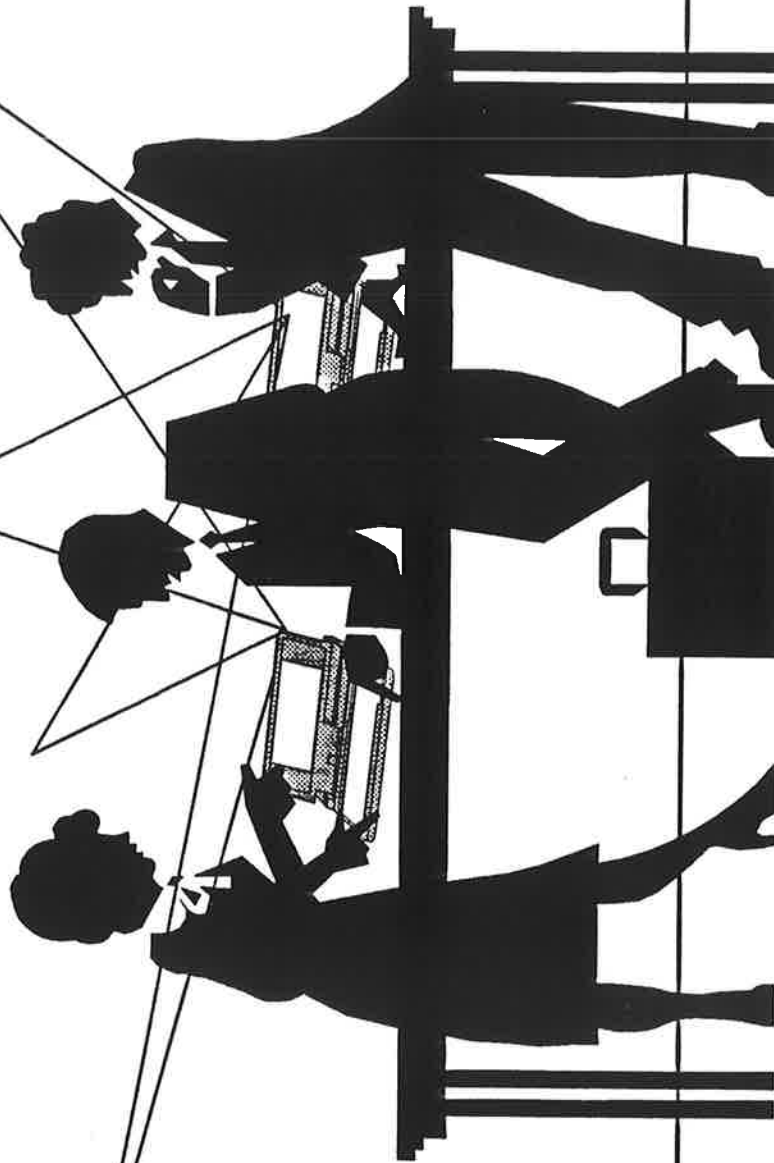
Directed Infrared Applications

Where should I use it?

- Local Area Networks
 - Open offices and manufacturing environments
 - Bus or star architectures (Ethernet or Appletalk)
 - High "churn" environments (project teams, auditors)
 - Temporary installations (leased facilities)
 - Security requirements
 - Disaster recovery
 - Repair of broken cabling
- Terminal-to-Host Connections
 - Open offices
 - 16 - 32 terminal clusters @ 9600 b/s
- Building-to-Building Links
 - Distances to 600 feet

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Diffuse Infrared "Flood" the room with IR



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Diffuse Infrared Characteristics

- Short range (< 30 ft)
- Low power (50 mW listening)
- Low cost (\$20 in OEM quantities)
- Moderate Speed (1 Mb/s)

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Diffuse Infrared Applications

- “Docking Station”
- Classroom training
- Conference room “Collaborative Computing”
- Cover larger areas using repeaters

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Alignment Methods

Permit easy installation

- Signal strength indicators
- Roll-call of infrared transceivers
 - Transparent to data traffic
 - Utilizes very little bandwidth
 - Assures network integrity (no hidden nodes)
- Diffuse systems require no alignment

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Infrared Access Methods

- CSMA
 - Point-to-Point, Directed or Diffuse systems
 - Collision detection possible with PPM
- Token Ring
 - Point-to-Point systems
- Token Passing Bus
 - Point-to-Point, Directed or Diffuse systems

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Power Requirements

- Typical directed or diffuse transceiver
 - 10 LEDs of average (<5%) efficiency
 - Pulse Position Modulation
 - 1 Mbit/sec data rate
 - 20 mW-sec/kilobyte
- Energy per data unit sent is the proper measure
 - Transmit duty cycles can vary among applications
 - Indicates battery drain for portable units
- "Listen" power can be as low as 50 mW
 - Rises during data reception
- Varies with level of circuit integration

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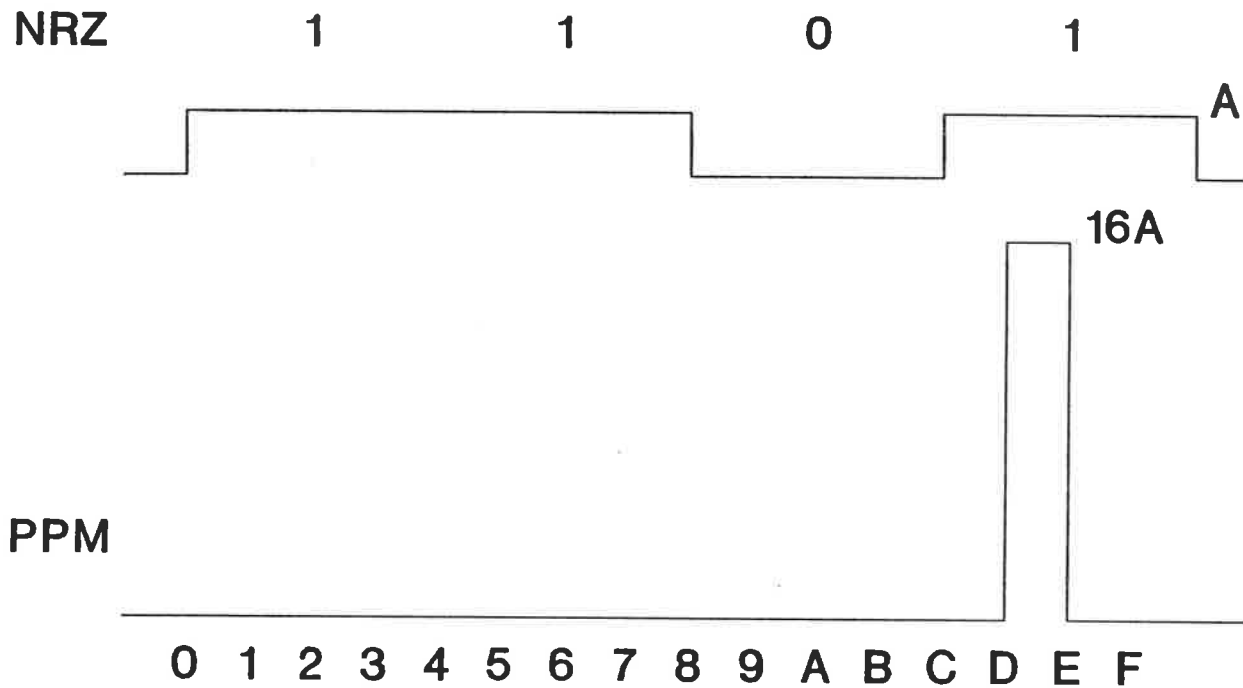
Infrared Noise Sources

- External noise sources
 - RF energy (eliminated by shielding)
 - External light sources (minimize by optical filtering)
 - + Produce shot noise
 - + Sunlight
 - + Incandescent lights
 - + Fluorescent lights
- Internal noise sources
 - Preamplifier noise
 - + Noise power rises as 3.0 power of bandwidth
 - Shot noise from Photodiode dark current (negligible)
 - Thermal noise from feedback resistance
 - + Shot & thermal noise power
rises as 1.0 power of bandwidth

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IR Modulation Methods

Pulse Position Modulation is Optimum



Permits erasure detection
Permits collision detection
Maximizes SNR



$P_{ppm}/P_{nrz} = 16$
 $SIGNAL_{ppm}/SIGNAL_{nrz} = 256$
 $BW_{ppm}/BW_{nrz} = 4$
 $SNR_{ppm}/SNR_{nrz} = 64 (+18 \text{ dB})$

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Infrared Suppliers

<u>Supplier</u>	<u>IR Type</u>	<u>Customer Type</u>
Photonics	Directed Diffuse	End-user OEM
BICC	Point-to-point	End-user
Texas Instruments	Diffuse	OEM/Custom
Spectrix	Diffuse	OEM/Custom

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Why Wireless Infrared?

- Ideal for portable applications
 - Low cost
 - High speed
 - Low power
- Completely eliminates wiring
- Links to other devices/networks
 - Desktop PCs
 - Wired or wireless networks
 - Nationwide packet radio nets
 - Cellular modems
 - Peripherals

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Infrared Summary

- Fast
- Economical
- Interference-Free
- Easily Installed
- Dependable
- Unregulated

-- For the open environment.

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Diffuse IR Suitability for Portable Power

e.g., LAPTOP w/ 7.2V, 1700mA-Hr = 12,240mJ
 Typical Battery life 2-3 hr
 Average Power 4.1-6.1 W

Diffuse IR modem IMPACT on life:
 ~1% LISTENING
 ~2%-10% MIX OF Send/Recv.

PRICE/COST

e.g. LAPTOP LIST PRICE	\$2000
Wireless modem %	10% - 20%
Wireless LIST	\$200 - \$400
DIST. Channel Discount	40% - 50%
MFG Sell Price	\$100 - 240
MFG. Gross Margin	40% - 50%
MFG. COST	\$60 - \$120

Diffuse IR can be built-in for
 \$20 - \$30

DIFFUSE IR vs Microwave Radio

SIMILARITIES & DIFFERENCES

& SO WHAT?

SIMILARITIES

- BROADCAST Media
- Limited Range
- PROTOCOLS can be the same

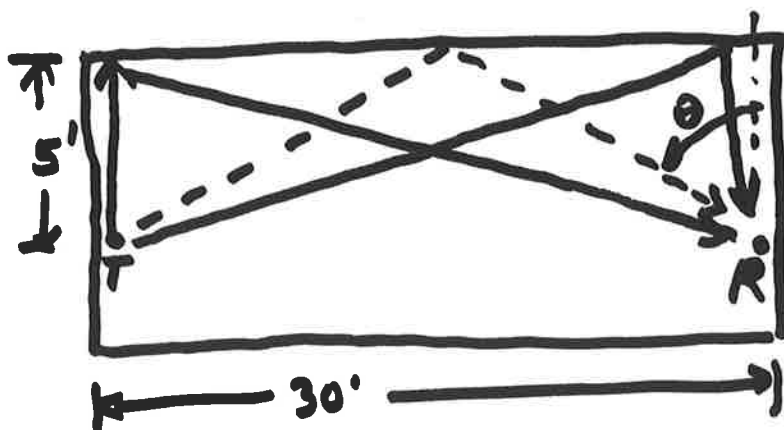
SO WHAT?

IT SHOULD BE
EASY TO
DESIGN A MAC
FOR BOTH

DIFFERENCES

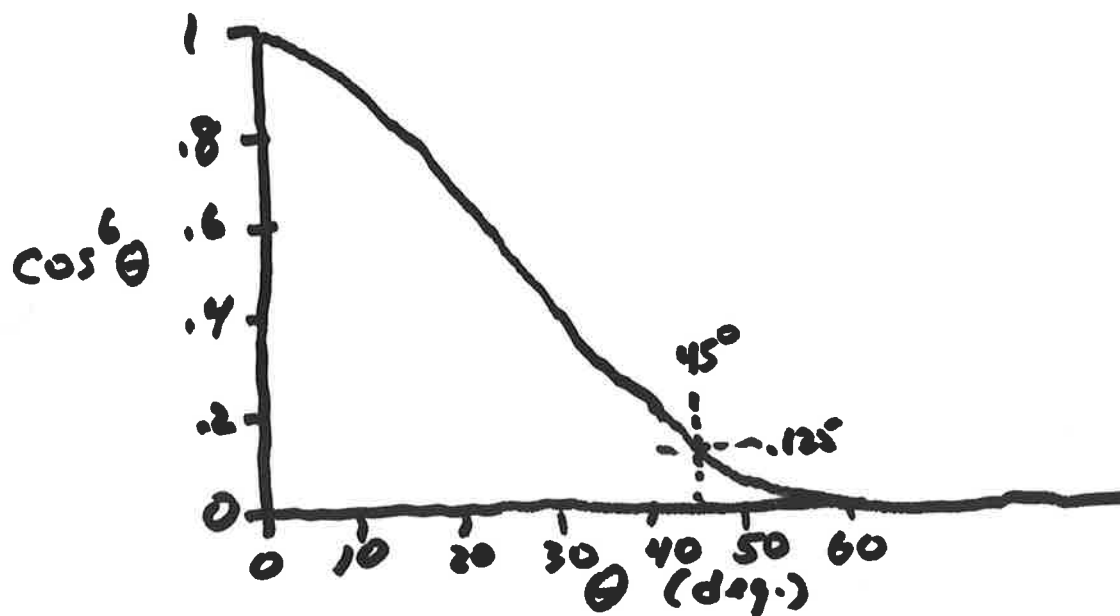
- INCOHERENT IR
 - LOSSY REFLECTIONS
compared to microwave
(diffuse vs specular)
(dielectric)
 - Signal Power varies as
2nd Power of Optical Signal
Power
 - LESS "OPEN" PHY
- No phase cancellations
- Higher attenuation
vs Distance
- Reduced
effects of
delay spread
- Fewer 'Secondary'
Users
(more easily
excluded)
more easily
secured

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**SIMPLE
MODEL**

**NOT: Incoherent
SOURCE
NO phase
cancellation**



X (5' centering)

$$X = 5 \tan \theta$$

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OPTICAL VS ELECTRICAL SIGNAL POWER



$$i_R = k P_{OPT}$$

$$P_{R_{elec}} = (k P_{OPT})^2 R$$

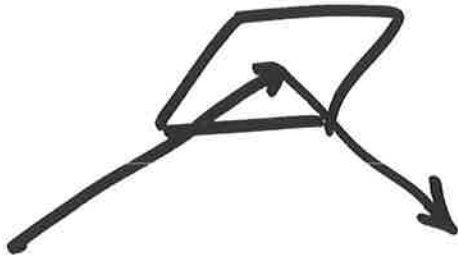
since $P_{OPT} \propto \cos^3 \theta \propto \frac{1}{x^3}$

$$P_{R_{elec}} \propto \cos^6 \theta$$

$$P_{R_{elec}} \propto \frac{1}{x^6}$$

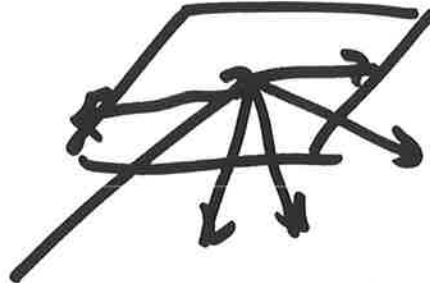
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DIFFUSE VS Specular Reflection



Specular

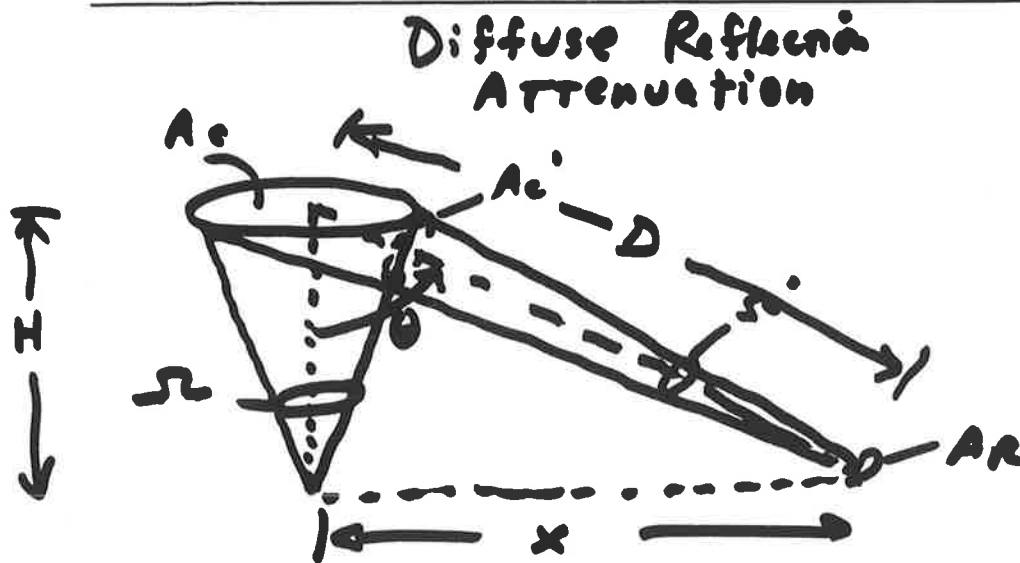
$$\theta_{in} = \theta_r$$



DIFFUSE

LAMBERTIAN (cos²)
DISTRIBUTION

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$$D = H / \cos \theta$$

$$A_c' = A_c \cos \theta$$

$$\Omega' = \frac{A_c}{H^2} \cos^3 \theta$$

$$P_{R_{opt}} = \frac{P_T}{\pi H^2} \cos^3 \theta A_R$$

(IF $H \ll x$:

$$P_{R_{opt}} \approx \frac{P_T}{\pi} \frac{H}{x^3} A_R$$

(IF FOV @ A_R includes all A_c)

NOTE: IF Room interior is uniformly illuminated

$$P_{R_{opt}} = w A_R \sin^2\left(\frac{FOV}{2}\right)$$

where w is ceiling optical power density

This is independent of position

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