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DSN Acquisition of Magellan High-Rate Telemetry Data

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The Magellan Project levied the stringent requirement of a 98-percent high-rate telemetry data capture rate on the Deep Space Network (DSN) during the Magellan Prime Mapping Mission. To meet this requirement, the DSN undertook extensive development of the DSN Telemetry System, as well as extensive DSN operations planning and test and training. In actuality, the DSN substantially exceeded the requirement by achieving a Prime Mapping Mission high-rate telemetry data capture rate of 99.14 percent.

This article details the DSN telemetry system development, and DSN operations planning and test and training. In addition, the actual high-rate telemetry data outages are comprehensively presented and analyzed.

I. Introduction

The preeminent science objective of the Magellan mission to Venus was the Synthetic Aperture Radar (SAR) mapping of 90 percent of the surface of Venus. To meet this objective, the Magellan Project levied a requirement on the Deep Space Network (DSN) to successfully acquire 98 percent of all available Magellan high-rate telemetry data (which contains the SAR mapping data). The DSN committed to a data capture rate of 96 percent and adopted a high-priority goal of achieving a 98-percent data capture rate.

In fact, the DSN achieved a composite Magellan high-rate telemetry data capture rate of 99.14 percent during the eight-month Magellan Prime Mapping Mission.

This article describes the DSN Telemetry System development and operations planning that allowed the DSN to capture over 99 percent of the available data. Also described are the detailed statistics of the DSN data outages.

II. Mission Overview

The Magellan spacecraft was launched on its 15-month trajectory to the planet Venus, from the Kennedy Space Center, at 11:46:00 Pacific Daylight Time (PDT) on May 4, 1989. Venus Orbit Insertion (VOI) occurred at 10:06:00 PDT (ground observed time) on August 10, 1990, but was not directly observed from Earth because the spacecraft was occulted by Venus. Shortly thereafter, at 10:06:38 PDT (ground observed time), the spacecraft emerged from behind Venus, which indicated that the spacecraft solid rocket motor burn had properly executed and had thereby placed Magellan into the desired (approximately) three-hour orbit about Venus.

Following the successful VOI, the Project began its in-orbit checkout (IOC) activities, which were nominally scheduled for three weeks, thus allowing a start of mapping operations on September 1, 1990. However, during the first IOC radar mapping test on August 17, the Magellan signal was lost and not fully recovered for approximately 12 hours. A second signal loss incident occurred on August 22, with the signal being recovered approximately 20 hours later.

During early September 1990, the Project continued to analyze the spacecraft signal disappearance incidents and took steps to lessen the likelihood of such incidents in the future. In the second week of September, the Project gradually restored the spacecraft to full functionality.

On September 15, 1990, at 9:29:42 PDT, the Magellan Project inaugurated mapping operations using the 34-meter antenna array at Goldstone. With the exceptions of superior conjunction (November 1990) and very occasional spacecraft malfunctions and Ground Control Team errors, DSN support of Magellan high-rate telemetry data, from September 15, 1990, through January 1992, has essentially been continuous.

III. DSN Telemetry System

The DSN Telemetry System at each Deep Space Communications Complex (DSCC) acquires, demodulates, decodes, and records the Magellan 268.8-Kbps high-rate telemetry data that contains the radar mapping data.

The major functions of the DSN Telemetry System can be stated as follows:

(1) Receive the radio frequency (RF) carrier and process to baseband.

(2) Demodulate the carrier and subcarriers.

(3) Perform symbol synchronization and data decoding.

(4) Perform frame synchronization to the transfer frame level.

(5) Format data and interlace status information.

(6) Generate Original Data Records.

(7) Transmit telemetry data from the Signal Processing Centers to the Space Flight Operations Center (SFOC) at JPL.

The DSN telemetry data flow path is shown in Fig. 1. The antenna collects the signal under the control of the Antenna Mechanical Subsystem. The low-noise maser amplifies the S-band (2297.962963-MHz) and/or X-band (8425.864197 MHz) signals in the Antenna Microwave Subsystem. The ultrasensitive S- and X-band receivers detect and downconvert the signals in the Receiver-Exciter Subsystem. The Telemetry Subsystem extracts the telemetry symbol streams from the downconverted signals, decodes the symbol streams into bit streams, and synchronizes them to the bit streams, which are the desired telemetry data. Finally, the Ground Communications Facility formats, records, transmits, and routes the telemetry data to the Project.

IV. DSN Telemetry System Development

The DSN began planning for Magellan mission support in 1982. It was almost immediately recognized that the Project intent of transmitting 268.8 Kbps of mapping data for two hours out of every three, continuously during the eight months necessary to fully map (one complete revolution of) Venus, would require very significant modifications to the then-existing DSN Telemetry System. The Magellan requirements that most significantly affected the DSN Telemetry System were as follows:

(1) The ability to simultaneously receive and process two coded downlink channels (one high-rate X-band and one low-rate S- or X-band). The high-rate X-band channel carries high-rate mapping telemetry, and the low-rate S- or X-band channel carries low-rate real-time engineering telemetry.

(2) The ability to receive, process, record, and simulate a high-rate coded telemetry downlink with a data rate of 268.8 Kbps.

(3) The ability to perform telemetry data acquisitions from the receiver through the frame synchronizer within one minute.

Figure 2 provides a more detailed diagram of the DSN Telemetry System at a DSCC and illustrates the assembly-level modifications that were necessary to support Magellan telemetry requirements.

To support a Magellan telemetry data acquisition requirement of one minute, extensive modifications were necessary for both the receiver and the baseband assembly (BBA), which acquires the telemetry subcarrier and performs the signal demodulation and symbol synchronization. In the receiver, a fast fourier transform (FFT) algorithm was added, which allows a ±1-KHz X-band signal uncertainty band (which encompasses the Magellan uncertainties) to be searched, with subsequent signal lockup in less than 20 seconds. In the BBA, the subcarrier acquisition bandwidth was broadened from ±0.75 to ±5.5 Hz to encompass the Magellan uncertainties. An FFT-like acquisition algorithm was added, which initiates a subcarrier search utilizing a frequency loop; upon detection, the subcarrier is then switched to a phase locked loop (PLL) for subsequent tracking. Finally, hardware modifications were implemented in the BBA to increase overall processing speed. These BBA modifications provide subcarrier acquisition and processing in less than 40 seconds. Thus, the combination of receiver and BBA performance allows telemetry acquisition to be accomplished within the one-minute Magellan requirement, as compared with a typical premodification acquisition time of approximately 5–20 minutes.

To meet the Magellan requirement of a high-rate downlink data rate of 268.8 Kbps, the Maximum Likelihood Convolutional Decoder (MCD) assembly was modified to provide higher processing speed; the new maximum MCD data rate has been doubled from 135 to 270 Kbps. In addition, a second MCD was added to allow the simultaneous reception and processing of two downlink coded channels, as per the Magellan requirement.

A Frame Synchronizer subassembly was added to the DSN Telemetry Subsystem, thereby giving greater monitoring capability to DSN personnel at the DSCC's and the Network Operations Control Center. Finally, to record the high-rate mapping data, a new Digital Data Recording (DDR) assembly was added to the Ground Communications Facility. The new DDR increases the Telemetry System (single) magnetic tape ten-minute record capacity at 268.8 Kbps to over one hour, primarily by switching from 1650-bits/sec tape drives to 6250-bits/sec tape drives. In addition, the new DDR produces two tape copies simultaneously, allowing one copy to be air-freighted to the Magellan Project personnel in Pasadena, while the second remains at the DSCC as a backup in the event of a loss during shipment.

V. Orbital Operations Preparation

During the first half of 1990, intensive DSN and Magellan Project test and training activities were performed to prepare for orbital operations and, more specifically, for acquisition of the Magellan high-rate telemetry data. For the DSN, the most significant activities were the mission readiness test program and the cruise mapping test (CMT).

During January 1990, the DSN embarked on a four-month test and training program to prepare for mapping operations. Four major DSN mapping phase antenna configurations, including (1) 70-m stand-alone support, (2) 70-m and 34-m high-efficiency (HEF) X-band uplink support, (3) 34-m standard and 34-m HEF arrayed support, and (4) 70-m dual X-band subcarrier support, were tested several times at each DSCC. At the conclusion of these tests, on May 10, 1990, the DSN was adjudged to be operationally ready to support Magellan Mapping Operations.

During May 21–25, 1990, the Project performed the CMT, which was the final, full dress rehearsal for the upcoming mapping operations. During the four days of the CMT, the spacecraft continuously simulated all the events and high-rate telemetry data playbacks as if it were in a three-hour Venus orbit. DSN performance during this test was exemplary; 94 percent of all acquisitions were performed within the one-minute requirement, and 97.7 percent of the high-rate telemetry (simulated mapping) data was successfully acquired by the DSN. This high level of performance indicated that all DSN systems were operating correctly, and that the DSN operations personnel had achieved a high level of mapping operations proficiency.

VI. Telemetry System Performance During the Magellan Prime Mapping Mission

The Magellan Prime Mapping Mission began on September 15, 1990, and continued to May 15, 1991. During that time, one or more DSN stations continuously supported the Magellan spacecraft, with the exception of an approximately ten-day period centered about solar superior conjunction (November 2, 1990). During each 3.26-hour orbit, radar mapping data were acquired and recorded for approximately 37 minutes by the Magellan spacecraft at 804.6 Kbps. Subsequently these data were replayed (within the same orbit) in two separate, approximately 57-minute, playback periods at 268.8 Kbps. At the start of each playback period, the DSN had one minute available from the time of signal appearance to acquire the signal and lock up the end-to-end DSN Telemetry System to avoid the loss of any radar mapping data.

During the Prime Mapping Mission, the DSN kept detailed records, on a day-by-day basis, of the total minutes of data transmitted by the spacecraft and the total minutes of data lost due to failures within the DSN Telemetry System. For the entire Magellan Prime Mapping Mission, the high-rate telemetry data acquisition performance by the DSN was as follows:

$$\text{Total data available} = 172{,}509 \text{ min}$$

$$\text{Total data lost (all DSN)} = 1{,}478 \text{ min}$$

$$\text{DSN data capture rate} = 99.14 \text{ percent}$$

The above calculations exclude (from total data available) all losses attributable to either spacecraft problems, Ground Control Team errors, solar effects, or terrestrial weather. Interim reports on the DSN cumulative data capture rate were published on a weekly basis (more frequently during the first month), and can be seen in Fig. 3. As can be seen in that figure, performance throughout the Magellan Prime Mapping Mission was remarkably stable, with the slight, but pronounced, upward trend probably attributable to increased proficiency on the part of station operations personnel. The average (single-incident) data loss was slightly over six minutes, with typically five occurrences per week, throughout the entire DSN. During the Prime Mapping Mission, there were only five failures that resulted in data losses greater than 30 minutes, and these are characterized in Table 1. Total data losses were substantially reduced by employing considerable redundancy; approximately 70 percent of the playbacks were supported by two totally independent Telemetry Systems (antenna through data recording), and even when only one antenna was engaged, approximately 90 percent of these (single-antenna) playbacks were supported by two independent sets of telemetry data-processing equipment (demodulation through recording).

To further characterize the nature of the data outages, the data outages were divided into "large" and "small" regimes, defined as follows:

$$\text{"large"} : 30 \text{ min } \leq \text{outage}$$
$$\text{"small"} : 30 \text{ sec } \leq \text{outage } \leq 30 \text{ min}$$

Figure 4 shows the cumulative "large" data loss total throughout the primary mapping mission, while Fig. 5 shows the average "large" incidents per month, and Fig. 6 shows the average "large" data loss per incident. By the end of the Prime Mapping Mission, it is seen that "large" losses accounted for a total data loss of slightly under 0.30 percent, with an average occurrence per month of approximately 0.7, and an average duration of approximately 90 minutes per incident. These are basically random occurrences, and these values probably would be characteristic of continuous DSN support of any flight project.

Figure 7 shows the cumulative "small" data loss total throughout the Prime Mapping Mission, while Fig. 8 shows the average "small" incidents per day, and Fig. 9 shows the average "small" data loss per incident. By the end of the Prime Mapping Mission, it is seen that "small" losses accounted for a total data loss of slightly under 0.60 percent, with an average occurrence per day of approximately 0.75, and an average duration of approximately 6 minutes per incident. Probably the most significant aspect of the "small" data losses is the rather smooth decrease in daily incidence from approximately 2.0 at the start of mapping, to approximately 0.75 at the conclusion. Undoubtedly, at least a significant portion of the decrease in "small" incidents is due to increase in operator proficiency, as the complex Magellan operational sequence was repeated many times each day at each DSCC.

Finally, statistics were kept on data unavailability due to terrestrial weather. Weather incidents in general were wind, rain, or snow. Figure 10 shows the cumulative weather data unavailability throughout the Prime Mapping Mission, while Fig. 11 shows the average data unavailability per weather incident. By the end of the Primary Mapping Mission, it is seen that weather accounted for a total data unavailability of approximately 0.20 percent, with an average data unavailability per incidence of approximately 25 minutes.

Table 1. Discrete DSN data losses in excess of 30 min.

Date	Complex	Loss, min	Failure characterization
October 1, 1990	Madrid	122	Hardware—complex-wide power failure
November 12, 1990	Canberra	147	Hardware—complex-wide failure of frequency and timing system
December 10, 1990	Canberra	48	Documentation—error in predicted acquisition frequency
April 10, 1991	Madrid	44	Hardware—antenna azimuth decoder power supply failure
April 25, 1991	Goldstone	108	Procedural—mislabled cables caused loss of connection to data recorders

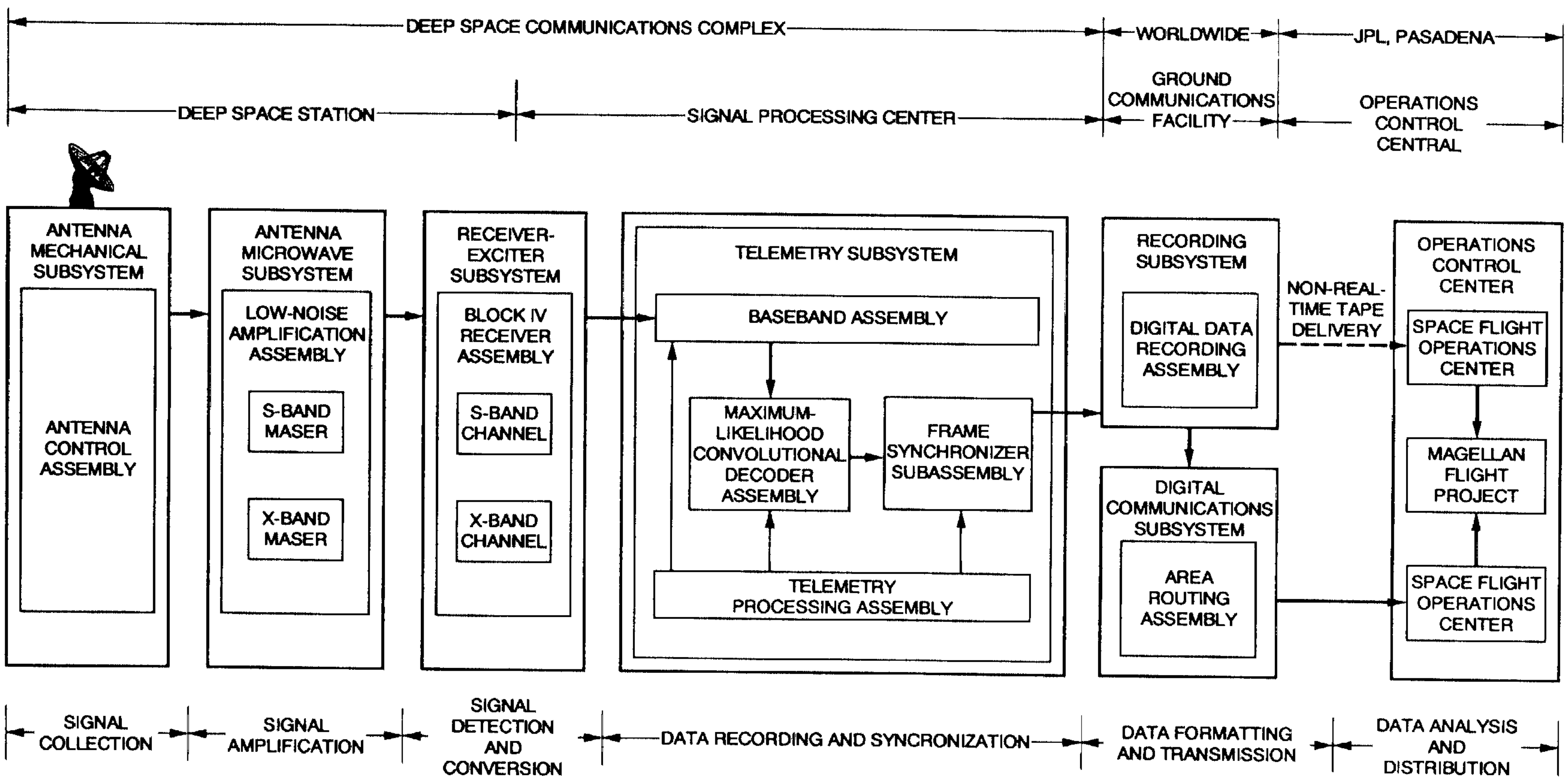

Fig. 1. Network telemetry data flow path.

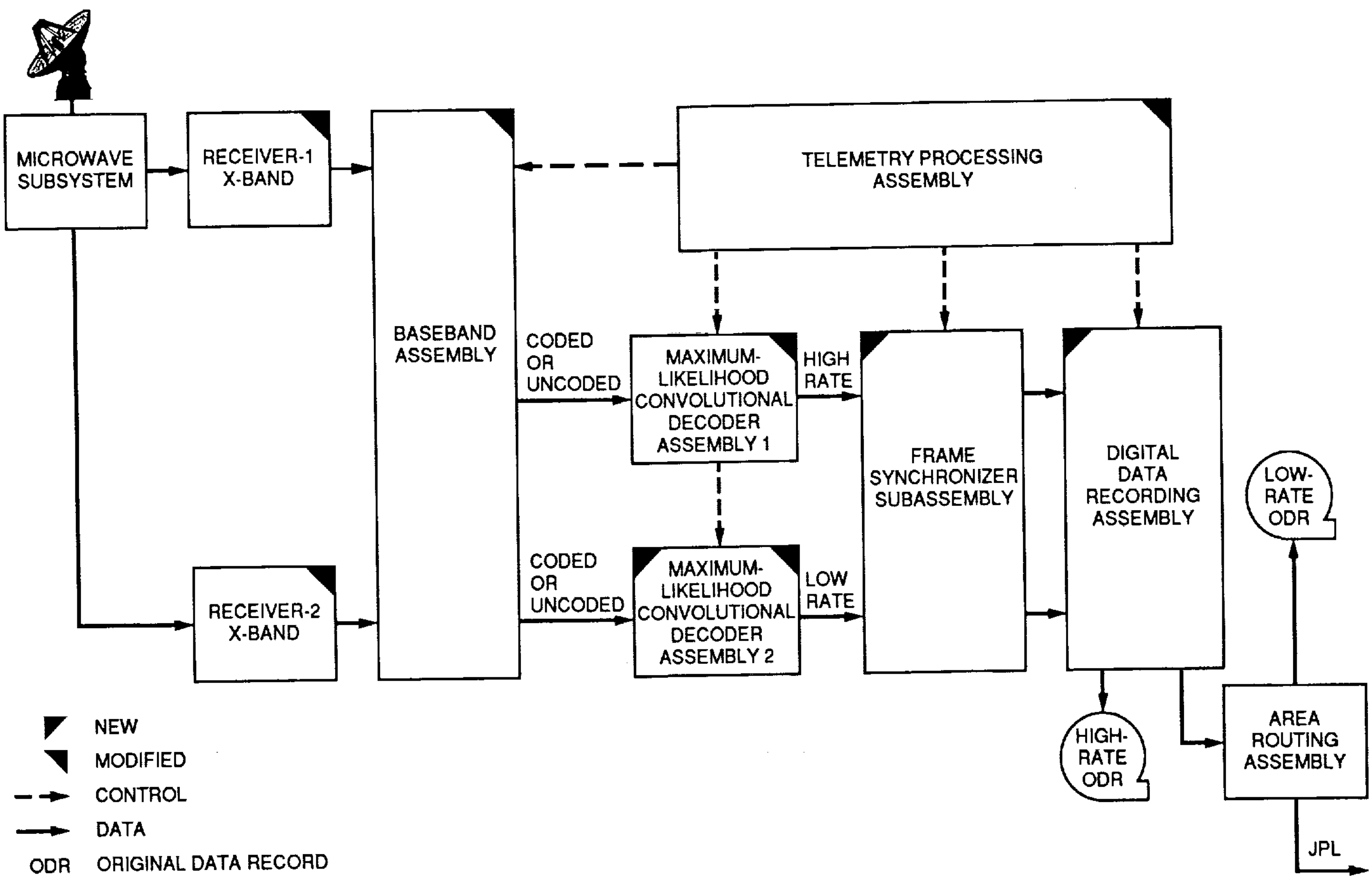

Fig. 2. Telemetry block diagram.

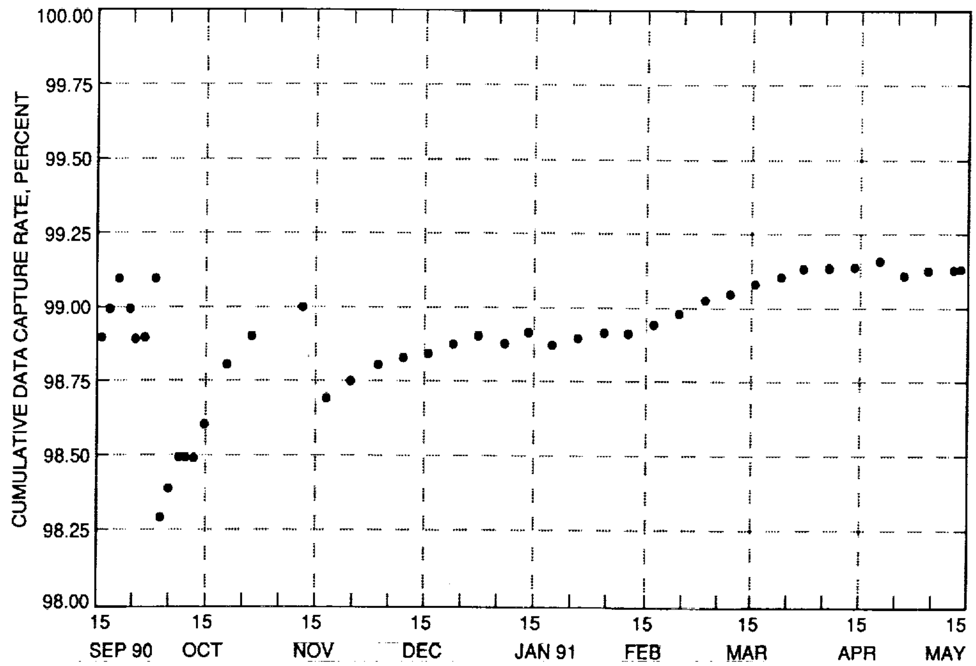

Fig. 3. Magellan high-rate telemetry cumulative data capture rate.

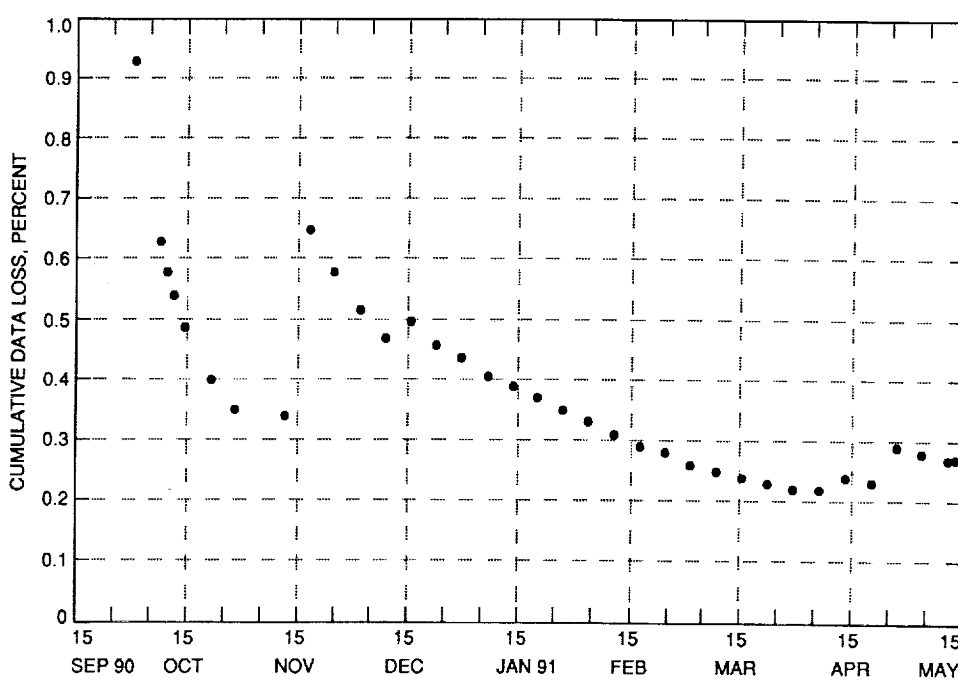

Fig. 4. Magellan high-rate telemetry, "large" data losses >30 minutes.

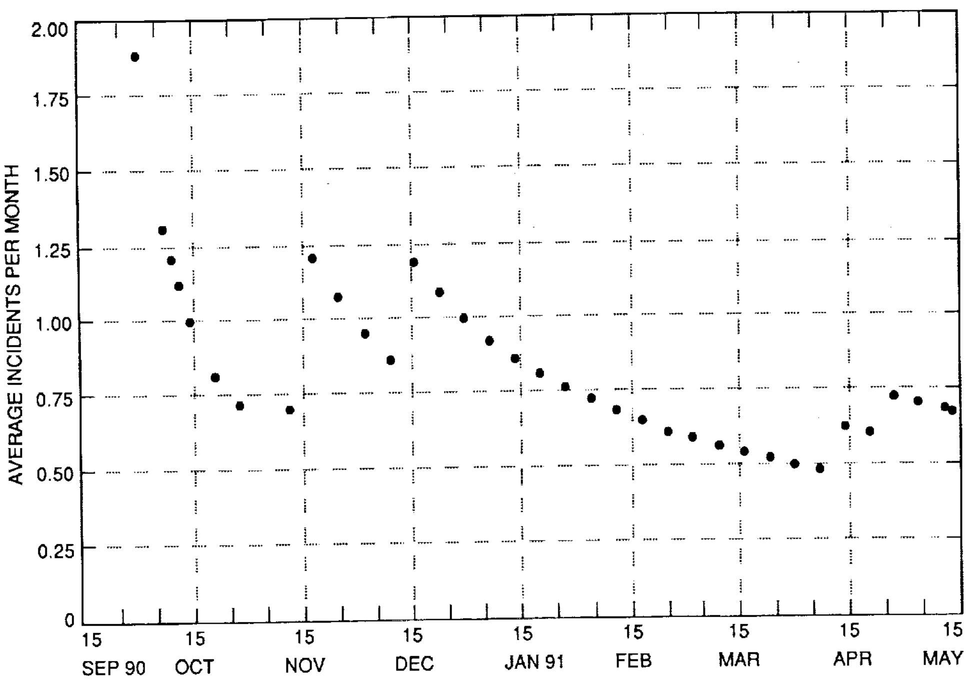

Fig. 5. Magellan high-rate telemetry, average "large" incidents per month.

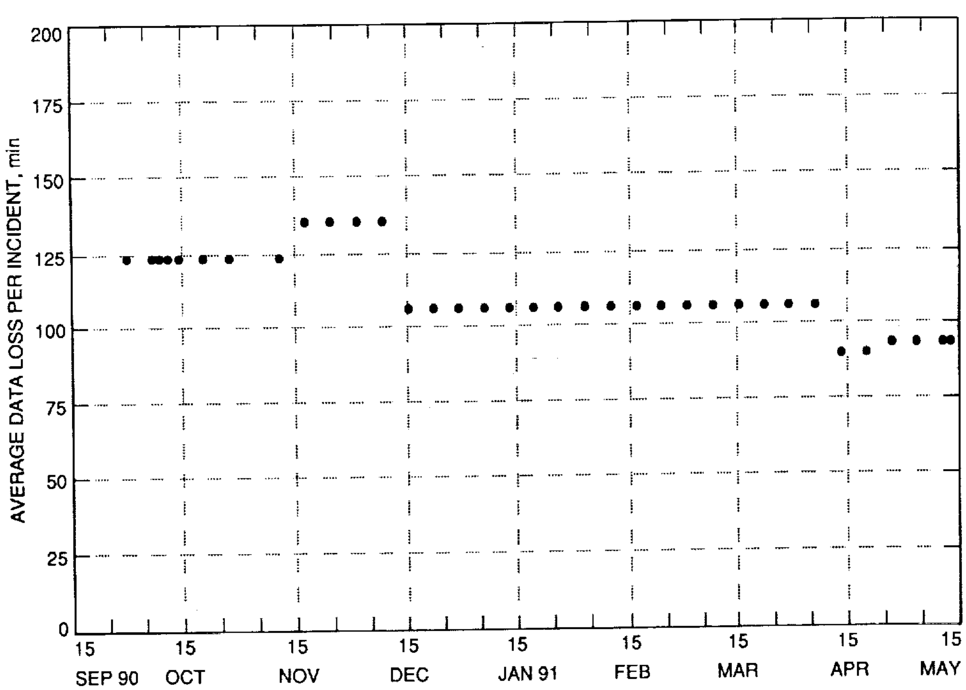

Fig. 6. Magellan high-rate telemetry, average "large" data loss per incident.

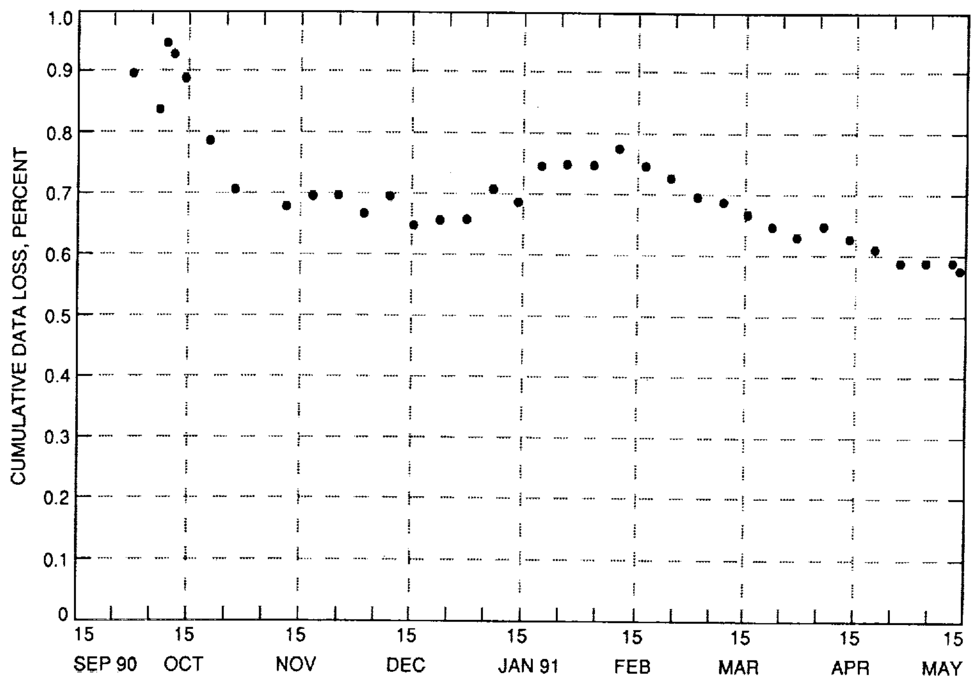

Fig. 7. Magellan high-rate telemetry, "small" data losses (<30 minutes).

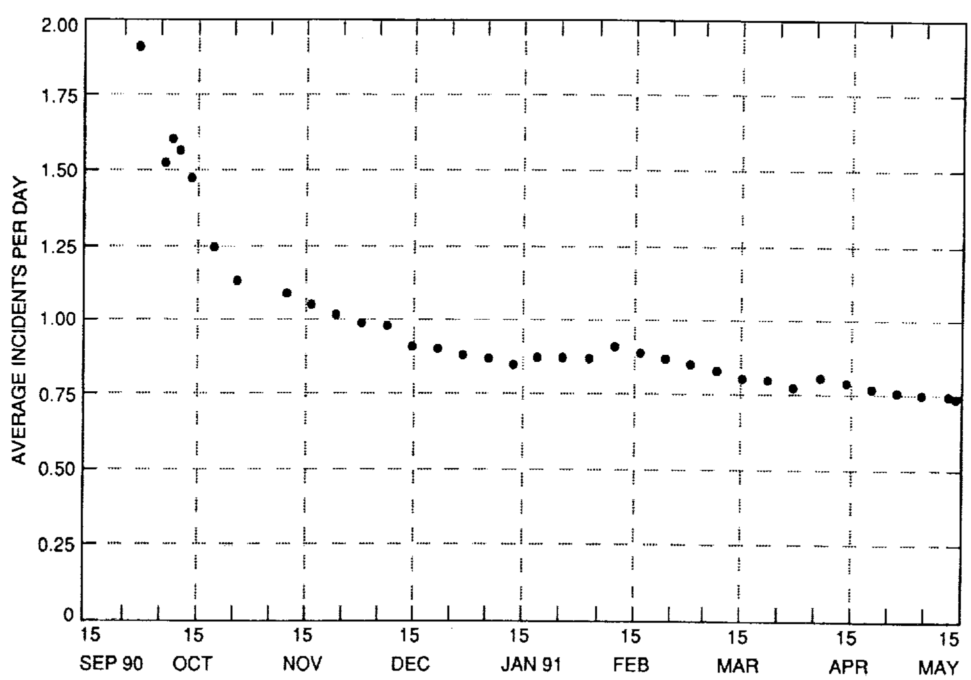

Fig. 8. Magellan high-rate telemetry, average "small" data incidents per day.

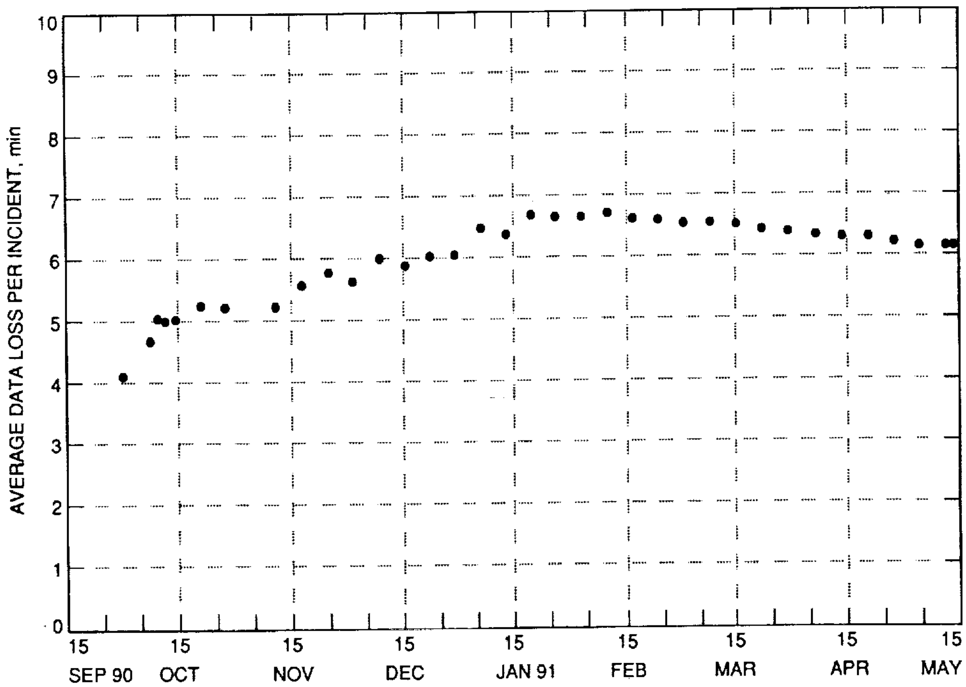

Fig. 9. Magellan high-rate telemetry, average "small" data loss per incident.

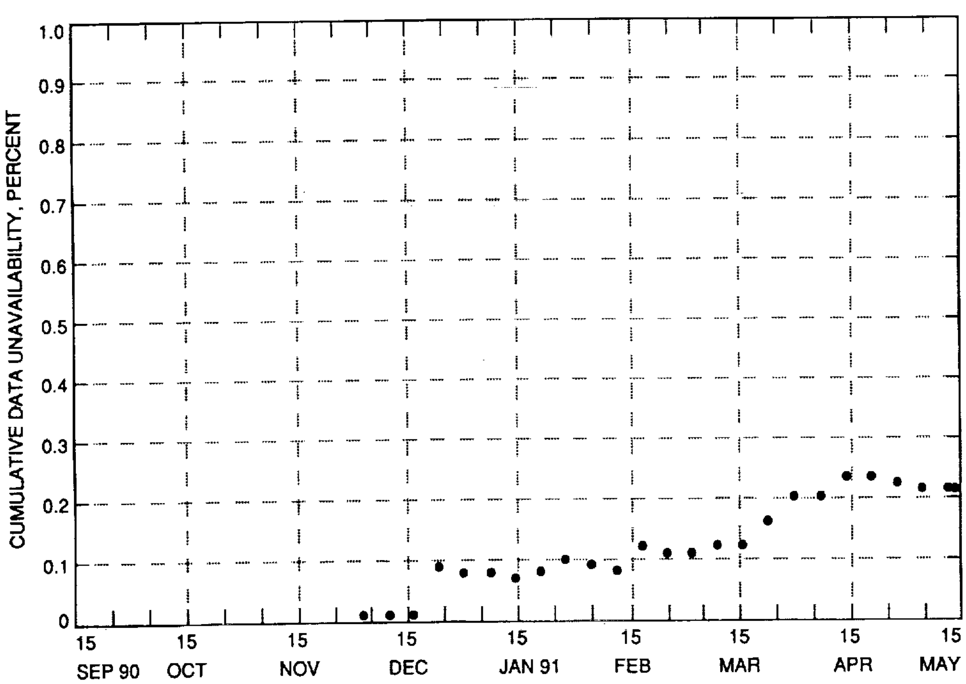

Fig. 10. Magellan high-rate telemetry, weather-induced data unavailability.

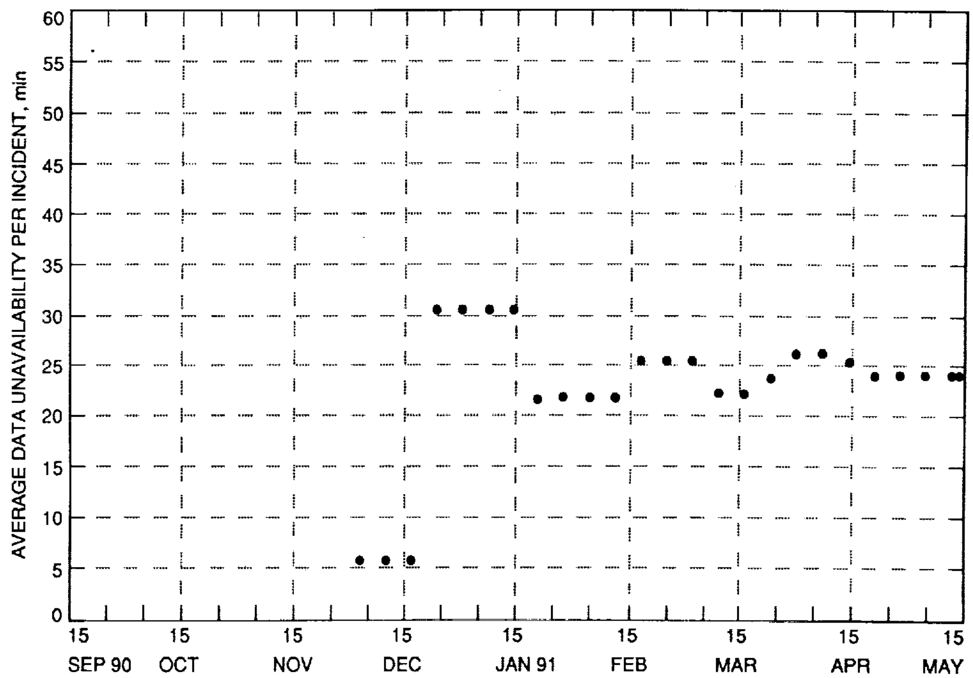

Fig. 11. Magellan high-rate telemetry, average weather-induced data unavailability per incident.

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