An Overview of Phase 3D/AO-40

Pre and Post Launch Activities
• AMSAT Area Coordinators

  – Tim Cunningham, N8DEU
    • n8deu@amsat.org
  – Dieter Schliemann, KX4Y
    • kx4y@amsat.org
AMSAT OSCAR-40
An International Satellite For All Radio Amateurs

What is AO-40?

• Largest, most complex and expensive Amateur Radio satellite

• Built by an international team of Amateur Radio volunteers

• Currently undergoing commission for Amateur Radio use.
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What is AO-40?

• Contains receivers and transmitters for all Amateur Satellite bands plus 360,000 GHz infrared laser
• Built and launched via financial contributions
• Available for use by all radio amateurs
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History

• ESA invitation to ride on Ariane 5
• Phase 3D Team formed in May 1990
• Assembled in Orlando, Florida
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History

• Built around Ariane 5 excess launch capacity
• Specific Bearing Structure (SBS) designed by AMSAT
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Main Features

- Amateur Satellite Bands 21MHz to 24 GHz (Analog & Digital)
- High Gain Antennas
- Sensitive Receivers
- 600W Power Budget
- High Inclination Elliptical Orbit
Facts and Figures

- Weight: 632 kg
- Diameter: 7.5 feet
- Wingspan: 20 feet
- Antenna Gain: 4 to 19 dBiC
- Stabilization: Three-axis with antennas always pointing towards Earth

Solar Panel testing
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An International Satellite!

Belgium
Canada
Czech Republic
Finland
France
Germany
Hungary
Japan
New Zealand
Russia
Slovenia
United Kingdom
United States
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Uplink Frequencies

<table>
<thead>
<tr>
<th>Band</th>
<th>Designator</th>
<th>Digital</th>
<th>Analog</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>V</td>
<td>145.800 - 145.840 MHz</td>
<td>145.840 - 145.990 MHz</td>
</tr>
<tr>
<td>70cm</td>
<td>U</td>
<td>435.300 - 435.550 MHz</td>
<td>435.550 - 435.800 MHz</td>
</tr>
<tr>
<td>23cm (1)</td>
<td>L1</td>
<td>1269.000 - 1269.250 MHz</td>
<td>1269.250 - 1269.500 MHz</td>
</tr>
<tr>
<td>23cm (2)</td>
<td>L2</td>
<td>1268.075 - 1268.325 MHz</td>
<td>1268.325 - 1268.575 MHz</td>
</tr>
<tr>
<td>13cm (1)</td>
<td>S1</td>
<td>2400.100 - 2400.350 MHz</td>
<td>2400.350 - 2400.600 MHz</td>
</tr>
<tr>
<td>13cm (2)</td>
<td>S2</td>
<td>2446.200 - 2446.450 MHz</td>
<td>2446.450 - 2446.700 MHz</td>
</tr>
<tr>
<td>6cm</td>
<td>C</td>
<td>5668.300 - 5668.550 MHz</td>
<td>5668.550 - 5668.800 MHz</td>
</tr>
</tbody>
</table>
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## Downlink Frequencies

<table>
<thead>
<tr>
<th>Band</th>
<th>Designator</th>
<th>Digital</th>
<th>Analog</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>V</td>
<td>145.955 - 145.990 MHz</td>
<td>145.805 - 145.955 MHz</td>
</tr>
<tr>
<td>70cm</td>
<td>U</td>
<td>435.900 - 436.200 MHz</td>
<td>435.475 - 435.725 MHz</td>
</tr>
<tr>
<td>13cm (1)</td>
<td>S1</td>
<td>2400.650 - 2400.950 MHz</td>
<td>2400.225 - 2400.475 MHz</td>
</tr>
<tr>
<td>13cm (2)</td>
<td>S2</td>
<td>2401.650 - 2401.950 MHz</td>
<td>2401.225 - 2401.475 MHz</td>
</tr>
<tr>
<td>3cm</td>
<td>X</td>
<td>10451.450 - 10451.750 MHz</td>
<td>10451.025 - 10451.275 MHz</td>
</tr>
<tr>
<td>1.5 cm</td>
<td>K</td>
<td>24048.450 - 24048.750 MHz</td>
<td>24048.025 - 24048.275 MHz</td>
</tr>
</tbody>
</table>
# AMSAT OSCAR-40

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## Telemetry Beacons

<table>
<thead>
<tr>
<th>Band</th>
<th>Designator</th>
<th>General</th>
<th>Middle</th>
<th>Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>V</td>
<td>none</td>
<td>145.880 MHz</td>
<td>none</td>
</tr>
<tr>
<td>70cm</td>
<td>U</td>
<td>435.450 MHz</td>
<td>435.600 MHz</td>
<td>435.850 MHz</td>
</tr>
<tr>
<td>13cm (1)</td>
<td>S1</td>
<td>2400.200 MHz</td>
<td>2400.350 MHz</td>
<td>2400.600 MHz</td>
</tr>
<tr>
<td>13cm (2)</td>
<td>S2</td>
<td>2401.200 MHz</td>
<td>2401.350 MHz</td>
<td>2401.600 MHz</td>
</tr>
<tr>
<td>3cm</td>
<td>X</td>
<td>10451.000 MHz</td>
<td>10451.150 MHz</td>
<td>10451.400 MHz</td>
</tr>
<tr>
<td>1.5cm</td>
<td>K</td>
<td>24048.000 MHz</td>
<td>24048.150 MHz</td>
<td>24048.400 MHz</td>
</tr>
</tbody>
</table>
## Suggested Ground Station Requirements

<table>
<thead>
<tr>
<th>Uplink</th>
<th>EIRPc</th>
<th>TX Power</th>
<th>Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>2M</td>
<td>20dBWi</td>
<td>1000W</td>
<td>7 Element X-Yagi</td>
</tr>
<tr>
<td></td>
<td>5000W</td>
<td>7 Element X-Yagi</td>
<td>Crossed dipoles over reflector</td>
</tr>
<tr>
<td>70cm</td>
<td>21dBWi</td>
<td>10W</td>
<td>10 Element X-Yagi</td>
</tr>
<tr>
<td></td>
<td>40W</td>
<td>10 Element X-Yagi</td>
<td>Crossed dipoles over reflector</td>
</tr>
<tr>
<td>1270 MHz</td>
<td>23dBWi</td>
<td>10W</td>
<td>12 turn Helix</td>
</tr>
<tr>
<td>2400 MHz</td>
<td>27dBWi</td>
<td>5 W</td>
<td>60cm Parabolic Dish</td>
</tr>
<tr>
<td>5670 MHz</td>
<td>34dBWi</td>
<td>10W</td>
<td>60cm Parabolic Dish</td>
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</tbody>
</table>
# Suggested Ground Station Requirements

<table>
<thead>
<tr>
<th>Downlink</th>
<th>S/N</th>
<th>Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>2M</td>
<td>16dB</td>
<td>7 Element X-Yagi</td>
</tr>
<tr>
<td>70cm</td>
<td>24dB</td>
<td>10 Element X-Yagi</td>
</tr>
<tr>
<td>2400 MHz</td>
<td>26dB</td>
<td>60cm Parabolic Dish</td>
</tr>
<tr>
<td>10450 MHz</td>
<td>24dB</td>
<td>60cm Parabolic Dish</td>
</tr>
<tr>
<td>24 GHz</td>
<td>13dB</td>
<td>60cm Parabolic Dish</td>
</tr>
</tbody>
</table>
A Tour of AO-40
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Bay 1

Liquid Ignition Unit

Cosmic Ray Energy Deposition Experiment

Propellant Flow Assembly

Sensor Electronic Unit

Battery Charge Regulator
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Bay 2

SCOPE Cameras
Internal Housekeeping Unit #2
2nd L Band Receiver
YAHU Camera
S2 Band Transmitter
HF Receiver
S1 Band Receiver and C Band Receiver
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Bay 3

S1 Band Transmitter
U&V Band Receiver
U Band Transmitter
Exciter
Cantemp 1
RF Relay Panel
U Band Transmitter Amplifier
V Band Transmitter
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Bay 4

K Band Transmitter & Antenna
K Band Transmitter Oscillator
Array Release Unit
Cantemp 2

Power Switching Unit
IF Matrix, LEILIA, #2 C/D
Electronic Propulsion Unit
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Bay 5

Infrared Laser Experiment
X Band Transmitter TWTA
RF Monitor Experiment
X Band Transmitter Exciter

Global Positioning Satellite 1 Experiment
GPS Power Switching Unit
Battery Charge Regulator #2
Bay 6

- GPS Receiver 2
- Stable Mode
- Sun Sensor
- Electronic Unit
- Battery Charge
- Regulator #1
- L Band Receiver & Command Arbitrator
- RUDAK
- Internal Housekeeping Unit & Input/Output Module
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AO-40 Antennas

<table>
<thead>
<tr>
<th>Designators</th>
<th>21 - 15m</th>
<th>24 - 12m</th>
<th>V - 2m</th>
<th>U - 70cm</th>
<th>L - 1.2 G</th>
<th>S1 - 2.4 G</th>
<th>C - 5.6 G</th>
<th>K - 24 G</th>
</tr>
</thead>
</table>
Three-Axis Stabilization via Momentum Wheels

- Magnetically levitated
- Spacecraft attitude flown via IHU
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Final Testing

- Vacuum Testing, Maryland - October 1998
- Vibration Testing, NASA Goddard Space Flight Center, Maryland - August, 1999
- Final Checkout – Phase 3D Orlando Integration Lab, Florida - November, 1999
Shipping AO-40 to Kourou, French Guinea
January 2000

- Orlando (ground) to Atlanta to Paris to Cayenne to Kourou
- AO-40, SBS and support equipment
- Stored in clean room at Ariane Final Assembly Building
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Integrating AO-40 on an Ariane 5

- Test SBS alignment and install pyro-cables
- Remove Oscar 40 from plastic baggie wrap

Unpacking the SBS and support gear
Integrating AO-40 on an Ariane 5

- Assemble rotisserie and mount AO-40
- Assemble solar array simulator, set up ground support computers and umbilicals to the spacecraft

AO-40 positioned on the rotisserie
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Integrating AO-40 on an Ariane 5

✓ Reinstall and test 400N bi-propellant engine

Dick Daniels, W4PUJ
with 400N engine
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Integrating AO-40 on an Ariane 5

✓ Install Infrared Laser Transmitter
  • 360,000 GHz/835nm wavelength
  • 0.5 Watt output
  • 400 bit/s data or CW transmitter
  • Receive with a telescope mounted infrared detector
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Integrating AO-40 on an Ariane 5

✓ Connect, charge and test main and auxiliary batteries
✓ Perform leak test on 400N propulsion system

Propulsion Leak Inspection: Peter Guelzow, DB2OS and Dick Daniels, W4PUJ
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Integrating AO-40 on an Ariane 5

✔ Test RF/telemetry from each of AO-40’s Amateur Radio bands

AO-40 RF Test: Freddy deGuchteneire, ON6UG; Mirek Kasal, OK2AQK; Michael Fletcher, OH2AUE; Horst Wagner, DB2ZB; Dick Daniels, W4PUJ
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Integrating AO-40 on an Ariane 5

✓ Install solar panels and apply final thermal coatings

Dick Jansson, WD4FAB adds the final touches to a solar panel
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Integrating AO-40 on an Ariane 5

- Take AO-40 off Rotisserie for last time and install:
  - Bottom GPS antennas
  - Rail-like runners for SBS deployment
  - Omni-directional Sunsensors

Bottom of AO-40 showing the thermal blanket, GPS and Omni-directional antennas
Integrating AO-40 on an Ariane 5

✓ Install in Static Bearing Structure (SBS) and load fuel

Fueling AO-40: Dick Daniels, W4PUJ, Martin Riehle and Thomas Maier
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Integrating AO-40 on an Ariane 5

✓ Mount to ASAP

AO-40 inside SBS mounted to ASAP containing two STRV microsatellites
Integrating AO-40 on an Ariane 5

Inside the Final Assembly Building (BAF)
Integrating AO-40 on an Ariane 5

Preparation of the launcher interfaces for mating with SBS, AO-40, ASAP and STRV stack
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Integrating AO-40 on an Ariane 5

Transfer of the full stack to the top of the rocket
Integrating AO-40 on an Ariane 5

AO-40 meets the launcher...
Integrating AO-40 on an Ariane 5

All Remove Before Flight items, such as protection caps for the cameras and sensors, have to be removed prior to the integration of PAS-1R.
Remove motor safety plug and install the flight plug.
The spacecraft is now “armed” and ready for flight. PAS-1R will be set on top.
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Integrating AO-40 on an Ariane 5

A last view of AO-40 before the adapter is bolted down and the fairing is closed
• Maintain spacecraft pre-launch operations and status
• Keep batteries charged
The roll-out from the BAF to the ZL took about 40 minutes.
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Launch
Commissioning AO-40
AO-40’s Intended Orbit

Ultimate Orbital Goal:
- Three-axis stabilization
- Apogee: 47,700km
- Perigee: 4000 to 10,000km
- Inclination: 63 degrees
- Orbital Mean: 16 hours
  (same pass every 48 hours)
How Can You Help?

- Monitor and record telemetry during orbital maneuvers
- Use the Satellite !!!
- Support AMSAT
  - Command and control expenses
  - www.amsat.org
  - Become a member of AMSAT (There is much more fun to come!)
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PHASE 3D

...Taking Amateur Radio into the 21st Century!
• **GOALS**
  
  – Eliminate common misconceptions about satellite operations  
  – Build a reliable two-way voice  
  – Ground Station for ~ $430  
  – No special knowledge techniques or tools required  
  – Something the neighbors will like
• Common Myths about Satellites
  – The equipment is too expensive
  – You need specialist microwave skills
  – You need expensive specialist tools and test equipment
• **Equipment needed to Receive AO-40**
  – Antenna
  – Downconverter
  – Receiver
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• Receive Antenna
  – 60cm TVRO Offset Fed Dish
  – G3RUH feed
  – 2 hours
  – Cost: ($0)
• **Offset Fed Dishes**
  
  – Feed does not obscure radiated beam
  
  – Slightly elliptical
  
  – Section of a full-size parabolic dish
Feeding offset fed dishes I

- Modified G3RUH feed (more turns, smaller beamwidth), very easy to fabricate
- Put feed phase centre at dish focus
- $\lambda/4$ transformer matching helix to 50$\Omega$
Feeding offset fed dishes II

- Match 10dB feed beam width to illumination angle
- Easier matching if odd number of $\lambda/4$ turns (including match)
• **Downconverter**
  - Convert 2.4GHz to an Intermediate Frequency (IF)
  - Cheap TV Receive converters can be used
  - Modifications can be very simple
  - Cost: $20-$84 including modifications
• AIDC Transystems Downconverter
  – Crystal for 144MHz IF (maybe)
  – Snip the \( \lambda/4 \) stub
  – Replace dipole/reflector feed with N-adapter
  – New filter to remove second IF image
  – http://members.aol.com/k5gna/
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• Receiver
  – Must be able to resolve SSB at the Downconverter IF (144MHz)
  – Must be cheap
  – FT-290R MK-I ~$142 or less
• **Testing the Receiver Configuration**
  – Pointing the feed (without the dish) to the ground should show increase in audible noise.
  – With the feed on the dish there will be a small increase in noise if you point the dish at the sun.
  – Point the dish at AO-40 and you will hear telemetry and be able to tune the downconverter LO.
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• Equipment to Transmit on AO_40
  – What band?
  – How much power for reliable voice communications?
  – Balancing Transmitter Power and Antenna Gain
  – What Transmitter?
  – What Amplifier?
  – What Antenna?
• Transmitter
  – Need to transmit SSB on 435MHz
  – Must be cheap
  – FT-790R MK-I ~ $128 or less
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• Amplifier
  – FT-790 1 watt output inadequate, so need some more power
  – Must be cheap.
  – Second user 50W amplifier ~ $111 or less
• Transmitting Antenna I
  – Small 435MHz band >10dBic gain
  – 3 hours
  – Cheap ~$31 including power splitter
• **Transmitting Antenna II**

  – Power splitter - Two $\lambda/4$ pieces of RG-59

  – Orthogonal elements offset by $\lambda/4$
• Putting it Together
  – Transponder pass-band tracking
  – Computer Doppler correction
  – Where’s the rotator?
Transponder Passband Tracking

- Old radio = no features?
- Or...
- Old radio = easily modified?
- Rotary encoder KISS modification
• **Computer Doppler Correction**
  
  – In practice, for an entry level system this is optional
  
  – Facilities of InstantTune with InstantTrack allow mic button up/down doppler correction
• **Where’s the Rotator**
  
  – Az-El rotator would completely blow budget
  
  – ‘Armstrong’ technique perfectly acceptable!
What do the neighbours think?

- Not any different to a conventional UHF TV antenna and TV Sat Dish
- Point it out of your window
What do the neighbours think?

- Not any different to a conventional UHF TV antenna and TV Sat Dish
- Point it out of your window
AO-40 – Apartment Dwellers’ Dream

- Antennas small enough to put on balcony...

- ...or underground!
What special skills and equipment do I need?

- Ability to use:
  - Soldering Iron
  - Screwdriver
  - Hack saw
  - Drill
  - Ruler
  - Magnetic Compass
• Did we hit the Budget?
  – $498.00 not quite

<table>
<thead>
<tr>
<th>Description</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>TransSystem Rx Converter, N Type adapter, 2m Xtal, Filter + PCB</td>
<td>59</td>
</tr>
<tr>
<td>FT-290 2nd Hand</td>
<td>100</td>
</tr>
<tr>
<td>FT-790 2nd Hand</td>
<td>90</td>
</tr>
<tr>
<td>50W 70cm Amplifier 2nd Hand</td>
<td>78</td>
</tr>
<tr>
<td>Dish + Feed</td>
<td>0</td>
</tr>
<tr>
<td>70cm Yagi Elements</td>
<td>10</td>
</tr>
<tr>
<td>70cm Yagi Boom</td>
<td>2</td>
</tr>
<tr>
<td>70cm Power Splitter</td>
<td>10</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>349</strong></td>
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