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Mariner Mars 1964 Telecommunication System

John A. Hunter

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Mariner Mars 1964 Telecommunication System

John A. Hunter

R. P. Mathison

R. P. Mathison, Manager
Spacecraft Radio Section

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ABSTRACT

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This Report describes the radio, telemetry, and command subsystems of the *Mariner* Mars 1964 telecommunication system and presents a summary of system performance during the mission. For this mission the *Mariner IV* required a telecommunications system providing telemetry, command, and doppler tracking capabilities over ranges approaching 260×10^6 km. By utilizing unique characteristics of the Mars 1964 minimum energy trajectories, it was possible to meet this requirement without a pointable antenna and the associated complex spacecraft equipment. Spacecraft equipment design was based on techniques used for the *Mariner II* spacecraft, with modifications to increase reliability and accommodate the increased maximum communication range.

I. INTRODUCTION

The telecommunication system for the *Mariner* Mars 1964 mission comprised spacecraft-borne equipment and the Deep Space Instrumentation Facility [DSIF (Ref. 1)] stations of the NASA Deep Space Network (DSN). The system was required to perform three functions: (1) track the position and velocity of the spacecraft, (2) telemeter engineering and scientific data from the spacecraft, and (3) transmit commands to the spacecraft as necessary. These functions had to be performed successfully for a period in excess of eight months in the hostile environments of deep space. The design of the spacecraft equipment was based on techniques used for the *Mariner II* spacecraft, for the 4-month mission to Venus conducted in 1962 (Refs. 2, 3). These techniques were extended and modified to improve equipment reliability, accommodate the increased communication range required for the Mars 1964 mission, and utilize the characteristics of the Mars 1964 trajectories to effect simplifications in the spacecraft equipment. The spacecraft that flew the *Mariner* Mars 1964 mission will be referred to as *Mariner IV*.

Mariner IV used both the Sun and the star Canopus for attitude reference, such that the roll axis of the spacecraft was always pointed toward the Sun for primary reference; the Canopus sensor provided roll position control so that the angular orientation of the spacecraft with respect to Earth was known. Figure 1 shows the spacecraft coordinate system and the locations of the reference stars relative to the low- and high-gain antennas. The low-gain antenna provided coverage for approximately the first 95 days of flight, while the high-gain antenna provided coverage for the remainder of the flight.

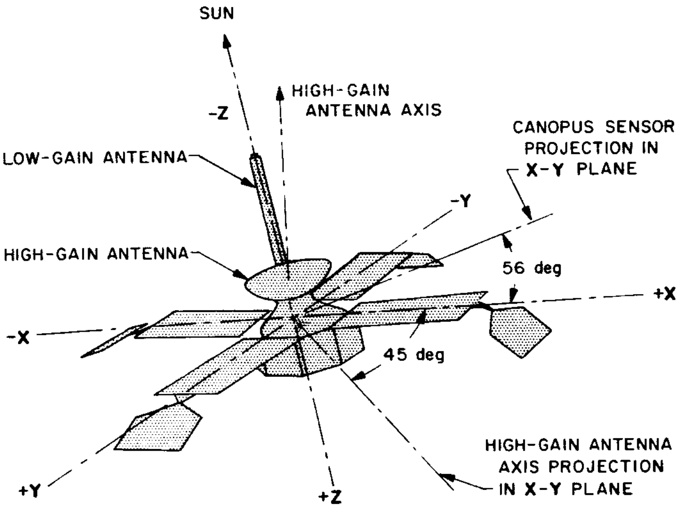

Fig. 1. ***Mariner IV* spacecraft coordinate system**

II. SPACECRAFT RADIO SUBSYSTEM

The radio subsystem for the *Mariner IV* spacecraft was required to receive a modulated or unmodulated RF carrier transmitted from ground stations of the DSN, demodulate command and ranging signals, if present; coherently translate the frequency and phase of the RF carrier by a ratio of 240/221; modulate the translated carrier with telemetry and ranging signals; and retransmit the carrier back to Earth. Figure 2 is a block diagram of the spacecraft radio subsystem.

The received signal was a 2116 Mc carrier that could be modulated by a composite command signal and/or a coded ranging signal. This signal was demodulated by the automatic phase control receiver that tracked the carrier signal in a phase locked loop. If command or ranging modulation were present, they were sent, respectively, to the command detector channel or to the ranging channel. When the receiver was phase locked to the received carrier, it generated a filtered phase-reference for the

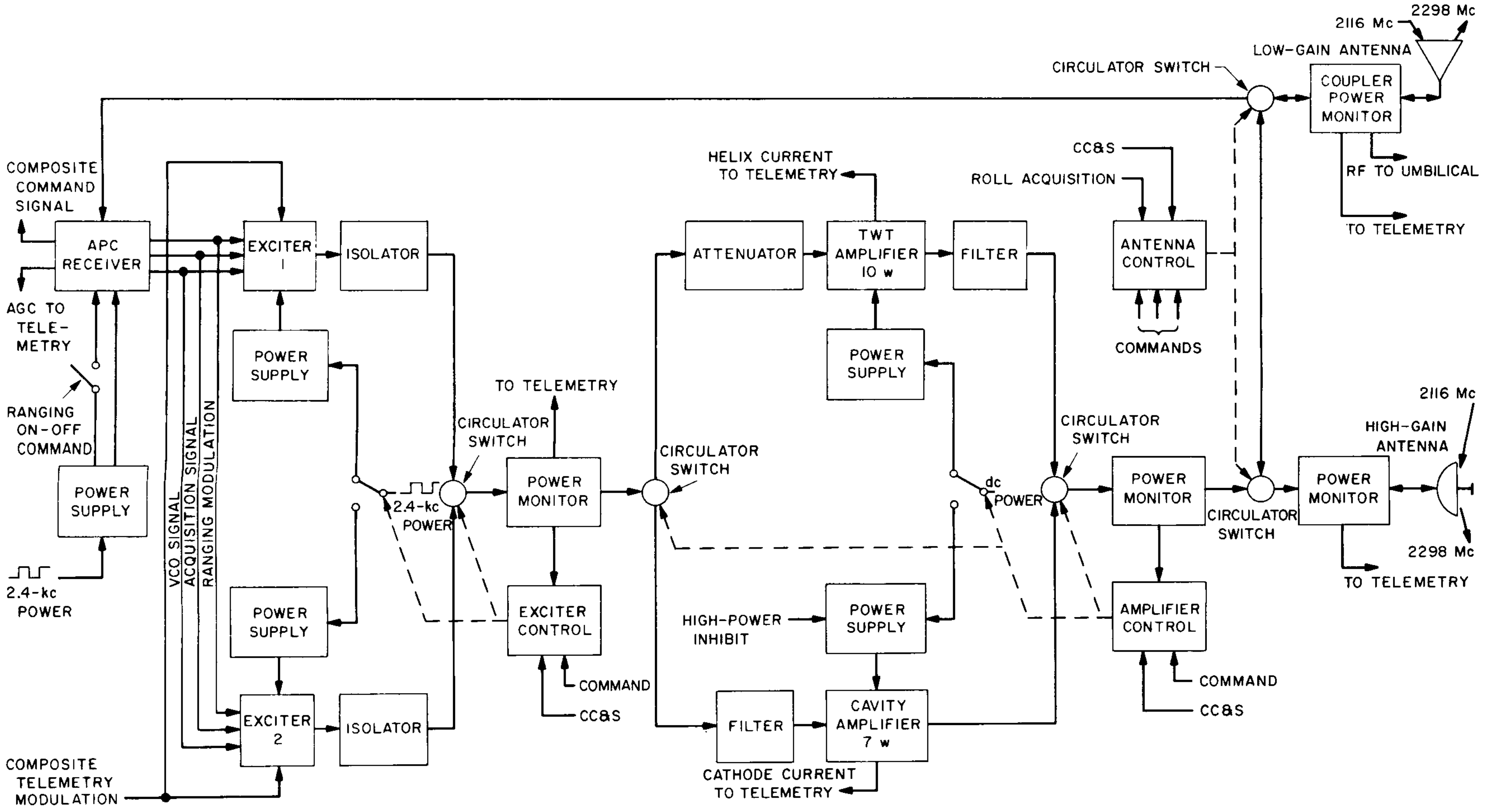

Fig. 2. Block diagram of the spacecraft radio subsystem

transmitter exicter that was coherent with the received carrier. The phase of the transmitted signal was thus related to the phase of the received signal by the constant ratio of 240/221. The signal generated by the transmitter exciter was phase modulated continuously (1) by a composite telemetry signal and (2) by a ranging signal, if ranging were turned on.

When the ground stations were not transmitting a signal to the spacecraft, the spacecraft transmitter exciter was controlled by an auxiliary crystal oscillator. This method provided a capability for noncoherent one-way tracking of the spacecraft and ensured that spacecraft telemetry would be available even when the ground stations were not in uplink lock with the spacecraft.

To provide increased reliability over the *Mariner II* design, redundant exciters, power amplifiers, and power supplies were incorporated into the transmitter. Either exciter could be used with either power amplifier by means of a circulator switching network. Similarly, either power amplifier could be used for transmitting through either antenna.

The control of switching between power amplifiers and exciters was provided by either ground command or onboard failure detection. For ground command control, the receipt of the appropriate direct command would cause the control unit to transfer power from the active to the inactive element and to reverse all necessary input-output functions. To allow switching by on-board failure detection, power monitors sampled the level of both the exciter and power amplifier RF power outputs. If the output power dropped below a preset level, a 66-hr cyclic pulse from the spacecraft central computer and sequencer (CC&S) would cause the control unit to switch from the offending element.

The *Mariner IV* RF power amplifiers form a hybrid configuration consisting of one cavity amplifier and one traveling wave tube (TWT) amplifier. This hybrid configuration was chosen, rather late in the process of spacecraft design, as the best system to fulfill mission objectives with available hardware and technology. The cavity amplifier was used during the launch phase in a low-voltage mode to prevent arcing when the spacecraft pressure passed through the critical region. As the spacecraft separated from the *Agena* stage of the launch vehicle, the cavity amplifier power supply was switched to the high-voltage mode, and the cavity amplifier began transmitting at full power. It was not possible to use the TWT amplifier during this period because it has no low-voltage mode, nor was it packaged to operate in a partial vacuum. Several days after launch, a switch to the TWT amplifier was directed by ground command. No changes to this configuration were contemplated.

This procedure was decided on because the cavity amplifier gradually degrades in RF power output if it is operated for a period of several thousand hours. Although the cavity amplifier had adequate power output at launch to safely fulfill the telecommunications function, it was possible that if operated all the way to encounter, it would not provide adequate performance to safely cover system adverse tolerances. Whereas, by turning the cavity off and operating with the TWT amplifier—which does not appear to degrade during the lifetime of this mission—the cavity would still be available for use as a redundant element, should catastrophic failure of the TWT occur later in the mission.

With two antennas and the associated circulator switches, three transmitting and receiving modes were available:

(1) Transmit low gain, receive low gain

(2) Transmit high gain, receive high gain

(3) Transmit high gain, receive low gain

These modes provided the required coverage during all phases of the mission. Selection of the proper mode for a given time in flight was by CC&S command with ground-command backup. Failure mode switching was also available to switch the spacecraft receiver to the low-gain antenna to take advantage of its broader coverage should roll reference be lost.

By designing antenna radiation pattern coverage to take advantage of the unique characteristics of the Mars 1964 minimum energy trajectories (Ref. 4), considerable savings in spacecraft weight and complexity were realized. Figure 3 shows a plot of the spacecraft-to-Earth vector for the *Mariner* trajectory across the spacecraft coordinate system. Note that during the latter portion of the flight, when it was necessary to use a high-gain antenna to communicate over the long ranges involved, the angular variation of the Earth track was small. This permitted the use of a fixed high-gain antenna and enabled spacecraft designers to eliminate the heavy and complex antenna pointing equipment required to steer a movable antenna.

The low-gain antenna had a gross pattern very much like a cardioid of revolution with peak gain along the roll axis in the forward (Sun) hemisphere, as shown in Fig. 4.

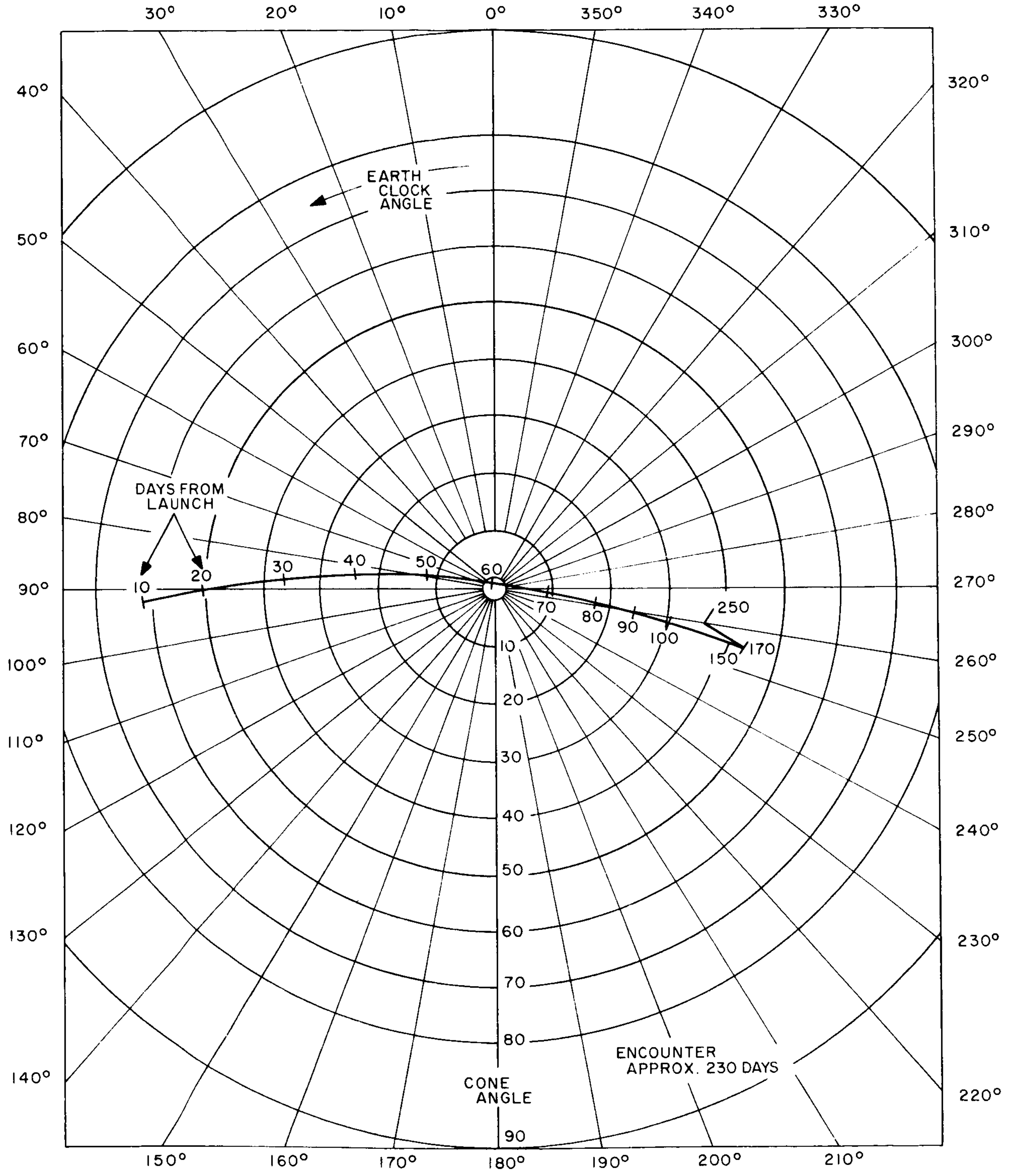

Fig. 3. Spacecraft-to-Earth vector for *Mariner IV* trajectory across the spacecraft coordinate system

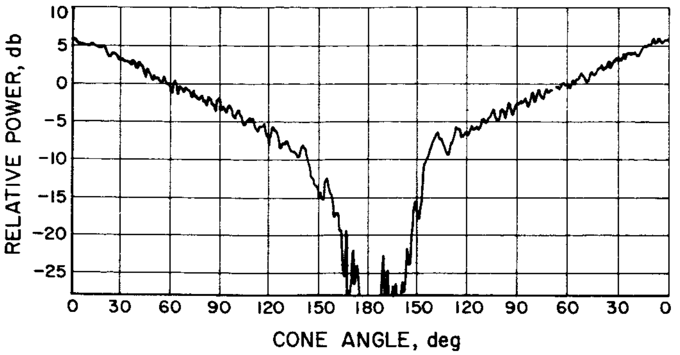

Fig. 4. *Mariner IV* low-gain antenna gain vs cone angle for constant clock angle of 101 deg, frequency 2298 Mc

Antenna gain was optimized in the forward hemisphere to take advantage of the locus of angles described by the spacecraft-to-Earth vector, which falls in the spacecraft's forward hemisphere for the entire flight.

The high-gain antenna pattern was nearly elliptical, oriented in such a way that the spacecraft-to-Earth vector during the time the high-gain antenna was in use passed along the major axis of the ellipse. During the encounter and post-encounter phase, when TV pictures and science data were being played back from spacecraft data storage, the spacecraft-to-Earth vector passed through the region of peak gain of the high-gain antenna. Physically, the high-gain antenna was a parabolic reflector with an elliptic aperture having a major axis of 46.0 in. and a minor axis of 21.2 in. Figure 5 is a plot of gain vs cone angle for a cross section through the major axis of the high-gain antenna.

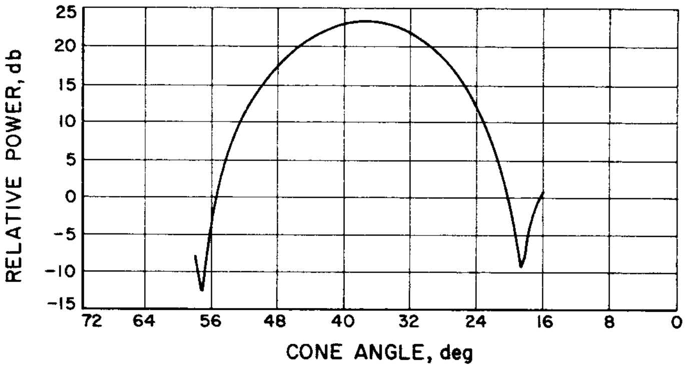

Fig. 5. *Mariner IV* high-gain antenna gain vs cone angle for constant clock angle of 101 deg, frequency 2298 Mc

III. SPACECRAFT TELEMETRY SUBSYSTEM

The *Mariner IV* telemetry subsystem accepted engineering data from 90 analog channels, time multiplexed (commutated) it into a predetermined sequence, and converted it into 7-bit binary words. It also accepted digital data from science, video storage, and command subsystems and time multiplexed this with the engineering data. The telemetry subsystem generated a cumulative count of specific spacecraft events, and a cyclic, binary, pseudorandom code from which bit and word synchronization was obtained. A composite telemetry signal (consisting of telemetry data bi-phase modulated on a square-wave subcarrier and the synchronization code phase modulated on a synchronization subcarrier) was generated and sent to the RF phase modulator. Two data rates were provided to take advantage of the higher signal strengths available during the early part of the flight, which supported a higher bit rate. The lower rate was used after the Earth-to-spacecraft range was so large that the ground-received signal level decreased to the point where excessive bit errors could be introduced at the higher bit rate.

Figure 6 is a block diagram of the *Mariner IV* data encoder showing the main functional elements. Analog data from telemetry transducers in the various spacecraft subsystems came into the solid-state commutator where it was time multiplexed into a predetermined sequence and converted to a pulse-amplitude-modulated (PAM) signal for presentation to the analog-to-digital converters. The commutator also provided several unique words of frame synchronization information for the ground decommutators to use in identifying the various data words.

In the analog-to-digital converters, the sequenced PAM data from the commutator were converted into 7-bit binary words which in turn went to the data selector for insertion into the data stream.

To obtain bit and word synchronization for telemetry, a cyclic 63-bit pseudo-random code was used (Ref. 5). This code was generated by a pseudo-random code generator which was driven by the synchronization subcarrier frequency of $2F_s$ and, thus, was synchronized with data and synchronization subcarriers. Bit and word synchronization were derived through a series of gates which generated pulses that synchronized the commutator, the analog-to-digital converters, and all digital data inputs.

To provide bit and word synchronization information to the ground decommutators, the pseudo-random code was phase shift keyed (PSK) modulated onto the synchronization subcarrier. The ground demodulator generated a local pseudo-random code, identical to the code received from the spacecraft, and stepped the two codes past each other until they were in phase. Word gates like those on the spacecraft then derived accurate word and bit synchronization pulses with which to drive the decommutation sequence.

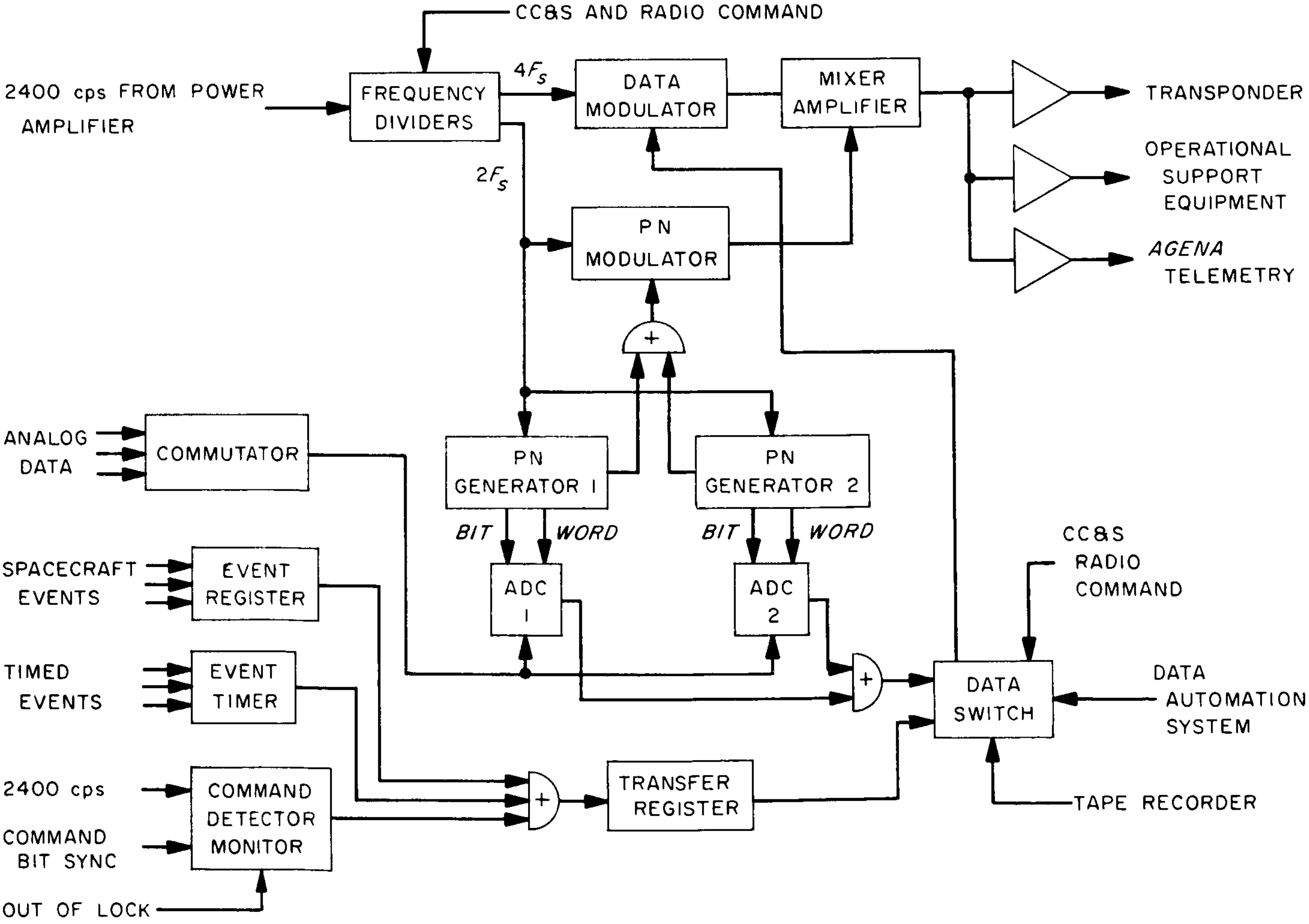

Fig. 6. Block diagram of *Mariner IV* data encoder

To obtain the $2F_s$ and $4F_s$ frequencies used for synchronization and data subcarriers and to provide basic subsystem timing, the spacecraft 2400-cycle power was divided down via a digital-counter chain in the frequency divider. Data bit rate was also determined in the frequency divider by switching in additional counters to obtain the lower bit rate. This switching function was controlled by a CC&S command with ground command backup. At launch, the data rate was 33⅓ bit/sec, with the CC&S commanding a switch to 8⅓ bit/sec at encounter minus 192 days.

In case of catastrophic failure of an A to D converter or pseudo-random code generator, a redundant A to D converter/pseudo-random code generator chain was available. The redundant combination was activated by a ground command which removed power from the failed unit and applied power to the standby unit.

In addition to the processing of analog data, several digital data inputs were accepted by the data encoder. The spacecraft command subsystem provided an input from the command detector (indicating whether or not the command detector was in lock) and the frequency of the command detector voltage control oscillator (VCO). Event registers that were maintaining a cumulative count of spacecraft events provided a 7-bit digital output which was commutated in with the engineering data words. The science subsystem provided a digital input (Ref. 6), consisting of data from the scientific instruments on board the spacecraft. Television picture data from the video storage subsystem were input during the post-encounter period when pictures were being played back.

Four data modes were available, either by CC&S command or ground command. They were (1) engineering data only, (2) engineering and science data, (3) science data only, and (4) stored video and science data with short blocks of engineering data every 9 hr. Mode 1 was used during checkout of the spacecraft and critical maneuvers where engineering data was of primary interest. Mode 2 was used during the cruise phase where both science and engineering data were required. Mode 3 was used during planetary encounter to obtain maximum real-time scientific data, and mode 4 was used during the post-encounter playback of stored data.

The output of the telemetry subsystem to the spacecraft transponder RF phase modulator was thus a composite signal composed of modulated telemetry and synchronization subcarriers. These subcarriers were linearly mixed to form the composite telemetry signal. This composite signal contained all the information necessary for demodulation and decommutation of telemetry data by the ground telemetry subsystem.

IV. SPACECRAFT COMMAND SUBSYSTEM

The spacecraft command subsystem was required to detect and decode any of 29 discrete commands or three quantitative commands that could have been sent to the spacecraft by the DSN ground stations. If the command received were a discrete command, a logical output was provided to the appropriate subsystem for execution of the command. If the command received were a quantitative command, the magnitude and polarity information it contained was stored by the CC&S for use during the execution of a maneuver. When a command word was received, the command detector had to be in lock or the command would be inhibited. The command decoder checked parity on the received command word in such a way that at least two bit errors had to occur in order for a wrong command to be executed. Telemetry information was provided to the data encoder including (1) command detector in lock or out of lock, (2) command detector VCO frequency, and (3) event pulse indication of command reception.

In order to execute a command, the spacecraft command subsystem must be in lock with the ground command subsystem. The command modulation transmitted to the spacecraft and received by the command detector contained a pseudo-random synchronization code similar to that used in the telemetry system. The spacecraft command detector generated a local model of the pseudo-random code and cross correlated it with the received code until the two codes were in phase. When synchronization was achieved, a command could then be detected and executed.

V. TELECOMMUNICATION SYSTEM PERFORMANCE

The *Mariner IV* telecommunication system was required to provide tracking, telemetry and command performance from launch to 20 days past encounter, including all of the intermediate phases. In order to reasonably assure this capability, it was desired to choose the system parameters so that the nominal received signal levels always exceeded the threshold signal levels by at least the linear sum (in db) of the adverse tolerances (Ref. 7). This criterion was met for all functions and flight phases, except for the telemetry, for a transition period of 15 days.

The *Mariner IV* spacecraft was launched at 14:22:01 GMT, November 28, 1964, from Cape Kennedy, Florida. At this time the spacecraft transmitter was in the low-power mode with a power output of approximately 0.5 w. After the spacecraft had passed through the critical pressure region, separation of the spacecraft from the launch vehicle initiated RF power up at 15:07:09 GMT. Telemetry received from DSIF 41, at Woomera, Australia, verified that all separation functions had occurred and that the spacecraft power amplifier was transmitting at full power output.

At launch, the spacecraft data encoder was operating at a data rate of 33⅓ bit/sec, since during the early portion of the flight the ground-received signal level was adequate to support the higher bit rate. It was predicted that after a little over a month of flight, the spacecraft-to-Earth range would increase to the point where the ground received signal would be too low to support 33⅓ bit/sec at a bit error rate less than 5×10^{-3}, the defined telemetry threshold. On January 3, an on-board command from the spacecraft CC&S caused the data encoder to switch bit rates to 8⅓ bit/sec. The ground telemetry subsystem locked up to the spacecraft data at the lower bit rate and telemetry indications were that the switch had occurred as planned.

On March 5, an on-board command from the spacecraft CC&S caused the spacecraft transmitter to switch from the low-gain antenna to the high-gain antenna. Performance predictions indicated that the spacecraft high-gain antenna would provide adequate telemetry margin from this time until the completion of picture playback. Spacecraft telemetry and ground-station-received signal levels subsequent to the switch indicated that the switch had taken place as planned.

The two antennas on the *Mariner IV* spacecraft are coupled to the receiver and transmitter via a network of circulator switches to provide receive and/or transmit capability over either antenna within the restrictions of spacecraft logic (Fig. 2). Characteristics of circulator switches are such that they do not provide perfect isolation to a signal traveling in the reverse, or *off*, direction. This makes it possible for a signal to reach either the spacecraft receiver or ground receiver through both antennas whenever the spacecraft-to-Earth vector falls in the area covered by both antenna patterns. The net effect as seen by the receiver will be a destructive or constructive interference, depending on the relative phase of the two received signals. Since the spacecraft antennas are several wavelengths apart, the relative phase of the signal from each antenna will vary with the angle at which the spacecraft-to-Earth vector intersects the antenna pattern.

Because of the difference in gains between the high- and low-gain antennas, the interference would only be significant on the low-gain antenna pattern in the region where it is intersected by the high-gain antenna. Spacecraft radio system logic was so designed that both receiving and transmitting functions could be carried on over the high-gain antenna whenever required to maintain reliable communications. It was found unnecessary to switch the receiving function to the high-gain antenna, despite the interferometer effect.

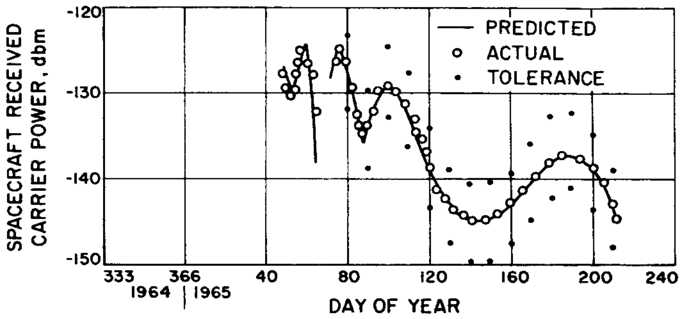

Fig. 7. Spacecraft received carrier power vs date, *Mariner IV* spacecraft-to-Earth vector intersecting both low- and high-gain antennas

Figure 7 shows the predicted Earth-to-spacecraft received signal level through the low-gain antenna as a function of calendar date during the portion of the mission when the spacecraft-to-Earth vector was in the area covered by the high gain antenna. The angle at which the Earth views the spacecraft, and hence the relative phase of the interfering signals, varies with date, giving alternately constructive and destructive interference as in an interferometer pattern.

As the *Mariner IV* spacecraft-to-Earth range increased, the time required for a radio signal to propagate from the spacecraft to Earth became a significant factor in operational procedures. During the planetary encounter and picture taking sequence, the transit time was over 12 min one way. The obvious implication of this is that if an event occurred on the spacecraft such that a backup ground command was required, there would be a minimum of over 24 min, plus decision time, after the event before a command would arrive at the spacecraft. Since the encounter picture-taking sequence was only about 25-min long, it was necessary to send some of the backup commands to arrive at the spacecraft at the correct time without waiting for indication of the events in spacecraft telemetry. Use of this procedure during the encounter phase provided a backup capability to significant events within the time scale demanded by the encounter sequence. Post-encounter analysis of spacecraft data indicated that the encounter sequence was carried out by on-board spacecraft commands and the backup commands did not alter the sequence.

Approximately an hour after the picture taking sequence was completed, the spacecraft trajectory passed behind the planet Mars, as viewed from Earth, for the occultation experiment. During the last few seconds before the spacecraft passed behind the planet and during the first few seconds after emerging, the RF signal from the spacecraft would pass through the atmosphere of

Mars. The effects of atmospheric refraction on the propagation of radio signals are well known. By tracking the spacecraft radio signal through the Martian atmosphere before and after occultation, refraction of the signal due to the Martian atmosphere was observed. By careful analysis of these data, experimenters hope to gain information on such physical characteristics of the Martian atmosphere as surface pressure and scale height.

Figure 8 illustrates, for the *Mariner IV* trajectory, the predicted received carrier level for the spacecraft-to-Earth channel vs time from launch. These curves were computed using the spacecraft RF parameters as measured before launch, and using the parameters for a standard Deep Space Station with a diplexed tracking antenna. The variations are due to both the increasing range and the variable antenna gains. It is apparent where the performance of the low-gain antenna becomes insufficient and the high-gain antenna takes over. Also noticeable is the point where the spacecraft transmitter was switched from the cavity amplifier to the TWT amplifier. This switch was initiated on December 13 by radio command from the Goldstone Tracking Station in the California desert. A bonus from the TWT amplifier, in addition to longer predicted lifetime, is a slightly higher nominal power output than the cavity. A comparison of ground-received signal levels, before and after the power amplifier switch, verified that the expected increase had occurred. Since then, the TWT amplifier has been operating continuously for over 5000 hr with no indication of degradation.

Agreement between performance predictions and actual data from ground stations has been generally good and within the assigned tolerances. Figure 8 shows actual data recorded at DSIF stations, from launch to the end of picture playback, superimposed on a curve of predicted data. As can be seen, ground-received carrier power has averaged near nominal during the flight and within the assigned adverse tolerance, thus meeting the design performance criteria. By meeting this criteria, telemetry subsystem performance was such that through the picture playback period, the telemetry bit error rate would not exceed 5×10^{-3}, the defined telemetry threshold. Comparison of telemetry threshold levels to received carrier power reported by DSIF stations during picture playback indicates that actual bit error rates were on the order of 10^{-5}. This estimate is based on the theoretical bit error-rate curve since there is no practical means of verifying this from spacecraft data.

The predicted received carrier levels for the Earth to spacecraft channel are shown in Fig. 9 and 7 for the nominal pattern and for the interferometer pattern between the two antennas. These curves are shown for a standard DSIF station transmitting at 10 kw. For emergency use, a 100 kw transmitter was available at the Goldstone tracking station.

Spacecraft-received signal level data, as indicated by spacecraft automatic gain control (AGC) telemetry, is shown in Fig. 9 for the period when the spacecraft-to-Earth vector fell on the low-gain antenna alone. As the spacecraft-to-Earth vector entered the region covered by the high-gain antenna toward the end of February, a variation in received-signal level was observed which was confirmed to be due to the interferometer pattern between

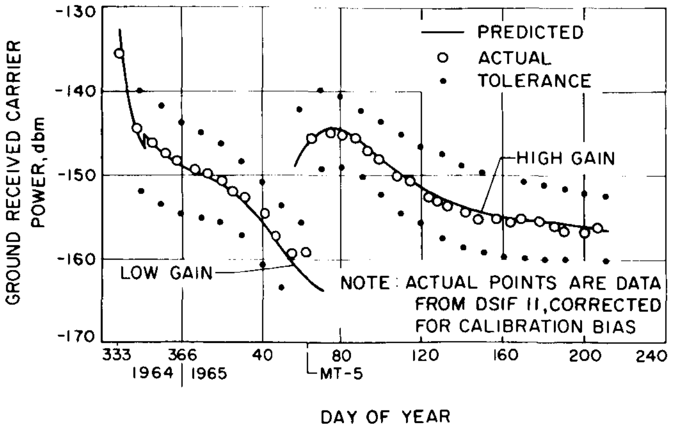

Fig. 8. DSIF received carrier power vs date, *Mariner IV*

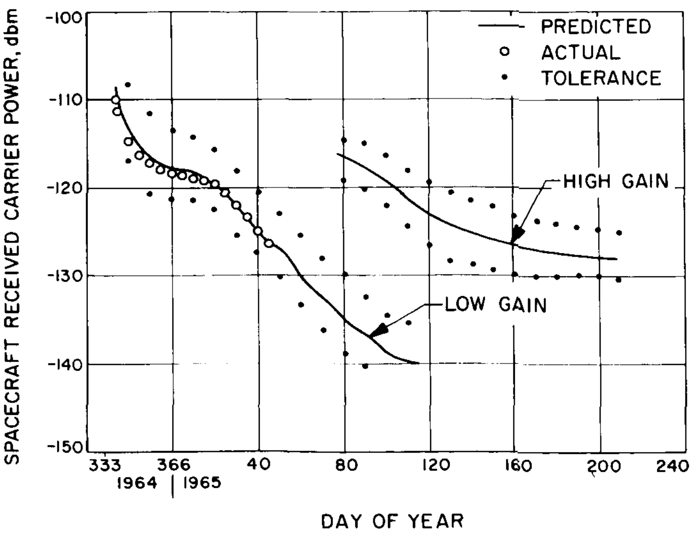

Fig. 9. Spacecraft received carrier power vs date, *Mariner IV*

the two antennas. The actual signal level data as indicated by spacecraft telemetry is shown in Fig. 7 as a function of date. Excellent agreement was achieved between predictions and observed signal levels, with data points falling very near nominal for the entire flight.

From launch until the end of the second picture playback, a total of 56 commands were sent to the spacecraft. Telemetry data confirmed that all commands were correctly received and interpreted by the spacecraft. Some of the functions carried out by these commands were to open the brightness gate limits on the Canopus sensor and to provide turn and motor-burn information for the delicate midcourse maneuver. Prior to encounter, the TV scan platform was positioned by a command that was precisely timed to arrive at the spacecraft at the very moment the platform was pointing at the planet (Ref. 8). Analysis of scan data indicated that the TV camera had been pointed within ¾ deg of the nominal aiming point.

As the spacecraft signal was tracked by the DSIF stations, accurate records were kept of the doppler rate and of the antenna pointing position. Estimates of the accuracy with which the velocity of the spacecraft can be determined from doppler data show standard deviations on the order of 2 mm/sec. Latest orbit determinations using tracking data have estimated the distance at closest approach to Mars[1] to within 5 km. As of the end of picture playback, the spacecraft was 242.4×10^6 km away from Earth and traveling at a velocity of 116,393 km/hr.

As of the end of the second picture playback, over 250×10^6 bits of data have been sent to Earth by the *Mariner IV* spacecraft. These data have been recorded at the DSIF stations and also sent in real time to the Space Flight Operations Facility at the Jet Propulsion Laboratory in Pasadena, California, for in flight analysis. In nonreal time, all sources of spacecraft data, including station tape recordings and teletype data, are analyzed and the best available data used to generate a Master Data Library. Final Master Data Library processing for the first two weeks of the flight has been completed, and it is estimated that over 99% of the spacecraft data have been recovered. It is predicted that for the entire mission, about 96 to 97% of the total spacecraft data stream[2] will be recovered. This includes a loss of data during periods when *Ranger* tracking-coverage needs prevailed over *Mariner IV*.

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[1] Private communication between H. D. Dalmiter and J. A. Hunter, September, 1965.

[2] Private communication between D. W. Douglas and J. A. Hunter, September, 1965.

VI. SUMMARY

The *Mariner* Mars mission for 1964 required a telecommunications system that would provide tracking, telemetry, and command capabilities over communication distances up to 260×10^6 km and which would operate for 8 mo in an interplanetary space environment. The design that has been described is an extension and modification of well proven techniques, where the modifications included required improvements in performance and limited redundancy to improve reliability.

By designing the antenna subsystem to utilize the unique characteristics of the Mars 1964 minimum energy trajectories, it was possible to meet mission requirements without a pointable high-gain antenna and the associated complex equipment. During the first 95 days of the flight, communications with the spacecraft was via a fixed low-gain antenna for both uplink and downlink channels. After this time, the downlink channel was switched to the fixed high-gain antenna, and the uplink channel remained on the low-gain antenna for the entire flight.

The *Mariner IV* radio subsystem included redundant exciters, power amplifiers, and the associated power supplies for increased reliability. Either exciter could be used with either power amplifier, and either power amplifier could be used with either antenna through a network of circulator switches. The redundant exciters were identical units that could be driven either by a signal from the spacecraft receiver VCO (two-way mode) or by an auxiliary oscillator when the spacecraft receiver was out of lock (one-way mode). A hybrid configuration, consisting of one TWT amplifier and one cavity amplifier, was used for the redundant power amplifiers.

The *Mariner IV* telemetry subsystem accepted engineering data from 90 analog channels, commutated it into a predetermined sequence, and converted it to 7-bit binary words. It also accepted digital inputs from science, command, and video storage subsystems and commutated this with the engineering data. Bit and word synchronization for telemetry were derived from a 63-bit pseudo-random code, which was also modulated onto a synchronization subcarrier and used to demodulate and decommutate the telemetry signal on the ground.

The spacecraft command subsystem was required to detect and decode any of 29 discrete commands (to be executed in real time) or 3 quantitative commands (to be stored as magnitude information for midcourse maneuver). Parity was checked on received command words in such a way that at least two bit errors must have occurred for a wrong command to be executed.

Telecommunication system performance since launch has been good, with actual signal levels falling on, or very near, nominal predictions for the entire flight. All commands sent to the spacecraft were successfully received, and analysis of data recovery to date indicates that 96 to 97% of the data transmitted by the spacecraft will be recoverable after final processing. Analysis of tracking data has enabled flight path personnel to accurately define the trajectory of *Mariner IV* and to increase the accuracy with which some of the physical constants of the universe are known.

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