TELEDESIC GLOBAL WIRELESS BROADBAND NETWORK:
SPACE INFRASTRUCTURE ARCHITECTURE, DESIGN FEATURES AND TECHNOLOGIES

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Agenda

- Low Earth Orbit (LEO) Wireless Communications Revolution
- Teledesic 'Broadband LEO' Services and Network Features
  - Teledesic Corporate and Program Overview
  - Teledesic Services and Applications, Capacity, Coverage and Spectrum Usage
  - Teledesic Network and Architecture Features
- Teledesic Space Infrastructure Architecture and Design
  - Teledesic System/Subsystem Design Features and Key Technologies
  - Teledesic Space Segment Power, Mass, ΔV and Reliability Budgets
  - Teledesic Launch Campaign Features and Debris Mitigation
  - Teledesic Integrated Software and Distributed Control Features
  - Teledesic Constellation Control Operations and Ground Segment Features
- Industrial Impact of LEO Communications Revolution
  - New Service Providers and New Equipment Suppliers
  - Commercial Space Industry Impact
- Emerging Applications for the Shrinking Satellite Evolution
  - Possible Future with Hybrid Networks of GSO's, LEO's and HALE/UAV's
  - General Features of Ideal Micro/Nano-Satellite Networks
  - A Vision of Future Micro/Nano-Satellite Designs for Comm Networks

Abstract: Teledesic represents a new paradigm for distributed space systems' design, production and operations. This paper will describe the Teledesic broadband services, applications, global network design and unique features of the new Teledesic space infrastructure, technologies and design approaches. The paper's introduction will discuss the wireless information revolution and the current 'Little' and 'Big' communications LEO's. The current technological and economic trends that drive us inevitably to higher frequency bands and much larger constellations (≥1000 satellites) will be briefly addressed. The Teledesic broadband network, services and architectural features will be described. Then the capabilities of the extremely high-performance and high-power Teledesic LEO satellites will be described (e.g., many kW's, 100's of MIPS, 1000 raps, 100's of beams, etc.). The Teledesic satellites are a new class of small satellites, which demonstrate the important commercial benefits of using technologies developed for other purposes by U.S. National Laboratories (e.g., Phillips, NRL, JPL, LeRC, etc.). The Teledesic satellite architecture, subsystem design features and new technologies will be described. The new Teledesic satellite manufacturing, integration and test approaches will also be addressed which use modern high volume production techniques and result in surprisingly low space segment costs. The constellation control and management features and attendant software architecture features will be addressed. After briefly discussing the economic and technological impact on the USA commercial space industries of the space communications revolution and such large commercial constellation projects, the paper will conclude with observations on the trends towards future systems architectures using networked groups of much smaller satellites.

J.R.Stuart 10/29/95
Global Information Infrastructure (GII)

- GII is a Vision of a Universally Accessible Web of Multiple Interconnected Networks
  Permitting Access to Widely Distributed Private/Public Data Bases
  Providing Ready Transmission of Information (Voice, FAX, Text, Images, Video, etc.)
  - In Any Format - To Anyone - In Any Place - At Anytime

- GII is an Entire GII System:
  - Human Users (and Developers)
  - User's Information Appliances (Computing and Consumer Electronics)
  - Accessed Information, Data Bases and Computing Resources
  - Networks

- The GII Network Will Be an Intricately Tangled Web of Multiple Overlaid Networks
  - Wired and Wireless
  - Terrestrial and Space
  - Physical and Virtual
  - Private, Commercial and Government

- GII (and Large Evolving Commercial Market) Will Migrate to Efficient Web Elements:
  - Reliable, Ubiquitous, Seamless, Interconnected, Flexible, Cost effective
  Successful Elements will be Interoperable:
    - 'Open' Interfaces with Accepted Standards
    - Wide Array of Competing Information Appliances and S/W Tools
      Interoperable and Interchangeable by Design
    - Standard User-Friendly (Easy) Interfaces for H/W and S/W:
      (e.g., Discovery/Recovery Applications, Operating Systems, etc.)
    - Many Interchangeable Competing Service Providers and Equipment Suppliers

A Current View of LEOs Role In the National Information Infrastructure (NII)
Low Earth Orbit (LEO) Wireless Communications Revolution

- LEO Communications Services Will Be Available Globally and Economically:
  Voice and Broadband Data, Fixed and Mobile Services, Personal Communications
  FAX, E-mail, Messages, Monitoring, Alarms, Positioning, Tracking and Location
- Personal Ground Terminal Business Is Enormously Larger Than LEO Space Segments
  LEO Constellations Enable This Much Larger 'Information Appliance' Business
  Hottest New Personal Electronic Products Since PC's and VCR's Will Be:
    - Mobile Communicators, Wireless Modems, Pocket Videophones, etc.
- Shift from Last 30 Years of Satellite Communications Evolution:
  Bigger, More Powerful, Longer Lifed Satellites
  Hierarchical Point-To-Point Communications Architectures
- Biggest Advance In Satellite Communications In 30 Years:
  Lightsats, Intersatellite Links, Distributed Networks, New Competitive Multiple-Choices
  Interconnectivity, Interoperability, Global Marketplace Determination of 'Best'
- Future Will Be Networks Of Hybrid Systems Connecting Everyone To Everyone
  Overlaid Interconnected and Interoperable Networks
    - Terrestrial Wire, Cellular, Coaxial Cable, Fiber Optic Cable, etc.
    - GSO Large Satellites, and the New LEO, MEO and GSO Lightsats
  Large, Competitive, Open, Diverse Global Markets
  Multiple Service Approaches Will Become Available to All Customers
  Continuous Evolution Of Most Effective Set of Communications Networks
    - 'One Size Fits All' is Victim to More Convenient 2nd-to-Market Choices
    - Bandwidth/Quality/Price/Convenience-On-Demand (Interoperable Choices)

Wireless Satellite Services on the Horizon
LEO Satellite Communications Systems Service Categories

- Mobile (MSS) "Little" LEO's (UHF, VHF)
  Noncontinuous Worldwide Coverage (Periodic to Near-Real Time Availability)
  "Bent Pipe" and "Store-and-Forward" Gateways, PSTN Connections
  Modulations: FDMA/TDMA or CDMA
  Non-RealTime and Near-Real Time Digital Mobile Services (2.4 kbps - 9.6 kbps)
    Digital Messages, Alarms, Monitoring Data, Tracking, E-Mail, FAX, Paging, etc
  Typical Delivery Delay Times
    Within Footprint (~4000 km Diameter): 2-10 minutes
    International (e.g., USA-Europe): 30 minutes - 8 hours
  Typical Subscriber Costs
    Terminals: $500-$100 (as low as $25 quoted for meter reading)
    Data: 1.0¢ - 0.001 ¢ per byte

- Mobile (MSS) "Big" LEO's (L-Band)
  Continuous Worldwide Coverage (~ Cellular Dial-tone Availability)
  Either 'Bent Pipe' or via Intersatellite Links
  Gateways, PSTN Connections
  Modulations: TDMA or CDMA
  Local Cellular Company Size
    Largest: ~250,000 Subscribers at 0.1 Erlang
  Real Time Mobile Services (~ 4.8 kbps): Digital Voice, Narrowband Data (<Toll Quality)
  Typical Long Distance Delay Times: < Terrestrial Delays
  Typical Subscriber Costs
    Terminals: $1000 - $500 (and lower for RDSS only)
    Voice/Data: $3.00 - $0.50 per minute
  Typical Time and Cost to Send Daily NY Times (1 MB): 3.47 hours, $60 to $600

- Fixed (FSS) and Mobile (MSS) 'Broadband' LEO's (Ka-Band)
  Continuous Worldwide Coverage
  Terrestrial Dial-tone Availability
  Small, Earth-Fixed Cells
  Regional Bell Operating Company Size
    >20,000 simultaneous T1 (1.5 Mbps) connections worldwide
  Intersatellite Links
  Gateways, PSTN Connections
  Modulation: FDMA/TDMA
  Real Time Interactive Services (16 kbps - 1.2 Gbps)
    Bandwidth On Demand
    Broadband Data, Video, Digital Voice, etc. (>Toll Quality, 10^-10 BER)
  Typical Phone Company Services and Features
  Typical Long Distance Delay Times: < Fiber
  Typical Subscriber Costs
    Interface Units: $10,000-$1,000 (falling sharply with volume and competition)
    Data: Comparable to local PTT charges
  Typical Time and Cost to Send Daily NY Times (1 MB): 5 sec., few cents (to ~local PTT charges)
'Little LEO' Satellite Communications Systems on the Horizon

- Mobile (MSS) "Little" LEO's (UHF, VHF)
  - **FCC Construction License Granted**
    - Orbital Communications Corp. (OrbComm)
      - 36 Satellites, 40 kg, 4 year lifetime
  - **FCC Construction License Pending (Experimental Licenses Granted)**
    - Starsys Global Positioning, Inc. (StarNet)
      - 24 Satellites, 125 kg, 5 year lifetime
    - Volunteers in Technical Assistance (VITA)
      - 2 Satellites, 136 kg, 5 year lifetime
  - **FCC Construction License Pending (2nd Round Applicants)**
    - CTA Commercial Systems, Inc. (GEMnet)
      - 38 Satellites, 45 kg, 5 year lifetime
    - E-Sat, Inc. (E-Sat), USA
      - 6 Satellites, 100 kg, 10 year lifetime
    - Final Analysis Communication Services, Inc. (FAI sat)
      - (Rec'd experimental lic for 1 satellite)
    - GE American Communications (Eyeteil)
      - 24 Satellites, 15 kg, 5 year lifetime
    - Leo One USA Corp. (LEO ONE USA)
      - 48 Satellites, 124 kg, 5 year lifetime
    - Orbital Communications Corp. (OrbComm)
      - (Requesting 12 additional satellites)
    - Volunteers in Technical Assistance (VITA)
      - (Requesting 1 additional satellite)

International 'Little LEO's' (in development/planning), e.g:
- Leo One Panamericana (Mexico), ECO-8 (Brazil), Gonetz, Courier, Elekon (Russia), MiniSat (Spain), Saifir (Germany), TAOS/S80T (France), Artes (Belgium), Leostar (ESA), KITCOM (Australia), etc.

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'Big LEO' Satellite Communications Systems on the Horizon

- Mobile (MSS) "Big" LEO's (L-Band)
  - **FCC Construction License Granted**
    - Globalstar Telecommunications Ltd. (Globalstar), USA
      - 48 Satellites (+ 8 spares), 426 kg, 7.5 year lifetime, 1.6 B$
    - Iridium Inc. (Iridium), USA
      - 66 Satellites (+ up to 12 spares), 700 kg, 5 year lifetime, 3.4 B$
    - Odyssey Worldwide Services, (Odyssey), USA
      - 12 Satellites, 1952 kg, 12 year lifetime, 2.5 B$
  - **FCC License Decision Deferred (Financial qualifications must be met by 1/96)**
    - Constellation Communications, Inc. (ECCO), USA
      - 46 Satellites (+ 8 spares), 500 kg, 6 year lifetime, 1.7 B$
    - Mobile Communications Holdings, Inc. (Ellipso), USA
      - 16 Satellites, 500 kg, 5-7 year lifetime, 1.1 B$
    - American Mobile Satellite Corp., (AMSC), USA
      - 12 Satellites, 3.1 B$

+ International 'Big LEO's' (in development/planning), e.g:
- Inmarsat P, UK (10 Satellites, 2.6 B$, 1.4 B$ committed), Russia, France, China, etc.
‘Broadband LEO’ Satellite Communications Systems on the Horizon

- Fixed and Mobile (FSS/MSS) Broadband LEO's (Ka Band)

**Teledesic Corporation** (Teledesic), Kirkland, WA, USA

**Partners:** Craig O. McCaw, William H. Gates III, McCaw Cellular Communications (AT&T)

**Constellation:**
- 840 Satellites (21 polar orbits at 700 km altitude)
- (+ 84 in-orbit spares)

**Satellite Mass, Lifetime:**
- 800 kg, 10 year

**Primary Market:** Rural and remote parts of the world that would not be economic to serve through traditional wireline means

**Typical User:**
- Educational institutions, government agencies, healthcare and industrial/commercial organizations, and people in remote areas

**Typ. Cost per Minute:**
- Comparable to local PTT charges (includes PSN charges for local, long-distance, int'l tails)

**Initial Interface Unit Cost:**
- $10,000-$1,000 (falling sharply with volume/competition)
  - (Standard Terminals, 16 kbps to 2 Mbps)
  - ('Gigalink' Terminals, 155 Mbps to 1.2 Gbps)

**Total System Cost:**
- 9 B$

**Communications:**
- Satellite switching (FDMA/TDMA)

**FCC Status:**
- FCC Filed 3/94 (FSS), Amendment 12/94 (MSS)

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**Teledesic Corporation Background and Status**

- **Teledesic Company Background**
  - Founded in June, 1990
  - Concept Originally Developed (reduced to writing) in 1988
  - Headquarters: Kirkland, WA

- **Corporate Mission Statement:**
  "Teledesic seeks to organize a broad, cooperative effort to bring affordable access to advanced information services to rural and remote parts of the world that would not be economic to serve through traditional wireline means."

- **Teledesic Shareholders**
  - Craig O. McCaw (Founder - McCaw Cellular Communications) 32%
  - William H. Gates III (Founder - Microsoft) 32%
  - McCaw Cellular Communications (AT&T) 24%
  - Others 12%

- **Teledesic Status**
  - Feasibility Study and Point Design (Phase A) Completed
  - > 5 Years by Extraordinary Team of Full-time Employees, Consultants, and Subcontractors
  - FCC Application Filed 3/94 (FSS ) and Amendment Filed 12/94 (MSS)
  - Currently in Pre-Phase B (Planning and Development)
    - Regulatory Process Support
    - Program Planning and Organizational Development
    - System Requirements Update and Technologies Assessment
    - Key Supplier/Partner Candidates Identification and Selection
Teledesic Network Overview

Teledesic Services and Applications

- Provider (Wholesale) of Telecommunications Services to 'In-Country' Distributors
  Interactive 'Network-Quality' Voice, Data, Video, Multimedia, etc.
  Bandwidth-on-Demand
    - 16 kbps to 2 Mbps (Standard Terminals)
    - 155 Mbps to 1.2 Gbps ('Gigalink' Terminals)

- Switched and Point-to-Point Connections

- Connections Via Gateways to Terminals on Other Networks

- Teledesic Service Quality
  Comparable to Modern Urban Network
  'Fiber-Like' Delays
  16 kbps Basic Channels (Support 'Network-Quality' Voice, Data, etc.)
  1.5 Mbps Channels (Support 'Network-Quality' Data, 'VCR-Quality' Video, etc.)
  1.2 Gbps Channels (Support 'Fibre-Quality' Broadband Applications)
  Bit Error Rates <10^{-10}
  High Link Availability (Comparable with Urban Terrestrial Networks)
Teledesic Capacity, Coverage and Spectrum Usage

- **Teledesic Network Capacity**
  (Note: Actual user capacity depends on average channel rate and usage)

  **Standard Terminals (16 kbps to 2 Mbps)**
  - >23 Mbps (standard terminal) capacity within Teledesic 53 km x 53 km Cell
  - >20,000 simultaneous T1 (1.5 Mbps) connections worldwide

  **'Gigalink' Terminals (155 Mbps to 1.2 Gbps)**
  - 16 steerable 'Gigalink' spots within Teledesic 1400 km diam. Footprint
  - >8,000 simultaneous 'Gigalink' connections worldwide

- Teledesic Network Handles Wide Variation in Channel Rates and User Densities
- Teledesic Network Grows 'Gracefully' to Much Higher Capacity
- Teledesic Spectrum Resource Bandwidth Requirements

<table>
<thead>
<tr>
<th>Type</th>
<th>Uplink (Bandwidth)</th>
<th>Downlink (Bandwidth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Terminal Uplink</td>
<td>500 MHz</td>
<td></td>
</tr>
<tr>
<td>Standard Terminal Downlink</td>
<td>500 MHz</td>
<td></td>
</tr>
<tr>
<td>Gigalink Terminal Uplink</td>
<td>800 MHz</td>
<td></td>
</tr>
<tr>
<td>Gigalink Terminal Downlink</td>
<td>800 MHz</td>
<td></td>
</tr>
<tr>
<td>Intersatellite Cross Links</td>
<td>2000 MHz</td>
<td></td>
</tr>
</tbody>
</table>

Teledesic Footprint and Cell Features
FCC Notice of Proposed Rulemaking (NPRM), 13 July 1995

- Proposed NGSO Allocation Can Accommodate Teledesic
  500 Mhz: Primary for Broadband LEO Service (NGSO)
  750 Mhz: Secondary for NGSO

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**LMDS**
- Secondary: FSS

**NGSO/FSS**
- Secondary: GSO/FSS

**GSO/FSS**
- Secondary: NGSO/FSS

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Source: FCC (NPRM, 7/13/95)

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"Broadband GEO" Communications Systems on the Horizon

- Broadband GEO Fixed (FSS) (Ka Band)

  **FCC License Applicants**
  - AT&T (Voicespan), USA: 12 Satellites
  - EchoStar (EchoStar), USA: 2 Satellites
  - GE Americom (xx), USA: 9 Satellites
  - Hughes (Spaceway/Galaxy), USA: 15 Satellites
  - KaStar (KaStar), USA: 1 Satellite
  - Lockheed (AstroLink), USA: 9 Satellites
  - Loral (CyberStar), USA: 3 Satellites
  - Motorola (Millenium), USA: 4 Satellites
  - NetSat 28 (xx), USA: 1 Satellite
  - PanAmSat (PanAmSat), USA: 1 Satellite*
Teledesic Broadband LEO Network and System Features

- LEO Constellation
- Geodesic Network
- Fast Packet Switching
- Adaptive Routing
- 20/30 GHz Links
- Multiple Access
- Earth-Fixed Cells
- Standard Interfaces
- Economy of Scale

Teledesic Satellite Configuration Features

- Teledesic Satellite Configuration Features
Teledesic Space Segment Key Features

- Modern, High Performance, High Power, Mass-Prodicible Satellite System
  Identical 3-Axis Stabilized Satellites for All Constellation Positions
  High Performance, High Reliability, 10 year Lifetime Satellite System
  - High Power (>6.6 kW EOL, >300AH, 15 kW surge capability)
  - High Computational Power (>300 MiPs, >2 Gbytes RAM)
  - High ΔV Low-Thrust Propulsion (>1000 mps)
  - Lightweight (795 kg)
  - Compact Launch Configuration (3.1-3.3 m diameter x 2 m height)

- Design Features Tailored Specifically for Large Constellation
  High Volume Production of Components
  - Large Economies of Scale
  Automated Integration and Test of Satellite Systems
  - On-Board Test SAW
  - Autonomatic On-Orbit Health Monitoring and Constellation Control
  Self-Stacked, Self-Deployed Group Launch by Variety of Launchers
  - Multiple International Launchers and Launch Sites
  - Assembly Facilities at Launch Sites
  Automatic Orbit Transfer, Insertion and Gap-Filling
  Active On-Orbit Spares with Routine Block Replenishments
  Reliable End-of-Life Disposal/Deorbit Capability

Teledesic Space Segment Key Technologies

<table>
<thead>
<tr>
<th>Baseline Modern Space Technologies</th>
<th>Technology Back-ups</th>
<th>Enhanced Technology Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIS Thin Film Solar Array (Copper</td>
<td>Crystal Si, Crystal</td>
<td>Thin Film CdTe (6% EOL)</td>
</tr>
<tr>
<td>Indium Diselenide, 6% EOL)</td>
<td>GaAS</td>
<td>Thin Film CIGS (8% EOL)</td>
</tr>
<tr>
<td>NH₂ (CPV) Batteries (6x60 AH)</td>
<td>NH₂ (IPV) Batteries</td>
<td>Poly-, Amorphous-Si</td>
</tr>
<tr>
<td></td>
<td>NH₂ Batteries</td>
<td>Sodium Sulphur Batteries</td>
</tr>
<tr>
<td></td>
<td>NiCd Batteries</td>
<td>Lithium Ion Batteries</td>
</tr>
<tr>
<td>High Voltage Distribution System</td>
<td>28 VDC (DET)</td>
<td>Thin Film Polymer Batteries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flywheels (Lightweight, Long-life)</td>
</tr>
<tr>
<td><strong>Propulsion</strong></td>
<td></td>
<td>AC Distribution</td>
</tr>
<tr>
<td>Pulse Plasma Electric Thrusters</td>
<td>Hall SPT Thrusters (80mN)</td>
<td>Dellagration Thrusters</td>
</tr>
<tr>
<td>(0.7 mN, 60 kN-s,1200 isp)</td>
<td>Arc-Jets</td>
<td>Zenon Thrusters</td>
</tr>
<tr>
<td><strong>Mechanisms</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shape Memory Solar Array Extension</td>
<td>Bistem Booms</td>
<td>Inflatable Solar Array Booms</td>
</tr>
<tr>
<td>Booms</td>
<td>Cont. Longeron Booms</td>
<td></td>
</tr>
<tr>
<td>Paralfin (HOP) Latch/Deploy</td>
<td>Motors, Spring/Dampers</td>
<td></td>
</tr>
<tr>
<td>Mechanisms</td>
<td>Tuned Static Attachments</td>
<td></td>
</tr>
<tr>
<td>Vibration Isolation (Passive)</td>
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<tr>
<td><strong>Structures</strong></td>
<td>Standard Composites</td>
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<tr>
<td>Advanced Composite Structures</td>
<td>Aluminum</td>
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<tr>
<td></td>
<td>Smart Structures</td>
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</tr>
<tr>
<td></td>
<td>Integrated Cabling/Thermal</td>
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</table>
### Teledesic Space Segment Key Technologies (cont'd)

<table>
<thead>
<tr>
<th>Baseline Modern Space Technologies</th>
<th>Technology Back-ups</th>
<th>Enhanced Technology Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attitude Determination and Control</strong></td>
<td>RLG, QRS IMU's</td>
<td>DOI IMU's</td>
</tr>
<tr>
<td>Lightweight IFOG IMUs</td>
<td>Multiple Back-up Wheels</td>
<td>Magnetic Suspension Wheels</td>
</tr>
<tr>
<td>Long-Life Reaction/Momentum Wheels</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Data Handling/Electronics</strong></td>
<td>RS3000/6000, 68020</td>
<td>PC604, Pentium, etc.</td>
</tr>
<tr>
<td>High Perf. Rad Hard Microprocessors (PC603)</td>
<td>1773 LAN Data Bus</td>
<td>High Perf. Optical LAN Bus</td>
</tr>
<tr>
<td>Optical LAN Data Bus</td>
<td>AT-cut Crystal Oscillators</td>
<td>CMOS A/D's</td>
</tr>
<tr>
<td>SC-cut Crystal Oscillators</td>
<td>ECL A/D's</td>
<td>CMOS DSP's</td>
</tr>
<tr>
<td>GaAs A/D Converters</td>
<td>ECL DSP's</td>
<td>CHFET, Optical FPS's</td>
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<tr>
<td>GaAs VLSI Digital Signal Processors</td>
<td>ECL FPS's</td>
<td>UHDI, 3-D Packaging</td>
</tr>
<tr>
<td>GaAs Fast Packet Switches</td>
<td>Advanced Hybrids</td>
<td></td>
</tr>
<tr>
<td>Multi-chip (MCM) Packaging</td>
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<tr>
<td><strong>Software</strong></td>
<td>Partially Automated S/W</td>
<td>Autonomous IA&amp;T/COCC S/W</td>
</tr>
<tr>
<td>Automated Prod., Ass'y, Test, On-orbit Ops S/W</td>
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<td></td>
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<tr>
<td><strong>Communications</strong></td>
<td>HBT MMICs</td>
<td>InP MMICs</td>
</tr>
<tr>
<td>PHEMT GaAs MMICs: HPA's and LNA's</td>
<td>Gimbaled Arrays/Reflectors</td>
<td>Multi-Beam Lens</td>
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<tr>
<td>20/30 GHz Phased Array Antennas</td>
<td>Gimbaled 60 GHz Reflectors</td>
<td>Optical Intersatellite Links</td>
</tr>
<tr>
<td>60 GHz Intersatellite Phased Arrays</td>
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### Teledesic Satellite Resource Budgets

<table>
<thead>
<tr>
<th>SATELLITE SUBSYSTEM RESOURCE BUDGETS</th>
<th>Mass Kg</th>
<th>Power Average W</th>
<th>Volume cm³</th>
<th>Reliability %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>87</td>
<td>0</td>
<td>9,846 K cm³</td>
<td>99.9986 %</td>
</tr>
<tr>
<td>Mechanisms</td>
<td>52</td>
<td>0</td>
<td>1,139 K cm³</td>
<td>95.3037 %</td>
</tr>
<tr>
<td>Cabling</td>
<td>22</td>
<td>0</td>
<td>8 K cm³</td>
<td>99.9996 %</td>
</tr>
<tr>
<td>C&amp;DH/TT&amp;C</td>
<td>9</td>
<td>8</td>
<td>11 K cm³</td>
<td>98.8493 %</td>
</tr>
<tr>
<td>Temperature Control</td>
<td>37</td>
<td>24</td>
<td>153 K cm³</td>
<td>99.9990 %</td>
</tr>
<tr>
<td>Attitude/Orbit Det. and Control</td>
<td>12</td>
<td>19</td>
<td>51 K cm³</td>
<td>96.6997 %</td>
</tr>
<tr>
<td>Propulsion</td>
<td>60</td>
<td>0</td>
<td>250 K cm³</td>
<td>99.9999 %</td>
</tr>
<tr>
<td>Power</td>
<td>239</td>
<td>2288</td>
<td>85 K cm³</td>
<td>98.9488 %</td>
</tr>
<tr>
<td>Communications Payload</td>
<td>144</td>
<td>3000</td>
<td>3,557 K cm³</td>
<td>80.0488 %</td>
</tr>
<tr>
<td>Contingency (20%)</td>
<td>132</td>
<td>1088</td>
<td>3,020 K cm³</td>
<td></td>
</tr>
<tr>
<td><strong>SATELLITE SYSTEM:</strong></td>
<td>795</td>
<td>6,407</td>
<td>18.1 m³</td>
<td>72.2 %</td>
</tr>
</tbody>
</table>

Component Volume Inside Satellite Bus (3): 0.553 m³
Bus Fill Factor: 25%
Teledesic Satellite Propulsion $\Delta V$ Budget

<table>
<thead>
<tr>
<th>PROPULSION $\Delta V$ BUDGET (10 yr)</th>
<th>Velocity Increment m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Transfer and Insertion</td>
<td>272 m/s</td>
</tr>
<tr>
<td>Orbit Drag Maintenance</td>
<td>47 m/s</td>
</tr>
<tr>
<td>Sunsync. Orbit Maintenance</td>
<td>30 m/s</td>
</tr>
<tr>
<td>Gap-Filling Maintenance</td>
<td>87 m/s</td>
</tr>
<tr>
<td>Deorbit Retro Maneuver</td>
<td>65 m/s</td>
</tr>
<tr>
<td>Contingency (20%)</td>
<td>100 m/s</td>
</tr>
<tr>
<td>TOTAL $\Delta V$ REQUIREMENT:</td>
<td>601 m/s</td>
</tr>
<tr>
<td>Total $\Delta V$ Capability</td>
<td>1010 m/s</td>
</tr>
<tr>
<td>TOTAL $\Delta V$ MARGIN (68%):</td>
<td>409 m/s</td>
</tr>
</tbody>
</table>

Teledesic Constellation Deployment

- Diverse Set of International Launchers (and Launch Sites) Baselined
  - Launch Site Throughput Capacity Assured
  - 973 satellites launched in 24 months
  - ~1 Launch per Month from 4-6 International Launch Sites (~6 Pads)
  - Multiple Satellite Stacked Launches
- Avoids Single-Point Interruptions (Launcher, Launch Site)
  - Launcher Production Problems
  - Launch Delays
  - Launch Failures
- Assures Stable Launcher Supply (Capacity)
- Assures Stable Launcher Economics (Competition)

- > 30 Viable International Candidate Launchers Identified

- Expected Phase B Design Results:
  - Satellite Stowed Dimensions: 3.1-3.3 m diam x 2 m
  - Satellite Launch Mass: 800 kg
  - Stack Dispenser/Tug (1100 kg, 3.1-3.3 m diam x 2 m)

- Initial Deployment and Replenishment:
  - Initial Launch of 973 Satellites
    - 840 Satellites Constellation On-Orbit
    - 84 Satellites On-Orbit Active Spare Satellites
    - 49 Satellites Launch Failure Margin
  - Routine Replenishment of 195 Satellites

- Autonomous Deployment, Orbit Raising and Positioning
  - Injection by Dispenser/Tug ~600km, Near-Polar
  - Low Thrust Spiral to Final Orbit (700km)
  - Drift to Adjacent Orbit Planes (12-16 weeks), as required

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Teledesic Debris Mitigation

- Teledesic Management is Committed to Debris Mitigation
  Early Establishment as Top Level Design Requirement
  Long Term Self Interest

- Teledesic Debris Mitigation Requirements
  Risk of Teledesic generated debris on Teledesic constellation and other Space Assets must be small compared to risk from ambient debris environment.

- Teledesic Debris Mitigation Actions
  Early Establishment Unique Government/Industry Debris Experts for Debris Mitigation Analyses and Trades
  Air Force Phillips Lab, The Aerospace Corp.
  Lockheed-Martin, Orion Int'l, Teledesic

- Completed Phase 1 of Two Phase Study
  Phase 1 focus: establish environments and requirements
  Phase 2 focus: formulate design rules and validation methodology

- Completed NASA/JSC Review of Phase 1 Study Results (29-30 Sept. 1994)

"Teledesic debris mitigation policy of limiting and managing the generation of debris to less than background is achievable."

Teledesic Debris Mitigation Phase 1 Study Report (Lockheed-Martin, Apr 1995)

Teledesic Ground Segment Key Elements

- Terminals
  Standard Terminals: 16 kbps to 2 Mbps
  'Gigalink' Terminals: 155 Mbps to 1.2 Gbps
  COCC, NOCC, SPAC Gateways 155 Mbps to 1.2 Gbps

- Network Operations and Control Centers (NOCC)
  Redundant Facilities, providing e.g.,
  - Feature Processors
  - Network Management
  - Subscriber and Network Databases
  - Global Administration and Billing Systems

- Service Provider Administration Centers (SPAC)
  Redundant Gateway Antennas
  Regional Administration, Billing Systems and Regional Network Control
  Owned and Operated by Service Provider

- Constellation Operations and Control Centers (COCC)
  Redundant Facilities for 4 Teams
  - Health Monitoring/Failure Detection Team ('Front Room')
  - Diagnostic/Failure Isolation Team ('Back Room')
  - Disposal/Deorbit Team ('Back Room')
  - Launch/Initialization/Replacement Team ('Back Room')

Owned and Operated by Teledesic
Large LEO Projects Will Stimulate the Commercial Space Industry and Global Competitiveness

- Global Information System Infrastructure
  - Wireless Bandwidth on Demand (16 kbps to 1.2 Gbps)
- Space Communications Technology
  - 20/30 GHz Phased Arrays, GaAs Receivers/Transmitters
  - 60 GHz or Optical Gigabit Intersatellite Links (>1 Gbps)
  - Gigabit Modems and Multi-Gigabit Packet Routing
- Low Cost, High Capacity User Terminals (rates up to 1.2 Gbps)
- Volume Satellite Component Production, e.g.:
  - 10 Million Watts of Solar Cells
  - 300,000 Amp-hours of Batteries
  - 24,000 Gigabits Modems
  - 8,000 Electric Thrusters
  - 8,000 Gigabits Crosslinks
  - 3,000 Space Computers (with Peripherals)
- Automatic Satellite Production, Assembly, Test and Constellation Operations
  - State-of-the-Art Software Engineering Techniques
  - Production, Assembly, Test and Operations SAW - Standard Operating System with Applications (3rd Party)
- Robust Launch Campaign
  - 1 Million Kilograms to Low-Earth Orbit
Emerging Applications for Smaller (Light-, Micro- and Nano-) Satellites

- Current revolution in size and capabilities of space components and systems
  - Driving from Lightsats (100's-10 kg) to Microsats (10-1 kg) to Nanosats (<1 kg)
- Shrinking satellites' attributes (small, light, focussed, high performance, quick development, producibility, distributed control, high-tech front-end investments, etc.) causing fundamental changes in choices:
  - New space systems capabilities, affordability and availability
  - New industry structure and business approach
  - New technologies expand marketplace, applications, opportunities
- New space applications within reach of unprecedented number of people, e.g.:
  - Scientists, battlefield commanders, farmers, businessmen, researchers, etc.
- Difficult to predict market by extrapolating from 'mainframe' satellite experience e.g., Apple couldn't foresee spreadsheets while developing Apple II
  - New unforeseeable powerful applications undoubtedly coming
- 5 early markets for increasingly smaller satellites apparent now:
  - Space science research
  - Environmental monitoring
  - Tactical military applications
  - Technology testbeds
- Communications
  - Commercial space dominated by sat comm goods/services
  - Evolutionary sat comm improvements over past 30 years
    - 1000 times more cost effective
    - 100 times higher power
    - 50 times higher frequency use efficiency
    - 10 times longer lifetimes
USA Satellite Communications Technology 'Firsts'

<table>
<thead>
<tr>
<th>First satellite with broadcast transmission capability from space (SCORE)</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>First teletype relay by satellite (Courier 18)</td>
<td>1958</td>
</tr>
<tr>
<td>First passive communications satellite (ECHO)</td>
<td>1960</td>
</tr>
<tr>
<td>First active communications satellite (Telesat)</td>
<td>1962</td>
</tr>
<tr>
<td>First communications satellite to transmit TV worldwide (Relay)</td>
<td>1962</td>
</tr>
<tr>
<td>First geosynchronous communications satellite (Syncom II)</td>
<td>1963</td>
</tr>
<tr>
<td>First operational military communications satellite (IDSCS)</td>
<td>1965</td>
</tr>
<tr>
<td>First operational commercial communications satellite (INTELSAT I, &quot;Early Bird&quot;)</td>
<td>1965</td>
</tr>
<tr>
<td>First communications satellite capable of multiple access transmissions (INTELSAT II)</td>
<td>1967</td>
</tr>
<tr>
<td>First satellite to provide UHF mobile communications (TACSAT)</td>
<td>1968</td>
</tr>
<tr>
<td>First satellite with a despun antenna (INTELSAT III)</td>
<td>1968</td>
</tr>
<tr>
<td>First satellite with high-power spot-beam antennas (INTELSAT IV)</td>
<td>1971</td>
</tr>
<tr>
<td>First communications satellite to achieve frequency reuse (INTELSAT IVA)</td>
<td>1975</td>
</tr>
<tr>
<td>First communications satellite to provide commercial mobile satellite services (MARSAT)</td>
<td>1976</td>
</tr>
<tr>
<td>First complex hybrid communications satellite capable of operating in multiple frequency bands with multiple frequency reuse (INTELSAT V)</td>
<td>1980</td>
</tr>
</tbody>
</table>

Source: ITRI NASANSF Panel Report on Int'l Satellite Communications, 7/93

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A Conservative Projection of the Annual Communications Service Business for the Next Decade

<table>
<thead>
<tr>
<th>Satellite Service</th>
<th>1992</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Satellite Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTELSAT</td>
<td>$4.5 billion</td>
<td>$8.5 billion</td>
</tr>
<tr>
<td>Regional and Other International Sat. Systems</td>
<td>1.8 billion</td>
<td>3.6 billion</td>
</tr>
<tr>
<td>U.S./Canada Nat'l Systems</td>
<td>2.3 billion</td>
<td>4.5 billion</td>
</tr>
<tr>
<td>Other National Systems</td>
<td>1.4 billion</td>
<td>3.4 billion</td>
</tr>
<tr>
<td>Fixed Satellite Service (Total)</td>
<td>$10.0 billion</td>
<td>$20.0 billion</td>
</tr>
<tr>
<td>Mobile/Low Orbit Services</td>
<td>$0.8 billion</td>
<td>$10.0 billion</td>
</tr>
<tr>
<td>Broadcast Satellite Services</td>
<td>$0.5 billion</td>
<td>$8.0 billion</td>
</tr>
<tr>
<td>Military Satellite Services</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Other (e.g., Data Relay, etc)</td>
<td>$0.1 billion</td>
<td>$0.3 billion</td>
</tr>
<tr>
<td>Total Services</td>
<td>$11.4 billion</td>
<td>$38.3 billion</td>
</tr>
</tbody>
</table>

* Table: does not include equipment sales (e.g., satellites, launch vehicles, ground stations, etc.), which were about $5 billion in 1992, and are predicted to double in the next decade.

** No accurate or meaningful figures for military services are readily available.

Source: Pelton, Edelson, Helm (ITRI NASANSF Panel Report on Int'l Satellite Communications) 7/93

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Space Communications Today

• Space Communications is a Big Business
  First and Still the Only Big Commercial Pay-off in Space
  160 Countries and Territories Involved with GSO Systems
  >100 Satellites in GSO
  > 20 Operational International, Regional and National Systems
  10 Countries have Significant Satellite Communications Industry Capabilities
  > 10 B$/year in Revenues from Space Communications
  > 5 B$/year Equipment Market (Satellites, ELV's, Terminals, etc.)

• US has Dominated the Space Communications Business for Past 25 Years
  R&D from NASA and DOD Played Key Role in USA Satellite Communications Industry Development
  USA Lead the World in Satellite Communications Technology Development

• Satellite Communications Business is Changing Fast and about to Explode
  Global Market will Expand Rapidly into Personal Communications
  Large Economic and World Power Stakes are Involved for Dominant Nation(s)

• USA Leadership (Technological and Economic) is Being Challenged
  Over Past 2 Decades Many Other Nations have Invested Heavily Sat Com R&D
  Dominant Role Played by USA in Past 25 years is Clearly Now Over
  Engaged in Global Competition for Dominance (Technological and Economic)

Trends to Micro/Nano-Satellite Networks

• Commercial space dominated by sat Communications goods/services
  Evolutionary GSO sat comm improvements over past 30 years
  1000 times more cost effective
  100 times higher power
  50 times higher frequency use efficiency
  10 times longer lifetimes
  LEO's and HALE's will be next revolution in communications
  Shrinking size and distance to user
  Nano-satellites in clusters and constellations will be following wave
  Distributed, networked/interlinked, virtual missions
  Driven by comms (and remote sensing) applications

• Bandwidth, Availability, Interoperability and Mobility will drive future comms
  Small user terminals require high power or large apertures on satellite
  Low power, distributed, large aperture, interlinked network of nano-sats

• General Features of Ideal Micro/Nano-Satellite Networks
  Low-Cost, Disposable, Low Power Highly Efficient Nodes
  Large, Distributed Aperture, Small Steerable Beams
  Capable Inter-satellite links with precision position determination
  Reliable Distributed Control and High Autonomy
  Shared Multi-Network Operating Systems and Interoperable Control
  etc., etc...

• A Vision of Micro/Nano-Satellite Designs for Comm Networks
Biography: Dr. James R. Stuart is the Vice President, Space Infrastructure for Teledesic Corporation (a global, wireless, broadband, LEO network), and has been an independent, international consultant specializing in advanced commercial space systems. He has played an important role in the creation and development of LEO and GSO communications satellites, and is currently an active principal and board member in several entrepreneurial technology and space companies involved with communications satellites and small launch vehicles. Dr. Stuart also acts as Chief Technical Advisor for two ‘Little LEO’ store-and-forward programs (a licensed Mexican constellation, and a recently filed U.S. constellation). Dr. Stuart previously held positions as Chief Scientist and Chief Engineer at Ball Space Systems Division in Boulder, CO. He was also founding Chief Engineer of Orbital Sciences Corporation, Assistant Laboratory Director of the Laboratory for Atmospheric and Space Physics, and creator and first Project Manager of the Mars Observer Project at NASA/Jet Propulsion Laboratory, where he was also Manager of Advanced Planetary Programs. Dr. Stuart has been on various graduate faculties of the University of Colorado at Boulder for over 15 years: in the Electrical Engineering, Telecommunications and Aerospace Engineering Sciences Departments, as well as in the Center for Space Construction. He received his Ph.D. in Systems Engineering (1979), M.S. in Operations Research (1977), and M.S. in Electrical Engineering (1974) from the University of Southern California, and his B.S. in Physics (1968) from the University of Washington. Dr. Stuart has received numerous professional awards, including NASA’s Exceptional Service Medal for his project management of the Solar Mesosphere Explorer Project, JPL’s highly successful, first modern small satellite project. He is also listed in Via Satellite’s “Top 100 Executives in the Satellite Communications Industry”. Dr. Stuart has published over 90 professional papers on the topics of small satellite systems, space technologies and communications satellite economics.