

Huygens Titan Experiment Rescued

After a failure aboard the Cassini Saturn probe, radio telescopes and digital data recorders on earth “hear” and record wind data in Titan’s atmosphere.

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A radio-telescope network strategically positioned around the globe and organized only six months before it was needed, coupled with high-speed disk recording and playback systems at ground stations, saved a crucial space experiment that was more than eight years in the making. On October 15, 1997, the NASA Cassini orbiter and the European Space Agen-

cy’s (ESA) Huygens atmospheric probe were launched toward Saturn and its largest moon, Titan, on an eight-year journey covering more than 2 billion miles.

On January 14, 2005, after separating from the Cassini spacecraft three weeks earlier, the Huygens probe began its descent to Titan’s surface as the first probe to land on the surface of a moon of an-

other planet. The Doppler Wind Experiment, conceived by NASA’s Jet Propulsion Laboratory (JPL), was designed to create an accurate profile of Titan’s winds along the probe’s descent trajectory as it dropped for 2 1/2 hours through the thick atmosphere of Titan.

Aerodynamic fins on the Huygens probe generated a slow controlled spin as

the probe descended beneath a parachute. Winds in the atmosphere affected the horizontal speed of the probe's descent; the component of the motion in the direction of the Earth produced a slight Doppler shift in Huygen's radio frequency of the signal as received on Earth, allowing that velocity component to be measured.

Critical additional measurements were conducted using Very Long Baseline Interferometry (VLBI), which used a global array of radio telescopes that simultaneously recorded the Huygens signal, as well as radio signals from a quasar nearby in the sky. When these recordings were cross-correlated and analyzed, the position of the Huygens probe on the two-dimensional plane of the sky was determined to within a few meters at the position of Titan.

Combining the Doppler measurements and the VLBI measurements allowed scientists to reconstruct an extremely accurate three-dimensional record of the motion and position of the probe during its descent to the surface. From this information, they were able to deduce the speed and direction of the winds at varying altitudes, concluding that Huygens encountered winds as high as 250 MPH during some parts of its descent.

Originally, the experiment called for measuring the Doppler shift in the probe's signal frequency both by the Cassini mother spacecraft and by ground-based radio telescopes in the U.S., Australia, Japan and China. Cassini was best positioned to gain information on the east-west component of the winds, and the ground-based telescopes were positioned to determine the north-south wind component.

Unfortunately, the Cassini wind data were lost due to an onboard configuration problem that prevented the re-transmission of the Huygens signal to the Earth with its high-gain antenna. Had the VLBI data not been available, only the single component of the probe's motion from the Doppler-shift data would have been available, considerably compromising the value of the

experiment.

It was the good fortune of forward-thinking scientists to conceive the VLBI experiment as a backup plan just six months before the Titan encounter. Under the leadership of Dr. Leonid Gurvits of the Joint Institute for VLBI in Europe (JIVE), a global network of radio telescopes was created, nearly all of which recorded the Titan and quasar signals onto Mark 5 high-speed, digital data recorders developed by MIT Haystack Observatory in collaboration with Longmont, Colorado-based Conduant Corporation.

Conduant's StreamStor direct-to-disk technology replaced MIT's earlier-generation magnetic tape systems that were unreliable, expensive to maintain and cumbersome to manage. MIT realized that the cost of disk storage was dropping rapidly and would soon fall below that of the special-purpose tapes being used at the time, concluding that the next generation of the VLBI data systems should be based on commercial off-the-shelf components (COTS) using standard IDE hard disk drives. Thus was born the Mark 5, which is now the global workhorse VLBI data acquisition system with more than 100 units deployed to more than 15 countries. StreamStor technology forms the foundation of the data capture process in these Mark 5 systems, the same ones that captured the faint signals from the Huygens experiment.

Mark 5 (Figure 1) is the first high data rate VLBI data system based on magnetic disk technology capable of sustained recording and playback at rates in excess of 1 Gbit/s. This PC-based disk recording

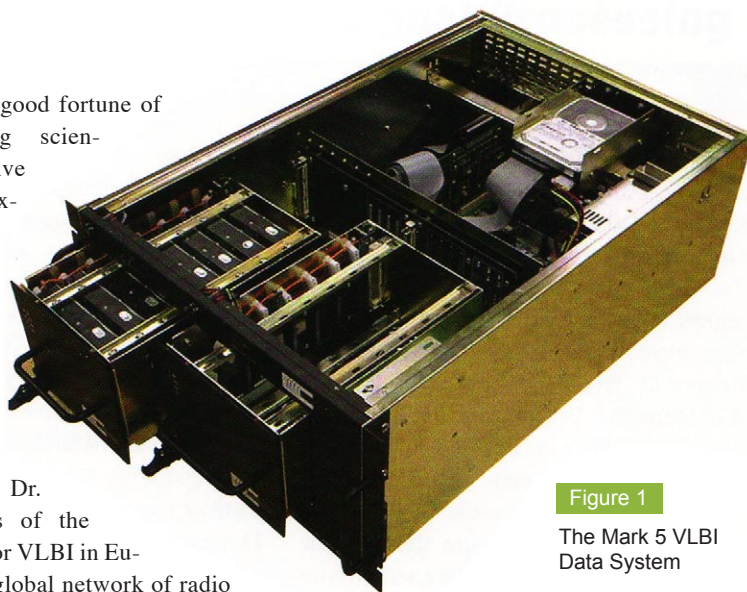


Figure 1
The Mark 5 VLBI
Data System

system flawlessly acquired the weak signals from the radio telescopes and allowed scientists to measure the probe's movements through Titan's dense atmosphere. And once again, embedded controllers, often the unseen workhorses in scientific research and industrial applications, had their "night in the moonlight" as they recorded the barely perceptible radio signals emanating from Huygens high above the Titan moon.

VLBI

VLBI is a technique that links multiple antennas together to act like a single large radio telescope and provides many of the advantages of having a giant radio dish as large as the distance separating the telescopes. The VLBI technique involves simultaneous reception of radio signals at the participating antennas, with each antenna operating independently using a highly accurate atomic clock to control time and frequency. The antennas at MIT Haystack were developed for them by Rockwell Corporation. Bob Vessot of CfA designed the physics package for MIT Haystack's atomic clock and Haystack engineers designed the electronics. The radio signals from the Huygens probe were recorded along with embedded timing marks onto the Mark 5's disks at a sustained rate

The ability to study the scientific wind data was made possible by the ultra-high-speed desk-based Mark 5, which was the workhorse of the Huygens wind experiment.

of 512 Mbits/s. The disks were shipped to JIVE in The Netherlands for processing on a large correlator system designed by JIVE and MIT Haystack Observatory.

Leading the list of 20 large antennas involved in the Huygens observations were the 100-meter-diameter NRAO Robert C. Byrd Green Bank Telescope (GBT) in West Virginia and the 64-meter-diameter CSIRO Parkes Radio Telescope in Australia. Special instrumentation was designed to receive the weak signals at 2040 MHz and measure the Doppler shift of a narrow-band “carrier” (tone) frequency transmitted by the Huygens probe. The VLBI signals were received by wideband receivers and recorded to Mark 5 systems. The VLBI component of the Doppler Wind Experiment was coordinated by the JIVE and ESA; the NASA Jet Propulsion Laboratory conducted the Doppler measurements.

Mark 5 Data System

The Mark 5 data system incorporates primarily low-cost PC-based COTS components and supports standard network connections. It accommodates sustained

recording and playback data rates up to 1024 Mbits/s, recording to an array of eight low-cost removable IDE/ATA disk modules. The disks are organized into two 8-pack modules that may be used in a ping-pong fashion for near continuous recording and playback. The 2 1/2 hour recording at 512 Mbits/s from the Huygens probe saved the Doppler Wind Experiment that scientists waited eight years to conduct.

The heart of the system that recorded the invaluable Huygens VLBI data is a “StreamStor” disk interface card from Conduant that is specially designed for high-speed real-time data collection and playback. The StreamStor card supports three physical interfaces in a “triangle of connectivity” as show in Figure 2; a maximum sustained data-transfer rate of 1200 Mbits/s can be maintained in either direction between any two vertices of the triangle, though only one connection path may be exercised at a time. The path exercised for traditional VLBI observations is between the FPDP bus and the disk array. In this mode, the VLBI data never touch the PCI bus, so the speed of the PC platform

is largely irrelevant. The path between the disk array and the PCI bus allows the PC to read and verify VLBI data written on the disks, or to send data via high-speed network connections. An onboard 512 Mbyte buffer provides the necessary “elasticity” between the three connection nodes to support real-time operation.

The StreamStor supports a module-switching mode that automatically switches from one module to another when the first is filled. This capability, along with hot-swappable modules, allows continuous data to be taken for an indefinite period of time. If one or more of the disks fail during recording, the recording load is automatically re-balanced to the other disks. If a disk or disks fail or are missing during playback, the Mark 5 fills any data gaps with a user-specified data pattern that can be detected and cause the data to be invalidated at the correlators.

Today, StreamStor direct-to-disk technology records data continuously, for days at a time, at sustained rates of up to 400 Mbytes/s. Scientists are confident that the wind data from the Huygens probe, once fully analyzed, will provide them with unprecedented knowledge about the winds swirling within Titan’s dense atmosphere. The ability to study the scientific wind data was made possible by the ultra-high-speed disk-based Mark 5, which was the workhorse of the Huygens wind experiment.

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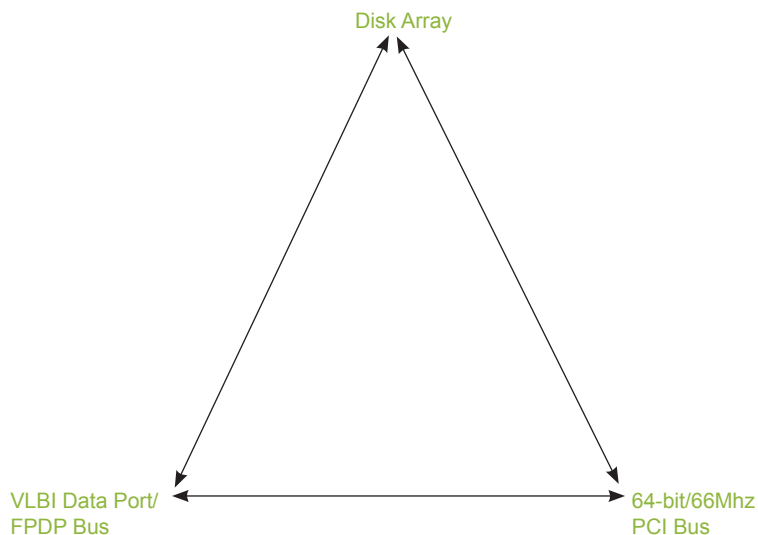


Figure 2 “Triangle of connectivity” of the StreamStor interface card.