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EQUATORIAL SCINTILLATIONS EXPERIENCED DURING APOLLO 13 SUPPORT MARCH 30 TO APRIL 18, 1970

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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EQUATORIAL SCINTILLATIONS EXPERIENCED DURING APOLLO 13 SUPPORT MARCH 30 to APRIL 18, 1970

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Greenbelt, Maryland

PREFACE

The information in the report was prepared by Westinghouse Electric Corporation under NASA contract NAS 5-21129 for inclusion in one of the regular "update" distributed to holders of the ATS Technical Data Report (TDR). However, it was recognized that many TDR holders would have no requirement for this extensive and detailed material, and many other people in the scientific community who do not receive the ATS-TDR would have a need for this material. As a matter of economy and ease of distribution it was decided to present the information as a separate document with availability to all who are interested in the material.

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SUMMARY

During Apollo 13 support by the ATS project, three signal levels were recorded at either of the ATS ground stations. The frequencies of the signals recorded were 136.47 MHz (telemetry), 135.645 MHz (ground station), 135.555 MHz (shipboard). The telemetry signal originates at the spacecraft telemetry transmitter. The ground station signal originates at the ground station at 149.175 MHz, is transmitted to the spacecraft, translated to 135.645 MHz and received and recorded by the ground station. The shipboard signal originates at the U. S. S. Iwo Jima at 149.265 MHz, translated by the spacecraft to 135.555 MHz and recorded by the ground station. The telemetry signal is used as a control to ascertain that the recorded "shipboard" signal variations are due to the up-link path variations from the ship to the spacecraft and not by the down-link from the spacecraft to the ground station.

Selected data from the recordings are depicted to indicate the fine grain structure of equatorial scintillations as well as the peak-to-peak variations encountered. Signal level recordings made during the Apollo 11 Support and the World Wide VHF tests are also included to confirm the "fine grain" structure of the equatorial scintillations encountered in the Apollo 13 Support. The effects of the ships roll on the recorded signal level is also indicated.

INTRODUCTION

The VHF transponder on the synchronous satellite ATS-1 was used as a backup communications link from the Apollo 13 recovery ship U. S. S. Iwo Jima and the ATS ground stations at Mojave, California and Rosman, North Carolina. Two channels of the VHF transponder were used to provide two way communications. The Iwo Jima was transmitting on 149.265 MHz and receiving on 135.555 MHz while the ATS ground stations were transmitting on 149.175 MHz and receiving on 135.645 MHz. The ground stations used circularly polarized antennas but the ship used crossed Yagis connected for circular polarization. Late in the experiment, (April 16) switched linear polarization was tried by the shipboard transmit station. The data illustrated in this report was taken with circular polarization except for Figure 6.

RESULTS

Received signal level tests were made at Rosman and Mojave during various time blocks (0700-0900; 1700-2100; 2200-2400Z) from March 30 to April 18, 1970. The exact times and dates are indicated in Table 1. The ship's position as well as sea swell height and comments on the experiments are also listed. It can be seen that the ship was in the general area of 160 to 170 degrees west longitude and 20 degrees north to 20 degrees south latitudes. Since the magnetic dip equator and magnetic dipole equator cross the geographic equator at approximately 170 degrees west longitude, it can be concluded that the ship was in the vicinity of the geomagnetic equator during these experiments. The spacecraft (ATS-1) was located at 150° west longitude which provided an elevation angle of approximately 70°.

Typical scintillations occurred on April 6, 10, 15 and 18 despite the fact that critical time blocks[1,2] (2000 to 0400 sub-ionospheric time) were avoided. This data indicates that scintillations do occur at times other than the critical time blocks and the peak-to-peak variations of the scintillations are equivalent. During the scintillations the ship was located at 10°N-161°W; 11°S-168°W; 15°S-169°W, and 15°S-169°W respectively on days April 6, 10, 15, and 18.

During the Apollo 11 support, scintillations were recorded as far north as 13°32" north, 165°00" west. The results of these tests indicate that scintillations occurred over latitudinal variations of 13°N to 15°S geographically or 25°N to 30°S (magnetic-dip coordinates) when both Apollo 11 and 13 are considered. If the Apollo 13 data only is considered the latitudinal distribution is also 25°N to 30°S (magnetic-dip coordinates). If magnetic dipole coordinates are used then the latitudinal variation is 12°N to 17°S.

Note in the comments section of Table 1, that periodic oscillations were recorded many times during the tests. Figure 1 depicts some of the largest variations recorded. These variations are too periodic and occur too often to be attributed to propagation anomalies. It was felt initially that the ship's roll could not affect signal level, since the antenna 3db beam width is ±20°. A check with the Department of Engineering of the U. S. Navy indicated that the roll period of the U. S. S. Iwo Jima is 16 seconds, exactly the same period measured on the data! It was therefore concluded that the ship's roll did affect the signal level.

Normal signal level with a short period of scintillations is depicted in Figure 2. This is shown as a reference for subsequent illustrations. Note that there is a residual amplitude variation of approximately 3db peak-to-peak on both the Mojave data and the Iwo Jima data. This 3db variation is the spin modulation caused by the spacecraft antenna system. The signal labeled Mojave is the record made

Table 1

(Summary of Data Taken)

DATE/STA.	START TIME (Z)	STOP TIME (Z)	LAT.	LONG.-WEST	AVG. SEA SWELL HT. FT.	COMMENTS
3/30/70/MOJ	2345	0130Z	20°58"-N	158°10"		No scintillations/ periodic oscillations, 4db p-p, 16 sec. period
3/31/70/MOJ	2331	0130	20°40"-N	158°28"		No scintillations, steady signal—115dbm avg.
4/01/70/MOJ	2330	0136	20°39"-N	158°24"		No scintillations, steady signal—115dbm avg.
4/05/70/MOJ	0700	0812	17°33"-N	159°15"		No scintillations, some periodic oscillations, 16 sec. period, 3db p-p
4/05/70/ROS	2200	2400Z	15°2"-N	160°28"		No scintillations, steady signal,—114dbm avg. some oscillations, 14 sec. period, 6db p-p
4/06/70/MOJ	0700	0856	10°23"-N	161°20"		Scintillations, 0708 to 0714Z, 15db p-p. Scintillations, 0721 to 0822Z, 30db p-p
4/06/70/ROS	2200	0100Z	9°00"-N	162°20"		No scintillations, some periodic oscillations, 16 sec. period
4/07/70/ROS	2200	2400Z	3°11"-N	163°57"		No scintillations, many periodic oscillations, 16 sec. period, 3db p-p
4/08/70/MOJ	0700	0900Z	0°23"-S	164°45"		No scintillations, some periodic oscillations, 16 sec. period, 3db p-p, -110dbm avg. (one osc. 12db)
ROS	1700	2100	3°39"-S	165°39"		No scintillations, many oscillations, 3 to 15db p-p variations
ROS	2200	2400	4°50"-S	165°45"		No scintillations, many oscillations, 16 sec. period, 3 to 10db p-p
4/09/70/MOJ	1700	2100	8°14"-S	166°40"	5	No scintillations, some osc. 3-6db p-p
	2200	2400	8°57"-S	166°53"		No scintillations, some osc. 16 sec., 0-5db p-p
4/10/70/MOJ	0700	0845	11°01"-S	168°3"	2-3	Scintillations 0744 to 0816Z (16db p-p) Scintillations 0734 to 0737Z (10db p-p) Scintillations 0723 to 0724Z (20db p-p) Avg. level—115dbm
MOJ	1700	2100	14°17"-S	168°59"		No scintillations, some small oscillations (-115dbm)
MOJ	2200	2400	14°26"-S	169°55"		No scintillations, some oscillations (6db p-p)
4/11/70/MOJ	0700	0900	16°50"-S	167°28"	3	No scintillations, periodic oscillations 16 sec., (6db p-p)
ROS	1700	2400	19°5"-S	160°53"		No scintillations, some periodic oscillations, 16 sec. period

Table 1 (Continued)

DATE/STA.	START TIME (Z)	STOP TIME (Z)	LAT.	LONG.-WEST	AVG. SEA SWELL HT. FT.	COMMENTS
4/12/70/MOJ	0700	0715	19°54''-S	167°46''	5	No scintillations, some periodic oscillations
ROS	1700	2100	18°33''-S	167°39''		No scintillations, a lot of periodic oscillations 3 to 6db p-p
ROS	2200	2400	18°05''-S	167°22''		No scintillations, periodic oscillations (6db p-p)
4/13/70/MOJ	0700	0900	17°12''-S	165°48''	5-6	No scintillations, a lot of periodic oscillations, (0-10db p-p)
ROS	1700	2100	16°41''-S	166°59''		No scintillations, small periodic oscillations, (0-3db p-p)
4/13/70/ROS	2200	2400	16°31''-S	167°16''		No scintillations, some periodic oscillations, (0-8db p-p)
4/14/70/MOJ	0700	0900	16°40''-S	168°02''	5	No scintillations, many periodic oscillations, (0-10db p-p)
ROS	1700	1900	15°5''-S	169°42''		No scintillations, some periodic oscillations, (0-12db p-p)
ROS	2200	2400	15°52''-S	169°34''		No scintillations, some periodic oscillations
4/15/70/MOJ	0700	0900	15°40''-S	169°38''	5	Scintillations start at 0740-0759Z (10db p-p) Scintillations start at 0804-0829Z Also shows telem. link variation with scintillations
ROS	1630	2100	15°24''-S	169°8''		No scintillations, some noise and periodic oscillations
ROS	2200	2400				No scintillations, periodic oscillations (16 sec.)
4/16/70/MOJ	0600	0900			3	No scintillations, small periodic oscillations
MOJ	1700	2100	18°54''-S	167°16''		No scintillations, some oscillations
MOJ	2200	2400				No scintillations, some oscillations (5db p-p)
4/17/70/MOJ	0600	0900	20°51''-S	165°59''		No scintillations, some oscillations (0-3db p-p) Shows effect of faraday rotation on a linear polarized antenna
MOJ	1510	2400	20°35''-S	165°25''		No scintillations, effects of faraday rotation evident, periodic oscillations present
4/17/70/ROS	1651	2400	20°35''-S	165°25''		No scintillations, large number of periodic oscillations
4/18/70/MOJ	0600	0800	18°42''-S	167°27''	3	No scintillations, periodic oscillations
ROS	1700	2100	15°42''-S	169°05''		No scintillations, periodic oscillations Long period variations (17db p-p)
	2100	2400	15°23''-S	169°38''		Variations continued until 2212Z

at the Mojave ground station of its own signal retransmitted by the spacecraft and received at Mojave. The signal labeled Iwo Jima is the Mojave recording of the signal translated by the spacecraft that was originally transmitted by the U. S. S. Iwo Jima.

Figure 3 depicts the signal level of three signals received at the Mojave ground station. The uppermost recording is the telemetry signal of 136.47 MHz emanating from the spacecraft transmitter. It is used as a control to ascertain that the scintillation is not occurring in the link from the ground station to the spacecraft. The signal labeled Mojave is the signal level emanating from the VHF transponder that originated at the Mojave transmitter. The VHF transponder has two carriers passing through it; one is transmitted by the ground station (Mojave), and the other is transmitted by the shipboard station (Iwo Jima). Because the two signals power share the transponder, a fade in one signal is reflected as an increase in the other signal. Therefore, scintillations in one signal path will reflect as scintillations in the other signal because of this power sharing design. When the ratio of the received levels becomes large, the stronger signal compresses the weaker signal[4] and the effect of scintillation becomes non-linear.

The signal labeled Iwo Jima is the received signal from the spacecraft VHF transponder that originated at the Iwo Jima transmitter. Its variation depicts the variation in the propagation path between the Iwo Jima and the spacecraft provided there is no variation in the telemetry signal record. Subsequent figures depict similar recordings except that the Mojave signal may be replaced by Rosman. This indicates that the recording was made at the Rosman ground station instead of the Mojave ground station.

Figure 3 was selected from the recordings to indicate a cross section of fine grain structure of the scintillations experienced. The scintillations begin at approximately 070740Z with relatively slow scintillations almost periodic. The period of the first undulation is approximately 10 seconds. It reduces to approximately 6 seconds with a peak-to-peak variation of 7db. The periods of the undulations become smaller and smaller until 0709Z they become undiscernible and noiselike in appearance. The peak-to-peak (p-p) variation is approximately 23db. The period of oscillation starts to decrease at 0712Z and the peak-to-peak variation is still very large until approximately 071310Z. At 071335Z the variations became slower, almost sinusoidal in appearance, about 3db (p-p), and finally level out at approximately 071430Z. The total time of this scintillation period is approximately 7 minutes.

Figure 4 was selected to show the fine grain structure of scintillations most often encountered. This data was taken on the same day as Figure 3 but approximately an hour later. The rapid scintillations occurring until approximately 075845 have a short term peak-to-peak variation of approximately 10db but a long term variation of approximately 30db. The type of scintillations depicted between 0806Z and 0820Z are the type most often seen. They are characterized by deep negative peaks of very short duration. A cumulative distribution of the type of fading is depicted in Figure 5. It can be seen that signal levels 6db and less than the average value occur 20% of the time and signal levels of 10db or less occur 7% of the time. This distribution was accumulated over a very short period of time (1 minute) and its use is intended only as an indication of the type of short term signal level variations experienced.

Figure 6 was selected for two reasons; the time of occurrence, and character of the fading. The scintillations period occurred between 1750Z to 1833Z or 0650 to 0733 local time. Because of the relative positions of the ship and spacecraft, the local time can be considered as the time at the ray intersection with the ionosphere. Since scintillations normally occur around local midnight[3] subionospheric time, this data is considered abnormal. The meteorological data at the time was as follows: wind 7 knots, sea calm, sea swell height 3 ft and period of 10 seconds, ships heading 325°, ship's speed 18 knots, sea swell direction 090°. The meteorological data implies that it would not cause sufficient roll or pitch to the ship to move the antenna signal beyond the 3db beamwidth of the antenna. However the combination of a calm sea and a sea swell period of 10 seconds could cause intermittent reflections from the sea surface and this could explain the near periodic oscillations indicated at 1812Z.

Another point to be brought out is the relatively slow fading rate indicated by this data in comparison to the data shown in Figure 4. If both sets of data are accepted as equatorial scintillations, then it could be said that the fading periods range from less than a second to a few minutes in duration.

Figure 7 depicts some data taken from the world wide VHF study made on November 12, 1969. These records were taken at Lima, Peru and indicate scintillations occurring on two signals arriving from two spacecrafts ATS-1 and ATS-3. ATS-1 was located at 150° west longitude and ATS-3 was at 45° west longitude. The change in fading period is quite evident when ATS-1 data from Figure 7A is compared to Figure 7D. It can be seen that the fading period (which is defined as adjacent negative peaks) ranges from less than a second on Figure 7A to 3-4 minutes in Figure 7D. This agrees with the conclusion made from the shipboard data and therefore confirms that the shipboard data is usable provided the periodic variations are discounted.

CONCLUSIONS

The latitudinal variations of equatorial scintillations experienced during the Apollo 11 and 13 support were measured to be 25°N to 30°S magnetic-dip pole coordinates or 12°N to 17°S using magnetic dipole coordinates.

Ships roll and calm seas produced periodic variations in received signal. The periodicity of the variations were in mark contrast to the periodic variations due to equatorial scintillations, therefore the two effects are distinguishable.

The period between adjacent peaks of recorded signal level varies from less than one second to 3-4 minutes.

The peak-to-peak amplitude variations caused by equatorial scintillations varies from 7db to 23db but the distribution is such that deep fades occur for a very short period of time.

Hard limiter transponders used for multiple access reflect the scintillations of one path to all other signals using the transponder.

RECOMMENDATIONS

It is suggested that on subsequent tests that signals be transmitted during the critical time block of 2200 to 0200 local sub-ionospheric time so more data can be collected on the latitudinal range of equatorial scintillations. It is also recommended that signal level be recorded aboard ship as well as the ground station to correlate ships roll with signal level. A fourier analysis of the data would be desirable to determine the frequency components of the scintillations.

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2. Harman, L., "Worldwide VHF Satellite Scintillations/Fading Tests," NASA Document X-460-70-127, April 1970.

3. Golden, J., "Ionospheric Distortion of Minitrack Signals in South America," NASA Document X-525-68-56, Feb. 1968.

4. Jones, J. J., "Hard Limiting of Two Signals in Random Noise," IEEE Transactions on Information Theory, Jan. 1963.

ACKNOWLEDGMENTS

I wish to thank Mr. J. R. McGarvey of the Naval Communications Command for obtaining the ship's location, weather conditions, and design characteristics for this report. I would also like to thank Messrs. E. Hartzel of NASA, Goddard, and C. Olson of Philco Ford for operating the equipment aboard ship and their comments on system quality during the experiments. I wish to express my gratitude to Mr. J. Buck of Bendix Corporation and Mr. W. Ewing of RCA for their parts in recording the data at the Mojave and Rosman ground stations. I am also most grateful to Mr. E. Metzger of NASA, Goddard, for providing spacecraft and ground station time and additionally for providing me the opportunity to perform this analysis.

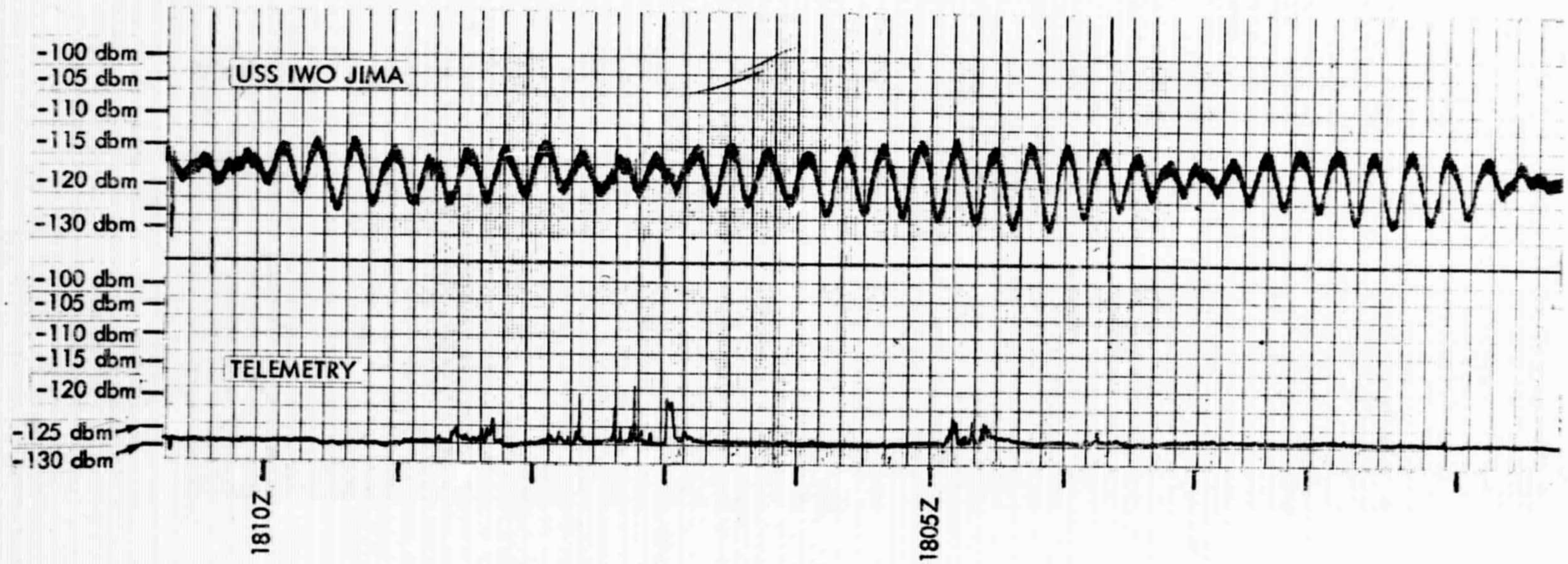

Figure 1. Signal Level of Rosman and U.S.S. Iwo Jima (April 8, 1970)

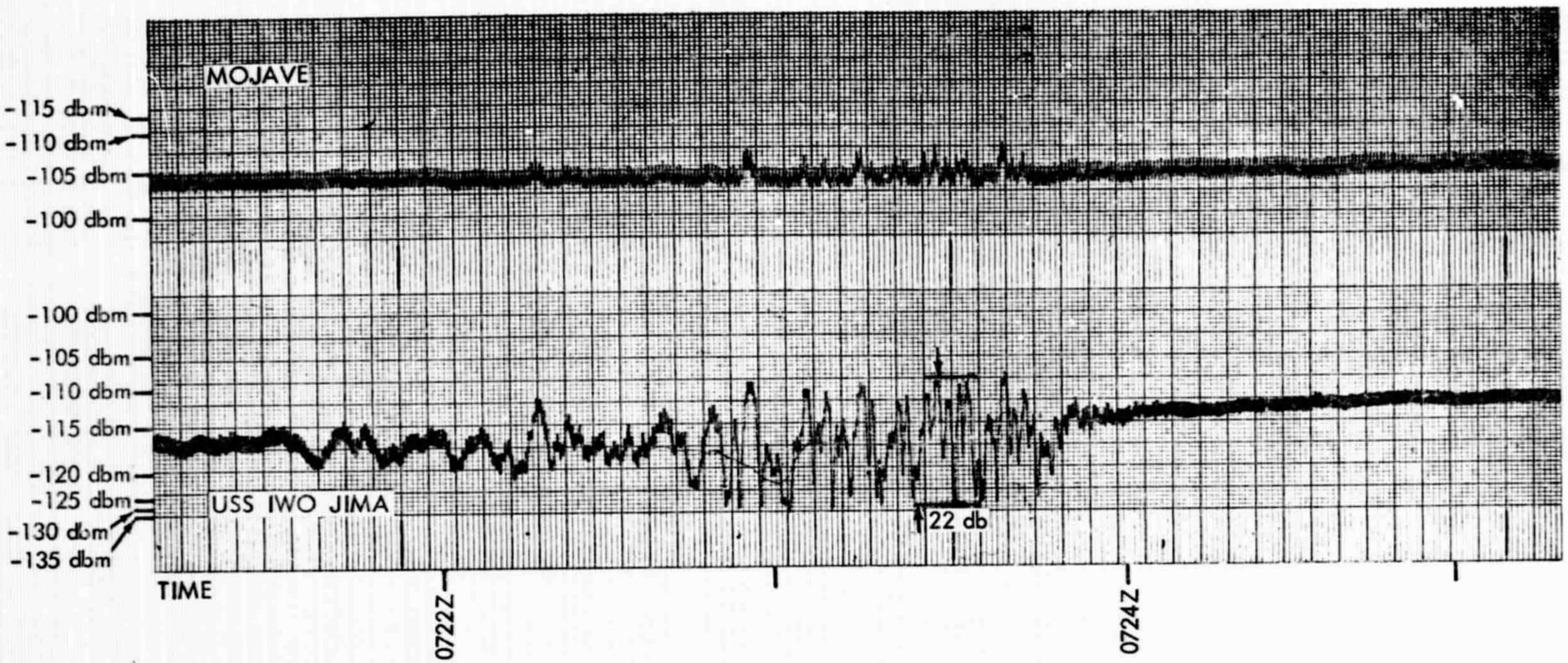

Figure 2. Signal Level of Mojave and U.S.S. Iwo Jima (April 10, 1970)

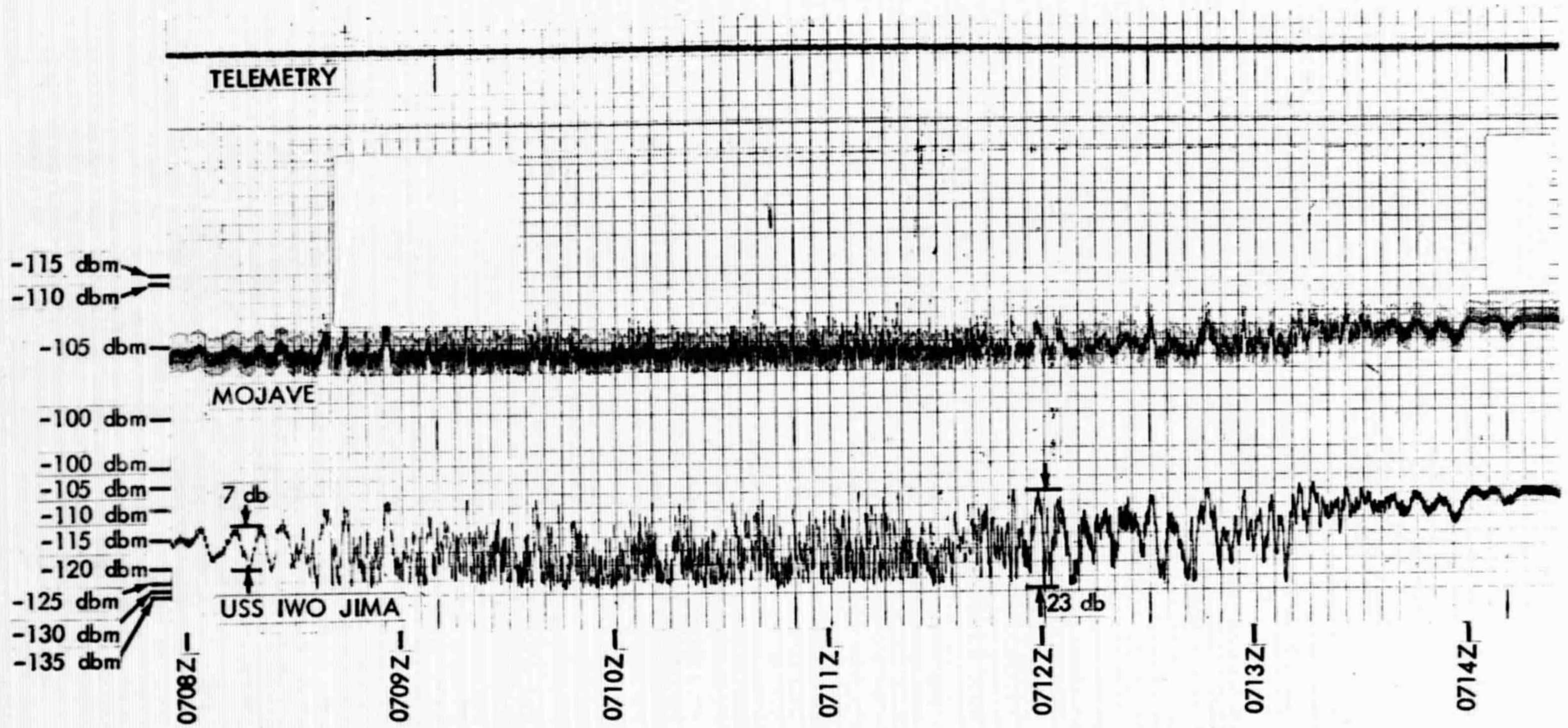

Figure 3. Signal Level of Mojave and U.S.S. Iwo Jima (April 6, 1970)

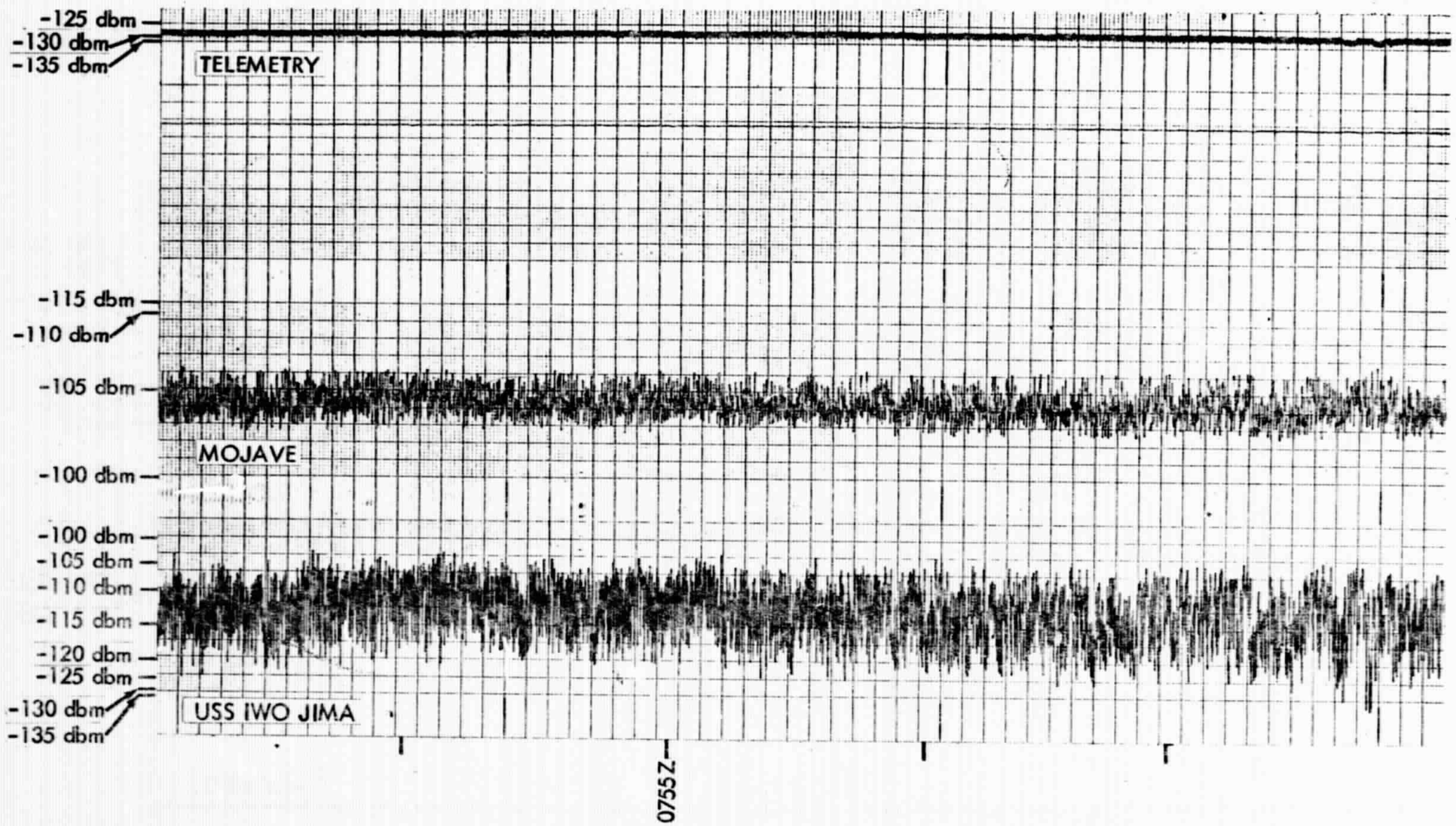

Figure 4a. Signal Level Mojave and Iwo Jima (April 6, 1970)

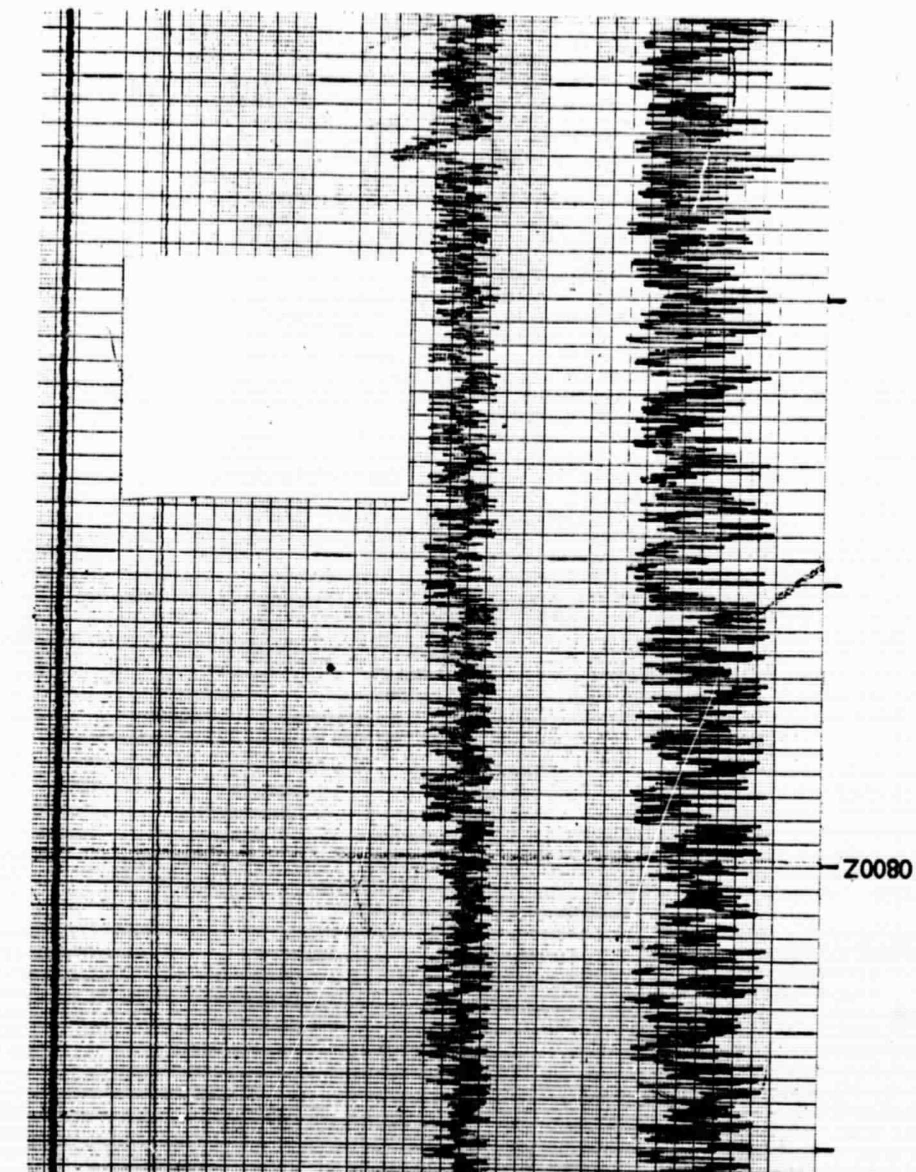

Figure 4b. Signal Level Mojave and Iwo Jima (April 6, 1970)

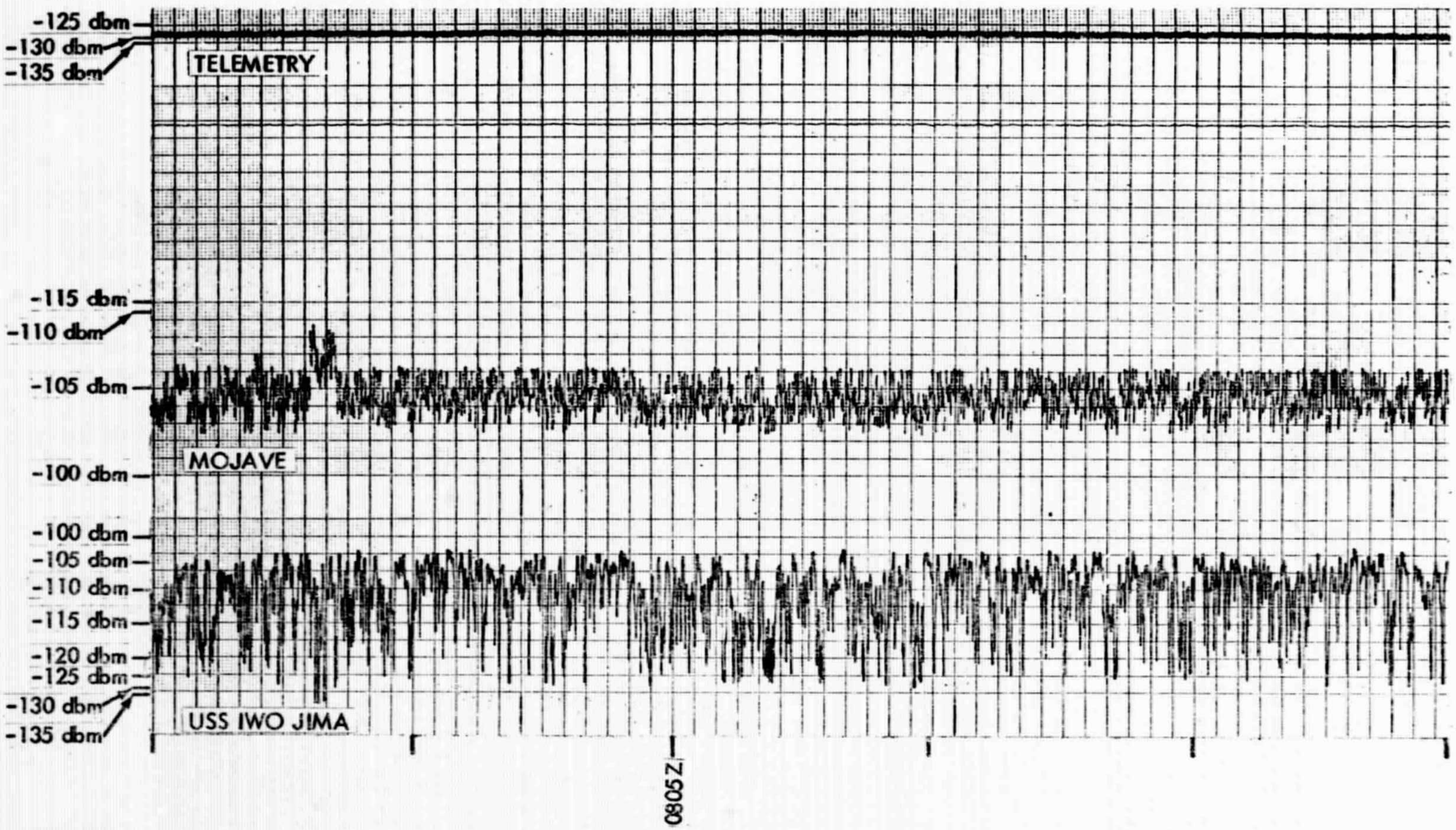

Figure 4c. Signal Level Mojave and Iwo Jima (April 6, 1970)

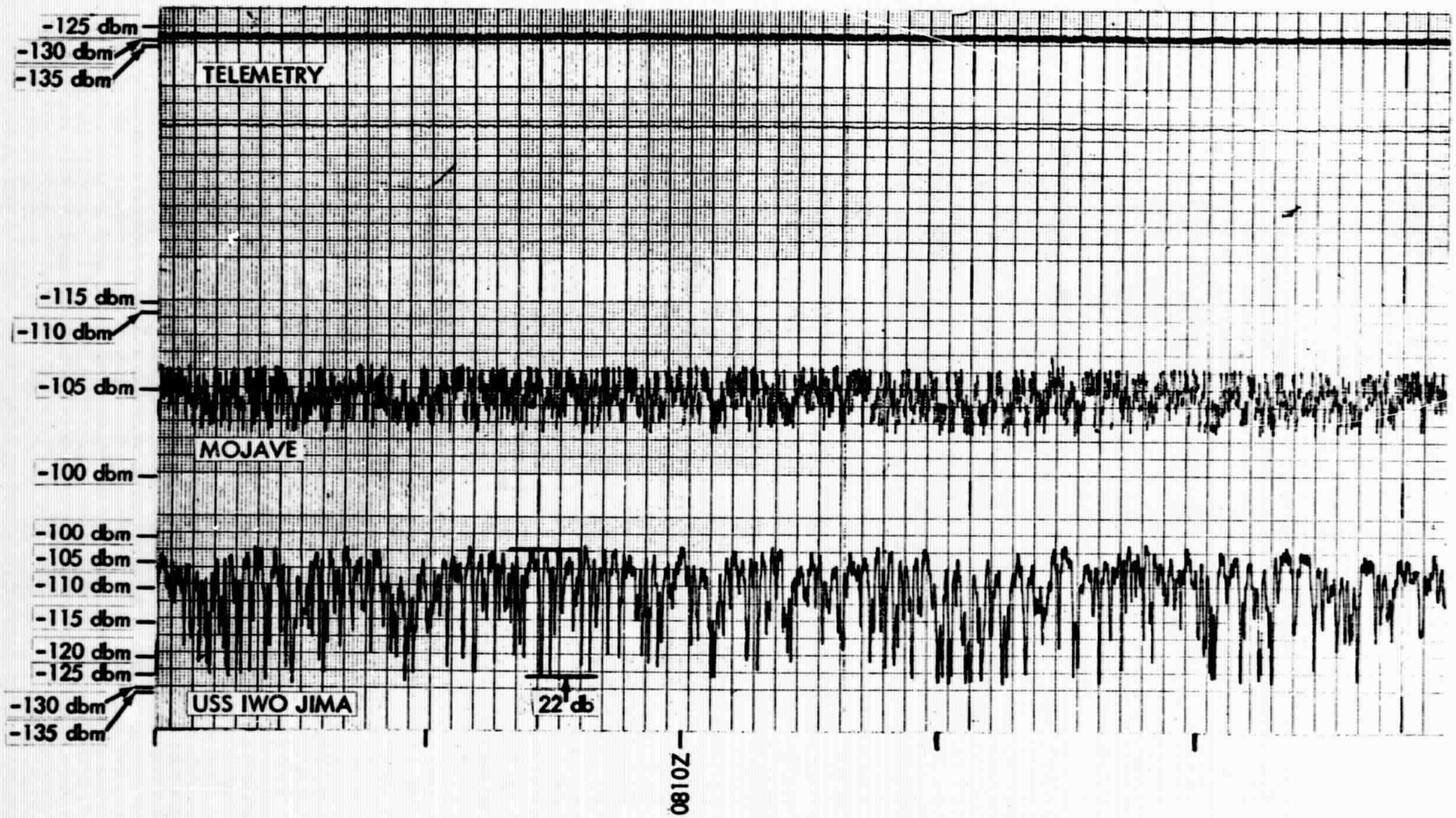

Figure 4d. Signal Level Mojave and Iwo Jima (April 6, 1970)

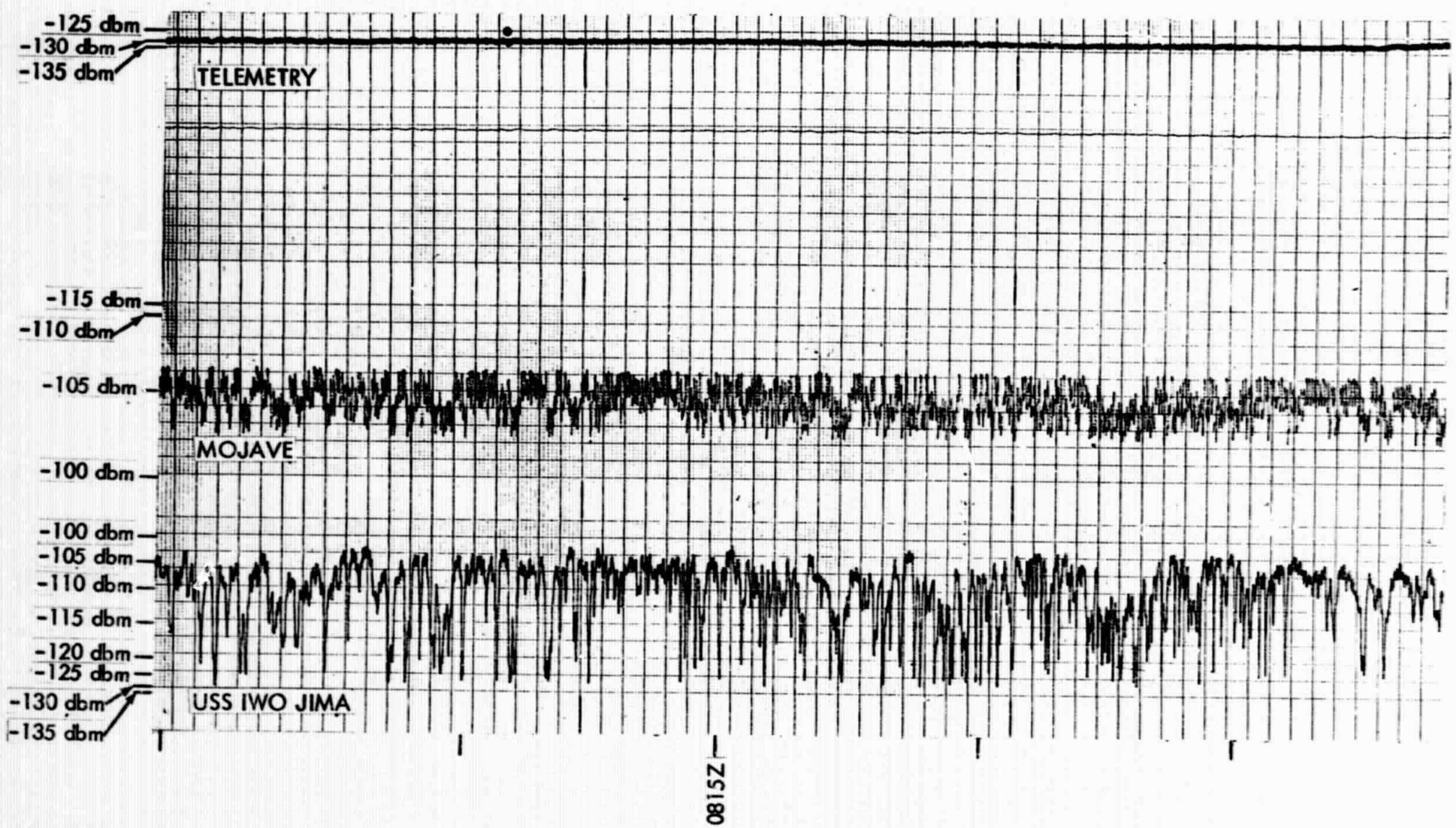

Figure 4e. Signal Level Mojave and Iwo Jima (April 6, 1970)

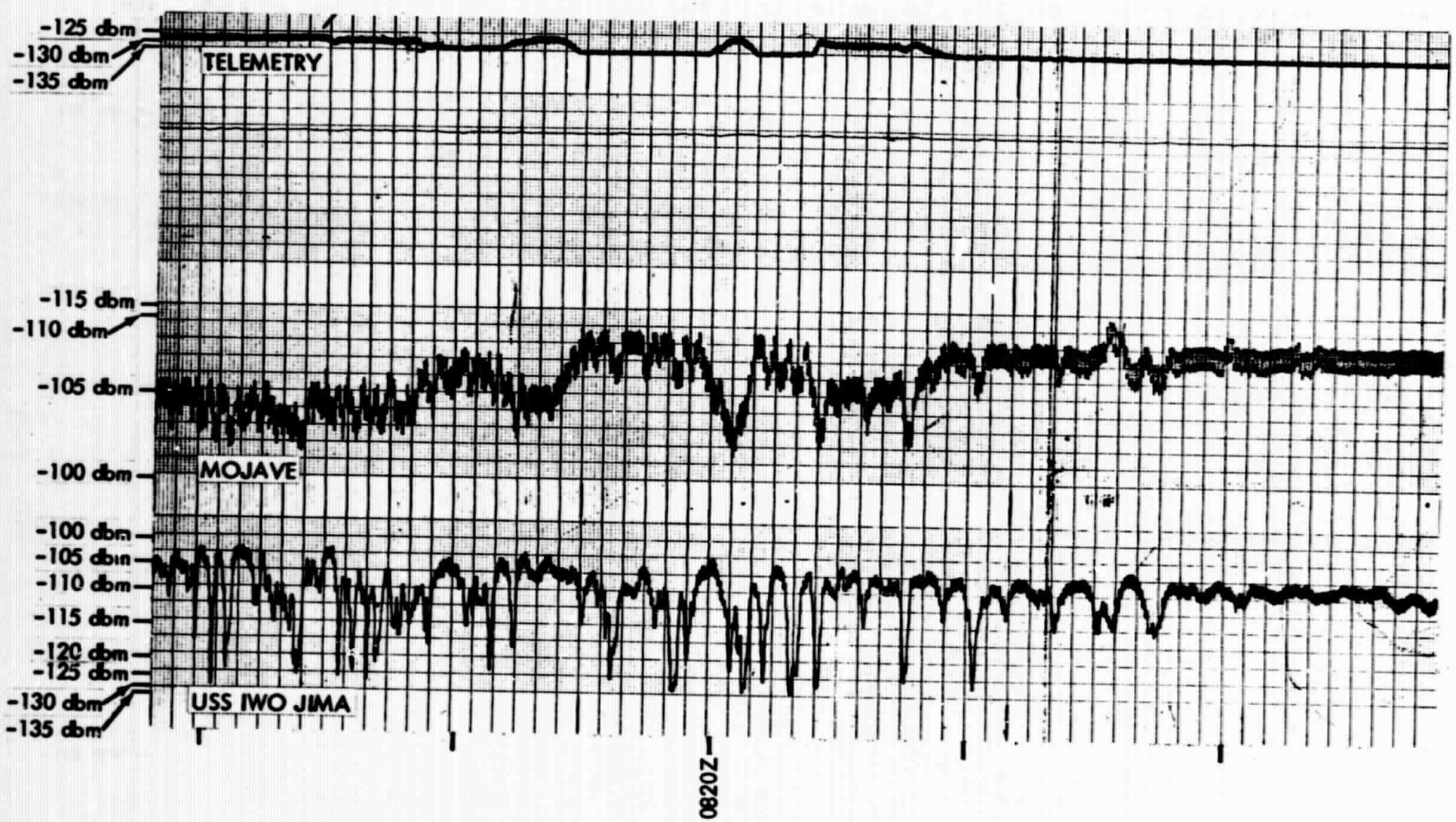

Figure 4f. Signal Level Mojave and Iwo Jima (April 6, 1970)

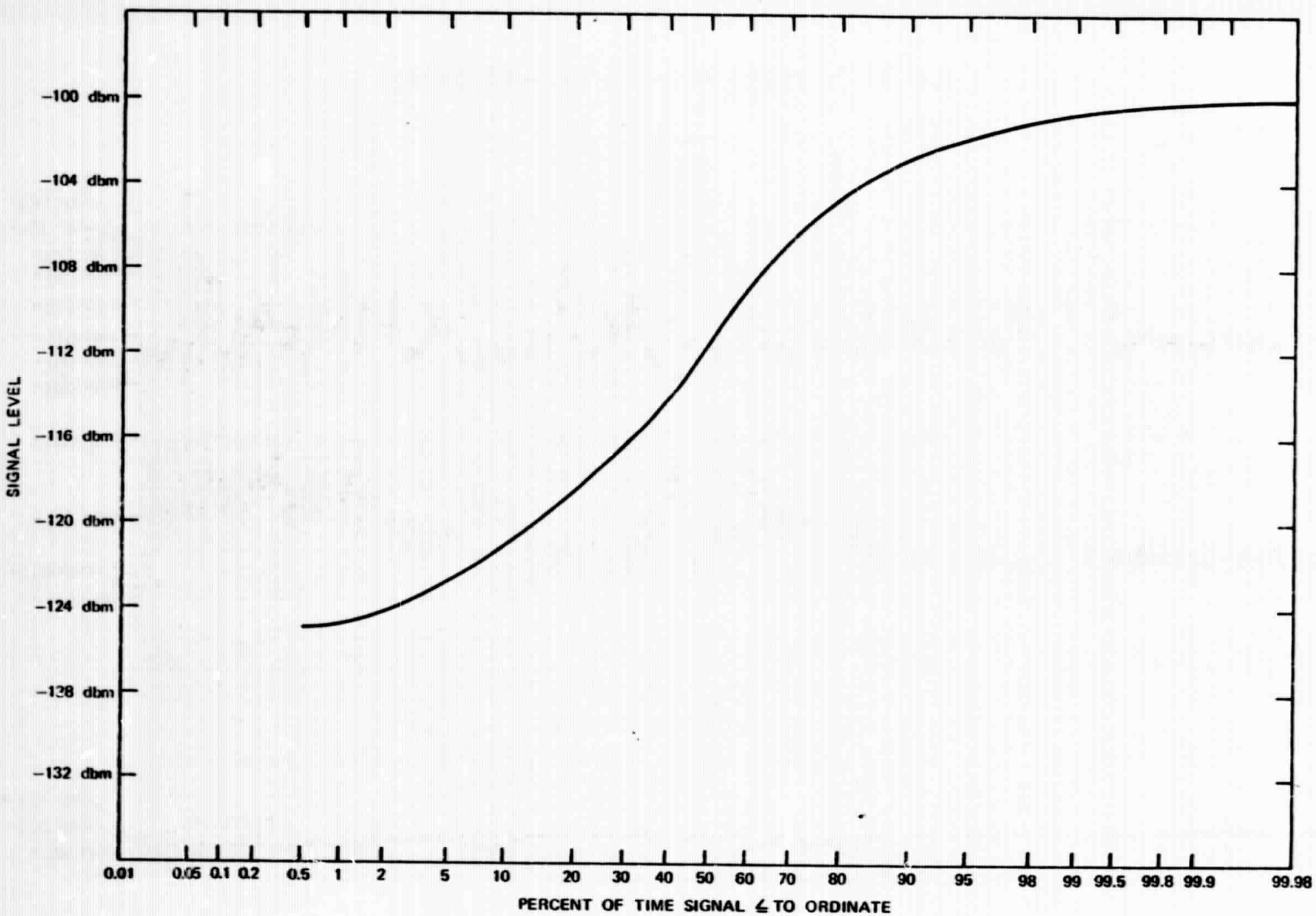

Figure 5. Cumulative Distribution of Signal Level

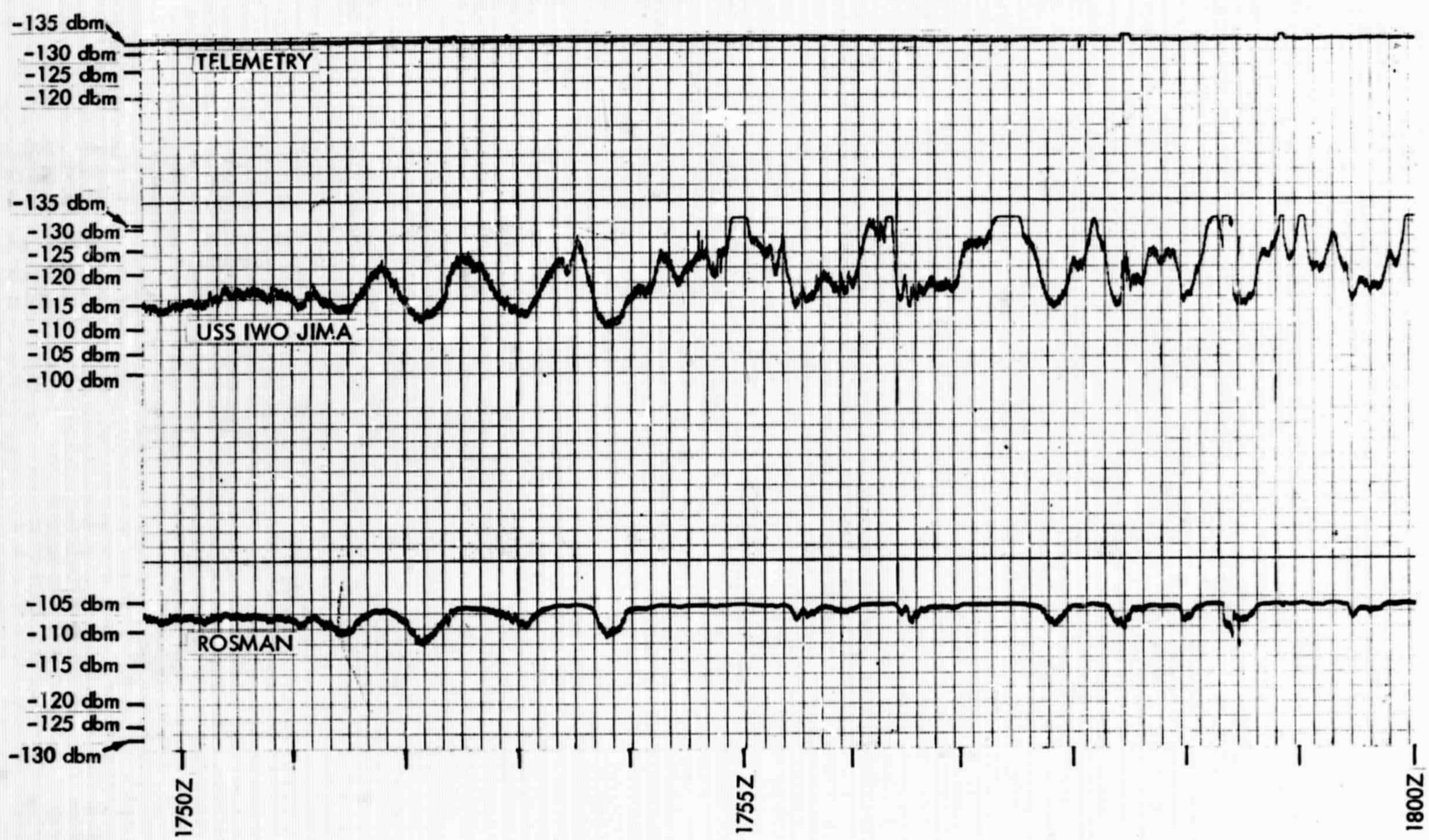

Figure 6a. Signal Level of Rosman and U.S.S. Iwo Jima (April 18, 1970)

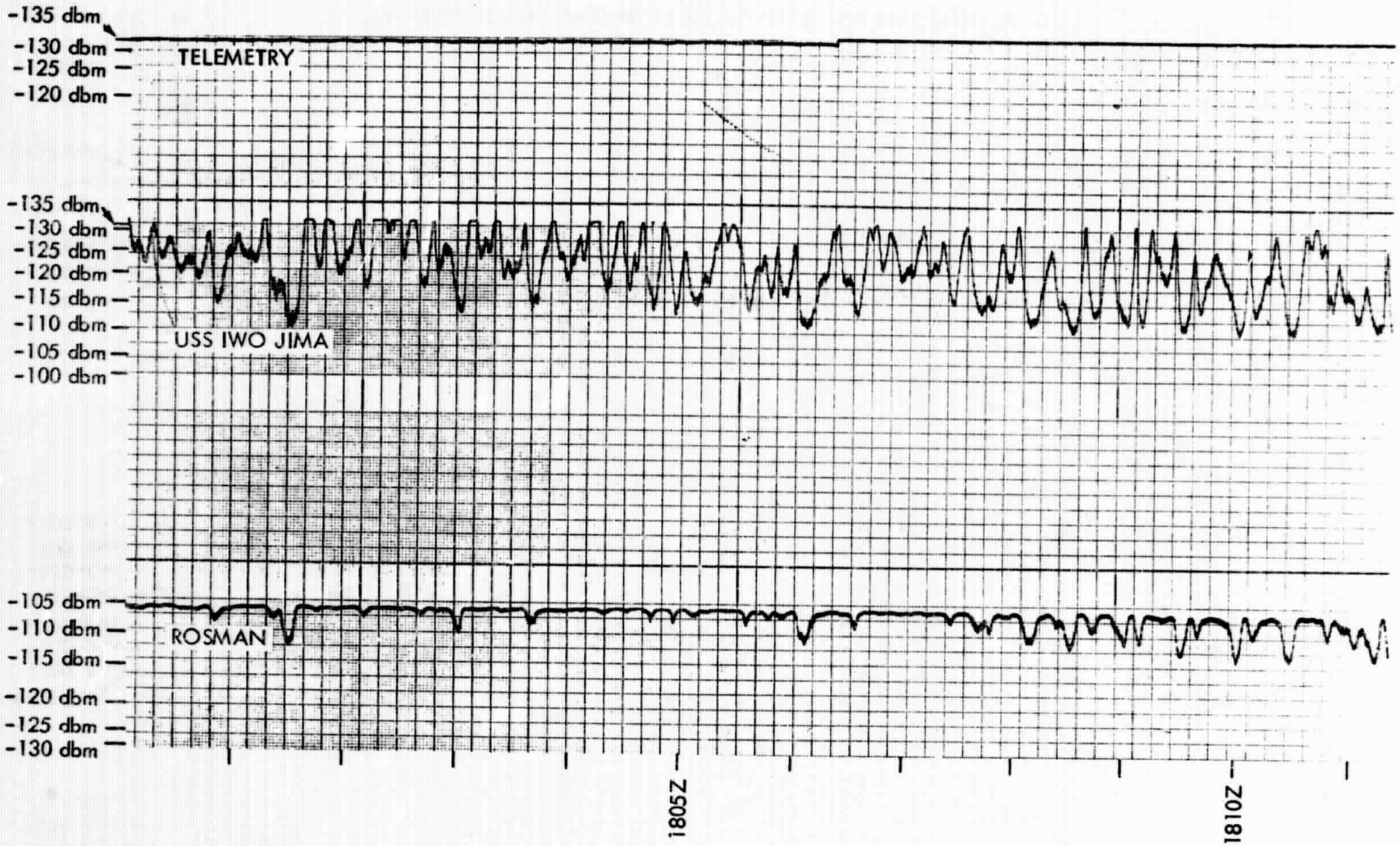

Figure 6b. Signal Level of Rosman and U.S.S. Iwo Jima (April 18, 1970)

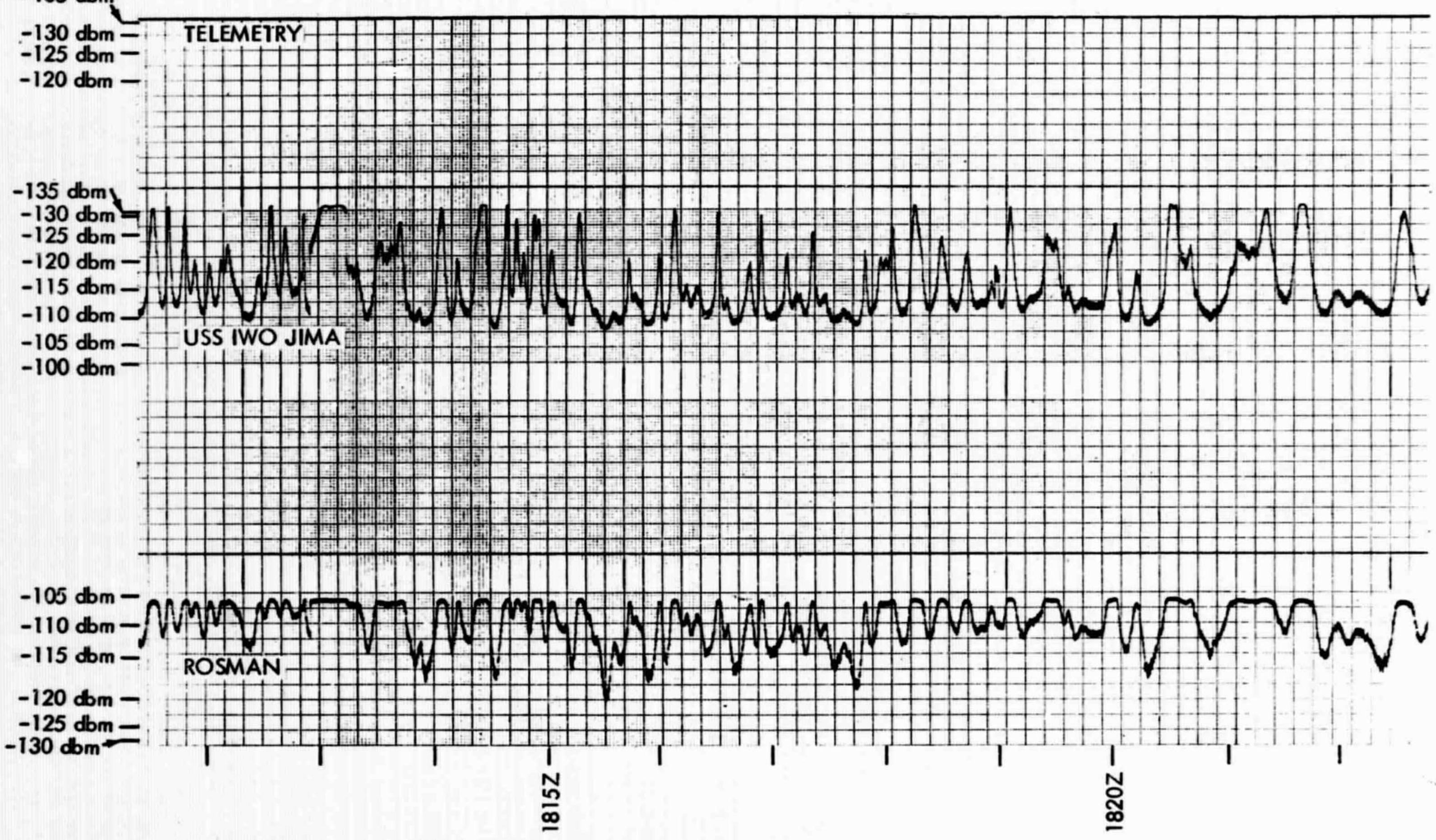

Figure 6c. Signal Level of Rosman and U.S.S. Iwo Jima (April 18, 1970)

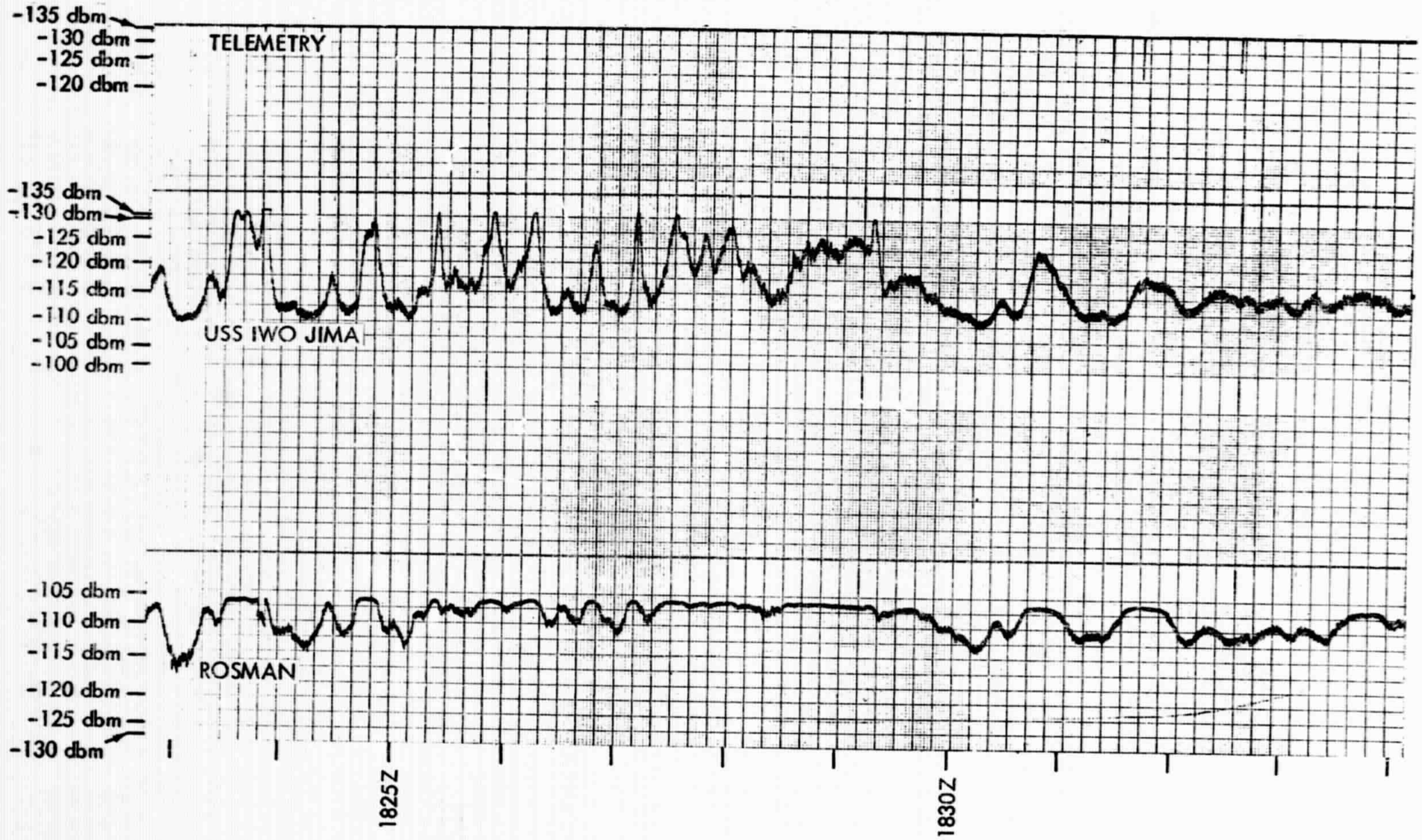

Figure 6d. Signal Level of Rosman and U.S.S. Iwo Jima (April 18, 1970)

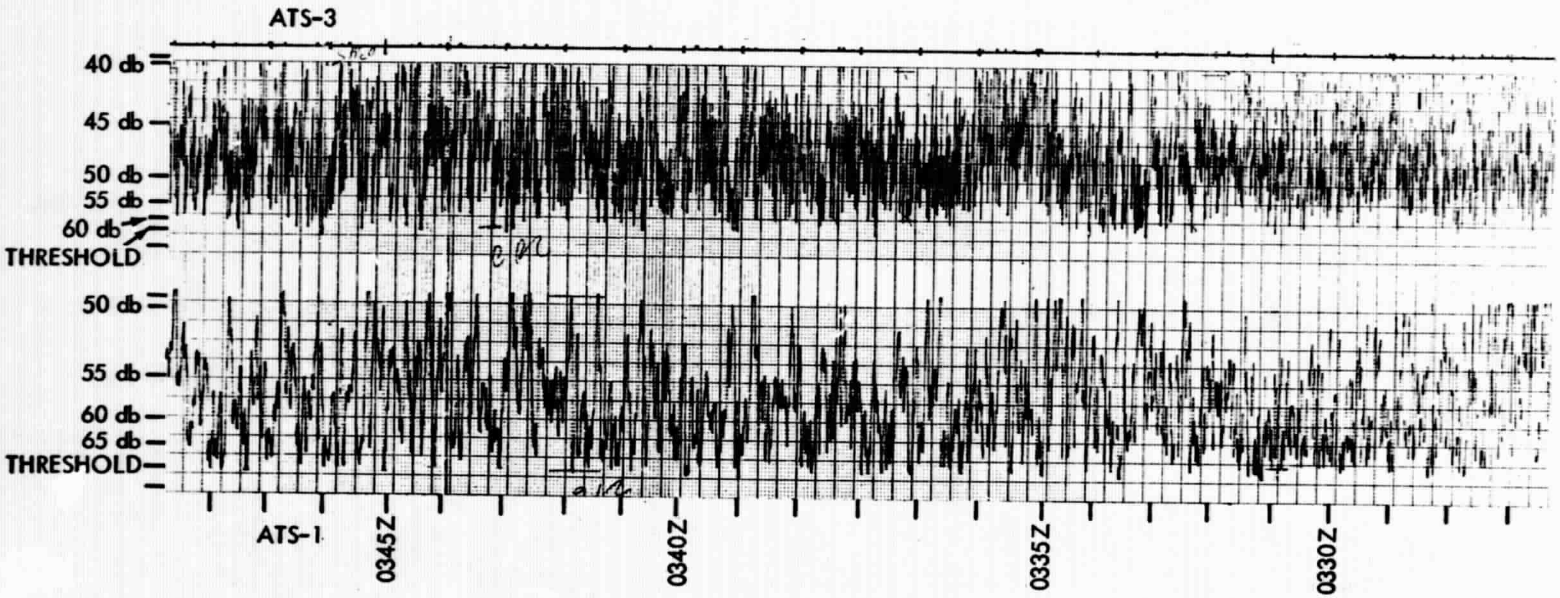

Figure 7a. Signal Level Lima, Peru ATS-1 and ATS-3 (Nov. 12, 1969)

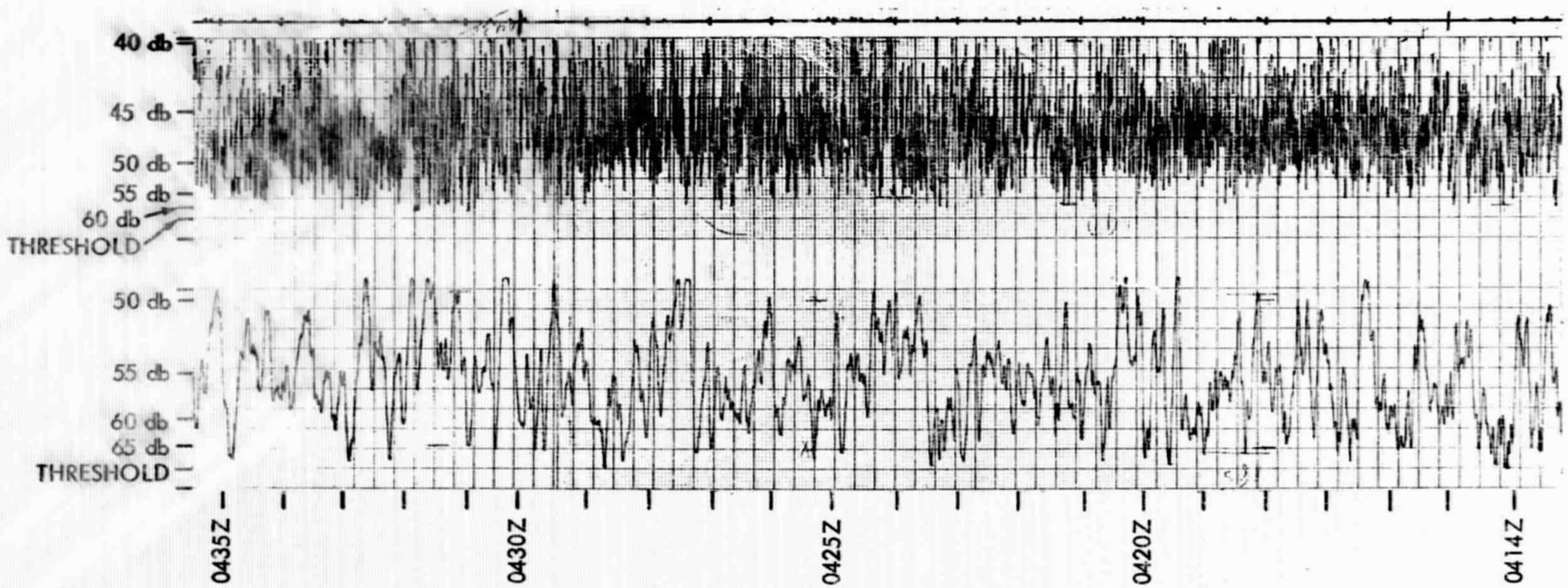

Figure 7b. Signal Level Lima, Peru ATS-1 and ATS-3 (Nov. 12, 1969)

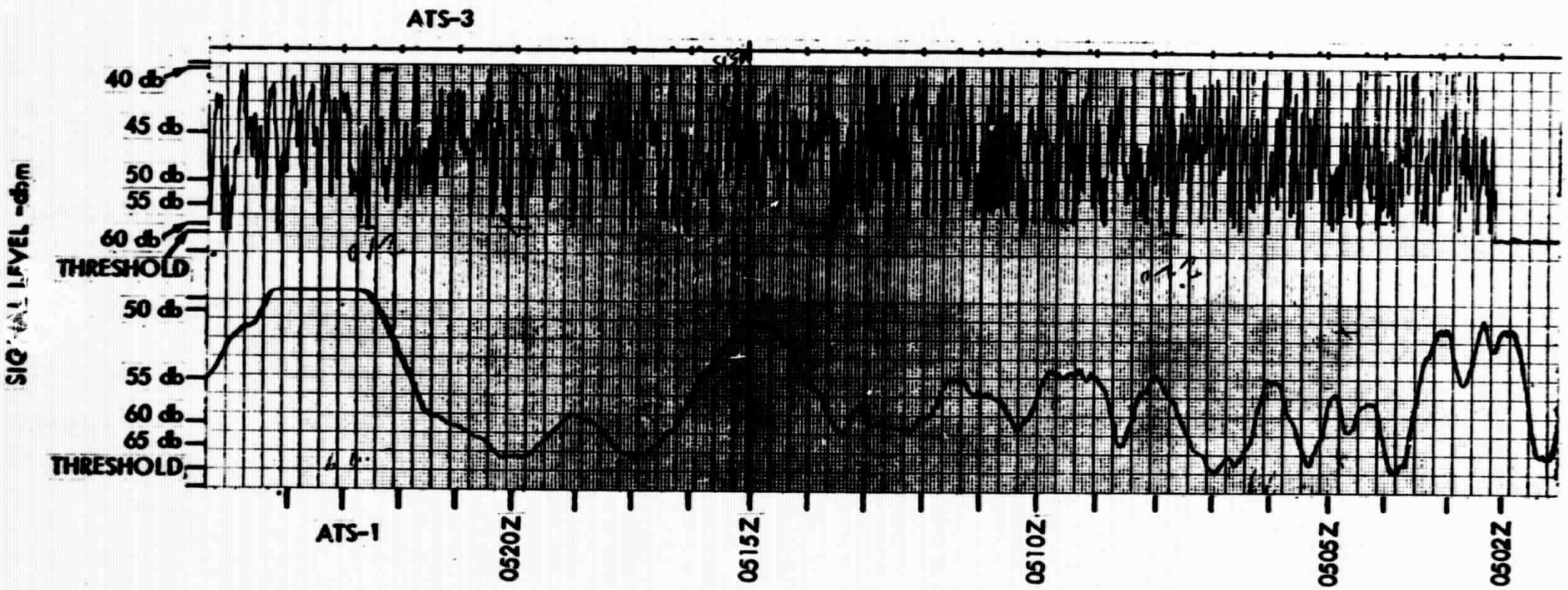

Figure 7c. Signal Level Lima, Peru ATS-1 and ATS-3 (Nov. 12, 1969)

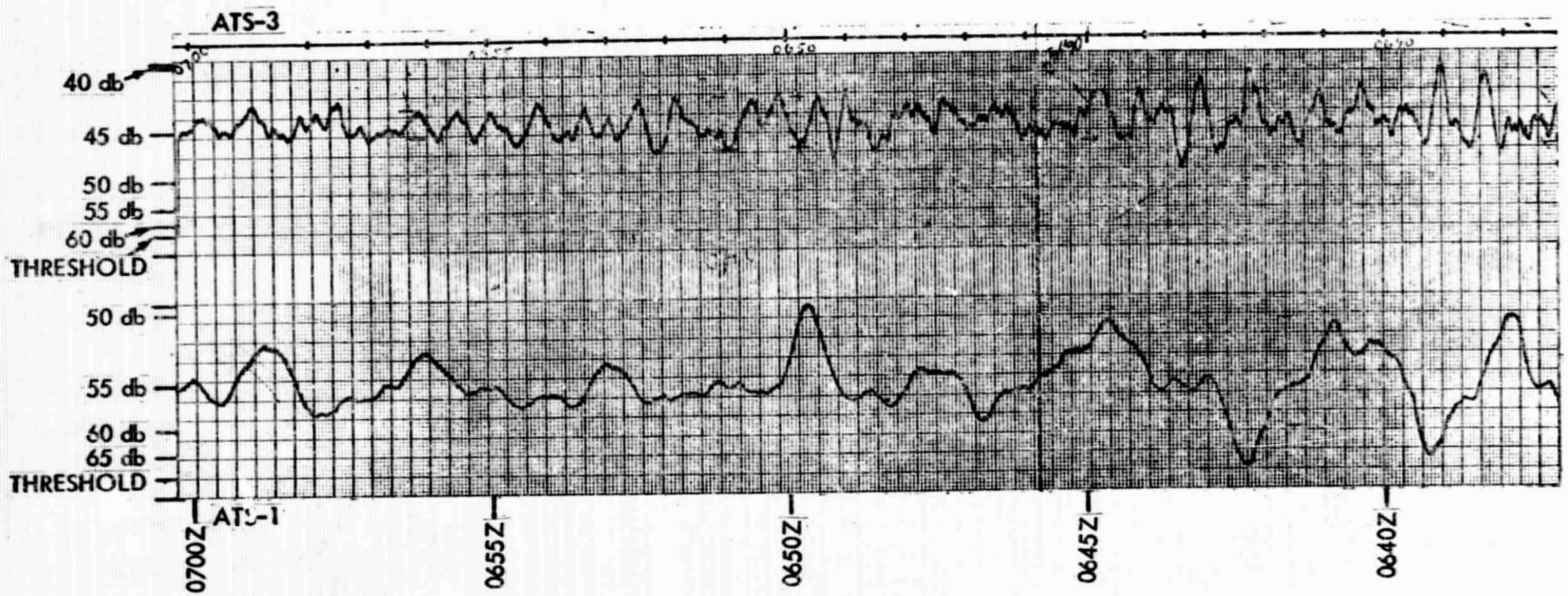

Figure 7d. Signal Level Lima, Peru ATS-1 and ATS-3 (Nov. 12, 1969)