AMSAT
Amateur Satellites For the 21st Century

An Introduction to Amateur Satellites

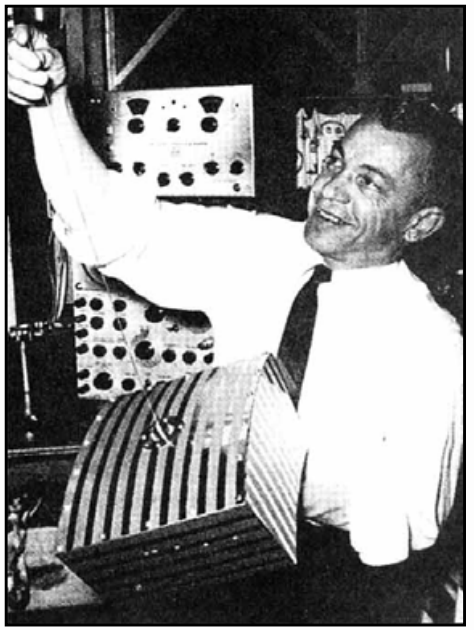
Presented by

Emily Clarke N1DID
(formerly WØEEC)
AMSAT Board of Directors

AMSAT
Amateur Satellites For the 21st Century

What is an Amateur Satellite?

- In the late 1950's, Project OSCAR was formed to put amateur radio equipment in space
- An OSCAR is an Orbiting Satellite Carrying Amateur Radio
- Built for non-commercial purposes
- OSCAR-1 Launched in 1961 carried a beacon
- Project OSCAR also launched OSCAR-III - the first "*repeater*" in space
- AMSAT formed in 1969 to take the amateur satellite effort worldwide



Chuck Towns K6LFH in his garage with OSCAR-II

Amateur Satellite Myth #1

Using Amateur Satellites is Hard.

Myth Busted

Aruni, VE4WMK, began working satellites at 10 years old (as do many kids).

10 year old Aruni VE4WMK (assisted by dad Kumara VE4WKP) has a QSO with N1DID

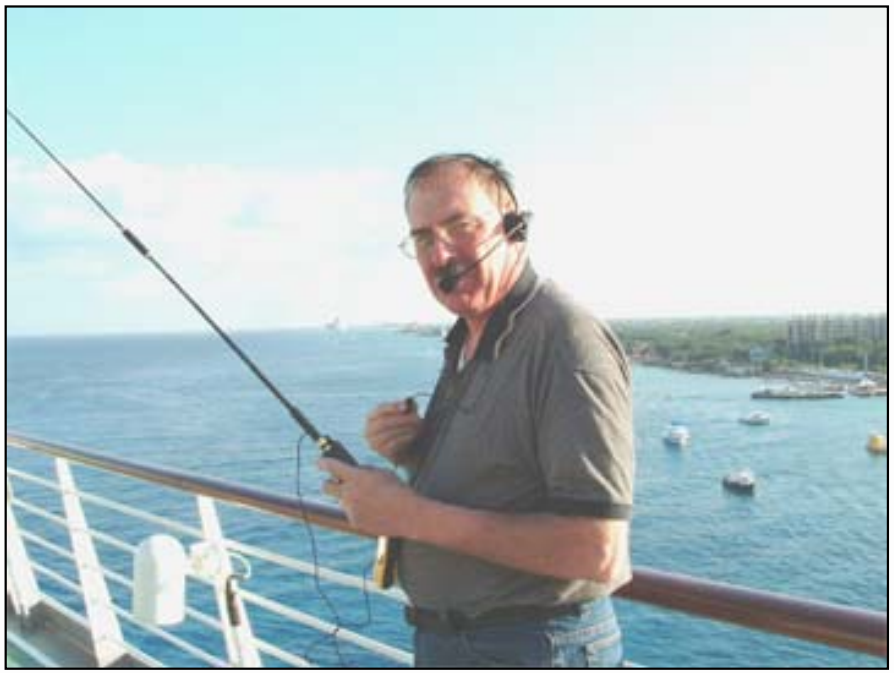
AMSAT
Amateur Satellites For the 21st Century

Amateur Satellite Myth #2

Using Amateur Satellites is Expensive

Myth Busted

Alan N5AFV has over 30,000 satellite contacts using a handheld or mobile rig and handheld antennas including marine mobile



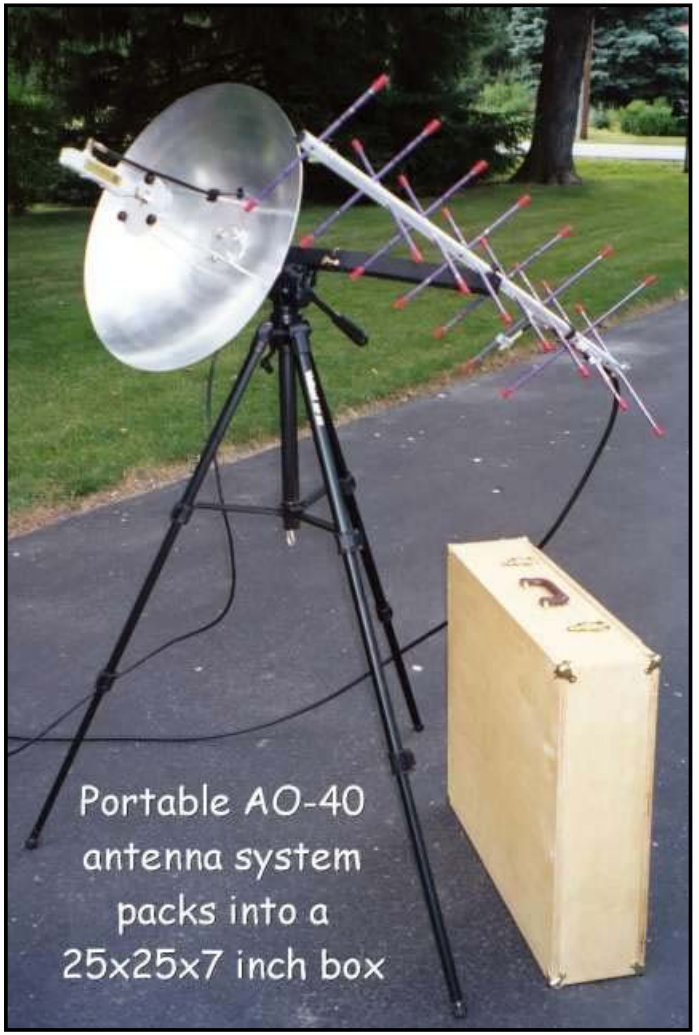
Amateur Satellite Myth #3

“I’ll Never Make it Over the Big Gun Stations”

Myth Busted

Viagra doesn't make someone a good lover.

You don't need power or big antennas - it's a combination of skill, technique and imagination.



Satellite Operations are Fueled by Imagination

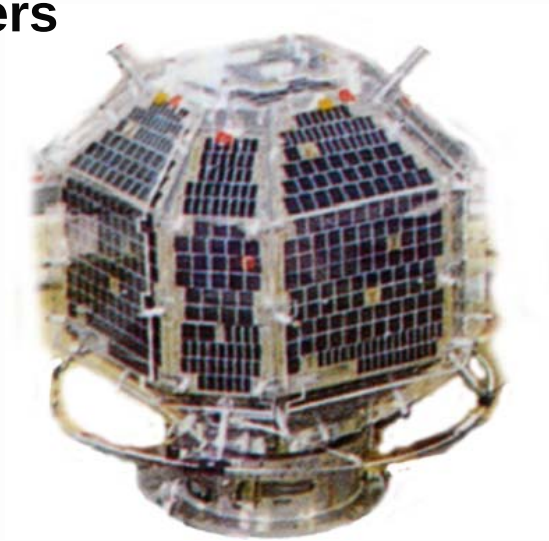
“Imagination is more important than knowledge. Knowledge is limited, while imagination encircles the world.”

-Albert Einstein 1929

The goal of this presentation is to provide the knowledge to fuel your imagination

So what should I know about OSCARs?

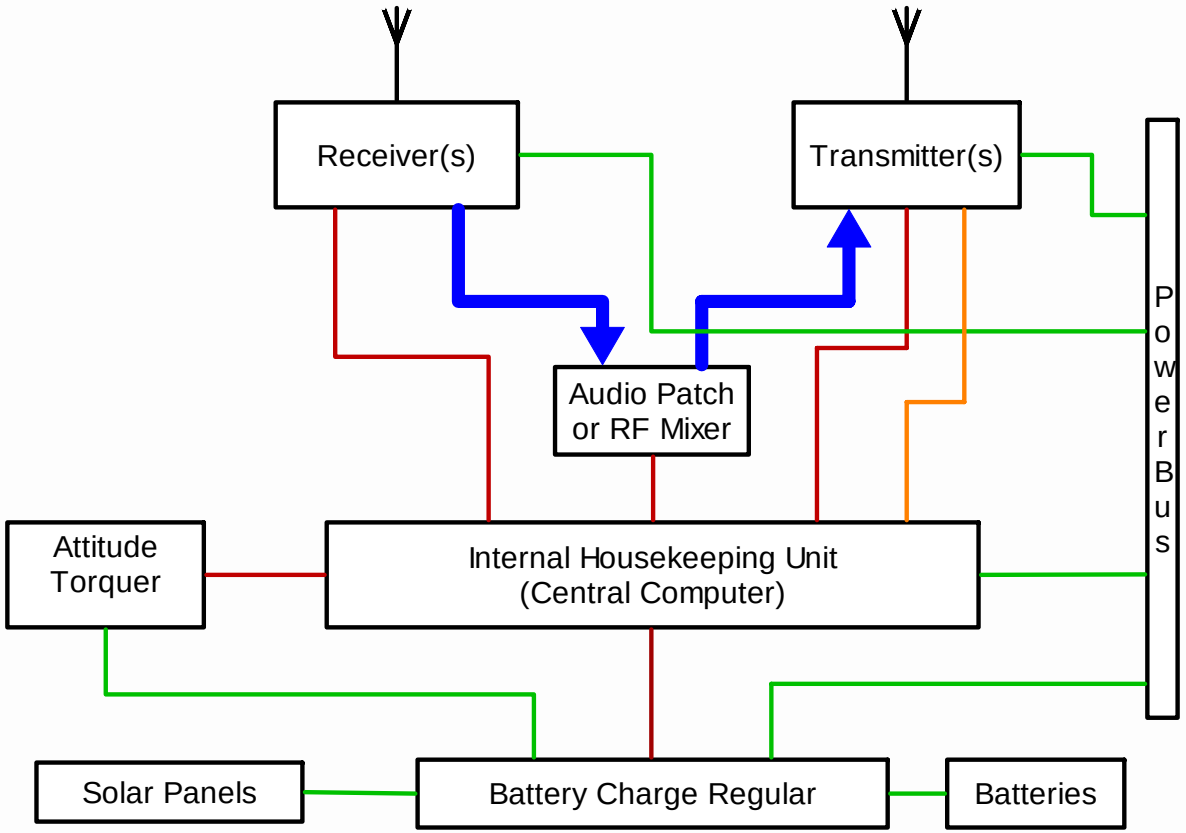
- Amateur satellites are built by radio amateur volunteers
- Though built by volunteers, OSCARs are space qualified vehicles and stand up to long duration space flights
- Builders need support (plug – if you like this presentation please give a donation to AMSAT)
- Satellite operations can be frustrating and gratifying – but the more you know, the better the experience (which is why I am here.)



JAS-2 (Fuji-OSCAR 29)

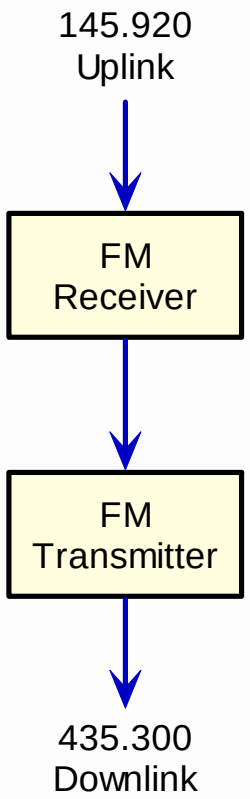
- Most answers are on the AMSAT website and if they aren't? Let us know.
- AMSAT works hard to build up "user services" – volunteers called Area Coordinators worldwide who will elmer anyone who needs advice.

Simplified Satellite Block Diagram

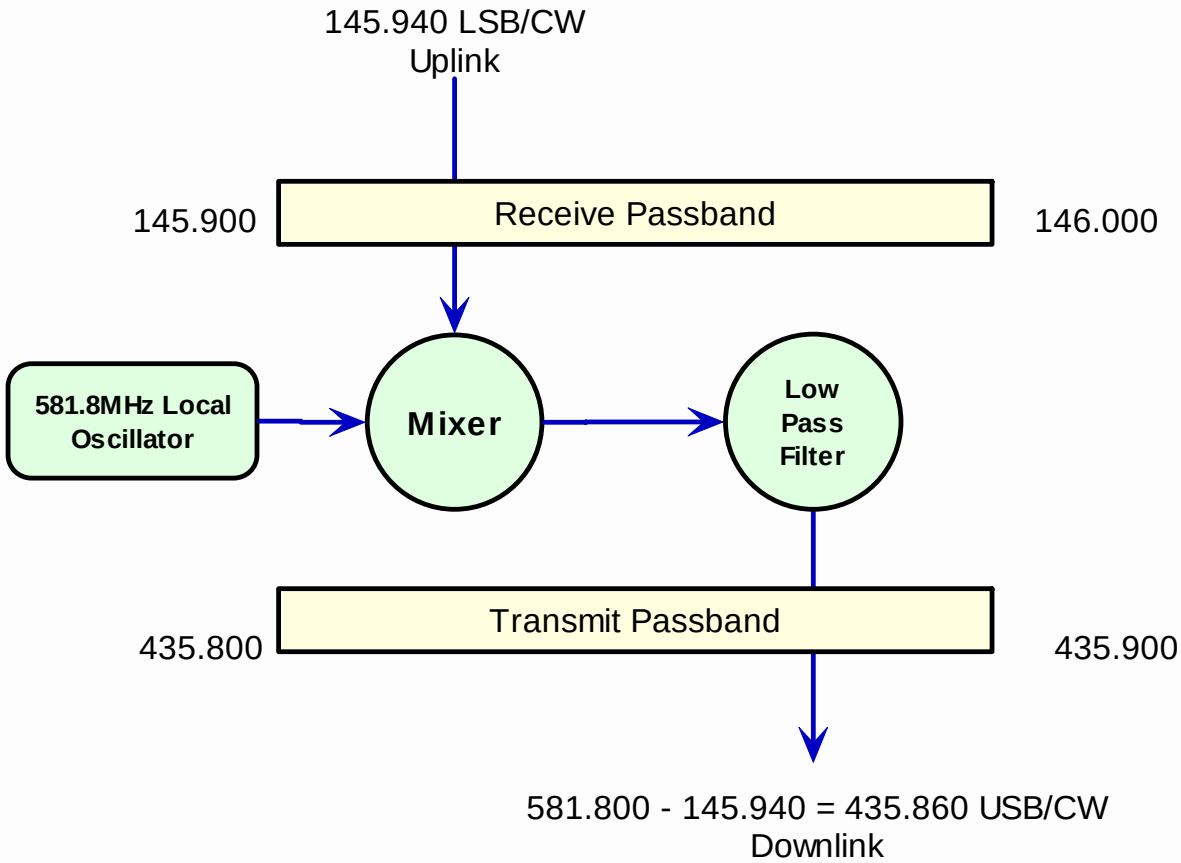


How Do Satellites Communicate?

V/U Single Channel FM Repeater



100 KHz Wide V/U Linear Transponder

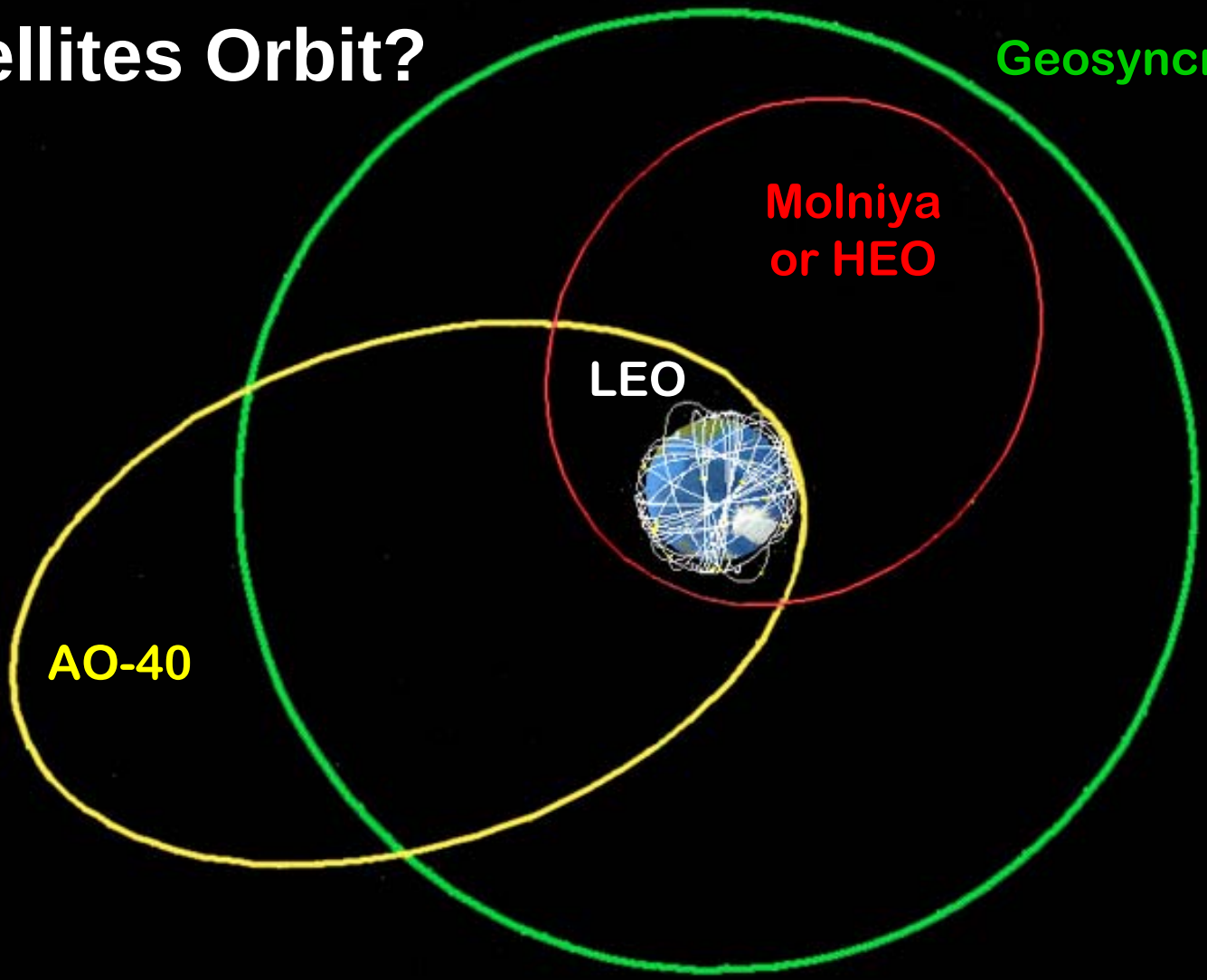


AMSAT
Amateur Satellites For the 21st Century

Where Do Satellites Orbit?

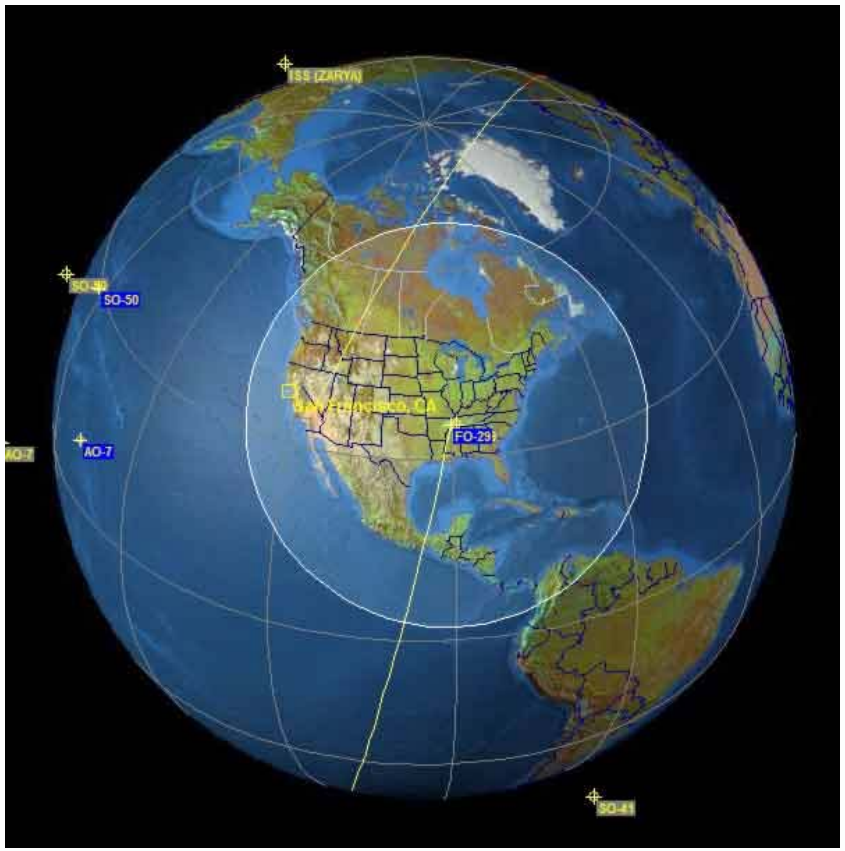
Hours per Orbit

LEO = 1.6
HEO = 12 –14
AO-40 = 16
Geo = 24

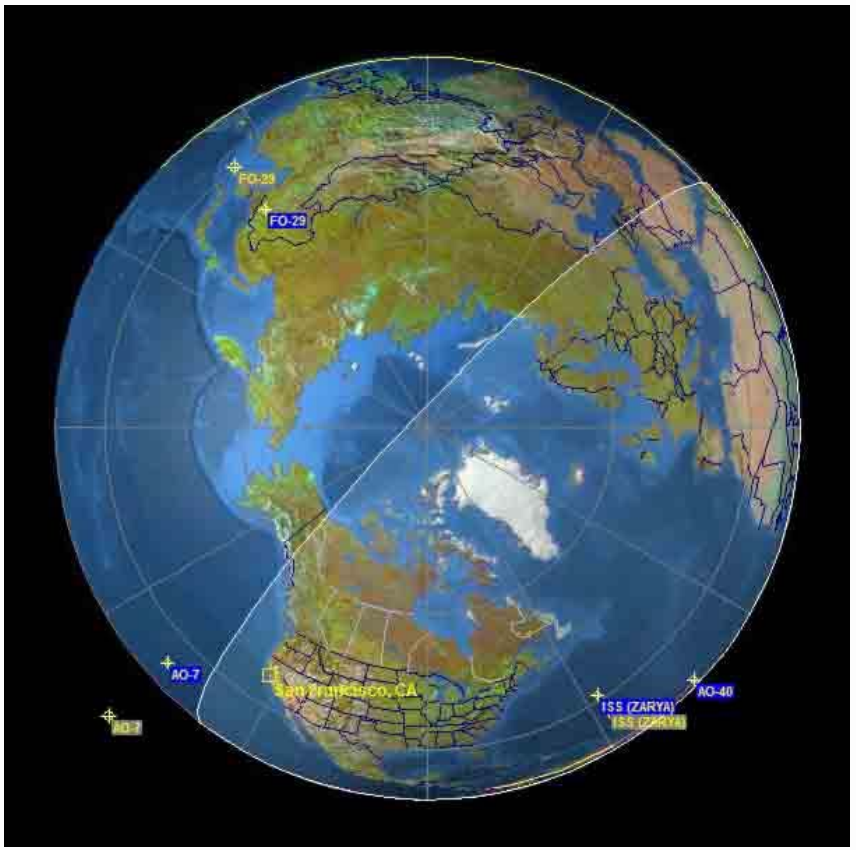


AMSAT
Amateur Satellites For the 21st Century

How Far Do Satellites Reach?



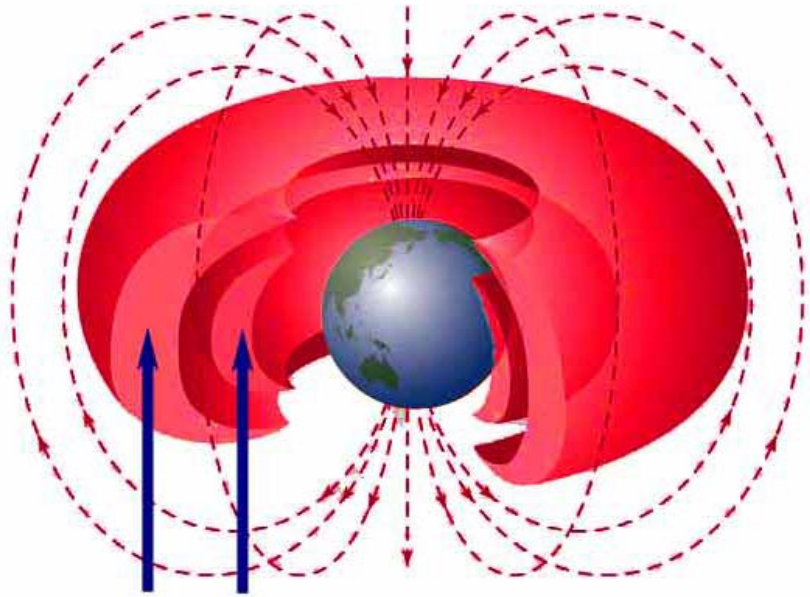
LEO (FO-29) – Continental Coverage Plus Time in Transit



HEO (AMSAT-Eagle) - Hemispheric Plus Earth Rotation

Why Don't LEO Satellites Orbit Higher?

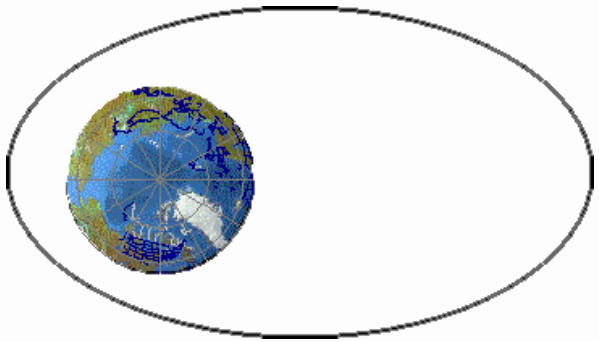
- The Van Allen belts are regions of protons and electrons, held captive by the magnetic influence of the Earth
- Radiation is concentrated and closest to the earth at the poles (aurora)
- Satellite orbits are designed to spend as little time as possible in the belts or avoid them completely
- Satellites that travel in and around the belts may be damaged
- Levels change because of magnetic storms, nuclear explosions



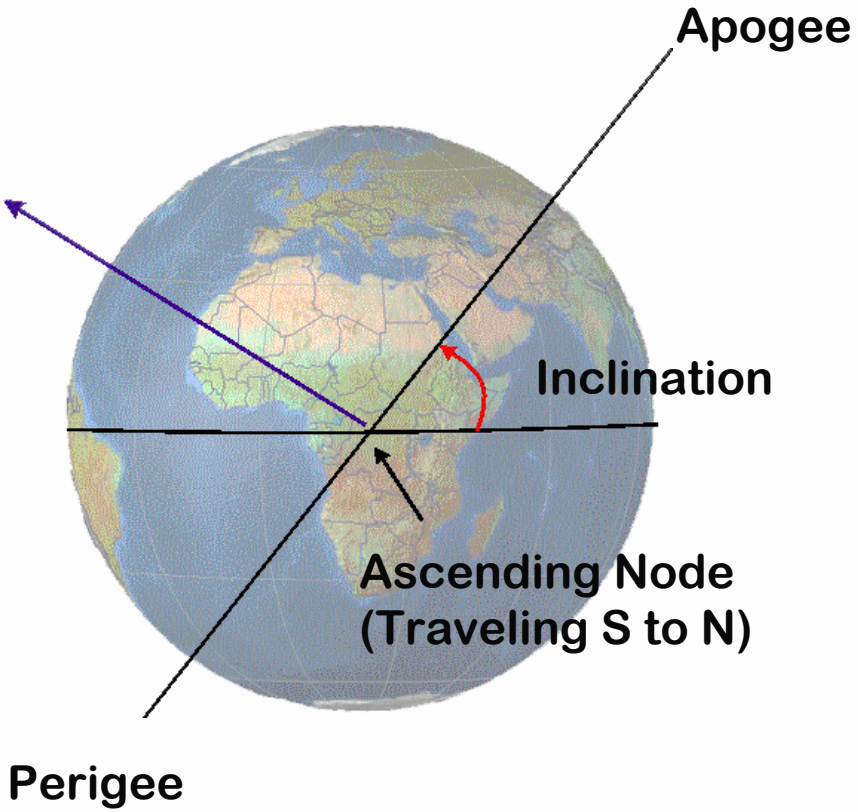
How do I know where they are?

Keplerian Elements - parameters that describe an orbiting body

- Epoch Time (A timestamp)
- Inclination
- Right Ascension of the Ascending Node
- Argument of perigee
- Eccentricity
- Mean Motion (rev/day)
- Mean Anomaly



Eccentricity



Fortunately we don't have to be astrophysicists!

How Do I Use Keplerian Elements?

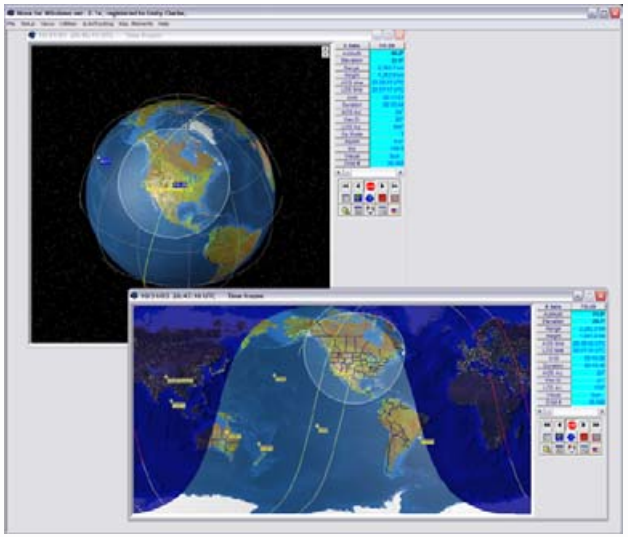
```
AO-51
1 28375U 04025K   06011.72150414  .00000043  00000-0  26247-4 0  4355
2 28375  98.1898  70.7097 0084454 321.6438  37.8766 14.40500056 80642
```

- **Elements are distributed generally in one of two formats –**
  - NORAD Two Line Elements (TLE) – most common and shown above
  - AMSAT Verbose Format – more descriptive
- **Elements should be updated periodically (esp. ISS – it can be maneuvered)**
- **Most tracking programs do this over the internet automatically (and may also synchronize your clock)**
- **SpaceTrack (USAFSC) is the agency that distributes elements - accounts are free but require you to register**
- **Celestrak and AMSAT are licensed by USAFSC to distribute Keps through their websites**

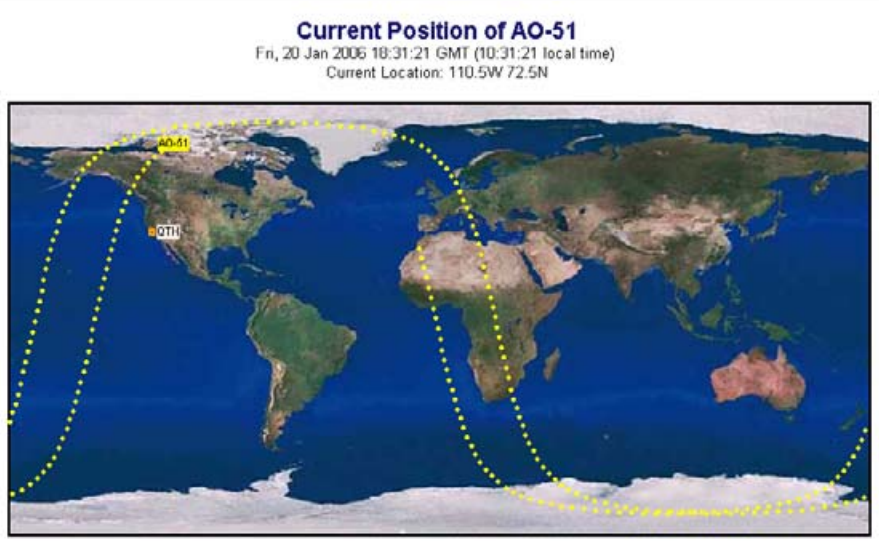
Basic Satellite Tracking

- "In the good old days…" There was the OSCARLocator (manual tracking system)
- The OSCARLocator plotted where the satellite would be based on the time the satellite crossed the equator from south to north (ascending node).
- Around 1978 QuickTrak appeared – a computer program written in Basic
- Now we have complex graphical programs to track satellites, control rigs, handle Doppler correction and control antenna pointing

Satellite Tracking Software



- **MacOS-X**
  - MacDoppler and MacDoppler Pro
- **UNIX/Linux**
  - Predict and multiple front end User Interfaces
- **MS Windows**
  - Nova for Windows
  - SatPC32
- **Handhelds and Cellphones**
  - PetitTrack
  - SatTrack
- **Some Shareware/Freeware programs**
- **Online pass prediction and tracking**
  - Available at AMSAT.org and others



AMSAT
Amateur Satellites For the 21st Century

Where do I transmit and receive?

HF Bands	29.300 – 29.500	200 KHz	Primary	Uplink & Downlink
V Band	145.800 – 146.000	200 KHz	Primary	Uplink and Downlink
U Band	435.000 – 438.000	3 MHz	Secondary	Uplink and Downlink
L Band	1260 – 1270	10 MHz	Secondary	Uplink Only
S Band	2400 – 2450 3400 – 3410*	10 MHz 10 MHz	Secondary Secondary	Uplink and Downlink Uplink and Downlink
C Band	5650 – 5670 5830 – 5850	20 MHz 20 MHz	Secondary Secondary	Uplink Only Downlink Only
X Band	10.45 – 10.5 GHz	50 MHz	Secondary	Uplink and Downlink
K Band	24.0 – 24.05 GHz	50 MHz	Primary	Uplink and Downlink
Q Band	47.0 – 47.2 GHz	200 MHz	Primary	Uplink and Downlink
W Band	75.5 – 76.0 GHz	500 MHz	Primary	Uplink and Downlink

* Not worldwide – no allocation in parts of Region 1

AMSAT
Amateur Satellites For the 21st Century

The FM Satellites

- FM Satellites are repeaters, and considered “easy” to use (though that is debatable.)
- Generally can be worked with a dual band HT and a good antenna
- Doppler correction less of an issue due to FM capture effect and AFC
- Always in Low Earth Orbit so path loss is less
- Frequency poaching is an issue (Tijuana Taxis, Alaskan Fisherman)
- Only one user at a time.
- May require a PL tone

AO-27 – Mode V/U (500mW)

SO-50 – Mode V/U (250mW)

AO-51 – Modes V/U, V/S
L/S and H/U
(350 mW – 2W)

PO-28 – Mode V/U (2W)

PO-28 is transitioning from commercial to amateur use

AMSAT-SA has a LEO amateur payload scheduled for 12/2006

FM Satellite Station Requirements

- Dual Band Handheld with dual VFOs and a good antenna such as an Arrow (dual band Yagi)
- Dual Band Mobile Rig with Dual VFOs
- Base Station with Eggbeaters (omni) or Yagis with rotators

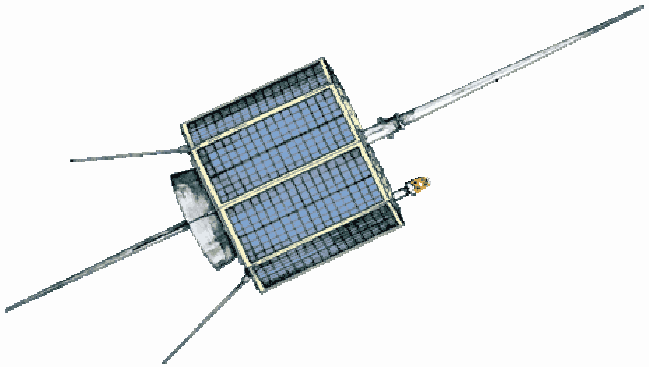
I have worked satellites with two VX-1R handhelds! The key is to have a good antenna. Stock antennas don't cut it.

N1DID with Arrow antenna, working VE6AB (Calgary) from the rim of the Grand Canyon

AMSAT
Amateur Satellites For the 21st Century

The SSB/CW Satellites

- SSB/CW satellites carry linear transponders that have wide bandwidths to allow many users to have simultaneous QSOs.
- SSB/CW satellites usually carry beacons that transmit station telemetry and act as a navigational aid
- AO-7 and FO-29 are in higher LEO orbits, so contacts up to 7500km away are possible



AO-7 – Mode A (V/H) (1W) and B (U/V) (2W)

FO-29 – Mode V/U (1W)

VO-52 – Mode U/V (1W)

SSB/CW Satellite Requirements

- Requires an all mode radio with 10Hz or better tuning
- Usually Yagi antennas or helixes
- Computer controlled rotators are recommended but not required
- Computer controlled Doppler tuning to stay on frequency is recommended but not required

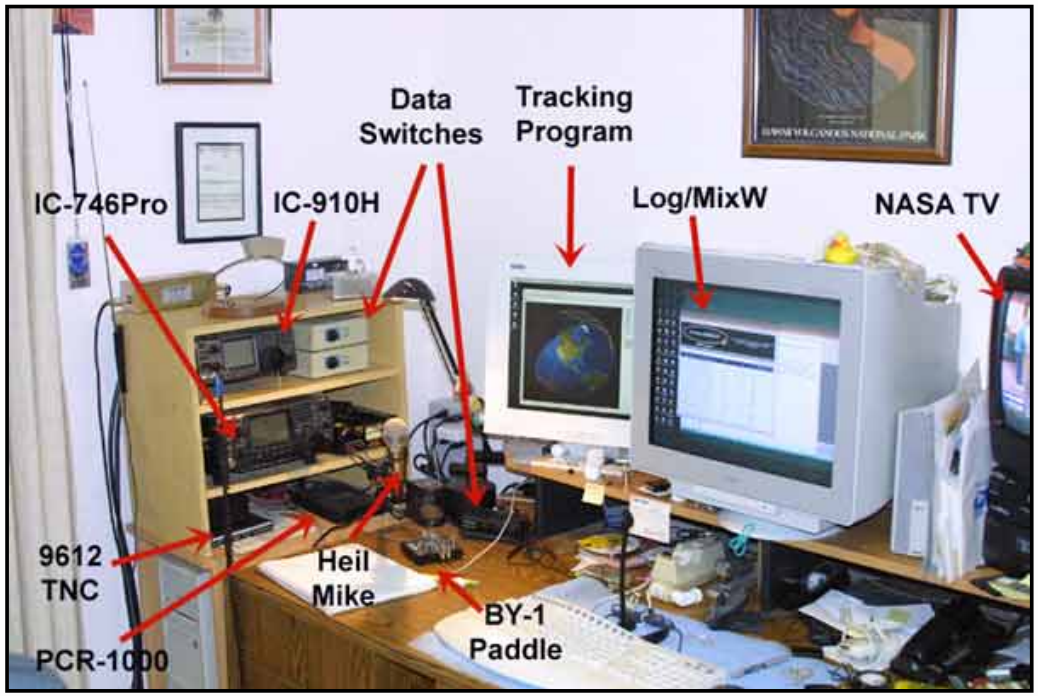
Digital Satellites

- Digital satellites come in two flavors – PacSat (packet satellites) and APRS digipeaters
- PacSats have digital BBS systems to store and forward messages around the world
- APRS satellites forward position and status information to ground stations called “SatGates” that transfer information to the internet
- AO-51 is both a PacSat and APRS digipeater

GO-32 – V/U Pacsat
NO-44 – Simplex APRS
AO-51 – V/U PacSat and APRS

Digital Satellite Requirements

- **Digital satellites have the same requirements as FM stations (generally) except:**
  - 1200/9600+ baud TNC *or*
  - Soundcard Interface
  - Radio with high speed data port (comes off the FM discriminator rather than from audio)
- **Additional software**
  - APRS tracking software
  - BBS software that uses the PacSat Protocol (PBBS)



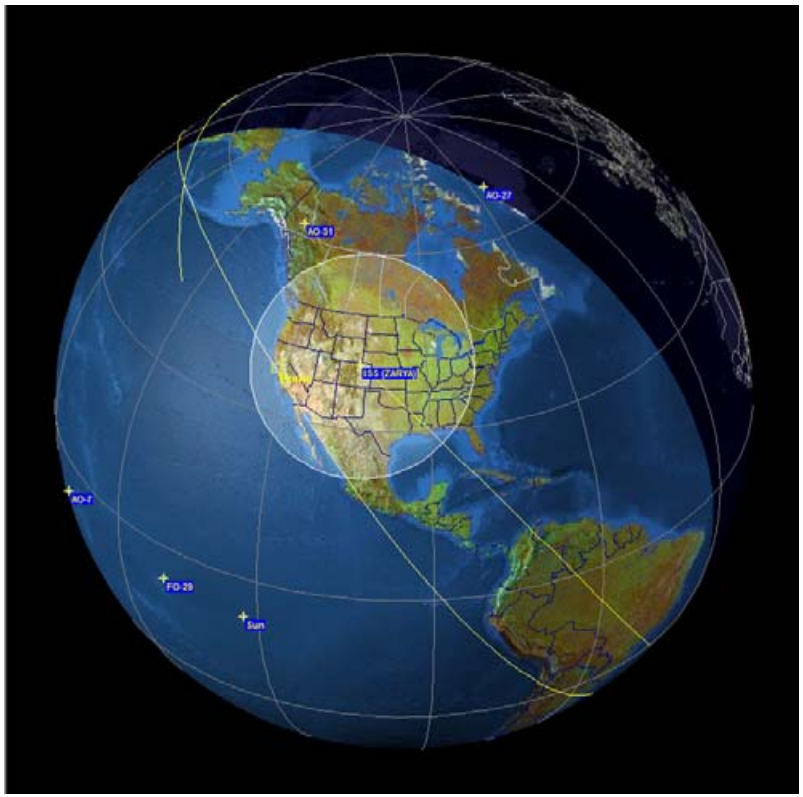
AMSAT
Amateur Satellites For the 21st Century

The International Space Station

- AMSAT works with NASA to sponsor ARISS (Amateur Radio on the International Space Station)
- ARISS designs and builds amateur radio equipment for installation on the ISS for use by station crew
- The primary mission is educational – contacts are made with school children around the world assisted by amateur radio operators
- Voice contacts can be made on VHF and UHF simplex, or VHF split frequency
- APRS and (terrestrial) packet BBS available when not in voice mode
- SSTV and HF equipment will be installed sometime in 2006

AMSAT
Amateur Satellites For the 21st Century

The ISS Is Very Easy to Hear…



- Circular orbit inclined ~66 deg
- Height ~375km so footprint is smaller (10 minute passes)
- Loud signal – typically operates at 10 watts FM
- Can be heard on any handheld transceiver (even with a stock antenna!)
- Mode and frequency changes depending on IARU region

…but Not Easy to Contact

There is a lot of competition for crew contacts – be patient!

AMSAT
Amateur Satellites For the 21st Century

ISS Considerations and Frequencies

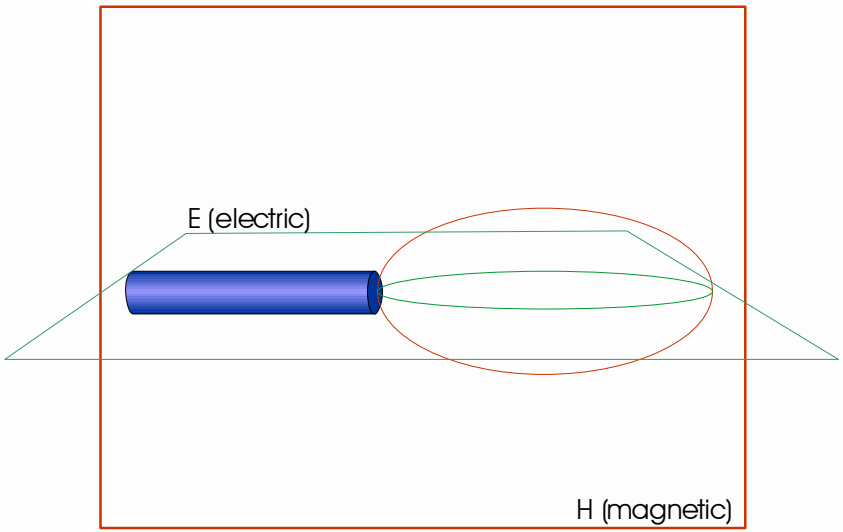
Expedition 10 Science Officer John Phillips makes a school contact

- **The ISS is very sensitive to over-deviation. Keep compression off and mike gain low.**
- **The ISS moves very fast – be prepared to move your antenna and tune Doppler quickly if the uplink is 70cm.**
- **The passes are very short. Keep QSOs to callsign and gridsquare.**

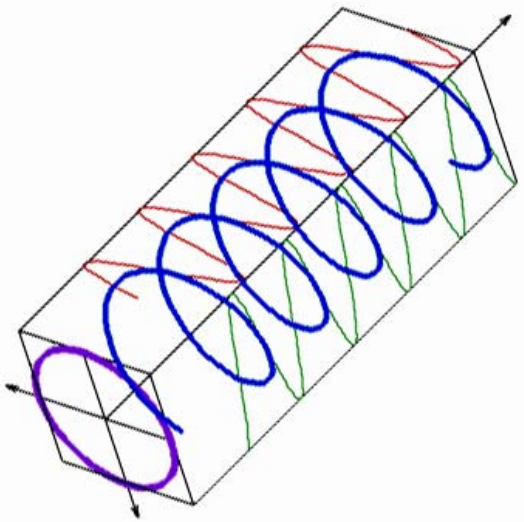
- **Crew Contact, V Split or U Simplex**
  - 144.490/145.800 FM (Region 2 & 3)
  - UHF Simplex 437.800 FM
  - Callsign NA1SS or RSØISS
- **FM Phone Repeater, U/V**
  - Uplink: 437.800 FM, No PL Tone
    Downlink 145.800 FM
- **FM Packet**
  - Uplink: 145.990 1200 Baud PSK
  - Downlink: 145.800, 1200 Baud PSK
  - Callsign for APRS: ARISS
  - BBS Callsign: RSØISS
  - Use ARISS, WIDE, IGATE Digipath

Antenna Polarization

- In the 1860s and 1870s, James Maxwell demonstrated that electric and magnetic fields travel through space, in the form of waves, at a constant velocity of 3.0×10^8 m/s.
- Electromagnetic waves have E (electric) fields and H (magnetic) fields that are 90 degrees out of phase
- Polarization is determined by the direction of the E field (in this linear example horizontal)



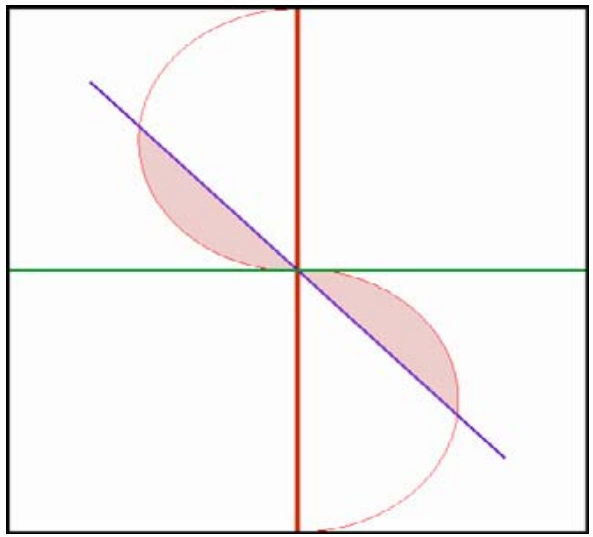
Horizontal Polarity



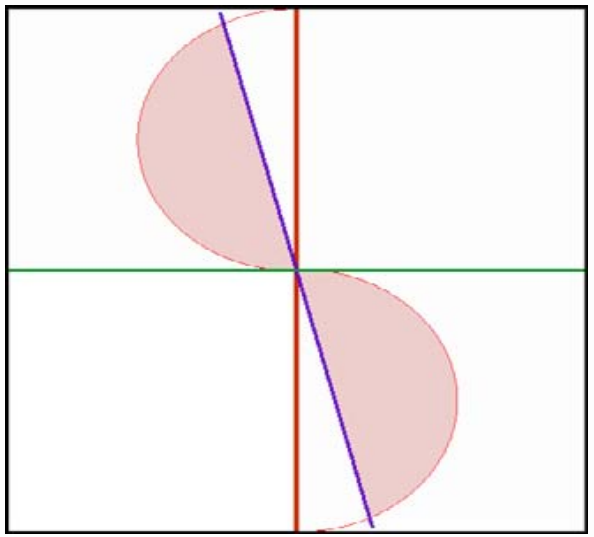
Right Hand Circular Polarity

Polarization Efficiency – *Catch the Wave…*

The better the match, the more of the wave you catch (and the stronger the signal)



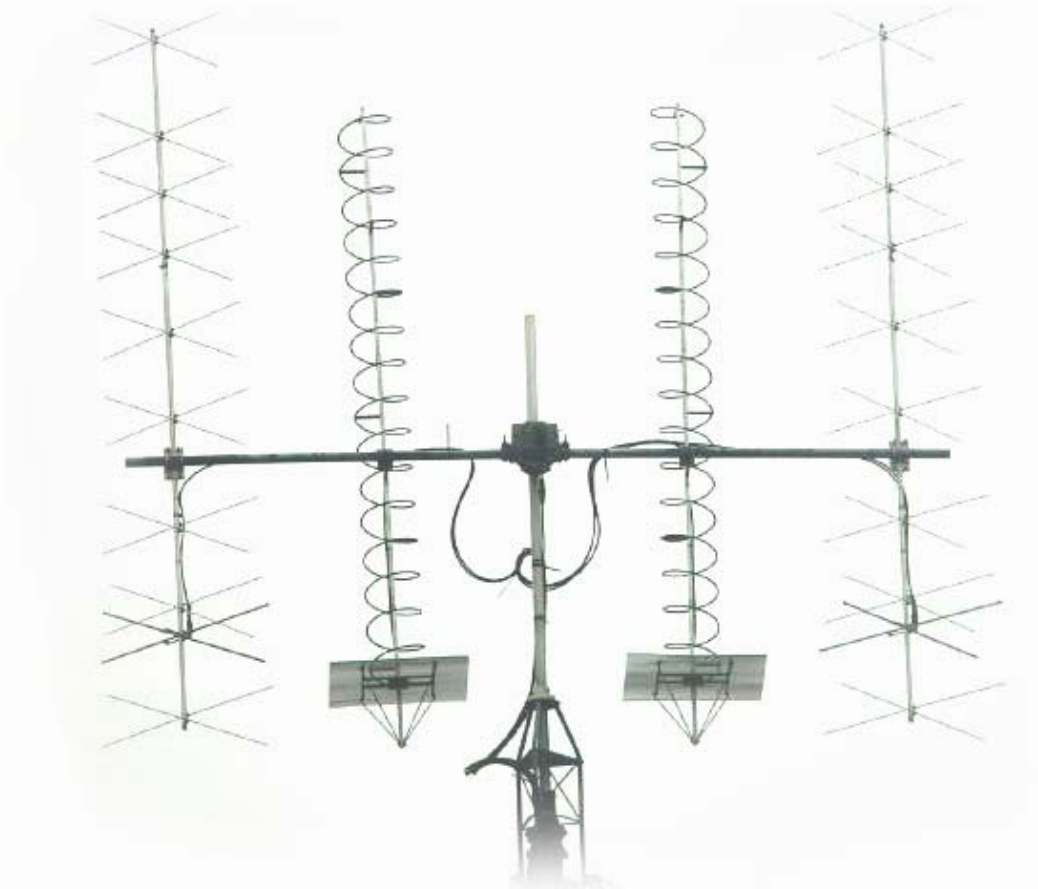
Inefficient (-3db)



Better (< -1db)

- A linear mismatch will result in a loss from 0db <> -20db (at 90deg)
- A circular mismatch (RHCP -> LHCP) also results in -20db loss
- A mismatch between circular and linear will result in -3db loss

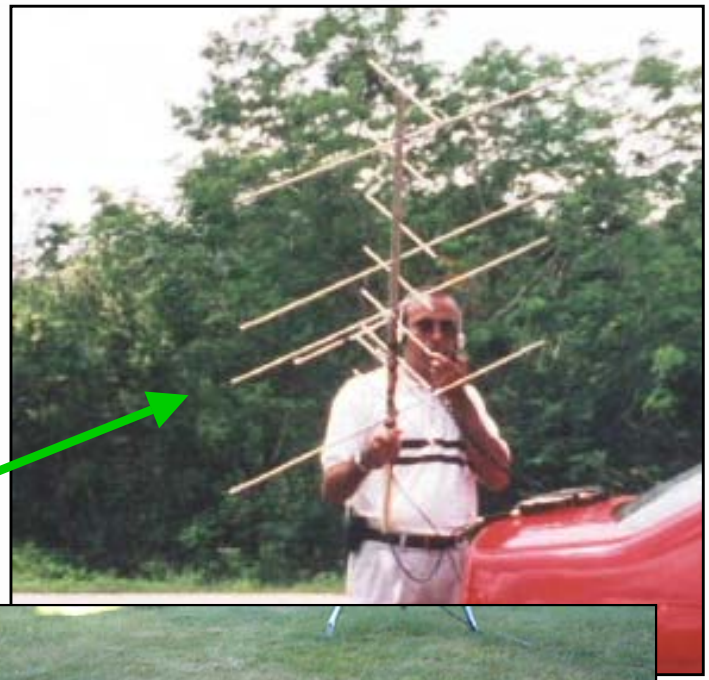
Phasing Helps

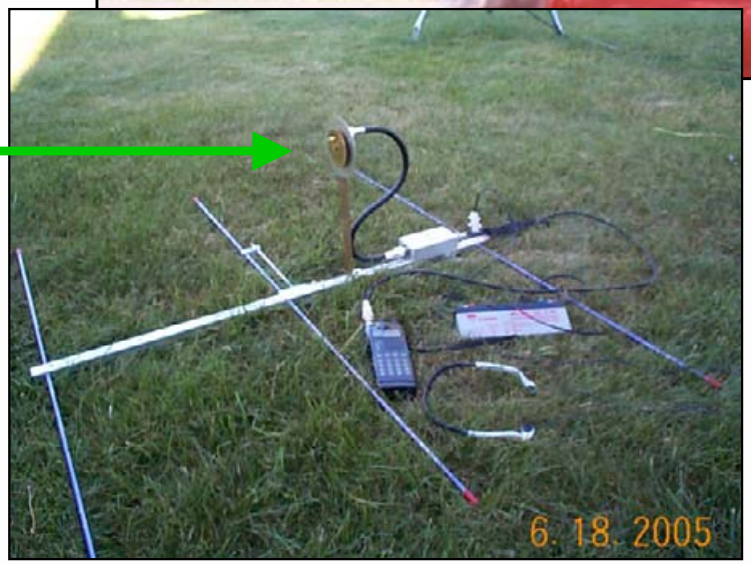


- Phasing antennas of opposite polarity insures you catch all of the signal

Portable Antennas

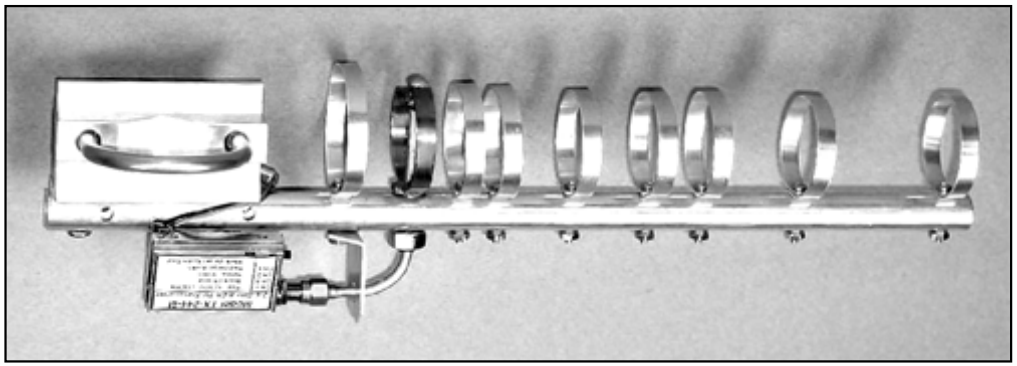
- Most popular is the 3el 2M/7el 70cm commercial Arrow antenna (built from aluminum arrow shafts)
- Arrow antennas can be homebrewed
- Alex Diaz, XE1MEX (right) designed a popular homebrew 4el 2M/8el 70cm
- John Meeks KC8ZFN uses a 3el 2M Arrow with an S-Band patch for mode V/S
- Can be mounted on tripods using PVC pipe (don't use metal)





High Gain Yagis, Loop Yagis and Helixes

- Generally high (> 15db) gain
- Generally narrow (~24 deg) 3db beamwidth
- Circularly polarized, should have polarity switches
- Must be controlled in azimuth and elevation (generally by computer)



Dish Antennas

- **The bigger the better?**
  - Big dishes have tons of gain but very narrow bandwidths
  - Big dishes are difficult to point and generally can't flip without expensive mounts
  - Real estate
- **On the other hand,you can hear everything**
  - May have feeds that cover many bands
- **Chose what's best for you**

W0LMD – 10' TVRO

K9DID – 36" DirectTV

Antenna Pre-amplifiers

- Generally mounted at the antenna to overcome feedline losses
- Tuned to an individual band (noise figures .7db or less) or broadband (noise figures as high as 2.7db)
- DC power supplied via coax or separate wiring
- Must be switched in during receive and out while transmitting
- May be VOX controlled

Attenuation (dB per 100 feet)					
MHz ->	**30**	**146**	**440**	**1200**	**2400**
RG-58	2.5	6.1	10.4	24.0	38.9
RG-8X	2.0	4.5	8.1	14.4	21.6
LMR-240	1.3	3.0	5.2	7.0	12.7
RG-8	1.2	1.9	5.1	8.0	13.7
9913	0.8	1.5	2.8	4.5	7.5
LMR-400	0.7	1.5	2.7	4.3	6.6

Manual Tracking

Regardless of where you are, most LEO satellites will travel in an arc in relationship to your location. If you know the time and azimuth where it will come over the horizon and the maximum elevation it will be fairly easy to track.

Rotator Types

Azimuth Rotator (with omni homebrew modified eggbeaters)

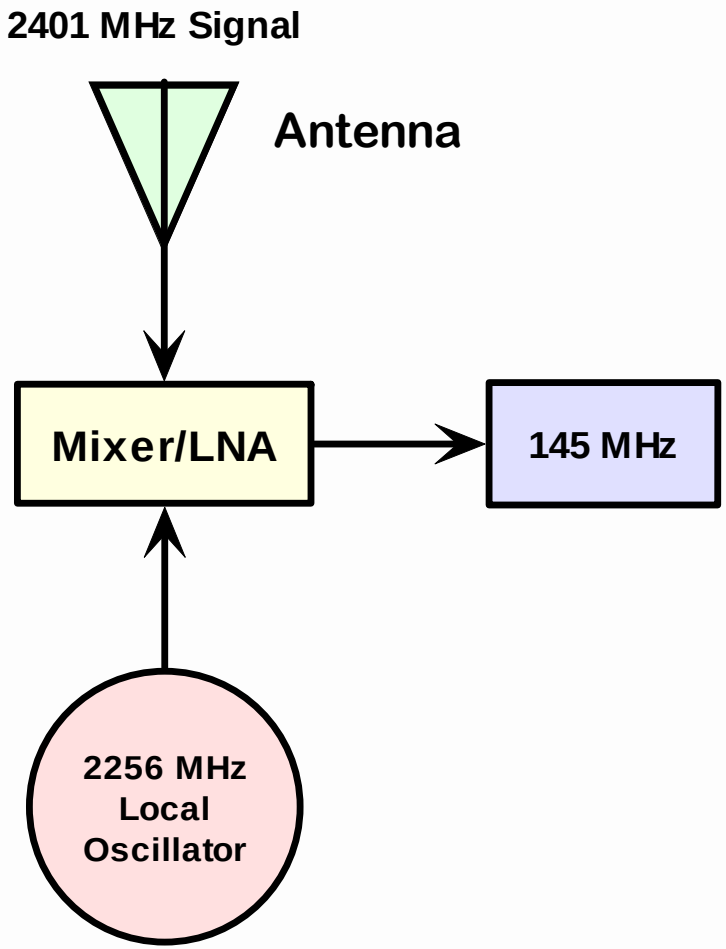
Az-El Rotator (with homebrew 2.4G helix)

Rotator Controllers

- **Computer controlled**
  - Yaesu GS-232 and M2 RC2800
  - Requires computer to send Az-El information
  - Only controls antenna
- **Stand Alone**
  - Generally has an embedded processor (PIC or AVR)
  - Keps are downloaded from computer but that's all – the computer can be disconnected
  - Many homebrew designs
  - Most control radio and antenna together

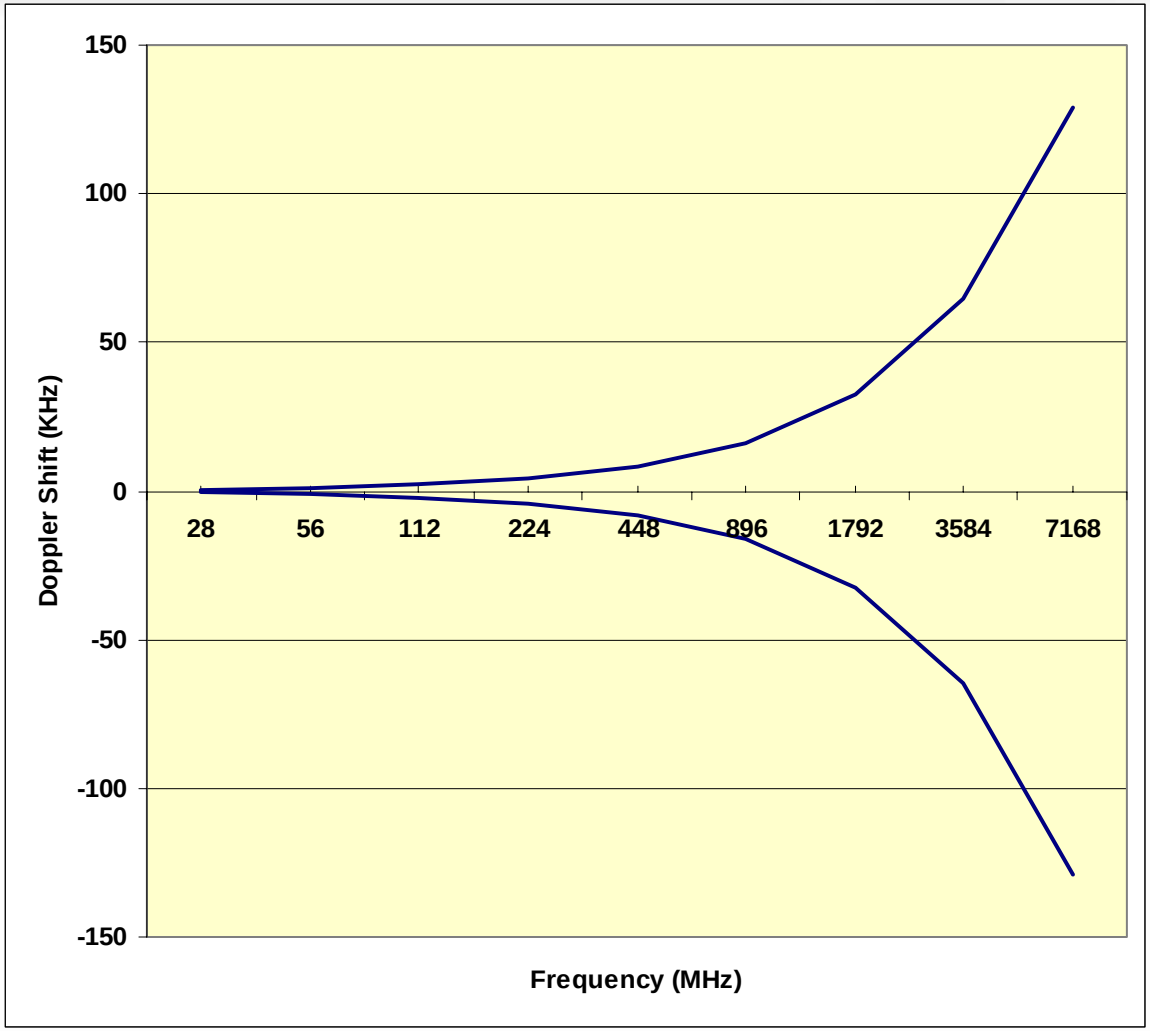
Downconverters – Not Scary…

- A downconverter acts like a first stage mixer to convert a signal from one frequency to another
- Commercial downconverters for MMDS as are easily converted to amateur use
- Impedance may not match if using commercial vs amateur
- Lower noise figures are better



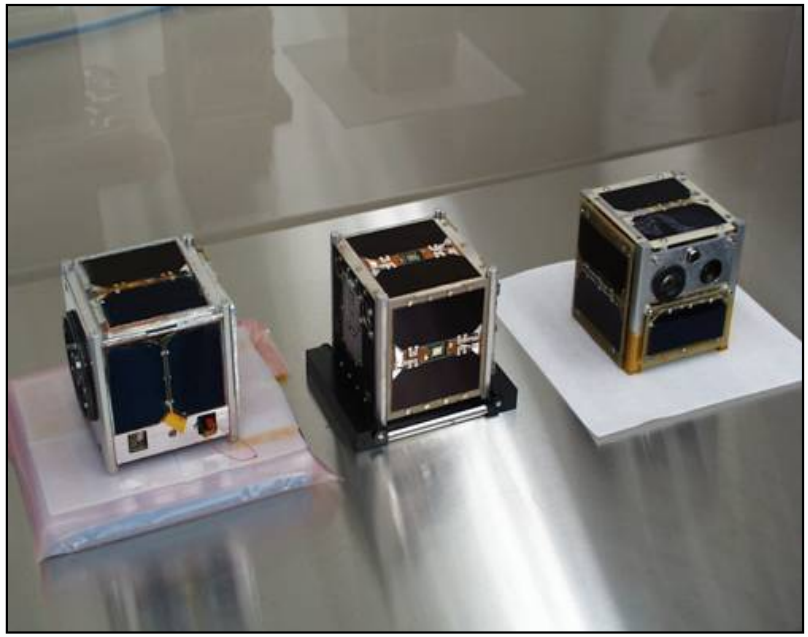
Doppler Shift

- A change in frequency due to relative motion between two bodies
- The greater the relative motion, the greater the frequency shift
- Doppler is proportional to frequency - as frequency increases, so does the shift
- Keplerian elements help us calculate this factor
- Computer control helps free the operator from constant retuning
- (Doppler Demo)



Typical LEO doppler shift from start of pass to end of pass

Cubesats



- Cubesats are picosatellites housed in 10cm cubes common to all designs, though 10cm x 20cm (double) and 10cm x 30cm (triple) are possible
- They share a common launcher called a P-POD that can launch 3 or 6 cubes at one time.
- Spaceframe developed at Stanford
- CalPoly SLO developed the P-POD
- Many Cubesats from many countries have been launched (Cute-1, CanX1, XI-IV, AUSat, Quakesat, nCube-2)
- 13 more Cubes to be launched in 2006
- AMSAT members support Cubesat builders but there is no official AMSAT Cubesat program

AMSAT
Amateur Satellites For the 21st Century

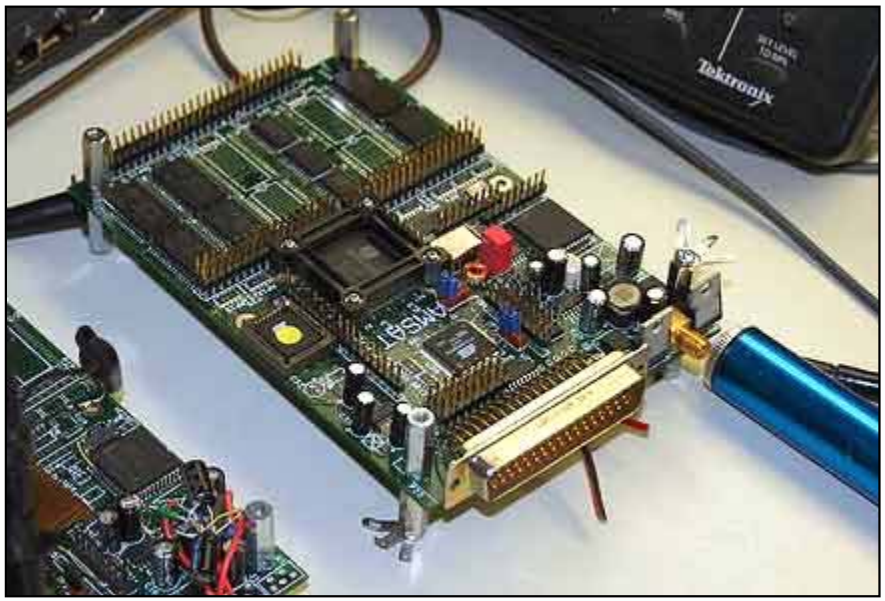
Amateur Satellites = Amateur Science

OSCAR 5	1970	First use of passive magnetic stabilization
OSCAR 6	1972	Codestore (CW Store and Forward) Message System), First Use of CMOS Chips
OSCAR 7	1974	Battery Charge Regulator, Store and Forward, First Emergency Beacon Locator Demo
OSCAR 11	1984	Imaging, Dust Impact Detectors, Geiger Counters, Digital Communications
OSCAR 14	1990	Packet Radio, 9.6K Data Rate, Imaging, Digital Store and Forwarding
OSCAR 23	1992	Wide and Narrow Imaging, Cosmic Ray detection, radiation dose monitor
OSCAR 24	1993	2.4GHz S-Band Transponder
OSCAR 25	1993	Imaging, IR Sensor Experiment
OSCAR 28	1993	38k4 Digital Link, GPS Experiment, Star Sensor, Cosmic Ray Detection, DSP
OSCAR 34	1998	Direct Sequence Spread Spectrum
OSCAR 36	1999	1MB/Sec Digital, Viterbi encoding
OSCAR 38	2000	First Automatic Launcher (6 Picosatellites)
OSCAR 39	2000	Space Plasma Experiment
OSCAR 43	2001	Solar Cell and Mirror Experiment
OSCAR 45	2001	Tunneling Horizon Detector (JPL/Stanford), Digital Camera
OSCAR 51	2004	Simultaneous Voice and High Speed Data
OSCAR 53	2005	Cold Gas Attitude thrusters, High Resolution Color Imaging, Cubesat Launcher

AMSAT
Amateur Satellites For the 21st Century

P3E and Eagle - The Next Generations

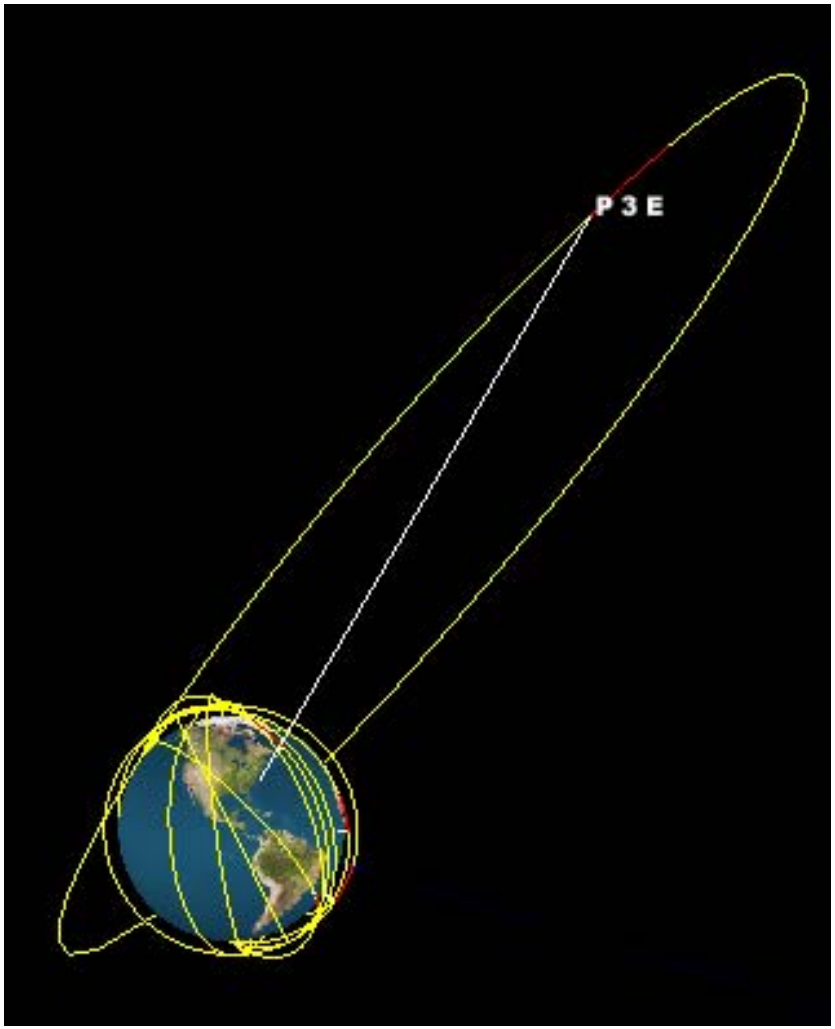
- **AMSAT has a goal to launch three HEO satellites over the next 6 years**
- **The goal is to provide 24/7 global coverage**
- **P3E Express is being built by AMSAT-DL in Germany**
- **AMSAT Eagle I and II are being built by AMSAT-NA**
- **Shared Technologies**
  - Can Bus module controllers
  - Software defined transceivers
  - Integrated housekeeping unit
  - Control software and antennas
- **TSFR (this space for rent) experimental module space**



AMSAT
Amateur Satellites For the 21st Century

P3E Overview

- Next HEO – built by AMSAT-DL to be launched in 2007
- Many linear SSB/CW passbands available to amateurs
- Mars Mission transponder experiment
- Highly elliptical orbit approx. 42,000km x 1200km X 62 deg
- Orbits approx. every 14 hours
- Coverage will be hemispheric when P3E is at apogee



AMSAT
Amateur Satellites For the 21st Century

P3E Proposed Frequency Chart

AMSAT-Phase 3E Transponder Frequencies				
Band	**Analog Uplinks**	**Analog Downlinks**	**RUDAK Uplinks**	**RUDAK Downlinks**
10 M			29.500 +/- 5 kHz	
2 M		145.845 - 145.945		145.837 - 145.837
70 cm	436.050 - 436.150		436.200 - 436.350	
23 cm (1)	1268.600 - 1268.750		1268.775 - 1268.925	
23 cm (2)	1260.100 - 1260.250		1260.275-1260.425	
13 cm (1)		2400.275 - 2400.425		2400.600 - 2401.000
13 cm (2)	2450 +/- 50 kHz			
6 cm	5668.600 +/- 25 kHz			
X-Band		10450 +/- 50 kHz		
K-Band		24048.300 +/- 25 kHz		
R-Band		47088.300 +/- 25 kHz		

AMSAT
Amateur Satellites For the 21st Century

AMSAT Eagles I and II

- Launches planned for 2009 and 2011 (preferably from Kennedy Space Center)
- HEO orbits, 13-30 deg inclination (similar to AO-40)
- C-C Rider transponder is a C-Band in-band system that will allow operation from one small (60cm) dish antenna
- V, U, L and S linear transponders
- Beacons and TLM in all bands
- Phased antenna array to minimize squint

OK – How Does One Get Started?

There are five factors that determine success

I. **Success with satellites is largely determined by imagination. If you can imagine it, you can most likely do it.**

II. **Set a budget and set expectations appropriately.**

III. **Keep your mind open to other alternatives and opinions.**

IV. **Find resources to help you get answers (mostly on the web), and know who you can go to for answers.**

V. **Using amatuer satellites is a skill, and like any skill there is a learning curve. Realize that success will come in stages as your skill level increases.**

AMSAT
Amateur Satellites For the 21st Century

2006 AMSAT Space Symposium

- The 2006 Symposium will be held at the Crowne Plaza hotel in Foster City, October 6-8 2006
- Friday, Saturday and Sunday presentations and demonstrations
- General Membership Meeting on Friday
- Awards Banquet with keynote speaker on Saturday Evening
- Exciting Tours
- Door Prizes, Vendors and More!
- Sponsored by Project OSCAR

Information on the web

- AMSAT North America –http://www.amsat.org
- Project OSCAR – http://www.projectoscar.net
- AMSAT Germany – http://www.amsat-dl.org
- Cubesats - http://cubesat.calpoly.edu/_new/index.html
- K5OE - http://members.aol.com/k5oe/
- N1DID – http://www.planetemily.com
- APRS – http://cadigweb.ew.usna.edu/~bruninga/aprs.html
- ARISS - http://www.rac.ca/ariss/
- ARRL - http://www.arrl.org/tis/info/satellite.html

AMSAT
Amateur Satellites For the 21st Century

Join AMSAT!

- AMSAT membership starts at $44 per year
- Membership includes subscription to the AMSAT Journal and discounts on publications, software and apparel
- Your membership helps to support the amateur satellite effort in North America
- Help Hatch Eagle! Contributions for specific satellites are greatly appreciated (and tax deductible.)

Thank you!

(And remember – please donate to AMSAT)

Questions and Answers…