The Radio Amateur Satellite Corporation

Barry A. Baines, WD4ASW

Amateur Satellite History and AMSAT Strategic Direction

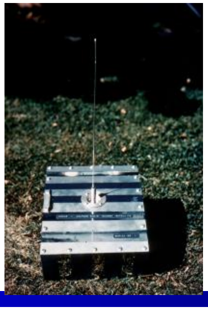
ARRL "Training Tracks" Satellite Workshop

17 JUL 14

Presentation Overview

- The Story of OSCAR-1and the Early Satellites
  - » How Amateur Radio got into Space
- How AMSAT Got Started
  - » Looking Back on 45 Years of “Keeping Amateur Radio in Space”
- A Review of Amateur Satellite Development
  - » The evolution of satellite programs/capabilities
- Historical “Firsts” Pioneered by Amateur Satellites
  - » Impacts on Industry
- Evolving Satellite Technology
- International Cooperation/Developments
- Evolution of AMSAT in the 21st Century

OSCAR-I
Amateur Radio's First Satellite



- Soviet Union's Sputnik launched on 4 OCT 57
  - » Transmitted on 20.005 MHz
- US launches Explorer-1 on 31 JAN 58
- OSCAR Association is formed in 1960
  - » OSCAR: Orbiting Satellite Carrying Amateur Radio
  - » Consisted of amateurs who worked in the Defense Industry/TRW
  - » Contacts within the US Air Force
- OSCAR-1 is built and flown in less than two years
  - » Launched on 12 DEC 61 from Vandenberg AFB
  - » First "Secondary Payload" (Primary was a "Scientific Mission")
  - » Less than 10 lbs, battery powered/measured 9"x12"6"
  - » Transmitted on 144.983 MHz with 140mW beacon transmitting "Hi" in CW
  - » Apogee 430 km
  - » Mission lasted 22 Days/de-orbited in 50 days

Lance Ginner, K6GSJ w/OSCAR-I

OSCAR-II

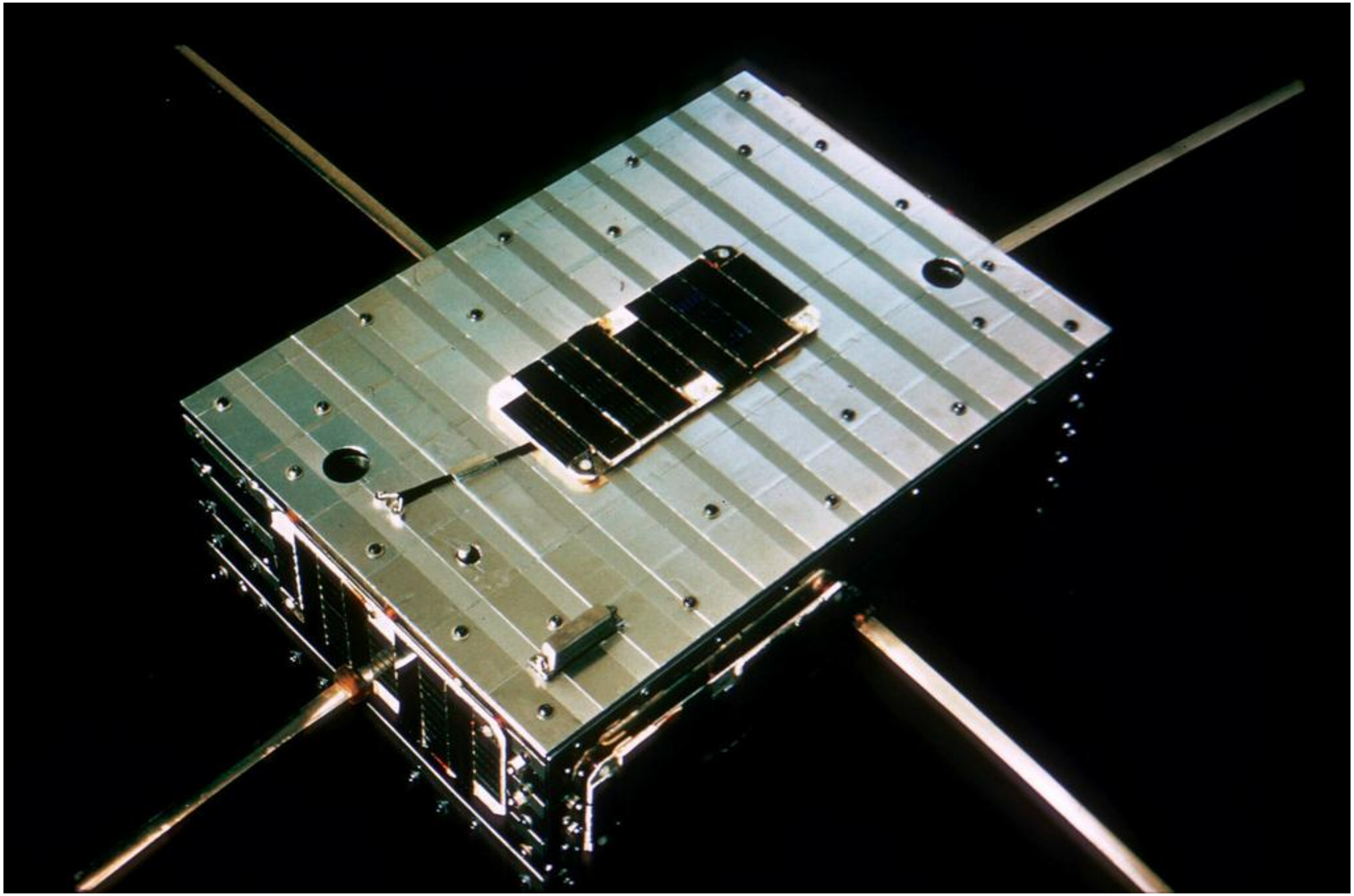
- OSCAR-2 Launched 2 JUN 62
  - Structurally/electrically similar to OSCAR-1
  - Power reduced to 100mw to extend battery life
  - Modifications to thermal coating to cool the spacecraft
  - Modified the sensing system to measure accurately s/c temperatures as battery decayed
  - Apogee 390 km
  - 19-day life/de-orbited

- First US Government/Commercial Transponder
  - Telstar launched in 10 JUL 62 (highlighted by The Ventures)
  - TV, Telephone & Data
  - Huge Ground stations w/conical cone antenna: 177 ft. weighing 380 short tons (340,000 kg) housed in a 14 story radome

OSCAR-III
Amateur Radio's first "Transponder"

- Launched 9 MAR 65 from Vandenberg AFB (Titan 3-C) with 940 km Apogee/70 deg. inclination
- 16.3 kg (30-lb.) Rectangular (20 x 30cm) spacecraft
- Transponder: 50 KHz Wide, 1-watt transmitter
- Received near 146 MHz/Transmitted near 144 MHz
- Battery Powered Transponder/18-day life/remains in orbit
- Battery/Solar Panels power beacons (145.85 + 145.95 MHz)
- Technology Demonstrator
  - » Transponder worked for 18 days/Beacons for several months
  - » Demonstrated free access, multiple-access transponder amateur transponder could work in space
  - » First long distance VHF contacts/1,000 hams from 22 countries
  - » Identified need to use separate uplink/downlink bands

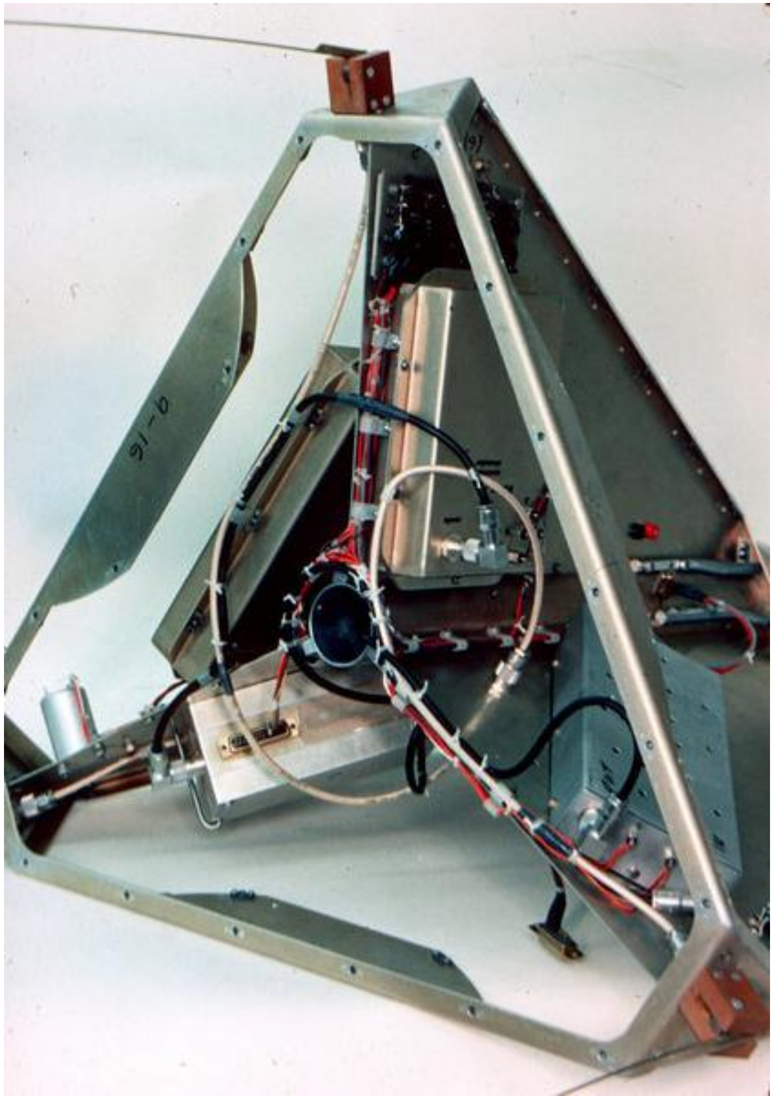
OSCAR-III



OSCAR-IV
Dealing with Unexpected Consequences

- Built by TRW Radio Club of Redondo Beach, CA
  - » Project OSCAR crew was readying OSCAR III for flight
- Designed for 21,000 mile circular orbit above the equator
- Only 1-year to design/build/test/deliver
- Minimal Design:
  - » 10KHz crossband transponder (2M uplink/70 CM downlink)
  - » Transmitter output: 3 watts
  - » Beacon for ID
  - » Power: Solar Panels and Battery/1 year expected life
  - » NO TELEMETRY
- 30 lb. satellite launched on 21 DEC 65 on Titan III-C
- Upper stage of launch vehicle FAILS/Sat placed in “wrong” orbit
  - » 26° inclination/ apogee 21,000 miles/perigee 100 miles

OSCAR 4's Tetrahedral Spaceframe



OSCAR-IV
Dealing with Unexpected Consequences

- Significant Challenges
  - Tracking (Limited resources to predict satellite position)
  - Doppler Shift due to orbital impacts (rapid relative movement to the earth). Doppler was greater than transponder bandwidth
  - Tumbling of spacecraft
- Short Lifespan
  - 85-day operation/de-orbited 12 APR 76
  - Probable battery failure/solar cell failure due to radiation
- First Two-Way amateur satellite contact between US-USSR

OSCAR-5

- Australian satellite built by University of Melbourne students
  - Started in late 1965
  - Design finalized in March 1966
  - Evaluate suitability of a 10 Meter downlink
  - Passive magnetic stabilization (reduce spin rate)
  - Uplink command capability /command receiver & decoder
  - Telemetry beacons at 144.040 MHz (50 mW) + 29.450 MHz (250 mW) w/7-channel analog telemetry system
  - Manganese-alkaline battery power supply
  - No transponder/solar cells

OSCAR-5

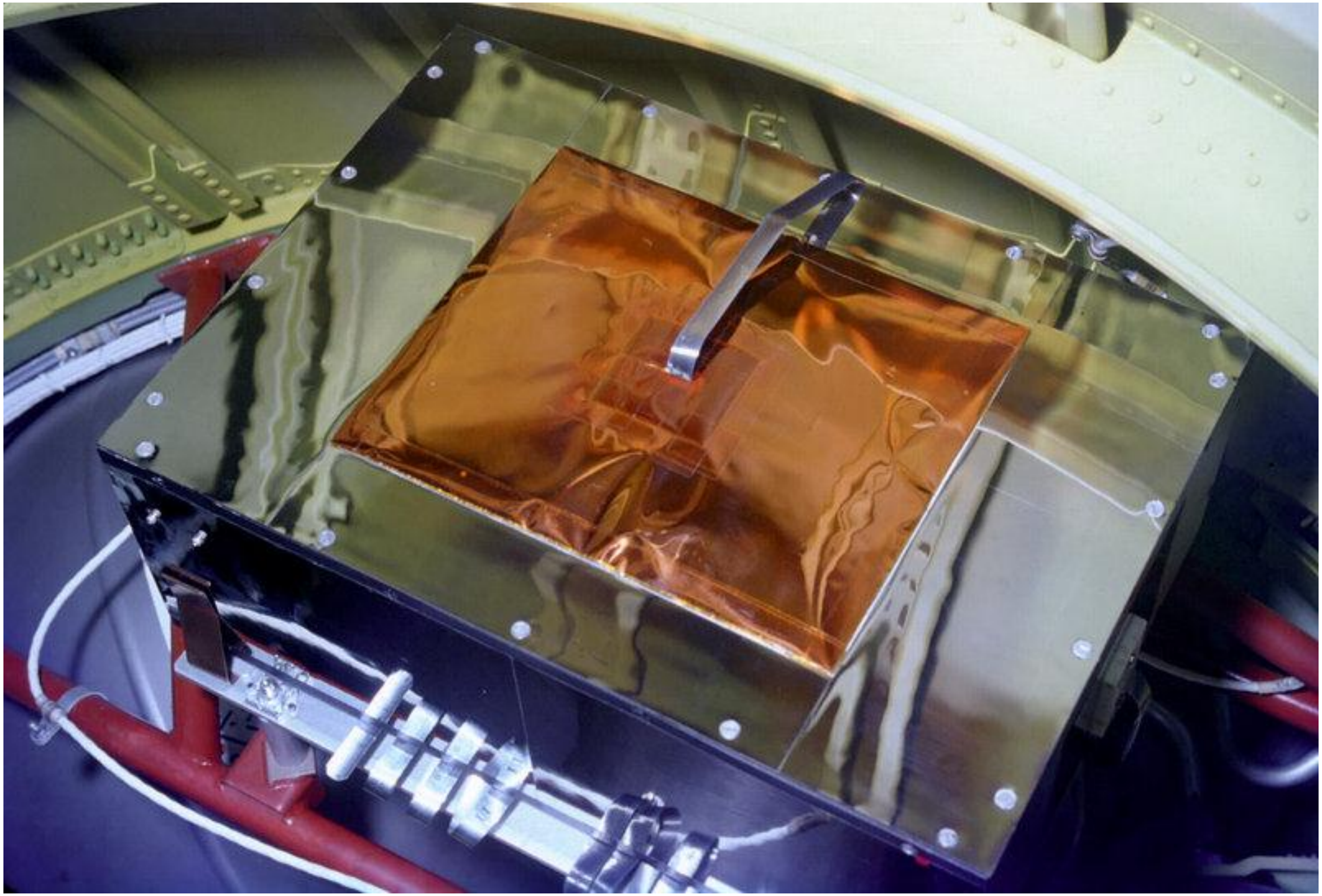
- Despite administrative frustrations, satellite completed on 1 JUN 67 and delivered to Project OSCAR in California
- Launch opportunity scheduled for early 1968
- Host mission was delayed and indefinitely postponed
- No other suitable launch could be identified
- The satellite sits in a garage in California

- Now What??

Birth of AMSAT

- Members of DC Area Ham Clubs affiliated with :
  - » Government Agencies
  - » Communications Companies
  - » Laboratories
  - » met in late 1968 in the home of George Jacobs, W3ASK
- Inspired by amateurs wishing to emulate Project OSCAR to Revitalize the Amateur Satellite Program
- Radio Amateur Satellite Corp. was charted on 3 MAR 69 in the District of Columbia as a 501-(c)-(3) scientific & education organization
- Connections with NASA provide an opportunity to find a launch following minor modifications to OSCAR-5

Australis OSCAR-5 Ready to Fly



OSCAR-5

- Launched on 23 JAN 70/1480 km Apogee
  - » Delta launch from Vandenberg AFB w/TIROS-M weather satellite
- Outstanding results
  - » Spin rate reduced by a factor of 40 (4 rpm to .4 rpm)
  - » Command capability demonstrated (29 MHz beacon turned on/off on 28 JAN 70)
  - » Ground station telemetry collection successful
  - » With dying battery, 10 Meter beacon heard on day 46

Birth of the Amateur Satellite Service

- ITU Convenes WARC-71 in June 1971
- One Outcome is the birth of the Amateur Satellite Service
  - » Separate entity from the Amateur Service in the International Radio Regulations
  - » Formal Designation of bands for amateur satellites allowing future satellites to use more bands, including:
    - 21.1-21.45 MHZ
    - 28.0-29.7 MHz
    - 435-438 MHz
- In the US, an FCC license covers both the Amateur Service and Amateur Satellite Service

Next Generation: Phase II Satellites

- Phase 1 Satellites
  - » Featured short duration missions designed to gather information on basic satellite system performance
  - » “Bleeding Technology” that attracted experimenters
- During the 1970s, a new class of satellites were flown
  - » Features included:
    - – Wideband Two-way Communications Transponder
    - – Relatively Long lifetimes
    - – Telemetry
    - – Ground Control of Spacecraft Functions with multinational Ground Station Command Stations
    - – Solar Panels
- Attracted satellite operators
  - » By 1983, between 10,000 and 20,000 amateurs had worked Phase II

OSCAR-6 Design Philosophy

- Built to operate for at least one year
  - » Protect the investment in $$$ and sweat equity
- Long lifetime could only be assured if a spacecraft contained
  - » A sophisticated telemetry system that could monitor onboard systems
  - » Flexible command system to turn on/off specific subsystems as conditions warrant
  - » Redundant critical systems
  - » A design strategy that anticipates possible failure modes, such as isolating and replacing defective subsystems
- AO-6 was a quantum leap in amateur satellite design
  - » 35 different commands to control/manage the satellite
  - » 24 channels of telemetry with a special system to forward data to the ground using morse code using a digital number format

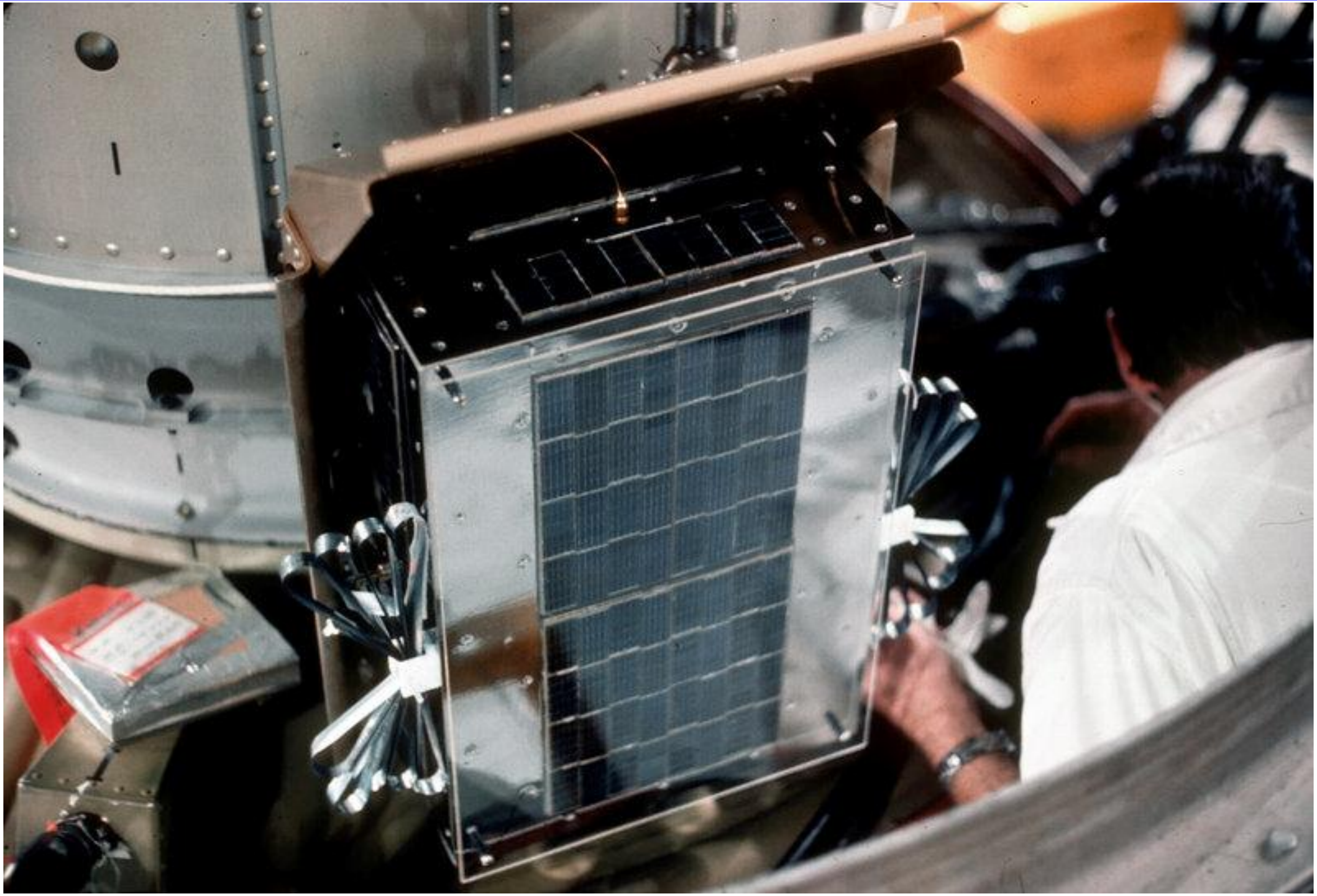
OSCAR-6

- First satellite to use 2M uplink/10 meter downlink (100 KHz bandwidth)—now called “Mode A”.
- 435.1 MHz beacon and morse code telemetry system
- 21 Channel Command Decoder to control systems
- Magnetic stabilization
- First Digital Store-and-Forward System (Codestore) w/discrete logic and memory capacity of 256 characters (Records CW characters)

OSCAR-6

- Prototype Transponder flown on a private aircraft to evaluate performance with real signals
  - » “Contest” generated 66 logs
- Thermal test of the flight transponder done in the kitchen oven of W4PUJ (“Burned the Cake”)
- Launched on 15 OCT 72 with a weather satellite
  - » 900 Mile Apogee

OSCAR-6 Mounted on the Delta Launch Vehicle



OSCAR-6 “Works”

- Static in the satellite affected the command system which read the noise as a command to shutdown
  - » Command stations around the world send continuous stream of ON commands to keep AO-6 turned on
    - – First audio tape loop audio and then digital logic
  - » Automated processes developed to send commands
  - » Over 80,000 commands sent per day in August 1973!

- Solar-Charged batteries allowed the satellite to remain operational for 4.5 years

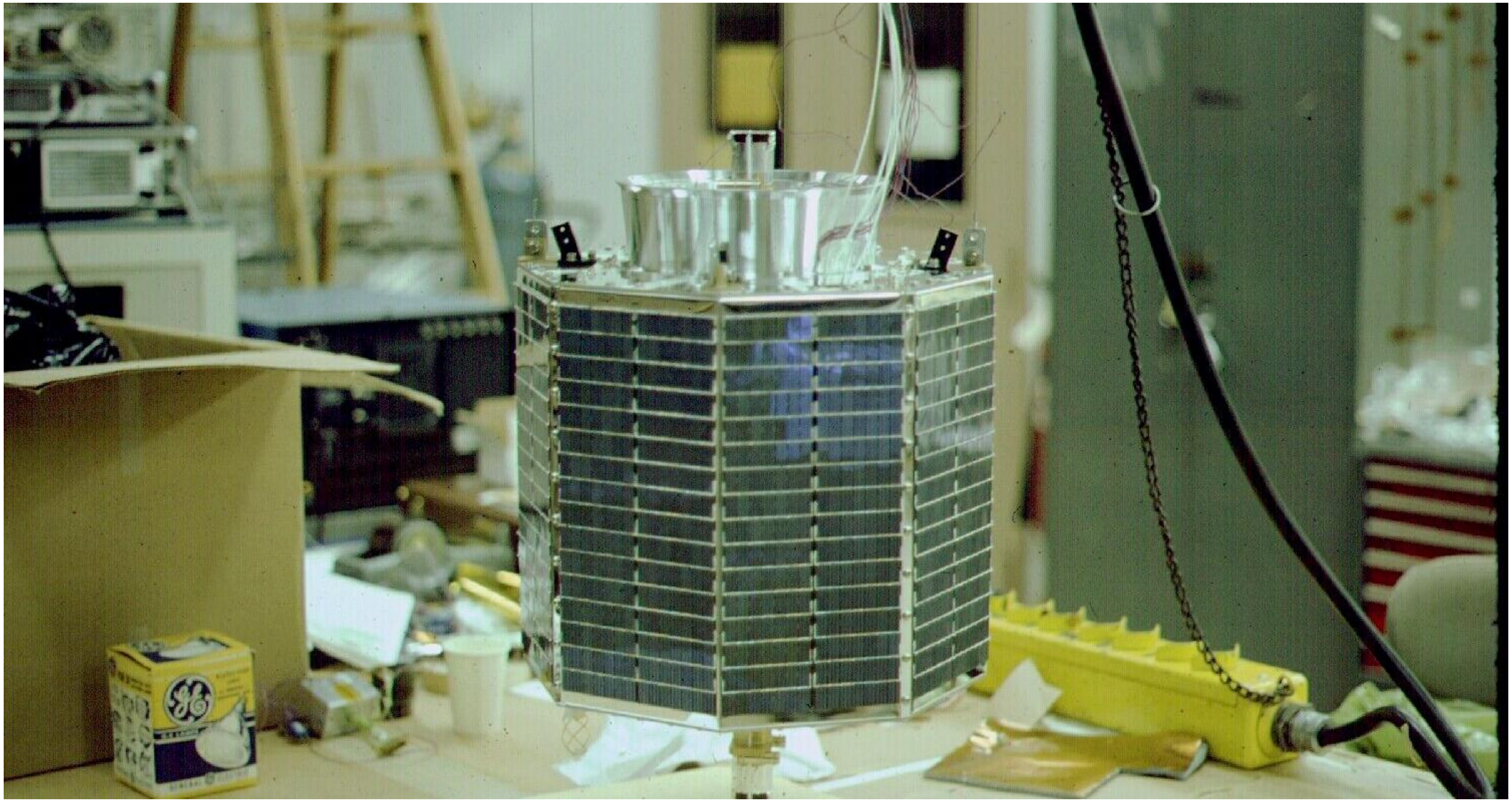
- 435 MHz beacon failed after three months/29 MHz provides the backup (“soft failure”)

OSCAR-6 Milestones

- First “International” Satellite
  - Subsystems built by US, Australia, West Germany
  - Ground stations in Australia, Canada, Hungary, Morocco, New Zealand, West Germany, UK, US
  - Used by amateurs in over 100 countries

- Educational Outreach
  - AMSAT and ARRL Collaboration
  - Space Science Involvement Manual released in 1974
  - Using Satellites in the Classroom: A Guide for Science Educators released in 1978

OSCAR-7



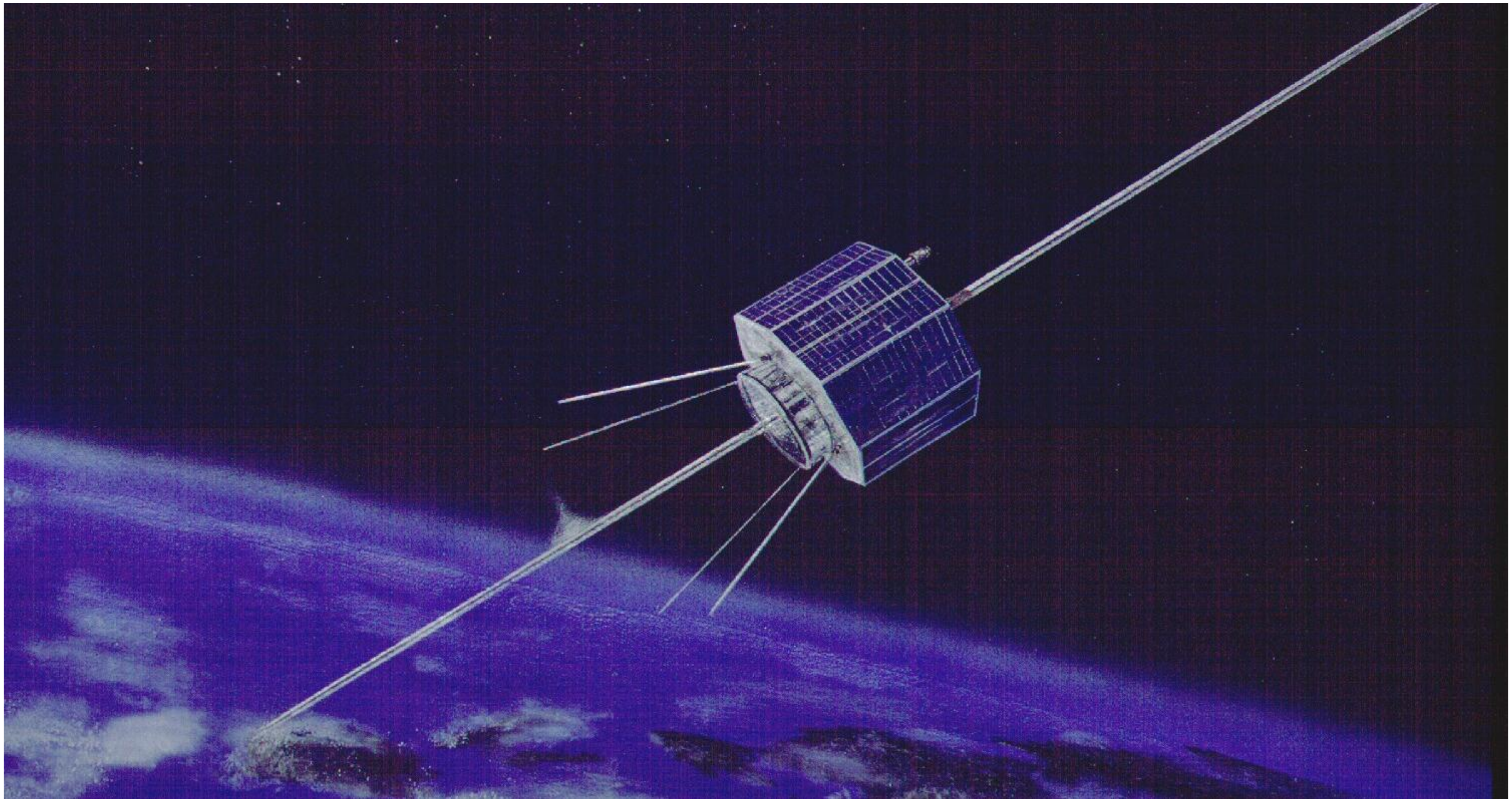
OSCAR-7

- Launched on 17 NOV 74
  - » Built in Jan King's basement
  - » 1,460 KM Apogee
  - » 8.0 W output (vs. 1.5 W for AO-6)
  - » Mode A (2M/10M)-built in the US
  - » Mode J (2M/432 MHz)-built in W. Germany (DJ4ZC) with a HELAPS amplifier (High Efficiency Linear Amplification through Parametric Synthesis)
  - » Beacons on 10M, 2 Meters, 70 CM, and S-Band (2304.1 MHz)
    - – S-Band never used due to lack of FCC permission to operate it
  - » Operating Life of "6.5 years" (1981)/returned to life in 2002

AO-7 Accomplishments

- First Satellite-to-Satellite Communication Path
  - » AO-6 and AO-7 in operation at the same time
  - » Line-of-sight link-up using the 2M output signals from AO-7 to the input of AO-6 and retransmitted on 10 Meters (Mode A)
  - » Linking later adapted by non-amateur spacecraft, including NASA's Tracking and Data Relay Satellites (TDRS)
- Location Experimentation
  - » A ground station transmits a 2M signal to AO-6 and AO-7
  - » Compute the location by comparing doppler shift
  - » Technique eventually led to development of the Search And Rescue SATellite (SARSAT) Project to located downed aircraft and lost mariners
  - » Accomplished BEFORE the advent of GPS

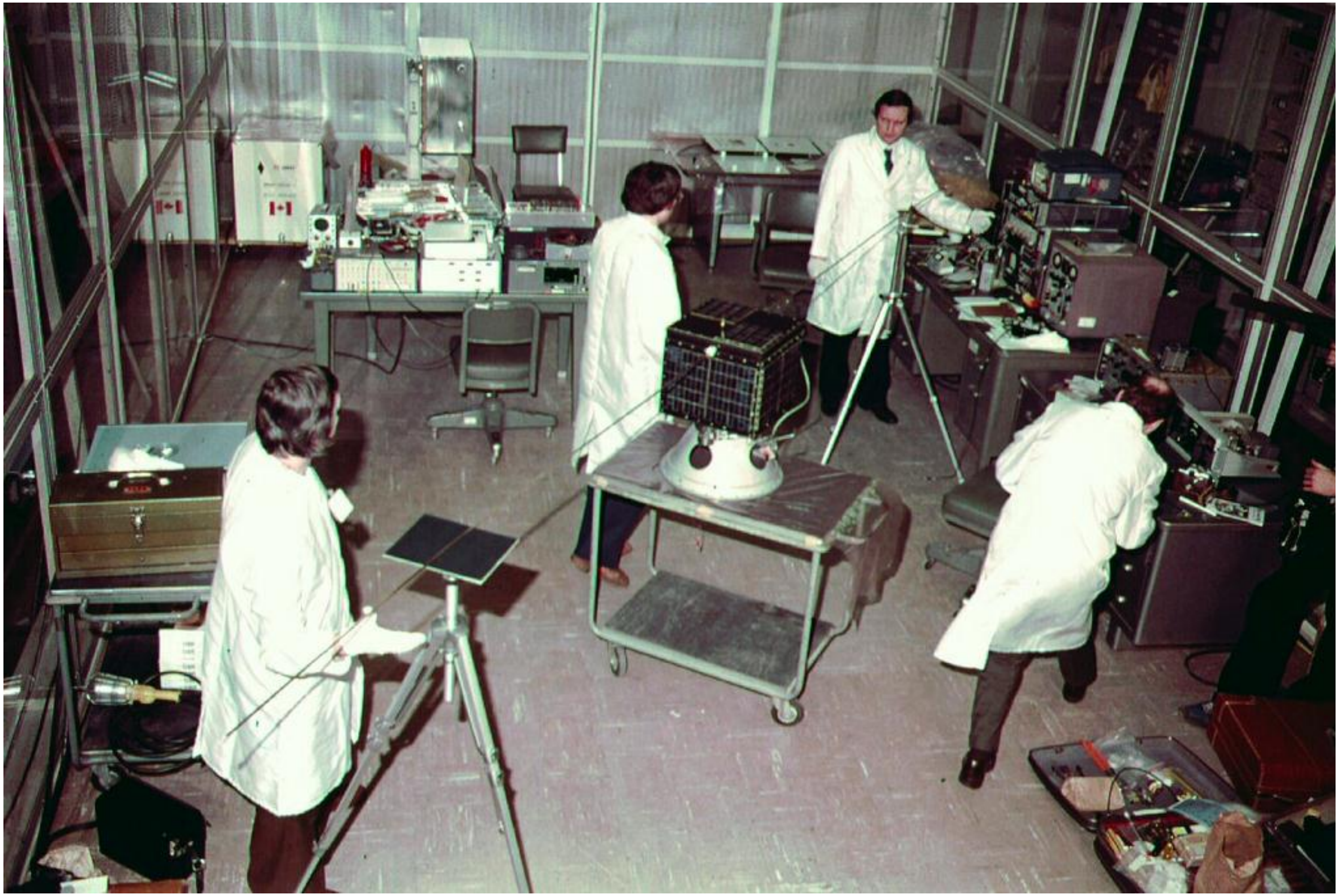
AO-7 Continues to Operate!



OSCAR-8 (“ARRL Satellite”)

- ARRL funds AMSAT’s development of OSCAR-8 to provide a Phase II/Mode A satellite superior to AO-7 and to replace AO-6 ($50,000.00)
  - West Germany & Canada involvement
- Carried 2M/70 CM transponder built by JAMSAT (“Mode J”)
- Possible for uplink signals on 2M could be heard on both downlinks if battery levels could support both modes
- Beacons on 29.402 MHz and 435.095 MHz
- Launched 5 MAR 78 from Vandenberg AFB
  - 910 KM/570-mile-high polar circular orbit
- 10 Meter antenna extended under ground command over the East Coast
  - Managed by ARRL Controllers for five years/worked until mid-1983

OSCAR-8 Testing



As the 1970s Close…

- Russia develops two “RS” Amateur Satellites
  - “Radio Sputnik-1” and “Radio Sputnik-2” built by amateurs who had visited the US during the Apollo-Soyuz Program
  - Article published in October 1975 in Radio Magazine highlights Mode A developments in Moscow and Kiev along with the OSCAR program
  - Prototype transponder mounted on Moscow rooftop (1 W)
  - USSR notifies ITU in July 1977 that satellites in the Amateur Satellite Service would be launched
- Both Satellites launched 26 OCT 78 on the same vehicle
- Mode A with sensitive145 MHz receiver due to 5-Watt limitation for Russian ground stations

As the 1970s Close…

- WARC-79 has impact on Amateur Satellite Service
  - » Frequency assigned from 1 GHz-10 GHz
    - – L-Band (1.5 GHZ uplink only)
    - – S-Band (2.400-2.500 GHz uplink/downlink)
    - – 3.4-3.41 GHZ
    - – 5.83-5.85 GHz
    - – 10.45-10.50 GHz

    Plus:
    - – 24.00-24.05 GHz
- Provides the bandwidth that will be used on the Phase-3 Satellites
- “Use It or Lose It” a concern

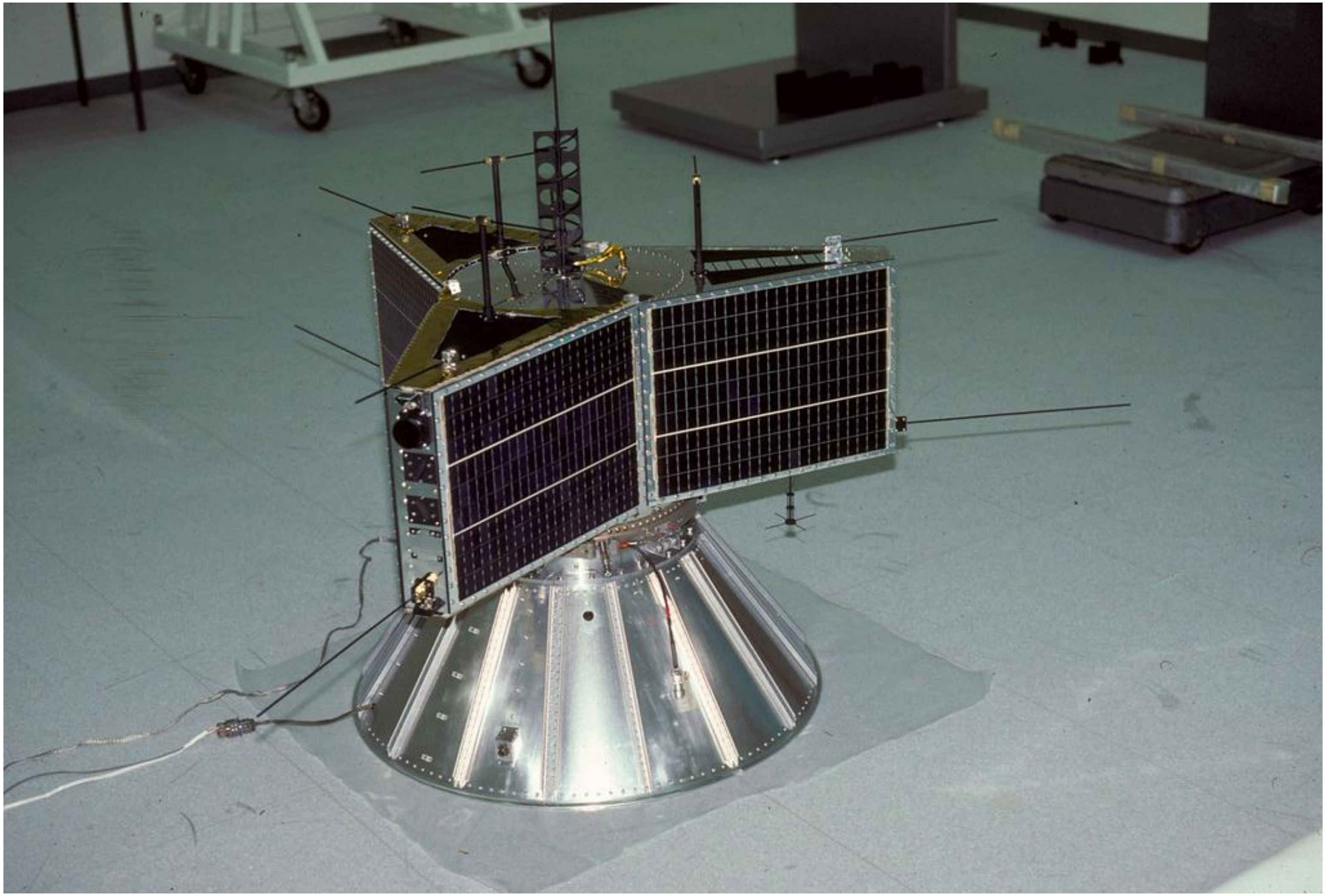
Phase 3 Satellites

- Next Generation Satellites
  - » Highly elliptical Molniya orbit with an apogee of several Earth radii
    - – High inclination (64°) favors the Northern Hemisphere
    - – Low Perigee (500 KM) allows orientation of the spacecraft w/on-board electromagnets
    - – Long duration availability (8+ hours) as satellite approaches apogee
    - – Large footprint (up to 40% of earth’s surface)/
      - Significant DX capability (equivalent to 20 Meter HF) using small antennas
    - – Predictable long range communications
  - » Large solar power systems
  - » High power transmitters/directional antennas
  - » Complex telemetry & control systems
    - – Including commanding of propulsion (Kick motor)
  - » Multi-Transponder operation
    - – VHF/UHF
    - – Microwave frequencies

Phase 3-A & Phase 3-B

- Phase 3-A launched on 23 MAY 80
  - AMSAT raised ≈ $250K plus funds from AMSAT-DL
  - Placed on second launch of prototype ARIANE-3 vehicle @ Kourou
  - First stage fails in flight/Phase 3-A is placed in “subterranean orbit”
  - Major loss for AMSAT and the amateur radio community
- Phase 3-B is Similar to Phase 3-A
  - Phase 3-A: 93 KG Launch Weight (1/2 of weight is the solid kick motor)
  - Phase 3-B: 130 KG (bi-propellant liquid 400 newton thrust motor)
  - 50 Watt Mode B Transponder/152 KHz bandwidth
  - Beacons on 145.810/145.987 and 436.02/436.04 MHz
  - New: Mode-L (1269.45 MHz uplink/70 CM Downlink (800 KHz bandwidth)

Phase 3-B in Kourou



Phase 3-B International Effort

- Satellite features international cooperation
  - A West German-lead project (Karl Meinzer, DJ4ZC & Jan King, W3GEY team leaders)
  - Subsystems from US, Canada, West Germany, Hungary, Japan
  - Built at GSFC Visitor Center by AMSAT w/paid staff and volunteers
  - First AMSAT project successfully launched outside the US
- Phase 3-B launched from Kourou on 16 JUN 83
  - Successfully placed in orbit on Ariane L6 Mission
  - Once deployed, it was bumped by the launch vehicle
    - Damaged antennas and caused spinning
  - Initial burn lasted longer than planned/placed in a 50% higher orbit
  - Helium tank leak prevents second burn of kick motor
  - Designated AO-10
  - Suffers radiation effects/loses IHU in 1986 and eventually batteries

Phase 3-C

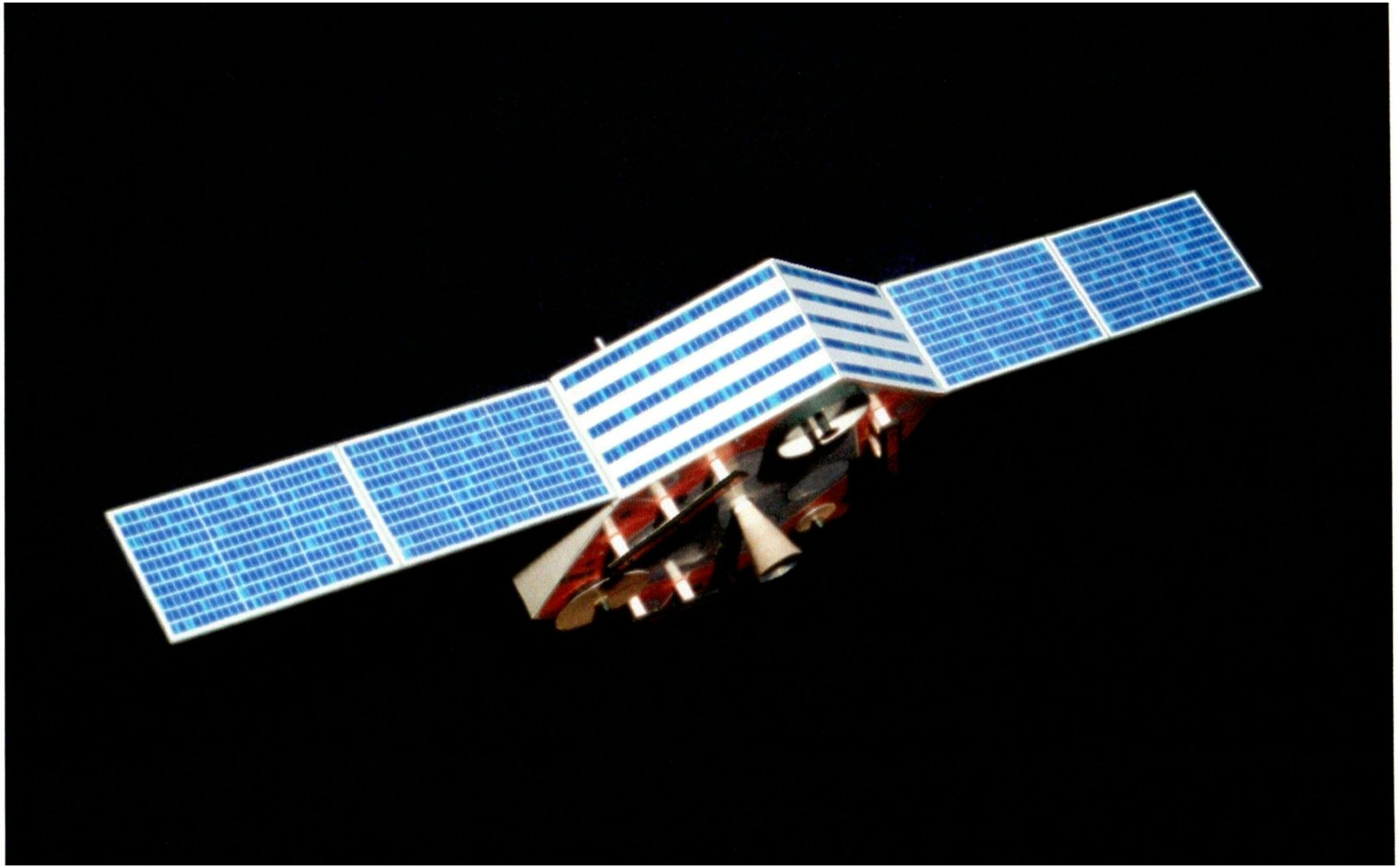
Phase 3-C

- Utilizes same spaceframe as Phase 3-A/3-B
- Built in Boulder, CO due to relocation of W3GEY
  - » AMSAT-NA invests about $220,000.00
- Harris Semiconductor donation of radiation hardened ICs
- Systems added/modified:
  - » Mode S Transponder (435 MHz uplink/2.4 GHz downlink)
  - » Digital repeater: RUDAK (435 MHz uplink/146 MHz downlink)
    - – Regenerativer Umsetzer fur Digital Amateur-Kommonikation (AX.25)
  - » Modified Mode L Transponder adds 50 KHz wide 2-meter secondary input channel to the 250 KHz downlink (Mode JL)
- Shipped to Marlburg, West Germany for balancing, vibration testing
  - » Shipped to Kourou in late 1987

Phase 3-C becomes AO-13
Perhaps the most popular amateur satellite ever

- Launched 15 JUN 88 from Kourou
- Two successful burns of the kick motor
  - » Demonstrated successful reorientation of spacecraft
  - » Demonstrated successful spin-ups/spin-downs
- Resulting orbital changes
  - » 36,265 km apogee/higher than expected perigee
- Systems Performance
  - » Mode B worked well/Less spin modulation/70 CM fails in June 1993
  - » Mode L initially used 20% of time (>200 stations used it in first three months)
  - » Mode S initial problems resolved
  - » RUDAK failed due to low temperature sensitivity of a device
- De-Orbited 5 DEC 96 due to influence of sun/moon/Earth

Phase 3-D



Phase 3-D
Amateur Radio's "Super-satellite"

- Initial AMSAT-DL proposal made in 1985
- Scaled-up version of Phase 3-C
  - 5x the size and weight (400 kg)
  - Four deployable solar panels + two side mounted on the spaceframe
    - 48 ft^2 surface area using solar cells with 14.3% efficiency=620 watts
  - 3-axis stabilization using three magnetically suspended reaction wheels
  - Use amateur bands from 21 MHz to 24 GHz
- In May 1990, International Team is Formed
  - AMSAT-DL received assurance of partial funding from the German Government
  - AMSAT-DL secures launch on second test flight of Ariane 5 (502)
  - Becomes AMSAT-NA's most expensive program both in terms of $$$ and man-hours/more than all other programs combined

Phase 3-D Size Comparison

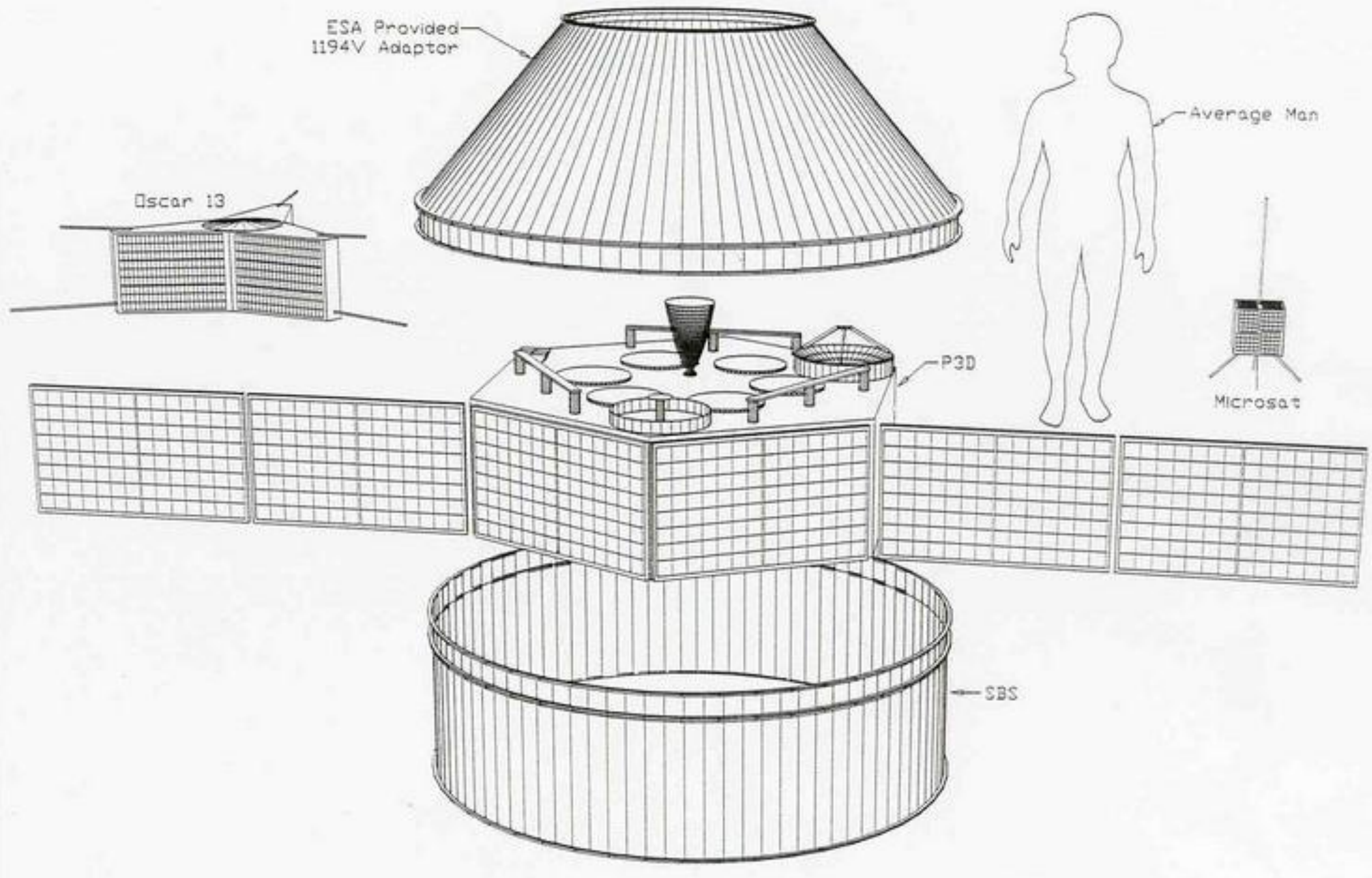


Fig.3. Phase 3D Spacecraft and SBS

Phase 3-D Development
"A Satellite for all Amateurs"

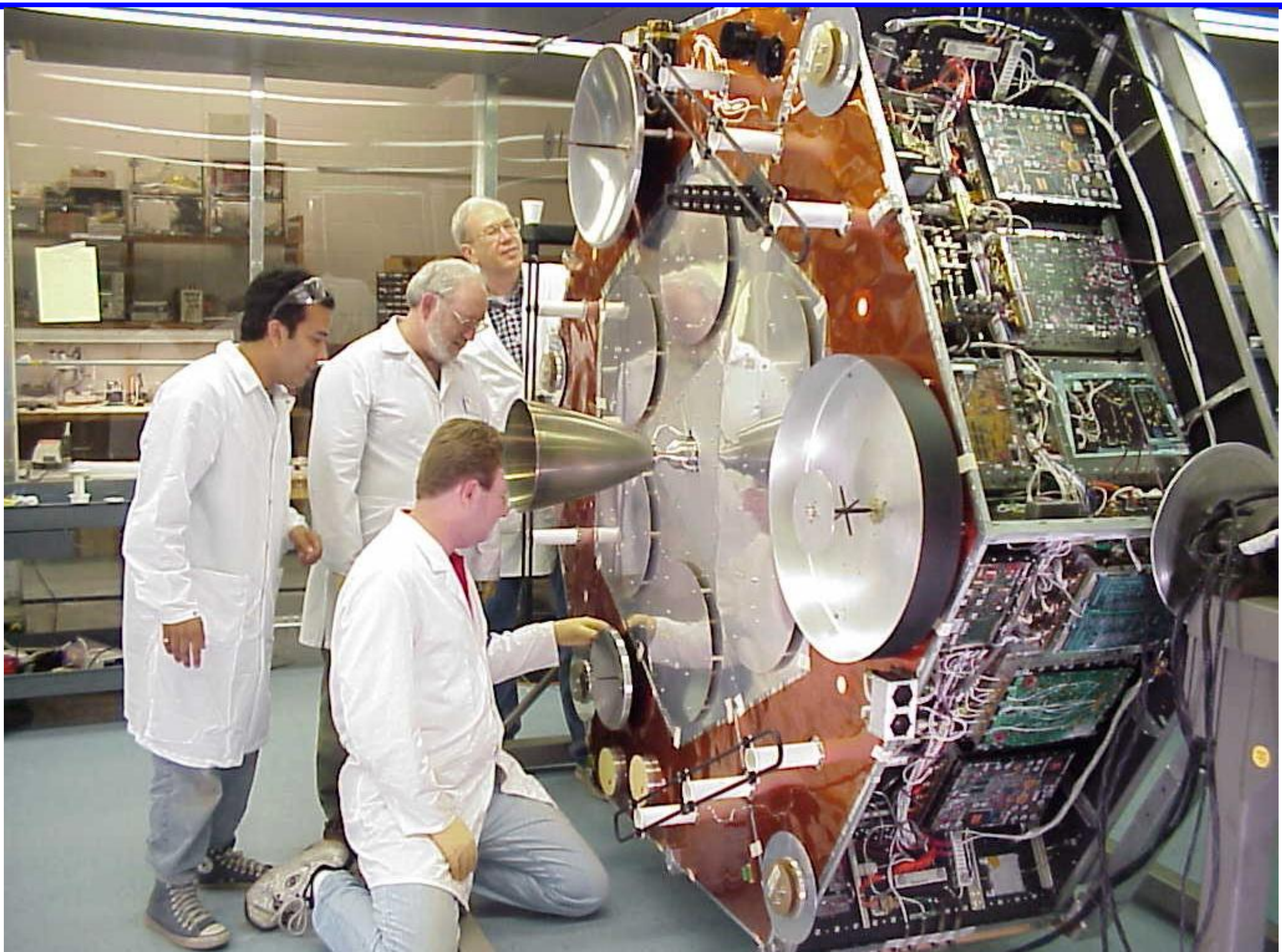
- Components from 13 Countries

» Russia	Propellant Tanks
» Japan	SCOPE Cameras
» United Kingdom	2M Transmitter/Auxiliary Batteries
» Finland	10 GHz Transmitter
» Czech Republic	Receivers
» USA	Space Frame/GPS/RUDAK/Integration
» Germany	70 CM Transmitter/LEILA/Project Management (LEIstungsLimit Anzeige)-"Alligator Eater" IF Strip
» Canada	Radiation Testing
» Belgium	146/435/2400 MHz Receivers
» Hungary	Battery Charger Regulators
» Slovenia	21 MJz/5.7 GHZ Receivers
» France	1.2 GHz Antenna/Test Support for SBS
» New Zealand	Machine Parts

Phase 3-D Development
"A Satellite for all Amateurs"

- Phase 3-D Integration Facility
  - » Leased space secured in 1993 at the Orlando International Airport Foreign Trade Zone
  - » Clean room constructed
  - » Satellite integration starts in 1994
  - » Weber State, UT builds the spaceframe/shipped to Orlando
  - » Lou McFadin, W5DID becomes lab manager in 1996

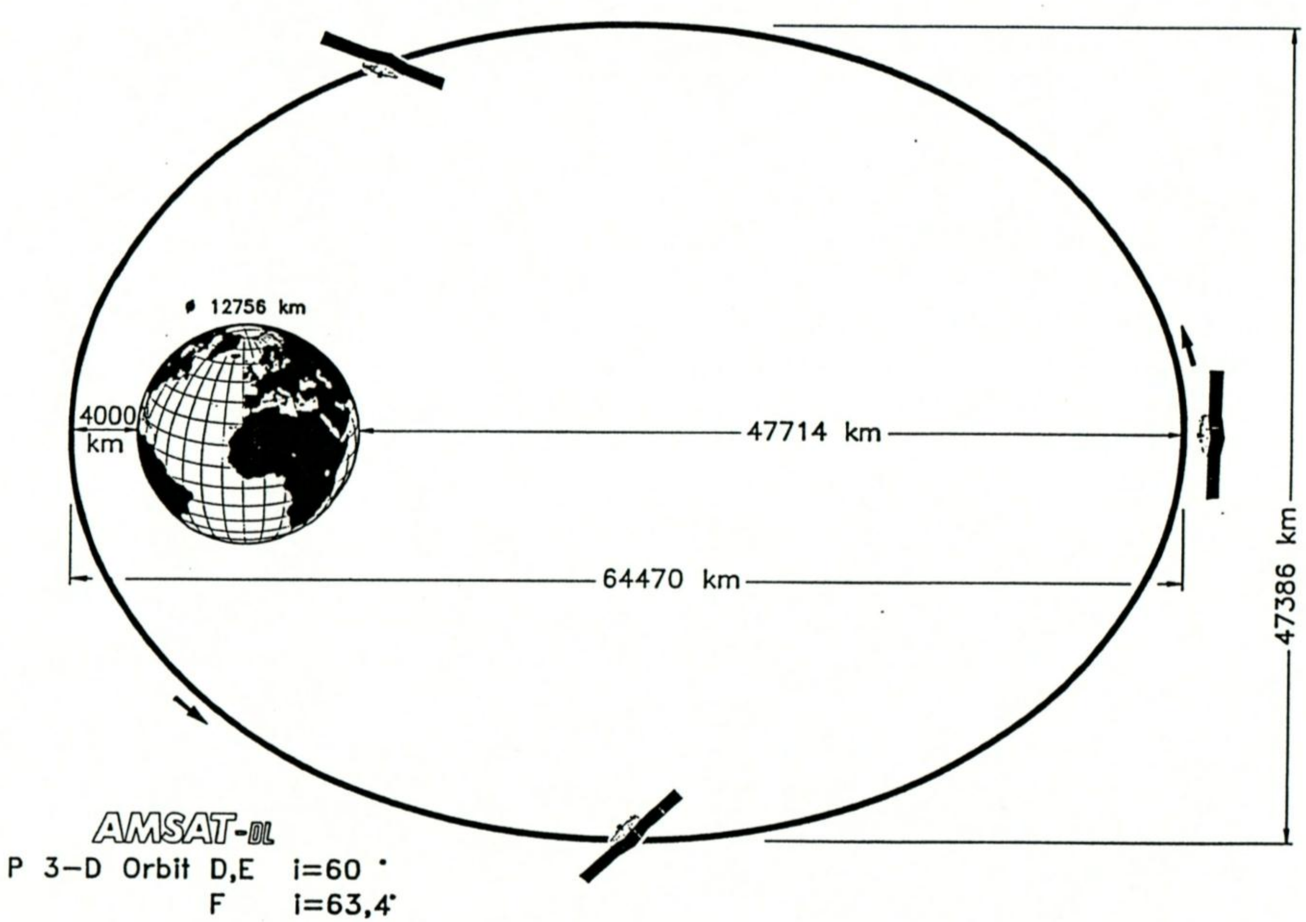
Phase 3-D in the Orlando Clean Room



Phase 3-D Design Considerations: Ease of Use and Greater Flexibility

- Transmitters will have significantly higher output powers
- Antennas will have higher gain than on AO-10 and AO-13
- Antennas will always point toward Earth
  - » Requires the satellite to “know” its orientation with respect to space as well as to Earth using sun and Earth sensors
  - » Re-orient the spacecraft using 3 magnetically suspended, orthogonally mounted reaction wheels coupled with three Nutation Dampers and two rings of electromagnets, the field of which can be stepped through six directions when operated in the Earth’s magnetic field
  - » Adjust the pointing angle continuously to cause the antennas on the top of the spacecraft to point towards the center of the Earth
  - » Thermal control system needed as spacecraft will not spin
    - – Use four passive heat pipes filled with anhydrous ammonia mounted inside
    - – Indirect re-radiation of the heat from internal equipment mounting panels to side panels that are deliberately allowed to become cold

Phase 3-D Orbit



Orbit: High Molynia 29,000 Miles x 2400 Miles/Orbital Period 16 Hours

RF Capabilities

- Major Improvement in RF Capabilities using a 10.7 MHz IF Matrix with LEILA used on V-Band thru L-Band uplinks
  - Multiple options for combining of uplinks and downlinks

Receivers (Earth > Satellite)

- 21.210 - 21.250 MHz
- 24.920 - 24.960 MHz
- 145.800-145.990 MHz
- 435.300-435.800 MHz
- 1268.075-1268.575 MHz
- 1269.000-1269.250 MHz
- 2400.100-2446.700 MHz
- 2446.200-2446.700 MHz
- 5668.300-5668.800 MHz

Transmitters (Satellite > Earth)

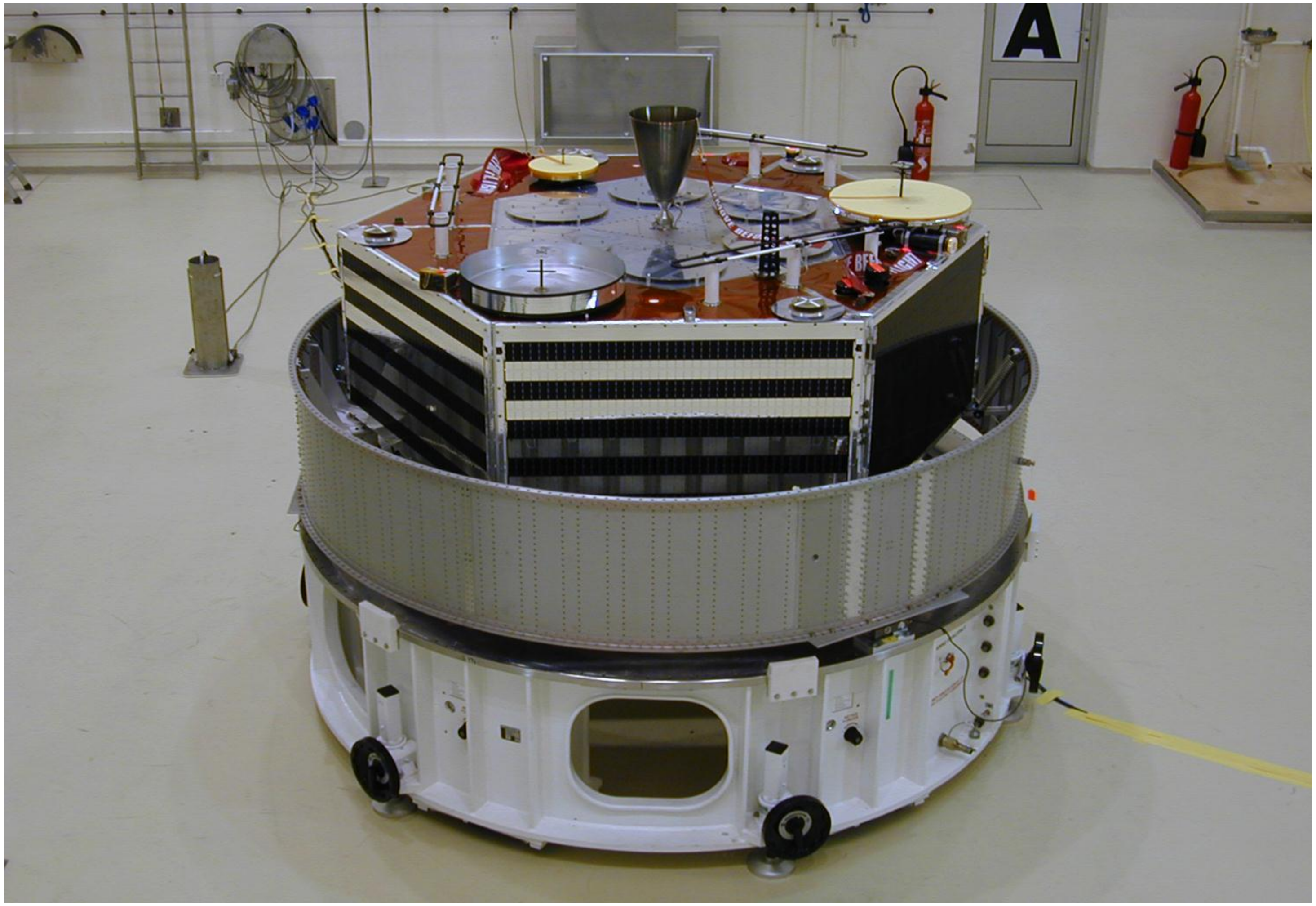
- 145.805-145.990 MHz (≈250W PEP)
- 435.475-436.200 MHz (≈250W PEP)
- 2400.225-2400.950 MHz (≈250W PEP)
- 10.451025-10.451750 GHz (≈ 40W PEP)
- 24.048025-24.048750 GHz

Microwave Frequencies: “Use it or lose it”

A Challenging Development Program

- AMSAT-NA raised $2 million (with help from ARRL)
- Integration facility built in Orlando in 1994
- Originally to fly on 2nd Ariane 5 (502) Test Launch in 1997
- First Ariane V flight demonstrated higher than expected forces exerted on payloads
- Phase 3-D required an upgrading of the spacecraft structure to meet new G-force requirements-delays completion
  - Development time also influenced by additional capabilities added to the spacecraft ("mission creep")
    - Example: The addition of a Laser Communications Experiment
- Extensive Testing
  - Thermal vacuum testing @ Orbital Sciences, Gaithersburg, MD
  - Vibration Testing @ GSFC, Greenbelt, MD

Phase 3-D mounted in the SBS



Fueling P3-D

Phase 3-D

- Satellite delivered to Paris and then Kourou in February 2000
- Weight @ Launch including fuel: 1,300 lbs
- Width: 7.5 ft. Height 3.0 ft.
- Solar Panel Wingspan: >20 ft./Cells produce 620 Watts
- AMSAT also built the Specific Bearing Structure (SBS)
  - Houses P-3D and supports the primary payload (commercial satellite)
  - Offsets a portion of the launch costs
- Launched on 26 NOV 00 on the 507 Ariane V launch
- Initially placed in GTO and designated AO-40
  - Temporary, “self-cleaning” orbit
  - 596 km perigee, 39413 km apogee, 6.5° inclination
- Desired orbit ≈63° inclination, 48,000 apogee km, 4,000 km perigee

Kick Motor Burn

- Same MBB engine used on AO-10 and AO-13 (400 N/95 lb thrust)
- Bi-propellant: hydrazine (NMH) & nitrogen tetraxoxide (N_2O_4)
- System is pressurized with helium
- First attempt failed-sticking helium value suspected
- Determined that fuel tanks could be properly pressurized by helium at a reduced helium flow rate over a five minute period, sufficient for 3-minute burn
- Motor fires and signal is given to shut down at the 3-minute mark. Signal received by satellite and acknowledged but burn continues for three more minutes, causing a higher apogee

13 DEC 2000

- While cycling the helium valve on 13 DEC 00, a sudden loss of all signals from AO-40 occurred.
- Believed that during this exercise the system became pressurized and a leakage of fuel was the end result
- Suspected damage to spacecraft structure as well as damage due to corrosive fuel entering the spacecraft interior
- With the assistance of NORAD and Ken Hernandez, N2WWD the satellite was found and radar cross section analysis suggests the satellite is in one piece
- News announced on 20 DEC 00

Disaster Recovery

- Communications re-established on Christmas Day 2000 with second attempt to activate the S-band transmitter by an Australian ground station
- Steps taken to regain control of spacecraft, including damage assessment, establishing proper spin and attitude control to allow proper power generation and antenna pointing
- Root cause: Closed pressure relief opening of a valve on the 400-N motor. As a result, the remaining fuel stayed in the cooling chamber of the motor, and it is assumed, exited forcibly by a small explosion from a resulting leak.

Disaster Impact

- Result:
  - Loss of V-band downlink
  - Loss of 70 cm downlink
  - Loss of omni antennas
- What was working
  - S-2 downlink
  - 2 L-band and 70 cm uplinks
  - 1 W 24 GHz downlink
  - IHU/Power Systems/Magnetic Attitude Control
- Apogee ended up being 57,000 km vice 36,000 km with low inclination

AO-40

- General amateur use started on 5 May 2001
- Satellite operates until 27 JAN 04 when main battery failure occurs
- Lessons Learned:
  - » Adding additional features has an exponential impact on spacecraft complexity
  - » "Soft Failure" does provide a means to keep the mission alive
    - – Kick Motor vs. ArcJet (used "cold" to make orbital adjustments)
    - – Multiple uplinks/downlinks provides backup
  - » Full and Complete Documentation/Procedures manuals are critical
  - » Large projects can exceed the capability of a volunteer team
    - – Missed deadlines/commitments
    - – Organizational & Team burnout
    - – All eggs in one basket
    - – Cultural differences can impact team performance/results

Phase 3-D/AO-40's Long Term Impact

- AMSAT's most expensive and time consuming project
- While AMSAT-DL was the project leader, AMSAT-NA members viewed AMSAT-NA leadership as responsible
  - » Impacts relationships
  - » Different expectations on keeping donors/members informed
- Loss of confidence in AMSAT's Project Management
  - » Need to revamp how projects are managed/documented
- Lack of HEO satellites leaves members frustrated
  - » Reduction in AMSAT membership
- AO-40 issues forces AMSAT to start on new projects
- AMSAT-DL decides on P3-E ("Express") HEO project->Phase 5
- AMSAT-NA decides on "Eagle" HEO project & Project Echo
- Both HEO projects fail to fly due to unaffordable launch costs

In Summary…

- Amateur Spacecraft development matures over 40 years
  - » Size/Weight/ Complexity
  - » RF options (bands/modes/power output)
  - » Power Sources
  - » Multiple Modes/capabilities
  - » International cooperation to spread workload/fund raising and launch options
  - » Most of the development work is in satellite support systems, not RF!
  - » Cost of Development/Organizational limitations reached
- Amateur Radio benefits from special relationships
  - » Low cost or “free” launches
  - » Agencies and Aerospace Companies willing to take risks
  - » A number of “firsts” are accomplished

Building Satellites 'on the Cheap'

- AMSAT Depends primarily on volunteers
- Only one full time employee (office manager)
- KISS Approach to satellite design/"home brew"
- Parts donation from corporate sources
- Systems built in garages/basements
- Develop university relationship (e.g. Weber State)

Launch Opportunity Strategy through the 1990s

- Secondary Payload/Go when the primary is ready
- Develop Innovative Designs to make available “unusable” space on launch vehicles
  - Example: 1990 launch of Microsats on Ariane IV
- AMSAT will trade knowledge, Skill and Manufacturing capacity for a reduction/waiver of launch costs
  - Example: Specific Bearing Structure for P3-D on Ariane V
- Take advantage of test launches w/inherent uncertainites
  - Example: Ariane III (Phase 3-A) and Ariane V (Ariane 502)
- Launch Insurance NOT normally purchased
- Cover risk by duplicating components, such as spaceframes

Microsats

- AMSAT-NA develops a new design: "Microsat"
  - » Genesis in a hotel room during 1987 AMSAT Space Symposium
  - » 9" x 9" x 9" Cube/ 20 lbs.
  - » 5 trays per satellite ("This Space for Rent" potential) "frame stack"
  - » Store and Forward capability/Packet radio "PACSAT"
  - » $50,000.00 allocated by AMSAT BoD to be completed in two years
- Interest in the Design Spreads: 4 Satellites Total
  - » Junior DeCastro, PY2BJO proposes "Dove"-voice messages
  - » Weber State: Earth Viewing Camera Satellite
  - » AMSAT-LU asks to be included for PACSAT support in South America
- Common Structure/Basic Utilities Incorporated
  - » Integration takes place at a leased office space in Boulder, CO
  - » Modules developed in batches of four & shipped to Boulder
  - » Satellites completed in Fall 1989

Microsat Design Philosophy

- Eliminate wiring harnesses whenever possible
- Create a mechanical structure that could be completely assembled/disassembled < 30 minutes
- Create a solar array design that minimizes the possibility of damage yet can be rapidly installed on the spacecraft body
- Use load-side power management to dynamically adjust the transmitter's power output to maintain an orbit-average balance
- Create a microsat design that can serve users employing omni-directional antennas
- Develop a suitable computer w/serial data comms over multiple channels, store at least 4MB of data, uses <1 Watt
- Aim for spacecraft mass of 10 kg

Microsats

- University of Surrey secures launches for the Microsats and two UoSats (UoSat-OSCAR 14, UoSat-OSCAR 15)
- Housed on the "Ariane Structure for Auxiliary Payloads" (ASAP)
- Launched on 22 JAN 90 on ARIANE 4
  - PACSAT (AO-16): 2M/70 CM + S-Band downlink on discrete frequencies
  - DOVE (DO-17): 2M + S-Band Downlink only (recorded messages)
  - WeberSat (WO-18): 2M/70CM Downlink 4 W (images)
    - Weberware ground station software to view images
    - L-Band ATV uplink
  - LUSat (LO-19): 2M/70 CM 4W + .8 Watt output on discrete frequencies
- 805 km circular Sun-synchronous orbit

All 4 Microsats and 2nd Gen UoSats on First Ariane-4 ASAP Ring

Microsat Design Impacts

- Microsat Design Generates Significant Interest
  - » IO-26 built by AMSAT-Italy included 9600 baud capability
    - – Limited amateur radio use
  - » AO-27 is a payload built by AMRAD as part of Interferometics EYESAT commercial satellite
    - – FM repeater “EasySat”
    - – Launched 26 SEP 93 (same launch as IO-26)
  - » SpaceQuest builds microsats for government & industry
  - » MO-30 built by students/staff of Autonomous University of Mexico
    - – Identical to UNAMSAT-1 destroyed by launch vehicle failure on 28 MAR 95
    - – Included a 70 W peak power radar transmitter @ 40.997 MHz to monitor micrometeorite impacts in the upper atmosphere
    - – Receiver failed shortly after placement in orbit on 5 SEP 96
  - » AO-51 built by SpaceQuest under AMSAT contract
    - – Launched 28 JUN 04 from Baikonour Cosmodrome (Dnepr launch)
    - – 4x capability of original microsat design

Project Echo Flies to Moscow

Microsat Design Impacts

- Design demonstrates utility for small satellites
  - » Impacts launch opportunities and launch costs
  - » As electronics improve, more can be done with same footprint
  - » Standardized design/footprint reduces costs
    - – First AMSAT satellites that could be built “cookie cutter”
  - » Initiates greater interest in “smallsats”
- AMSAT becomes “victim of our own success”
  - » University, Industry and Government interested in smallsats
  - » Closes the door on AMSAT taking advantage of “unused space” on launches
  - » Forces real $$$ to be spent on launches

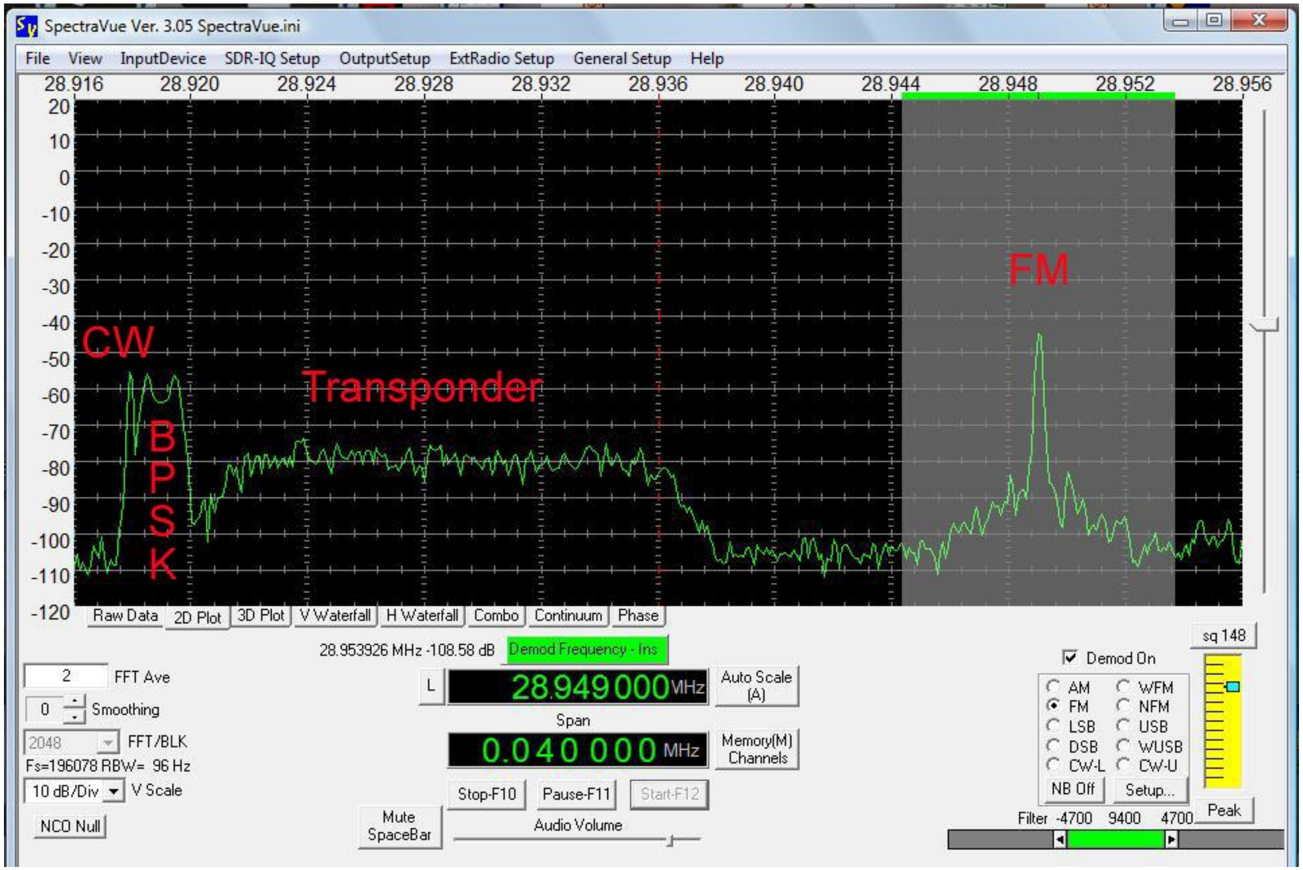
Why did AMSAT Build ARISSat-1?

- Educational Outreach
  - » One of AMSAT's key mission statements ("Promote space education")
  - » Provide a vehicle for student experiments
  - » Provide telemetry for student analysis
  - » Provide 'student messages' in various languages for students to receive
  - » An opportunity for students to learn about satellites and orbital tracking in the classroom and then listen for ARISSat-1 using basic equipment
  - » Video (SSTV)
- In exchange for educational outreach:
  - » 'Free Launch' of amateur radio capability
  - » <u>A platform for technology development (SDX)</u>
  - » Potential for recurring opportunities

Satellite Purpose: Technology Demonstrator

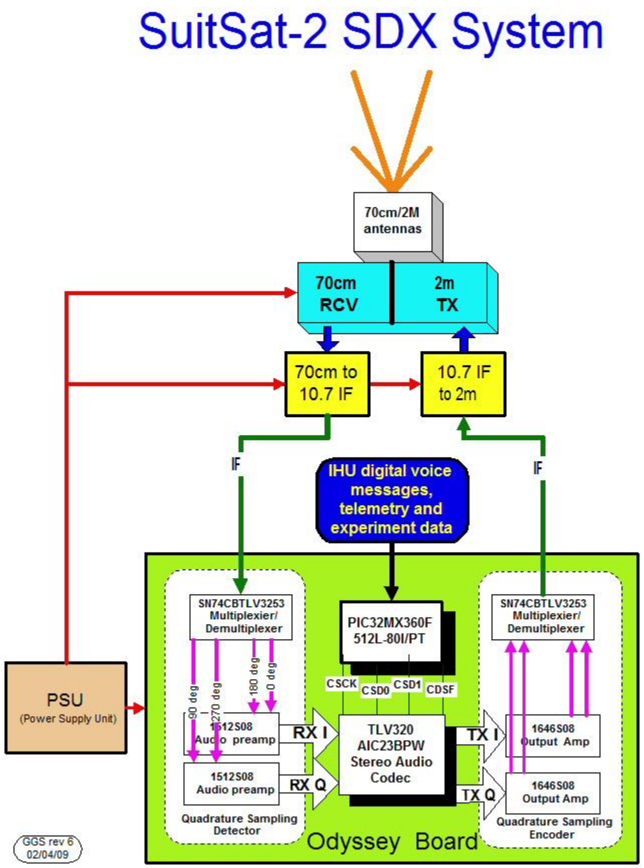
- Communications Technology Platform: Testbed for SDX
  - 4 different carrier frequencies transmitted simultaneously
  - Different transmission modes (CW, FM, Digital Data, Transponder)
  - First amateur radio satellite to have both its receiver and transmitter (“transponder”) operate as software defined units
- Power Management Technology Platform: MPPT
  - Maximum Power Point Trackers are dc-to-dc power converters
  - Designed to maximize power provided by solar panels (19 watts of power from each panel) independently of ground control’
  - Each solar panel had a MPPT attached to it
- Use of commercial off-the-shelf video cameras provided SSTV imagery

The ARISSat-1 SDX Band Plan



CW 25 mW BPSK 100 mW Transponder 125 mW FM/SSTV 250 mW

Software Defined Transponder SDX

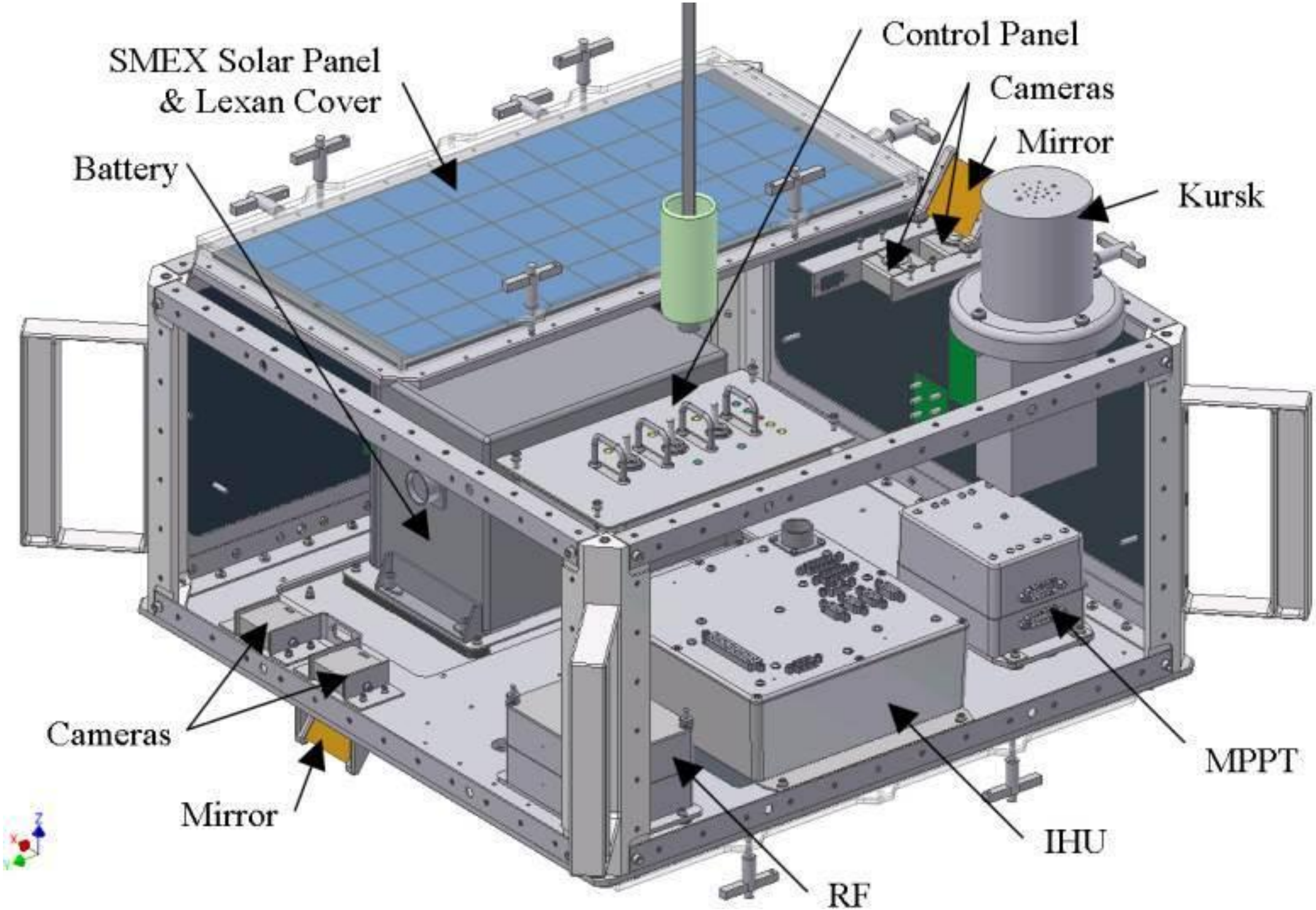


Not a “Bent Pipe” Transponder

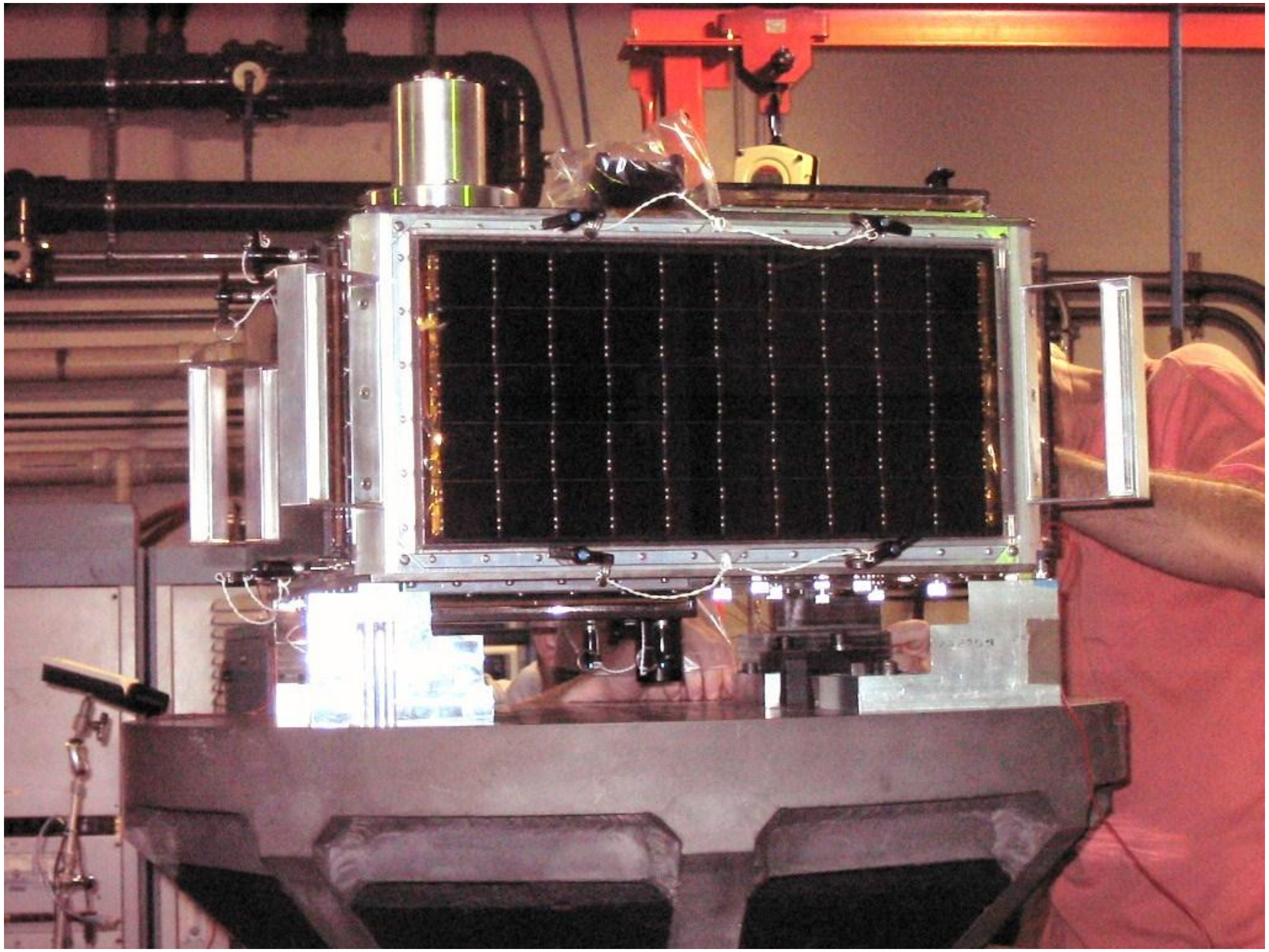
Satellite Purpose: Technology Demonstrator

- Demonstration of a new Data Communications Protocol
  - » BPSK-1000 protocol developed by Phil Karn, KA9Q
  - » Designed to allow a significant amount of data (satellite telemetry and student experiment data) despite signal nulls and fading
  - » Significant performance improvement over earlier protocols
- Amateur Radio Transponder
  - » 70CM uplink/Two meter downlink w/16 KHz wide bandwidth
  - » Four independent sets of conversations at one time
- CW (“Morse Code”) Reception
  - » Transmission of amateur radio callsigns of key individuals who made contributions to amateur radio in space
  - » Focus on “trying CW”
  - » Served as “relative tuning indicator” as well as to indicate which telemetry downlink was in operation (BPSK-1000 vs. BPSK-400)

ARISSat-1 Hardware



Vibration Testing



ARISSat-1

- Deployed from ISS on 3 AUG 11
- De-orbited on 4 JAN 12
- Prototype satellite for supporting student experiments
- Prototype for Ground station telemetry and payload data collection
- SDX proven to be very successful. Expect future satellites (Fox-2) to use this technology
- Education Outreach Lessons Learned
- Critical that AMSAT maintain commitments to Partners
- First AMSAT-NA satellite placed in service since AO-51

CubeSats

- Further miniaturization of spacecraft
- Initial design created by CalPoly in 2003, including a “Pod” to house/deploy the sats on a launch vehicle
- 10 cm x 10 cm x 10 cm (4” x 4” x 4”)
  - 1 KG mass (about 2.2. lbs.)
- Designed for universities
  - Offer spacecraft design/construction/project management courses for students
  - Relatively low cost to fly (low mass/size)
- Offers potential for university scientific payloads
- Standardized footprint/small size reduces launch costs
- Can be expanded in multiple units (e.g. 2U, 3U, 6U, etc.)

AMSAT in a New Environment

- Launch costs continue to Rise/"No Free Launch"
  - Supply & Demand + ability of firms with "real $$$" drive launch fees
  - $10 million for a Phase-3 HEO project
  - $10 million for a payload placed on a Geosynchronous Satellite
  - $1 million to deploy an ARISSat-x from the ISS
  - $500K to launch a Microsat into LEO
  - $300K to launch a 3U CubeSat to LEO
  - $100,000 to launch a 1U cubesat into LEO

AMSAT in a New Environment

- ITAR prevents AMSAT from collaborating with International Partners
  - » "Deemed Exports" refers to any technical exchange with foreign nationals
    - – Can occur anywhere (e.g. in the US)
    - – E-mail exchanges, telcons, face-to-face meetings, etc.
  - » Voluntary self-disclosure in February 2009 on P3-E involvement to DDTC
  - » DDTC Denied ITAR exemption for P3-E Subsystem Development in late 2009
    - – CAN-Bus
    - – Software Defined Transponder (SDX)
    - – Internal Housekeeping Unit (IHU)
    - – Mechanical/Thermal Design Analysis

AMSAT in a New Environment

- Any Future Satellite Program would be “AMSAT-NA” Only
  - » Satellite building is the essence of AMSAT
  - » Membership support for AMSAT predicated on projects
  - » Need to rebound from HEO Satellite disappointments
  - » Must be a self-contained program due to ITAR that essentially prohibits technical collaboration with foreign nationals
  - » Must be affordable based upon expected ability to raise funds with the membership or from the amateur radio community
  - » Must be a project that is manageable with realistic deadlines

AMSAT's Strategic Direction

- In 2009, the AMSAT BoD realized:
  - » Satellite builders were retiring/AMSAT Engineering needed to be reseeded
  - » Launch costs for even a Microsat were beyond AMSAT's current means
  - » AO-51 was suffering degrading performance and needed to be replaced
  - » Technology improvements would allow a cubesat to work as well as a FM repeater satellite as AO-51 from a ground user's perspective
- Decision made that a CubeSat would be AMSAT's next project
  - » Manageable project filling a critical need (replace AO-51) where new project management processes would be instituted
  - » A basis for rebuilding the AMSAT Engineering Team
  - » NASA ELaNa program potentially offered potential grant to fly a cubesat
  - » A dependable CubeSat RF design to support scientific experiments would be of interest to universities & provide launch opportunities
  - » "An OSCAR in every CubeSat"

Partnerships Opens the Door for Launches

- Partner with Universities to provide the justification for someone else to pay for a Launch
  - ELaNa based on scientific research that matches NASA goals
  - AMSAT raises funds to pay for spacecraft development
- Education Outreach in support of STEM can provide outside support
  - ARISSat-1 had an educational component
  - Student projects on AMSAT Spacecraft (such as Fox-1A)
    - Penn State-Erie MEMS (Micro-Electro-Mechanical Systems) Attitude Experiment
  - Challenge is to build an educational package that is attractive to schools/teacher
    - FUNCube-1 has a science experiment for Middle School
- Downside: Launch opportunities may be 3-5 years after program acceptance

The Future is Relatively Bright for Keeping Amateur Radio in Space

- Fox-1A will be completed this year/flown in 2015
- Successful flight will improve chances for having more cubesats supporting amateur radio
- Engineering experience rebuilds AMSAT Engineering
- Lessons learned will be applied to Fox-2
  - » Software Defined Transponder was first flown on ARISSat-1
  - » Larger spacecraft offers more power generation/antenna real estate
- Established University relationships set the tone for networking for payloads that justifies future launch support
  - » Virginia Tech
  - » Vanderbilt
- Never say Never Concerning Future HEO projects
  - » Is there a scientific payload that will justify a HEO mission?