Helios Mission Support

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Project Helios, a joint endeavor between the United States and West Germany, will place two unmanned spacecraft into heliocentric orbits whose perihelion distance will come closer to the Sun than any previous or presently planned free world deep space undertaking. The first spacecraft is expected to be launched in mid-1974 and the second in late 1975. Prior volumes of this series describe the history and objectives of this program, the contemplated spacecraft configuration, and the spacecraft's radio system. This article deals with the capabilities of the telecommunications link between the spacecraft and the Deep Space Network.

I. Introduction

This is the fifth of a series of articles pertaining to Project *Helios*. The previous article (Ref. 1) completed a detailed description of the *Helios* spacecraft radio system. Specifically, it covered the operation of the spacecraft's command system and its compatibility with the Deep Space Network (DSN). Reference 1, and the several articles that preceded it, provides the necessary background for a discussion of the various telecommunications links between the *Helios* spacecraft and the DSN, which are treated in this article.

II. Telecommunications Link Design

A. Required Communications Links

As might be surmised from previous articles (Refs. 1–4), there is a multitude of telecommunications link combinations between the *Helios* Spacecraft and the DSN and/or West German ground stations. For instance, there are three different spacecraft antennas (low, medium, and high gain) available for use, three different spacecraft RF power output levels (0.5, 10, and 20 W), and six different spacecraft telemetry modes which can be transmitted at ten separate bit/symbol rates, in communication with either the 26-m or 64-m-diameter antenna stations within the Deep Space Network or with the West German 100-m antenna at Effelsberg. Since the number of such combinations far exceeds that needed to accomplish mission objectives, the *Helios* Project Office has chosen to restrict their nominal mission design to the 21 combinations listed in Table 1. While this does not imply that other combinations cannot be used under abnormal or emergency conditions, these 21 preselected telecommunications links should provide ample flexibility to accomplish mission objectives while at the same time not impose undue constraints upon the spacecraft from a thermal, electrical power, or attitude control system viewpoint. Therefore, this article will confine its discussion to those links listed in Table 1.

B. Telecommunications Analytic Model

The performance of any telecommunications link is obviously dependent upon the amount of power transmitted, the gain of the transmitting and receiving antennas, the distance (i.e., loss) between the transmitter and receiver, and, of course, the information bandwidth to be transmitted. In addition, there are losses internal to the transmitter and receivers themselves. Many of these parameters are usually either pre-established or represent the desired solution from an analytical calculation of telecommunications link performance. For instance, the transmitter/receiver losses associated with the Deep Space Network Stations are well known from prior experience and may be found in such documents as DSN Standard Practice 810-5. In contrast, the losses associated with the spacecraft transmitter/receiver are not usually known accurately until at least a working model of the spacecraft has been fabricated. To compensate, an early analytical model of the spacecraft, together with stringent specifications concerning its telecommunications design performance, are needed prior to the actual fabrication of spacecraft hardware. These are developed to insure that the actual spacecraft design can be made to meet its mission objectives. The analytic model used for the *Helios* telecommunication subsystem losses is depicted in Fig. 1. The values used in computing these losses for the various links depicted in Table 1 were taken from the Project Office's specifications to the spacecraft prime contractor, and as such represent the best data currently available.

C. Uplink Considerations

The DSN has been requested to provide continuous coverage to the *Helios* spacecraft from initial acquisition through completion of the primary mission (i.e., first solar occultation). The spacecraft design goal is for this coverage to be provided by the DSN 26-m sub-network with occasional coverage being provided by the DSN 64-m sub-network for mission enhancement purposes. For a 0.25-AU *Helios* trajectory, first solar occultation occurs at a range of 1.5 AU from Earth (see Fig. 3, p. 28, in Ref. 3). If the mission is nominal, the spacecraft will be oriented such that after the first DSN Goldstone pass its medium-gain antenna pattern will be directed toward Earth from that time onward through perihelion and solar occultations to the end of the spacecraft's lifetime. If such is the case, the uplink performance from the DSN to the spacecraft will be as depicted in Fig. 2 of this article. If not, the uplink signal will have to be received by the spacecraft's low-gain (omni) antenna whose performance is depicted in Fig. 3 of this article. In the latter case, the transmission of commands via the 26-m links becomes somewhat questionable at a range of 1.5 AU. However, two alternatives are possible: (1) transmit the command via a 26-m station that has 20-kW power output capability, or (2) transmit the commands via the DSN 64-m sub-network. Since either of these represents reasonable alternative solutions to a situation that would only occur during a nonstandard mission, the performance of the link between a DSN 26-m antenna and the spacecraft low-gain antenna at a 1.5-AU range from Earth is not considered a serious problem at this time. In contrast, the performance of the uplink for a standard mission, as shown in Fig. 2 of this article, appears comfortably adequate to meet all primary objective missions.

D. Downlink Power Modes

As mentioned above, the *Helios* spacecraft has several downlink power output levels that can be chosen via ground command. In addition, the spacecraft telecommunications system has redundant channels for generating the downlink signal in order to provide reliability through redundancy. These are shown in Fig. 4 of this article. Obviously, the circuit losses associated with these various paths will differ—even for the same nominal power output level. However, the exact value of these losses will have to await the construction of actual spacecraft hardware. For the purposes of the present discussion, it will be assumed that the path loss for any given spacecraft power output level will be the same regardless of which channel is in use at a particular time.

E. Downlink Performance

The *Helios* downlink contains spacecraft telemetry and, upon occasion, also a turnaround ranging signal. Since the latter is used infrequently (see Table 1), it will be discussed separately. A reasonable measure of the performance of the telemetry portion of the downlink is the maximum information bit rate that can be transmitted over a given distance from the spacecraft to Earth. Since the bit rate from the spacecraft can only be changed in steps of a factor of two, a plot of the maximum bit rate versus spacecraft distance from Earth will appear to be a stair step drawing. Further, multiple stair steps can be drawn depicting the adverse, nominal, and favorable tolerances associated with the individual entries within the telecommunications link analysis calculations.

1. Performance to a 26-m network. The *Helios* downlink telemetry performance to a DSN 26-m network is shown in Figs. 5 and 6 of this article. Figure 5 depicts the link via the spacecraft medium-gain antenna, while Fig. 6 depicts the link via the spacecraft high-gain antenna. Both figures are for the spacecraft high-power (i.e., 20 W) mode; however, a conversion factor is provided for the medium-power (i.e., 10 W) mode. From these figures it can be seen that if the spacecraft's despun high-gain antenna is working properly and the spacecraft is capable of transmitting in its high-power mode, bit rates of 256 bps are possible out to 1.5 AU from Earth. However, if either the medium-gain antenna or the medium-power mode has to be used, the telemetry performance from perihelion (i.e., 1.0 AU) is marginal.

2. Telemetry performance to 64-m network. The *Helios* telemetry performance at perihelion (1.0 AU) and again at first solar occultation (1.5 AU) improves considerably with the use of the DSN 64-m network, as can be seen from Figs. 7 and 8. For a completely standard mission, it is theoretically possible to receive 4096-bps telemetry from perihelion and 2048 bps up to first solar occultation (Fig. 8). However, if a failure occurs in the spacecraft's high-gain antenna, these telemetry bit rates would be reduced to 32 bps at perihelion and 16 bps at first solar occultation for the case of adverse tolerance (Fig. 7).

3. Telemetry performance to 100-m antenna. A representative case of the *Helios* telemetry performance to the West German 100-m antenna located at Effelsberg is shown in Fig. 9. Since this is for the spacecraft medium-gain antenna case, the maximum bit rates at perihelion and first solar occultation are 256 bps and 32 bps, respectively.

4. Ranging performance. The DSN Planetary Ranging System in the 64-m network will be used around each solar occultation of the *Helios* spacecraft to provide data for the celestial mechanics experiment. The uplink range code will be transmitted by the 64-m stations to the spacecraft's medium-gain antenna and then to the transponder in the turnaround ranging mode for retransmission back via the spacecraft's high-gain antenna to the originating 64-m station where the received code will be correlated with the transmitted code. The principal criterion for the performance of the ranging loop is the time required for the 64-m stations to acquire and correlate the received code with the transmitted code. This time, which is in addition to the round trip light-time for the RF signal to travel from the station to the spacecraft and return to the station, is plotted in Fig. 10. Of particular interest is the region between 1.0 and 2.0 AU from Earth, since the *Helios* solar occultations occur at 1.5 and 2.0 AU from Earth. Under the most favorable conditions, this acquisition time is between 1 and 2 min, while under the most adverse conditions the acquisition time can be in the region of 40 to 80 min. Nonetheless, range code acquisition times of 1 h will still permit several unique range measurements to be made during any one 64-m antenna station's available view period for the *Helios* spacecraft. Therefore, the predicted performance of the ranging loop appears to satisfy mission requirements.

III. Conclusions

From the foregoing discussion and figures, one may conclude that *Helios* can meet its mission objectives via these telecommunications links—*providing, of course, that the specifications for the radio system are met and that the spacecraft flies a nominal mission.* However, to achieve certain objectives, support will be required from the DSN 64-m and/or Effelsberg 100-m antennas when the range exceeds 1 AU, i.e., beyond perihelion. The greatest uncertainty in achieving mission objectives lies in the assumption of a "nominal mission." For instance, an unexpected failure of the mechanically despun high-gain antenna would significantly reduce the amount of telemetry (data rate) and/or ranging data (celestial mechanics experiment) that can be obtained at perihelion (1 AU) and beyond. Nonetheless, a meaningful mission can be accomplished using only the spacecraft's medium-gain antenna system, which is practically free of such potential mechanical failures.

Another conclusion that can be drawn is that the telecommunications link performance is dependent upon having proper spacecraft attitude orientation. For instance, an attitude control system failure that would preclude the spacecraft's medium-gain antenna pattern from impinging upon Earth (or doing so only intermittently) would also preclude the high-gain antenna from being directed toward Earth. Such a situation would force the use of the spacecraft's omni-directional antenna system which would greatly reduce the maximum distance from Earth that one could communicate with the spacecraft, even at the lowest data rates. However, even under such a situation, some telemetry data should still be received at perihelion or even from first solar occultation, using the 64-m or 100-m ground antennas.

The foregoing two examples are considered the most serious sources of potential failure in the telecommunications link design, because most of the electronics in the spacecraft's radio system has been redundantly designed (Fig. 4).

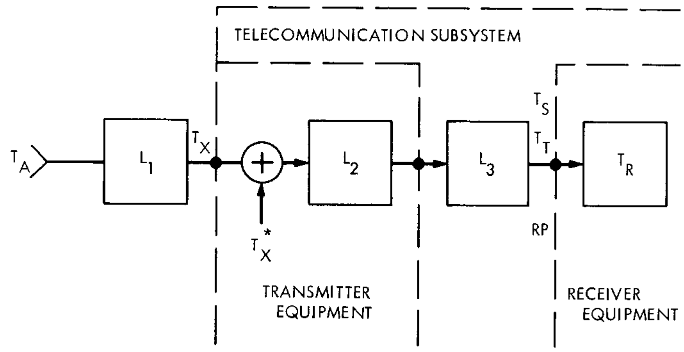
In summary, one may, therefore, conclude that, barring a catastrophic failure in the spacecraft's attitude control system, the calculated *Helios* telecommunications link design provides ample optional modes for a meaningful mission.

References

1. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. V, pp. 17–21. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1971.
2. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. II, pp. 18–27. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.
3. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. III, pp. 20-28. Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1971.
4. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. IV, pp. 22–31. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1971.

Table 1. Required *Helios* communication links

Link number	Ground station	Spacecraft antenna	Maximum range, AU	Channel bit rate, bps	Command capability	Ranging capability
1	26 m	Low	0.1	64	Yes	—
2	26 m	High	0.4	2048	Yes	—
3	26 m	High	1.3	128	Yes	—
4	26 m	High	1.6	64	Yes	—
5	26 m	High	2.0	8	Yes	—
6	64 m	High	0.4	2048	Yes	Yes
7	64 m	High	1.3	128	Yes	Yes
8	64 m	High	1.6	64	Yes	Yes
9	64 m	High	2.0	8	Yes	Yes
10	100 m	High	1.6	2048	Yes	—
11	64 m	Low	2.0	—	Yes	—
12	26 m	Medium	0.1	2048	Yes	—
13	26 m	Medium	0.3	128	Yes	—
14	26 m	Medium	0.4	64	Yes	—
15	26 m	Medium	0.8	8	Yes	—
16	64 m	Medium	2.0	8	Yes	—
17	100 m	Medium	0.3	2048	Yes	—
18	100 m	Medium	1.3	128	Yes	—
19	100 m	Medium	1.5	64	Yes	—
20	100 m	Medium	2.0	8	Yes	—
21	64 m	High	1.0	4096	Yes	—
22	Near Earth			64	Yes	—



$$T_S = T_R + T_0 \frac{L_3 - 1}{L_3} + T_0 \frac{L_2 - 1}{L_2 L_3} + \frac{T_X^*}{L_2 L_3} + T_0 \frac{L_1 - 1}{L_1 L_2 L_3} + \frac{T_A}{L_1 L_2 L_3}$$

L_1 LOSSES (>1) OF ANTENNA CABLING

L_2 LOSSES (>1) OF DIPLEXER

L_3 LOSSES (>1) OF CONNECTION CABLING BETWEEN TRANSMITTER AND RECEIVER EQUIPMENT

RP REFERENCE POINT

T_A ANTENNA NOISE TEMPERATURE

T_R RECEIVER EQUIPMENT NOISE TEMPERATURE

T_S SYSTEM NOISE TEMPERATURE

T_T TELECOMMUNICATION SUBSYSTEM NOISE TEMPERATURE

T_X TRANSMITTER EQUIPMENT NOISE TEMPERATURE

T_X^* NOISE FROM TRANSMITTER POWER STAGES AFTER NOTCH FILTERS

Fig. 1. *Helios* spacecraft analytic model

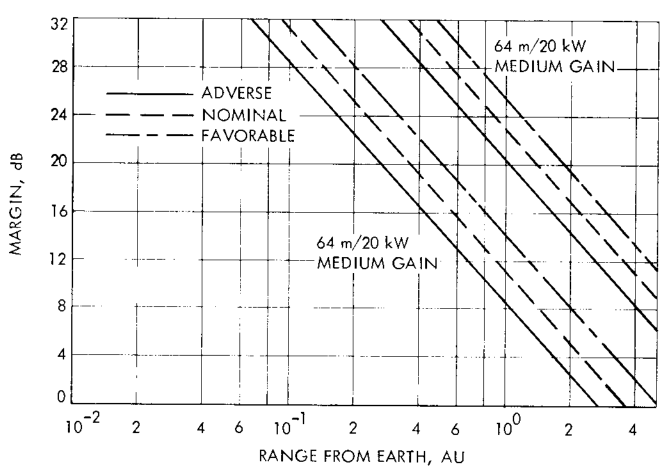


Fig. 2. *Helios* spacecraft medium-gain antenna uplink performance margin

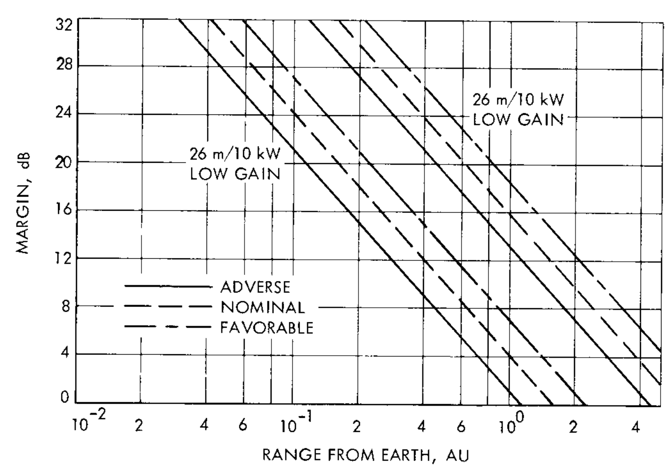


Fig. 3. *Helios* spacecraft low-gain antenna uplink performance margin

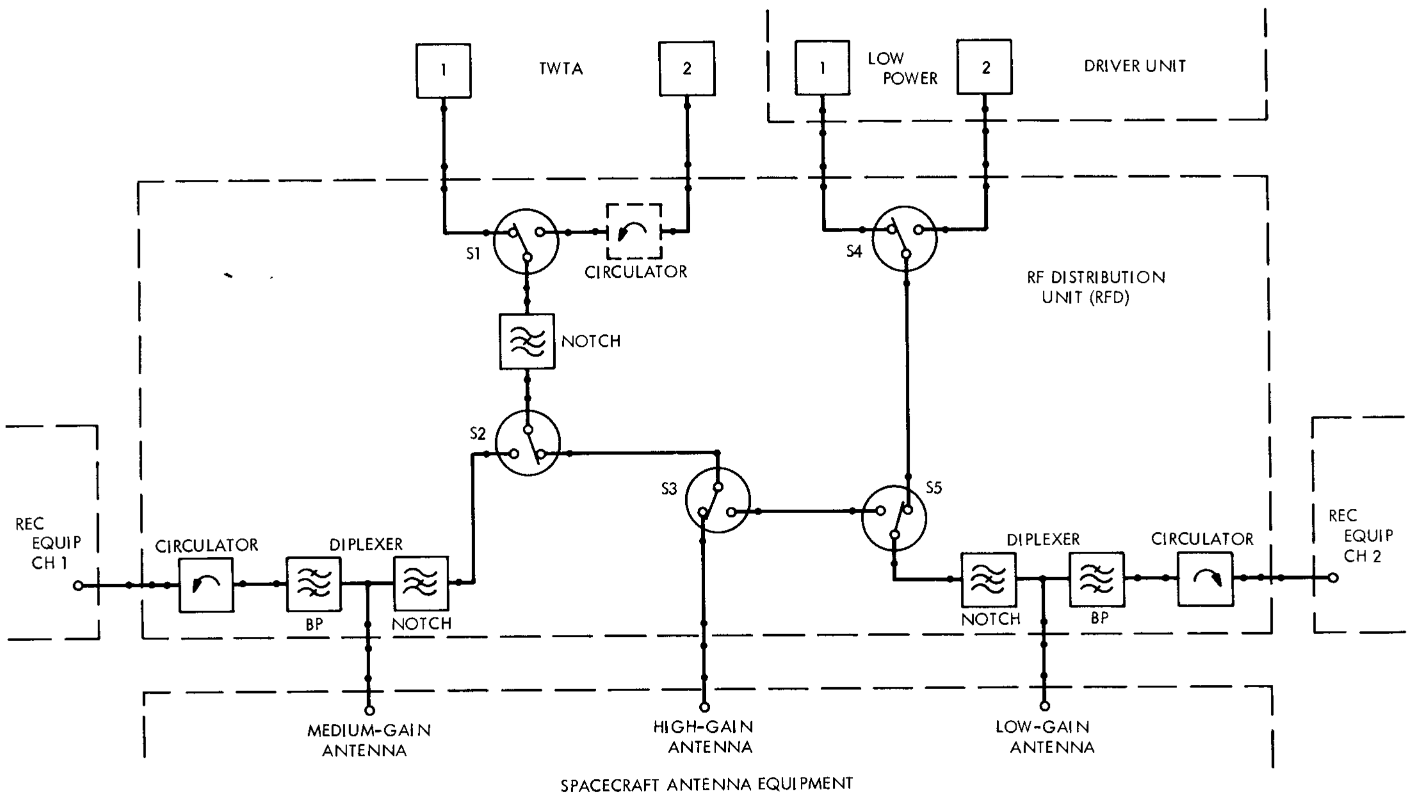


Fig. 4. *Helios* RF signal distribution block diagram

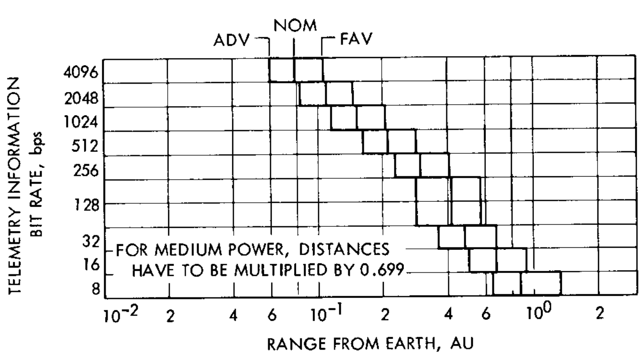


Fig. 5. *Helios* spacecraft medium-gain antenna (high-power mode) downlink to 26-m antenna

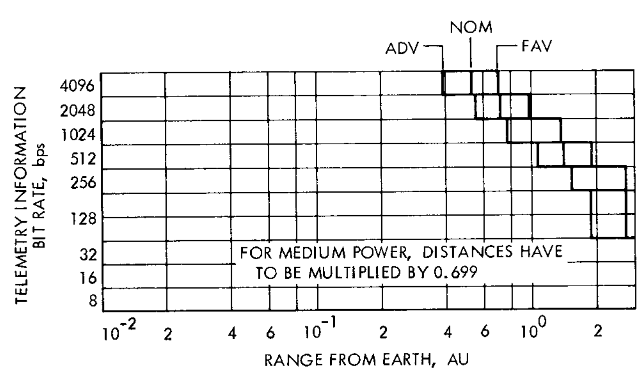


Fig. 6. *Helios* spacecraft high-gain antenna (high-power mode) downlink to 26-m antenna

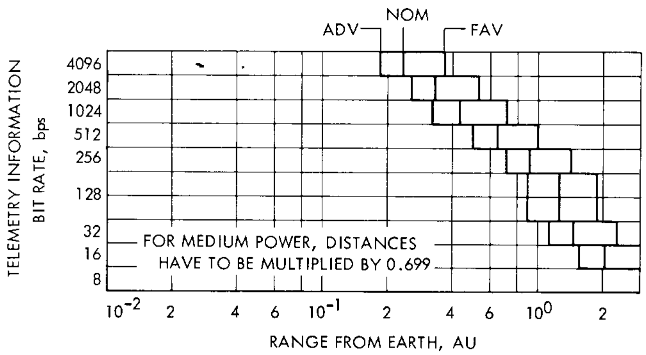


Fig. 7. *Helios* spacecraft medium-gain antenna (high-power mode) downlink to 64-m antenna

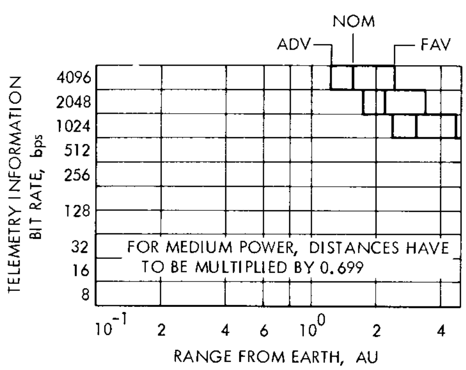


Fig. 8. *Helios* spacecraft high-gain antenna (high-power mode) downlink to 64-m antenna

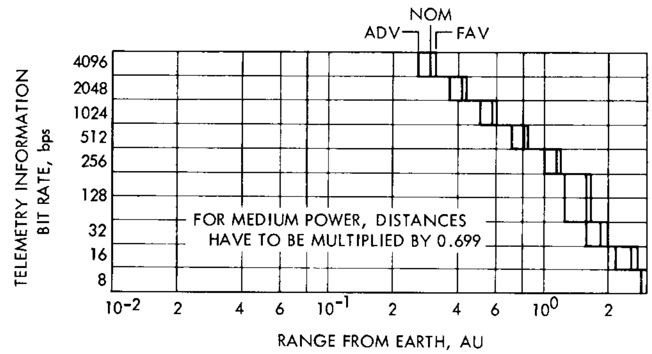


Fig. 9. *Helios* spacecraft medium-gain antenna (high-power mode) downlink to 100-m antenna

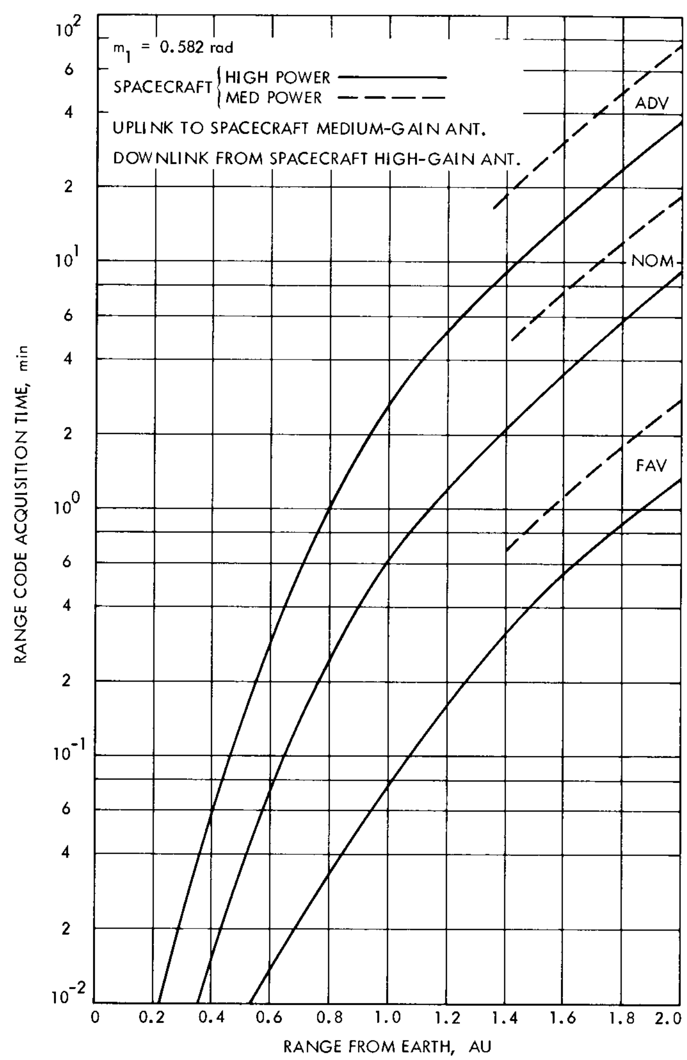


Fig. 10. 64-m/20-kW Tau Ranging System