JASON Global Grid Study

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JRS-92-100

July 1992

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 28, 1992

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
JASON Global Grid Study

5. FUNDING NUMBERS
PR - 8503A

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The MITRE Corporation
JASON Program Office A020
7525 Colshire Drive
McLean, VA 22102

8. PERFORMING ORGANIZATION REPORT NUMBER
JSR-92-100

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
DARPA/TIO
3701 North Fairfax Drive
Arlington, Virginia 22203-1714

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
JSR-92-100

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report documents, in presentation form, the results of a JASON Summer Study that examined issues related to the role and technology of global communications grid.

14. SUBJECT TERMS
global grid, theater UAV, traffic volume, laser sat com

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

What Is "Global Grid"?

- Global Grid refers to an incipient explosion of World communications, in several dimensions:
  - Data Rates
    - Kbps to Mbps to Gbps
    - Copper or Microwave to Fiber
  - Connectivity
    - Global percolation of heterogeneous services
  - New Services
    - High bandwidth digital data
    - Personal Communications Services (PCS)
  - Aggressive World standards
- It is happening now (1992-2000)
- Much or most of the impetus is abroad
  - France
  - Japan

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- Scope the Global Grid as both technology and infrastructure
- Predict what traffic it will be carrying in 2000-2005, characteristics and volume
- What should U.S. Gov't be doing near-term (5 years, existing assets or technology)?
- What should U.S. Gov't be doing far-term (10-20 years, starting new technology development now)?

Political Context for the Global Grid

- **Revolution of Freedom Around the World**
  - Required for a country's good standing in the new world order
  - Few(er) denied areas
  - Decrease in travel restrictions on nationals/foreigners
  - Toleration/encouragement of foreign infrastructure
- **Increasingly Integrated World economy**
  - Toleration/encouragement of entrepreneurial commerce
  - Requires transnational communications infrastructure
  - Requires toleration of commercial privacy/secrecy
- **Except for US/EUR/JAP, decline of traditional nation-state autonomy**
  - UN sanctions/interventions (e.g. Iraq)
  - IMF, World Bank, etc. leverage (e.g. Russia)
  - Implicit dependency on World security infrastructure

How Does the Global Grid Relate to Warfighting?

- **Success**

  will be defined not only by objectives achieved, but also (as in Desert Storm) by the extreme minimization of U.S. and allied casualties. This can be achieved only by

- **Tempo**

  the ability to be inside an adversary's decision loop with one's own decision loop, at all levels of combat from Theater commander to individual troops. Tempo is enabled by

- **Information**

  The military function of the Global Grid is to provide the necessary information, in real time, to all echelons, in all possible future Theaters.

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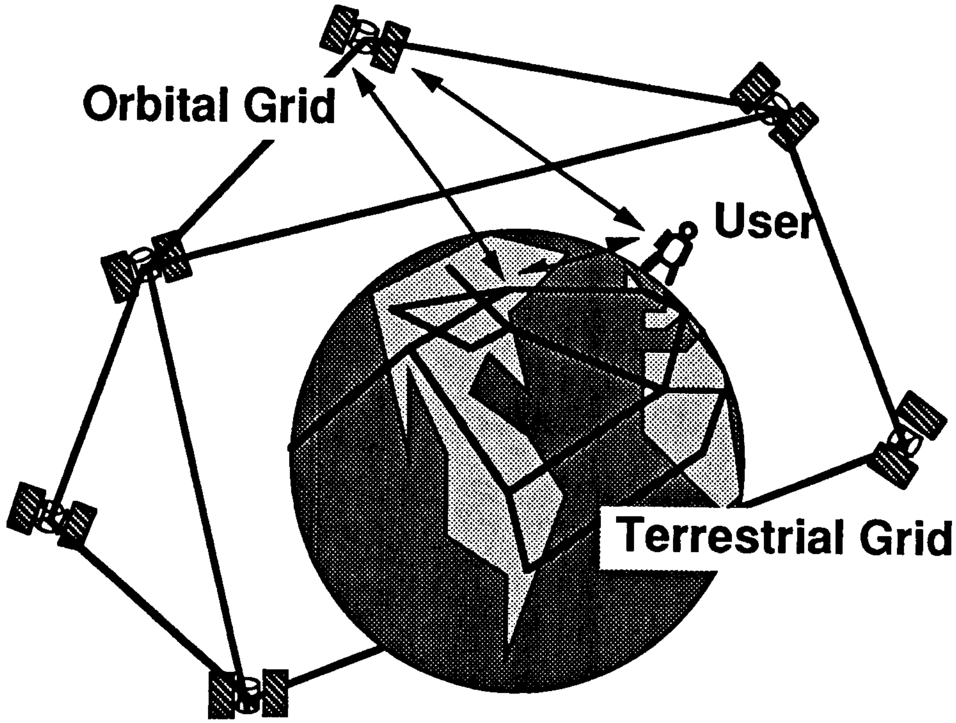
Two Global Grids
Three Kinds of Interconnects



- Grid to Grid (Uplink/Downlink)
- User to Terrestrial Grid (the "Last Mile Problem")
- User to Orbital Grid -- explosion of activity

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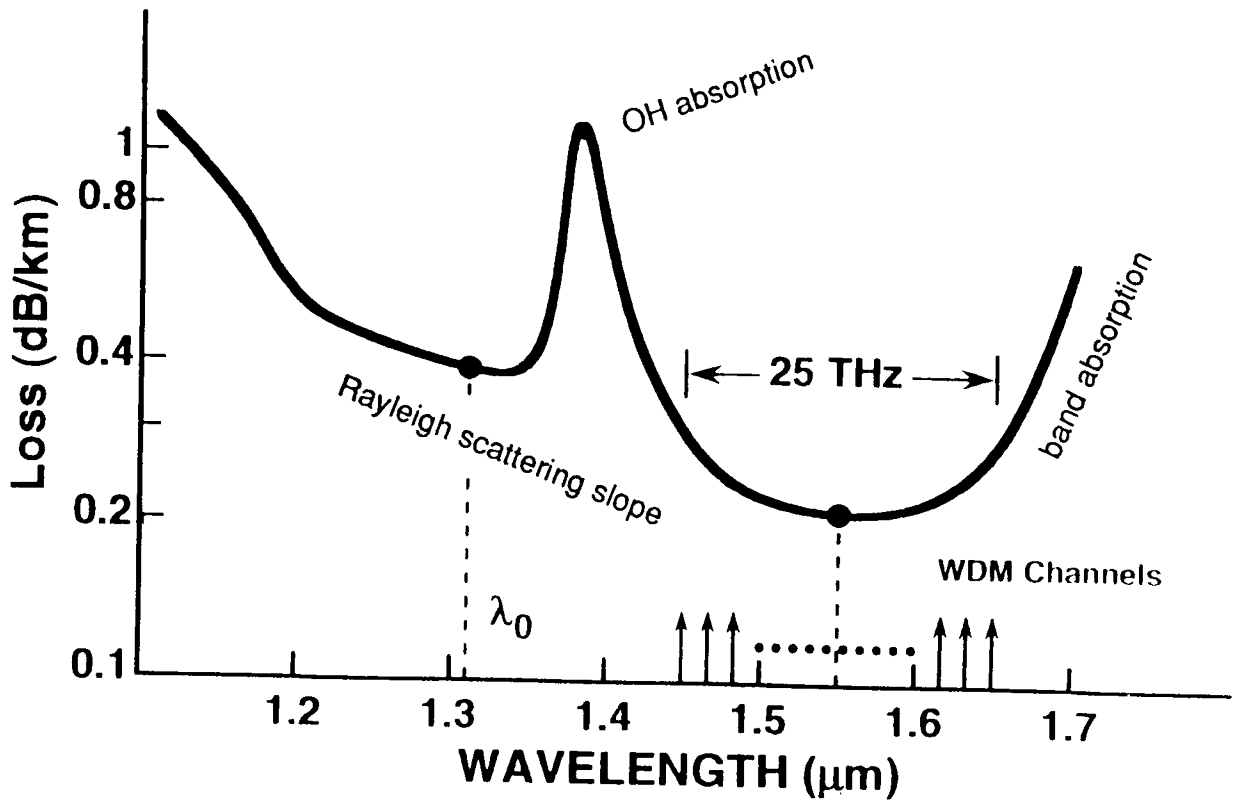
The Terrestrial Grid: Physics and Technology of Fiber

LOSS SPECTRUM OF SINGLE-MODE SILICA FIBERS

- Tens of terahertz potential bandwidth
- Physics limits fiber to about 100 km between repeaters



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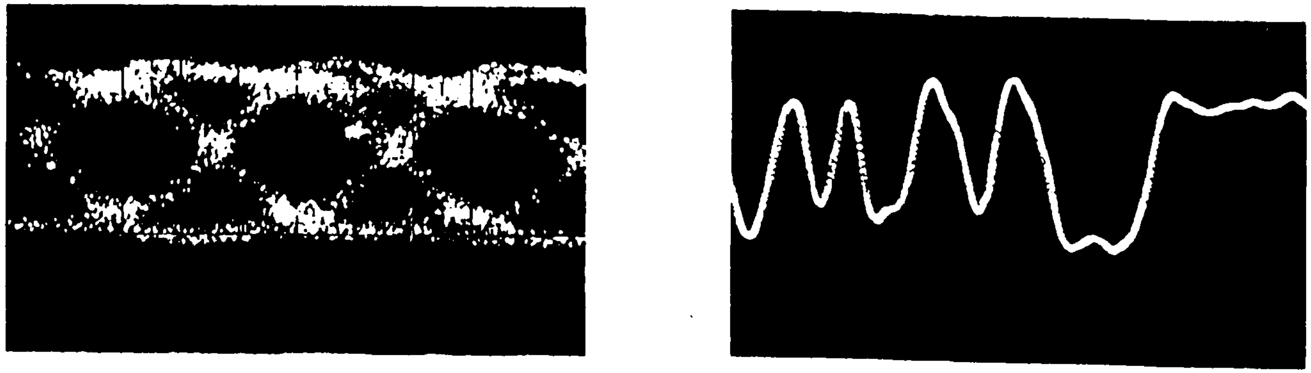
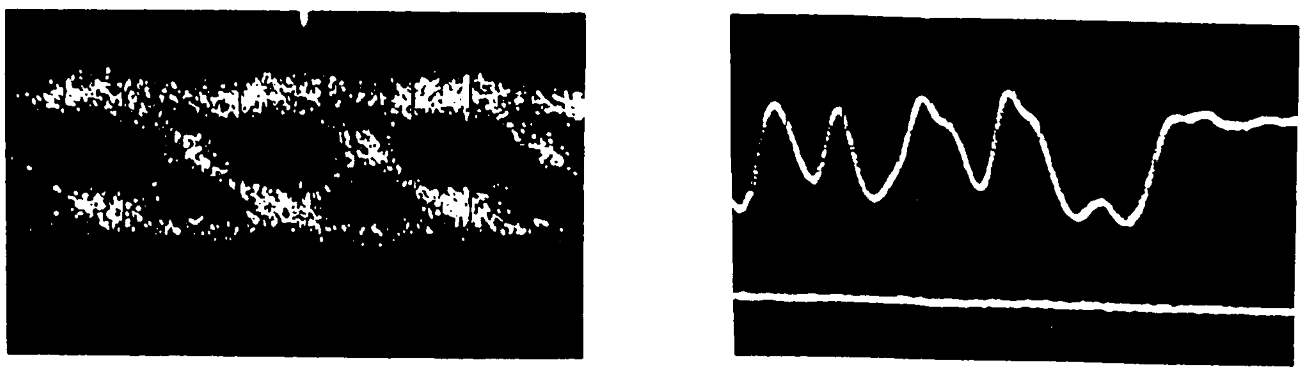
DIRECT LASER MODULATION AT 16 Gb/s



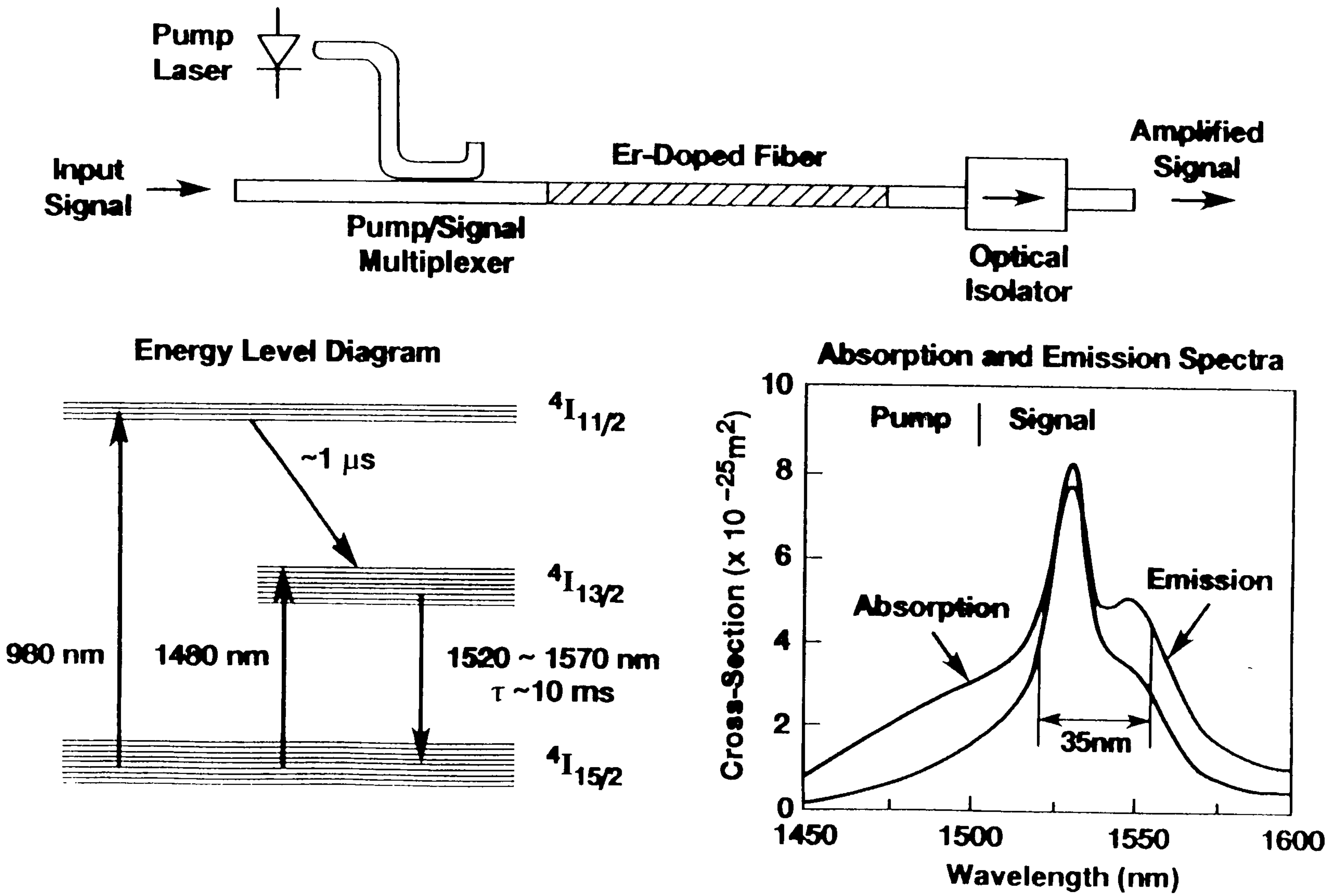
ELECTRONIC DRIVE SIGNAL (1.5V p-p)



DETECTED OPTICAL SIGNAL

GNAUCK & BOWERS

Er-DOPED FIBER AMPLIFIER



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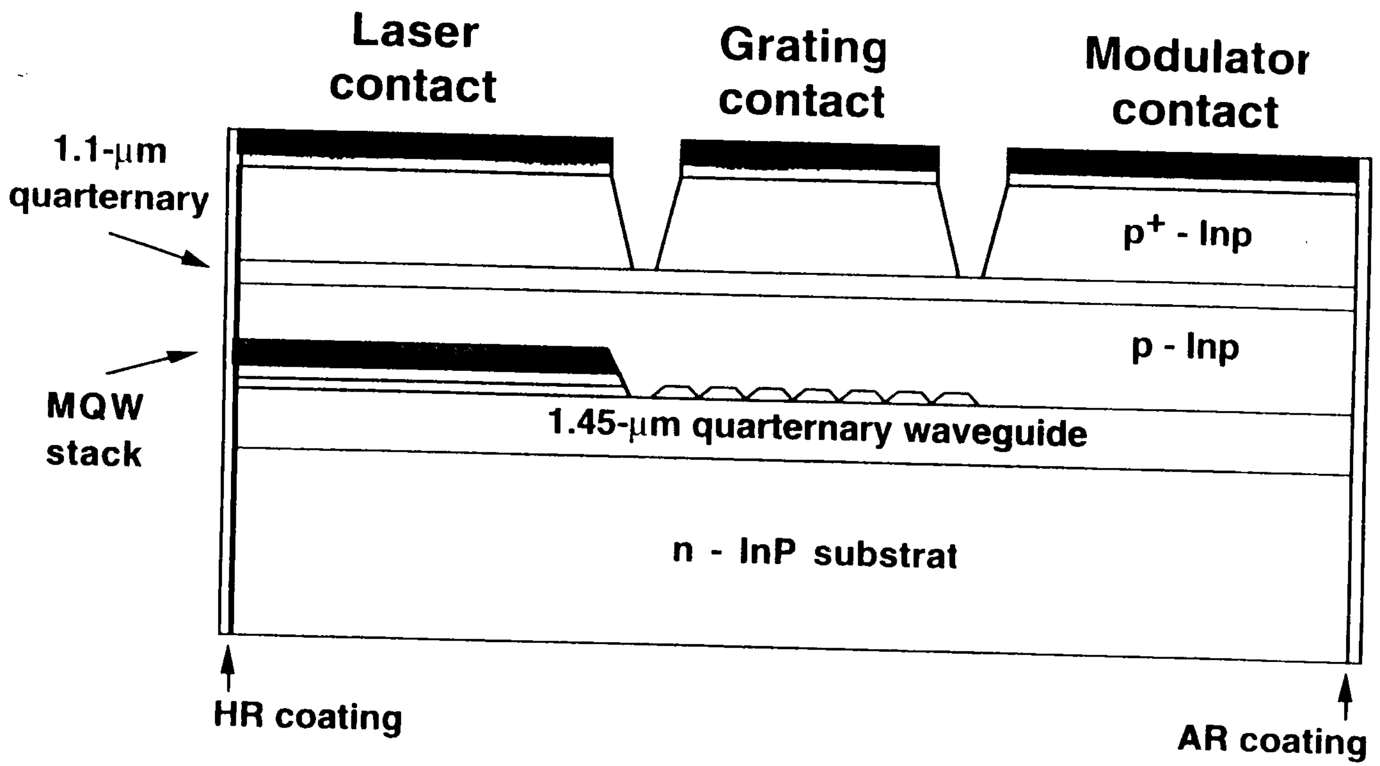
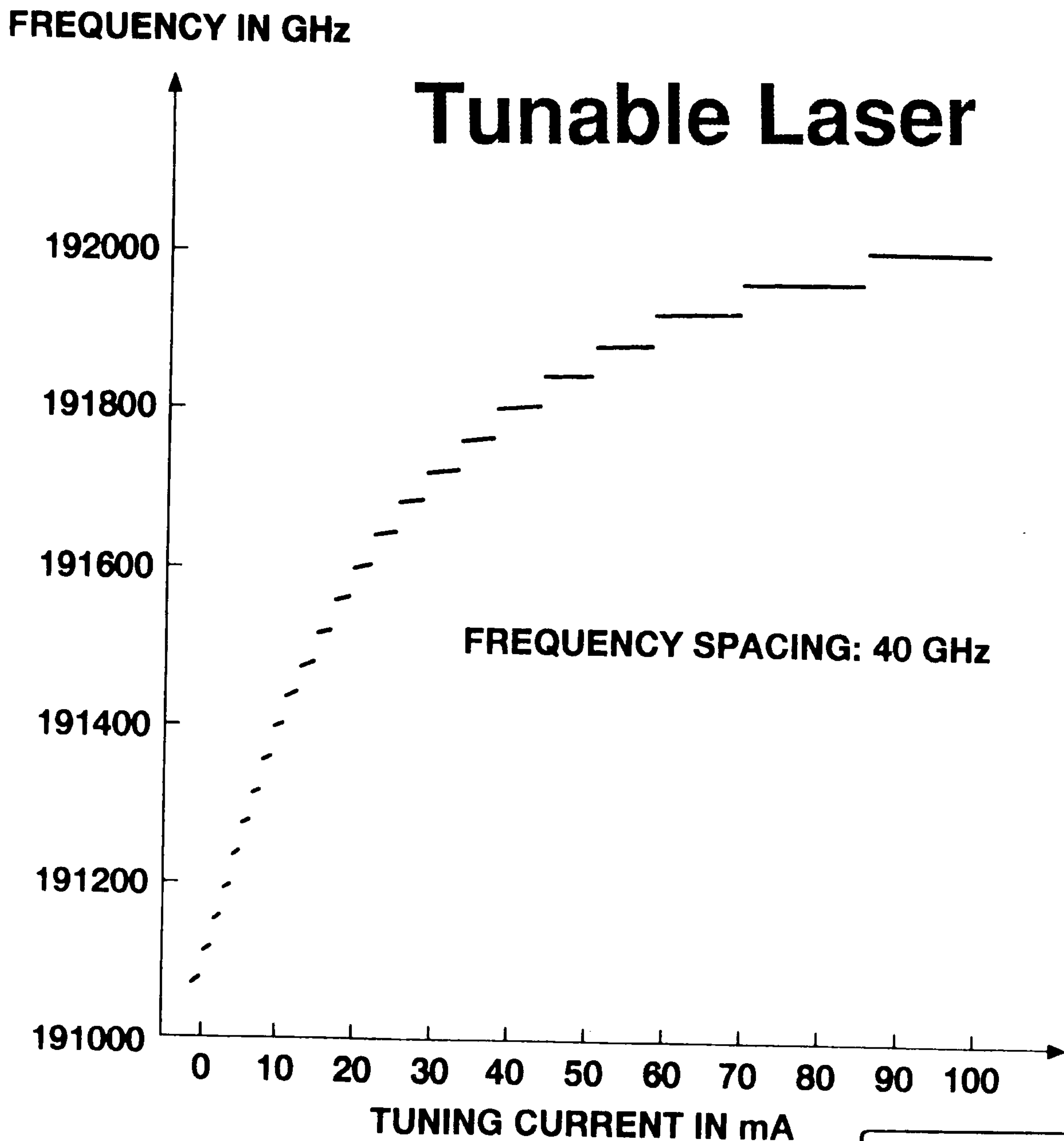
Monolithic Integrated Tunable Laser Transmitter



Tunable Laser



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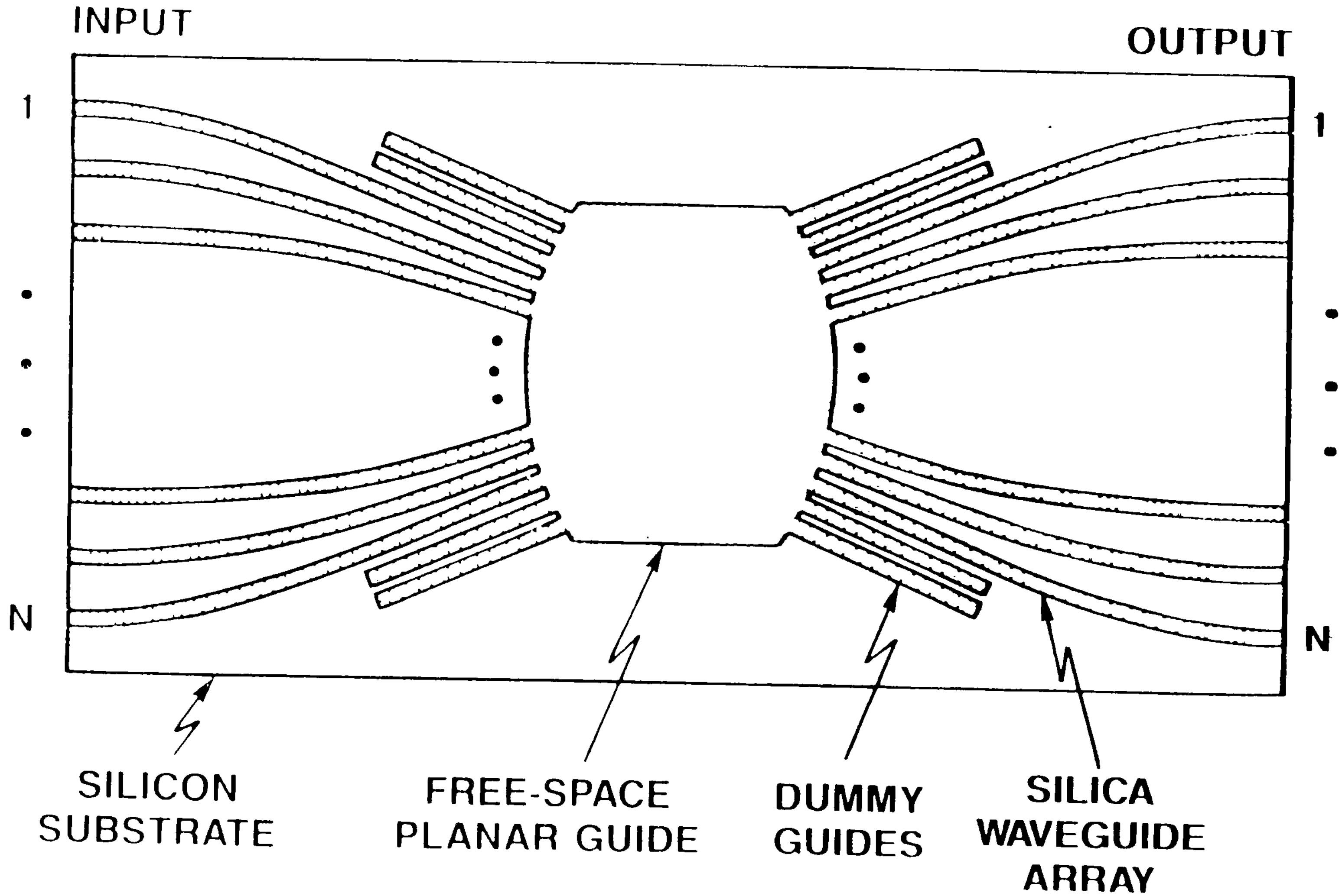
Planar Integrated Coupler



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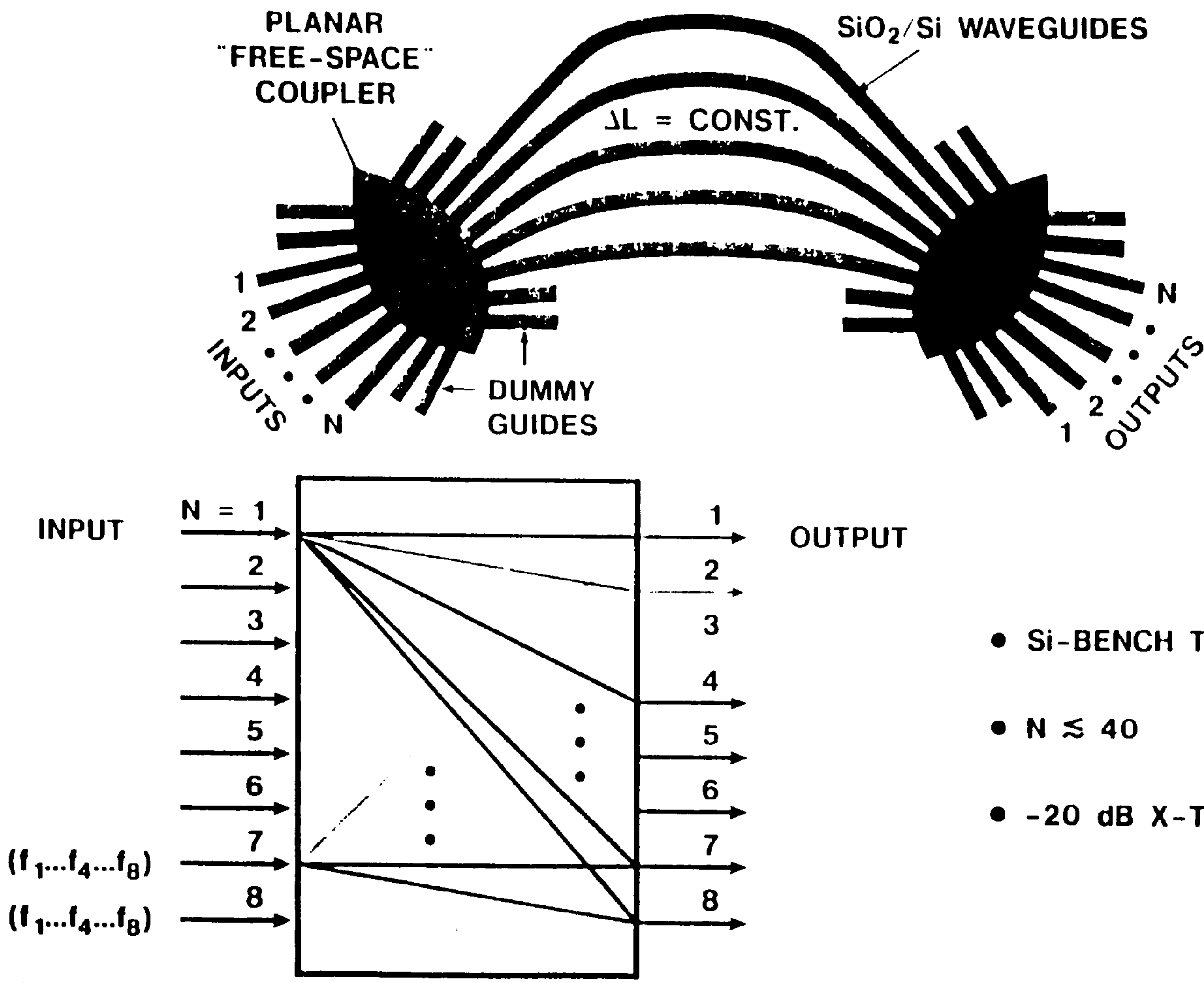
WAVELENGTH ROUTER



- Si-BENCH TECHNOLOGY
- $N \lesssim 40$
- -20 dB X-TALK

203594-2

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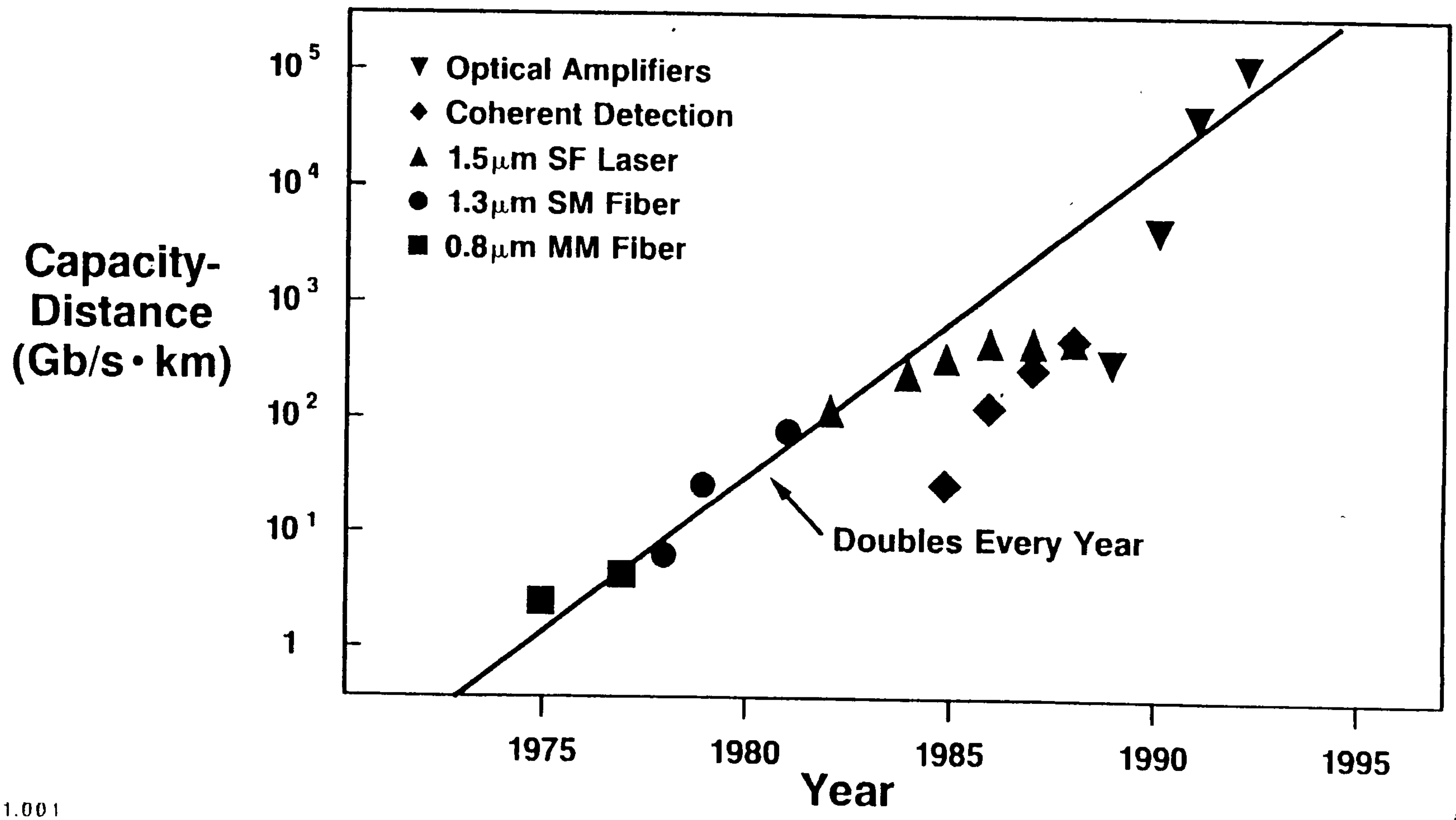
Lightwave Technology Capacity-Distance Achievements



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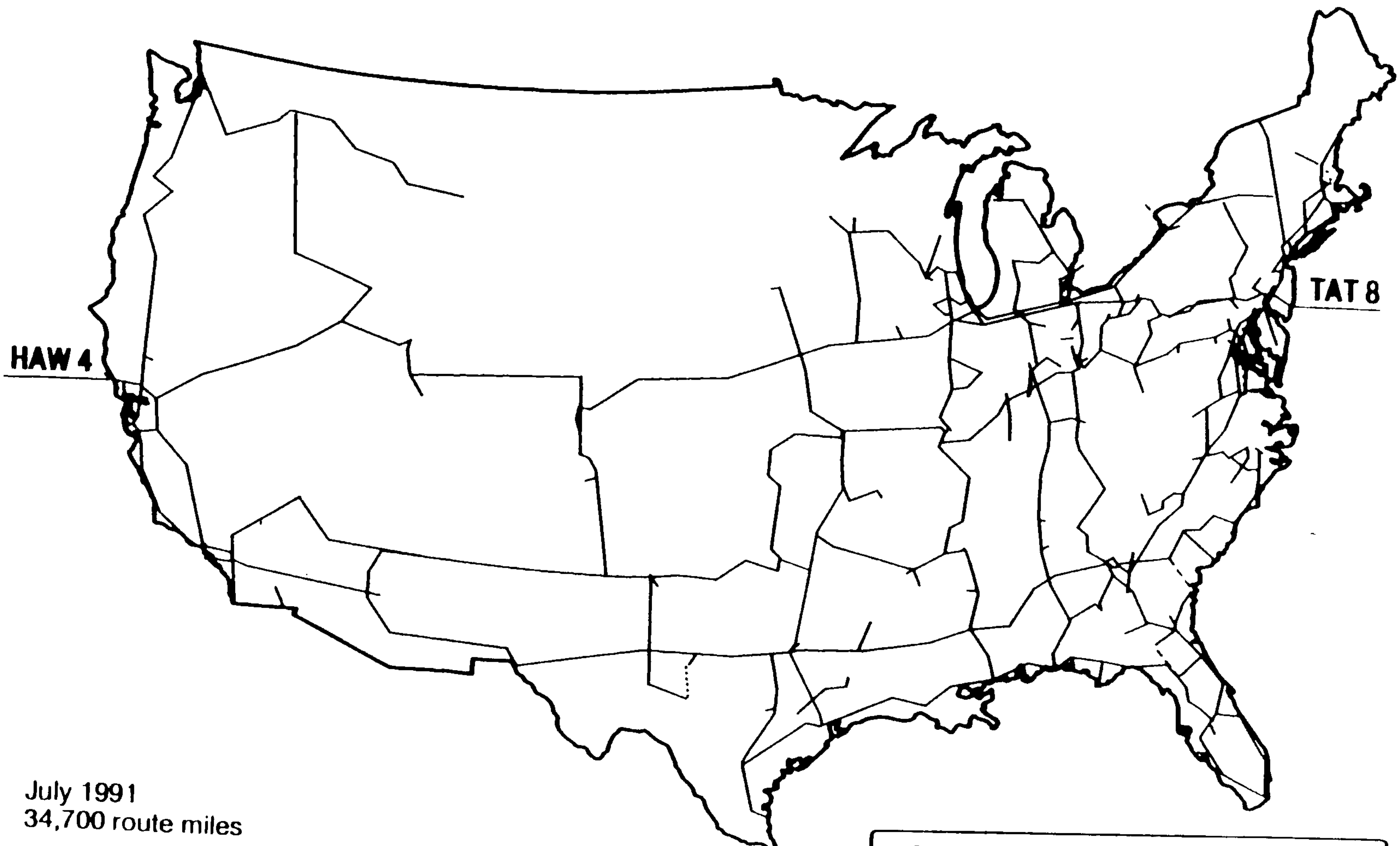
AT&T FIBER NETWORK



July 1991
34,700 route miles

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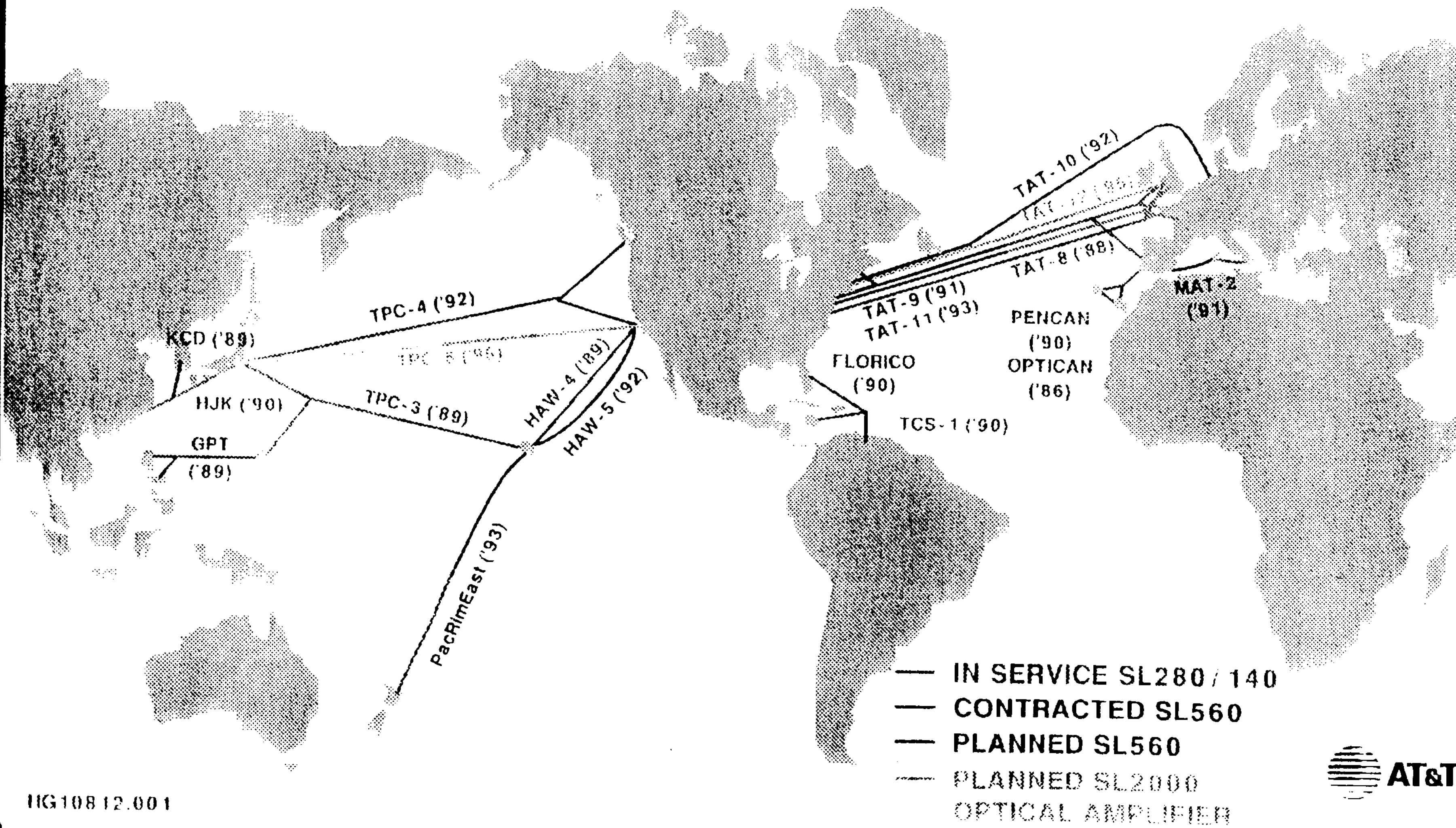
AT&T Fiber Network (cont'd)



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SL2000 OPTICAL AMPLIFIER SYSTEMS

- Repeaters utilize erbium-doped fiber amplifiers; no regenerators
- Designed for 5 Gb/s capacity - also operate at 622 Mb/s and 2.5 Gb/s
- Repeater long haul spacing function of system length and transmission rate
- SDH compatible
- Supports up to 4 fiber pairs
- Uses dispersion shifted fiber
- Experimentally verified

AT&T

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The Terrestrial Grid:
Fiber Communications Protocols

SONET
(Synchronous Optical Network)

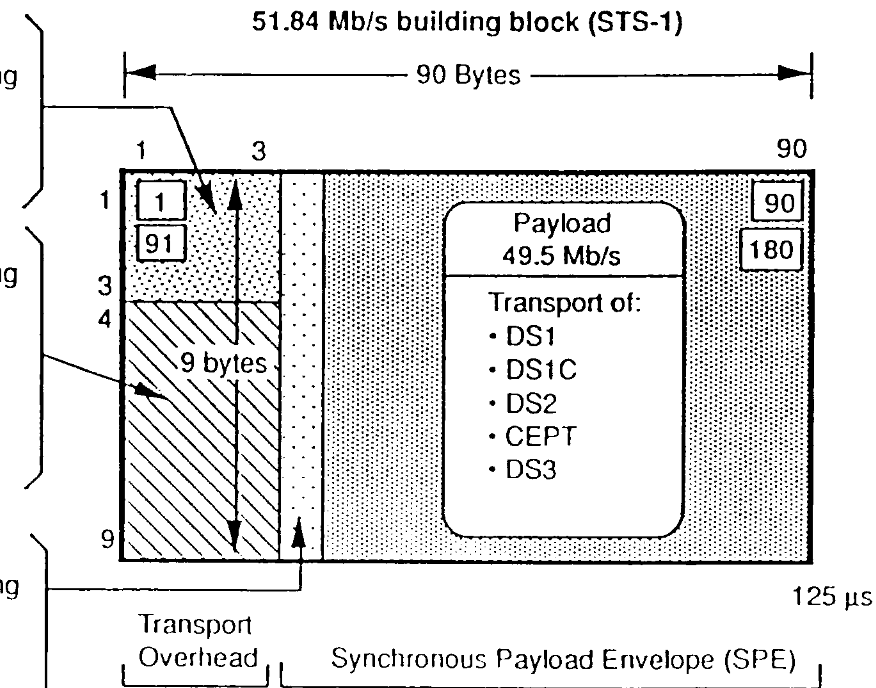
Basic building block is 90 x 9 bytes, at 8000 Hz = 51.84 Mbps

- **Electrical form called STS-1**
- **Optical form called OC-1**

Section Overhead:
Performance Monitoring
Local Orderwire
Data Channel
Framing

Line Overhead:
Performance Monitoring
Express Orderwire
Data Channel
Pointer
Protection Switching
Line AIS
Line FERF

STS Path Overhead:
Performance Monitoring
Signal Label
Path Status
Path Trace



VT Path Overhead (not shown):
Performance Monitoring
Signal Label
Path Status

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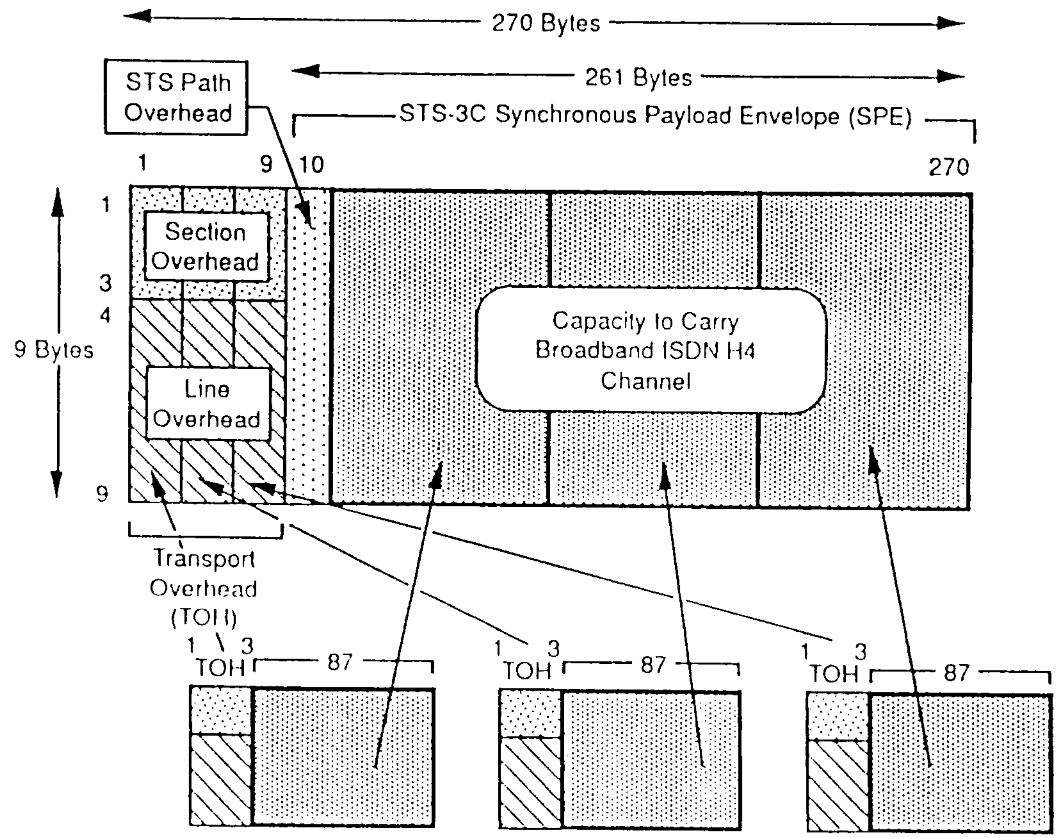
SONET Defines a Hierarchy of Rates

- **OC-3 (155.52 Mbps) is the lowest one of interest at the cutting edge**
- **OC-12 (622.08 Mbps) is another designated "customer access rate"**
- **OC-48 (2.448 Gbps) and OC-192 (9.953 Gbps) are of future interest**

Example: STS-3C (155.52 Mb/s) formed by 3 concatenated STS-1 (51.84 Mb/s) signals



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SONET/SDH Rates

SONET is a hierarchy of optical signals that are multiples (called OC-N) of basic signal rate of 51.84 Mb/s called OC-1, or Optical Carrier at Level 1.

The electrical counterpart of these optical signals are called Synchronous Transport Signal at Level N (STS-N).

The STS-N signals have standardized frame formats with a frame format with a frame duration of 125 microseconds (8 kHz rate).

The STS-1 frame consists of 90 columns and 9 rows of 8 -bit bytes.

The STS-N signal is by synchronously byte-interleaving N STS-1 signals.

The OC-3 (155.52 Mb/s) and OC-12 (622.08 Mb/s) have been designated as customer access rates in future B-ISDN networks.

Other important SONET rates are OC-48 (2.488 Gb/s) and, in the future, OC-192(9.953 Gb/s).

Table shows the most important SONET rates and their equivalents in the in the international SDH hierarchy.

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SONET/SDH Rates CONT.

Of special interest to B-ISDN and gigabit networking is the Concatenated Synchronous Transport Signal Level N(STS-Nc) which is an STS-N in which the N STS-1s have been combined together as a single entity and is transported not as several but as a single channel.

The concatenated signal provides a contiguous high speed channel to support services that require large bandwidths

Standard SONET/SDH rates

OC LEVEL	STS LEVEL	SDH LEVEL	RATE (Mb/s)	REMARKS
OC1	STS1		51.840	
OC3	STS3	STM1	155.520	UNI rate
OC12	STS12	STM4	622.080	UNI rate
OC24	STS24	STM8	1244.160	
OC48	STS48	STM16	2488.320	
OC192	STS192	STM64	9953.280	

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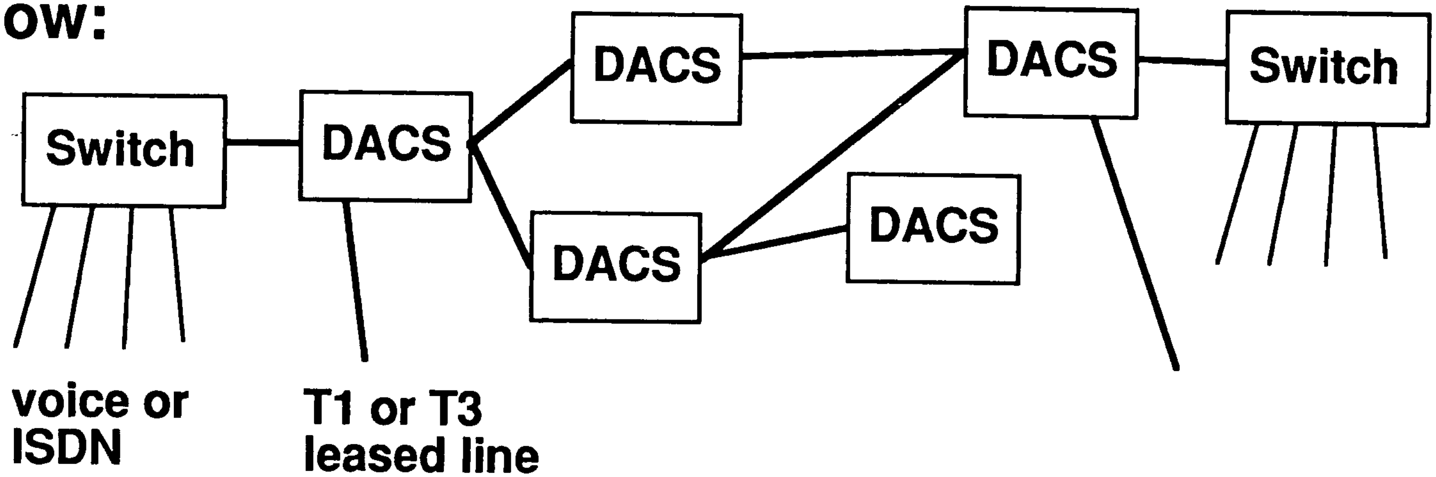
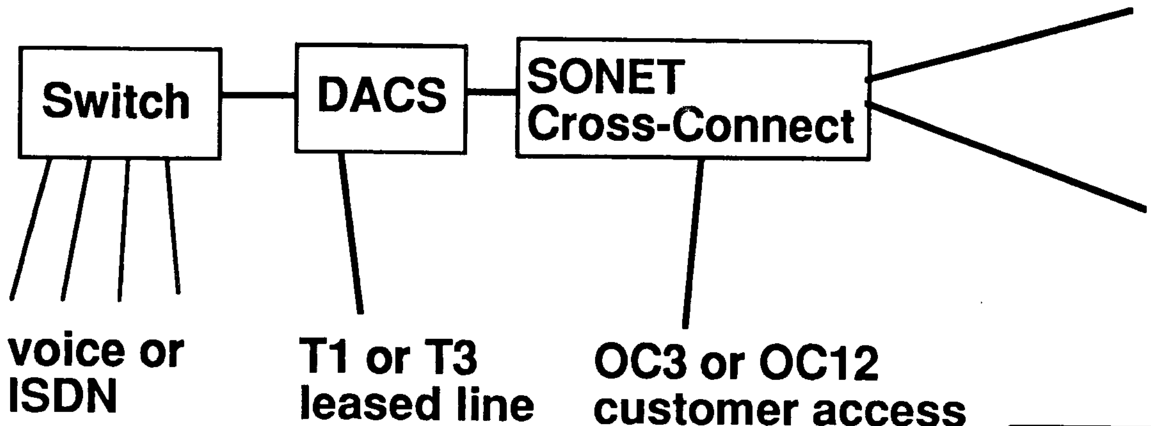
SONET (By Itself) Implies No Radical Change in Interacting With the Net

Now:



(DACS = Digital Access Cross-Connect System)

Soon:



ATM (Asynchronous Transfer Mode)

- Also known as B-ISDN (Broadband Integrated Services Digital Network)
  - formerly known as ATDM (asynchronous time division multiplexing)
- Information is transferred in fixed-length 53-byte "cells"
  - 5-byte header, followed by 48-byte payload
- Virtual circuit protocol
  - circuit setups and teardowns are accomplished by control packets
  - once circuit established, packet headers carry virtual circuit address
- Layered on top of SONET
  - many virtual circuits asynchronously interleaved into synchronous SONET channel
  - *ATM switches* route the packets to intended destinations

"ATM, while not quite the same as circuit switching, is also not packet. The key principle behind ATM is a simple, if slightly risky, one: If an ATM network is fast enough, it can emulate both packet and circuit-mode bearer services. It is a bearer service for all seasons, one size fits all. Making this work, of course, poses quite a challenge!"

--Goldstein, "ISDN in Perspective", 1992

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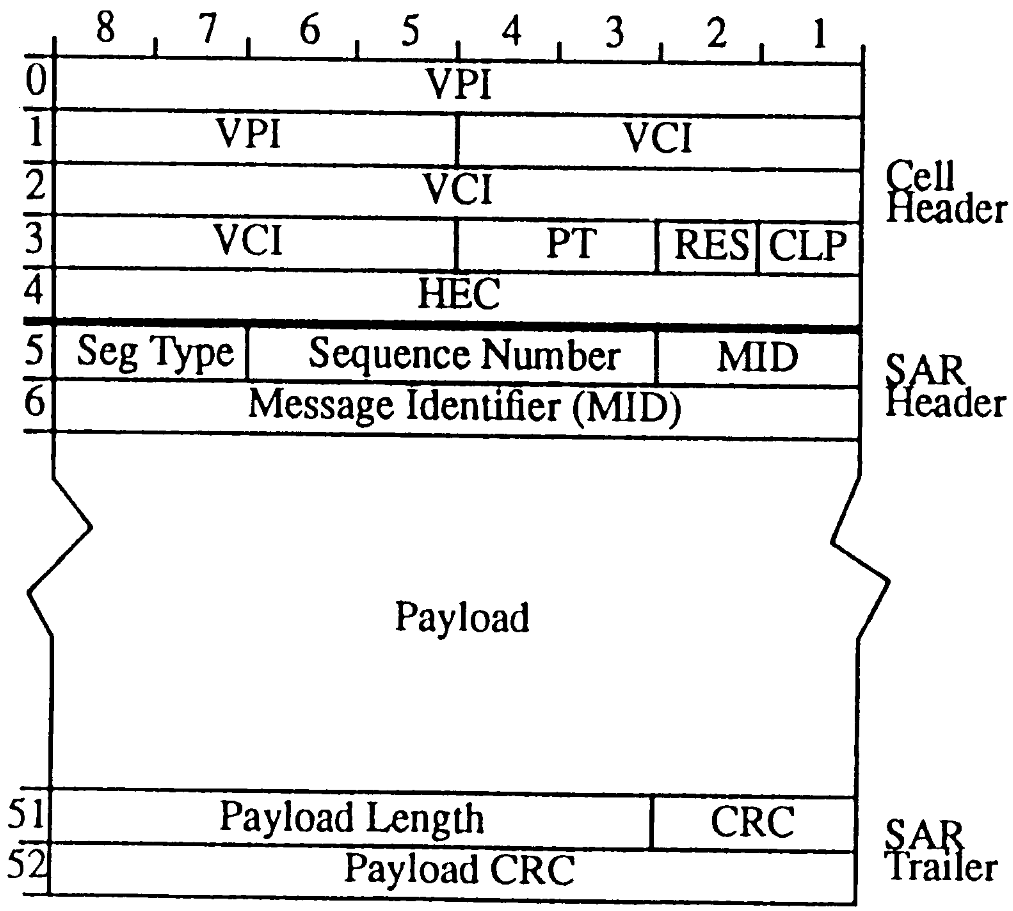
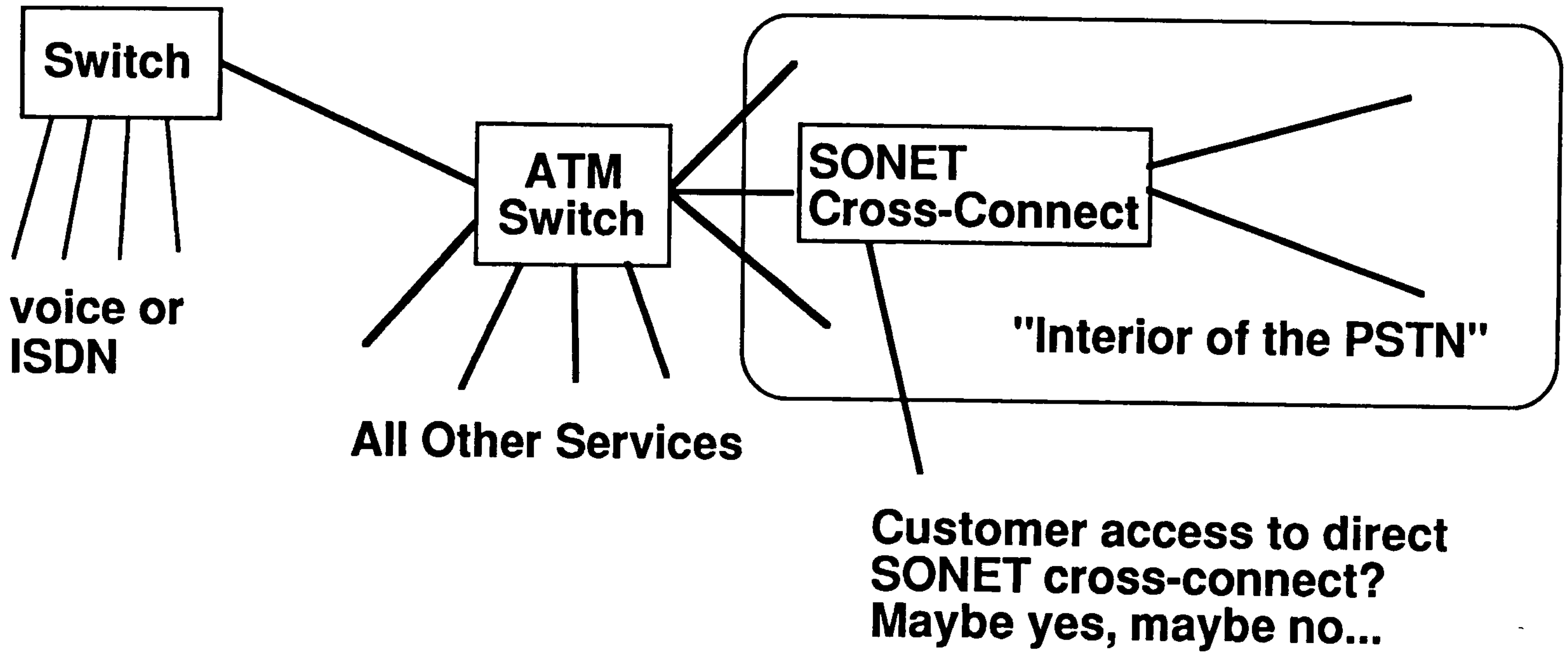
ATM Cell With Adaptation Layer (AAL) for Segmentation and Reassembly



VCI: Virtual Channel Identifier
VPI: Virtual Path Identifier
HEC: Header Error Check
PT: Payload Type
CLP: Cell Loss Priority
RES: Reserved

ATM Packet-Switched Network Is Radically Different



- Leased line services are emulated by ATM packet service
- An AT&T study has concluded that all existing services can be offered through ATM on top of SONET
- Detailed quality of service statistics will not be known for a long time; ATM switching is in its infancy

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SONET/ATM VLSI

THE ATM LAYER CHIP: C.A. JOHNSON AND H.J.C CHAO, BELLCORE,1991

This chip performs common asynchronous transfer mode (ATM) layer functions such as cell assembly and cell disassembly. The chip interfaces to the B-ISDN through a SONET STS-3c framer chip.

A SONET STS-3c USER NETWORK INTERFACE INTEGRATED CIRCUIT: T.J. ROBE AND K.A. WALSH, BELLCORE,1991.

This user network interface (UNI) chip, also known as the STS-3c framer, transmits and receives a SONET STS- 3c line signal. This CMOS IC also scrambles the serial STS-3c line signal, provides payload mapping of ATM cells. The user can choose between serial operation at 155.52 Mb/s or parallel operation at 19.44 Mb/s.

2.488 Gb/s SONET MULTIPLEXER/DEMULTIPLEXER WITH FRAME DETECTION CAPABILITY: D. T. KONG, BELLCORE,1991.

A research IC was designed to operate at speeds up to the SONET STS-48 rate of 2.488 Gb/s. This GaAs chip performs 1:8 , byte alignment, and SONET frame detection functions. A separate chip performs 1:8 multiplexing.

Layers above ATM: Now the Frontier

- At present not specified; various proprietary schemes and schemes under development
- Addressed by DARPA's "Gigabit Local Area Networks BAA"
- Important that US Gov't make its needs known to vendors, regulators, and standards bodies *now:*

  Circuit setup and teardown:

  - Provision for guaranteed bandwidth, zero-loss circuits
    - work by Golestani, Zhang, Clark, Parekh shows that this can be implemented within ATM if switches have the appropriate architecture
  - Provision for path diversity requests, path reporting, node rejection
  - Hooks for encryption, e.g., out-of-band Message Indicator

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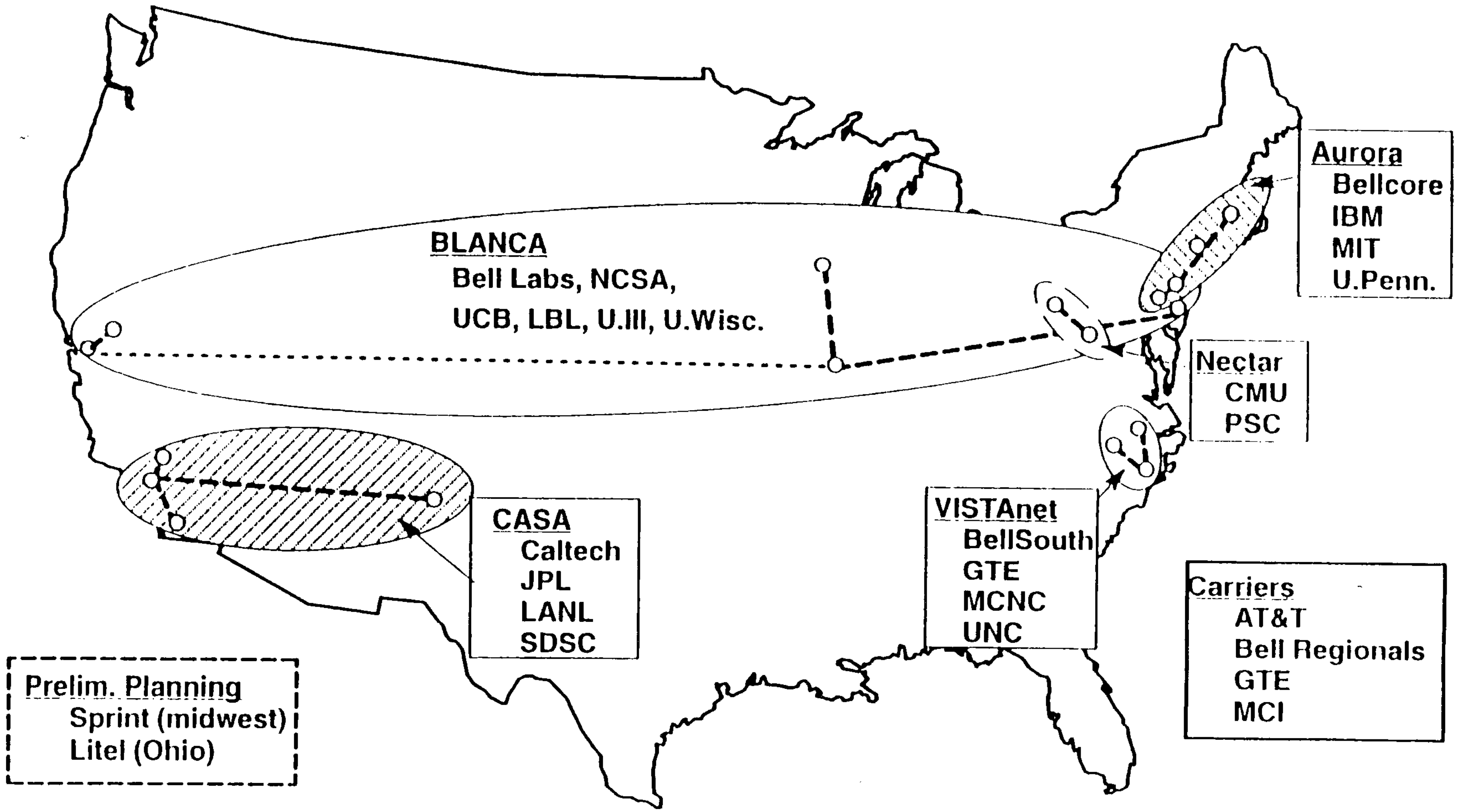
DARPA/NSF Gigabit Testbeds



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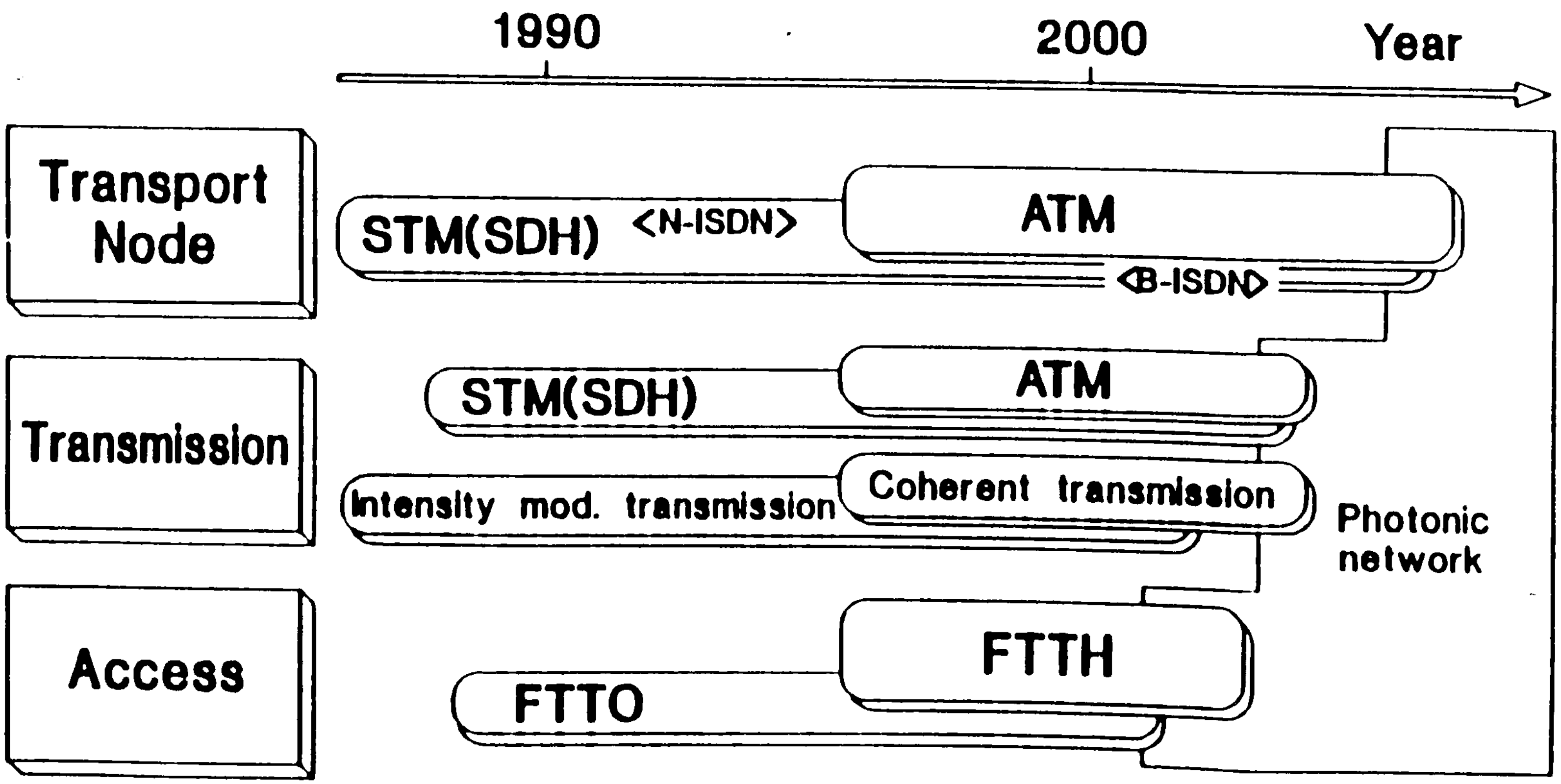
Japan Is a (the?) Technology Leader

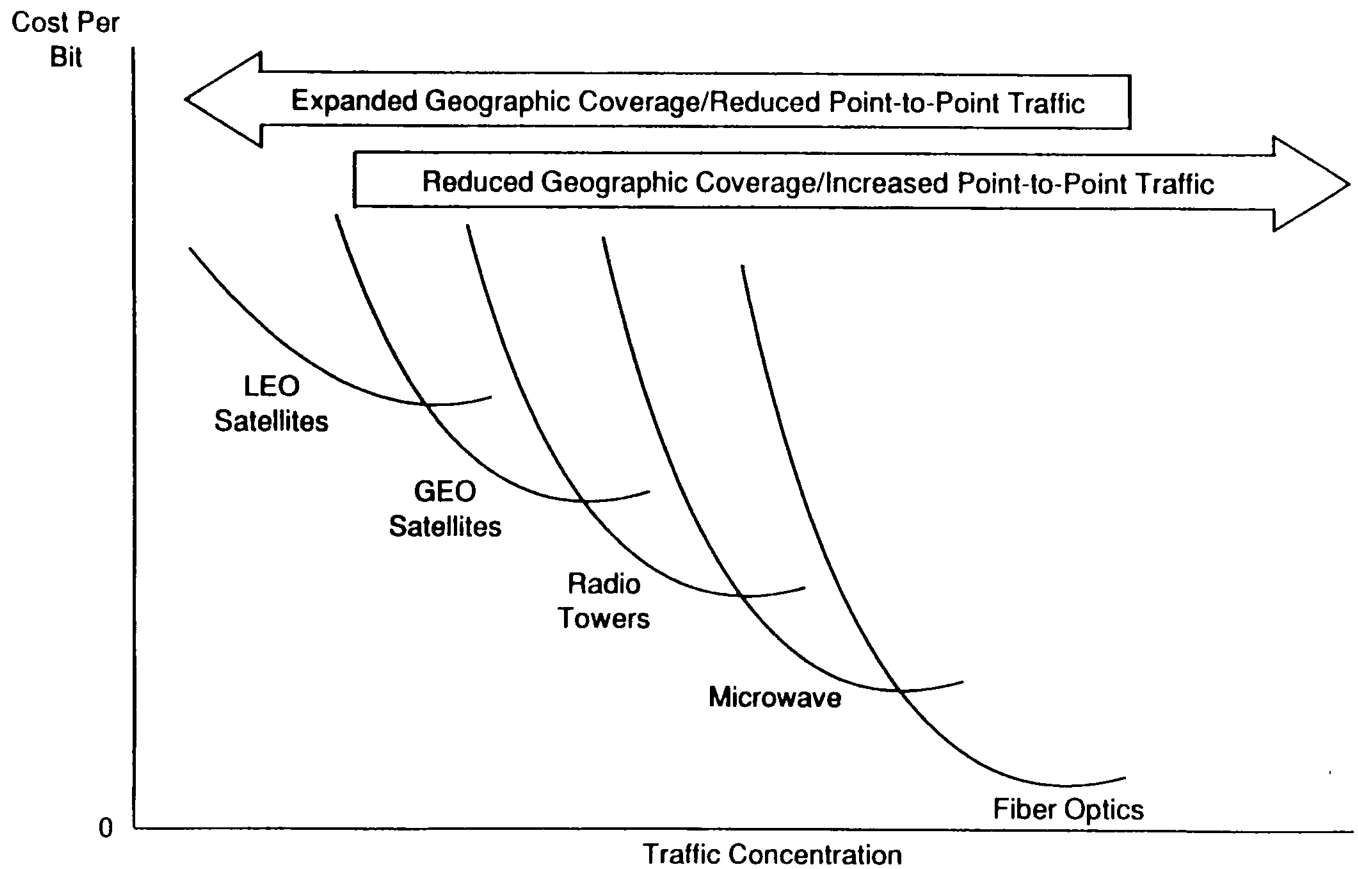
通信網エレメントの展開
Evolution of Network Elements



NTT

Personal Communications: The "Last Mile"

Different Media Span Different Concentrations of Traffic



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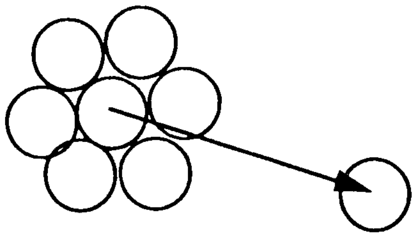
The "Cellular Shannon Equation"



$$r_0 = \text{ cell radius}$$
$$R_0 = \text{ distance to channel reuse}$$
$$R_c = \text{ cutoff distance (horizon)}$$

$$\text{available channel fraction} = \left(\frac{r_0}{R_0}\right)^2$$

$$S \propto \frac{1}{r_0^2} \qquad N \propto \int_{R_0}^{R_c} \frac{1}{\pi R_0^2} \frac{1}{r^2} 2\pi r \, dr \propto \frac{2}{R_0^2} \ln\left(\frac{R_c}{R_0}\right) \qquad \frac{S}{N} \propto \Lambda \left(\frac{R_0}{r_0}\right)^2$$

maximize:

$$\text{fraction} \times \ln(1 + \frac{S}{N}) \propto \left(\frac{r_0}{R_0}\right)^2 \ln\left[1 + \left(\frac{R_0}{r_0}\right)^2\right]$$

finite max as $\frac{R_0}{r_0} \to 0$

Conclusion: Always pays to go to the poorest feasible S/N, with close-in cell reuse.

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Capacity of Cellular Implementations

	Analog AMPS (ref)	GSM Full rate	GSM Half rate	ADC	JDC
Total bandwidth (B_t)	25MHz	25MHz	25MHz	25MHz	25MHz
Bandwidth per voice channel (B_c)	30kHz	25kHz	12.5kHz	10kHz	8.33kHz
Number of voice channels (B_t/B_c)	833	1000	2000	2500	3000
Re-use factor (N)	7	3	3	7	4
Voice channels per site (M)	119	333	666	357	750
Erlang per sq. km (3km site-site distance)	12	40	84	41	91
Capacity gain	1.0 (ref)	3.4	7.1	3.5	7.6

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Cellular Implementations

Time Division Multiple Access Digital Cellular Technical Characteristics

	GSM	ADC	JDC
ACCESS METHOD	TDMA	TDMA	TDMA
CARRIER SPACING	200kHz	30 kHz	25kHz
USERS PER CARRIER	8(16)	3	3
VOICE BIT RATE	13 kb/s (6.5kb/s)	8kb/s	8kb/s
TOTAL BIT RATE	270 kb/s	48kb/s	42kb/s
BANDWIDTH PER VOICE CHANNEL	25kHz (12.5kHz)	10kHz	8.3kHz

GSM: European Global System for Mobile Communications
ADC: American Digital Cellular, Telecommunications Industry Assoc.
JDC: Japanese Digital Cellular, Ministry of Posts and Telecommunications

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Satellite-Based Personal Communications Systems

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Unusual Action by WARC
(World Administrative Radio Conference)

- WARC-92 in Malaga/Torremolinos, Spain (February, 1992)
- Solid European bloc opposed to new allocations for Mobile Satellite Services (MSS); Europe's dense population better served by Land Mobile Terrestrial (cellular) services.
- Unprecented 11th hour coalition of U.S. and Third World countries prevailed with new allocations:

	Uplink (MHz)	Downlink (MHz)
"Big LEOs"	1610.0 - 1626.5	2483.5 - 2500
"Little LEOs"	148 - 150.05	137 - 138, 400.15 - 401
	312 - 315	387 - 390
Future Public LMTS	1885 - 2025	2110 - 2200
MSS (secondary)	1980 - 2010	2170 - 2200
MSS (R2 secondary)	1930 - 2010	2120 - 2200

- Japan relatively neutral; domestic needs like Europe, but whatever the system is, they expect to build it.

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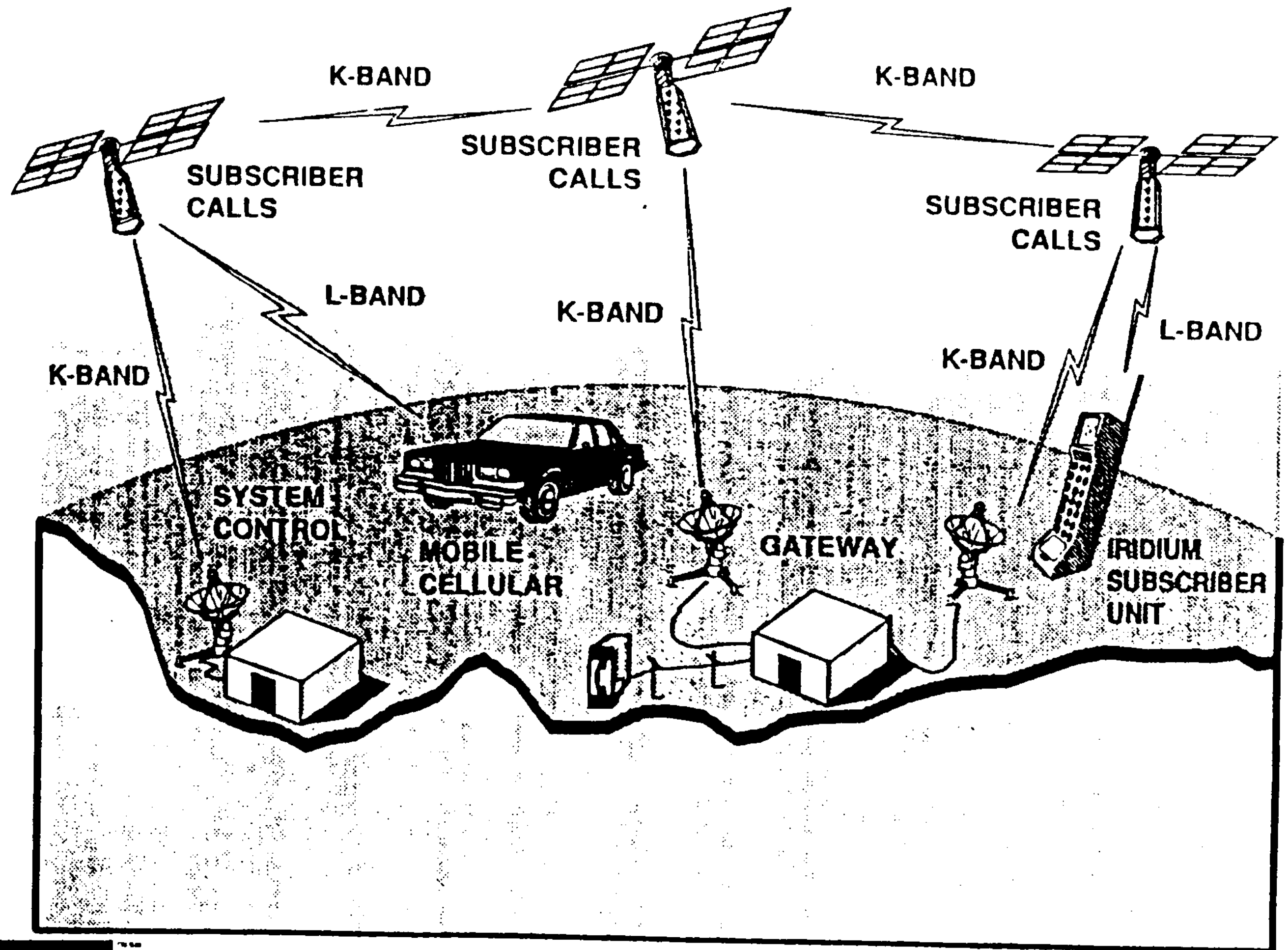
Proposed Orbital PCS Systems

ARCHIMEDES	European Space Agency
ARIES	Constellation Communications, Inc.
ELLIPSO™	Ellipsat Corporation
GLOBALSTAR	Loral Cellular Systems Corporation
GONETS	COSSCASP
IRIDIUM™	Motorola, Inc.
LEOCOM	Italspazio
LEOSAT	Leosat, Inc.
ODYSSEY℠	TRW, Inc.
ORBCOMM	Orbital Sciences Corporation
STARSYS	Starsys Global Positioning, Inc.

IRIDIUM SYSTEM OVERVIEW



IRIDIUM

11347-18

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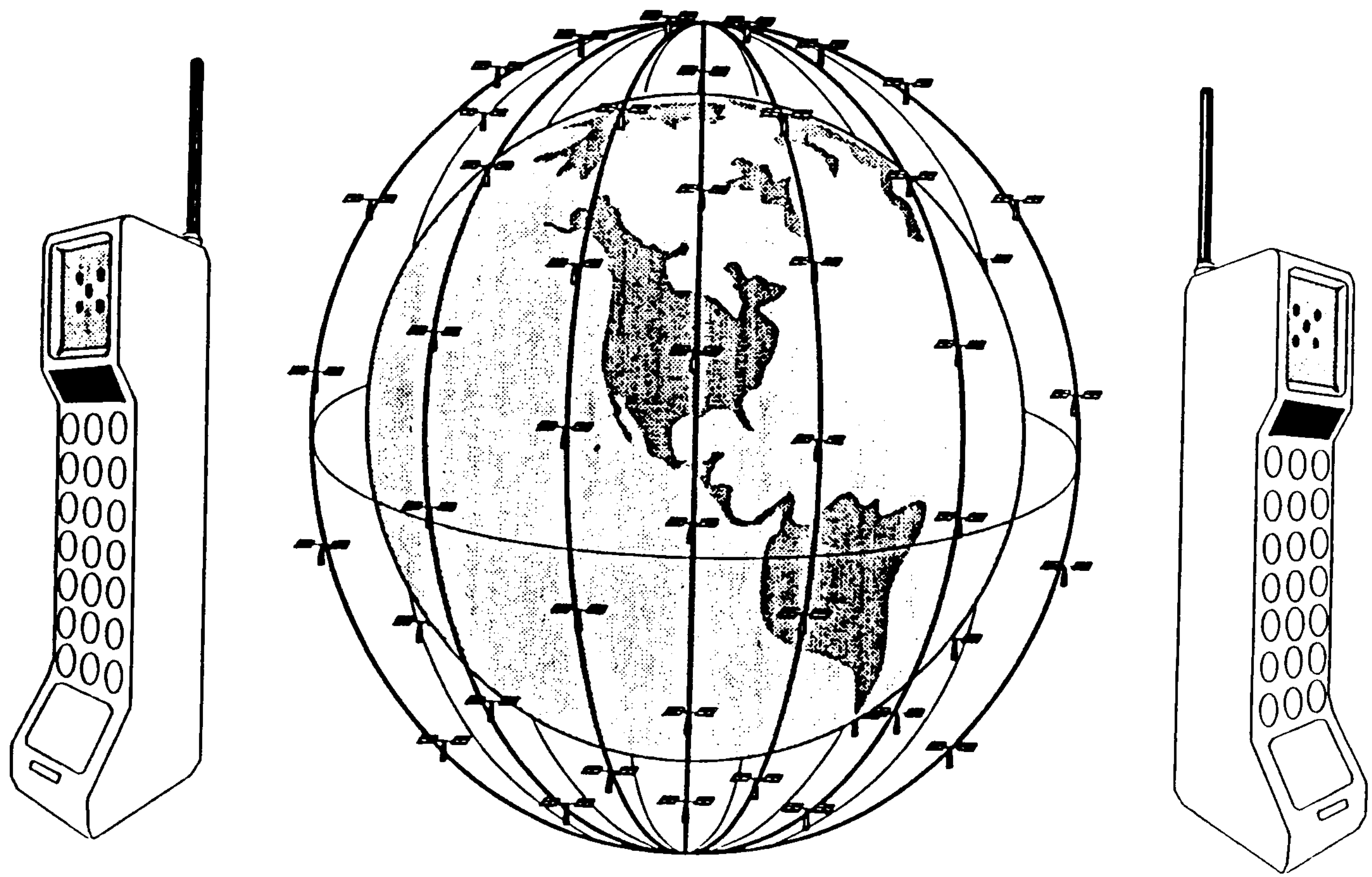


Communicate from one Handheld to another Handheld
anywhere in the world

IRIDIUM™

11347-60

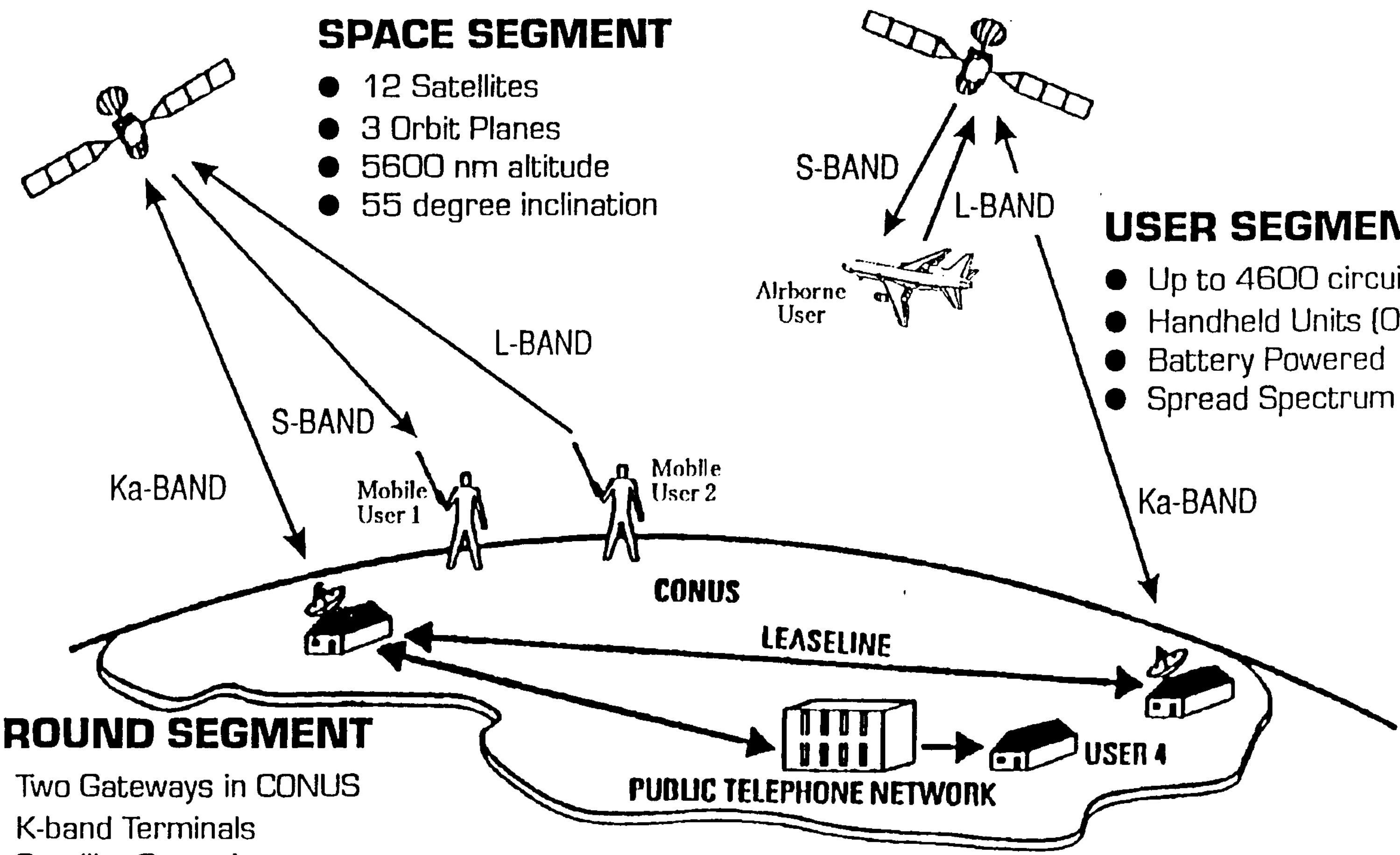
ODYSSEY

Odyssey System Overview

TRW Space & Technology Group

SPACE SEGMENT

- 12 Satellites
- 3 Orbit Planes
- 5600 nm altitude
- 55 degree inclination



USER SEGMENT

- Up to 4600 circuits
- Handheld Units (0.5 watts)
- Battery Powered
- Spread Spectrum / CDMA

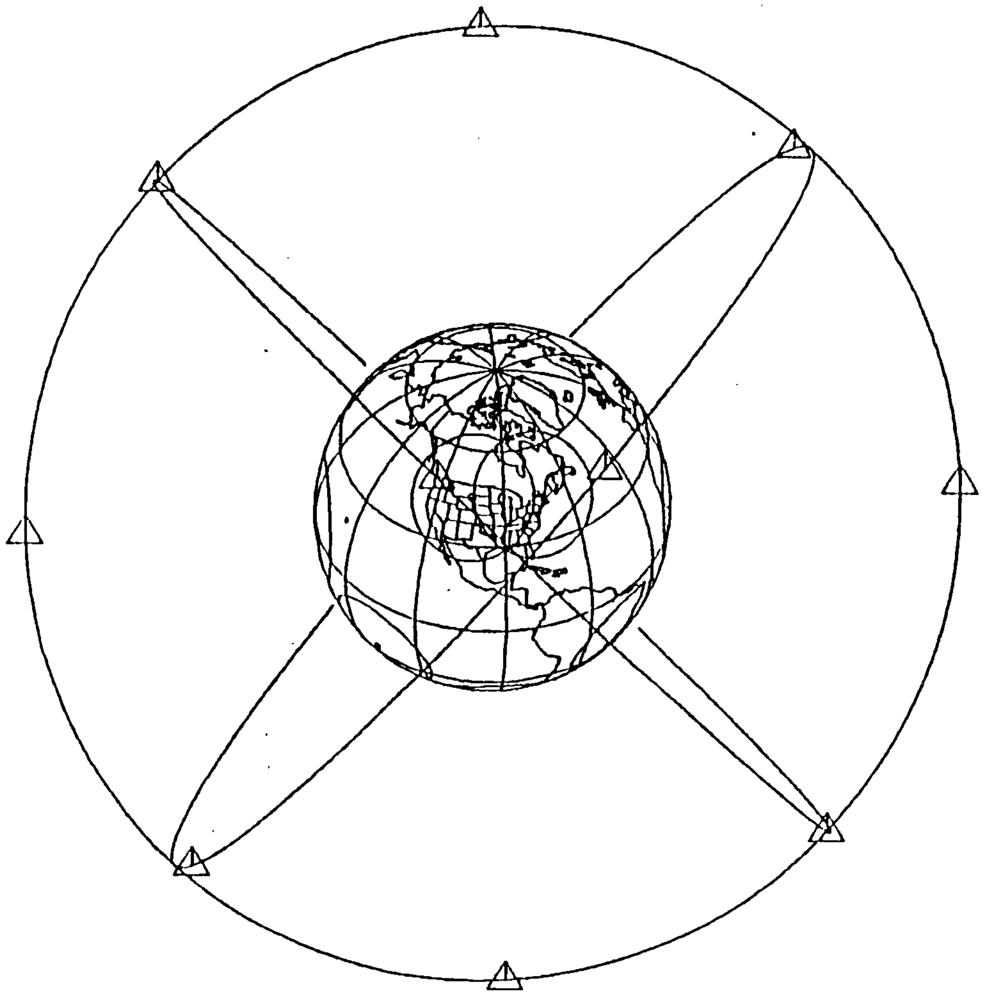
GROUND SEGMENT

- Two Gateways in CONUS
- K-band Terminals
- Satellite Control
- Network Control
- Traffic Routing

Odyssey Satellite Constellation

ODYSSEY

TRW Space & Technology Group



- NUMBER OF SATELLITES – 12
- NUMBER OF PLANES – 3
- ALTITUDE (CIRCULAR) – 5600 nmi
- INCLINATION – 55°

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R11M92.022.005

Orbital PCS Services

	Voice Kbps	Data Kbps	Geolocation Accuracy
ARIES	4.8	2.4	≈ 5 miles
ELLIPSO	4.8	No	100 meter
GLOBALSTAR	2.4/4.8/9.6	1.2 to 9.6	1-2 miles (1 sat) 275 meters (2 sats)
GONETS	No	Store and forward 100	No
IRIDIUM	4.8	2.4	≈ 1 mile
LEOCOM	No	1.2/9.6/16	No
LEOSAT	No	4.8	GPS option
ODYSSEY	4.8	9.6	400 meter
ORBCOMM	No	4.8	19-1100 meters*
STARSYS	No	Down 8.3 Up 4.2	≈100 meter

* Depends on single/dual frequency and length of time

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Orbital PCS Capacity

ARIES	50 duplex voice channels per satellite
ELLIPSO I II	150 carriers in CONUS 216 simultaneous users per satellite without voice activations 605 simultaneous users per satellite with voice activation
GLOBALSTAR	2600-2800 duplex voice channels per satellite
GONETS	System throughput is $7x10^9$ bits per day
IRIDIUM	110 duplex voice channels per cell averaged over 37 cells per satellite
LEOCOM	30 channels per satellite
LEOSAT	Expect to service over 100,000,000 intermittent users
ODYSSEY	4600 simultaneous transmissions
ORBCOMM	Down 18 channels per satellite Up 74 channels per satellite
STARSYS	Due to short messages and auto rebroadcast not limiting factor

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Orbital PCS Constellations

	# Sats	# Planes	# Sats/Plane	Inclination	Altitude (nm) Circular	Elliptical Apogee	Elliptical Perigee
ARIES	48	4	12	90° (polar)	550		
ELLIPSO I II	6 18	2 2	3 9	63.5° 63.4°		675 1567	270 230
GLOBALSTAR CONUS GLOBAL	 24 48	 8 8	 3 6	 47° 47°	 750 750		
GONETS	36	6	6	83°	≈ 755		
IRIDIUM	77	7	11	90°	413		
LEOCOM	24	4	6	90°	421		
LEOSAT	18	3	6	40°	524		
ODYSSEY	12	3	4	55°	5600		
ORBCOMM inclined orbits polar orbits	 18 2	 3 2	 6 1	 40°-60° 90°	 524 524		
STARSYS	24	3 (or 4)	8 (or 6)	60°	702		

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Orbital PCS Frequencies

	User Uplink	User Downlink	Feeder Uplink	Feeder Downlink	Cross Links
ARIES	1610-1626.5	2483.5-2500	6525-6541.5	5150-5166.5	
ELLIPSO I	1610-1616.5	2483.3-2500	1610-1616.5	2483.3-2500	
II	1610-1626.5	2483.5-2500	1610-1626.5	2483.5-2500	
GLOBALSTAR Syst A	1610-1626.5	1610-1626.5	6525-6541.5	5199.5-5216	
Syst B	1610-1626.5	2483.5-2500	6484-6541.5	5158.5-5216	
Syst C	1610-1626.5	1610-1626.5	2483.5-2500	2483.5-2500	
GONETS	200-400				Modernization Option
IRIDIUM	1610-1626.5	1610-1626.5	27.5-30.0 GHz	18.8-20.2 GHz	22.55-23.55 GHz
LEOCOM	950-959 960-980	905-914 1000-1020	6 GHz	4 GHz	
LEOSAT	148	137	478	370	
ODYSSEY	1610-1626.5	2483.5-2500	29.5-30.0 GHz	19.7-20.2 GHz	
ORBCOMM	148.0-148.85	137.2-138.0	148.85-148.9	137.0-137.05	
STARSYS	148.0-149.9	137-138	148.0-149.9	137-138	

MHz unless noted otherwise

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Orbital PCS Satellite Characteristics

	Estimated Weight Pounds	Estimated Prime Power Watts
ARIES	275	107 average 278 peak
ELLIPSO I II	40 385	22 peak 174 peak
GLOBALSTAR	510	150 average 875 peak
GONETS	496	40 average 48 peak
IRIDIUM	851	1429 average
LEOCOM	97	112.4
LEOSAT	50-100	23.4 average
ODYSSEY	2500	1800
ORBCOMM	331	360 average
STARSYS	110-220	120

MARKET ASSESSMENT

WSO

- Internal Motorola market research, combined with independent evaluations and geographic market studies, project at least 1.1 million IRIDIUM voice and data subscribers can be captured by the 5th year of operation.
- Specific sales forecasts by service, market segment, country and subscriber type were developed by Motorola.
- IRIDIUM's service growth and market penetration is enhanced by the projected growth of world cellular and paging services.

(millions of subscribers worldwide)

	1986	1990	2000	Growth 1990/2000
Cellular	1	11.2	110	25% per year (approx.)
Paging	11	23	110	18% per year (approx.)

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USERS

WSO

- Business Travelers
- High Income Consumers
- Corporate Communications
- Governmental Communications
- Commercial Air Travel
- General Aviation
- Business Aviation
- Recreational Vehicles
- Pleasure Boats
- Tourists
- Marine
- Construction and Oil/Mineral Exploration
- Developing Countries
- Rural and Mobile Service Extensions

Global Grid Traffic Volume and Characteristics

Telecommunications Now: 50 - 150 Gigabit/s

	U.S.	World
Telephone Subscribers	180,000,000	610,000,000
Long Lines Trunk Capacity	[500 Gbps]	[1.5 Tbps]
E-W across Mississippi	120 Gbps (= 2.1 M circuits)	
N-S thru New Jersey	120 Gbps	
Long Distance Calls per day	100 million	[300 million]
TV Distribution Channels	[200]	[1000]
Satellite Ground Stations	61	1083
Commercial Comm Satellites		ca. 100
Average Total Data Rate	[50 Gbps]	[150 Gbps]

- Values in brackets are rough estimates

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Common Carrier Services (2005): 0.5 - 2 Terabit/s

Qty	Type	bps	duty cycl	Ave Rate (bps)	burst fac	Peak Rate (bps)
1.E9	telephone subscribers	56000.	0.004	2.2E11	5	1.1E12
2000	TV distribution chans	1.0E7	0.5	1.0E10	2	2.0E10
1.E6	switched video subscr	1.0E6	0.05	5.0E10	10	5.0E11
10000	business WANs	1.0E7	1	1.0E11	1	1.0E11
100	supercomputer WANs	1.0E9	1	1.0E11	1	1.0E11
	Total:			4.8E11		1.8E12

- Assumes moderate growth for existing services
- Plus some new video/data services at plausible levels

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World Broadcast/Publishing Rates: Several Gigabit/s

Type	Amount	bps	duty cycl	Ave Rate (bps)	burst fac	Peak Rate (bps)
Radio Broadcast	5.2E7 hr/yr	56.K	1	3.6E8	2	7.3E8
TV Broadcast	1.6E7 hr/yr	1.5M	1	3.0E9	2	6.0E9
Press Agencies	1.5E11 words/yr			2.0E5	2	4.0E5
Serials	6.0E11 words/yr			8.0E5	2	1.6E6
Total:				3.4E9		6.7E9

- Source: FBIS

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World Broadcast/Publishing Rates Now Collected by FBIS or BBC: 10 Megabit/s

Type	Amount	bps	duty cycl	Ave Rate (bps)	burst fac	Peak Rate (bps)
Radio Broadcast	1.6E5 hr/yr	56.K		1.1E6		1.1E6
TV Broadcast	3.0E4 hr/yr	1.5M		5.6E6		5.6E6
Press Agencies and Serials	2.0E8 words/yr			2.7E2		2.7E2
Total:				6.7E6		6.7E6

- Source: FBIS

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EOSDIS Data System: Example of Near-Term Needs

- EOS is NASA system of satellites for earth observations and global change research. Launches in late 1990's and early 2000's.

- Data stream and archive size larger than anything NASA has done to date. Planning for:
  - 260 GB / day raw data (360 GB/day with precursor missions)
  - 1200 GB / day processed data, all archived (for decades).

- Data base usage wider than any present NASA system:
  - 10,000 users worldwide
  - Project 400 data base queries per hour (average rate), peak rate 4 times larger.

EOSDIS Data Rates: 100 - 200 Mbps

Type	Amount	Avg. Rate (bps)
Raw EOS data	240 GB / day	2.2E7
Earth Probe data	28 GB / day	2.6E6
Processed data	1180 GB / day	1.1E8
Total:		1.4E8

- Source: EOS restructured program-level architecture

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Data Rates for Desert Storm: ca. 1 Gigabit/s

Qty	Type	Size	bps	duty cycl	Ave Rate (bps)	burst fac	Peak Rate (bps)
200000.	voice calls/day	400 sec	9600.	1	1.1E6	6	1.1E6
10000.	documents/day	1.E8 bytes		1	1.2E7	1	1.2E7
800000.	sq mi imagery/day	3.E7 bits/sq mi		1	2.8E8	3	8.3E8
200.	video conf chans		1.0E5	.25	5.0E6	4	2.0E7
1.	intel data stream		3.0E8		3.0E8		3.0E8
	Total:				6.0E8		1.2E9

- Values are as if sent electronically
- Actually, much done by airlift of hard copy or materiel

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Albertville Olympics: A Mini-Theater Peak Rates ca. 10 Gigabit/s

- All Comms supplied by ALCATEL TELSPACE and FRANCE TELECOM
- 200,000 telephone calls / day
- TV (including HDTV), telephone, data, unattended sensors
- Environment -30 to +60 F, to 3000 m altitude
- 147 lightweight mobile microwave links (6 - 22 GHz) yielding 800 km of network over 13 sites
- 13 ground satellite stations (KU band) to TELECOM-2 and EUTELSAT satellites

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Troops Expect/Demand A High Level of Connectivity

Desert Storm Factoid:
Thousands of unexpected/unauthorized PC's appeared in Theater and were connected to the net.

Desert Storm Factoid:
Hundreds of off-the-shelf commercial GPS receivers were purchased by relatives/friends in CONUS and sent to troops in Theater.

- All-volunteer forces expect to fight high-tech wars.
- Troops demand no less connectivity in battle than they have walking down the street at home.
- The next war will be fought by troops who are accustomed to personal cellular communications.

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Data Rates for "Regional Storm 2010" 10 - 20 Gigabit/s

Qty	Type	bps	duty cycl	Ave Rate (bps)	burst fac	Peak Rate (bps)
100000.	ground troops	4800.	0.1	4.8E7	10	4.8E8
1000.	combat vehicles	1.0E6	0.1	1.0E8	10	1.0E9
1000.	a/c, weapons in flight	1.0E7	0.1	1.0E9	10	1.0E10
100.	command centers	1.0E8	1	1.0E10	1	1.0E10
	Total:			1.1E10		2.1E10

- Continuous connectivity to every soldier and vehicle
- Data rate is Desert Storm x 20

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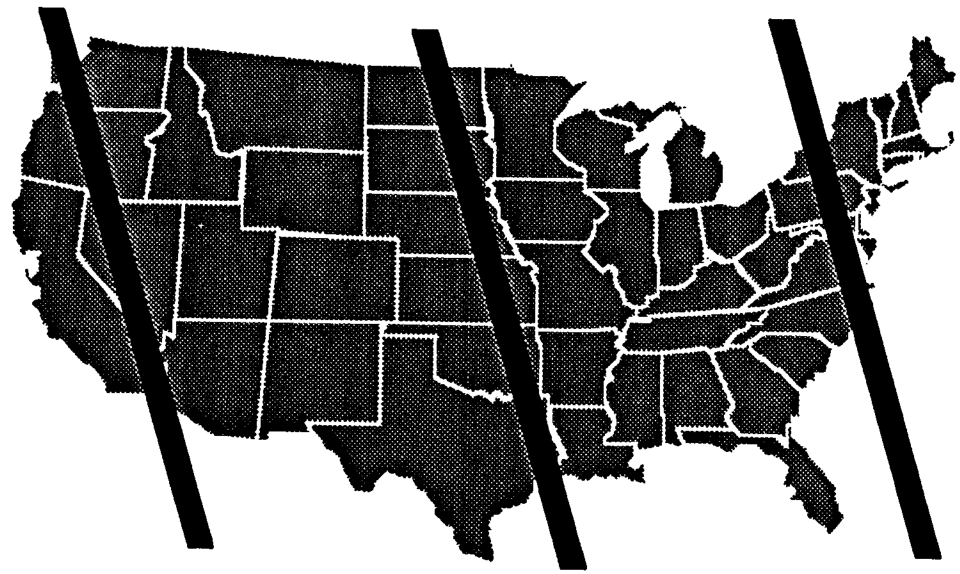
Generic IMINT Data Rates

Nominal parameters:

- ca. 90 min. orbit period
- 16 orbits per day
- 7400 m/s ground track



$$\text{Bit Rate} = 7.4 \times 10^{8}\ \text{bps} \left(\frac{\text{swath}}{100\ \text{km}}\right)\left(\frac{\text{resolution}}{1\ \text{m}}\right)^{-2}\left(\text{bits per pixel}\right)\left(\text{collection fraction}\right)$$

"Landsat:" $7.4 \times 10^{8} \times 1 \times 10^{-3} \times 20 \times 1 = 1.5 \times 10^{7}$

"Hi-Res:" $7.4 \times 10^{8} \times 10^{-1} \times 10^{2} \times 4 \times 10^{-1} = 3 \times 10^{9}$

Generic SIGINT Data Rates

$$\text{Bit Rate} = 3.2 \times 10^{9} \text{ bps} \left(\frac{\text{Bandwidth}}{100 \text{ MHz}} \right) \left(\frac{\text{bits per sample}}{16} \right)$$

- Nyquist critical sampling
- 16 bits = 96 db; might use more or less

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Industrial Information Infrastructure

- Three-dimensional, centrally controlled models throughout the design/manufacturing cycle
  - Boeing found unique convergence of ECOs
- Computer-integrated manufacturing network
  - Electronics company calculated actual 38% return on investment
- Near-term, expect to see only within single sites
  - Boeing (with 777, the paperless airplane) spends $1.5 Billion/yr on computer-related expenses
  - But <<5% on networking; only a few leased lines to subs, at 56 Kbps - 1.5 Mbps
  - A 45 Mbps line is used for financial data!
- Far-term, internal data flow rates should migrate out onto the global grid to subcontractors, suppliers
  - Boeing internal data flows are probably in the Gigabit range

Ops per Bit is Surprisingly Constant

Basic Research:			
NCAR	Atmospheric and climate research	1.7 Mbps	750 ops/bit
SDSC	NSF supercomputer center	0.4 Mbps	3300 ops/bit
Weapons Design:			
LANL	Design nuclear weapons	7 Mbps	570 ops/bit
Intelligence Processing:			
Data Stream #1		n.a.	750 ops/bit
Data Stream #2		n.a.	650 ops/bit

- Conclusion: Gigabits requires Teraflops (pretty much independent of what is being done!)
- Network architects should inquire whether their users have the necessary computing capacity. If not, the bits are going to fall on the floor.

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Data Storage Capabilities

Medium	Areal Density (Mb/sq cm)	Data Rate (MB/sec)	Cost
Mag Disk	45	8 MB/sec	$1000/GB (drive & disk)
Mag Tape	40	10 (home) 1000 (studio)	$2/GB (tape cassette)
Optical Disk (CD-ROM)	100	1.5 (burst) (read only)	$10/GB (disk only)
Optical Disk (MO read-write)	20	4	$200/GB (disk only)
Mag Disk (yr 2000)	650	30 (1 head)	$200/GB (drive & disk)
Optical Disk (yr 2000)	1100	8	$5/GB??
Holographic (photorefractive crystals)	1Gb/cc*	1000 (read) 1 (write)	??

*Volume Density

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Near-Term Goals (next 5 years)

- Regulatory issues
- Security issues
- Techniques for efficient utilization of the grid
- International standards
- Bridge the culture gap
- Tactical fiber
- Agile waveform radio
- Global intelligence dialtone

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Government Action is Needed on Common Carrier Regulatory Issues

- Deregulation allows/requires secondary resale of bulk channels
- Carriers therefore tariff channels as if for audio phone use

Name	Rate	no. chans	Typical Cost per mo.
ISDN	56000 bps	1	$100
T1	1.544 Mbps	24	$2000
T3	44.736 Mbps	720	($50,000)
OC24	1.244 Gbps	20000	$1,000,000 (to Bellcore!)

- Not clear whether Carrier can impose contractual limitations on resale as a condition of offering service. Politically risky to carrier.
- Need for USG actions:
  - Clarify current situation
  - Enunciate a policy of encouraging high-bandwidth services
  - Propose legislative measures to further such a policy

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There Exists a "Culture Gap"

Internet Culture:

- Diverse, open Internet community
- Growing 10-15% per month
- Belief in un- or lightly-managed network
- "Put in enough bandwidth and don't worry"
- Goal is highest rate, aggregate throughput; little concern for variance
- Multiple experiments: let 1000 Gigabits bloom
- Evangelistic

OPS Culture:

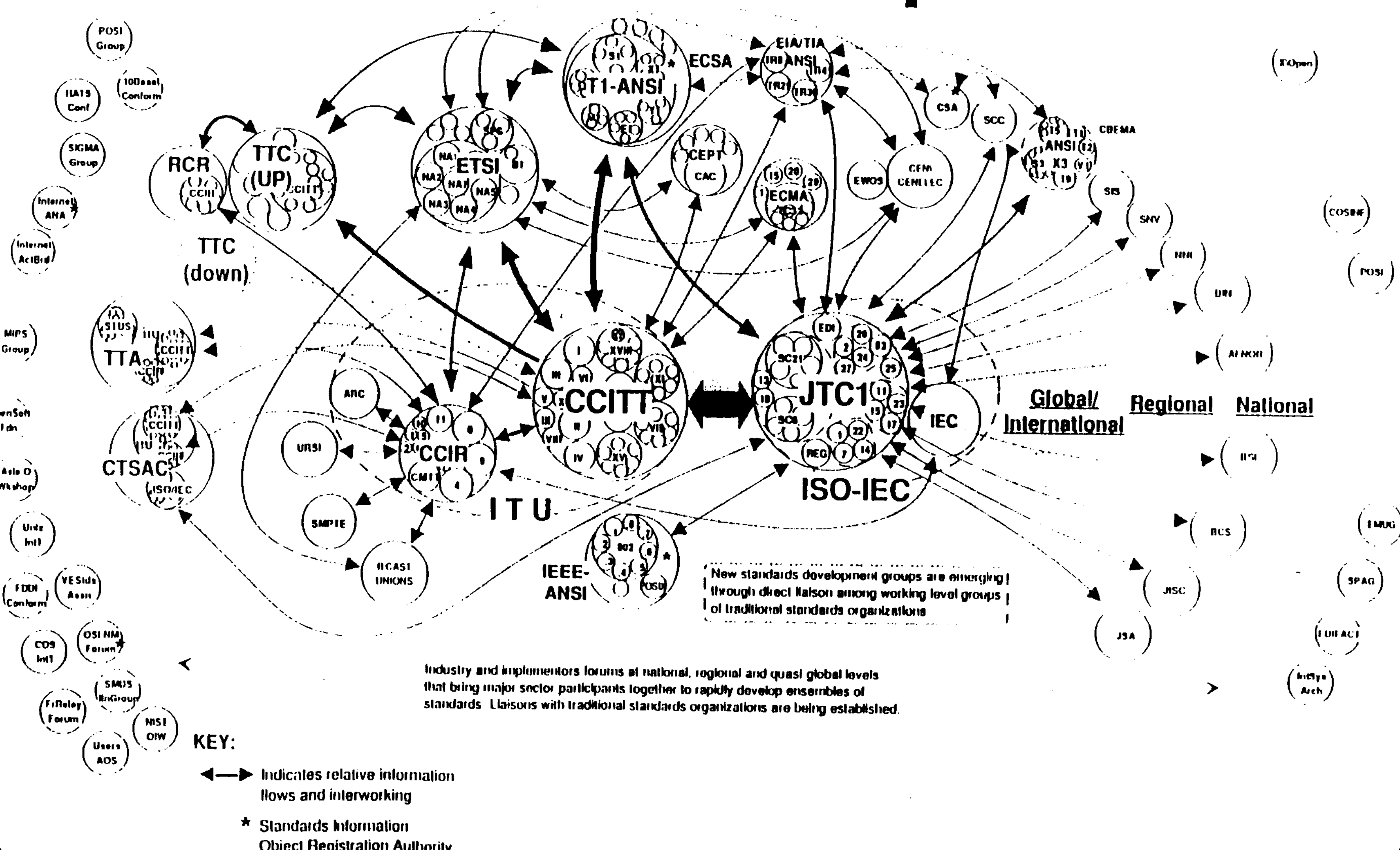
- Vertically integrated, compartmented
- At mature end of growth curve
- Each mission strongly controls its own dedicated infrastructure
- "We can't put a billion $ spacecraft at risk to some hacker's email loop"
- Conservative infrastructure design, highly reliable and sized for peak needs
- Won't switch without performance guarantees at 0.99999... level
- Suspicious of evangelists

What is needed: Common discussion of requirements and metrics

- *Not just* average rate , throughput, latency
- *But also* worst-case distributions, guaranteed bounds, guaranteed bandwidth on demand, reliability (various time scales), enforced path diversity, security, etc., etc.

* The regulated Carriers are another culture yet! So is DISA.

Interface to Standards-Making Bodies is Complex



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Security Issues

Financial Industry is Using Simplistic (Arguably Obsolete) Standards

CONNECTION INTEGRITY (referred to in the industry as "message integrity")
This can be provided with digital signatures. The ANSI X9.9-1986 and ISO 8730 standards define the process.

CONNECTION CONFIDENTIALITY.
Financial community uses DEA X3.92-1981, which is equivalent to DES, to protect data. Also use encryption to protect personal PINs.

ACCESS CONTROL MANAGEMENT.
Effort underway in ANSI to develop a standard (ANSI X9.26-DRAFT) TO protect sign-on information such as passwords.

KEY MANAGEMENT.
Financial community relies on a key management center to distribute keys to subscribers. Communication among centers is being studied so that subscribers of different centers can communicate in a secure manner.

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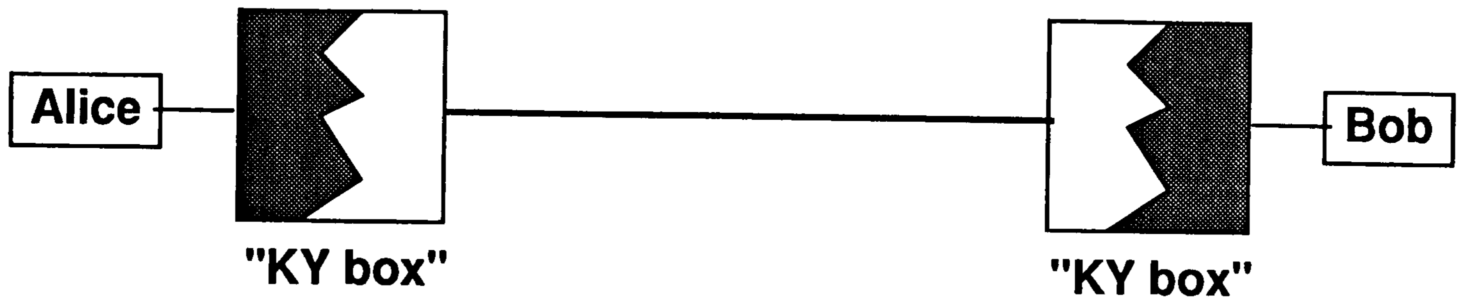
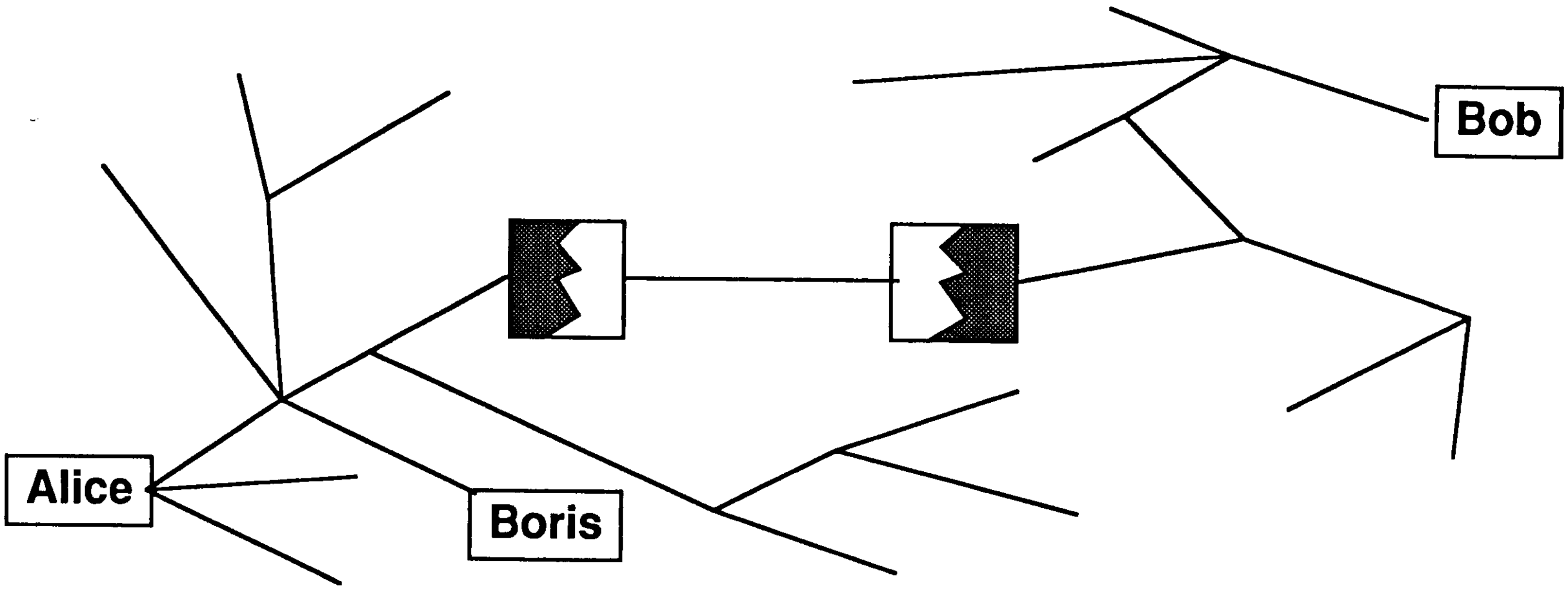
Traditional Link Encryption



- Cryptovariable (key) unique to two ends of a link
- Must physically control the ends of link
- Requires "off-link" system of key distribution

Link Encryption Has Limited Utility on a Switched Net



- Prevents interception on one link
- Does not prevent interception by/on other routes

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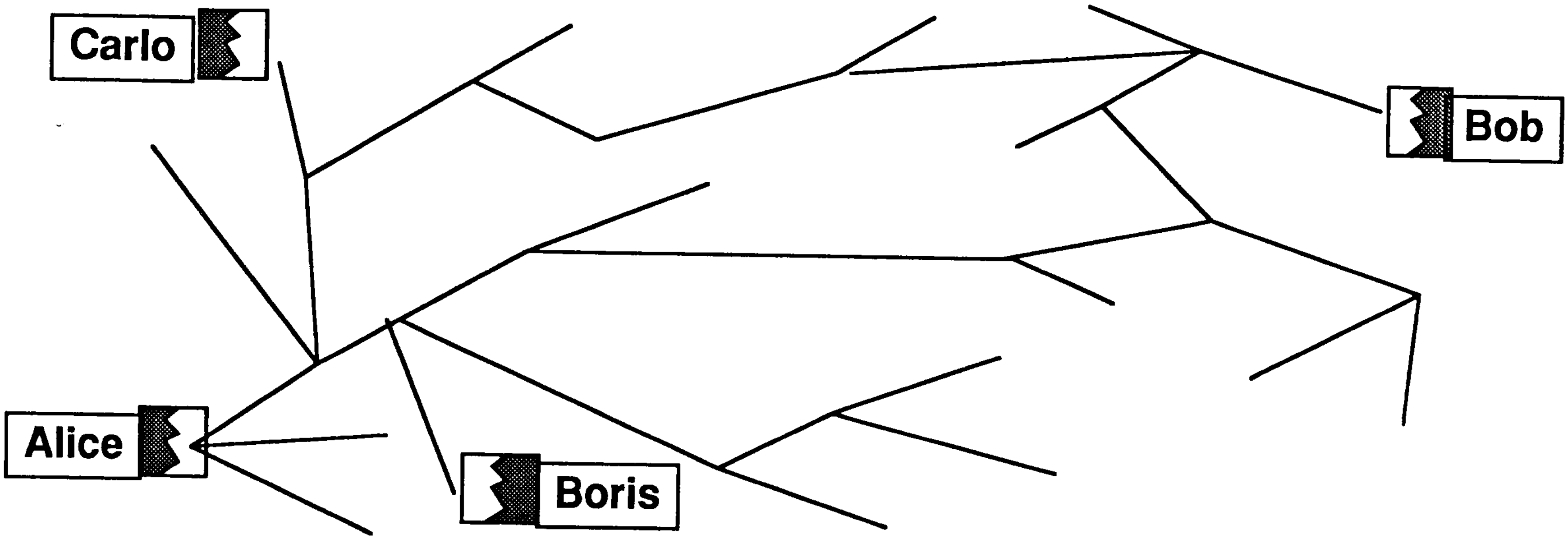
Each User Must Separately Encrypt (millions of users)



- How to enforce operational security??
- How to manage key distribution?? (*"Rekeying the world"*)
- How to implement multilevel security??
- How to give NSA shaking nightmares!

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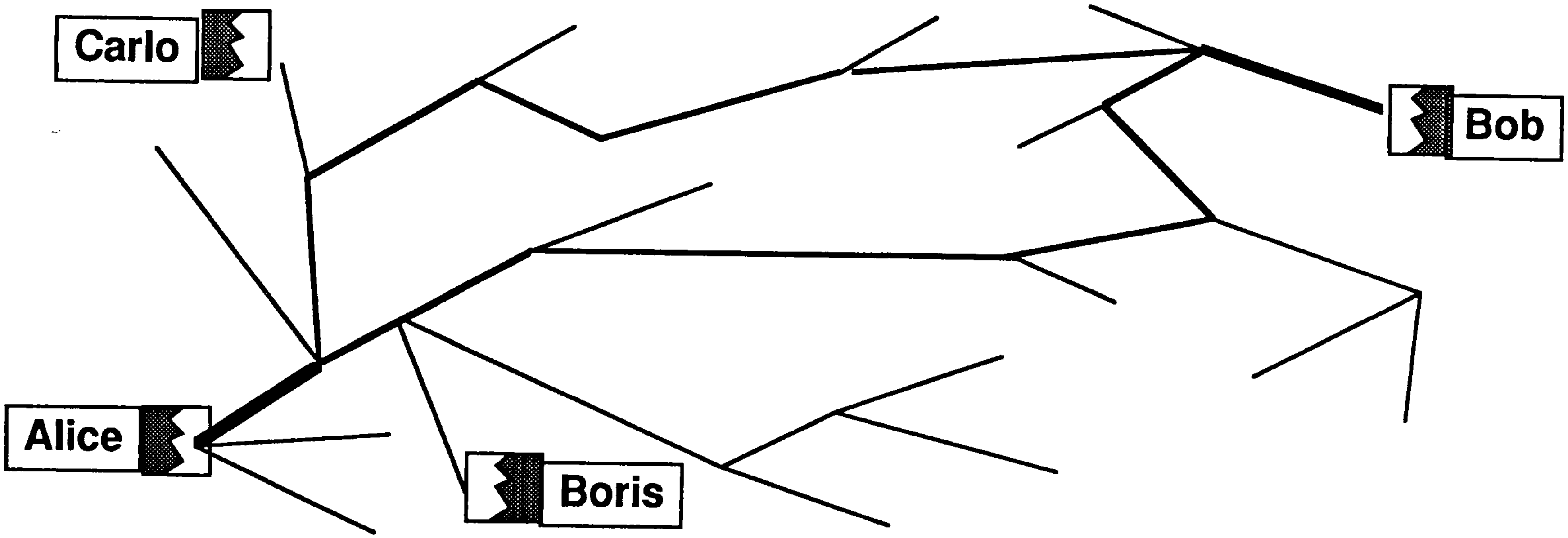
Combination of Techniques Can Address Security Issues

Balance between classical encryption and other types of COMSEC:

- Enforced path diversity possible on the net (or by other assets)
- Public Key Cryptography
- Algorithms/Unique Cryptovariables in secure (anti-intrusion) chips
- Exploit virtual ciruit architecture of ATM/SONET

Enforced Path Diversity Makes Hostile Collection Much More Difficult



- Establish two virtual circuits by maximally different paths
- Send Message Indicator (MI) on one circuit (unique for each message)
- Send rest of message, encrypted using MI, on other circuit
- Need USG to push for CCITT standards defining/allowing path diversity
- Also necessary for establishing high-reliability virtual circuits

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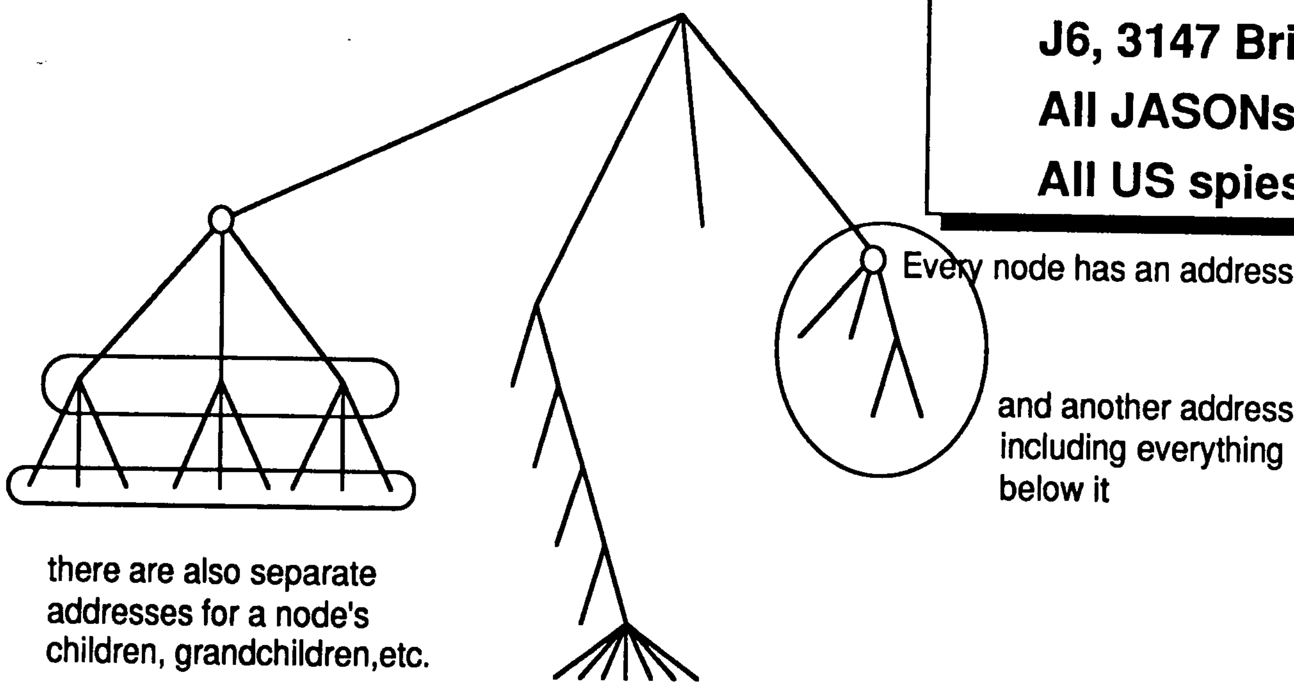
Public Key Cryptography Can Provide Agility and Decentralization

- Cryptovariable has Private and Public pieces
- Each user "publishes" the Public piece
- Anyone can encode, but not decode, with the Public piece
- Messages can include a digital signature and certificate of authenticity
- Is SLOW; generally used only for key exchange on a per-message basis
- Is a proven technology, e.g. in STU III
- Multicast/Broadcast of messages is no harder than addressing them

Multicast/Broadcast Is No Harder than Addressing

To: Company Cmdrs, III Corps
J6, 3147 Brigade
All JASONs
All US spies in Iraq



- Every addressable group has a public/private key pair
- Every multicast message encrypted with a unique (one-time) CV
- Header includes that CV encrypted for each addressable group's private decrypt (size comparable to address)

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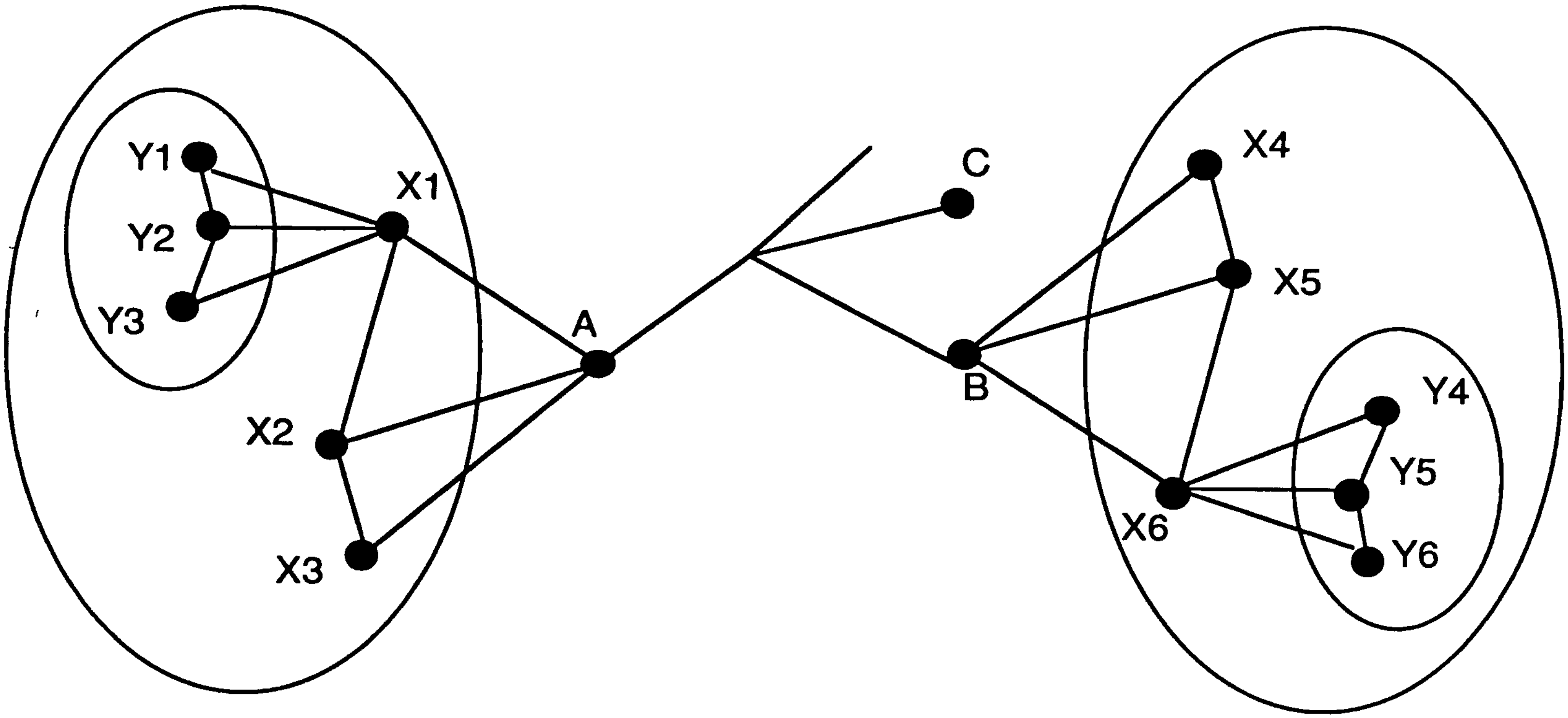
Multilevel Security: the Problem



- Y1 needs a secure circuit to Y5, who is in the same compartment
- Y's want a transparent net with addresses Y1...Y6 all equivalent, and no visible encryption among themselves
- Outside of the Y's, no one is allowed to know even their existence
- Must enforce that Y1 does not accidentally compromise Y-level material to C, or B, or X4, e.g., either content or existence

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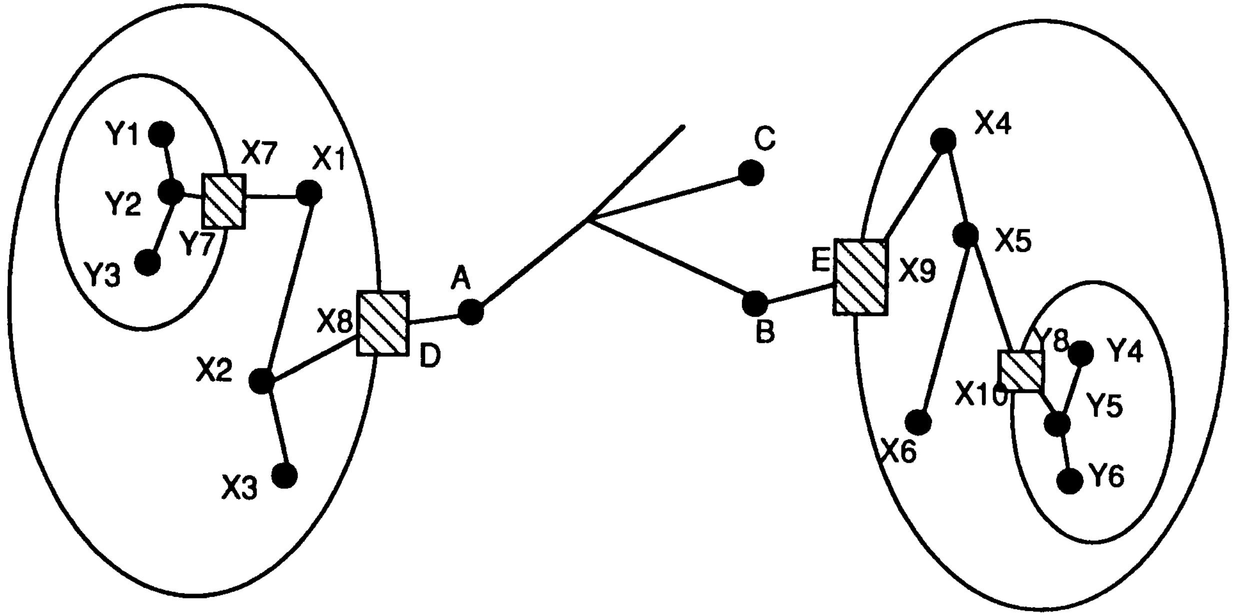
Multilevel Security: One Protocol



- Membrane boxes (▧) have "inside" and "outside" addresses
- They have address translation tables (e.g., Y4 -> X10)
- They encipher/decipher all outgoing/incoming trafficwith the "inside" cipher (which is the only one they know)
- Translated outside address is prepended in clear as a call setup
- This multilevel security is additional to that already provided by Public Key Encryption

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Multilevel Security: Example

In the Y layer:

To: Y4
From: Y1
ATTACK
AT
DAWN

In the X layer:

To: X10
From: X7
yyyyyyyy
yyyyyyyy
yyyyyyyy
yyyyyyyy
yyyyyyyy

In Public:

To: E
From: D
xxxxxxxx
xxxxxxxx
xxxxxxxx
xxxxxxxx
xxxxxxxx
xxxxxxxx
xxxxxxxx

Cn a pure packet architecture, growth of packet size precludes this model

- However, in a virtual circuit architecture like ATM/SONET, the addressing all occurs at circuit setup. Subsequent packet sizes are unaffected
- Multiple encryptions of message can be reduced to a single one in innermost layer, if desirable (slightly weakens security)

Efficient Use of the Global Grid

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Need Techniques That Promote Efficient Use of the Global Grid

- Data Compression: Modern data compression techniques can conserve network bandwidth.
- Data Caching
  - Multicasting: Send only one copy to the net.
  - Local Cached copy: Provide local response to net queries.
- Net Cables and E-Mail: Send only a notification token. User then queries the source.
- Remote Computing: Send small query programs to a large data base. (Esp. if data is 10 yrs at 10 Mbps !)
- Efficient Queries
  - Gaze Tracking
  - Et cetera.

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Efficient Global Queries

- Often only a small percentage of data in a file (accessed over a network) is of interest.
- Most current access methods either
  - move the whole file across the net, employ viewing tools, or
  - execute queries remotely, with the response transmitted over the net as a block.
- One can envision more sophisticated paradigms in which data and instructions or algorithms flow back and forth in the net more transparently.
- A comprehensive system in which only the correct and interesting data is transmitted, would save valuable bandwith on the net.

Gaze Tracking

- Gaze tracking can be used to emulate a perfect resolution monitor (4000 lines, 70 fps) for distances < 3000 Km.
- Idea: Track the eye, provide high resolution image only where eye is gazing.
- Performance:

Crude......	Better......	Still Better
50 Gbps	50 Mbps	1 Mbps
(image)	(MPEG)	(gaze-tracked)

- Gaze-tracking services can be provided by the network at level transparent to the application (new service for the presentation layer: "indexed next")

How the Global Grid Might Respond To a Simple Query

- **First: Fetch Meta-Data (then wait for a response)**

Directories:	Number of files, types and sizes
Reports:	Abstract
E-mail:	Subject Line
Data-Base:	Cost of query
Raw:	Single ATM frame

- **Second: Fetch Main Data (then wait for a response)**

Text:	Fetch only first two screens
Image:	Fetch only a low-resolution version of image and /or only high-resolution where gaze is focused.

- **Third: Fetch Ahead (then wait for a response)**

Text:	Fetch ahead one screen at a time
Image:	Fetch ahead one more level of resolution, track graze.

Present Net Query Systems

Remote DB Query:	E-Mail, rsh
File Transfer Systems:	ETP, etc.
Remote Viewing Systems:	rlogin, X-windows
Virtual Global File System:	Prospero, Archie
Global Search Tools:	Wais, knowbots

Datagrams / Split-Transmissions

None meet all our goals for efficient communication! New paradigms are needed.

What's Needed?

- **Several Possibilities:**
  - Each application tool provides its own data flow control.
  - The global grid provides flow control.
  - Mixture of both of above, e.g. options for special applications.
- **Best Bet:**

  The Mixed Strategy. Global Grid should provide:
  - Transparent flow-control protocols for frequent message formats such as e-mail, reports, images, directories, etc.
  - Options to allow applications to provide to the user more arcane meta-information such as cost of a DB query.

OPEN SYSTEM INTERCONNECTION REFERENCE MODEL OSIRM

Layers of the Open Systems Interconnection Reference Model

Layer	*Function**
Application	Support of user functions such as file transfer, transaction processing, *et cetera*
Presentation	Transfer syntaxes (character coding)
Session	Coordination services, dialogue, synchronization
Transport	Reliable end-to-end communication
Network	Delivery within a single subnetwork; end-to-end aspects, such as addressing and internetworking
Data Link	Delivery of blocks of data between two points
Physical	Bit transmission

*Refer to ISO 7498 or X.200 for a more formal and complete description of these functions.

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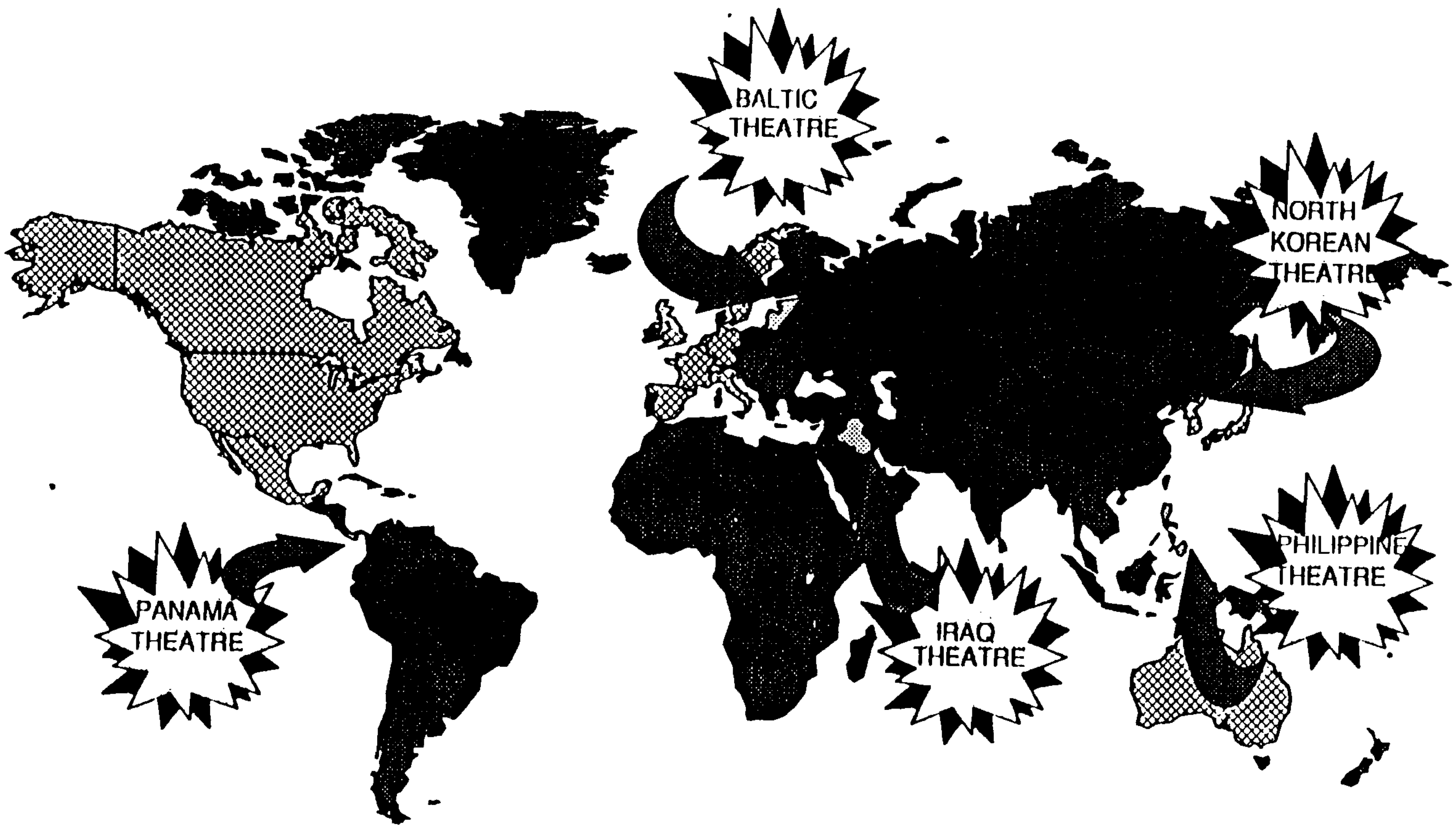
The Global Grid and Regional Conflicts

The Commercial Global Grid May Not Serve the Next Theatre



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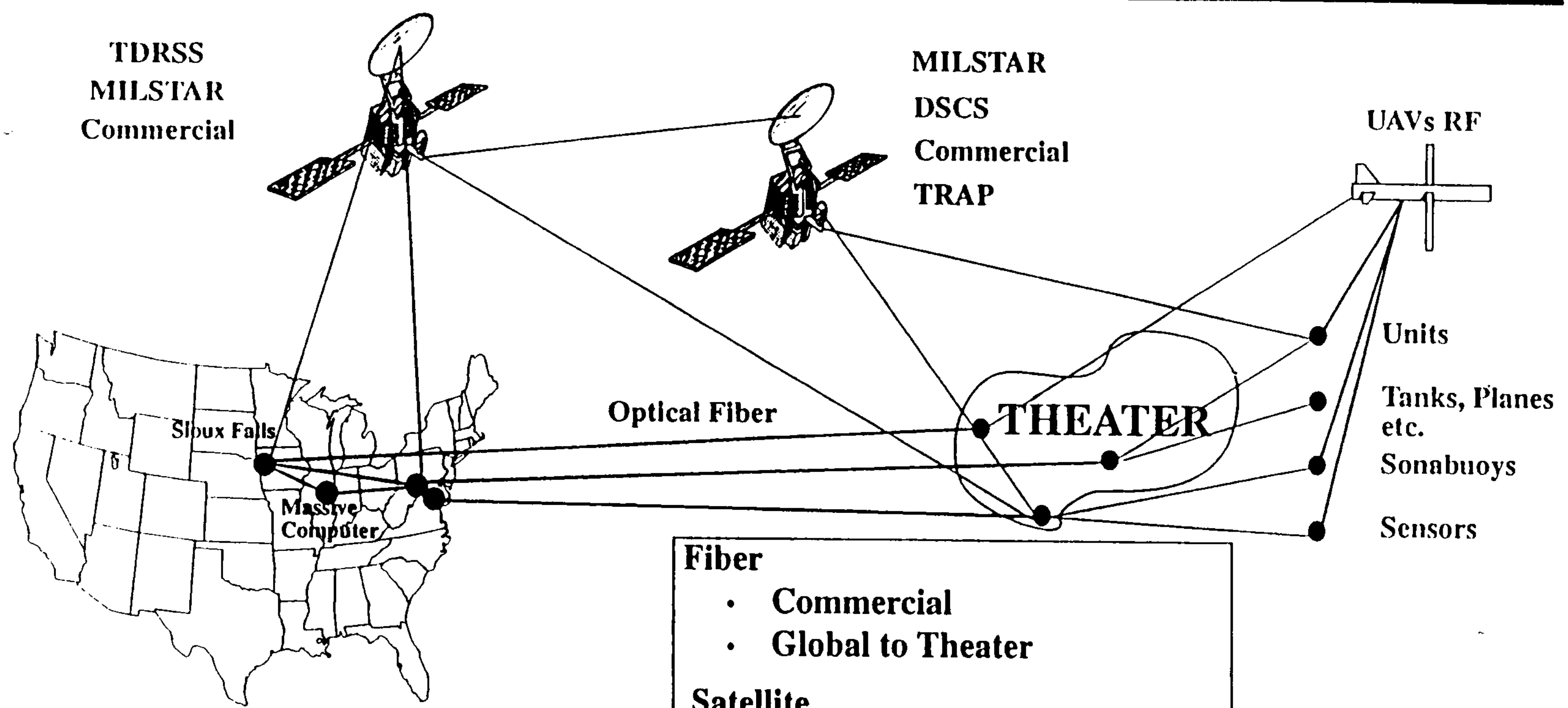
COMMUNICATIONS CONCEPT
(Surge to Theater)



Fiber
- Commercial
- Global to Theater

Satellite
- DoD Secure in Theater
- Commercial out of Theater

UAVs
- Surge in Theater

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Theater Fiber Is A Serious Option

- **Advantages**

  Very high data rates to/from CONUS

  Very high data rates to/from in-theater forces

  No emissions

  Rapidly improving civilian technology and equipment

- **Disadvantages (vary by theater/scenario)**

  Hard to connect to ships

  Can be cut

- **If it had been used in**

  Afghanistan
    no control of roads (less than one day lifetime)

  Falklands
    no land bases

  Desert Storm
    big win as far forward as the jumpoff points

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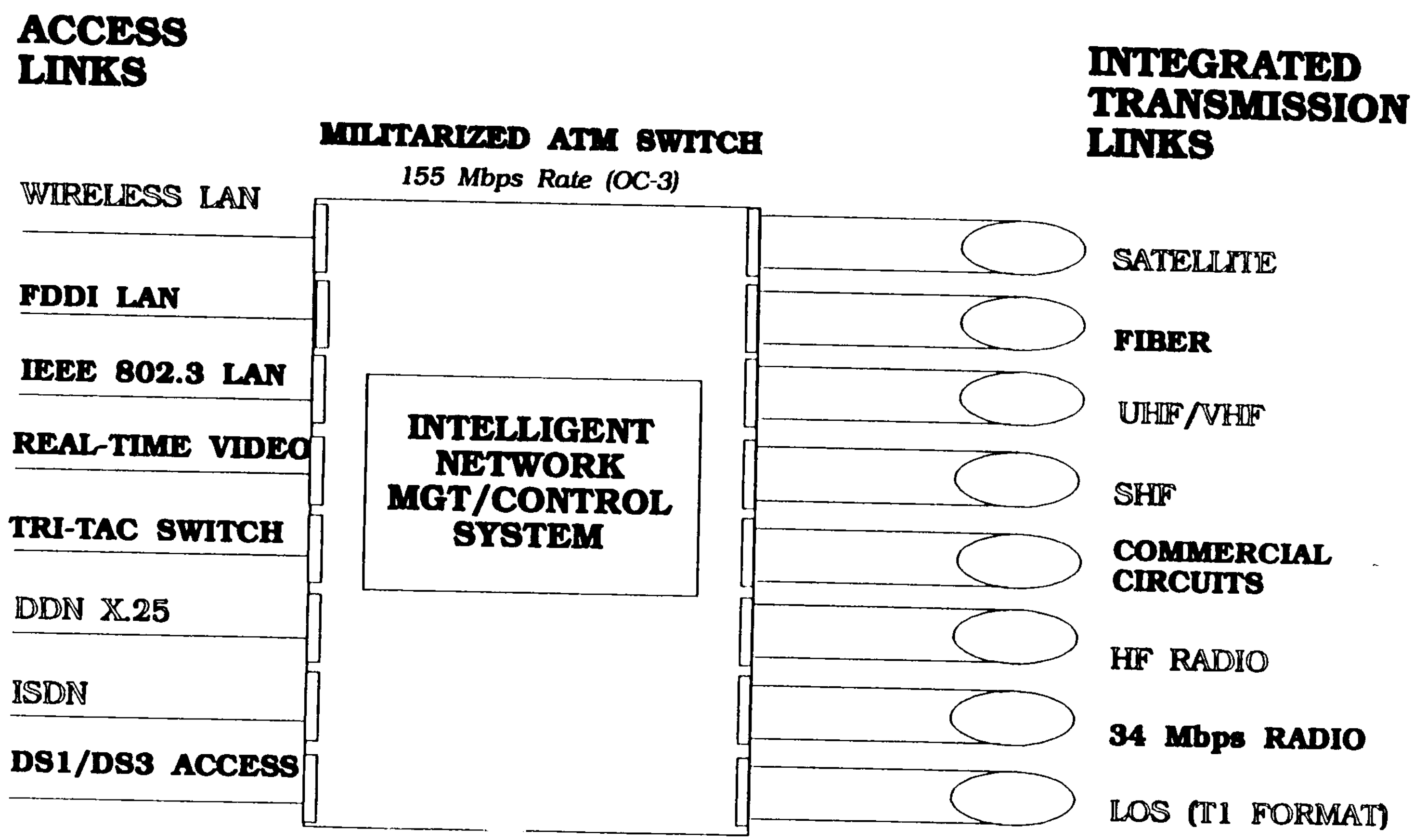
Theater Fiber Facts and Issues

- Distance between repeaters/amplifiers > 40 km
- Commercial fiber cable is 400 to 800 lb/mi, 12 km reels, volume is cubic meter (35 cubic feet)
- Deploy from wheeled or tracked vehicle: underground, by plough, saw, or shaped-charge stripline; perhaps 10 mi/hr rates
- Deploy by helicopter, letting it lie where it falls
- Other extreme is FOG-M. 10 km of naked fiber, 5 pounds, 150 m/sec. Could be done with tougher fiber (`tethered')
- Need good techniques for gap filling, terminus distribution
  - Crossing roads, ravines, or other small features
  - Might use EHF repeaters and antennas near 60GHz
  - No chance of detection at appropriate frequencies
- Hazards to helicopters and personnel
  - Hanging cable (as from helicopters or missiles)
  - Ground cable tangled in equipment
- Deserves careful study

ROME LABORATORY PROPOSAL

TACTICAL ATM SWITCHING NODE



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Near-Term Theater UAV System for SAR and Relay

- UAVs at 18 km (59kft); 24hr mission.
- Primary tasks:
  - SAR, stripmode and focussed
  - Dedicated UAV for relay from forward UAVs
  - Global Grid relay for theater radio
- Wideband microwave relay antenna, e.g.,
  - 20cm x 100 cm dish in faired radome
  - Link Xmit Power = 0.6 W/Gbps to a similar relay antenna at 800 km distance

Theater UAV
(Perseus B)

- 600 kg gross, 150 kg payload on orbit
- At 18 km altitude, propulsive power is 25 kW; 48 hr mission: 74 m/s (266 km/hr)
- 97% coverage (near base) for $6M down and $4M / yr
- Add SAR and wide-band 20 GHz relay (to ground station at 400 km or UAV relay at 800 km; total reach 1200 km from base)

Theater UAV
SAR Performance

- 1 ft pixel, 20,000 sq km/h
- Stripmode
- Antenna height 80 cm, length 60 cm, transmitted power of 30 W avg at 10 cm (S band)
- SAR image 100 km swath by 260 km/h, data rate of 1300 Mbps via microwave to airborne relay at 800 km
- Transmit power goes like resolution cubed, swath-width squared, and speed

Theater UAV
Ground Radio Relay Operations

- **500,000 links at 4Kbps each (with 20% duty cycle)**
  - FDM, TDM, or CDM
  - CDM best for Anti-Jam enhancement (next slide)
  - Need > 400 Mbps capability; available at 1 GHz and up
- **Relay at 18km altitude covers 400 x 400 km^2**
  - Uplink power 2 mW / 4 KHz for S/N=1, no antenna gain
  - Downlink power 200 W for S/N=1
  - Power scales as frequency^2 for omni antennas
- **Base Case has little Anti-Jam capability**
  - Jammers are highly vulnerable targets

Theater UAV Anti-Jam Enhancements

- **Downlink**
  - Spread 400 Mbps across 1GHz (10 dB gain)
  - Azimuthal-scan beam (10 dB gain)
  - Shape directivity as cosecant square of nadir angle for equal irradiance on ground (20 dB gain); similar directivity for receive antenna
- **Uplink**
  - Spread 400 Mbps across 1GHz (10 dB gain)
  - 1 W uplink power (17 dB gain, i.e. 100,000 W on ground)
  - Possibly form adaptive beam on UAV with square antenna (10 dB gain)
- **Can readily force jammer to > 10^7 W EIRP**
  - Now can be only small numbers of easily targetable jammers

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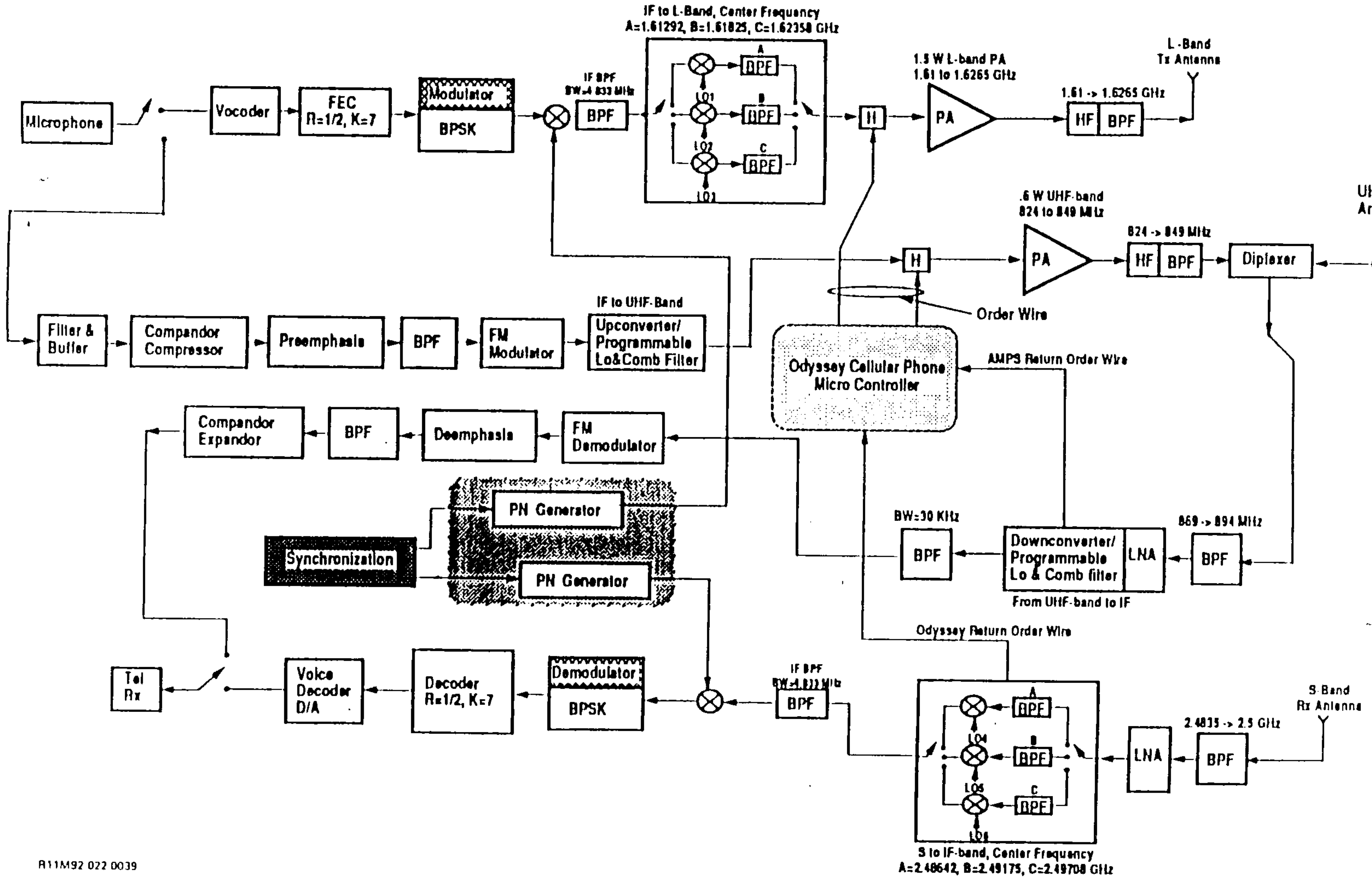
Present-Day Radios are Complicated and Very Specialized



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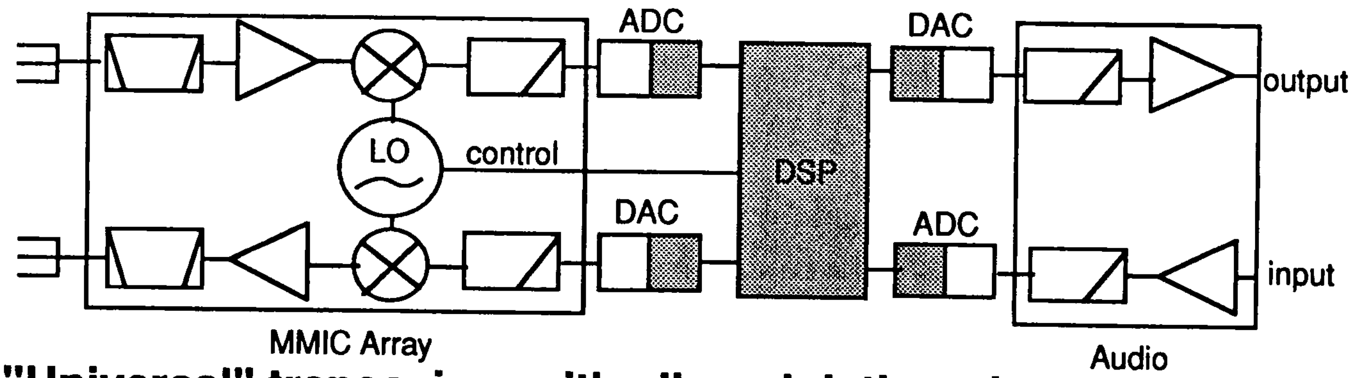
Needed: Waveform-Agile Radio



- "Universal" transceiver with all modulation, demodulation, syncronization, protocol implementation, encrypt/decryption done in a single Digital Signal Processor (DSP)
- MMIC integrated downconverter covers entire broad band (e.g., L-S, Xu)
- Provides user-transparent connectivity to the Global Grid: diverse local cellular, on-orbit PCS (Irridium, Odyssey, Orbcomm), national assets, etc.
- DSP can contain secure, anti-tamper logic with covert or war-reserve modes for use when externally authorized; new protocols can be downloaded (encrypted) in real time
- Currently limited by DSP and ADC/DAC speed and power; no fundamental limits

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In-Situ Sensing

- We believe that the opportunities presented now by in-situ sensing are comparable in importance and scope to those presented by remote sensing 25 years ago.

In-Situ Sensing

- **Advantages:**
  - Access to local (non-propagating) phenomena
  - Resistance to clutter
  - High sensitivity
  - Excellent spatial resolution
- **Challenges:**
  - Degree of covertness
  - Long post-sensor data path
  - Power supply
  - Small size
- **Global Grid is the enabling infrastructure**

In-Situ Sensing: A Catalog

- **Electromagnetic**
  - Radiofrequency emissions
  - Imaging (day and night)
  - Spectroscopy
  - Photometry
  - Magnetometry
  - Conductivity
  - Ionizing radiation
- **Mechanical**
  - Accelerometer
  - Pressure sensor
  - Tilt
  - Geometry
- **Chemical / Thermodynamic**
  - Temperature
  - Chemical potential
  - Chromatography
  - Mass spectroscopy

In-Situ Sensing: Targets

- Vehicles
  - image them (day or night)
  - weigh them
  - "sniff" what they are carrying
- People
  - count
  - identify individuals
- Industrial facilities
  - monitor effluents, tracers, bulk and liquid inventories
  - detect/classify machinery and production schedules
  - measure energy consumption or production
- Railroads, highways, waterways
  - monitor traffic
  - indication and warning of unusual activity
- Portals and perimeters
  - verify declared activity or inactivity
- Power lines
  - aggregate energy production or consumption
- Radar and other transmitters

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In-Situ Sensing: Electromagnetic

- **Spectroscopy**

  monitor or search for volatiles from manufacturing operations, or environmental contamination

- **Imaging**

  portal monitoring, scene monitoring (can be slow scan, compressed, IR) ; individual identification.

- **Magnetometry**

  power lines; presence and motion of vehicles; operation of machines; geophysics, oceanography

- **Photometry**

  activity monitors (passive IR); exhaust monitor; meteorology

- **RF emissions**

  radar use; circuit or power line emissions; communications

- **Conductivity**

  aqueous effluent monitoring; meteorology, oceanography

- **Ionizing radiation**

  nuclear facilities, reprocessing plants

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In-Situ Sensing: Mechanical

- **Accelerometer**

  machinery monitoring; traffic (human and vehicular); seismograph

- **Pressure sensor**

  acoustic (air, earth, water); machinery detection and assessment; fluid flow; meteorology

- **Tilt meter**

  traffic (human and vehicular); ground loading; reservoir or tank filling; earth settling

In-Situ Sensing: Chemical, etc.

- **Chemical potential**

  CHEMFET and SAW devices; effluent monitoring for classes of chemicals of interest

- **Chromatography**

  High specificity monitoring for chemicals of interest

- **Temperature**

  effluent monitoring; heat rejection monitoring (energy or industrial production)

- **Mass spectroscopy**

  Can be used as a second analysis stage with gas chromatography; effluent monitoring; isotopic indicators of nuclear programs

Needed: Global Intelligence Dialtone

- Define standard protocols for the collection of bits from cooperative transmitters with existing assets
- Is enabling infrastructure for a variety of systems
- When infrastructure exists, new applications can be put into place rapidly, and responsively to new or changing threats
- Examples:
  - Intelligence data collection
  - Semi-overt monitoring (FSU bilateral agreements, UN interventions)

<u>In wartime:</u>

  - Weapons in flight (e.g., differential GPS)
  - Last-resort connectivity to/from all combat units

Goals for the Mid- to Far-Term (Today's Research Agendas)

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Laser Satellite Communication

- **Advantages**
  - High Bandwidth
  - Small Size and Weight
  - Low Power

$$B = \varepsilon_r \, \varepsilon_t \, \frac{P_L}{nh\nu} \left[\frac{\pi D_t \, D_r}{4 \lambda R} \right]^2$$

$$\frac{[PD_t^2 D_r^2]_L}{[PD_t^2 D_r^2]_{\mu w}} = \frac{kT}{h\nu_L} \left[\frac{\lambda_L}{\lambda_{\mu w}} \right]^2 \cong 10^{-6} \quad [1 \mu m \text{ vs } 1 cm]$$

- **Issues**
  - Laser Osc. and Amp. - high power and long mission reliability
  - Acquisition, Pointing, Tracking - challenging but within current tech.
  - Modulation / Demodulation
  - Wavelength Multiplexing for >> 10 Gb/s
  - Ground Link - Site Diversity

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Laser Sat Com Examples

$$B = \varepsilon_r \varepsilon_t \frac{P_L}{nh\nu}\left[\frac{\pi D_t D_r}{4\lambda R}\right]^2$$

$R = 50{,}000$ km $\lambda = 1\ \mu m$ $D_t = D_r = 0.25$ m   [<1 μrad pointing req'd]

$n = 100$ photons/bit $\varepsilon_r \varepsilon_t = 1/5$

$B = 1$ Gb/s $\Rightarrow$ $P_L \cong 100$ mW   Technology: Exists

Total Package Power ≅ 150 W, Weight ≅ 75 kg

$B = 10$ Gb/s $\Rightarrow$ $P_L \cong 1$ W   Technology: Near-term

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Laser Sat Com
Planned Demonstrations

Japan				
LCE	1994, ETS VI	GEO - Ground	15 mW LD	1 Mb/s
Europe				
SILEX	1995, SPOT 4	GEO - LEO	50 mW LD	65 Mb/s
US				
LCS	1993, DSP	GEO - GEO	LD/Nd:YAG	1 Mb/s
LITE	Not Sched.	GEO - LEO (+Gnd)	40 mW LD	45 Mb/s

JPL / Space Station Demo for Deep space - Gnd

Laser Sat Com Oscillator/Amplifier Options

- **Semiconductor Laser Diodes**
  - High Efficiency - 50%
  - Degradation and Lifetime
  - Rapid Advances: Quantum Well, DFB, Graded Index, Strained Layer
  - Current Technology: 40 - 100 mW Quantum Well Oscillators
  - Coherent Power Amplifiers: 1 W demonstrated
  - Diode Array Transmitter - relative phase control
- **Solid State / Diode-Pumped**
  - Coherence in Diode Array not Req'd
  - Nd:YAG - highly reliable but currently 7 % overall efficiency
  - Erbium-doped Rod or Fiber

Laser Sat Com
Acquisition, Pointing, Tracking

- **Beacon Laser for Acquisition**
  - Higher Power - lower optical beam quality req'd
  - Leo - Geo Acquisition: < 1 min using 10 W spread over 1 mrad
- **Pointing / Tracking**
  - Low Bandwidth Coarse Pointing
  - High Bandwidth Fine Pointing to 0.5 μrad
    - viz. 20 dB, 300 Hz bandwidth rejection of satellite jitter
  - Point Ahead - tens of μrad

Laser Sat Com Modulation Issues

- Coherent Modulation - FSK, PSK

- Modulators
  - Materials - crystals (e.g. $LiNbO_3$), semiconductors
  - Power Dissipation - modulate before power amplifier
  - Difficulties above 10 GHz
    - RF and optical speed matching in mod. materical

- Receivers
  - High Bandwidth Detectors
  - Local Oscillator Locking - PSK homodyne demodulation

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Laser Sat Com
Toward Tb/s

- **Wavelength Division Multiplexing**
  - Allows Moderate RF Modulation Rates (≅ 10 GHz)
  - Fiber-connected, Monolithic Couplers - insertion losses
- **Large Area Receiver Array**
  - Space- or Ground- Based (cross- or down- link)
  - Coherent at Modulation Frequency (not optical frequency)
  - Pointing Accuracy of Array Elements
    - determined by element size, not array size
  - 1 Tb/s Requires $(10\ m)^2$ Receiver and 1 W Transmitter
- **Geo - Ground Link**
  - Atmospheric Turbulence - 10 cm coherence cell
  - JPL Study of 10 m Class Gnd. Station for Deep Space Probe Comm.
  - Site Diversity

Goal: An Accurate, Real-Time Global Database of Structures

- Use orbital assets to collect and maintain a database of all man-made structures
  - Record absolute position, wireframe shape, details as needed
  - Recognition of interesting structures requires 1 meter resolution
  - Targeting use requires location accuracy of order 1 meter
  - Ability to get << 1 meter resolution on limited areas desirable
- Map the earth: database will be large, collection and processing must be fully automated
  - Data rates, processing rates and storage requirements are of EOSDIS scale
- System has obvious civil / economic applications

World Structure Inventory

- **Socio-Economic Guesstimate for US:**

  Population: 2.5x10^8 — Household size: 2.5

  Single-family dwelling: 75% — Residential structures: 0.8x10^8

  Comparable number of non-residential structures

  Grand total: 1.6x10^8 — One per 1.5 inhabitants

- **Socio-Economic Guesstimate for India:**

  Population: 8.7x10^8 — Household size: 6.0

  Single-family dwelling: 75% — Residential structures: 1x10^8

  Comparable number of non-residential structures

  Grand total: 2x10^8 — One per 4.3 inhabitants

- **Socio-Economic Guesstimate for World:**

  One structure per 3 people: — Grand total of ~10^9 structures

N.B. : US residential numbers can be extracted from Census data and are accurate

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Sizing the Database

- **How Much Data to Record?**

  Wireframe of external shape of each structure:

  tens of lines in 3D at 3x8 bits per line

  One-meter-accurate map location of each structure:

  3 coordinates at 24 bits each

  Generous estimate, including intelligence/targeting data:

  1000 bits per structure

  Total database size: Few Terabytes

- **Filtering the Database**

  No info on size/volume distribution of structures

  "Small" structures may not be "interesting"

  Reduce the number of structures to record by factor 10?

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Data and Processing Rates

- **Collection Kinematics:**

  Mapping rate determined by swath width, orbital speed (7km/s)

  For 10 km swath: sweep .7x10^8 m^2/s, cover earth in 10^7 s

- **Data Rates:**

  Determined by resolution cell: assume 1mx1m, 10 bits per cell

  For 10 km swath, image data produced at 1 Gbps

  For SAR with 1 Ghz bandwidth, raw data at 10 Gbps

  Consistent with technology elements of Global Grid

- **Processing Issues:**

  SAR: raw EM data into imagery requires ? flops

  Processing imagery for cultural features:

  - extract structures -> automated target recognition problem
  - rule-of-thumb: 500 ops per bit -> teraflop processing load

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Strawman SAR Design

- **Basic SAR Scaling:**

  Transmitter power goes like resolution cubed, swath-width squared and inverse of wavelength.

- **Application to Surveillance Task:**

  Nominal parameters: 500 km altitude, 7 km/s speed, 3cm wavelength

  Required performance: 1 m pixel, 10 km swath, 10^8 pixels/sec

  Radar antenna: height 2 m x length 2 m

  Average power: 200 watts (if σ~ -10dB), PRF: 10^4 per sec

- **Satellite Technology (except data link)**

  Not Stressing

  100 km swath (fast revisit) *would* pose problems

Geodesy and Mapping

Need a strategy to convert 1m SAR resolution into 3m map accuracy
Several elements will have to play together to achieve this:

- Need precise satellite location and orientation
  - GPS technology should be adequate!
- Multiple views of regions of interest needed
  - Stereo for 3D location to ~ SAR accuracy
  - Stereo problem: objects look different from different directions. Solve by best fit techniques
  - Multiple looks: systematic reduction of errors and distortions

All of the above issues are currently dealt with in a systematic way by DMA in their production of digitized map databases. What's missing is full automation of the process.

Image Processing Strategy

Can't store the full data stream of the imaging satellite. Need filters to identify substreams to store and process. Strawman strategy:

- Identify regions with cultural features: keep surrounding context
  - Reject .99 of land area, keep about 10^12 m^2 (10 Terabytes)
  - Processing load? Known algorithm?
- Absolute 3D location of radar- reflecting surfaces at 1 m accuracy
  - Least-squares massaging of multiple-look data
  - Algorithms known. Database access, processing load?
- Extraction of wireframe model of structures and surface detail
  - Analogous to "feature extraction" in DMA production
  - Algorithms not mature, but automation should be possible
  - Loose estimate of processing load?

This scopes the goals of a research program. The chances for success on a ten-year timescale are good.

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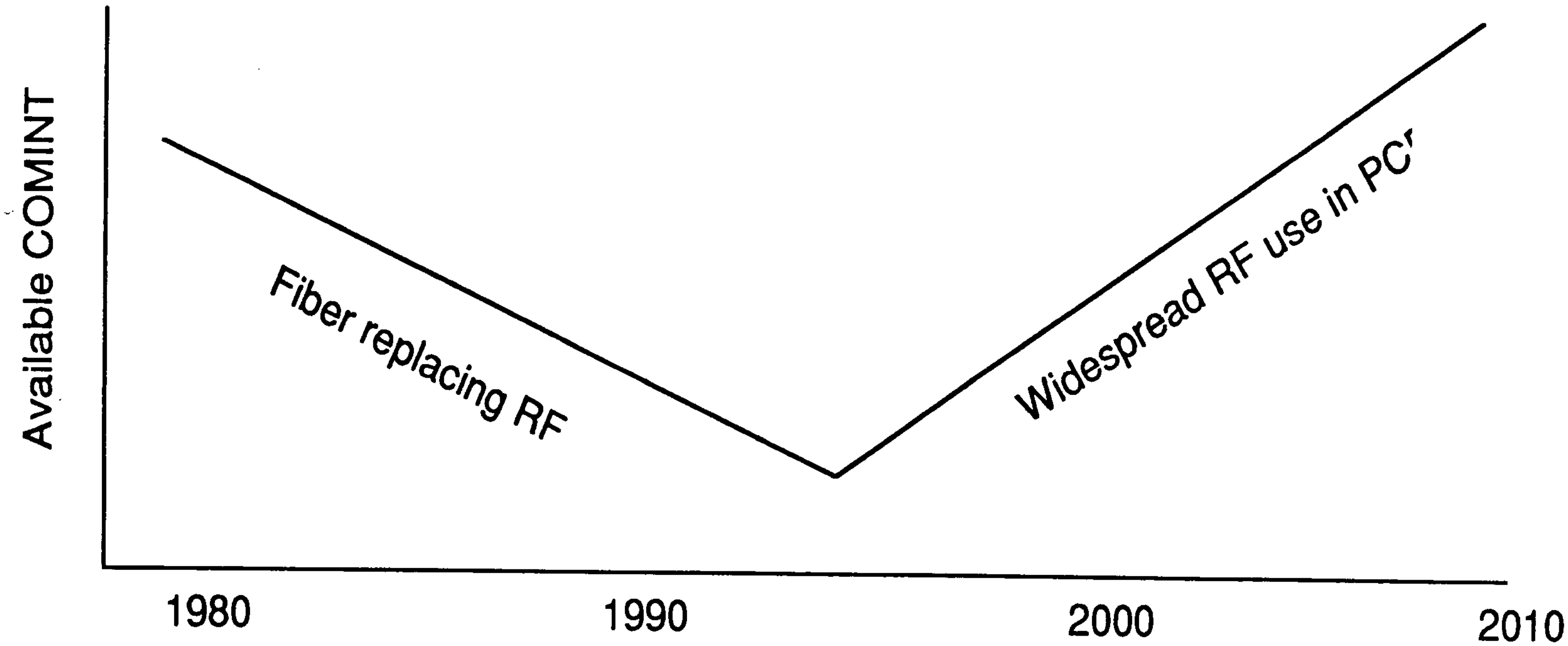
Renaissance of RF in Communications



- Expect explosive increase in RF use in next decade and beyond
- But it will be in cellular/local links, not in point-to-point relays

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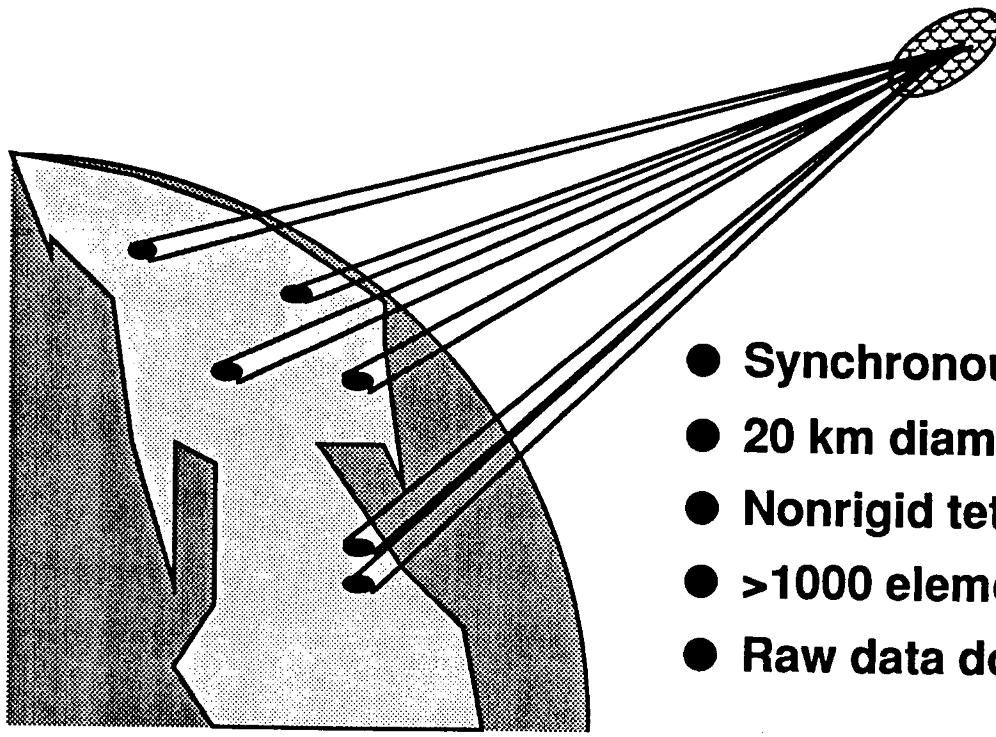
Straw-Man Technology Driver. A Sparse Phased Array Collector



- Synchronous Orbit
- 20 km diameter (!)
- Nonrigid tethered structure
- >1000 elements
- Raw data downlink

Primary and Secondary Missions:

- Collect cellular/PCS communications and data
- In peacetime, provide Global Dialtone to overt and covert sensors
- In wartime, provide universal connectivity to all troops and systems

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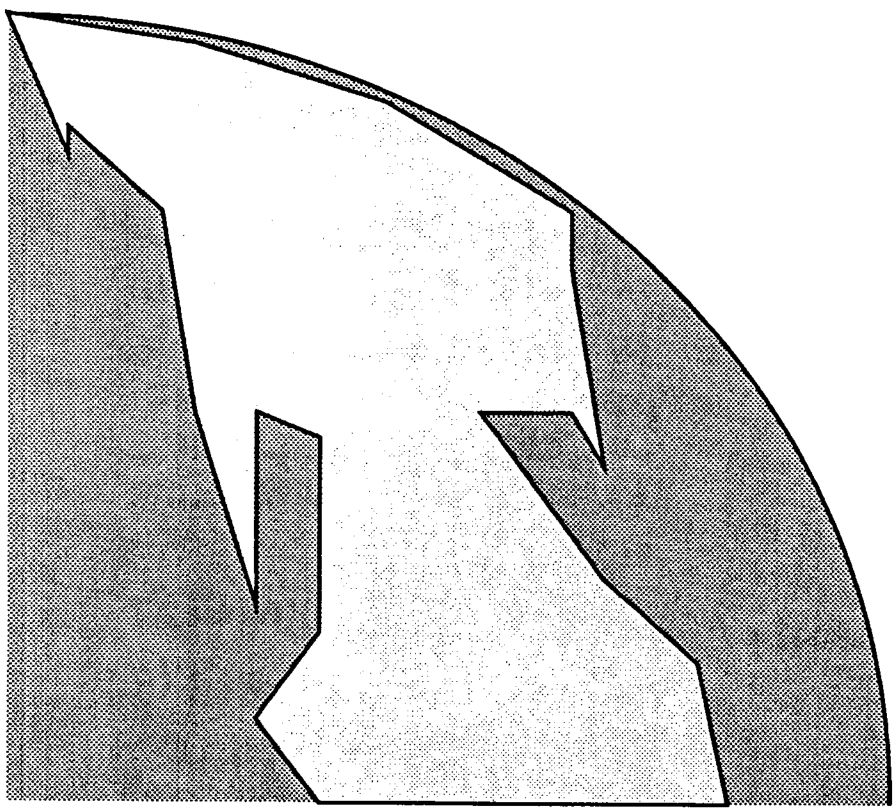
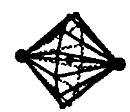
Sparse Phased Array Collector: Technical Characteristics

- Is optimized against source confusion, not just S/N
- Data stream consists of time/location stamped complex amplitudes for each element
- Entire data stream is downlinked by Terabit laser downlink with site diversity
- Beam forming, channel selection, demodulation is done by individual users. Multiple users are intrinsically non-interfering.
- However, frequency *band* tasking is global to system (choice of, e.g., which 100 MHz collected)
- Beam forming can be retrospective on stored data
- XMIT beams likewise non-interfering, up to total saturating system power

Tethered Satellite Array

Conventional tethered satellites are 1-dimensional. The tether is held in tension by the vertical gravity gradient.





Also possible are 2-dimensional or 3-dimensional spinning arrays. Tension is created in one direction by gravity gradients, in the other two directions by centrifugal force. Spin axis precesses once per orbit to keep alignment.

Spinning Body in Orbit

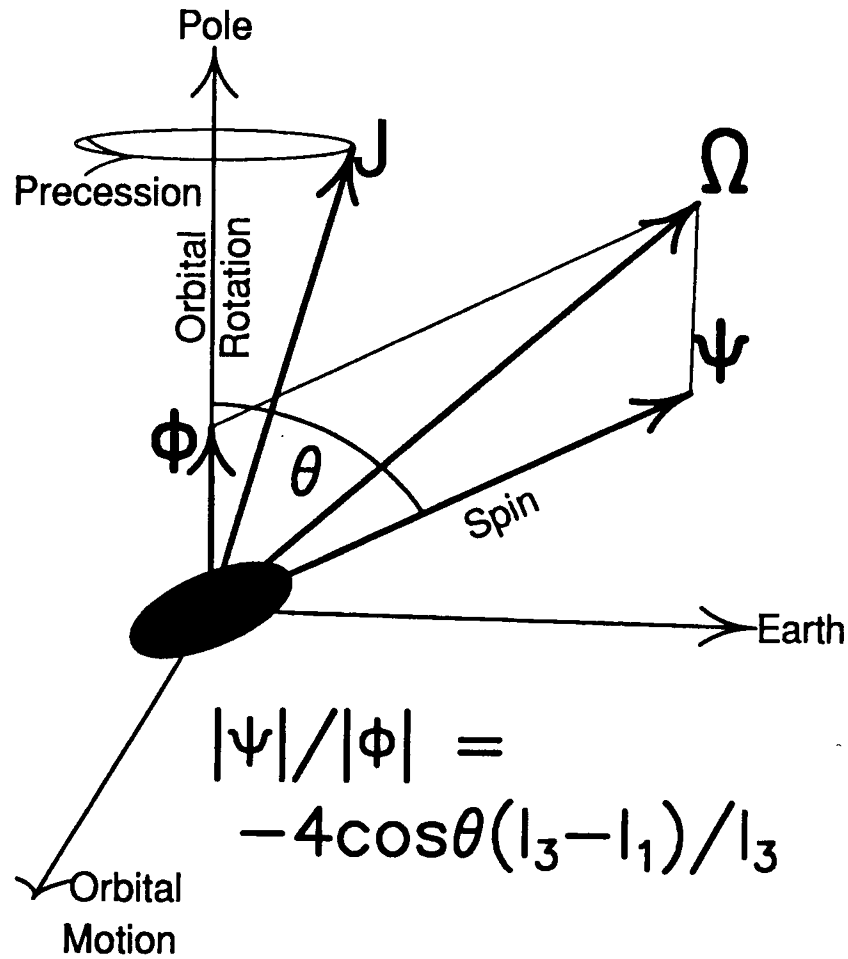
A spinning satellite will precess as it orbits the Earth, for two reasons:

a) free precession, and

b) gravity gradients.

The designer can choose to synchronize precession with orbital rotation, so that the satellite spin axis Ψ always points toward the Earth in the same way, by setting the ratio $|\Psi|/|\Phi|$ of spin rate to orbital rate appropriately.

For spin rate much faster than orbital rate, the satellite must behave dynamically as a prolate (rodlike) body, in order to synchronize precession with orbital rotation.



$$|\Psi|/|\Phi| = -4\cos\theta(I_3 - I_1)/I_3$$

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Tethered Satellite Array

Geosynchronous Orbit

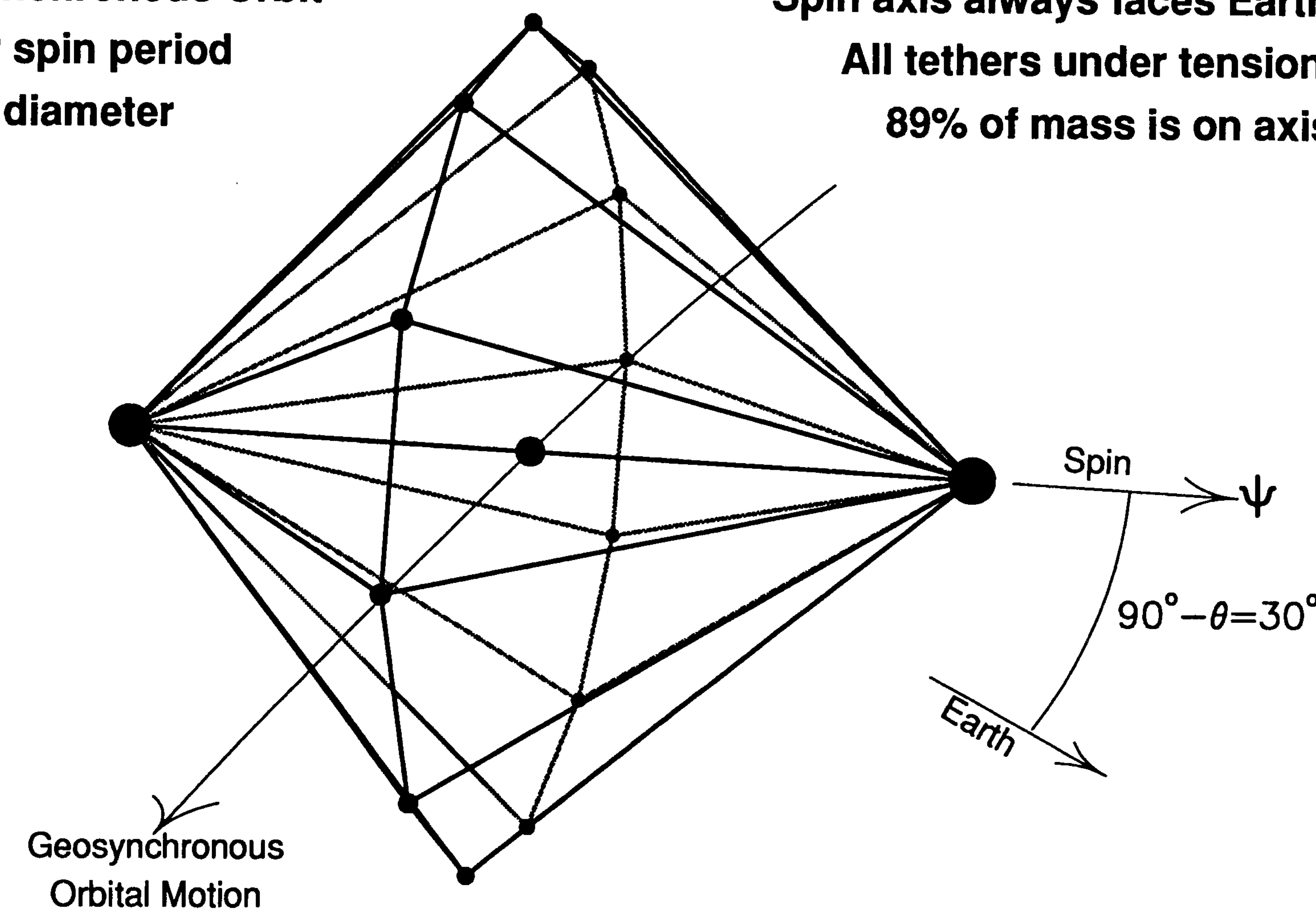
2 hour spin period

20 km diameter

Spin axis always faces Earth

All tethers under tension

89% of mass is on axis



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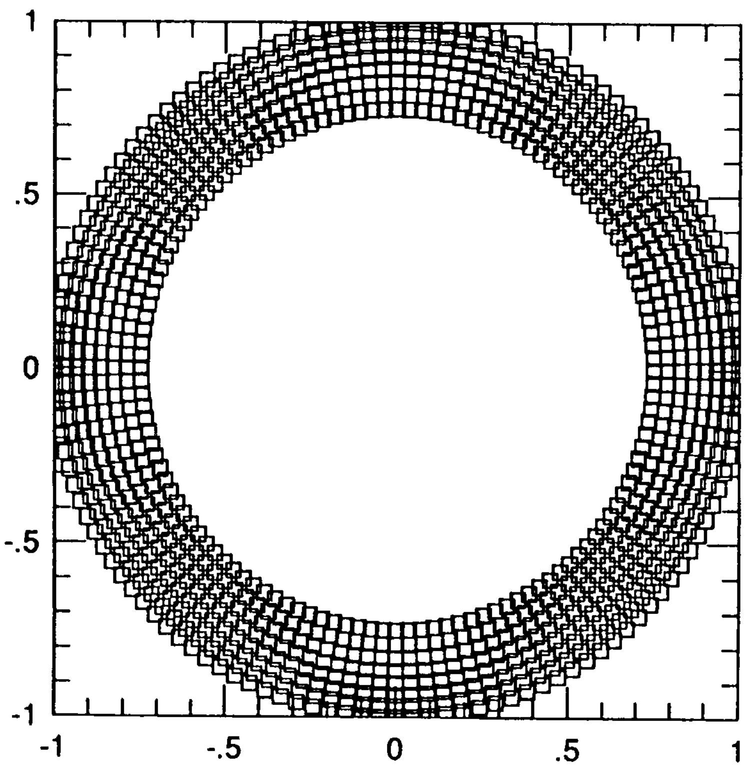
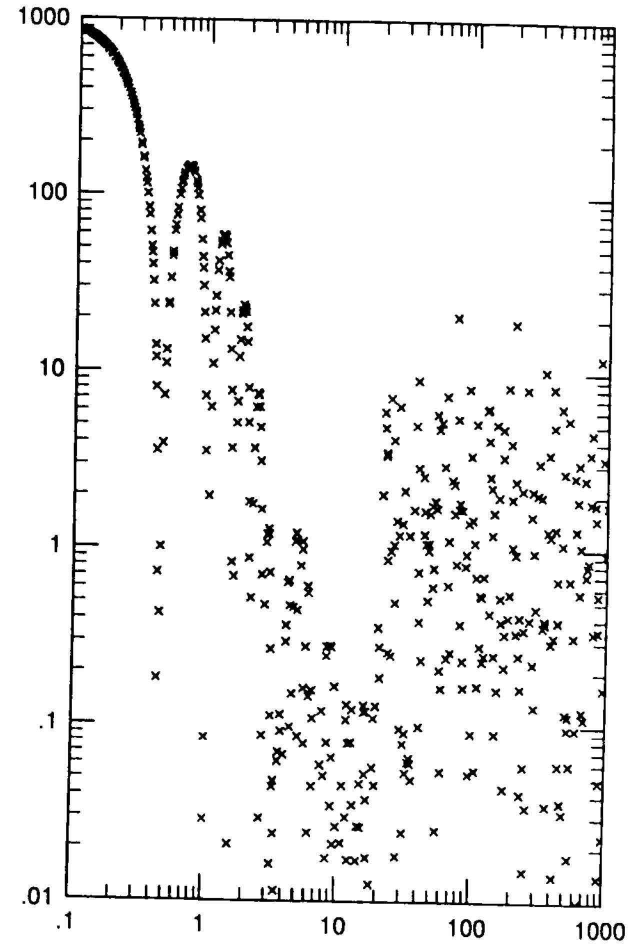
Phased Array Antenna Beam Pattern



in units of R_0



$R_0 = 10$ km $\Rightarrow R_1 = 1.2$ km
(1GHz, synchronous)

in units of $R_1 = \lambda L / R_0$

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Power-Bandwidth to a Phased Array

$$S = \frac{P}{4\pi R^2}\frac{\lambda^2}{4\pi}n_{el} \qquad N = kTB$$

$$\frac{n_{el}}{B} = \left(\frac{4\pi R}{\lambda}\right)^2 \frac{kT}{P}\left(\frac{S}{N}\right) = 11.6 \text{ elements/KHz}$$

$R = 40,000$ km
$\lambda = 30$ cm
$P = 1$ W
$T = 300$ K

$$\frac{B\ln\left(\frac{S}{N}\right)}{n_{el}P} = \left(\frac{\lambda}{4\pi R}\right)^2 \frac{1}{kT}\,\frac{S/N}{\ln(S/N)} \approx 200\frac{\text{bps}}{\text{W-element}}\left(\frac{\lambda}{30\text{cm}}\right)^2$$

$$\approx 200\frac{\text{bps}}{\text{W-element-SqFt}}$$

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Sparse Phased Array Collector: Nominal Parameters

Target Parameters:		
Signal Power	1 W	10 W
Antenna Gain	1	100
Noise Temperature	300 K	300 K
Confusion (other sources in band)	1000s	few
Number of simultaneous targets	1000+	10-100
Collectable data rate per target	kilobits/s	megabits/s

Collector Parameters:	
Aperture	20 km
Number of elements	1000
Antenna Gain each element	1
Distribution of elements	optimizable (see following)
Receiver noise temperature	200 K
Downlink/On-Orbit Data Rate	3 Gbps *per element*

Commendations and Recommendations

Commendations

- NRL

  High Speed Optical Network (HSON)

- NSA

  R2 Infosec Technology Plan / Multilevel Network Secure System (MNSS)

- Lincoln Laboratory

  Space Laser Communications System

Recommendations

Recommendations

<u>SONET Data Rates.</u> Relevant agencies should require all new national intelligence systems to be compatible with SONET data rates. Minimal compatibility is net (payload) data rate that is compatible with a multiple of that in OC-3. Preferred compatibility is a SONET-formatted synchronous data stream at a multiple of OC-12 or OC-48.

<u>Towards ATM compatibility.</u> Relevant agencies should pursue an aggressive R&D effort aimed at efficient packetizing, and delivery to the user by ATM switched circuits, of intelligence data streams. ATM (or whatever commercial standard emerges) should move as far up the data stream (toward the sensor) as feasible, certainly to the initial procesing point, and possibly to the overhead asset.

<u>Gigabit networking.</u> DARPA and relevant agencies should establish an ongoing technical dialog on network quality-of-service metrics. Beyond the simplest measures (raw bit rate, latency), what other quantifiable characteristics of current comm links are assumed, explicitly or implicitly, by users? How can these be measured as a part of DARPA's program? Which can be met or exceeded by a planned switched gigabit network? What are the costs associated with relaxing different parameters (e.g., in buffering, protocol conversion, etc.)?

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Recommendations (cont'd.)

Encryption technology. NSA should develop a packet-level encryption protocol for ATM which does not assume delivery of packets in order, or of all packets. The protocol may assume an initial exchange of data at the time of virtual circuit setup. ■

Commercial encryption. NSA/NIST should establish an ongoing U.S. Government interface to standards-setting organizations and commercial vendors in the area of commercial encryption, with the charge of promoting reasonable world-wide standards for commercial encryption. ■

Global Intelligence Dialtone. Considering national assets as a unified system, relevant agencies should develop a "publishable" (at appropriate classification level) standard for a global data dialtone. NTM will undertake to collect, and deliver to the authorized subscriber, bits transmitted according to the published standard, with quantifiable quality-of-service. ■

■ = recommendation has additional details

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Recommendations (cont'd.)

<u>Global World Security Dialtone</u>. As a follow-on to the Global Intelligence Dialtone, relevant agencies should study whether a similar service can be offered, unclassified, for world-wide security applications deemed by the U.S. to be in its national interest. Systems using the Security Dialtone could include in situ sensors associated with bilateral arms control agreements, UN Security Council actions, etc. ■

<u>Eschew bit-serial thinking</u>. DARPA should pursue a more aggressive marriage of its Gigabit network and Teraflop computing efforts. There should be increased R&D on interfacing networks to massively parallel computers without serial-to-parallel and parallel-to-serial conversions. Can the bits of an ATM packet be moved in parallel through 424 WDM channels on a single fiber? Let's find out!

<u>Laser up, down, and cross-link</u>. DARPA should establish a higher-profile R&D effort in laser satellite links, with the initial goal of data rates larger than 20 Gbps to synchronous orbit. The program should be structured to pursue an ultimate goal of Terabit-per-second rates (as will be in terrestrial fiber) within 15-20 years.

■ = recommendation has additional details

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Recommendations (cont'd.)

<u>Tactical fiber</u>. DARPA/ARMY should establish a unified R&D effort in the laying of tactical fiber (and associated "railhead" links, e.g., short distance, high-bandwidth links at 60 GHz). The goal is for Corps and larger units to have an organic capability to maintain fiber (or similarly high bandwidth) connectivity to the Global Grid.

<u>Waveform agile radio</u>. DARPA should develop the technology for "universal" radio: except for an integrated MMIC downconverter, all processing (including modulation/demodulation) should be be in a unified digital signal processor, which should be rapidly reconfigurable. Various DoD, cellular and PCS formats should be emulated in software.

<u>Regulatory or Deregulatory changes</u>. DoD or OSTP, in consultation with Common Carriers, should determine whether regulatory changes would further the offering of high-bandwidth services at reasonable tariff rates (as dictated by competition and actual costs). Determine, in particular, if rates are now artificially high because of Carrier's fear of circuit retailing. Propose regulatory or legislative changes.

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Recommendations (cont'd.)

Advanced Network Services. DARPA should maintain an active research program addressing alternatives to promiscuously moving bits through the network. Examples include file storage/archiving as a network service allowing transmission of pointers or tokens instead of full texts, e.g. for multicast; protocols for moving algorithms to data, rather than the reverse; enhanced presentation layer services, etc.

Higher Visibility in Standards Setting. Not only DARPA, but also NSA, DISA, and other affected agencies should take much more pro-active positions in the arena of standards-setting, by establishing direct interfaces to vendors, regulators, and standards bodies. The traditional low profile of the intelligence community, if not appropriately modified, is likely to result in standards that are poorly matched to Governmental needs, leading to increased costs and/or reduced capabilities. The Government can no longer afford to "go it alone".

Global Grid Acronym and Abbreviation List

AAL	ATM adaptation layer (standard specializations of ATM packet payloads)
ADC	analog to digital converter
ADC	American digital cellular (proposed standard)
AIS	alarm indication signal (SONET)
AMPS	present U.S. analog cellular phone standard
ARP	address resolution protocol (Internet)
AR	anti-reflection
ASDL	asymmetric digital subscriber loop (method for bringing 1.5 Mbps to home on existing copper wires)
ATDM	asynchronous time division multiplexing (old name for ATM)
ATM	asynchronous transfer mode (packetized communications protocol on top of SONET)
B channel	a 64 Kbps "bearer" (i.e., user) channel
B-ISDN	broadband integrated services digital network
BAA	broad area announcement
BBC	British Broadcasting Corporation
BER	bit error rate
bps	bits per second
BTG	basic target graphics (imagery for pilot)
CCITT	International Consultative Committee on Telephony and Telegraphy
CDMA	code division multiple access
CMOS	complementary metal oxide semiconductor (chip technology)
CNRI	Corporation for National Research Initiatives
COMINT	communications intelligence
COMSEC	communications security
CONUS	continental U.S.
CO	central office (phone company node above LO)
CS	convergence sublayer (ATM)
CV	cryptovariable (the "key" in a code)
DACS	digital access cross-connect system (in current use)
DAC	digital to analog converter
dB	decibels
DDN	Defense Digital Network (uses X.25 standard)
DS-*n*	digital signalling level *n* (DS-1 is 1.544 Mbps, see T1)
DSP	digital signal processor
DSS1	digital subscriber signaling system no. 1 (signalling protocol for ISDN)
E164	addressing based on U.S. standard "phone numbers", owned by the local carriers
ECO	engineering change order
EHF	extremely high frequency
EOSDIS	Earth Observation System Data and Information System
Erlang	unit equal to one duplex channel
Er	erbium
EUR	Europe
FBIS	Foreign Broadcast Information Service
FDDI	fiber distributed data interface (100 Mbps successor to Ethernet, probably will be superceded by ATM on OC-3)
FDMA	frequency division multiple access
FEC	forward error correction
FERF	far end receiver failure (SONET)
FOG-M	fiber optical guided missile
FSU	former Soviet Union
FTP	file transfer protocol (Internet)
FTTH	fiber to the home

FTTO	fiber to the office
GaAs	gallium arsenide
Gbps	gigabits per second
GEO	geosynchronous earth orbit
GHz	gigahertz
GPS	Global Positioning System
GSM	proposed European global system for mobile communications (cellular)
HAW	Hawaii (undersea cable)
HDTV	high definition television
HEC	header error check (ATM cell)
HEO	high earth orbit
HPPI	High Performance Parallel Interface (de-facto computer standard at 800 and 1600 Mbps, from Crays)
HR	high reflection
IAB	Internet Architecture Board
IMF	International Monetary Fund
IMINT	image intelligence
INMARSAT	international marine satellite consortium, or its satellites
InP	indium phosphide
inter-LATA	long distance phone carriers, e.g. MCI, AT&T
IP	internet protocol
ISDN	integrated services digital network (speeds only up to 2 Mbps)
JAP	Japan
JDC	proposed Japanese digital cellular standard
JPEG	Joint Photographic Experts Group (image compression standard)
K-band	18 to 27 GHz, nominally 1.5 cm
Ka-band	27 to 40 GHz, nominally 1 cm
Kbps	kilobits per second
Ku-band	12 to 18 GHz, nominally 2 cm
L-band	1 to 2 GHz, nominally 30 cm
LANL	Los Alamos National Laboratory
LAN	local-area network (computer network)
LATA	local access and transit areas (local phone regions)
LD	laser diode
LEO	low earth orbit
LMTS	land mobile terrestrial services (e.g., cellular)
LO	local oscillator; also local office (phone network terminus just before subscriber)
mA	milliamps
Mbps	megabits per second
MID	message identifier (ATM cell)
MI	message identifier (cryptography)
MMIC	monolithic microwave integrated circuit
MM	multimode
MPEG	Motion Picture Experts Group (video compression standard)
MQW	multiple quantum well
MSS	mobile satellite services (up/downlink to LEOs)
NCAR	National Center for Atmospheric Research (in Boulder, CO)
nm	nanometer, or nautical mile
NREN	National Research and Education Network
NSTAC	National Telecommunications Security Advisory Council
NTT	Nippon Telephone and Telegraph
OC-*n*	optical carrier at level $n \times 51.84 Mbps$ (SONET signalling rate)
octet	same as byte, 8 bits

OH	hydroxyl ion
OPS	operations
OSIRM	open systems interconnection reference model (protocol layers)
p-p	peak to peak
PC	personal computer
PCM	pulse code modulation
PCS	personal communications services
POP	point of presence (of a telephone carrier)
PSTN	public switched telephone network
PTT	foreign governmentally owned post, telegraph, and telephone service
QPSK	quad phase shift keying (modulation method)
R2	WARC geographical region 2, North and South America; also COMSEC research group at NSA
RBOC	regional Bell operating company (local telephone company)
RF	radio-frequency
S-band	2 to 4 GHz, nominally 10 cm
S/N	signal to noise ratio, also SNR
SAR	segmentation and reassembly (of ATM packets)
SDH	synchronous digital hierarchy (CCITT form of SONET)
SDPSK	symmetrical differential phase shift keying (modulation method)
SDSC	San Diego Supercomputer Center
SIGINT	signals intelligence
SL	submarine lightwave (undersea cable)
SMDS	switched multi-megabit data service (connectionless packet service now being offered by some RBOCs)
SM	single mode
SONET	synchronous optical network (standard)
SPE	synchronous payload envelope (in SONET packet)
STM	Japanese term for SDH
STS-*n*	synchronous transport signal at level n (electrical counterpart of OC-n)
STU	secure telephone unit, as STU-3
T1	standard carrier on copper wire at 1.544 Mbps (DS-1 rate)
T3	standard carrier at 44.768 Mbps, can carry 28 T1 channels
TAT-*n*	trans-Atlantic telephone cable number n
Tbps	terabits per second
TCP	transmission control protocol (Internet)
TDMA	time-division multiple access
THz	terahertz
TOH	transport overhead (in SONET packet)
TPC-*n*	trans-Pacific cable number n
TWTA	travelling wave tube amplifier
UAV	unmanned air vehicle
USG	U.S. Government
VCI	virtual channel identifier (ATM cell)
VLSI	very large scale integrated circuits
VPI	virtual path identificer (ATM cell)
WAN	wide-area network (computer network)
WARC	World Administrative Radio Conference
WDM	wavelength division multiplex
X-band	8 to 12 GHz, nominally 3 cm
XMIT	transmit