N72-25192

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-535

Telecommunications System Design for the Mariner Mars 1971 Spacecraft

F. J. Taylor
G. W. Garrison

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

May 1, 1972

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-535

Telecommunications System Design for the Mariner Mars 1971 Spacecraft

F. J. Taylor
G. W. Garrison

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

May 1, 1972

PREFACE

The work described in this report was performed by the technical divisions of the Jet Propulsion Laboratory, under the cognizance of the Mariner Mars 1971 Project.

ACKNOWLEDGMENT

This report was compiled by Glenn W. Garrison and Francis H. Taylor II, using many Interoffice Memorandums as source data. The following people contributed to the IOM's and to the success of the telecommunications system:

W. Allen
A. Brejcha
W. F. Gillmore
D. R. Hersey
B. D. Trumpis
O. L. Irvin
C. T. Timpe

CONTENTS

CONTENTS (contd)

TABLES

FIGURES

CONTENTS (contd)

FIGURES (contd)

ABSTRACT

The configuration of the Mariner Mars 1971 spacecraft telecommunications system is detailed, with particular attention to modifications performed to accommodate the orbital mission. The report covers analysis and planning to launch. Results of major analyses and tests are summarized.

I. INTRODUCTION

The Mariner Mars 1971 telecommunications system was an adaptation of the Mariner 1969 system, modified to meet the requirements of a Mars orbital mission rather than a flyby. The Deep Space Instrumentation Facility (DSIF) ground equipment was functionally identical to that used on Mariner 1969, but several new items of multimission modulation (command) and demodulation (telemetry) equipment were developed during this time period and first used on Mariner 1971.

The total launch period was from approximately May 5 through June 6, 1971. Planning was for two launches. Mission A, to be launched on May 7, 1971, was to be inserted in a Mars orbit on November 14, 1971. Mission B was planned for launch on May 17, 1971, and for insertion on November 24. Orbit periods for missions A and B were to be 12 and 20 hours, respectively. Most of the discussion in this report is related to the 12-h orbit. Telecommunications problems for this orbit are similar to that encountered for a 20-h orbit.

II. SPACECRAFT CONFIGURATION

A simplified block diagram of the Mariner 1971 telecommunications system is shown in Fig. 1. The overall system consisted of three subsystems, the radio frequency subsystem (RFS), the command subsystem (FCS), and the S-band antenna subsystem (SBA). Areas of modification from Mariner 1969 which were implemented to accommodate the orbital mission are shown by asterisks. A number of other items were modified to improve performance but were not specifically required for the orbital aspect of this mission. They are discussed in separate reports for the individual subsystems. The specific modifications for the orbital mission are discussed in the following subsections.

A. Phase-Lock-Loop Receiver

The loop gain was increased by a factor of 10 to reduce loop phase error with frequency offsets. This eliminates requirements for retuning the uplink during the orbital phase, where doppler shifts on the uplink approach 40 kHz over one station pass.

B. S-Band Antenna Coupler and Medium-Gain Antenna

The medium-gain antenna (MGA) was added to the system using a passive 6-dB directional coupler in the low-gain antenna (LGA) circuit. The MGA was mounted to provide telemetry coverage and two-way doppler during the orbit insertion and orbit trim phases of the mission. Although the MGA has a boresight gain of approximately 14 dBi, when installed with the 6-dB coupler the effective peak gain was approximately the same as the LGA.

C. High-Gain Antenna

Mariner 1971 uses the same high-gain antenna (HGA) used on Mariner 1969, a 1.02-meter circular parabola. However, rather than being fixed in position as on Mariner 1969, the antenna was used in two positions. The first position was used preinsertion and for the first 60 days of orbit operations (assuming a November 14, 1971, orbit insertion). The second position was used for the remainder of orbit operations and provides an effective gain greater than the LGA until approximately 140 days in orbit (April 1, 1972).

The low-gain antenna, which is a shortened version of the Mariner 1969 LGA is always used for receiving the uplink signal and for transmitting (downlink) during the early cruise phase and for maneuvers. The HGA is used exclusively for transmitting during the late cruise and orbital phases.

Downlink telemetry modulation is provided by the flight telemetry subsystem (FTS) as shown in Fig. 1. Telemetry data rates, required bit error rates, and required periods of coverage are shown in Table 1. The high-rate data at 1 to 16 kbps is block-coded. Low-rate data at 8 1/3, 33 1/3 or 50 bps is uncoded. Table 1 requirements covers only the standard mission since the extended mission requirements are undefined.

III. TELECOMMUNICATIONS REQUIREMENTS AND CONSTRAINTS

A. Cruise and Midcourse Maneuvers

Cruise is the mission time beginning after launch transients have died out until shortly before the Mars orbit insertion sequence. During cruise, one or two midcourse maneuvers are planned, the first about one week after launch, the second several weeks before encounter.

Telecommunications requirements during early cruise were to provide 33 1/3-bps telemetry data, ranging, doppler, and command capability. For engineering telemetry and command communication between the earth and the spacecraft, the broadbeam low-gain antenna provides coverage in the hemisphere centered at 0 deg cone angle (in spacecraft coordinates). During the latter part of cruise, and for orbital operations, high-rate science at several kbps must be transmitted from the spacecraft through the high-gain antenna. Downlink RF power of 20 W during the latter part of cruise and for orbital operations together with 10 W for the launch and early cruise environment was provided by the radio frequency subsystem (RFS).

During the midcourse maneuvers, the spacecraft will be rolled off the Canopus reference, then yawed off the sun. Engineering telemetry at 33 1/3 bps must be provided during the motor burn. In order to meet this requirement, the earth vector after the yaw turn must lie within approximately 90 deg of the LGA or within 35 deg of the MGA boresight for the first midcourse maneuver. Owing to the greater distance to the spacecraft at the time of the second midcourse maneuver, the corresponding angles are within 65 deg of the LGA and 30 deg of the MGA. This midcourse motor burn duration is less than 10 s. Doppler rates during these burns do not impose special tuning or receiving bandwidth constraints.

Two telecommunications mode changes are planned during cruise. The first, not later than 100 days after launch, is to switch the TWTA from its low-power (10-W) state to the high-power (20-W) state. The second, about 110 days after launch, is to switch the downlink from the low-gain antenna to the high-gain antenna. The first mode change is not time-critical. It can be done as soon after launch as thermal and power considerations permit, and should be done enough in advance of the antenna switch so that the radio is well-stabilized in the high-power mode. The second mode change is more time-critical. It cannot be done until the HGA boresight comes close enough to earth so that the effective gain from the HGA at least equals the gain from the LGA at the same time. It should not be delayed because (a) telecommunications performance will be better on the HGA, and (b) an interferometer effect between the HGA and the LGA may degrade telecommunications performance over the low-gain antenna below that predicted for either antenna alone. This effect is described in a later section.

Representative telecommunications performance during cruise is shown in Fig. 2. The upper curve indicates the design performance margin in dB above minimum required signal-to-noise ratio (threshold) for the 33 1/3-bps engineering telemetry channel. The lower curve shows the sum of the adverse tolerances for this channel. These curves show that with design (normal) telecommunications performance, the 33 1/3-bps channel is above threshold throughout cruise. In the worst case, including the linear sum of the adverse tolerances, the 33 1/3-bps channel drops below threshold briefly before switch to the HGA. Thus, under worst-case conditions it may be required to switch to 8 1/3-bps telemetry to maintain a positive performance margin.

B. Mars Orbit Insertion and Orbit Trim

The prime telecommunications requirement during these phases of the mission is to provide engineering telemetry during the motor burn. Orbit insertion maneuver turns require that the LGA be directed away from the earth. Therefore, to provide telemetry during the motor burn, a medium-gain antenna, passively coupled to the LGA, is oriented so as to be directed toward the earth during the insertion. Orbit trim maneuvers will use either the MGA or LGA, depending on the turns required, or fall outside the capabilities of either antenna. The gain of the LGA is adequate for these maneuvers. The earth vector, however, is outside the useable range of the LGA. Therefore, the boresight gain of the MGA (including coupling losses) was made approximately equal to that of the LGA. As a result of the simultaneous use of two antennas at the same frequencies (both are used for receiving the uplink signal as well as transmitting on the downlink), an interferometer effect is present in the areas between these two antennas. This LGA/MGA interferometer effect and the results it has had on the planning for maneuvers are described in a later section.

C. Orbit Mission

Mariner 1971 is required to provide high-rate 8- or 16-kbps science data for the first 90 days after orbit insertion. The planned orbit for Mission A is highly elliptical, with a periapsis (after trim) of 1250 km and a period of 12 hours. The orbit causes a wide variation in the doppler shift throughout the orbit period. In addition, throughout the orbit phase the distance between the earth and Mars will increase, continually decreasing performance margins. The geometry between the sun- and Canopus-oriented spacecraft and the earth also changes, making it impossible to have a fixed-position high-gain antenna with sufficient gain to meet the stated orbit requirements.

Figure 3 illustrates the doppler environment near the beginning and end of the orbital phase for a 12-h orbit. The Mariner 1969 receiver would not have maintained phase lock in the uplink doppler environment without retuning of the uplink at least twice during each orbit. To preclude this operational difficulty with the consequent possibility of dropping downlink lock, the loop gain of the Mariner 1971 receiver was increased by a factor of 10 over that of the Mariner 1969 receiver. No uplink tuning will be required during any single station pass, including the periapsis pass.

Analysis showed that the science bit rate requirement could be met by allowing the Mariner 1969 HGA to assume a second boresight position about two months into the orbital mission. The first position would take care of the preorbit science and the first two-thirds of the orbital science. The second position maintains the 16-kbps capability for the remainder of the 90-day orbital phase, assuming design-point telecommunications performance.

Figure 4 shows the telecommunications performance margin (referenced to 0 dB at insertion) variation over the mission, taking into account the shift in HGA position on January 15, 1972. This decrease in margin must be taken into account during planning for the orbital science sequences. Additional margin is gained by decreasing the science bit rate from 16 to 8 kbps. Margin can also be provided by restricting the DSS 14 pass to higher and higher elevation angles as the mission progresses. Some of these tradeoffs are shown in Fig. 5. This figure compares fixed elevation angle rise times of DSS 14 to performance-based rise times, taking into account the decrease in margin shown in Fig. 4. The 0-dB reference curve shows design telecommunications performance at 16 kbps, with the other curves showing the effect of having either better (by means of decreased bit rate) or worse (through performance degradation) performance than design. Figure 5 shows that design performance results in a useable 16-kbps pass at DSS 14 throughout the planned 90-day orbital mission.

IV. TELECOMMUNICATIONS DESIGN CONTROL

A. Design Control Documentation

The Mariner 1971 telecommunications design control document (PD 610-57) titled Mariner Mars 1971 Project Telecommunications Link Performance was the single authoritative source for the Mariner 1971 telecommunications system, including spacecraft and DSIF elements. The major items covered were:

(1) Spacecraft subsystems.

(2) Detailed characteristics of the spacecraft and DSIF elements.

(3) Link performance requirements and comparison to capabilities.

(4) Detailed link performance for major modes by mission phase, using design control tables and plots of performance versus time.

(5) Parameters and calculation methods used in link calculations.

Two basic philosophies were followed. First, the document was to be a comprehensive working level document in order to be of maximum use in mission analysis and planning. Second, the document was to be released early in the program, using design parameters, then updated prior to launch when measured system parameters were available. A preliminary version was published in May 1970. The first formal release was in August 1970; the final issue was released in April 1971.

As an example of how design control techniques maintain link performance through a project see Fig. 6. This figure illustrates how the performance predictions of the prime 16,200-bps channel on Mariner 1971 changed through three issues of PD 610-57. The design value dropped 0.3 dB, favorable tolerances were reduced 0.5 dB, and adverse tolerances were reduced 0.9 dB. Design control leads to consistent design values through a project, and reduced tolerances as parameters are better understood.

B. Telecommunications Prediction and Analysis Program

One of the major telecommunications efforts on Mariner 1971 was updating the Telecommunications Prediction and Analysis Program (TPAP). The connotations of "prediction" and "analysis" in this title are as follows:

Prediction is the generation of performance predictions for a link; analysis is the comparison of predicted versus observed performance. The TPAP program is an updated combination of the Mariner 1969 Predicts Program (CP2M) and the Mariner 1969 Comparison Program (CMPM).

1. Predictions. The predicts portion of TPAP will, at the option of the user, generate telemetry, command or ranging link predictions. Major changes to this portion of the program on Mariner 1971 were as follows:

(1) The design control tables were reformatted to 8 1/2 × 11-in. size such that they could be used directly in reports. This modification has led to considerable cost savings.

(2) Performance and trajectory data is provided in tabulated or plotted form for easy use by the telecom analysts.

(3) A data save tape may be generated to be used for comparing actual versus predicted data.

Figures 7 and 8 illustrate typical telemetry and trajectory plots.

2. Comparison. The comparison, or analysis, version of TPAP was extensively modified, using the Mariner 1969 CMPM program as a starting point. The program compares data previously generated in a telemetry prediction run with actual flight data. Comparison is made of uplink carrier level, downlink carrier level, and telemetry (engineering and science) signal-to-noise ratios.

Outputs provided are:

(1) Plots of actual and predicted data.

(2) Plots of the difference between actual and predicted (residuals).

(3) Histograms of the difference between predicted and actual.

This data is used to evaluate both spacecraft and DSIF performance during mission operations. Typical plots are shown in Figs. 9, 10, and 11.

V. TELECOMMUNICATIONS PERFORMANCE VERIFICATION TESTS

One of the major activities of the telecommunications system group is to verify proper link performance through testing. On Mariner 1971 there were four major areas of test:

(1) Subsystem tests in the Telecommunications Developmental Laboratory (TDL), which is operated by project personnel, and in the Compatibility Test Area (CTA-21), a typical DSIF facility.

(2) System tests on the spacecraft at JPL and AFETR.

(3) Spacecraft/DSIF compatibility tests in CTA-21.

(4) Spacecraft/DSIF compatibility tests at DSS-71, a DSIF test station at AFETR.

A complete description of all tests and results is beyond the scope of this report. However, the overall program is outlined in summary form, with major items emphasized. The data accumulated in these tests is invaluable in planning flight sequences and as backup data for anomaly investigations.

A. Telecommunications Developmental Laboratory Description

The TDL was developed during Mariner 1971 to support the test effort. For Mariner 1969 the TDL was located in CTA-21. Expansion of CTA-21 necessitated moving the TDL to new facilities in Building 161. Layout of the TDL and a functional block diagram are shown in Figs. 12 and 13.

B. Overall Test Sequence

Table 2 is a test matrix showing tests performed during various phases of Mariner 1971. Tests are shown as rather broad categories. In many areas there were a large number of subtests. However, the matrix gives a good feel for the overall test program.

The tests were intended to provide a comprehensive program, maintaining a good awareness of system condition at all times and exercising the equipment to the levels expected during the mission. In nearly all cases, analysis of expected performance was performed prior to the test so that the test results could be compared with predicted performance or design specifications.

VI. SPECIAL DESIGN OR ANALYSIS PROBLEMS

A. LGA/MGA Interferometer Effect

The MGA is connected electrically to the LGA through a directional coupler such that the LGA and the MGA form an antenna system. This antenna system can be considered as an array of two antennas separated from one another by many wavelengths. Antenna theory predicts that such a system will take on the gain of the individual elements of the array within the main lobe of each of the elements. In the regions between the elements, an interferometer or lobing effect will occur. Since the LGA and MGA are both used for receiving the uplink at 2215 MHz and transmitting the downlink at 2295 MHz, the interferometer effect will be present at both frequencies.

Given the constraint that a medium-gain antenna is required, and its location is determined by the probable orbit insertion parameters, the effect of the interferometer nulling on other phases of the mission had to be ascertained. The specific problems examined prior to launch included (a) the probable profile of uplink and downlink signal strength during the launch, sun acquisition, and Canopus acquisition sequences, (b) the possibility that downlink telemetry might drop below threshold over some discrete range of clock and cone angles of the tracking stations during the first two weeks of the mission, and (c) the profiles of uplink and downlink signal strengths during the roll and yaw turns associated with the first midcourse maneuver.

Figure 14 and Table 3 together define the main characteristics of the Mariner Mars 1971 antenna system. The MGA is almost diametrically opposed from the LGA, and the principal interferometer nulling would be expected to occur in or near the plane of the solar panels. The insertion loss of the MGA coupler is such that the overall antenna system gain is approximately 7 dB near the boresight of both the LGA and the MGA.

Figure 15 shows a representative overall gain pattern of the LGA/MGA system at the downlink frequency. With 90 deg cone angle representing the spacecraft solar panels, this pattern was measured essentially in the plane containing both the LGA and the MGA and passing through all cone angles (roll cut). Since it was measured on a full-scale antenna test model with flight antennas, this pattern closely approximates the actual Mariner 1971 pattern, including the effect of the spacecraft itself.

1. Launch phase. Analyses of the antenna pointing directions during the powered-flight trajectory, during separation, and during sun and Canopus acquisition sequences for launches on May 7 and May 15, 1971, showed that severe fading was possible though not certain. The variable preventing a definitive assessment was the tipoff forces and directions at separation of the spacecraft from the Centaur. Figure 16 shows the extent of variation in signal levels possible at DSS 51 (Johannesburg). If spacecraft orientation was such as to maintain the LGA boresight pointing continuously at DSS 51, the upper curve indicates the signal level predicted. The two lower curves indicate the envelope of the interferometer-effect fading, assuming that zero tipoff rates occur. The lower limit of the envelope assumes destructive interference between the LGA- and MGA-radiated signals. The upper limit assumes constructive interference. The spacing between successive nulls in the interferometer pattern, as indicated by Fig. 15, is 4 deg, but the phasing of the nulls is not known. Figure 16 assumes a nominal Mission A launch date of May 7. A similar analysis was made for the other near-earth phase station, Ascension Island. Figure 17 shows potential downlink loss times for these two stations. Because of different antenna angles to the two stations and the absence of significant time overlap, it was predicted that loss of downlink at both stations simultaneously was not likely.

2. Early cruise phase. For the Mariner 1971 mission, the later the launch date the more favorable the geometry for maintaining adequate downlink signal levels during the first 48 hours of the mission. A consideration of the tolerances on the MGA and the LGA antenna gains, beamwidths, and cabling losses showed that for a May 7, 1971, launch there would be some risk of the downlink dropping below the threshold for 33 1/3-bps engineering telemetry two days after launch, should the phasing between the LGA and the MGA also be worst-case, even with normal sun-Canopus orientation (Fig. 18). No such potential loss of 33 1/3-bps downlink telemetry was anticipated for the nominal Mission B launch or for a delayed launch date. Figure 15 shows significant potential for interferometer-effect fading at cone angles exceeding 90 deg. For comparison, the maximum earth cone angle reached for a May 7 launch would be 102 deg; for a May 14 launch, 88 deg, and for the May 30 launch, 62 deg.

3. First midcourse maneuver. Planning for the first midcourse maneuver, to occur within one week of launch, again showed that the amount of interferometer-effect fading occurring would depend on the launch date, with lesser amounts for the later launches. The reason is that the first midcourse event is a roll turn; the earth cone angle remains constant during a roll turn, and the earth cone angle during the roll turn is larger the earlier the launch and, hence, the maneuver date.

Figure 19 shows the "trajectory" of the earth cone and clock angles during the turns of a typical midcourse maneuver sequence on June 4/5, 1971. Note the long roll turn at a constant earth cone, followed by a yaw turn which actually causes the earth vector to come nearer the boresight of the LGA. During planning for the midcourse maneuver, a telecommunications constraint was to avoid turn sets (roll and yaw) which would pass through the LGA/MGA interferometer region defined by the "crosshatched" region of Fig. 19. This region is defined by a series of LGA/MGA patterns, such as in Fig. 15, for various fixed clock angles. It is based on the antenna test model measurements. The smooth envelopes in Fig. 19, which generally follow the measured interferometer regions, are based on theoretical considerations of the antenna system. Correlation between the two is good. During this maneuver sequence [consisting of (a) the roll turn about the spacecraft Z axis, (b) a yaw turn about the spacecraft Y axis, (c) a short motor burn, and (d) yaw and roll "unwinds" back to the original sun-Canopus stabilized position] little interferometer effect was predicted (Fig. 20). Figure 20 is a good indicator of the influence of the interferometer effect at this cone angle. The solid curve shows the gain of the LGA alone; the dotted curve shows the gain of the LGA/MGA system during the maneuver.

B. HGA/LGA Transmit Interferometer Effect

This effect occurs because of imperfect isolation between the LGA and the HGA outputs of the Mariner 1971 RFS and because of reflection of RF from the antennas back into the transmission lines. The effect is dependent on which combination of TWT and antenna is being used and on the specific amounts of isolation between the two RFS ports (Fig. 21). The effect was predicted to occur when the spacecraft is still transmitting via the LGA and the HGA beam begins to swing onto the earth about 110 days after launch. It might also be present during the second midcourse maneuver and during the orbit insertion, from the moment the switch is made from the HGA to the LGA until the HGA beam swings off earth at the beginning of the roll turn.

The physical mechanism of the HGA/LGA transmit interferometer effect is the same as that of the LGA/MGA effect discussed in the previous section. The HGA and the LGA form an antenna system consisting of an array of two elements of different gains and beamwidths but transmitting at the same frequency and separated by several wavelengths at S-band. The HGA is "inefficiently" coupled to the system when the spacecraft is transmitting via the LGA. However, the gain of the HGA is 19 dB higher than that of the LGA at boresight (Table 3), and even with a typically specified 20 dB of isolation between the LGA and the HGA ports of the RFS, a noticeable interferometer effect was predicted when the earth is near the HGA boresight.

1. <u>Cruise phase, at the switch from LGA to HGA</u>. The initial switch from the LGA to the HGA was planned to occur on September 21, 112 days after a May 30 launch, to maximize the earth-received signal level throughout cruise. Trajectory calculations showed that the boresight of the HGA would be moving toward the earth at about 0.4 deg per day at this time, with the net gain of the HGA increasing by more than 1 dB per day. Analysis of the LGA/HGA system showed that the spacing from one interferometer null to the next is about 4 deg. Hence, any interferometer-effect fading occurring before switch to HGA would take place very slowly and require many successive station passes to be seen. Figure 22 shows the magnitude of the predicted interferometer effect near the time of the initial switch to the HGA. The greater the isolation between the two RFS ports, the nearer the HGA boresight the earth must come before a significant interferometer fading occurs.

2. <u>Second midcourse maneuver and Mars orbit insertion</u>. The first time a switch back to the LGA from the HGA is required prior to initiation of the turns is during the second midcourse. Except by observation of the amount of interferometer fading occurring just prior to the initial use of the HGA (see paragraph above), it is not possible to predict whether the HGA/LGA transmit interferometer will be a significant factor in the second midcourse maneuver and the orbit insertion. The reason is that there is a relatively narrow range of dB isolation between the ports required before interferometer fading can occur. The amount of isolation actually present is

difficult to measure; it is dependent on RFS temperature, and temperature is variable through the mission. At most, it can be asserted that there may be sufficient fading to cause loss of 33 1/3-bps telemetry when the switch to LGA is made preparatory to a maneuver and before the HGA beam swings off of the earth. Such fading is considered rather unlikely owing to the large number of "worst-case" effects which must occur simultaneously. However, planning for the second midcourse maneuver has included delaying the switch to LGA to shortly after the roll turn start so as to eliminate loss of data during the maneuver.

C. Insertion and Orbital Doppler Rates

The Mars orbit insertion sequence is monitored by the 64-meter antenna at Goldstone, beginning about 2 hours before motor burn start and concluding with the first occultation of the spacecraft, occurring about 15 min after motor burn end. During this sequence, the spacecraft will go through a roll turn, a yaw turn which takes the earth from the LGA to the MGA region of influence, a 15-min motor burn during which significant doppler rates occur, and the beginning of the unwind turns. There are a number of telecommunications problems involved in planning the insertion sequence. Perhaps the most important of these is whether to carry out the entire sequence while the spacecraft is in two-way with DSS-14 or to allow the high-doppler portions of the sequence to occur with the spacecraft in one-way (downlink only). The downlink doppler offsets and rates are one-half as large in one-way as in two-way, other factors being equal.

1. Signal levels. The magnitude of the doppler effect on the downlink depends on (a) the signal levels present during the several phases of the sequence, and (b) the DSN strategy, including receiver and demodulator bandwidths and tuning. Figure 23 shows the "trajectory" of the earth coordinates (clock and cone) during the roll and the yaw turns. The earth coordinates at roll start on the day of insertion (November 13) are known, and the possible variation in roll and yaw turn magnitudes is also known. The roll will keep the LGA boresight 43 deg from the earth, resulting in a worst-case 13-dB SNR in the downlink receiver loop bandwidth $2B_{Lo}$ of 12 Hz. The yaw turn will take the earth into the domain of the MGA as shown, and the worst-case SNR in $2B_{Lo}$ will be 16 dB at the end of the yaw turn. As shown, downlink telemetry will be lost during the yaw turn regardless of whether

33 1/3- or 8 1/3-bps telemetry is chosen; 33 1/3 bps has been chosen to maximize data return during the motor burn. Uplink lock (if two-way is chosen) will also be dropped for 10 to 30 s during the yaw turn. These dropouts are due to the LGA/MGA system gain being too low to support the links throughout the yaw turn.

2. Doppler shift and doppler rates. Figure 24 shows the range rate in km/s and the resulting uplink and one-way downlink doppler shifts during the insertion sequence. Two-way downlink doppler would be twice the value shown at each time. Figure 25 shows the range acceleration (in m/s^2) and the resulting uplink and one-way downlink doppler rates during the sequence. Again, two-way doppler rate would be twice the values shown. Figure 26 shows the downlink phase error ($2B_{Lo}$ - 12 Hz) resulting from the doppler rate alone. The major contributor is the acceleration from the motor burn itself, with the planetary effect at first periapsis (coincident with motor burn stop) a secondary effect.

3. Telecommunications strategies. The plan for insertion is to operate in the two-way RF mode. The two-way mode offers operational and scientific advantages in that commanding will be possible through nearly the entire insertion sequence, and two-way doppler permits a more precise and timely determination of the orbit parameters than one-way doppler. On the other hand, one-way tracking after the uplink drops out during the yaw turn is operationally much less complex for the DSIF operators. In the two-way tracking mode, the DSIF S-band receiver and engineering channel SDA will be set to the medium bandwidth since this minimizes the possibility of dropping lock due to high doppler rates. The penalty is several tenths of a dB decrease in engineering channel SNR and receiver loop SNR. However, the chosen insertion roll and yaw turns insure adequate margin to make this penalty acceptable.

Table 1. Mariner 1971 data rates and usage requirements

Data Rate	Data Type	S/C Antenna	DSIF Antenna	Required Coverage Days	Bit Error Rate
16.2 KBPS	Tape Playback	HGA	64m	0I-20 to 0I+30	$5x10^{-3}$
8.1 KBPS	" "	HGA	64m	0I-20 to 0I+90	$5x10^{-3}$
4.05 KBPS	" "	HGA	64m	0I-20 to 0I+90	$5x10^{-3}$
2 KBPS	" "	HGA	26m	0I-20 to 0I+30	$5x10^{-3}$
1 KBPS	" "	HGA	26m	0I-20 to 0I+90	$5x10^{-3}$
16.2 KBPS	High Rate Science	HGA	64m	0I-20 to 0I+30	$5x10^{-3}$
8.1 KBPS	" " "	HGA	64m	0I-20 to 0I+30	$1x10^{-4}$
8.1 KBPS	" " "	HGA	64m	0I-20 to 0I+90	$5x10^{-3}$
33 1/3	Engineering	HGA	26m	0I-20 to 0I+90	$1x10^{-2}$
8 1/3	"	LGA or HGA	26 or 64 m	Launch to 0I+90	$1x10^{-2}$
8 1/3	CC&S Playback	HGA	26m	0I-20 to 0I+90	$1x10^{-5}$

Table 2. Mariner 1971 test matrix

Unit(s) Tested	Test Description	Test Type/Location				
		Subsystem Test		System Tests	SC-DSIF Compatability	
		TDL	CTA-21	JPL/ETR	CTA-21	DSS-71
RFS	1. RCVR Sensitivity	X		X	X	X
	2. RCVR Acquisition	X			X	
	3. RCVR Tracking	X			X	X
	4. RCVR Best-Lock & Aux. Osc. Frequencies	X		X	X	X
	5. RCVR SPE	X		X		
	6. Downlink Spectrum	X		X	X	X
	7. XMTR Power	X		X		
	8. XMTR Phase Jitter	X		X	X	X
	9. Ranging Polarity	X			X	X
	10. Ranging Threshold				X	X
	11. Ranging Delay Calibration/Check	X			X	X
FCS & RFS	1. CMD Bit Error Rate	X		X		
	2. CMD Operational Check	X	X	X	X	X
	3. VCO Frequency	X		X		
	4. CMD Acquisition	X		X	X	X
	5. Modulation Index Optimization	X				
	6. Command with Doppler	X			X	X
FTS & RFS	1. Block Coded TLM Bit Error Rate/SNR	X	X	X	X	X
	2. Uncoded TLM Bit Error Rates/SNR		X	X	X	X
	3. FTS Output Waveforms	X		X		
	4. Downlink Spectrum	X		X	X	X
	5. Modulation Index Adjust/Check	X		X		
	6. Subcarrier Frequency/ Phase Jitter	X		X	X	X
SYSTEM	1. TLM Operational Software				X	X
	2. Command Software				X	X

Table 3. Mariner Mars 1971 spacecraft antenna characteristics

Antenna	Boresight locations		Gains and beamwidths	
	Cone angle, deg	Clock angle, deg	Boresight gain, dB	-3 dB beamwidth, deg
Low gain	0	---	7	±45
Medium gain	158	305	14	±18
High gain (position 1)	42.5	282.8	25	±4
High gain (position 2)	38.3	279.9	25	±4

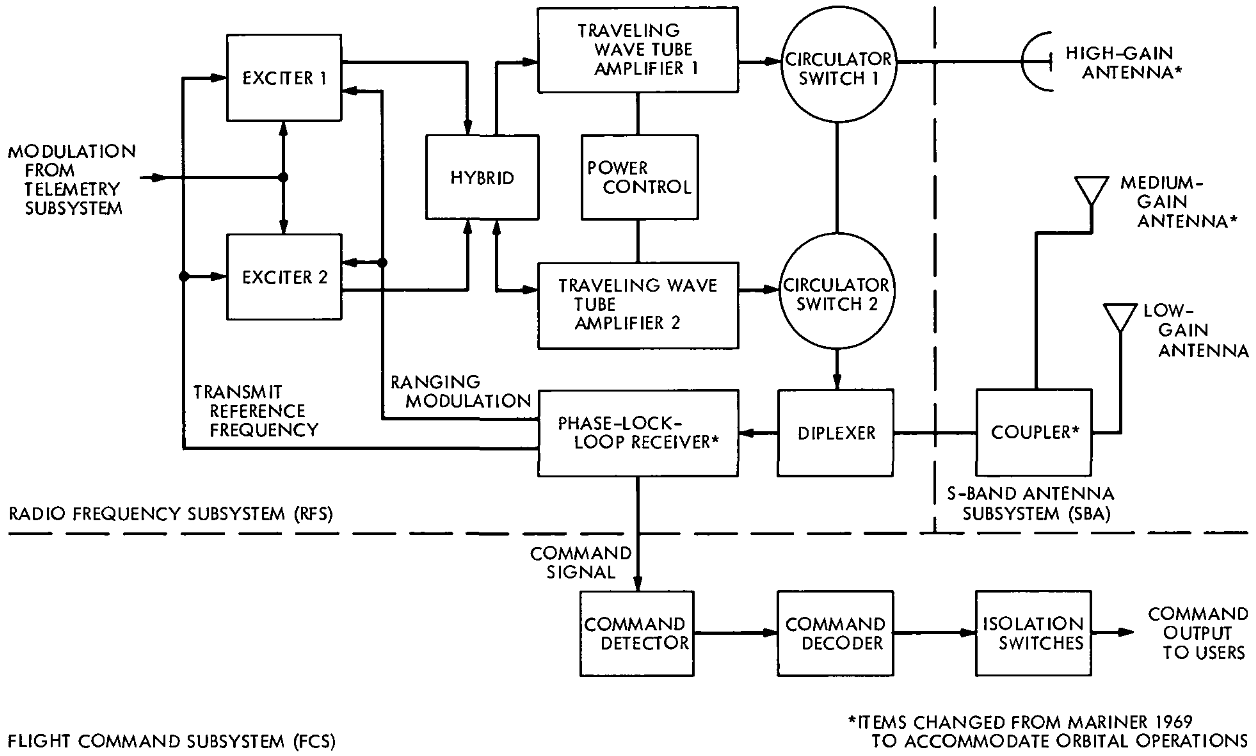


Fig. 1. Simplified block diagram of Mariner Mars 1971 telecommunications system

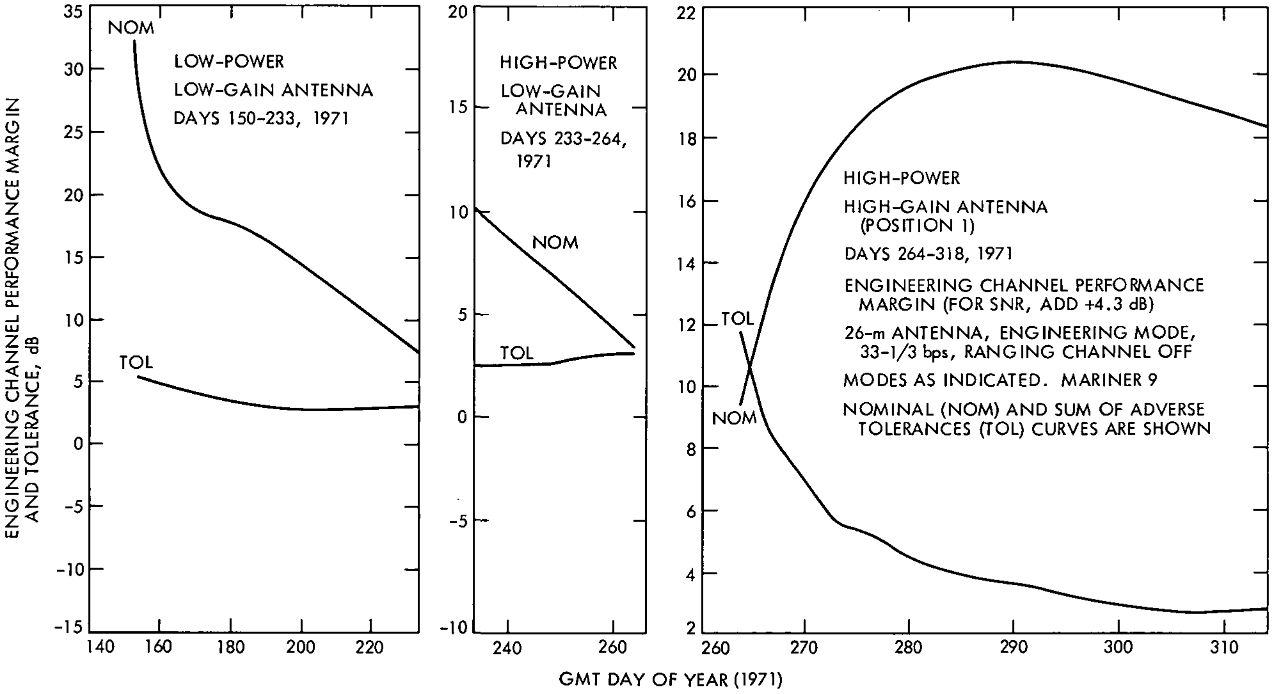


Fig. 2. Engineering channel (33 1/3 bps) performance margin and tolerances, cruise phase

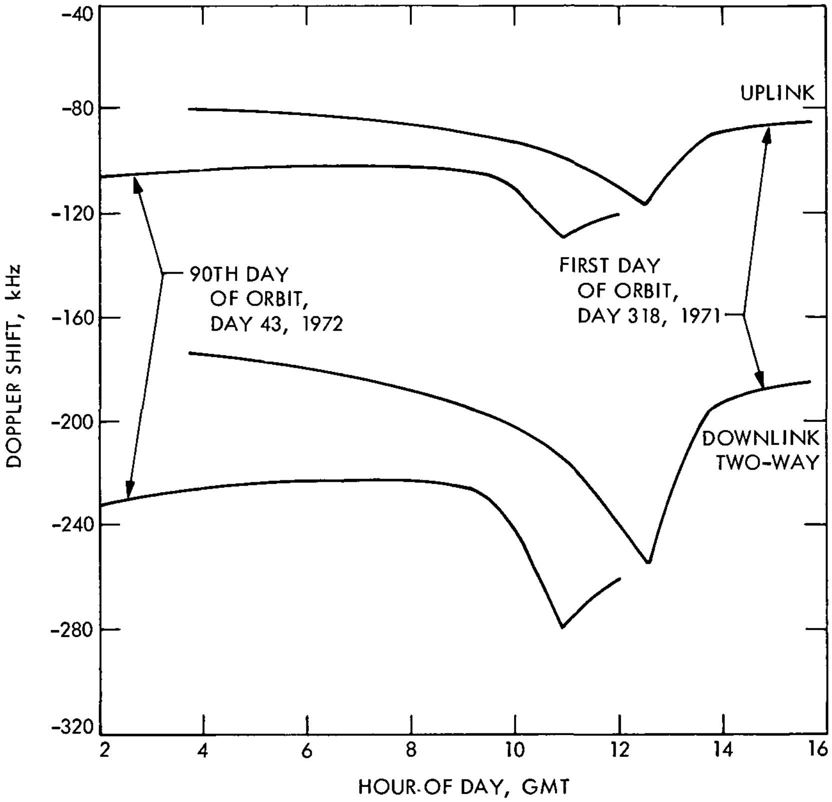


Fig. 3. DSS 41 orbital doppler shift, 12-hour orbit

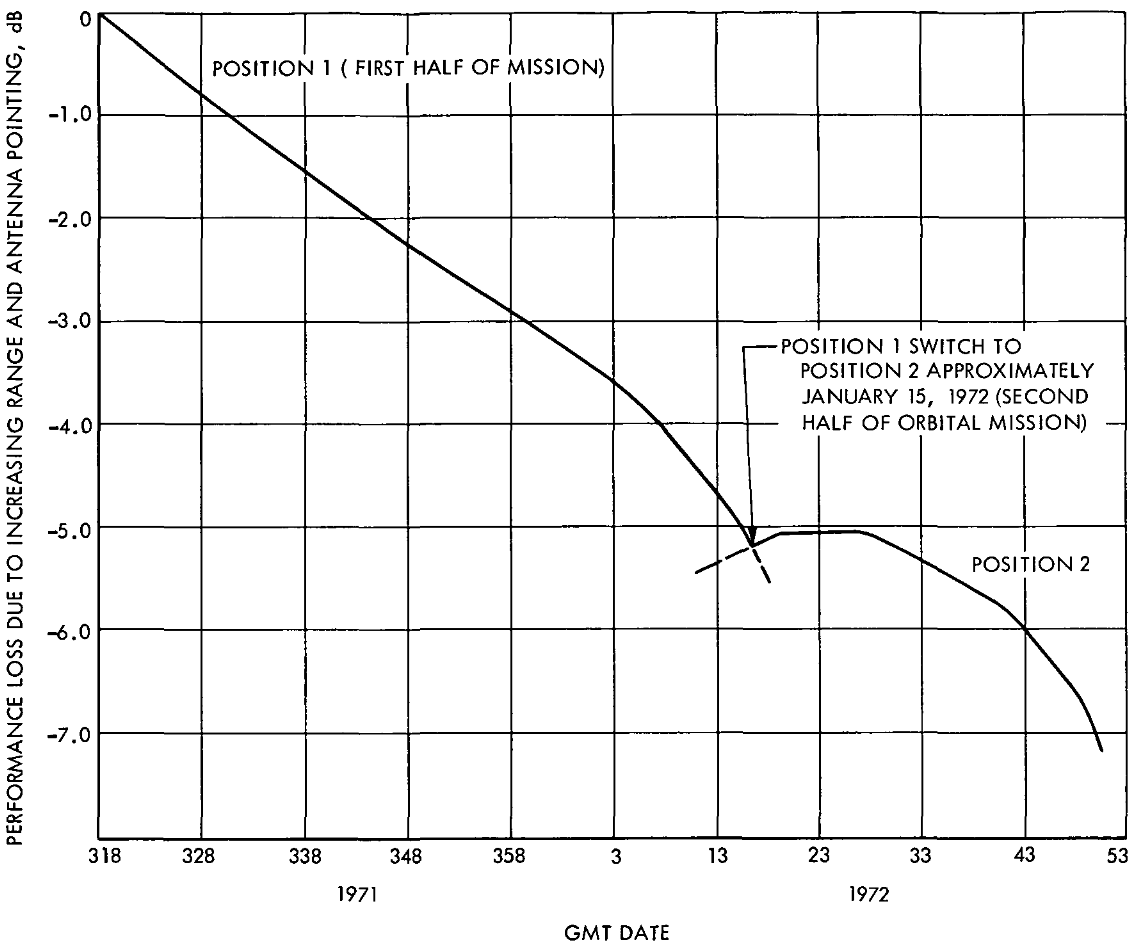


Fig. 4. Performance loss due to increasing range and to antenna angle between earth and HGA

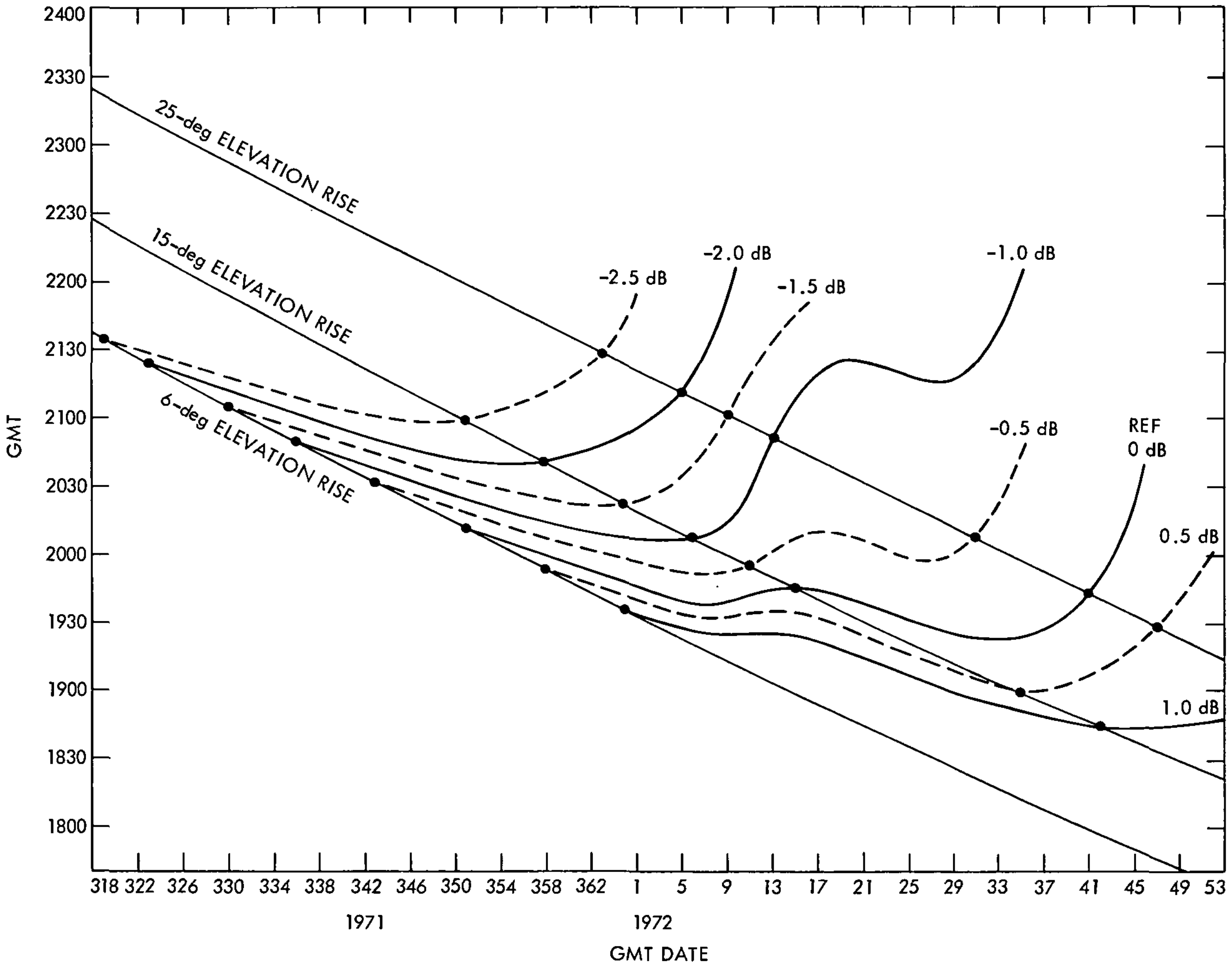


Fig. 5. DSS 14 rise times

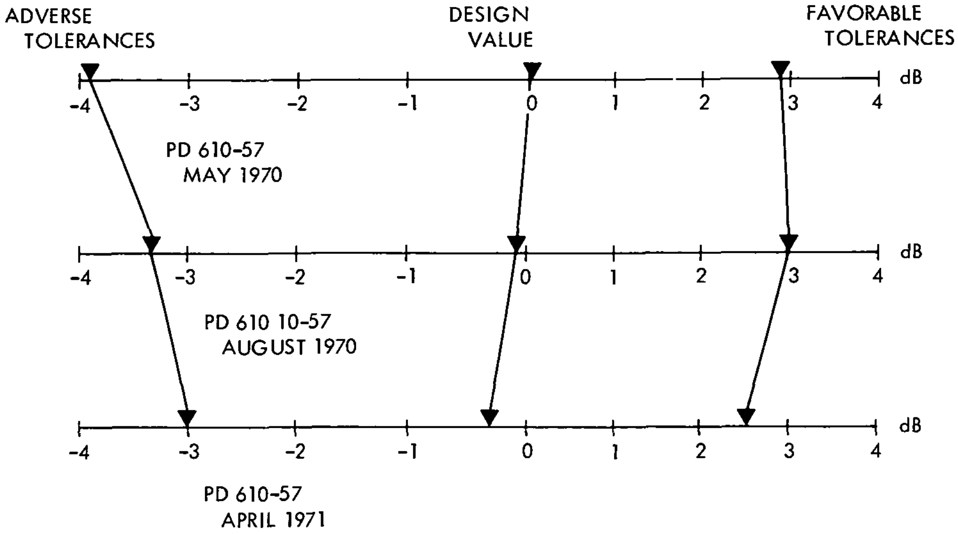


Fig. 6. Variation in design value and tolerance with time for 16.2-kbps channel, referenced to Mars encounter

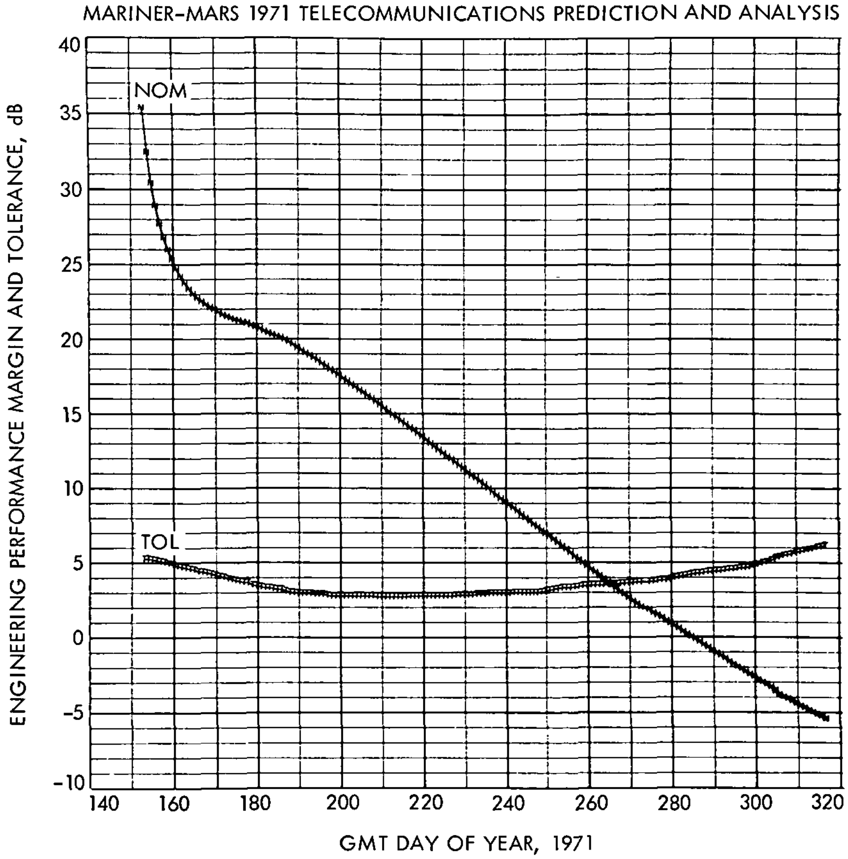


Fig. 7. TPAP plot of engineering channel performance margin and adverse tolerances vs time

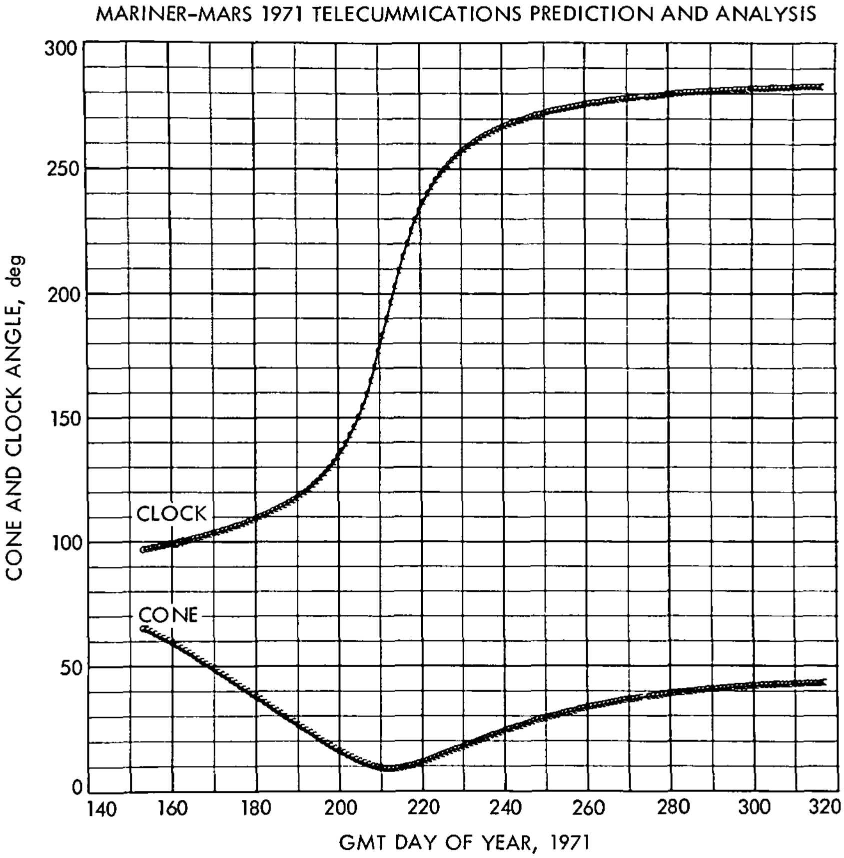


Fig. 8. TPAP plot of earth clock and cone angles vs time

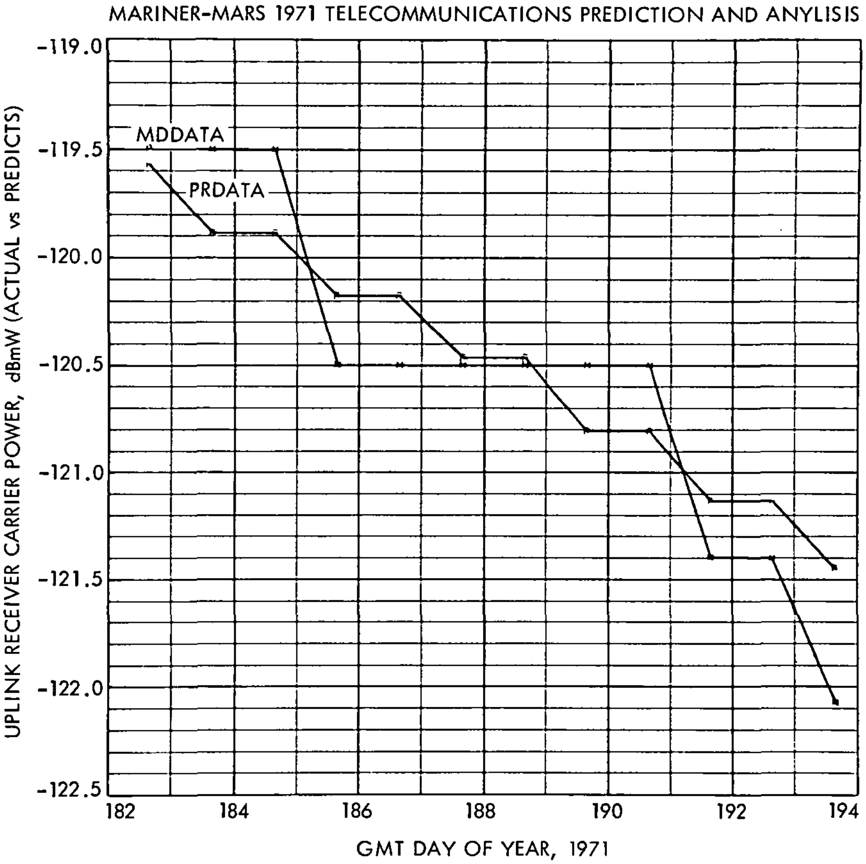


Fig. 9. Typical TPAP plot of actual (MDDATA) vs predicted (PRDATA) performance

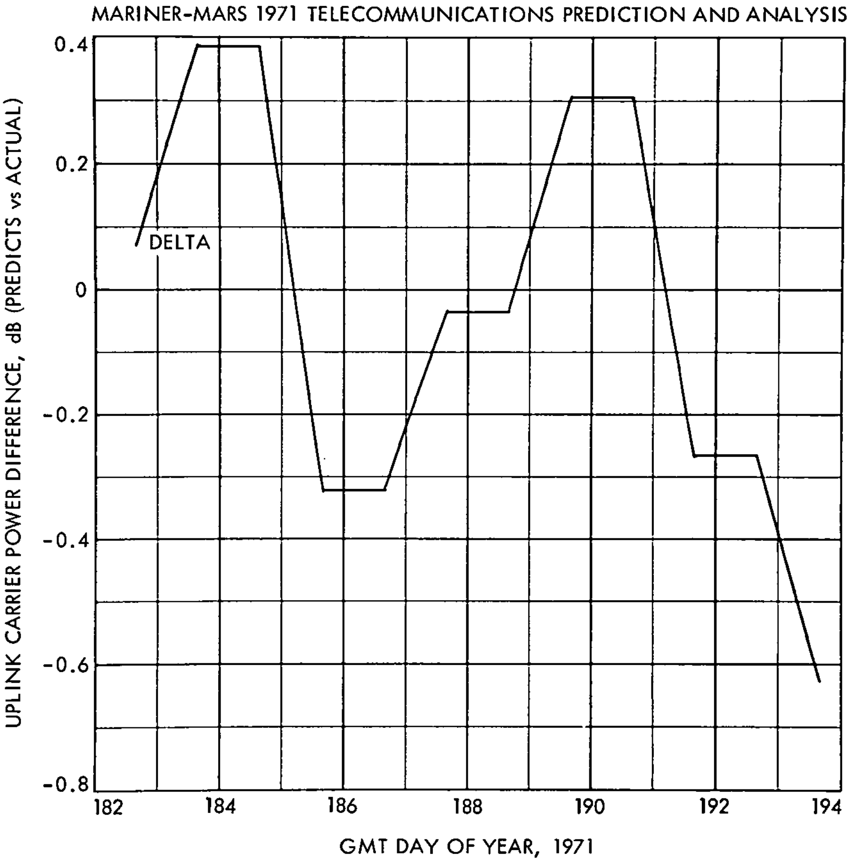


Fig. 10. Typical TPAP plot of the difference between actual and predicted performance

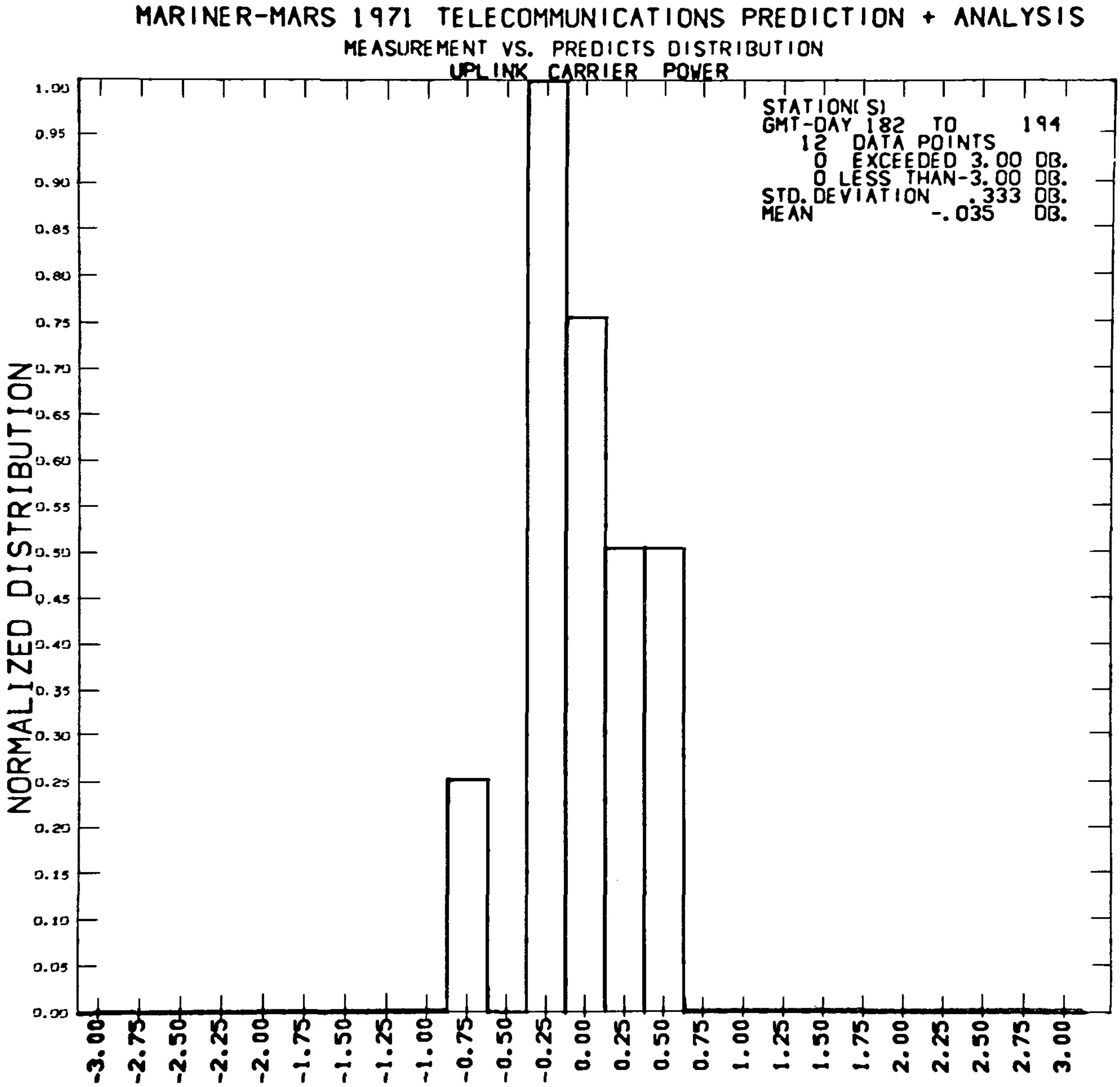
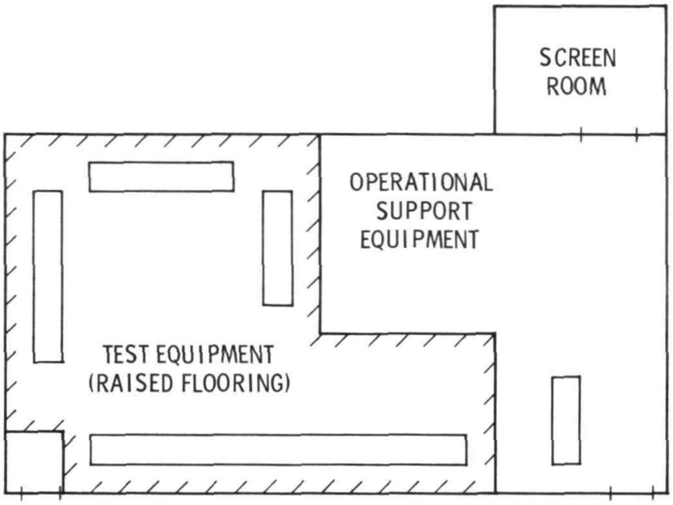


Fig. 11. Typical TPAP histogram of the difference between actual and predicted performance



MAIN LAB	7.6 X 14 m =	106.0 m^2	(25 X 46 ft = 1150 ft^2)
SCREEN ROOM	3.6 X 2.7 m =	9.7 m^2	(9 X 12 ft = 108 ft^2)
	TOTAL	115.7 m^2	(1258 ft^2)

Fig. 12. Telecommunications developmental laboratory floor layout

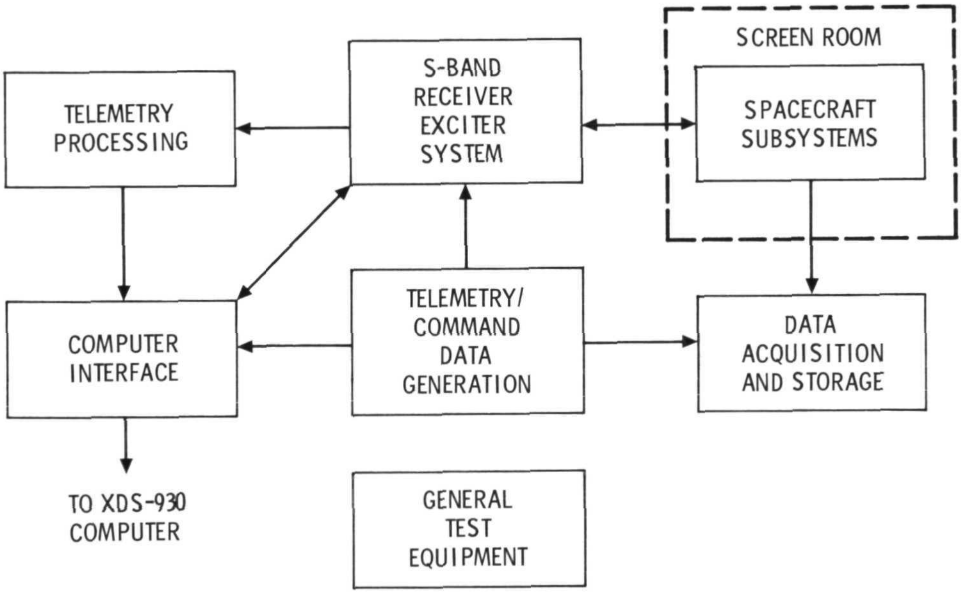
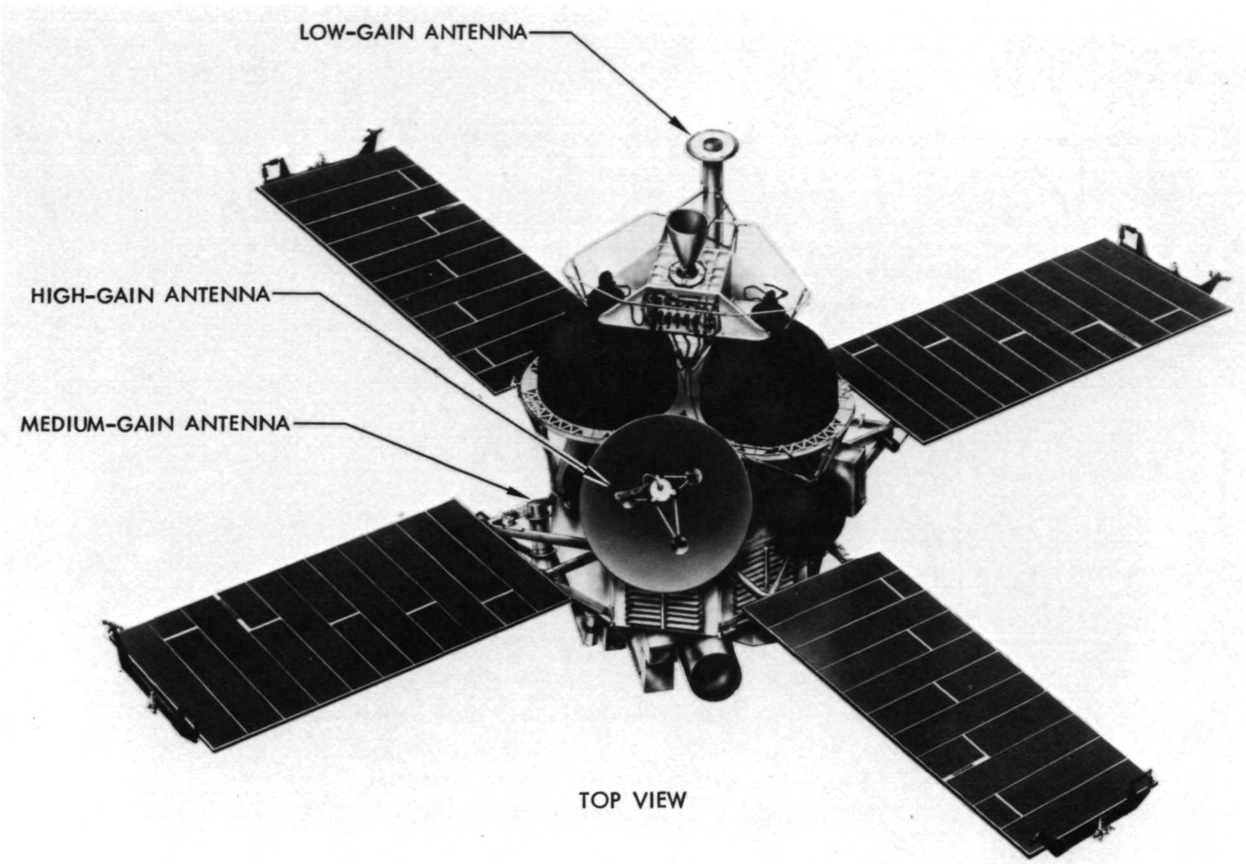


Fig. 13. Telecommunications developmental laboratory functional block diagram



TOP VIEW

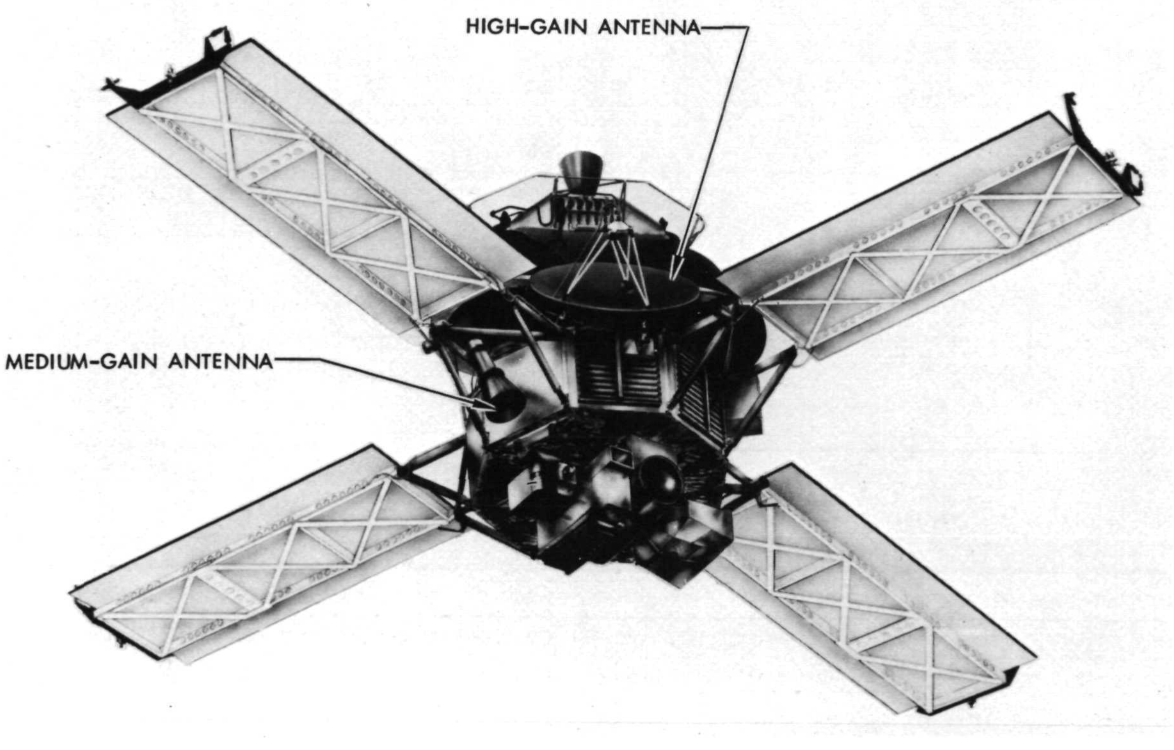


Fig. 14. Mariner Mars 1971 spacecraft, antenna locations

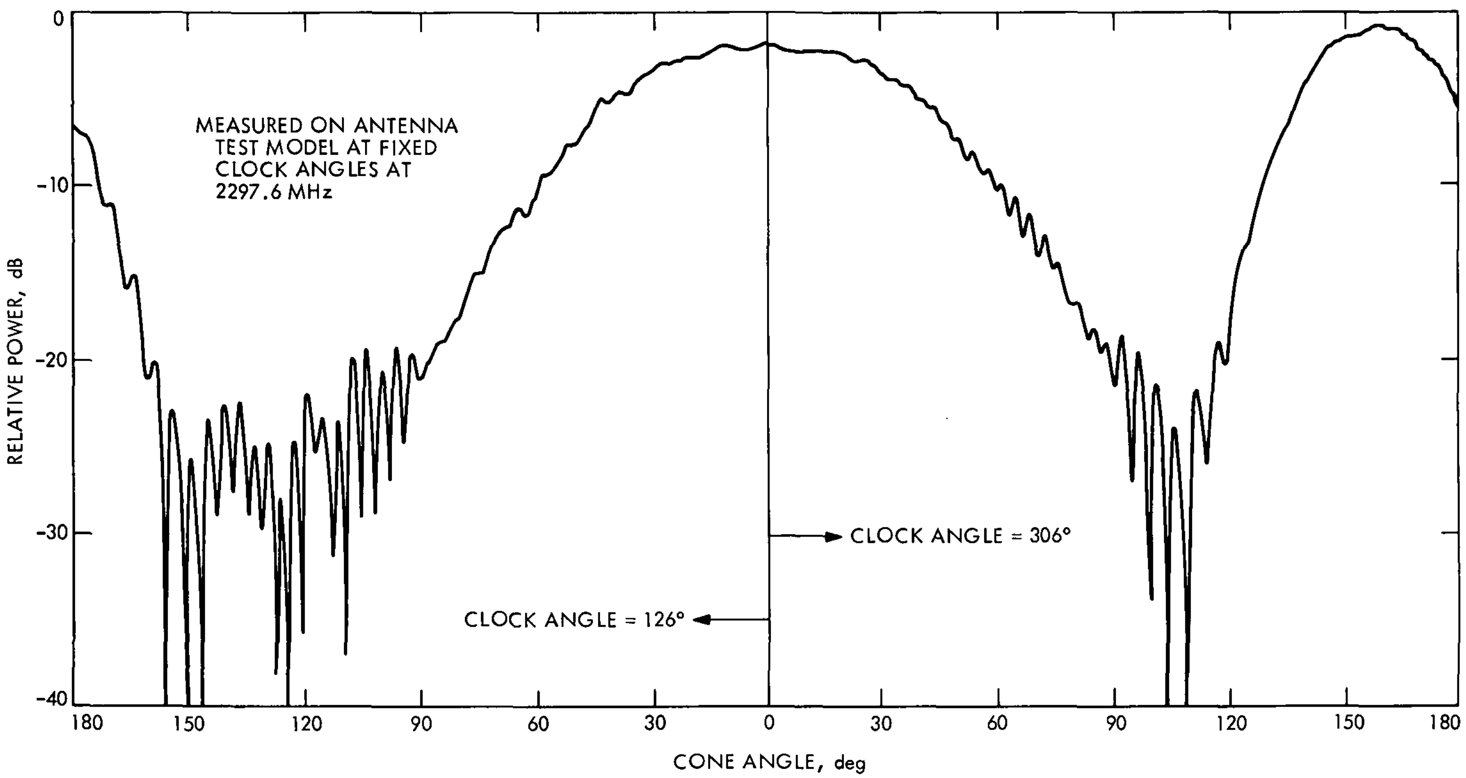


Fig. 15. LGA/MGA antenna system relative gain pattern

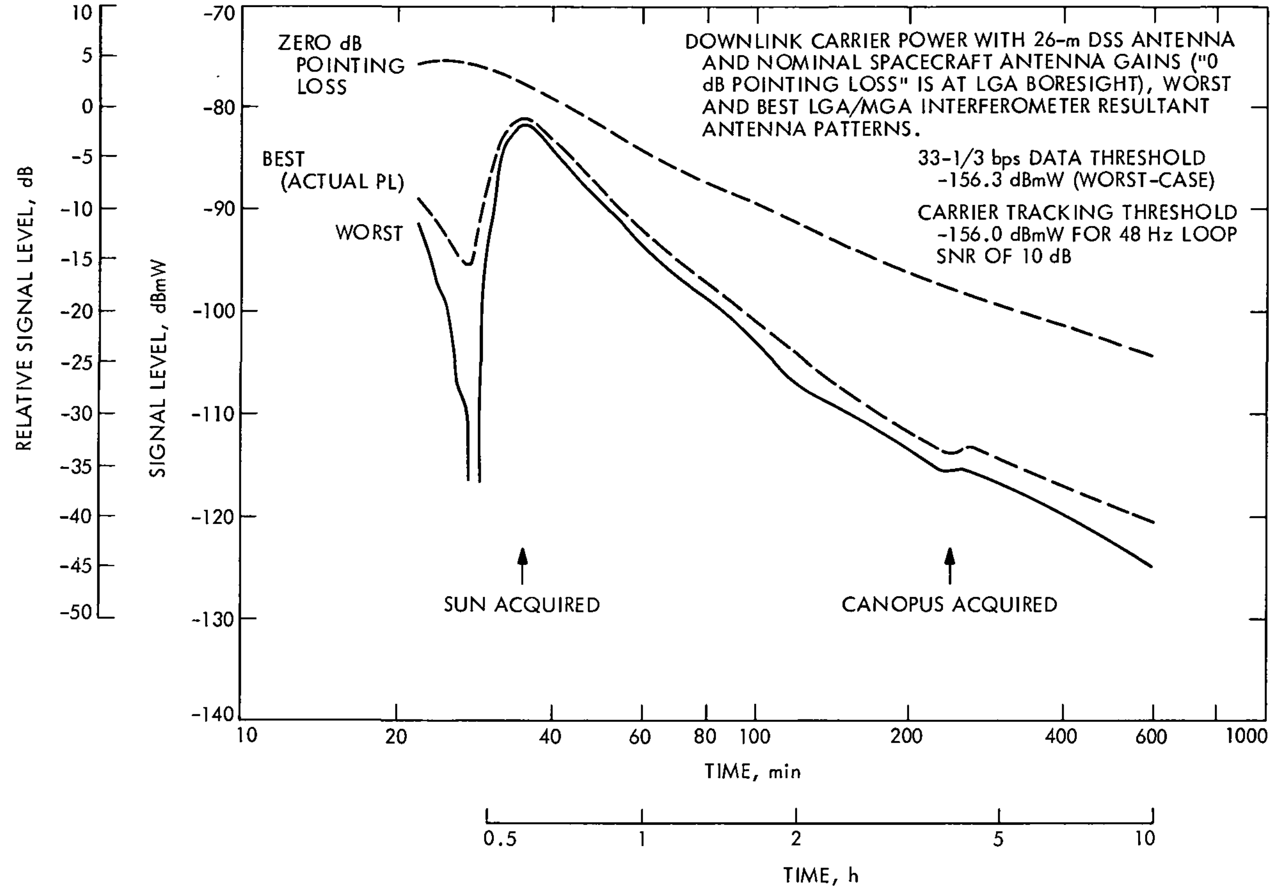


Fig. 16. Nominal Mission A downlink power with interferometer effect, DSS 51

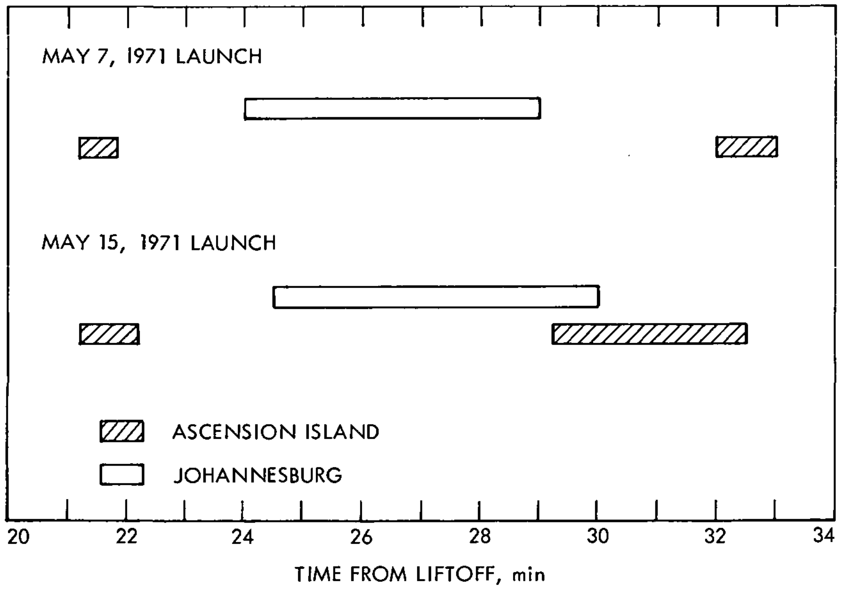


Fig. 17. Intervals during which 10-dB peak-to-peak fading (or more) is possible during initial minutes of mission (prior to sun acquisition)

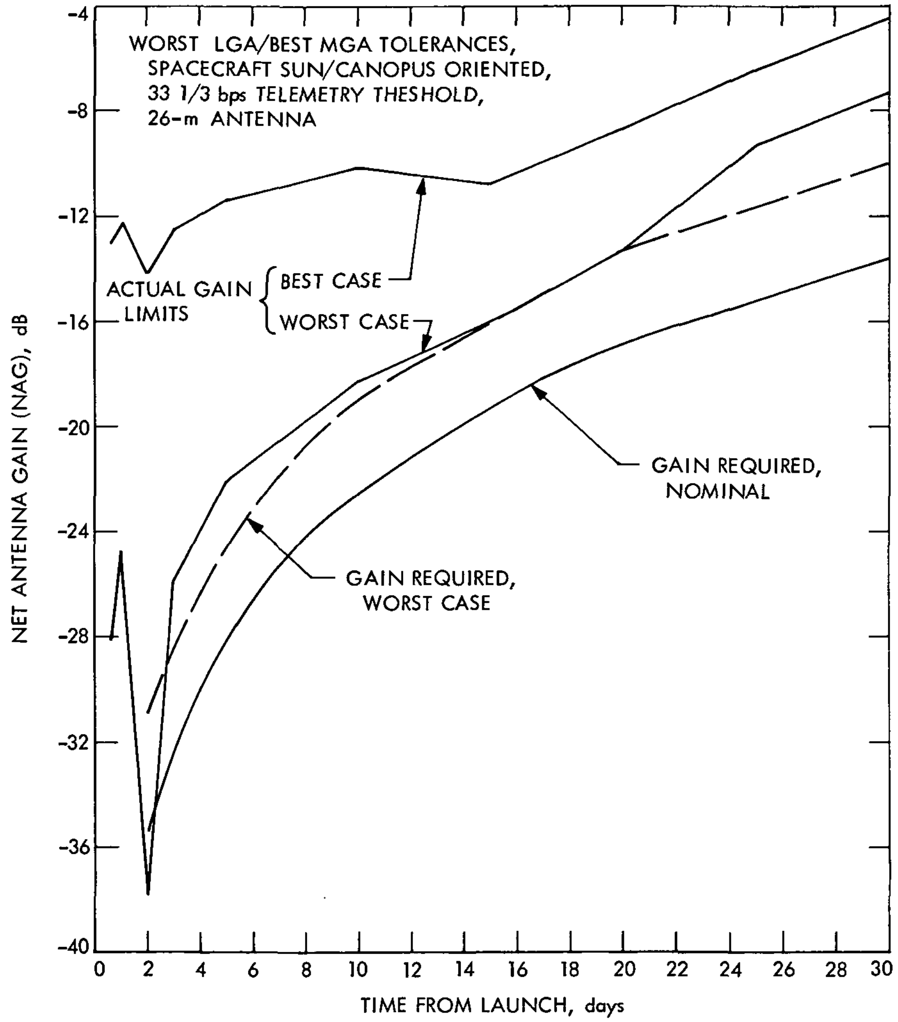


Fig. 18. Mission A downlink time history

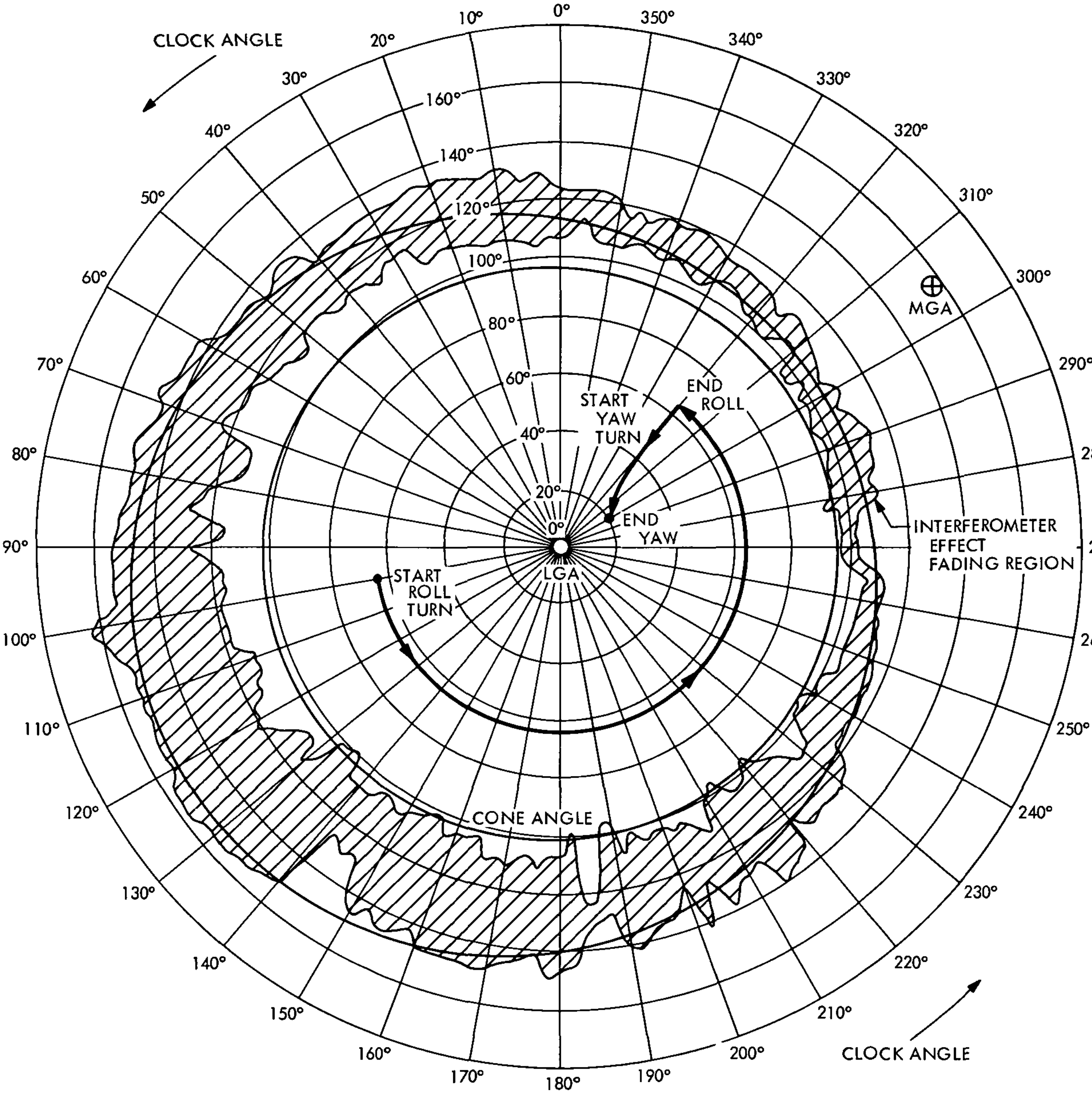


Fig. 19. Cone/clock trajectory of typical first midcourse maneuver (2297 MHz)

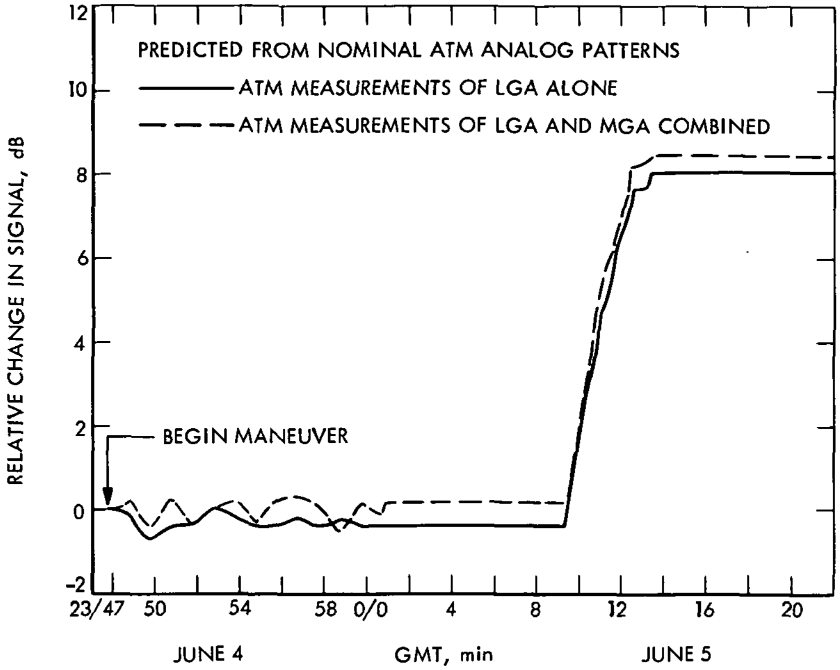


Fig. 20. Predicted performance during midcourse maneuver; relative change in downlink signal vs time

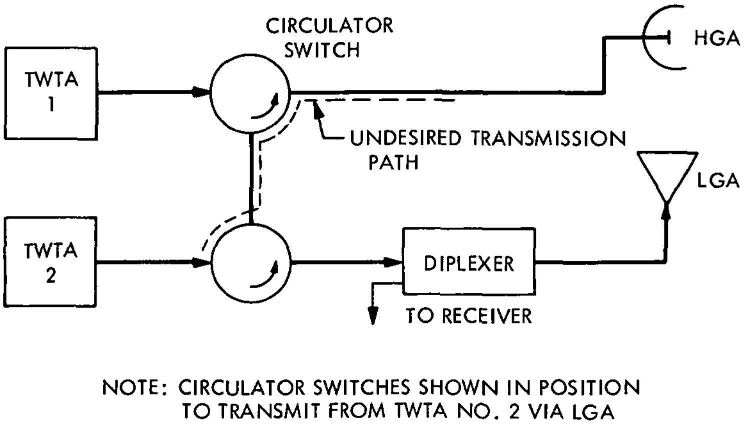


Fig. 21. Mechanism of HGA/LGA transmit interferometer effect

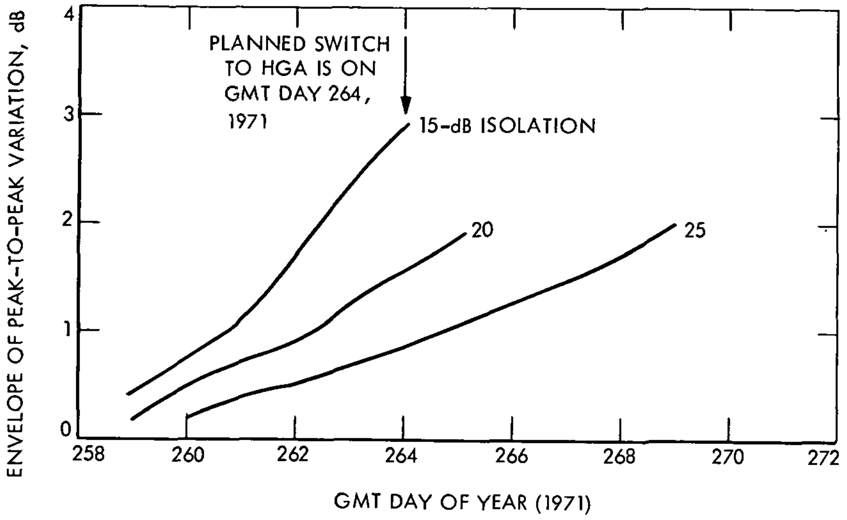


Fig. 22. Range of possible variation in downlink AGC due to interferometer effect between HGA and LGA as a function of GMT day (in LGA mode)

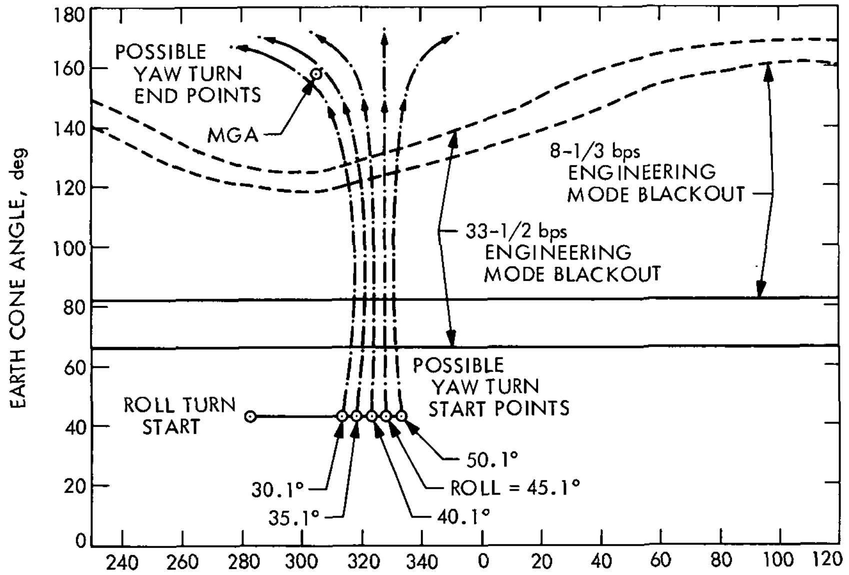


Fig. 23. Positive yaws of 12-min duration

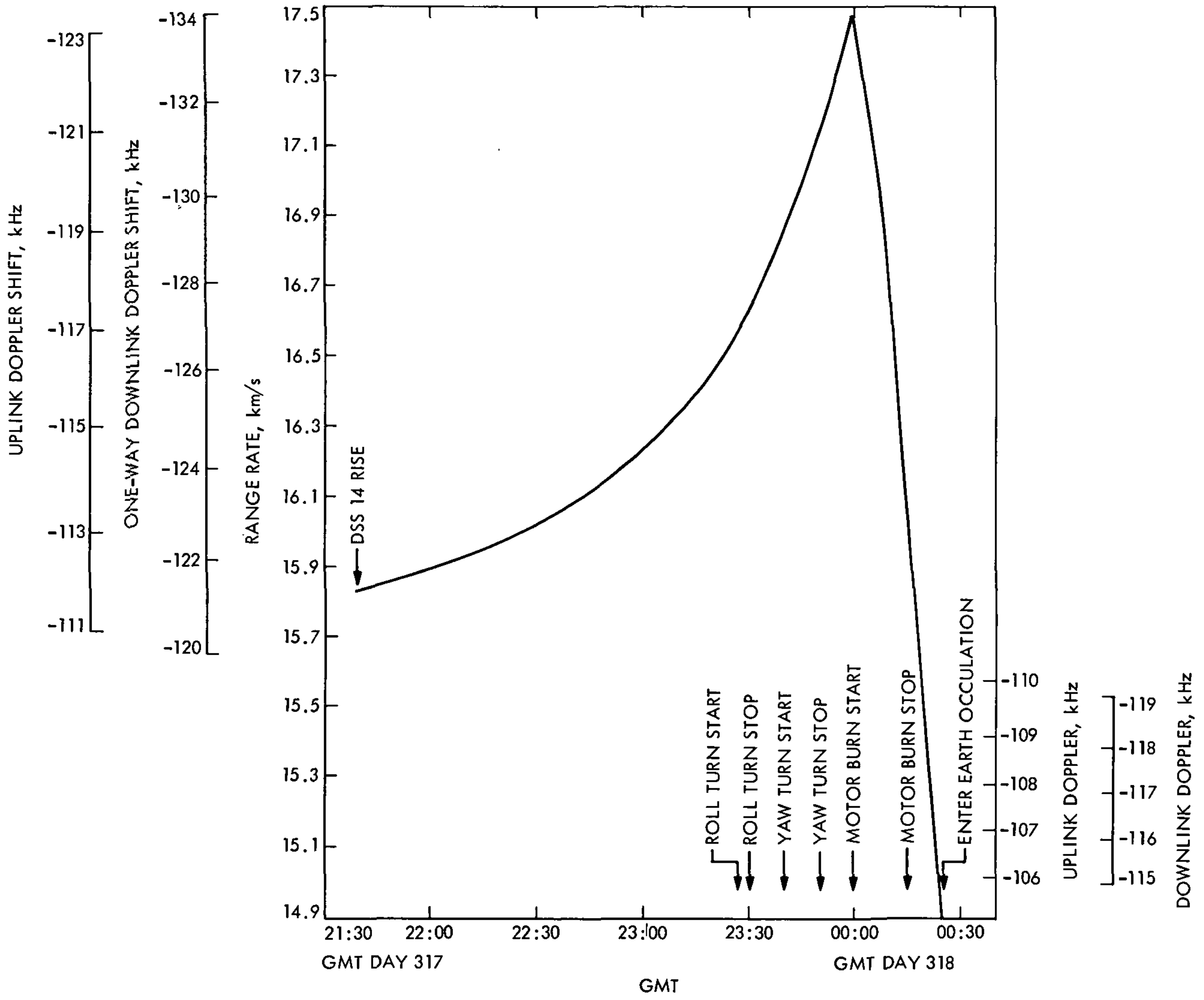


Fig. 24. Range rate vs earth observed time (GMT); orbit insertion

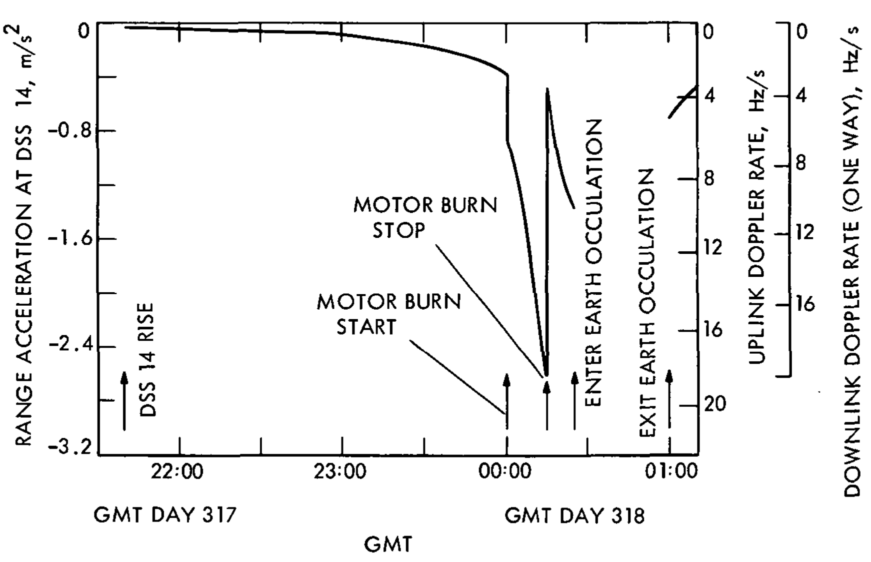


Fig. 25. Range acceleration vs earth observed time (GMT): orbit insertion

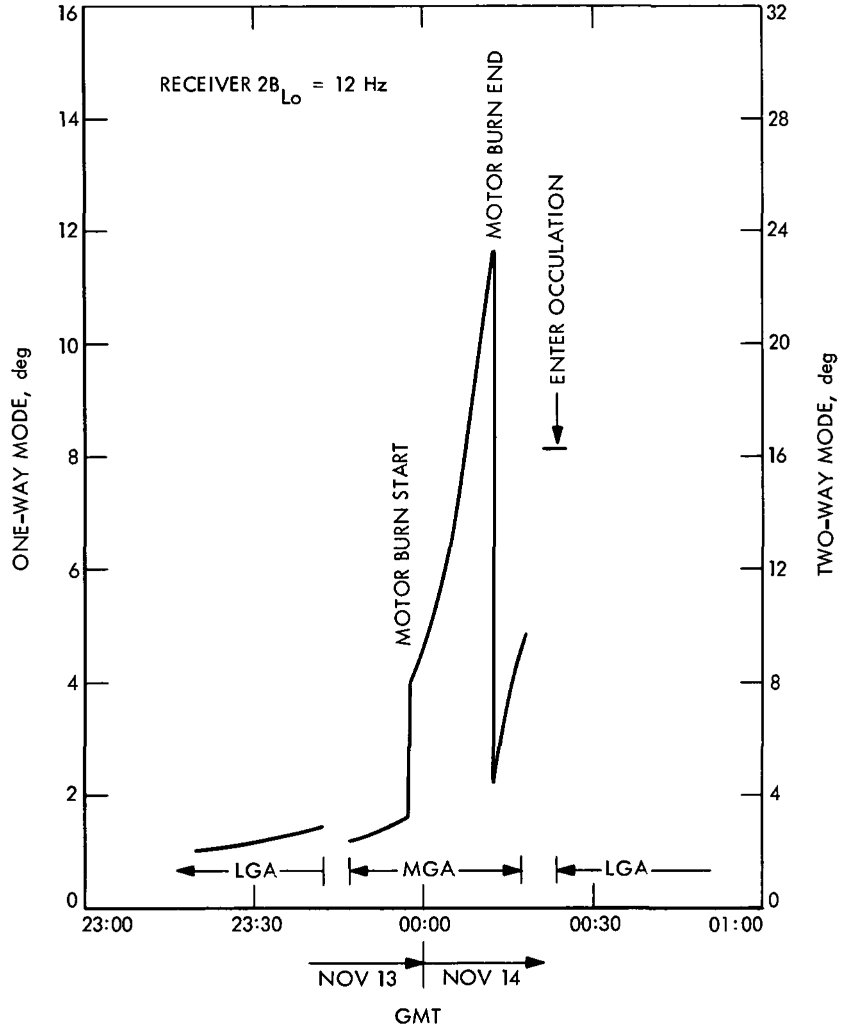


Fig. 26. Typical downlink receiver phase error due to range acceleration (doppler rate) only, in one- or two-way tracking mode

NASA — JPL — Coml., L.A., Calif.