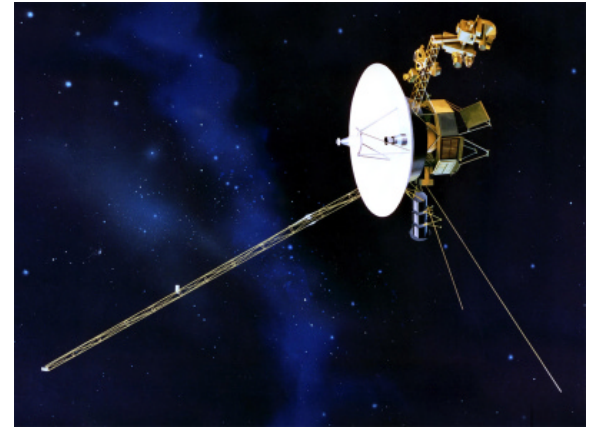


Reception of Voyager 1 the best DX ever!



Achim Vollhardt, DH2VA/HB9DUN
Amsat-UK Colloquium 2006
July 29th, 2006



Overview

- Some basics
- Teaming up
- Data Mining
- Calculations+Simulations
- Hardware
- Let's go!
- Results and Outlook



Some basics

- Deep space probes transmit in X-band: 8400-8450 MHz
- Biphase PSK modulation
- Deep Space Network uses 34&70 m dishes
→ beyond our capabilities
- +/- 90 deg modulation would result in complete carrier suppression
- Probes use 60 or 70 deg: residual carrier (enhances tracking loop robustness in receiver)
- Typical carrier suppressions: -6 or -10 dB
- Amateurs CAN receive this constant carrier with small RX bandwidths and small antennas



First ideas

- Sept '04: Attended lecture of Paul Horowitz at physics conference : "SETI uses Voyager as beacon"
- Asked Jill Tarter for information (director SETI Institute)
- Response by SETI institute member just 24h later !
- James Miller, G3RUH confirmed possibility of detection with Bochum's 20m dish
- Target date:
30 year anniversary Amsat-DL at Sept 24, 2004
→ No success
- Reactivated idea on beginning of March 2006





Pull together the team

- James Miller, G3RUH
- Freddy de Guchteneire, ON6UG
- Hartmut Paesler, DL1YDD
- Achim Vollhardt, DH2VA

And many more..!





Ask the experts !

- Write email to Voyager mission PI : Prof. Edward C. Stone
- Got forwarded via Mission Manager to Mission Telecommunications Analyst Roger Ludwig
- Provided us with valuable and steady flow of information



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From: Ed Stone <. .>

Date: March 2, 2006 8:20:26 AM PST

To: Ed Massey <. .>

**Subject: Fwd: Technical Question to Voyager
radio downlink**

**Ed- I doubt they can detect VGR with an 18 m
dish and amateur receivers, but could some
one respond to this? Thanks, Ed**

Nevertheless .. thank you all!



Data mining

DEep
Space
Communications
And
Navigation
Systems
Office

DESCANSO

(descanso.jpl.nasa.gov)

- Has detailed (!) communications link information for multiple deep space missions
- Provided us with almost everything...

NASA Jet Propulsion Laboratory California Institute of Technology + View the NASA Portal

JPL HOME EARTH SOLAR SYSTEM STARS & GALAXIES TECHNOLOGY

DESCANSO
Deep Space Communications and Navigation Systems

DESCANSO HOME RELATED SITES FEEDBACK

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Welcome to DESCANSO
- A JPL Center of Excellence

Vision
Continuous Communication
Precise Navigation
Anytime
Anywhere

Mission
To Promote Excellence
and Innovation in Meeting the
Communications and navigation
Needs of Future Space Exploration Missions

Excellence
Innovation
Navigation
Communications

Ordnance Release No.: CL 01-1004
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What's New:
► Propagation Program - Ka-Band Studies
- Added "Estimation of Microwave Power Margin Losses Due to Earth's Atmosphere and Weather in the Frequency Range of 3-30 GHz" and "Ka-Band Propagation Model Based on High Resolution ACTS Data"

FIRSTGov
For First Choice in U.S. Government

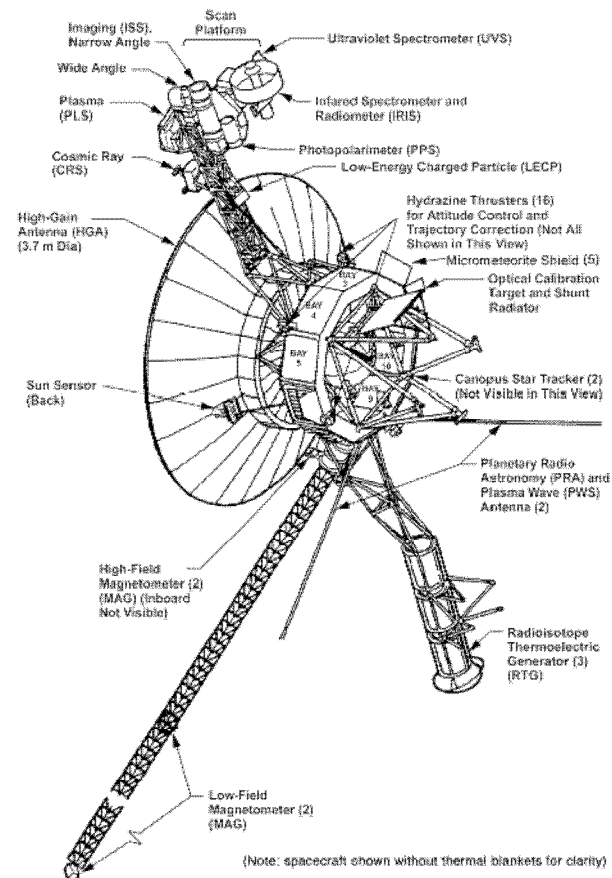
+ IND
+ Telecom Link Design HB (000010-005)
+ IND Progress Report

NASA
Site last updated on June 15, 2005.
Site Curator: Joseph Yu
Site Developers: Tu-Ping Phan, Cara Cheung, Gerald Orsini



Voyager Spacecraft

- Three-axis stabilized s/c
- 3.74 m diameter HGA
- Radioisotopic Thermoelectric Generator (RTG)
- Mission life determined by
 - Hydrazine fuel (2040)
 - RTG power (2020)
 - Funding (4 Mill. USD per year)
- Magnetometer on 13 m long boom
 - Needs to be calibrated about 6 times per year (MAGROL)



(Note: spacecraft shown without thermal blankets for clarity)



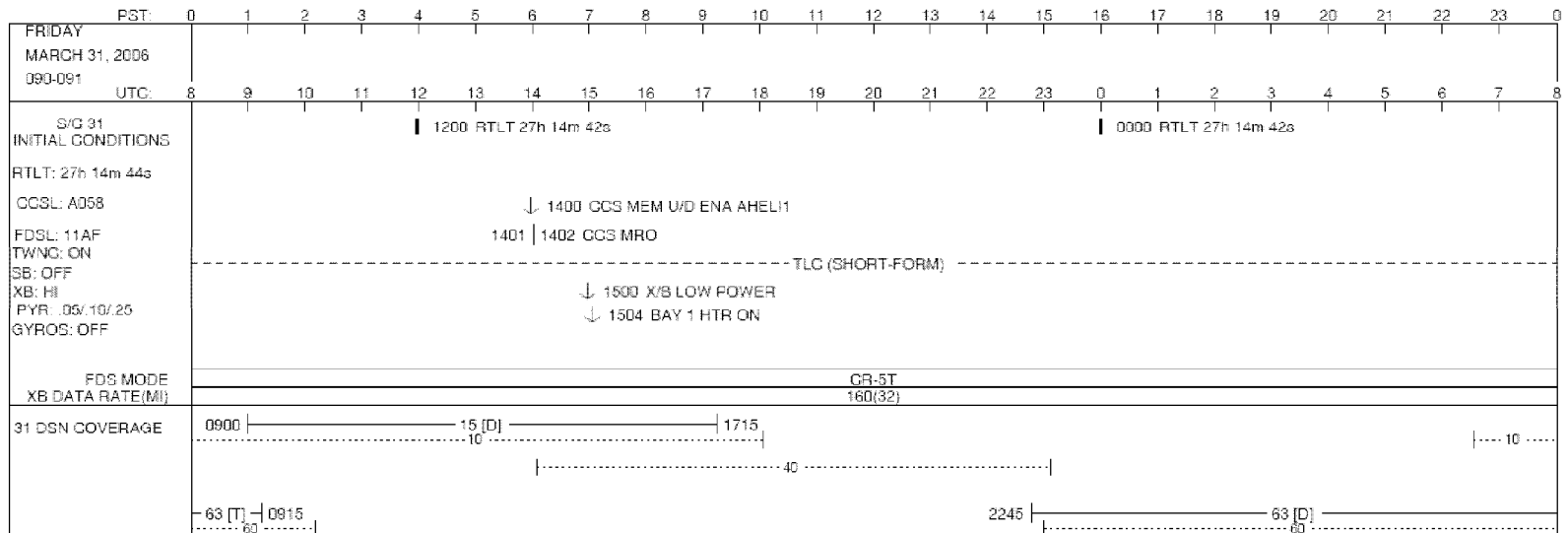
Voyager link parameters

- Frequency: 8415.000000 MHz (non-coherent)
8420.432097 MHz (coherent)
- Polarisation: LHCP (not RHCP!) since failure of TWTA-2 in 1987
- Transmit power: 12/18 W in low/high power mode
- Carrier suppression: -6 dB
- Data rate: 160/1400 bps
- UltraStableOscillator (USO) failed in Sept. 1992,
Voyager 1 relies now on crystal AUXOSC



SFOS: space flight operations schedule

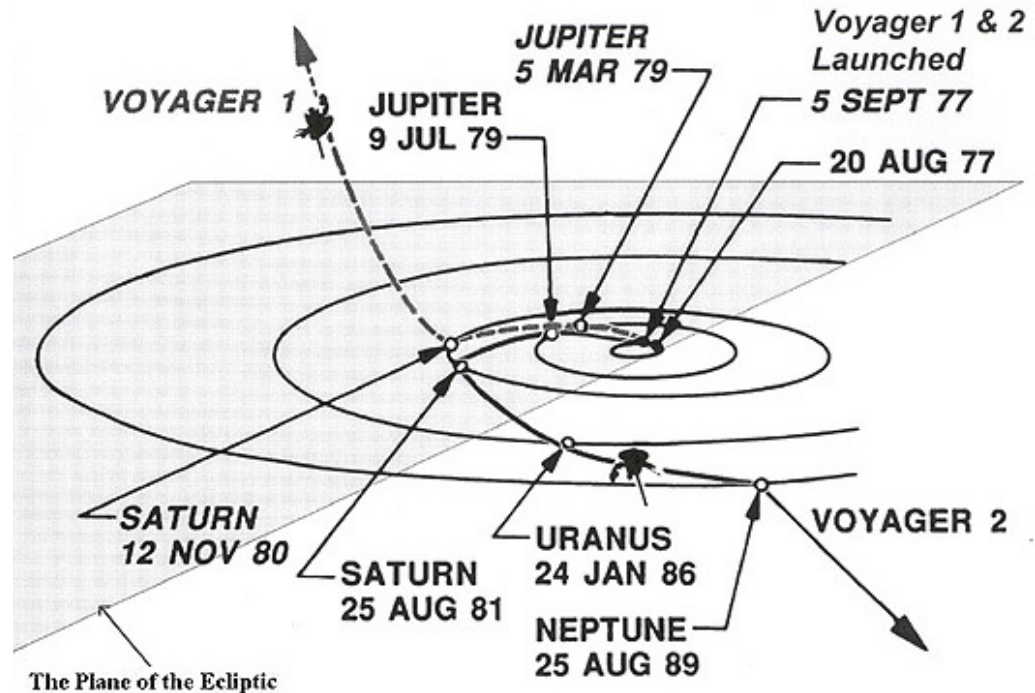
Available on Voyager Mission Homepage: <http://voyager.jpl.nasa.gov>





Where are Voyagers today?

- Voyager 1:
98 AU
(northbound)
- Voyager 2:
80 AU
(southbound)



© NASA/JPL



One-way 'Radar' equation

Standard version:

$$\begin{aligned}\text{Path loss [dB]} &= 20\log(fR) + 20\log(4\pi/c) \\ &= 20\log(fR) + (-147.55 \text{ dB}) \quad (f = [\text{Hz}], R = [\text{m}])\end{aligned}$$

Set $f = 8.4 \text{ GHz}$ and express R in astronomical units $\rightarrow$

DH2VA version:

$$\text{Path loss [dB]} = 20\log(R) + 274.4 \text{ dB} \quad (R = [\text{AU}])$$



How to use?

- 1 AU distance → path loss = 274.4 dB
 - 1.5 AU (Venus today) → path loss = 276.2 dB
 - 2.5 AU (Mars Today) → path loss = 278.8 dB
 - 100 AU distance → path loss = 314.4 dB
-
1. Find out EIRP of spacecraft carrier :
Transmit power + antenna gain - carrier suppression
 2. Subtract path loss
 3. Add RX antenna gain
 4. Compare to receiver noise in assumed bandwidth (1 Hz)
 5. Result: Signal-to-Noise Ratio in 1 Hz Bandwidth



Transmit side

Find out EIRP of spacecraft (DESCANSO + Google):

- MRO:
100 W (50 dBm) + 3m dish (45.5 dBi) = 95.5 dBm (3.5 MW !)
carrier suppression -10 dB: 85.5 dBm
- VEX:
65 W (48.1 dBm) + 1.3m dish (38.3 dBi) = 86.4 dBm (436 kW)
carrier suppression -10 dB: 76.4 dBm
- Voyager 1:
18 W (42.5 dBm) + 3.74 m (48.2 dBi) = 90.7 dBm (1 MW)
carrier suppression -6 dB: 84.7 dBm



Receive side

- Antenna gain

$$G = 10^{*}_{10} \log(\eta^{*}(\pi^{*}D/\lambda)^2)$$

- System temperature (Noise figure) → Noise power in 1 Hz

$$P = k^{*} T_{sys}^{*} B$$



Results for Bochum

- Diameter : 20 m
- Efficiency : 55%
- Gain: $G = 61.9 \text{ dBi}$
- Moon noise : 3.3 dB $\rightarrow$ $T_{\text{sys}} = 189 \text{ K}$
 $P = k * T * B = \underline{\underline{-175.8 \text{ dBm}}}$

spacecraft	EIRP	Path loss	Gain	Noise	SNR (1 Hz)
VEX	76.4	276.2	61.9	-175.8	37.9
MRO	86.5	278.8	61.9	-175.8	45.4
Voyager 1	84.7	314.4	61.9	-175.8	8.0



Detection principle

- Depending on signal level:
 - 40 dBHz: can be easily heard in speaker
 - 20 dBHz: can be heard with headphones
 - <20 dBHz: requires DSP (soundcard)
 - <10 dBHz: requires integration >1 sec
- Display signal power vs. AF frequency (Fourier display)
- Waterfall display: color code signal strengths and plot one line per integration period
- Integration: average over multiple FFT's and plot only one line for x FFT's: noise evens out, while signal persists



Performance Simulation

- G3RUH generated sample WAV files with 3 dBHz (735 seconds) to test analysis techniques
- G3RUH used own analysis package, same algorithm implemented in SCILAB (DH2VA)
 - Record audio samples
 - Perform FFT
 - Add to previous FFT results (integrate)
 - Use 10 Hz convolution filter to compensate for finite VFO step size
- Same algorithm on two different machines and software packages perform equally well and within expectations

