Opportunities and Challenges for 60 GHz Wireless Communication

Presented at: 1998 Asia Pacific Microwave Conference
Yokohama, Japan
11 December, 1998

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Gbps Free Space Interconnects with 60 GHz Unlicensed Radio

Presented at: 11th Annual Workshop on Interconnections Within High Speed Digital Systems

Santa Fe, NM

23 May, 2000

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Communications and Optics Research Laboratory
Agilent Laboratories
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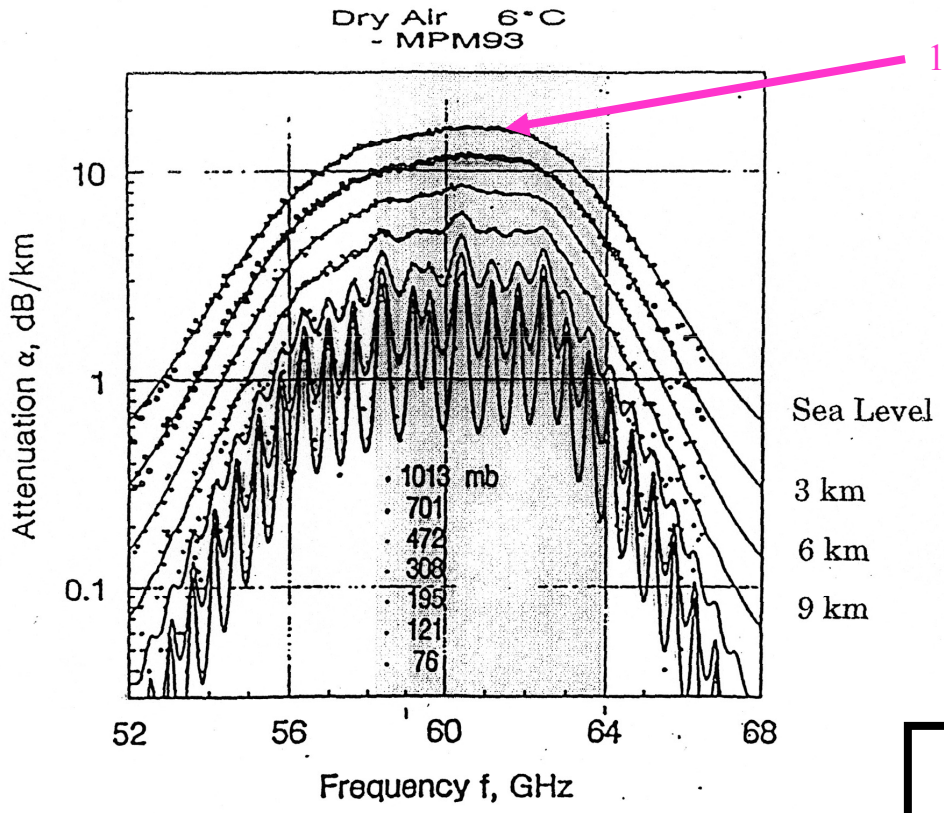
Nature Has Created a Short Range Band

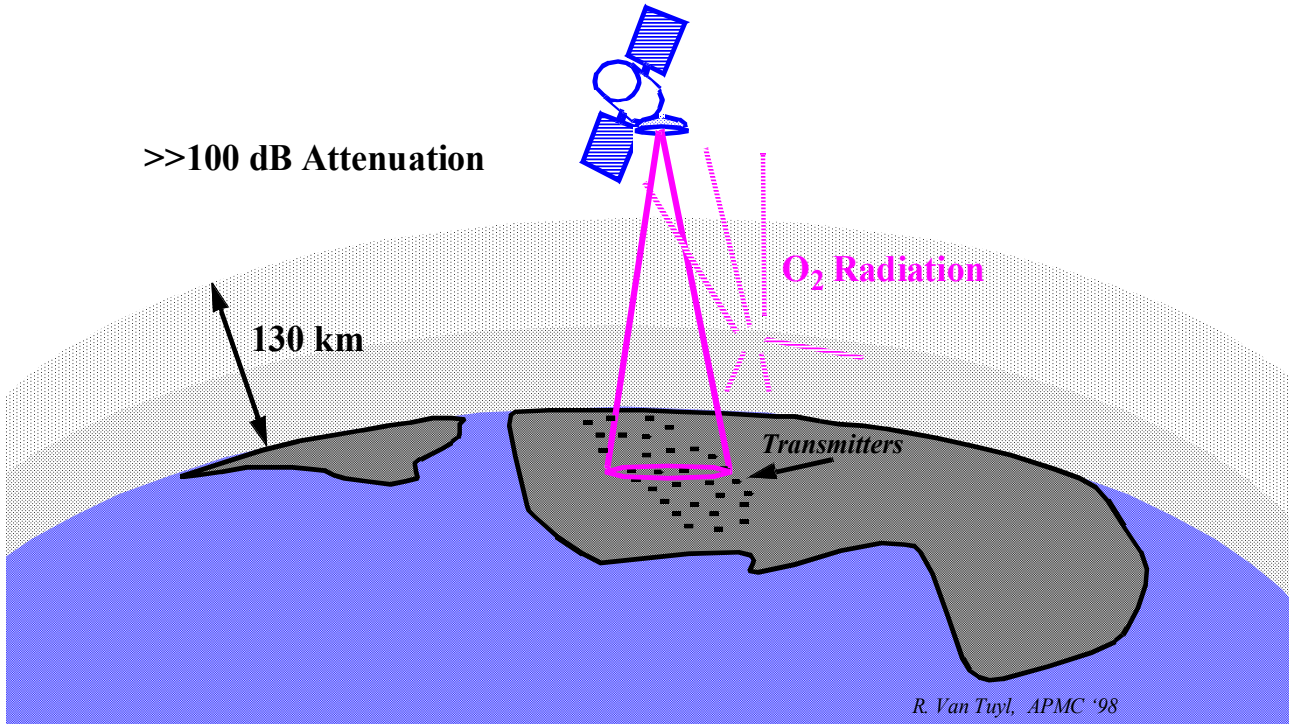
.....56 - 64 GHz is Severely Range-Limited by Oxygen



For Details of this study, contact US Dept. of Commerce,
NTIA/ITC, Boulder, CO, USA.

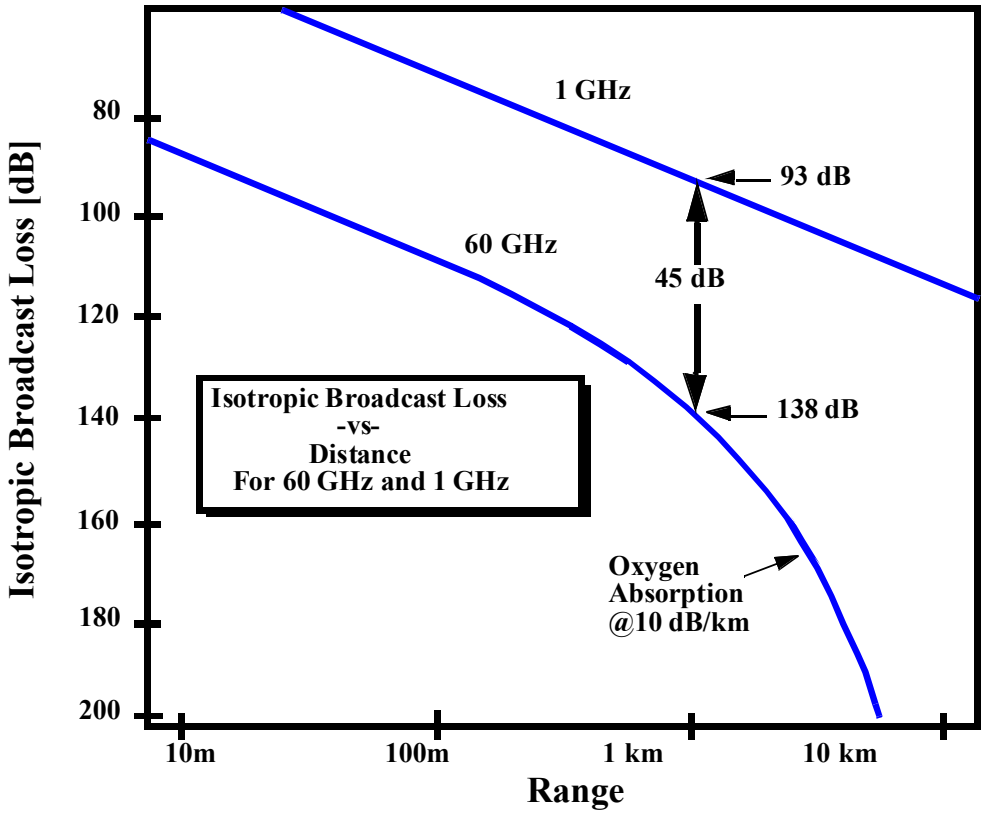
Source:
H.J. Liebe et al.,
1993 AGARD
Conference Proceedings

Terrestrial Transmitters
Can Not Interfere With Satellites.....



Terrestrial Range is Limited

.....60 GHz Compared to 1 GHz



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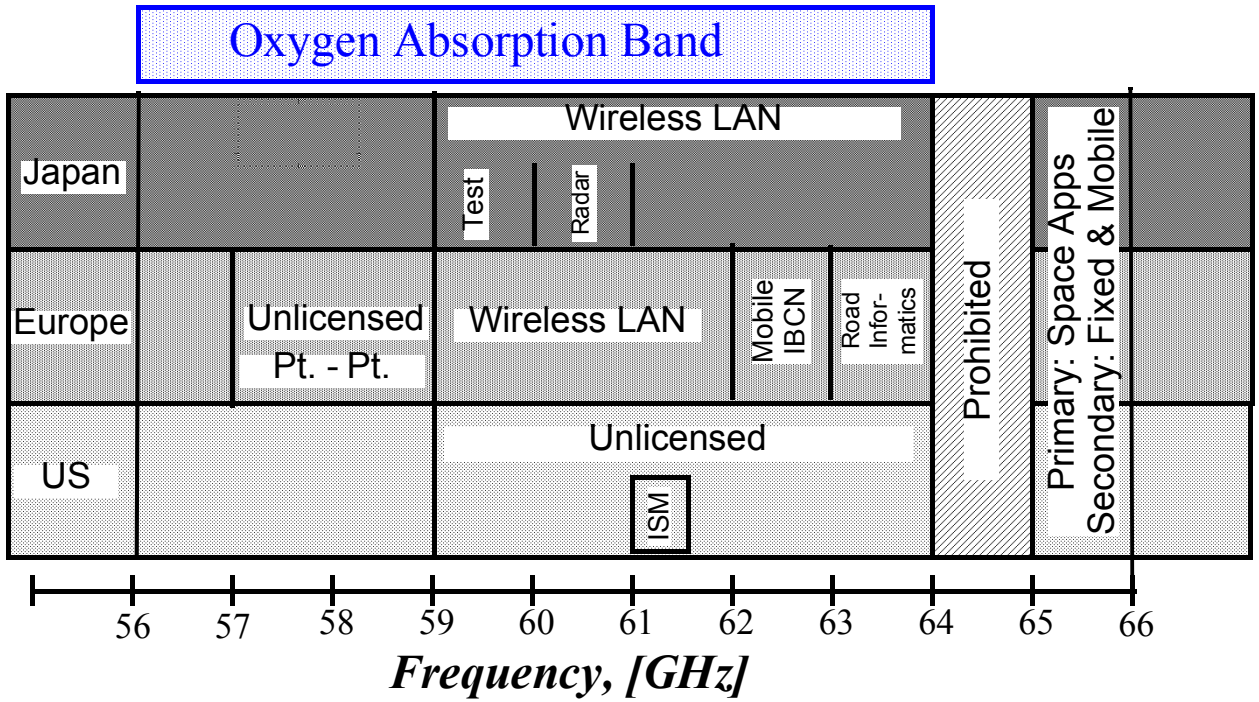
International Spectrum Allocations

.....Present and Proposed



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Are 60 GHz mmWaves Safe?

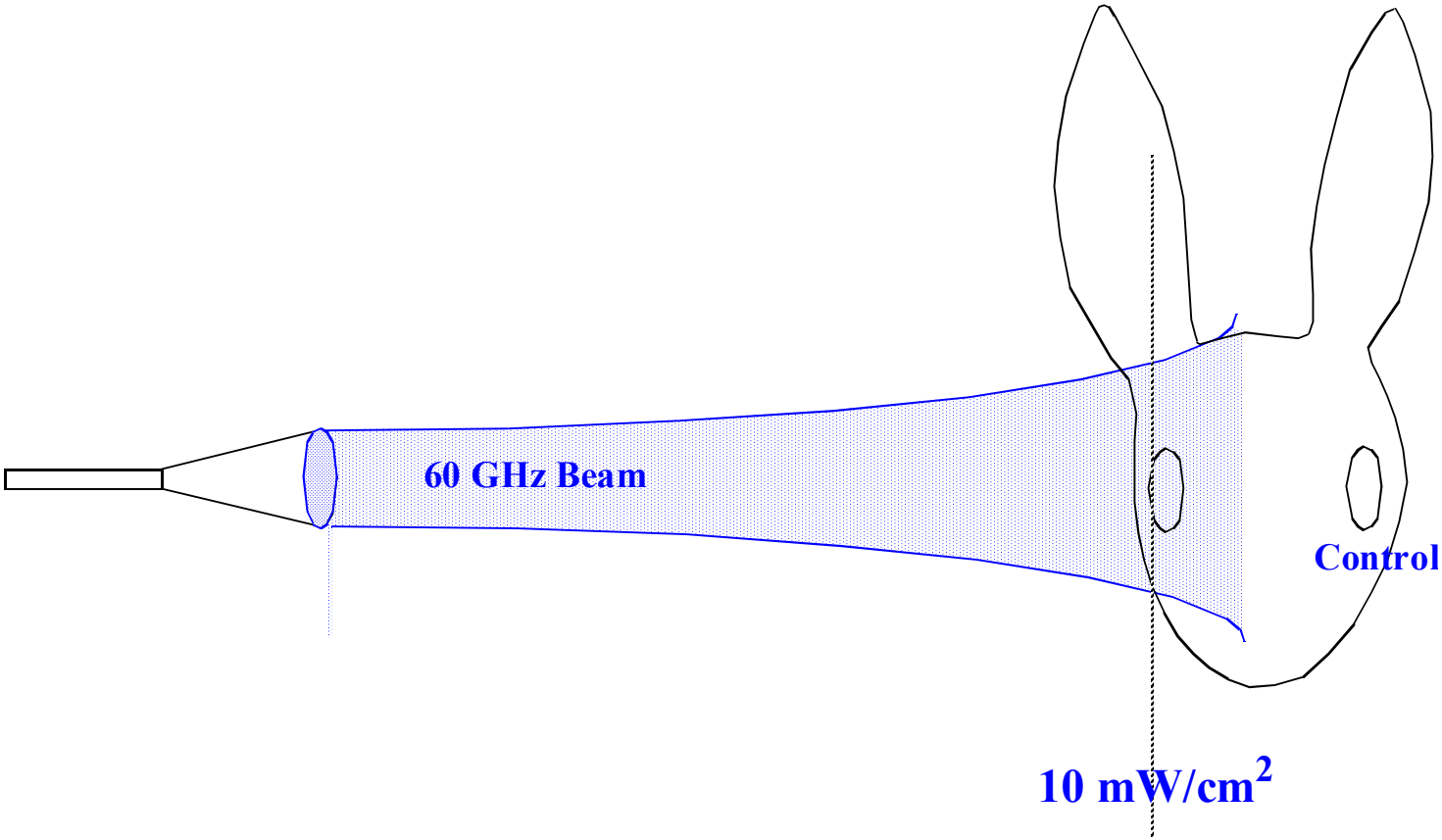
If There Were a Problem, It Would

Be With the EYE

Recently, Johns Hopkins Applied Physics Laboratory Has Studied the Question

Reference: Kues, H.A. et al., "Absence of Ocular Effects Following Either Single or Repeated Exposure to 10 mW/cm^2 from a 60-GHz Source," submitted to *Bioelectromagnetics Journal,* for 1999 Publication. For details, contact Henry A. Kues at Johns Hopkins University Applied Physics Laboratory: [hak@aplcomm.jhuapl.edu].

Johns Hopkins Experimental Setup



Are 60 GHz mmWaves Safe?

If There Were a Problem, It Would Be With the EYE

Recently, Johns Hopkins Applied Physics Laboratory Has Published Results of a Study which Indicates that 60GHz waves are Eye-Safe at Power Densities 10x Greater than the FCC Legal Limit

Reference: Kues, H.A. et al., "Absence of Ocular Effects Following Either Single or Repeated Exposure to 10 mW/cm² from a 60-GHz Source," ***Bioelectromagnetics*****, 20:463-473 (1999).**

Applications for 60 GHz Wireless Communications

Indoors:

Wireless Lans

Point-to-Point Links

Sensors

Outdoors:

Point-to-Point Data Links

Wireless LANs at 60GHz

.....Are they Possible and Useful?

Positives:

Compact Antennas are Possible

Very High User Data Rates are Practical

Highest Aggregate System Data Rate

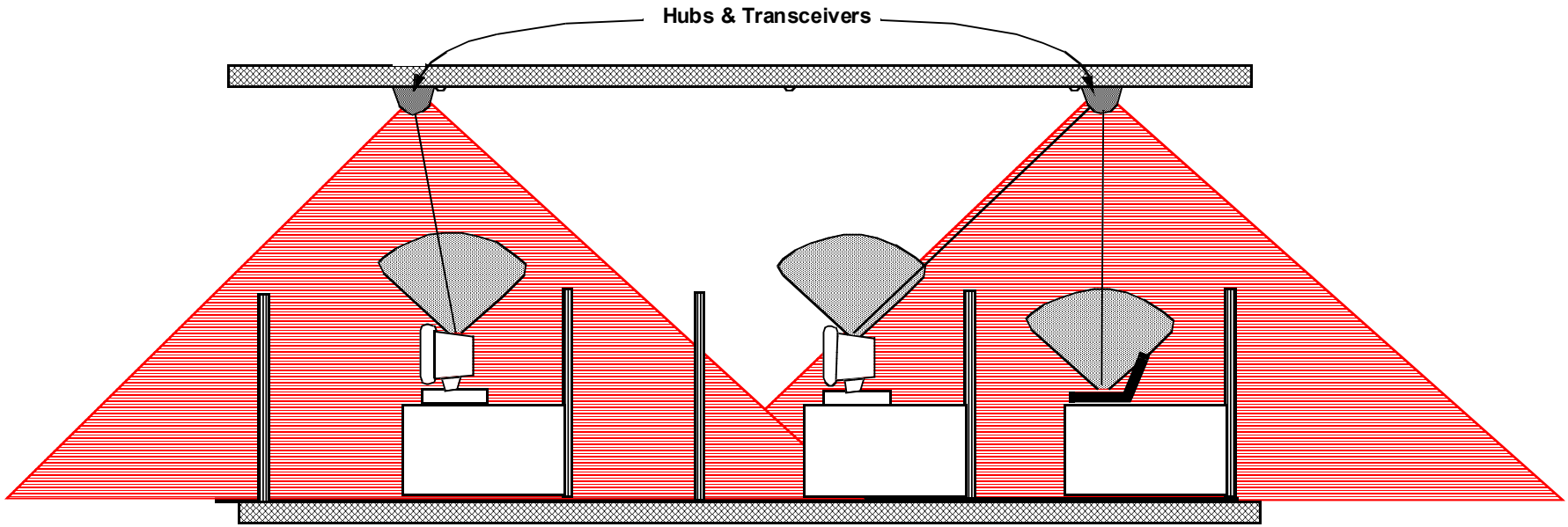
Negatives:

Range is Short

Line-of-Sight Required in Most Cases

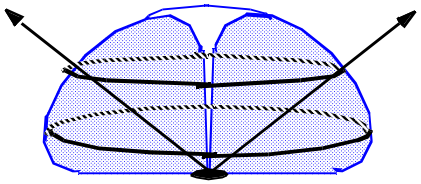
Wireless LANs in Offices

.....A Ceiling Mounted Network

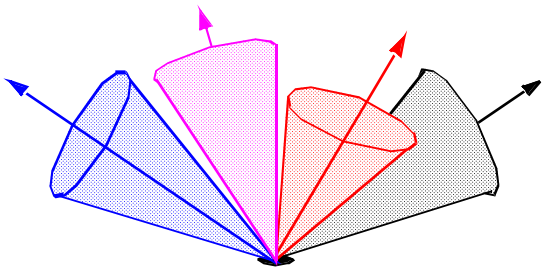


Useful Antennas for Wireless LAN

Up-Tilted Omni



Steerable Four Sector Patch



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60GHz Office Environment Channel Sounder

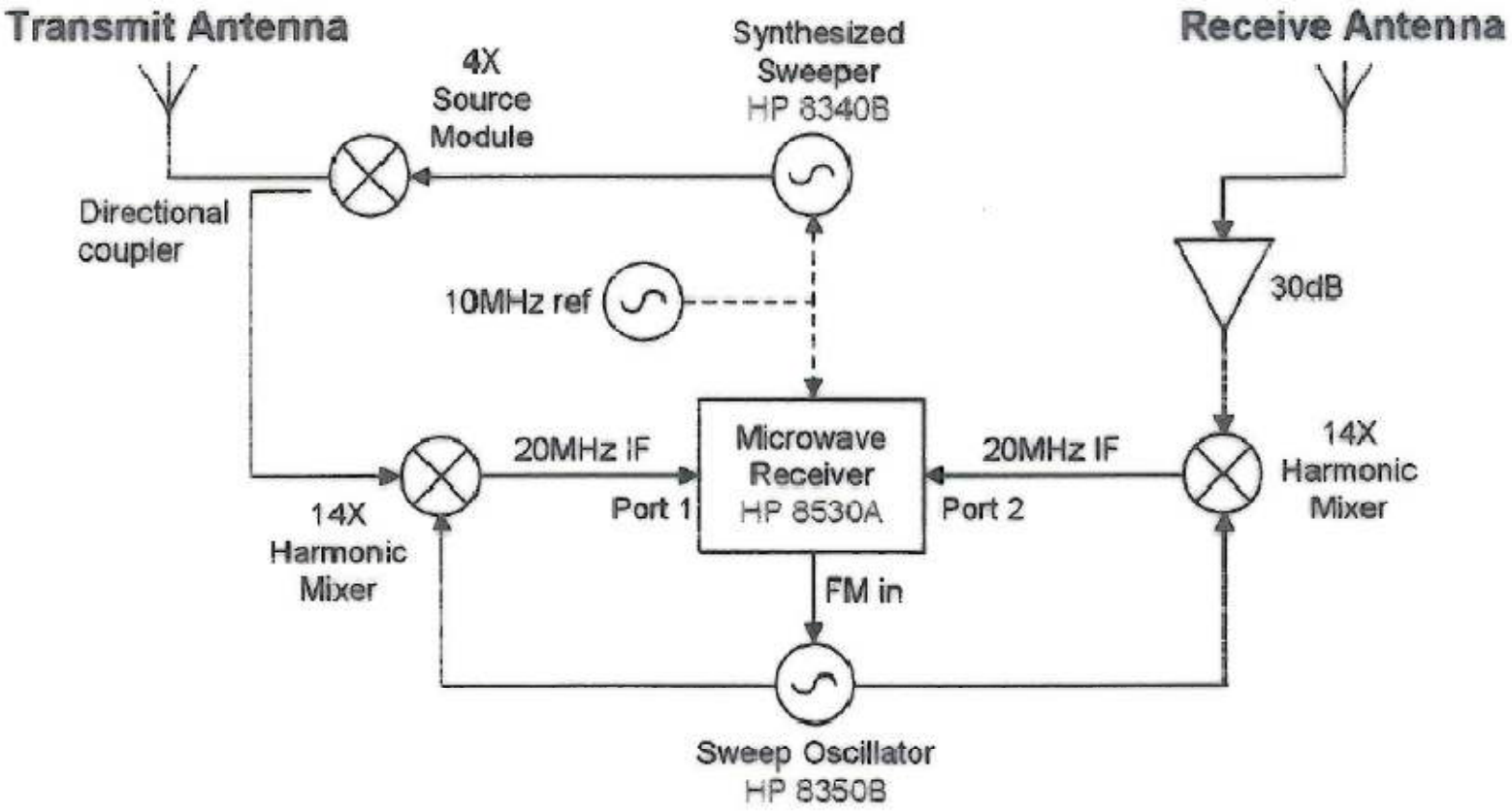
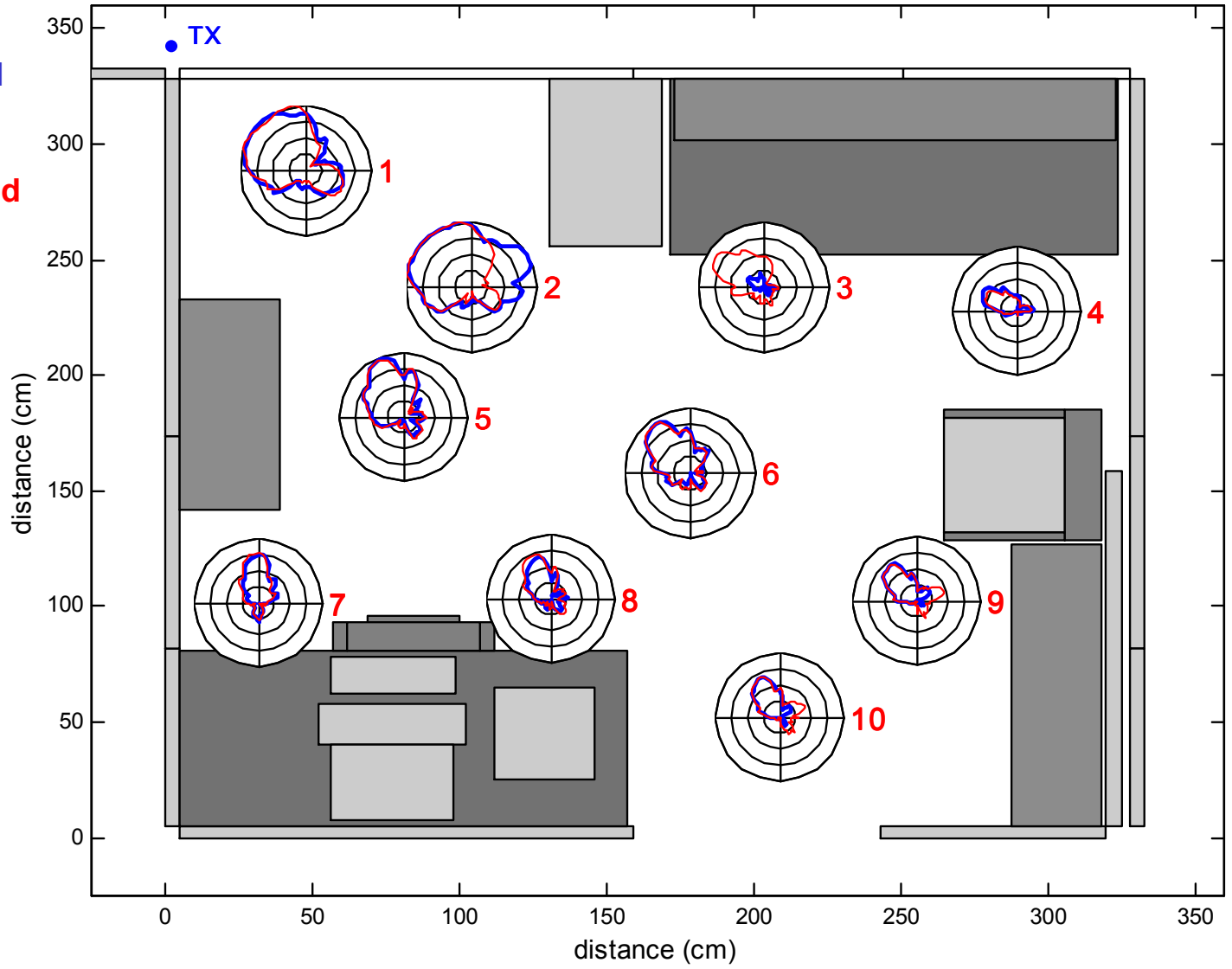


Figure 2.1 Measurement Setup

60 GHz Measurements in a Typical Office Cubicle

Angular Variation in Received Power



Furnished

Unfurnished

6dB/Division

Maximum
-60 dBm

Minimum
-90 dBm

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2.4 Example Measurement

Figure 2.4.1 shows a typical frequency domain response over the 58-62GHz range, in this case using a 90° directional antenna at the transmitter and an omni-directional antenna at the receiver. This measurement was taken over a distance of 3m in a small, empty cubicle environment with the transmitter pointed directly towards the receiver. The multipath effects give rise to nulls across the measured range, with a depth of up to 20dB.

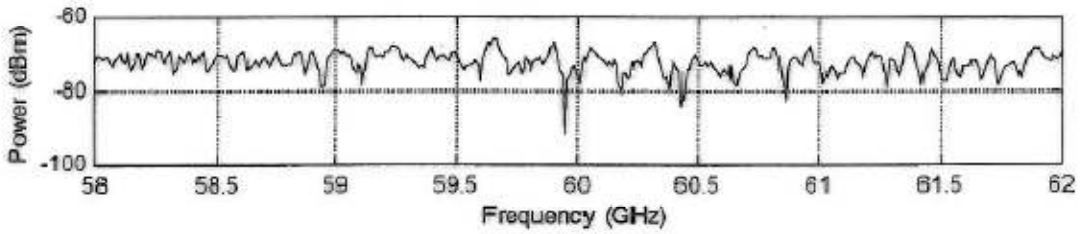


Figure 2.4.1 Typical Frequency Domain Response

Figure 2.4.2 shows the corresponding time domain after the frequency domain data has been windowed and the IDFT performed. By convention this report refers to the **power delay profile** when the time domain is shown on a power scale and the **impulse response** when voltage is displayed. For this particular measurement the total received power is –71.9dBm, the power in the LOS component is –72.6dBm, the RMS delay spread is 3.3ns and the K-factor is +7.0dB.

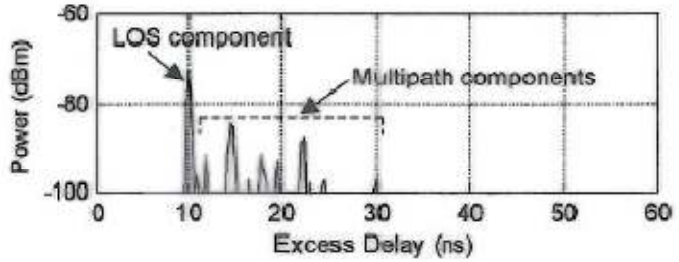


Figure 2.4.2 Typical Time Power Delay Profile

The LOS component arrives after an excess delay of 10ns, corresponding to the direct path length of 3m. A number of multipath components can be seen to arrive with power greater than –100dBm. The first multipath component arrives

minimum value (0.3ns) whilst the K-factor is at its maximum (+18.4dB). Once again we see a second signal component arriving after a further 2ns, having been attenuated by around 20dB. This represents a reflection off the ceiling.

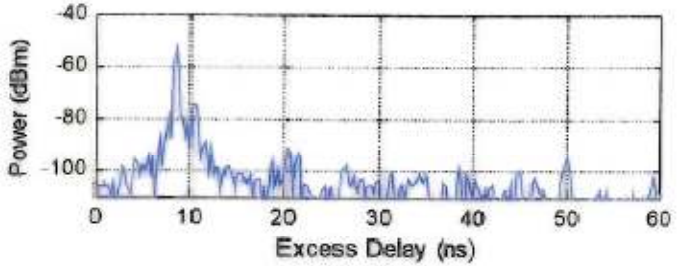
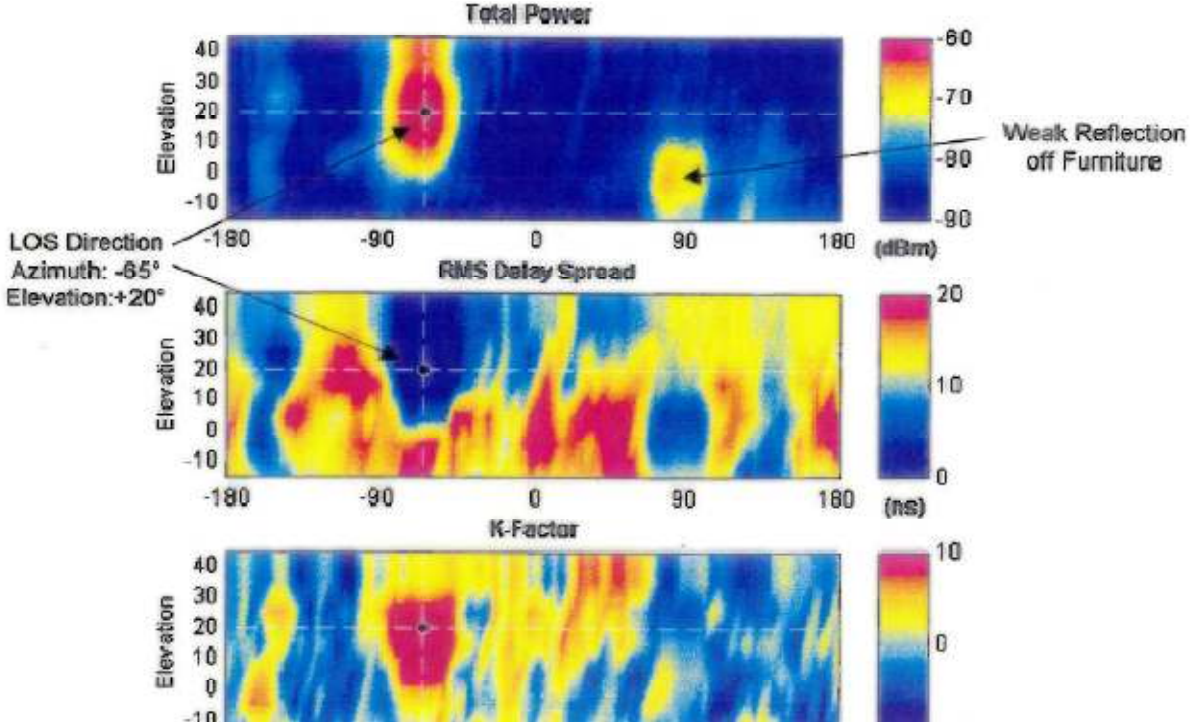
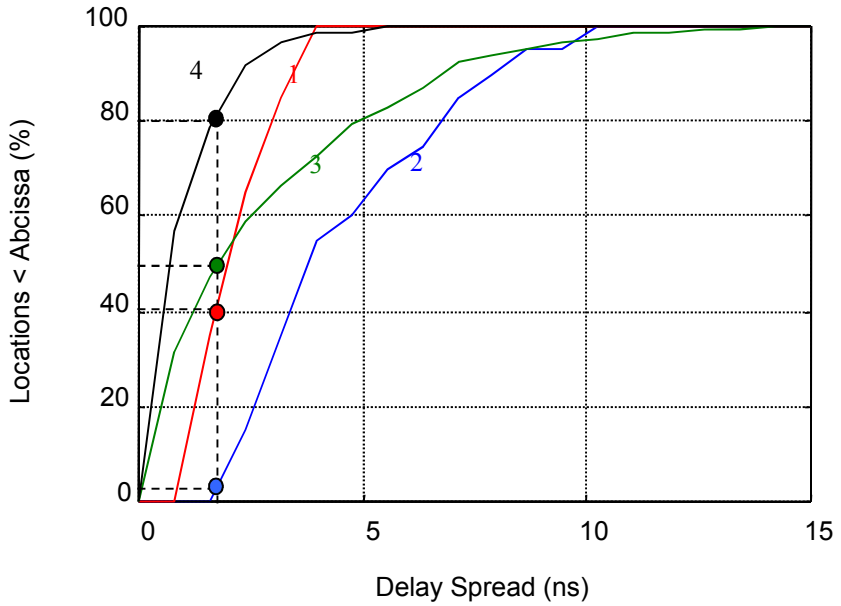


Figure 7.3.3 Power Delay Profile at Azimuth Angle –65° (Measurement Set 2)

For this particular receiver location, the 10° antenna was swept through 360° azimuth for six different elevations –10°, 0°, 10°, 20°, 30°, and 40°. (Note that Figure 7.3.2 showed the variation in average power, RMS delay spread and K-factor for the particular case of +20° elevation). Figure 7.3.4 shows the spatial variation in these three parameters over the range of azimuth and elevation angles measured, using colour shading to represent different values.



Delay Spreads for Office Cubicle Environment



1) Ceiling-Mounted Base Station Configuration : Directional Mobile
2) Cubicle-Mounted Base Station : Omni-Directional Mobile
3) Cubicle-Mounted Base Station : Directional Mobile, using single BS
4) Cubicle-Mounted Base Station : Directional Mobile, choice of BS1 or BS2

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VERSION	% LOC ≥100 Mb/s
(1) CELL MNT BS; UP-POINTING MS	39%
(2) CUBE BS; OMNI MOBILE	5%
(3) CUBE BS; QUAD MOBILE	42%
(4) CUBE BS; QUAD MOBILE/CHOICE OF 2	66%

Wireless LANs at 60GHz

.....Are they Possible and Useful?

Answer:

YES!

However:

The Case is Not Compelling At Present

Point-to-Point Data Links at 60GHz

.....Are they Possible and Useful?

Positives:

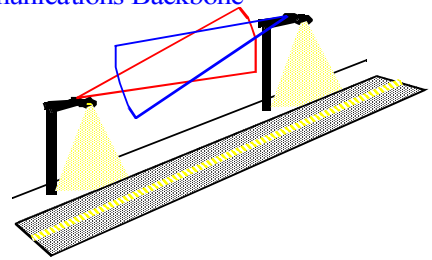
- **Compact Directional Antennas are Available**
- **Very High Data Rates are Practical**
- **Low Interference Probability**
- **No License Needed**
- **Simple, Cheap Radios May Be Possible**

Negatives:

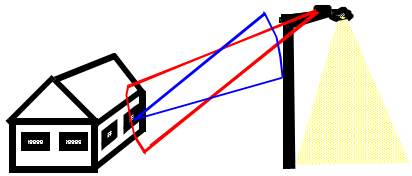
- **Range is Short**
- **Line of Sight is Required**

Some Point-to-Point Applications

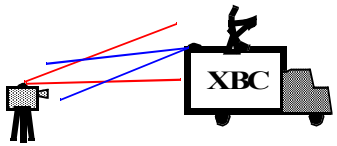
Communications Backbone



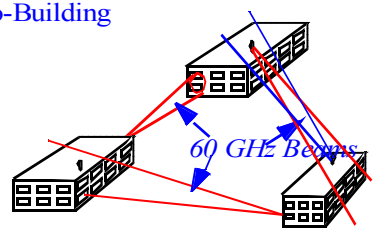
"Last 100 meters"



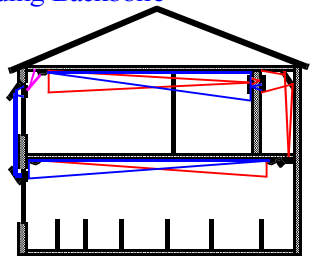
Ad Hoc Video Links



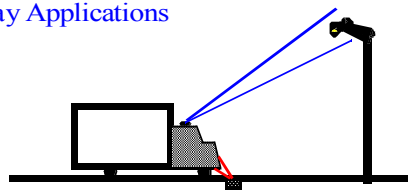
Building-to-Building



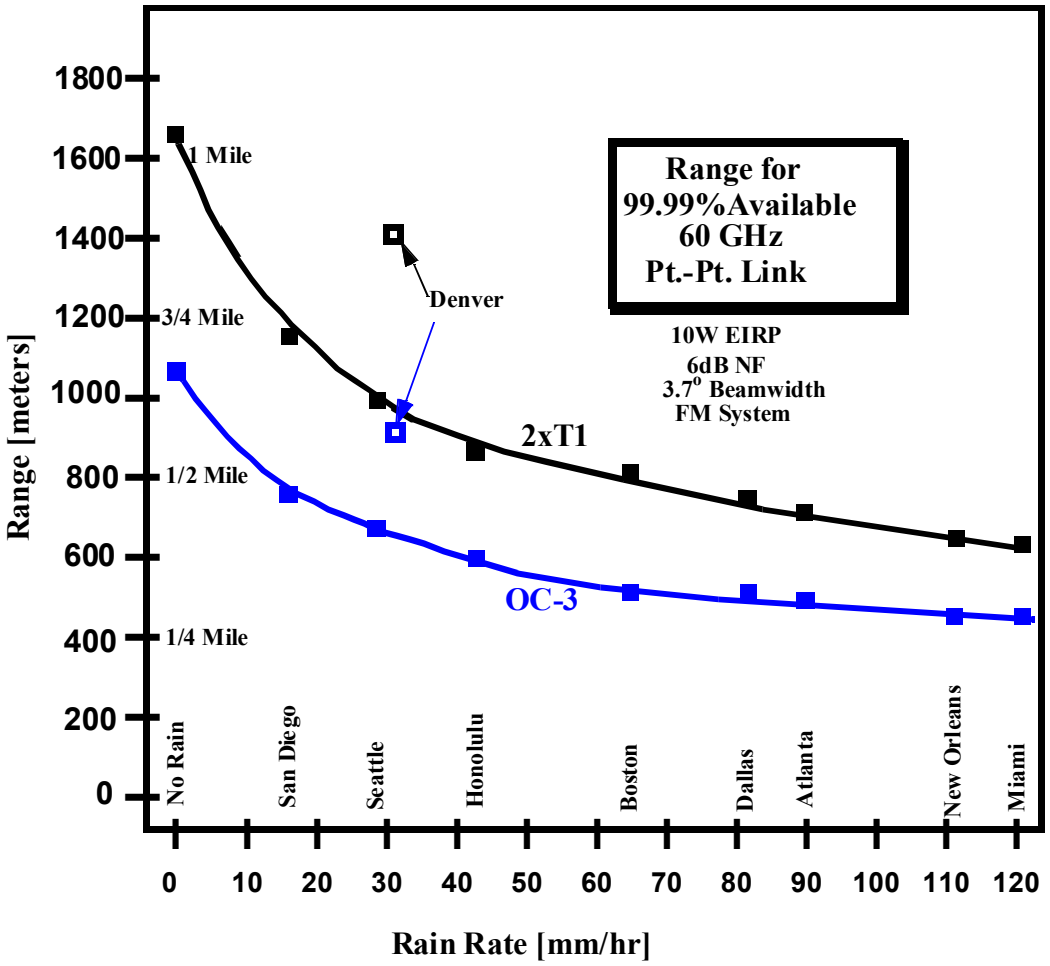
In-Building Backbone



Highway Applications



Range -vs- Rainfall Rate for 60 GHz Links



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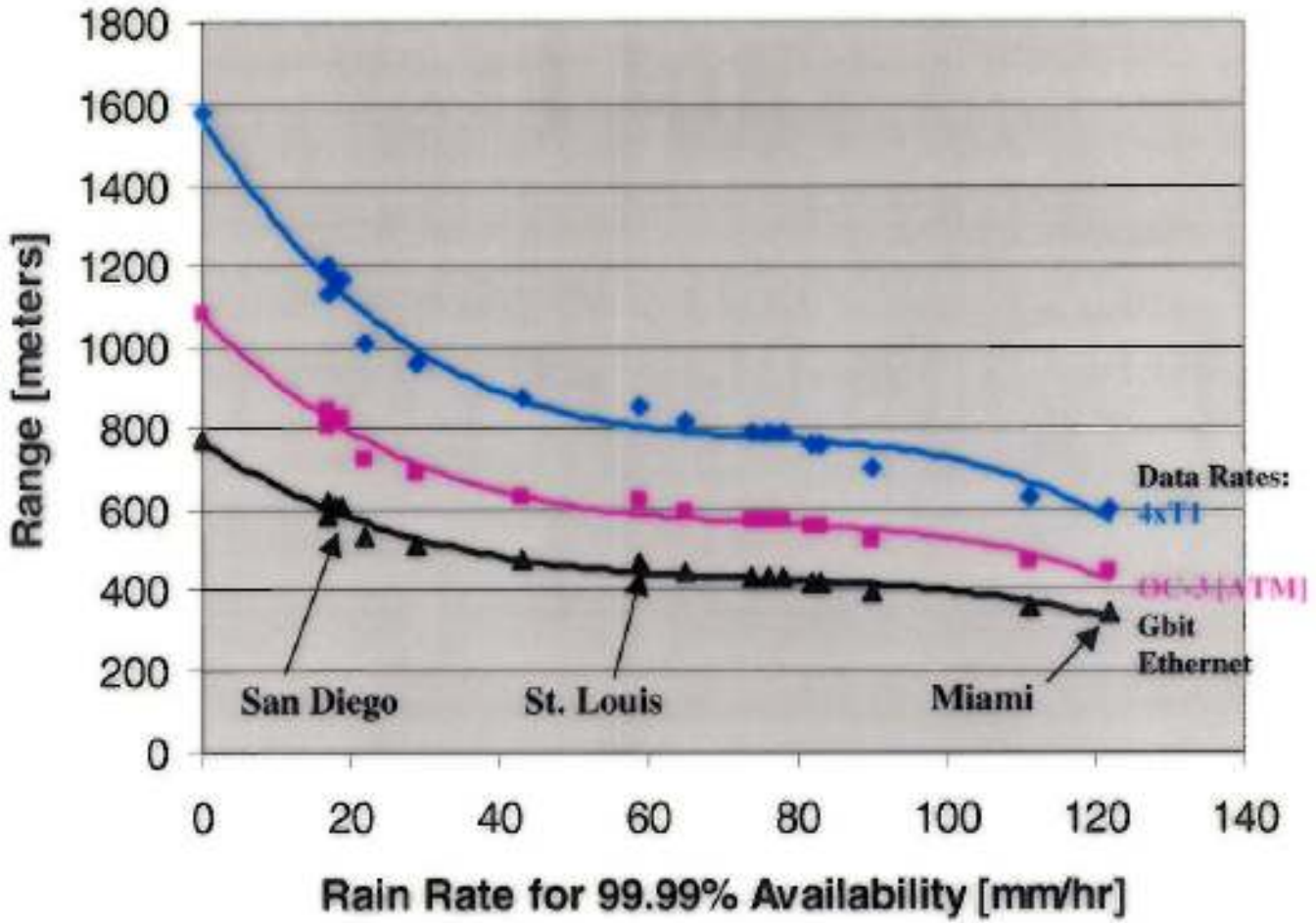
Projected Range for HP 60GHz Data Links



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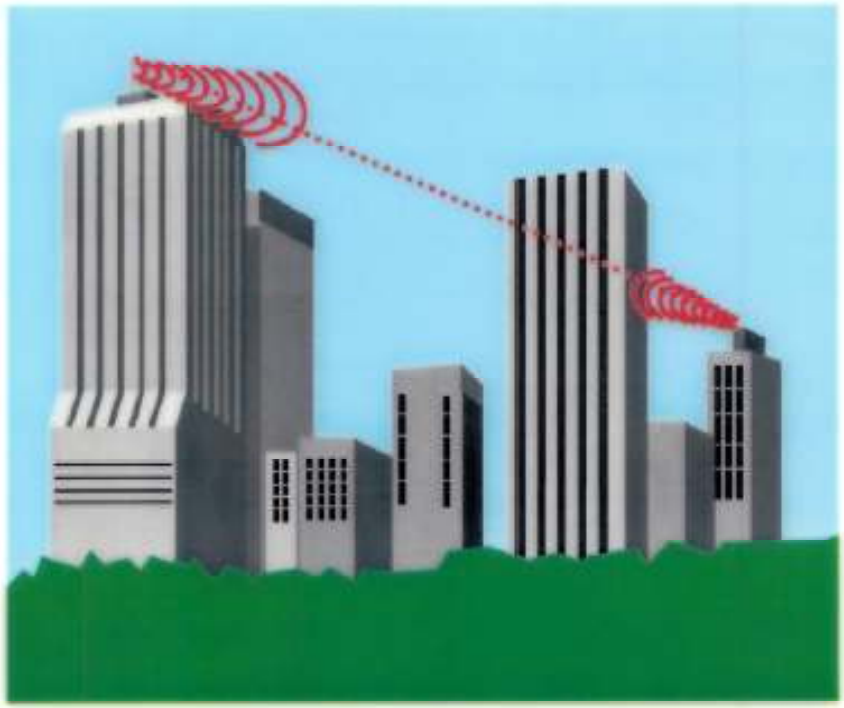
High Data Rate Point-Point Links

- For Telecom and Datacom "Wireless Fiber"
- Data Rates >100 Mbps
- Indoor/Outdoor
- Full Duplex

Value:

Cheap to Install
Quick to Install
No Right-of-Way Needed
No License Needed



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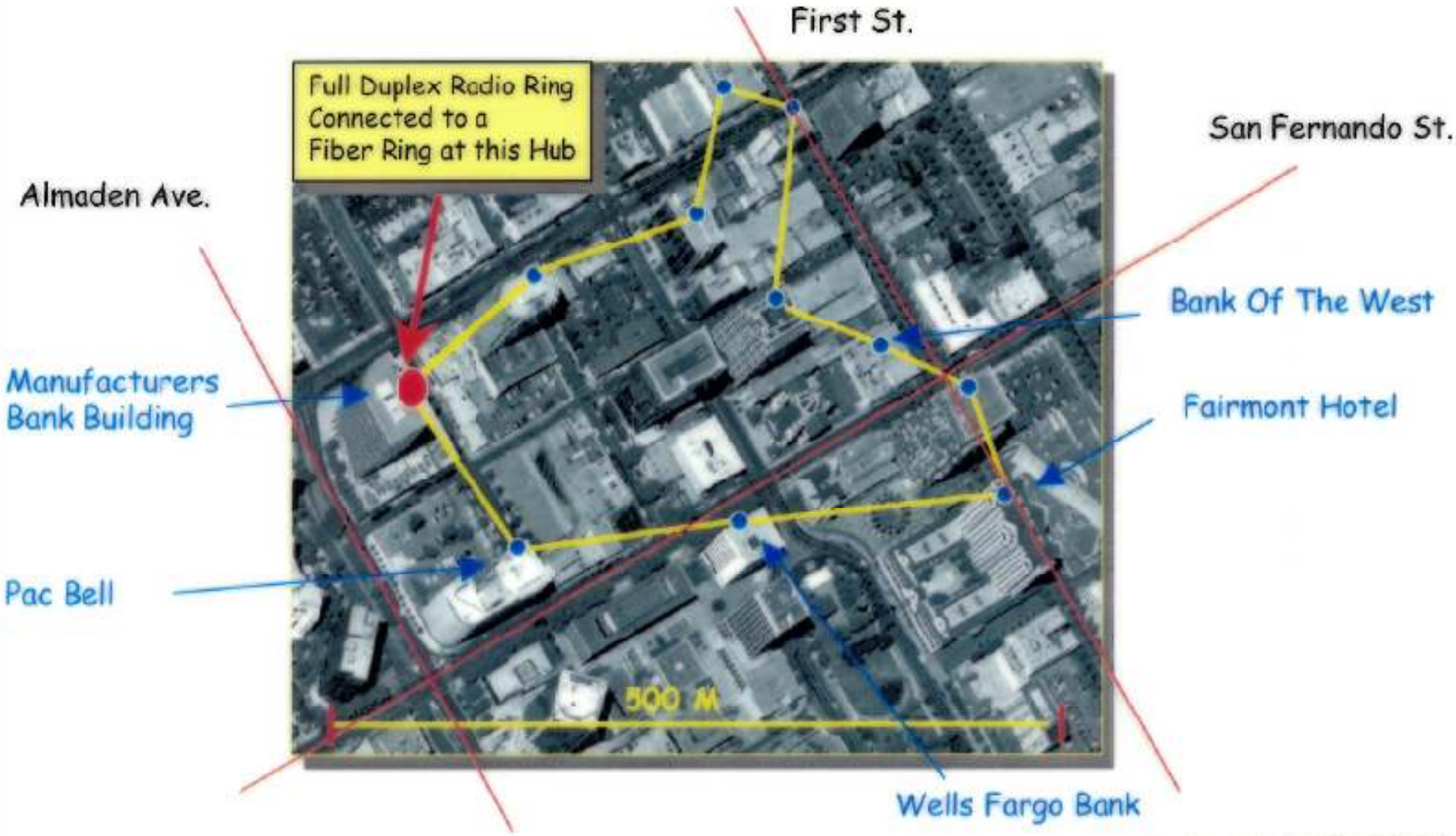
Radio Ring Detail For San Jose



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First Products are Being Announced... As of 1998

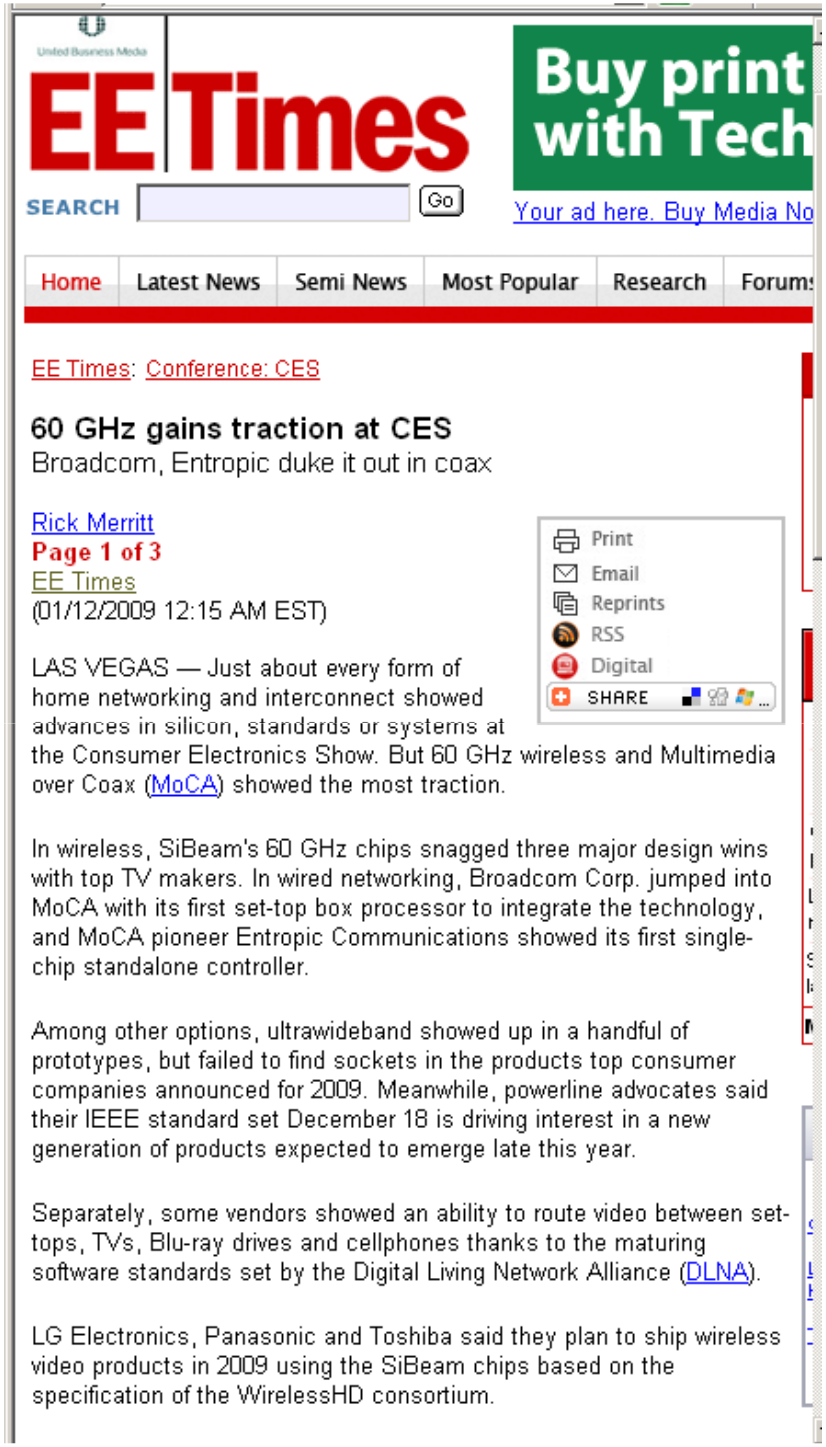
Nokia launches a new solution capable of increasing a network capacity ten-fold...

(October 26, 1998) **- Nokia today launches the new MetroSite capacity solution... intended for networks in areas of dense call traffic, such as business sectors, train or subway stations and shopping districts.**

"Using revolutionary new access transmission at the 58 GHz frequency, this solution makes it possible to select sites virtually anywhere..."

Source: http://wwwdb.nokia.com/pressrel/webpr.nsf

2009



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EE Times: Conference: CES

60 GHz gains traction at CES

Broadcom, Entropic duke it out in coax

Rick Merritt

Page 1 of 3

EE Times

(01/12/2009 12:15 AM EST)

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LAS VEGAS — Just about every form of home networking and interconnect showed advances in silicon, standards or systems at the Consumer Electronics Show. But 60 GHz wireless and Multimedia over Coax (MoCA) showed the most traction.

In wireless, SiBeam's 60 GHz chips snagged three major design wins with top TV makers. In wired networking, Broadcom Corp. jumped into MoCA with its first set-top box processor to integrate the technology, and MoCA pioneer Entropic Communications showed its first single-chip standalone controller.

Among other options, ultrawideband showed up in a handful of prototypes, but failed to find sockets in the products top consumer companies announced for 2009. Meanwhile, powerline advocates said their IEEE standard set December 18 is driving interest in a new generation of products expected to emerge late this year.

Separately, some vendors showed an ability to route video between set-tops, TVs, Blu-ray drives and cellphones thanks to the maturing software standards set by the Digital Living Network Alliance (DLNA).

LG Electronics, Panasonic and Toshiba said they plan to ship wireless video products in 2009 using the SiBeam chips based on the specification of the WirelessHD consortium.

Point-to-Point Data Links at 60GHz

.....Are they Possible and Useful?

Answer:

YES!

However:

Work is Needed to Reduce Cost

How to Reduce Hardware Costs?

.....What Will Make 60GHz Competitive?

Answer:

MMICs!

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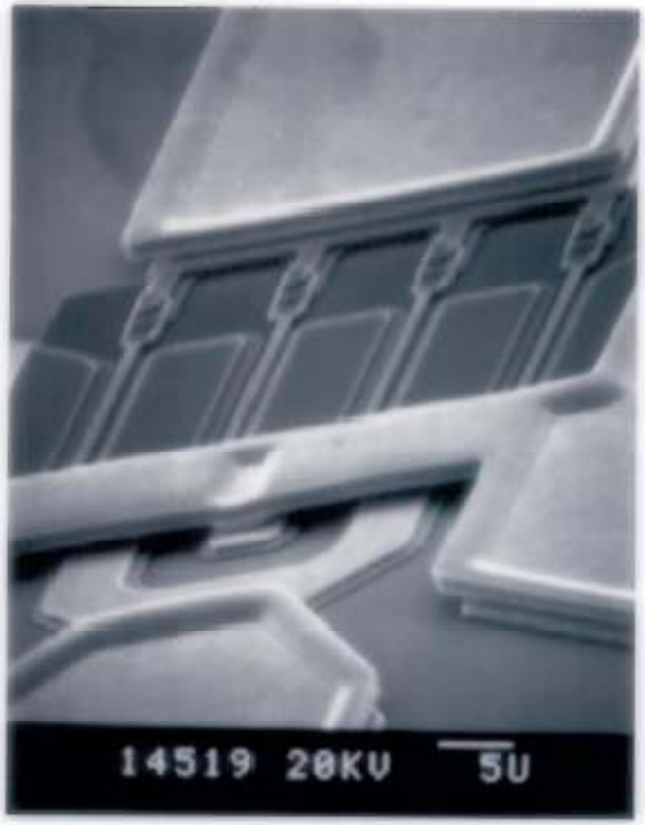
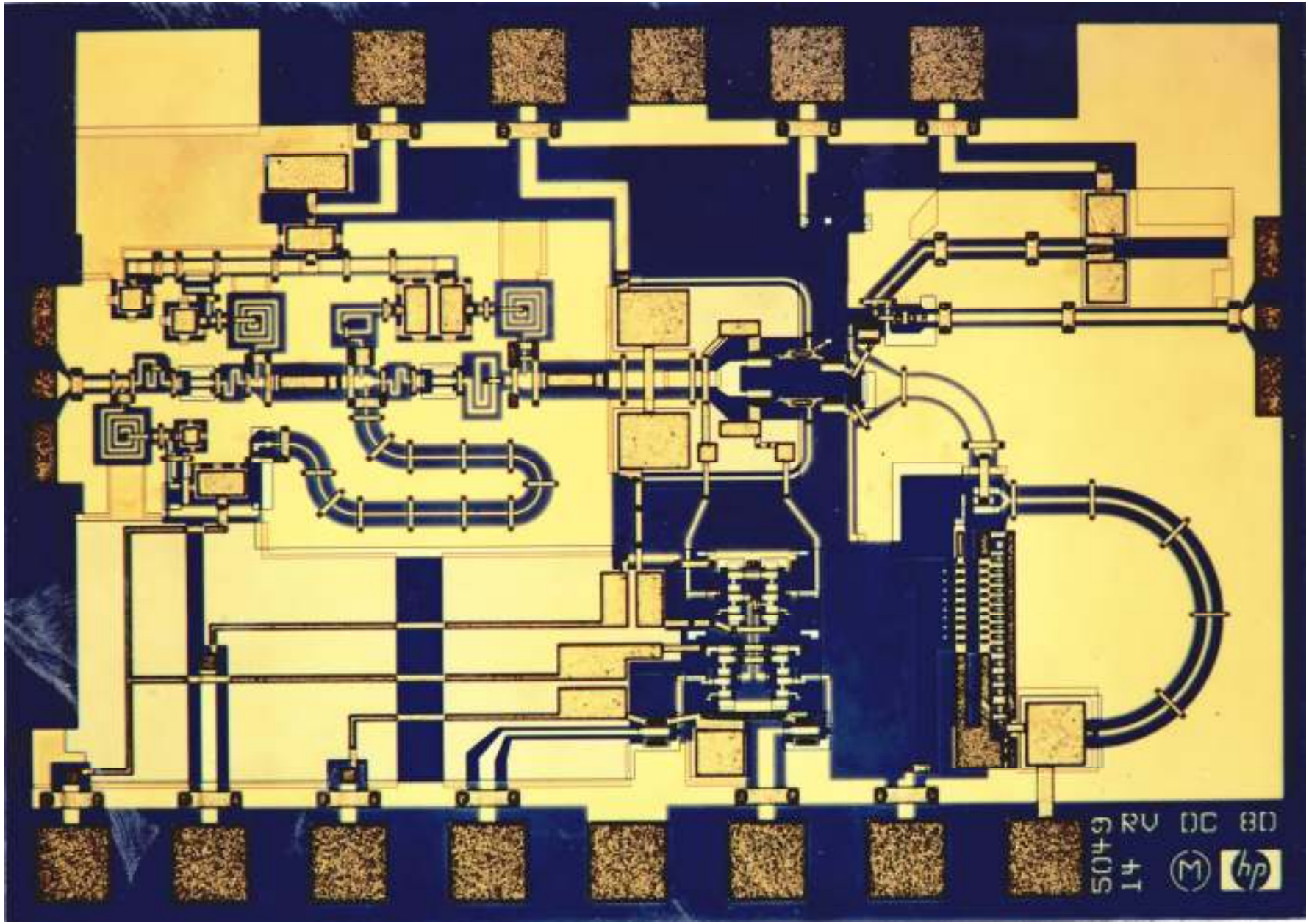
0.1μm InP HEMT Process



- **E-beam, Direct-written 0.1 μm T-gate using a Double Exposure Process**
- **Silicon Nitride Device Passivation and Capacitor Dielectric**
- **Airbridge Second Metal**


5049 RV DC 80
14

What MMIC Technologies?

GaAs pHEMT

InP HEMT

GaAs MHEMT

CMOS in 2009!

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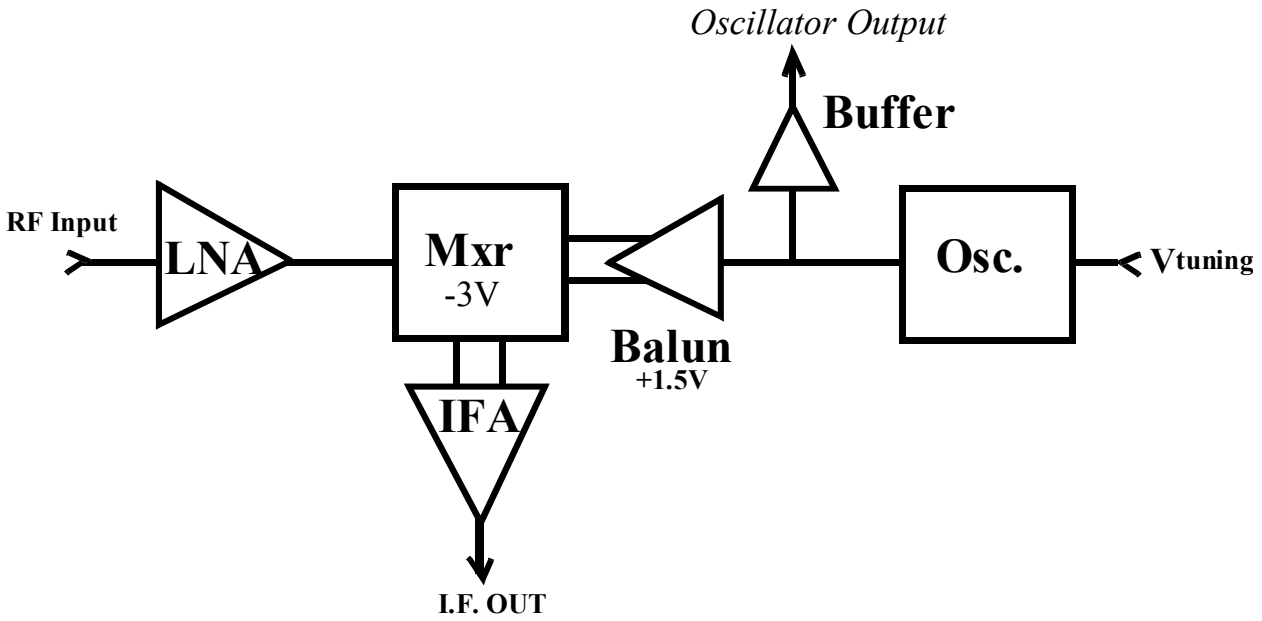
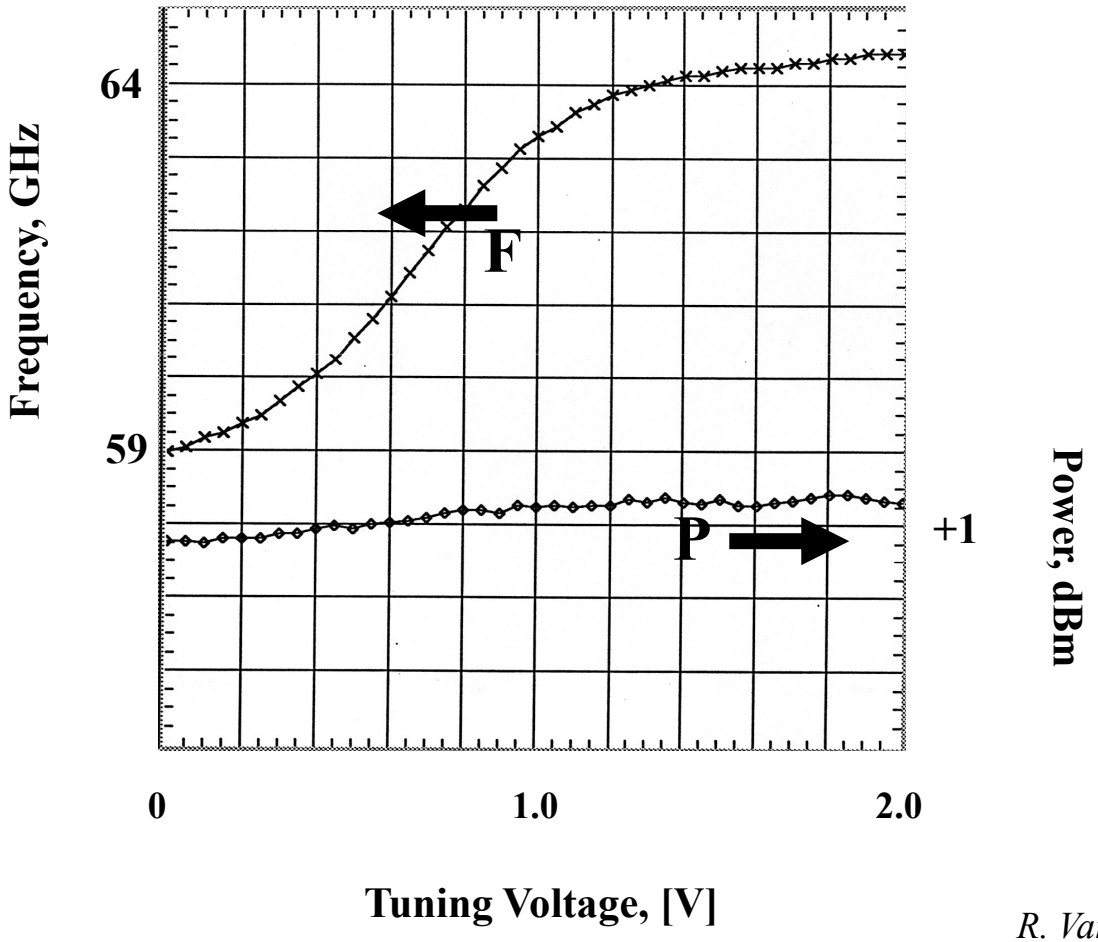
Single-Chip Downconverter

.....Block Diagram



Receiver VTO Tuning Curve



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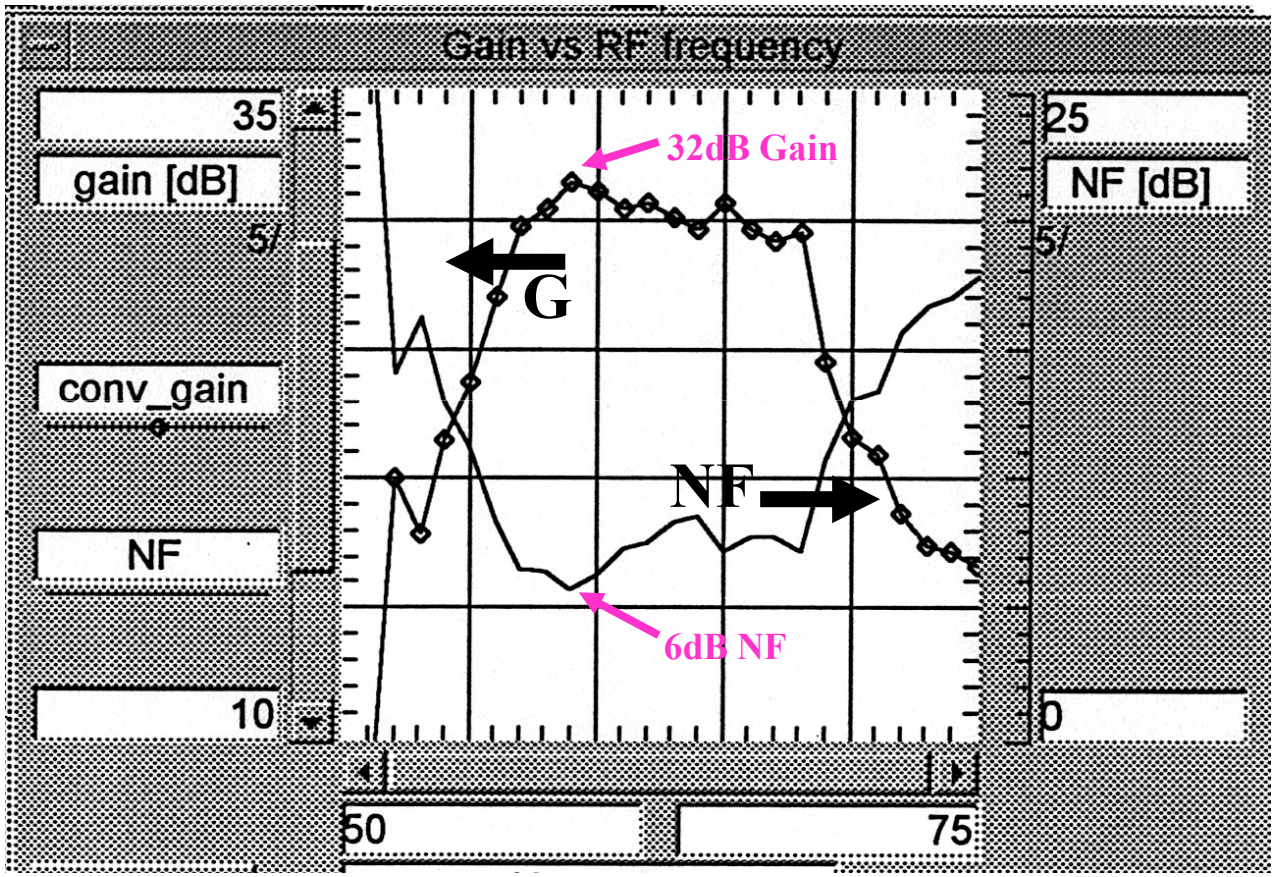
Receiver Gain and Noise Figure (Tested with External LO)



Frequency, [GHz]

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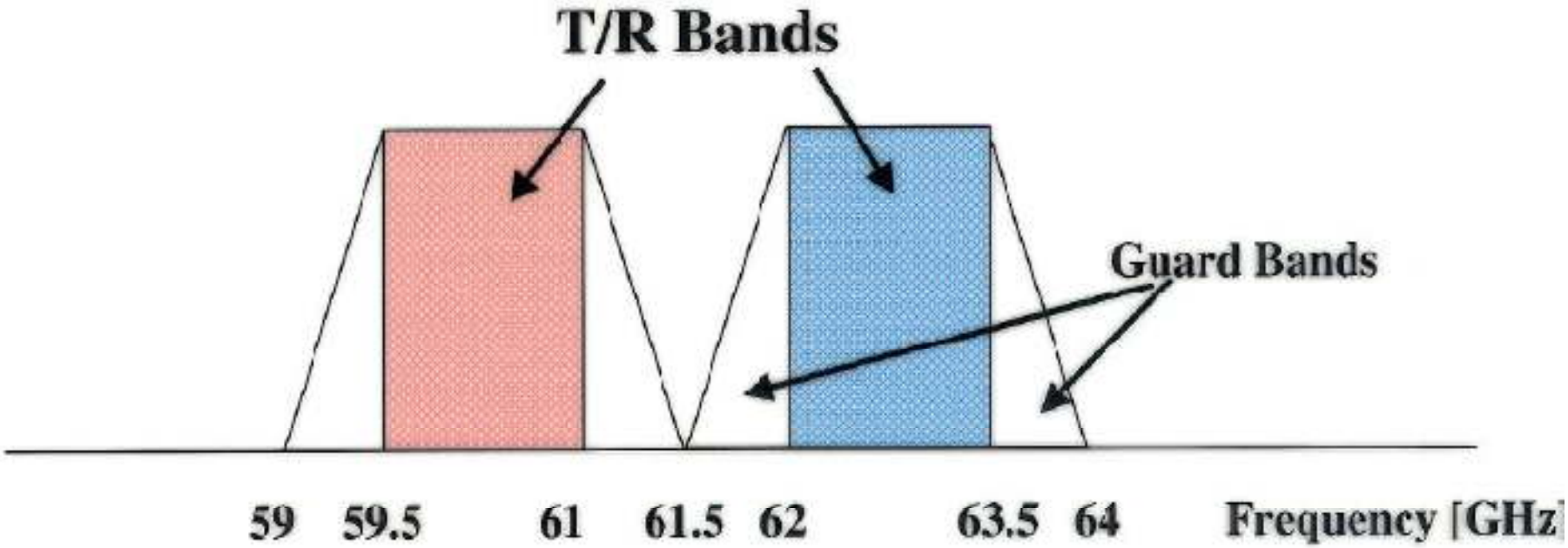
A Band Plan Example



Characteristics of Links

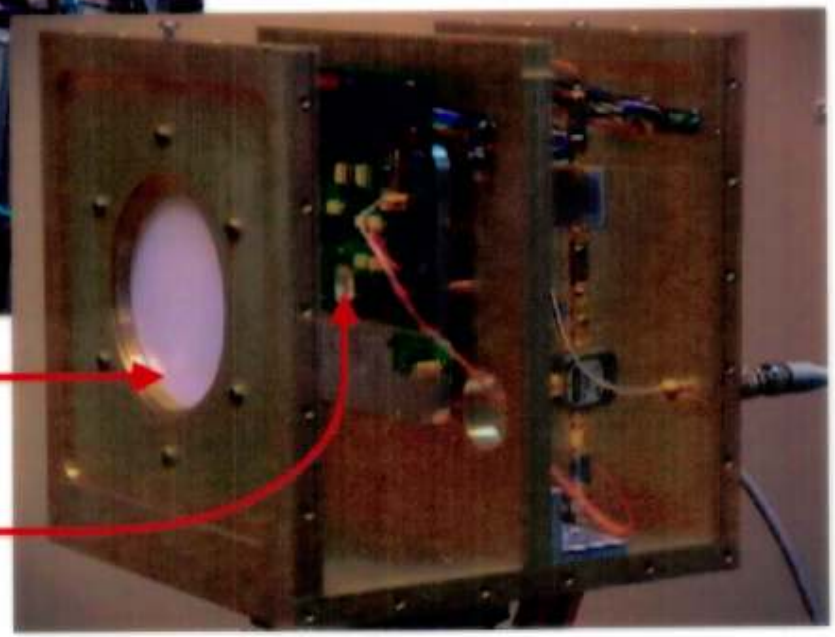
Transmit Power (Px)	**10 mW**
Antenna Gain (Ga)	**30 dB**
EIRP (Px * Ga)	**10 W**
Spectrum	**59-64 GHz**
Channel Plan	**Various**
Data Rates	**>100 Mbps**
Modulation Type	**FSK**

Application Examples

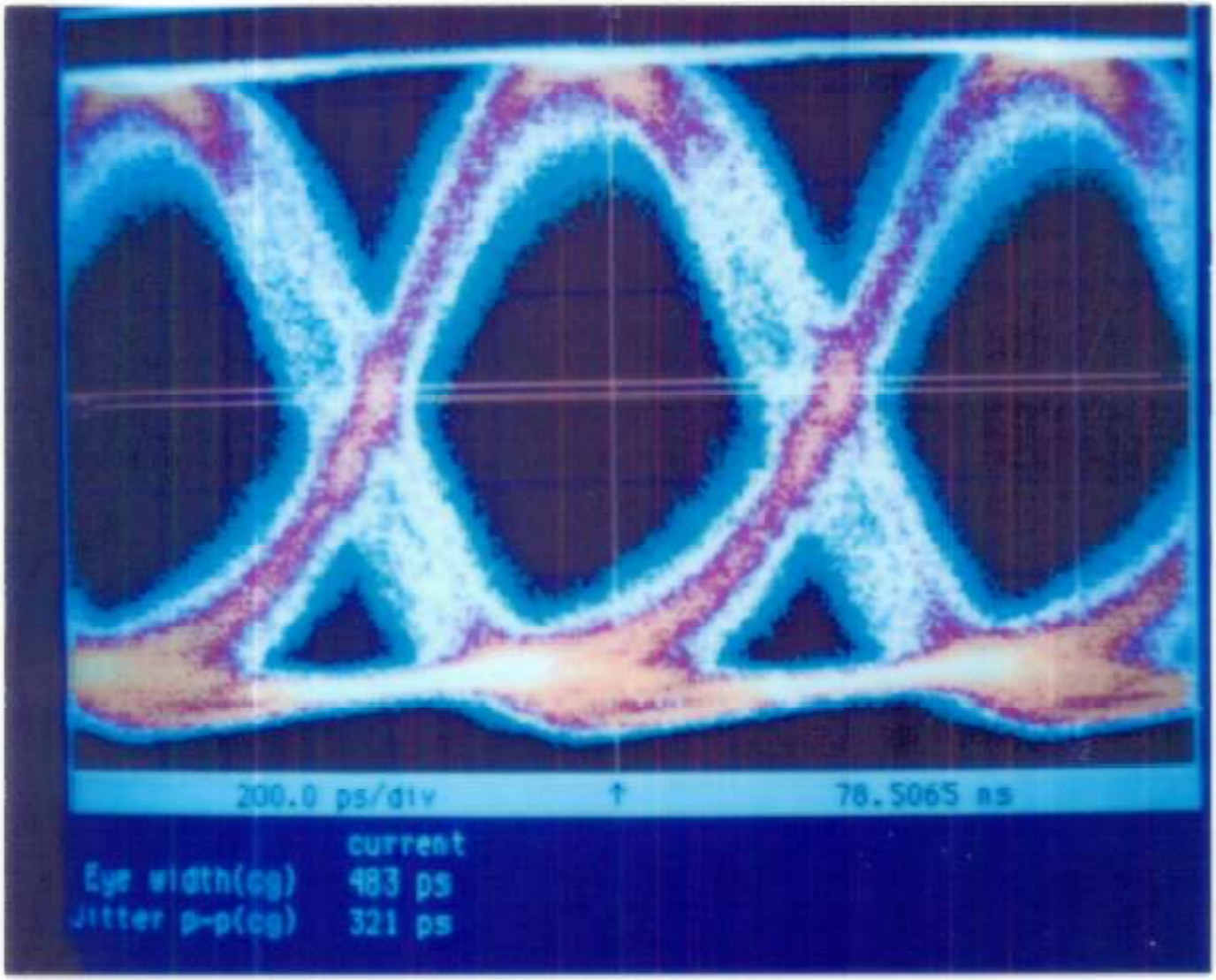
Wireless Fiber Service	Data Rate	Channels	Bandwidth per Channel
OC-48	2488 Mbps	1	2.2 GHz
Gb Ethernet	1250 Mbps	1	1.5 GHz
OC-12	622 Mbps	2	750 MHz
OC-3	156 Mbps	8	200 MHz
Fast Ethernet	125 Mbps	11	150 MHz

Agilent Technologies
Innovating the HP Way

Laboratory Prototype



1.25 Gbps RP36 Eye Pattern in Loopback Test



483 ps Eye Opening, 321 ps Jitter

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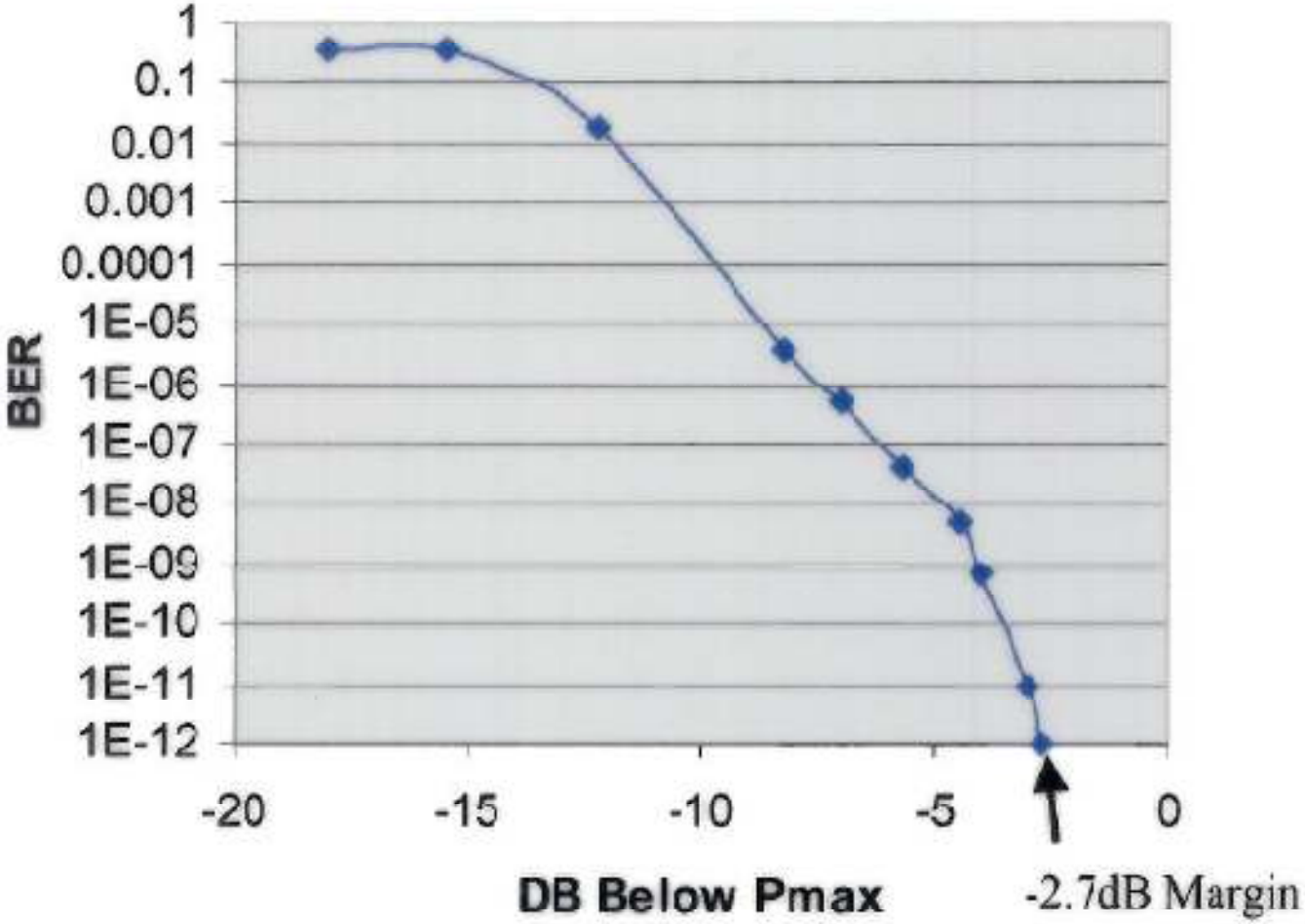
Bit Error Rate-vs-Transmitter Power
for
350m Field Test



Predictions for the Future

.....Of 60GHz Wireless Communication

First Point-to-Point Links in 1999

Technology Costs Will Fall Over 5 Years

Cheap Indoor/Outdoor Data Links Will Follow

LANs Will Emerge When Demand for Ultra High Data Rate Arrives

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A Special Plea for Standardization

.....But Not Government-Imposed Rules

Worldwide Harmonization of Frequency Spectrum Allocations

Industry Needs to Work Toward Basic Standards

Governments and Standards Bodies Should Be Permissive: ***No Licenses! No Lockouts!***

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