The Venus Balloon Project

R. A. Preston and J. H. Wilcher
Tracking Systems and Applications Section

C. T. Stelzried
TDA Mission Support and DSN Operations Office

During the Soviet Vega Mission to Venus and Comet Halley, two instrumented balloons will be placed into the Venusian atmosphere in June 1985. These Soviet/French balloons will be used to study the structure and dynamics of the Venusian atmosphere by means of in situ measurements and earth-based VLBI determination of balloon position and velocity. The DSN 64-meter subnet will be part of an international network of antennas organized by the French to support this mission. The DSN is installing new L-band receiving systems for this task. All scientific data from the balloons will be analyzed by a joint Soviet/French/U.S. science team.

I. Introduction

Two Soviet spacecraft were launched in December 1984, and will arrive in the vicinity of Venus in mid-June 1985. Upon arrival, each spacecraft bus will release an entry module containing both a lander and a balloon, then continue on to Comet Halley. Each balloon and associated gondola will drift along the Venusian equator at an altitude of about 55 km for a lifetime of 24 to 60 hours. Since the Venus encounters are separated by about four days, the balloons will not transmit simultaneously. L-band (1668 Mhz) downlinks from the balloon and spacecraft bus will provide three types of information:

(1) Spacecraft bus trajectory from delta differential one-way ranging (ΔDOR) and one-way doppler data taken by the NASA Deep Space Network (DSN).

(2) Balloon position and velocity obtained from ΔVLBI measurements between the spacecraft bus and balloon taken by an international network of ground antennas.

(3) Venusian in situ atmospheric data from the balloon telemetry data.

The balloon experiment is a cooperative French/Soviet venture. The French space agency, CNES, is responsible for organizing an international network of about a dozen antennas to track the balloons and flyby spacecraft bus. The DSN plays a key role in this international network. The Soviets will also provide more limited tracking with an internal Soviet network. All data will be analyzed by the joint Soviet/French/U.S. science team.

II. The Balloon Experiment

The purpose of the balloons is to study the structure and dynamics of the Venusian atmosphere. The Pioneer Venus probes and previous Soviet missions have obtained nearly instantaneous vertical profiles of physical characteristics of the Venusian atmosphere. The balloons will provide an extended temporal history of the atmospheric parameters at a nearly constant altitude. The combination of in situ measurements from the balloon gondola and earth-based VLBI determination of the Venusian winds (i.e., balloon velocity) will allow a study of the transport of momentum and heat in the atmosphere by means of eddy motions. Cloud characteristics will also be studied.

Figure 1 shows the path of the balloons across the face of Venus as viewed from the earth. At the time of encounter, the Sun-Venus-Earth angle is about 90 degrees, causing the terminator to appear near the center of the visible hemisphere. The balloons will be injected into the Venusian atmosphere near the equator and at almost Venusian midnight, just visible on the limb as seen from Earth. The balloons will drift across the equator during their 24 to 60 hour lifetimes, reaching the terminator after about 40 hours.

The configuration of the balloon and gondola are shown in Fig. 2. The small, 1.5-meter-high gondola is suspended 15 meters below the 3.4-meter-diameter, helium-filled, pressurized balloon. The gondola contains sensors to measure pressure, temperature, vertical wind velocity, cloud density, and the frequency of lightning flashes. On the top of the gondola is a helical L-band antenna for one-way transmission of the sensor telemetry as well as VLBI tones. The onboard frequency and timing reference for the transmissions is a temperature-controlled crystal oscillator (ultra-stable oscillator).

III. Concept of VLBI Determination of Balloon Position and Velocity

At least three antennas must simultaneously observe the balloon and flyby spacecraft to determine a complete set of three-dimensional position and velocity components relative to Venus. Utilizing the technique of VLBI, transverse velocity information is provided by measurements of the differential received RF frequency of the balloon signals at widely separated antennas. This is essentially the same method as that used in the Pioneer Venus Wind Experiment. The transverse position is obtained by using bandwidth synthesis to effectively yield observations of the balloon differential range.

Simultaneous observations of the balloon and flyby spacecraft are algebraically differenced to cancel common errors, such as those resulting from unknown station clock offsets, baseline uncertainties, and troposphere and ionosphere delays. Knowledge of the flyby trajectory is used to tie the balloon position and velocity to a Venus-centered reference frame. The trajectory will be determined by VLBI measurements at L-band taken over a 2-week period around the time of balloon insertion into the Venusian atmosphere. For flyby orbit determination, cancellation of observation errors will be achieved by differencing the spacecraft measurements with those acquired on an angularly nearby natural radio source (ΔDOR).

To obtain measurements of the line-of-sight balloon position and velocity, VLBI data from the balloon will be augmented by one-way Doppler data extracted from the VLBI recording at a single antenna, and by estimates of altitude and altitude rates obtained from in situ measurements of pressure. The line-of-sight velocity is provided by the one-way Doppler data (not differenced with flyby), which is dependent on knowledge of the balloon reference oscillator frequency. A calibration of this reference frequency will be based on balloon altitude rate information. The altitude is required to provide line-of-sight position, which is not sensed by VLBI.

Because of the low power of the balloon signal, and the frequency instabilities introduced by the balloon reference oscillator and by the erratic balloon motion, continuous coverage by sensitive, 64-meter DSN antennas will be required to detect the signal phase with integration times shorter than the coherence time of the balloon signal. Using models based on the phase observed at the 64-meter antennas, the data from the less sensitive antennas of the international French network can be processed with longer integration times to achieve adequate SNR.

IV. L-Band Transmissions

The spectra of balloon and spacecraft bus one-way L-band transmissions are essentially identical. The spectra consist of sequenced pure carrier, telemetry, or VLBI tones. The L-band carrier is transmitted at a frequency of 1667.92 ± 0.01 Mhz. The telemetry is transmitted on subcarriers of 254.5 Hz at a rate of 1 or 4 bits/second. The spacecraft bus transmits dummy telemetry for testing purposes. The carrier signal is used for the VLBI determination of balloon velocity relative to the flyby. The spacecraft bus transmits continuously during the lifetime of the associated balloon, but the balloon transmits at most 11 minutes out of every hour in order to conserve its batteries. During some of the balloon transmissions, the only signals emitted are two sideband tones spaced at ±3.25 Mhz from the highly suppressed carrier. These tones are used in the bandwidth synthesis VLBI determination of balloon position relative to the flyby spacecraft and for the ΔDOR determination of the flyby spacecraft orbit with respect to Venus.

Two days prior to Venus encounter the Soviets can predict the timing of the balloon transmissions to within 1 or 2 minutes and will set the phasing of the flyby spacecraft transmissions so that the flyby and balloon signals always display a similar spectra. The flyby and balloon L-band transmitters are identical in design. The radiated power is about 4.5 watts with left-hand circular polarization. The antenna gain for the spacecraft bus is about 9, while that of the balloon ranges from 0.4 to 1. The maximum balloon antenna gain is achieved when the balloon is near the center of the Venusian disk as viewed from Earth.

The Soviets will be in two-way communication with the spacecraft bus at their new space communication frequency of 6 Ghz. Each spacecraft bus will be commanded to turn the L-band transmitter on for short periods during the cruise phase to Venus for network testing and training.

V. DSN Involvement

A. DSN Tracking Requirements

The major implementation requirements of the DSN for the Venus Balloon Project are as follows:

(1) Modify the 64-m antenna subnet for receiving the RF carrier and VLBI tone signals in the 1668 MHz (L-band) range and subsequent upconversion to S-band.

(2) Modify the VLBI Block 0 subsystem to be compatible with the wide frequency separation of the Venus balloon project VLBI tones.

The major operational requirements for the DSN are as follows:

(1) Receive the following L-band data from the two spacecraft bus/balloon pairs:

  (a) Doppler data from the spacecraft bus.

  (b) ΔDOR data from the spacecraft bus and an angularly nearby quasar (Block 1 recording system).

  (c) Telemetry data from the balloon (radio science recording system).

  (d) ΔVLBI data from a balloon/flyby pair (Block 0 recording system).

(2) Provide near real-time demodulation/decoding of the telemetry spectrum for operational verification purposes.

B. DSN Signal Paths

The L-band 1668 MHz configuration will contain an L-band microwave feed-horn subsystem mounted to the 64-m antennas at DSS 14, DSS 43, and DSS 63 (Fig. 3). Another subsystem will contain a low-noise amplifier (LNA) and frequency upconverter to convert the L-band spectrum to a DSN-compatible S-band spectrum for inputting the signal into the S-band microwave subsystem (see Fig. 4).

The S-band microwave subsystem will deliver the signal to the existing DSCC VLBI, radio science, and doppler tracking system receivers. The doppler tracking system will use the Block IV closed-loop receiver-exciter subsystem to obtain one-way doppler data.

The radio science receiver will downconvert the S-band spectrum to an intermediate frequency (IF) spectrum centered about 300 Mhz. The 300 MHz IF signal will be power-divided at the DSCC Signal Processing Center (SPC) to provide signals to existing DSCC VLBI (Block 0 and Block 1) and radio science subsystems.

Both the VLBI Block I and radio science subsystems will be capable of acquiring VLBI and telemetry data directly without hardware modification to their assemblies. The VLBI Block 0 subsystem will require minor modification of the IF-video downconversion stage to allow the received tones, which are spread over a 6.5-MHz bandwidth, to be compressed into the 2-MHz bandwidth of the Block 0 subsystem. Near real-time demodulation/decoding of the telemetry spectrum for operational verification purposes will be provided.

C. Balloon Telemetry

Telemetry data are required to be provided to the project in the form of non-real-time detected, demodulated, and decoded telemetry streams recorded on computer-compatible magnetic tape. While the balloons are in the Venusian atmosphere, the DSN will record (in open-loop mode) the telemetry spectrum, including the carrier and the data-modulated subcarrier. At the conclusion of each balloon telemetry transmission, the participating DSN station will detect the carrier for selected portions of the transmission to obtain an SNR measurement of the received spacecraft signal. The recorded spectrum will then undergo carrier detection, demodulation, and decoding at the DSN station or at JPL. Both the original recorded spectrum data and the decoded data will be sent to the project.

D. VLBI Determination of Flyby Orbit

The DSN will determine the trajectories of both the Vega 1 and 2 spacecraft during the Venus flyby phase. To establish the flyby trajectories, DSN L-band one-way doppler and ΔDOR will be acquired from encounter (E) -10 days to $E + 8$ days. The ΔDOR data require identification of sufficiently strong (greater than 0.5 Jy) L-band Extra-Galactic Radio Sources (EGRS) in the vicinity of the Vega spacecraft trajectories. Such sources are needed for both the cruise phase and the Venus encounter phase. Candidate L-band radio sources will be selected from the DSN EGRS S-band source catalog. Source strengths for the candidate S-band sources at L-band will be validated by scheduling observing sessions from February through May 1985. Also during this cruise phase, ΔDOR and doppler data acquisition is required for test and training, and navigation data validation.

E. Balloon/Flyby VLBI

As part of the international network, the DSN 64-meter stations will provide coverage for the acquisition of VLBI data. The DSN 64-m stations will provide VLBI data from each balloon/spacecraft bus pair while the two are in the same antenna beam (a period of approximately two days near each Venus encounter). During balloon transmission, the DSN will record the L-band spectra of the balloon and the spacecraft bus simultaneously. During cruise, VLBI data will also be acquired for network testing and calibration.

The DSN will also provide the following VLBI processing capabilities for these data:

(1) "Local model" correlation of Block 0 VLBI recordings of spacecraft signals.

(2) Cross-correlation of single-channel quasar VLBI data in Block 0 formats.

(3) Post-correlation processing of single-channel quasar VLBI data to yield the clock offset and received phase.

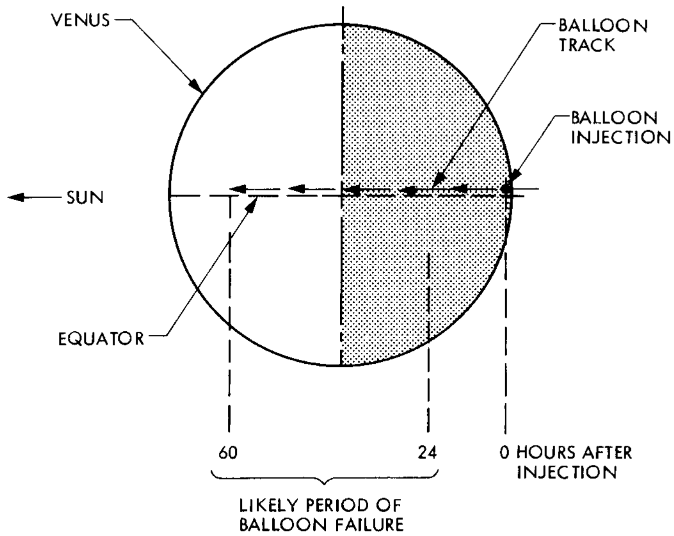

Fig. 1. Balloon path as viewed from Earth

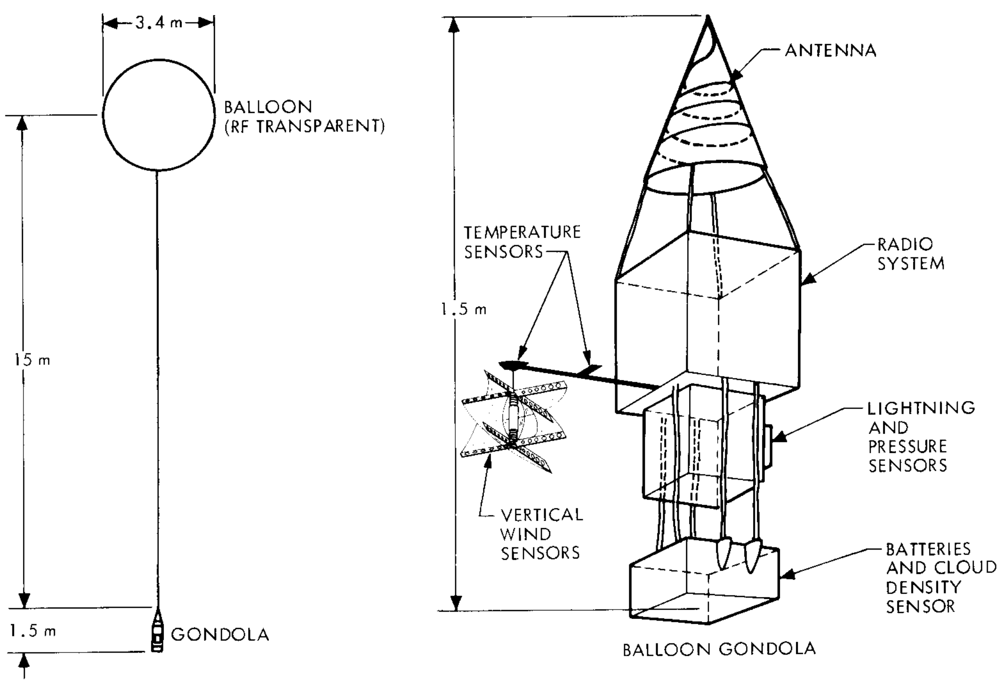

Fig. 2. Configuration of balloon and gondola

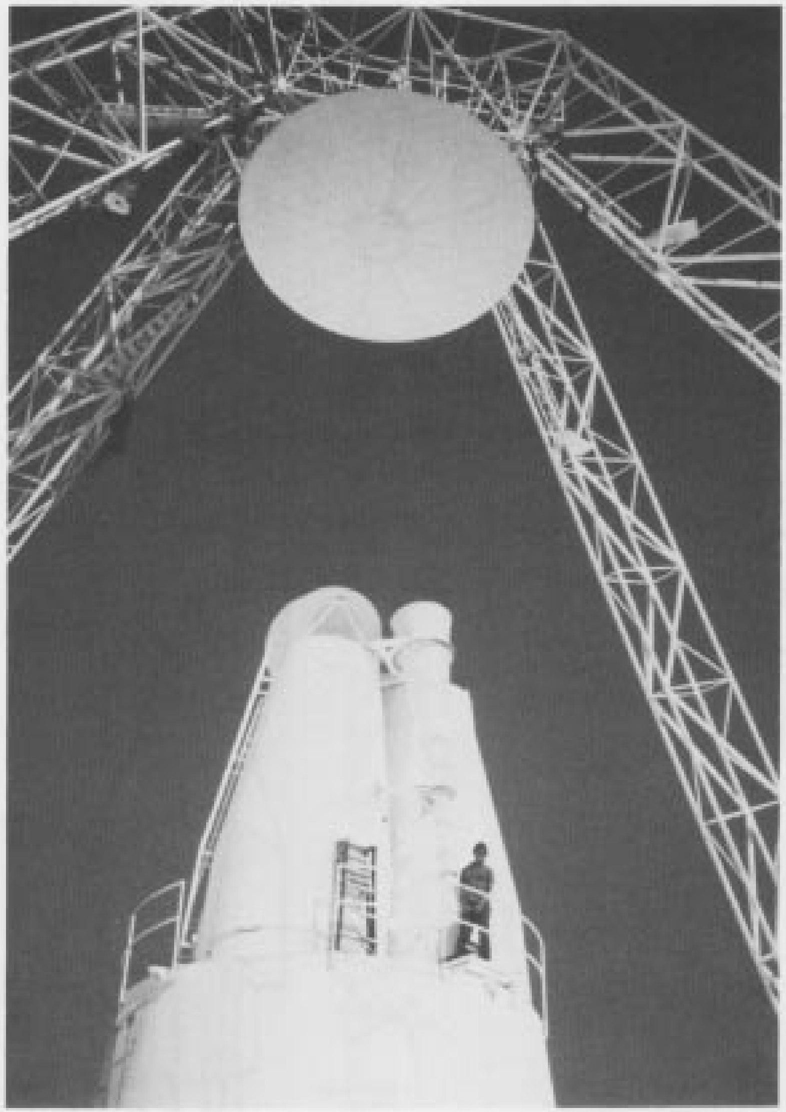

Fig. 3. L-band feed installed on the Goldstone DSCC 64-m antenna

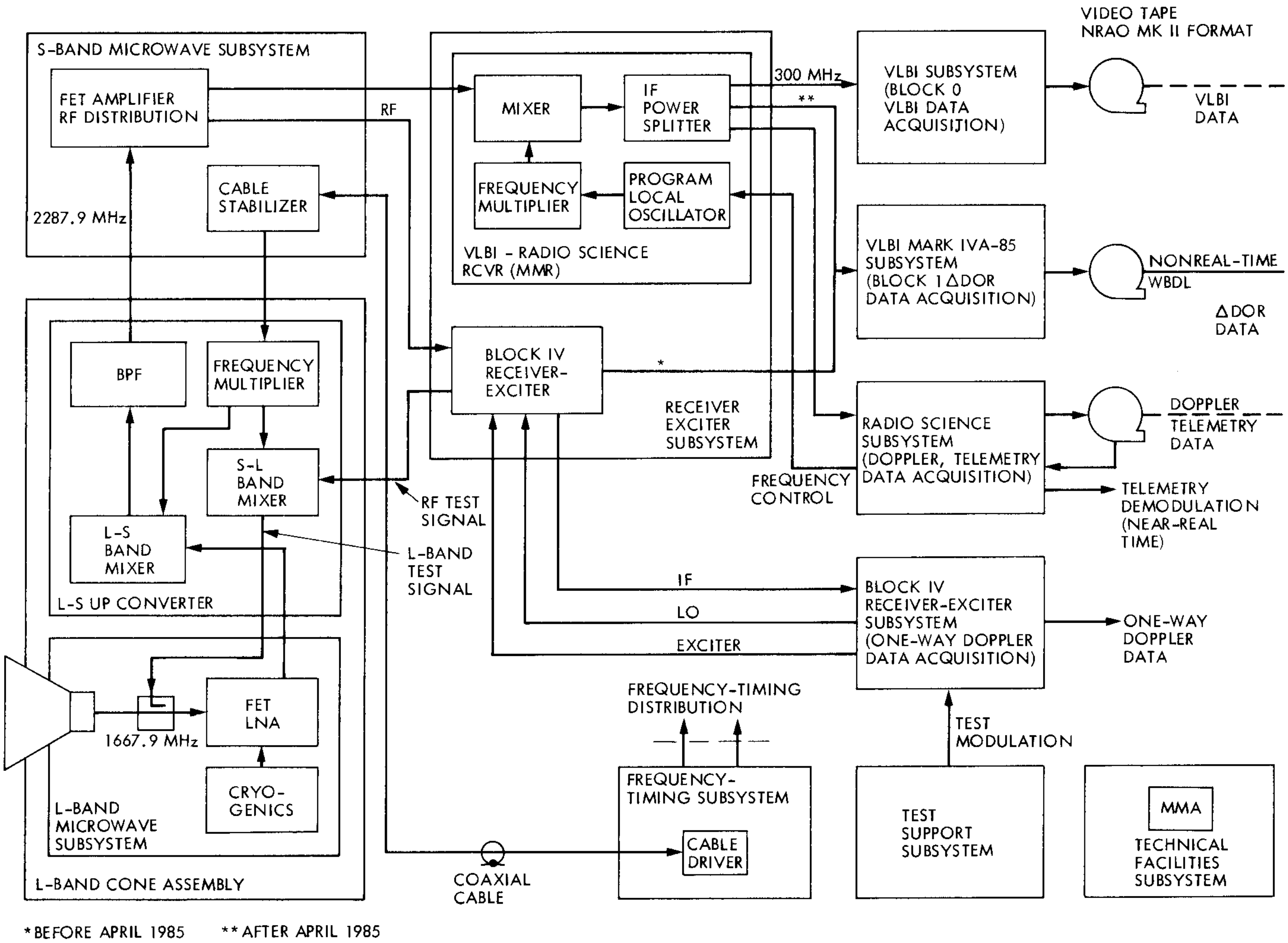

Fig. 4. DSN L-band implementation configuration