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APPARENT SCATTERING CROSS-SECTION OF ECHO II

by

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Department of ELECTRICAL ENGINEERING

THE OHIO STATE UNIVERSITY
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Grant Number	NAS5-9507
Investigation of	Tracking, Receiving, Recording and Analysis of Data from Echo Satellite
Subject of Report	Apparent Scattering Cross-Section of Echo II
Submitted by	Stephen L. Zolnay Antenna Laboratory Department of Electrical Engineering
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ABSTRACT

This report presents experimental data about the received signal strength on a Dallas-Echo-OSU link. The data are evaluated to display the scattering cross section of the satellite as a function of time on a two-second average basis. The calculated scattering cross section is πr^2, where r is the radius of the satellite; the result is 31.2 db for Echo II, and 28.6 for Echo I ($1\ m^2 = 0$ db). The target gain introduced to compensate for the bistatic scattering is unity. The measured data are found to be practically never the same as the calculated value; discrepancies on the order of 10 db are quite common. The measurements of these discrepancies is limited by the maximum available signal and the dynamic range of the receiver; thus the actual peak scintillations could have been much greater, but they were at least 10 db. Discrepancies that exceed 3 dbs and prevail for periods of minutes are quite common. It is suggested that the origin of the scintillations is the surface irregularities of the satellites. The available data evaluated for Echo I show that the variations in the scattering cross section for this satellite are very similar to the variations experienced with Echo II. On the basis of these data and of previous measurements, it seems that the apparent average cross section of the Echo satellites increases as a function of time. An increase of 3 db over the calculated cross section has been observed during two Echo I revolutions and the same amount of increase has been noted for Echo II in at least one instance.

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APPARENT SCATTERING CROSS-SECTION OF ECHO II

I. INTRODUCTION

Signals received from Echo II at the Satellite Communications Center of the Antenna Laboratory (The Ohio State University, Columbus, Ohio), have a randomly fluctuating amplitude. The peak-to-peak amplitude scintillations are known to cover at least the dynamic range of the receiver (20 dbs) [1, 2]. It can be stated, that amplitude scintillations on the order of 20 dbs are neither of atmospheric nor of ionospheric origin[3, 4, 5]. This statement is further substantiated by the fact that the scintillations occur at all pointing directions, regardless of elevation or azimuth angles. Instabilities in the transmitted power or gain instabilities in the receiving equipment or a combination of the two that would result in at least 20 dbs of fluctuation simply do not occur. In this report it is assumed that the fluctuations in the received power level are caused by variations in scattering cross section of the Echo satellites. The purpose of this report is to present experimental data showing the variations in the scattering cross section of Echo II and of Echo I. Specifically five Echo II revolutions and two Echo I revolutions have been selected for analysis. These are Echo II: 2626, 2653, 2816, 3040, and 3483; and Echo I: 18,166 and 18,966. The Echo II revolutions selected are representative of all data during the period of revolutions 2000-3500; Echo I revolutions were selected from data obtained during the same period as the Echo II revolutions. The various aspects of reduction and analysis are discussed in detail elsewhere[4].

II. CALCULATED SCATTERING CROSS SECTION

Echo II is a predominantly spherical balloon 135 feet in diameter; the diameter of Echo I is 100 feet. The operating frequency was 2260 Mc/sec ($\lambda \simeq 5$ inches). The scattering cross section, σ, for a sphere whose diameter is large in terms of the wavelength is given by[6]

$$(1) \qquad \sigma = \pi r^2 ,$$

where r is the radius of the sphere. The transmitted signal originated from the Collins Space Communication Facility, Dallas, Texas; hence the scattering was bistatic. To compensate for this effect in the calculations, the artifice of assigning a gain G_t for the target has been introduced. It is known[7] that the scattering cross section of a perfectly conducting sphere whose diameter is large in terms of the wavelength is that given by Eq. (1), for both E and H planes, for bistatic angles of less than about 90°. The material used in the Echo baloons is aluminum, which may be assumed to be a perfect conductor for our purposes. The conservative limitation of 90 degrees on the bistatic angle is more than adequate on a Dallas-Echo-OSU link and both Echos amply satisfy the "large in terms of wavelength" criterion. Therefore, the gain of the target G_t is taken as unity.

III. MEASURED SCATTERING CROSS SECTION

The measured scattering cross section follows from the radar range equation:

$$\sigma = \frac{(4\pi)^3 \, d_R^2 \, d_T^2 \, P_R}{P_T \, G_R \, G_T \, G_t \, \lambda^2} , \qquad (2)$$

where
P_r = received power,
P_T = transmitted power,
G_T = gain of transmitting antenna,
G_R = gain of receiving antenna,
G_t = gain of target = 1,
d_R = range from target to receiver,
d_T = range from transmitter to target, and
λ = free space wavelength of transmitted frequency.

The received power, P_r, was monitored and compared with the calculated power level. Figure 1 shows a chart recording that was produced from the original magnetic tape recordings of the instantaneous received power. In producing chart recordings, such as Fig. 1, the data were passed through a filter whose time constant; τ, was 2 seconds. The horizontal lines on Fig. 1 are 3 db apart. A calibration scale relative to one watt is included on the left. The slanting line on Fig. 1 is the calculated received power level on the basis of an assumed scattering cross section of 31.2 db for Echo II and 28.6 db for Echo I, (a scattering cross section of 1 m^2 is taken as 0 db). The difference between the pen deflection, corresponding to the actual received power, and the slanting line, corresponding to the calculated power, expressed in decibels is taken as the variation in the scattering cross section of the satellite.

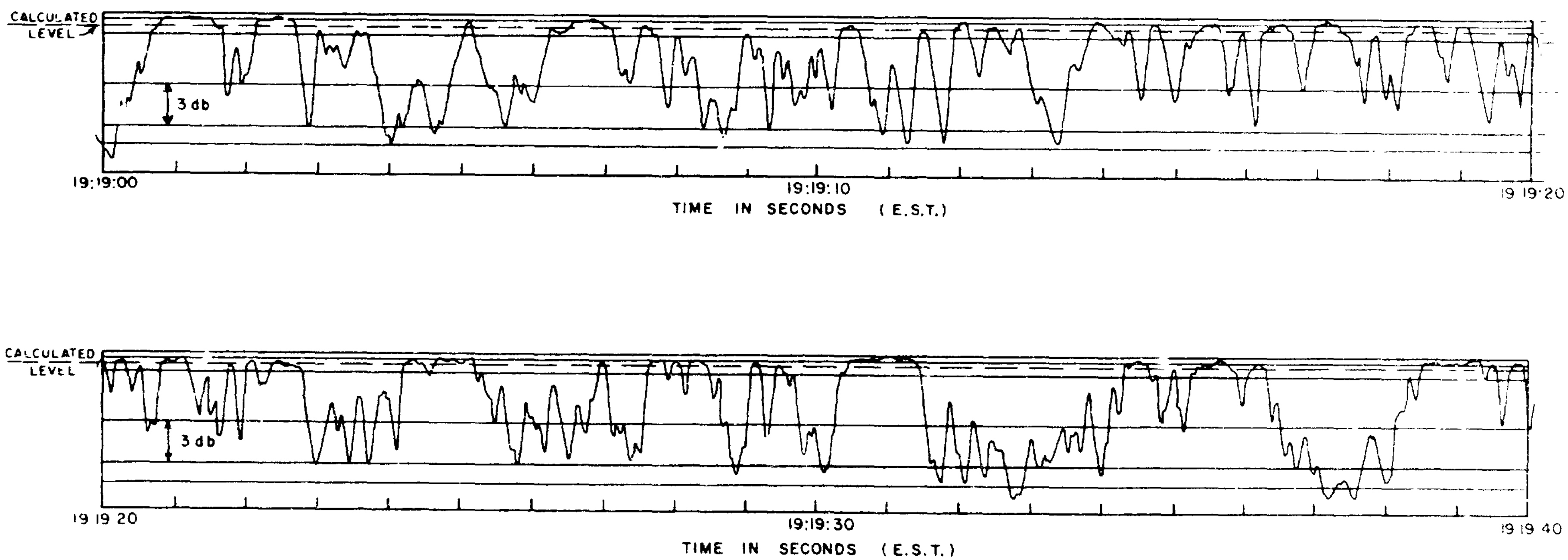

Fig. 1. Chart recording of averaged (τ = 2 seconds) received power level obtained during Echo II revolution 2626

A comprehensive description of the receiving system has recently been published by Eberle[8], and a description of the Collins transmitting system is available[9].

The accuracy of the data is ± 4 db[2], based on the best presently available measurements and/or estimates of the parameters in Eq. (2).

IV. EXPERIMENTAL DATA

The chart recordings, such as the one shown in Fig. 1, were sampled at two-second intervals and the differences in decibels between the calculated and measured values were replotted on a linear scale as a function of time. Seven such plots were prepared corresponding to the data collected on five Echo II and on two Echo I revolutions; these are shown in Figs. 2-8. The horizontal time scale on these figures is continuous, but the graph is not. The discontinuity is caused either by a break in the automatic tracking or by the received signal saturating the receiver. In the latter case arrows are used on the graph while the receiver was saturated, since it was pointless to continue with the graph.

In general, the measured scattering cross section is practically never the same as the calculated one. Maximum observed discrepancies are about 10 dbs and discrepancies that exceed 3 dbs and prevail for several minutes or for the duration of the pass are quite common. Figure 2 is an example for this case, where the average cross section is 4 dbs below the calculated one for approximately the first three minutes of the graph, then for the last minute the average level of the measured data is about 7 dbs below the calculated level. These average levels are indicated in Fig. 2. This is in agreement with previous findings based on the first 4[illegible] revolutions where it was ascertained that in general the apparent scattering cross section of Echo II is about 3 dbs below the calculated value[illegible].

Figure 6 shows an example of when the average level of the measured data for about two minutes is 3 dbs above the calculated level; this finding is contrary to the earlier one. Careful checks have been made on all accuracies involved in the measurement and according to the best possible determination all the figures are accurate within the limit given above. Thus it appears that the average of the apparent scattering cross section of Echo II is no longer 3 dbs below the calculated one. It is 3 db below on occasions, but it is 3 dbs above on other occasions, and approximately the same as the calculated one on still other occasions (see Figs. 3, 4, and 6). The average level of the

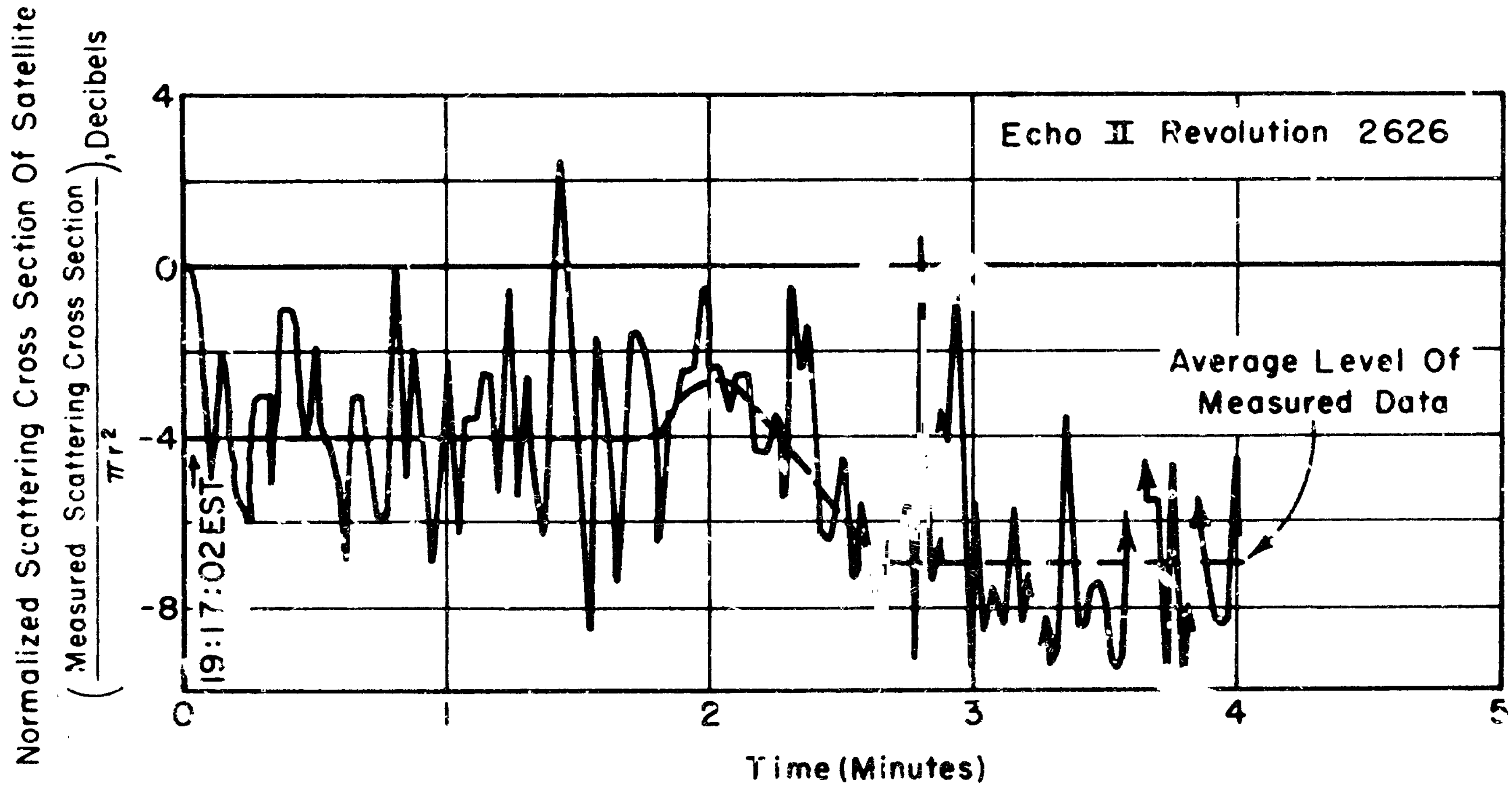

Fig. 2. Measured scattering cross section of Echo II, revolution 2626.

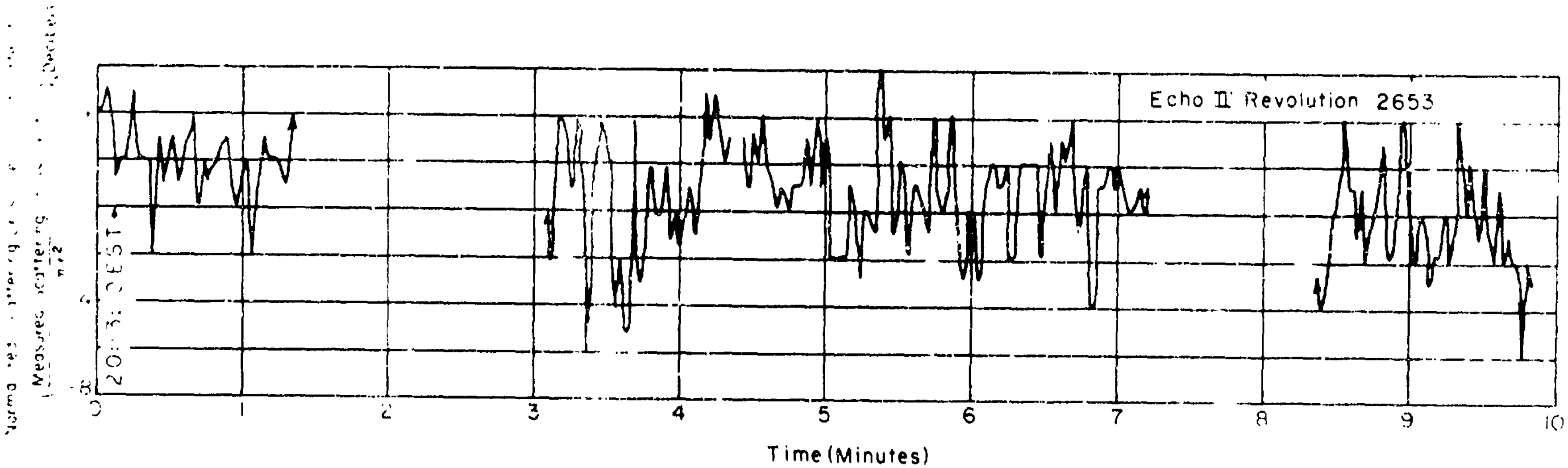

Fig. 3. Measured scattering cross section of Echo II, revolution 2653.

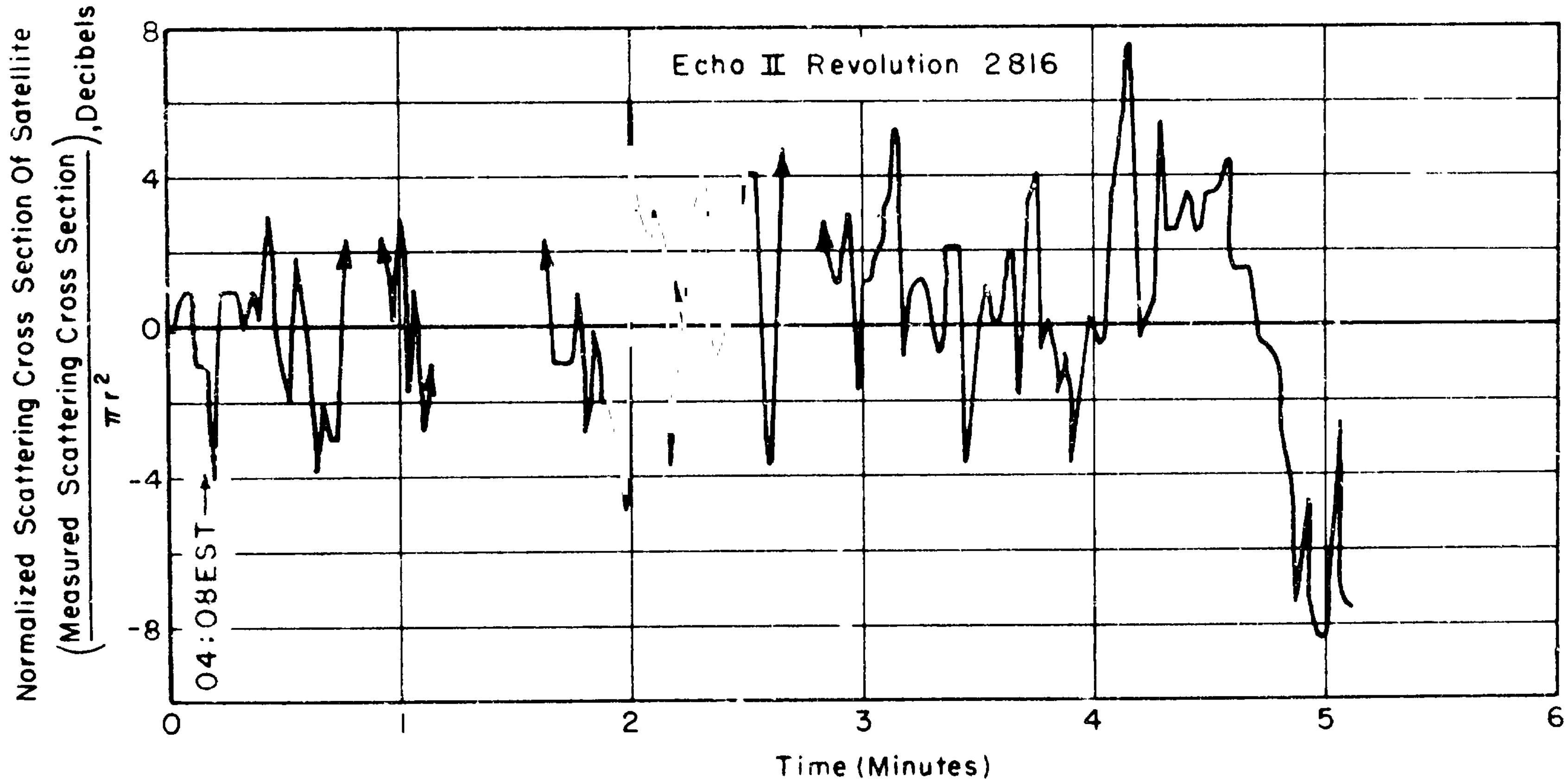

Fig. 4. Measured scattering cross section of Echo II, revolution 2816.

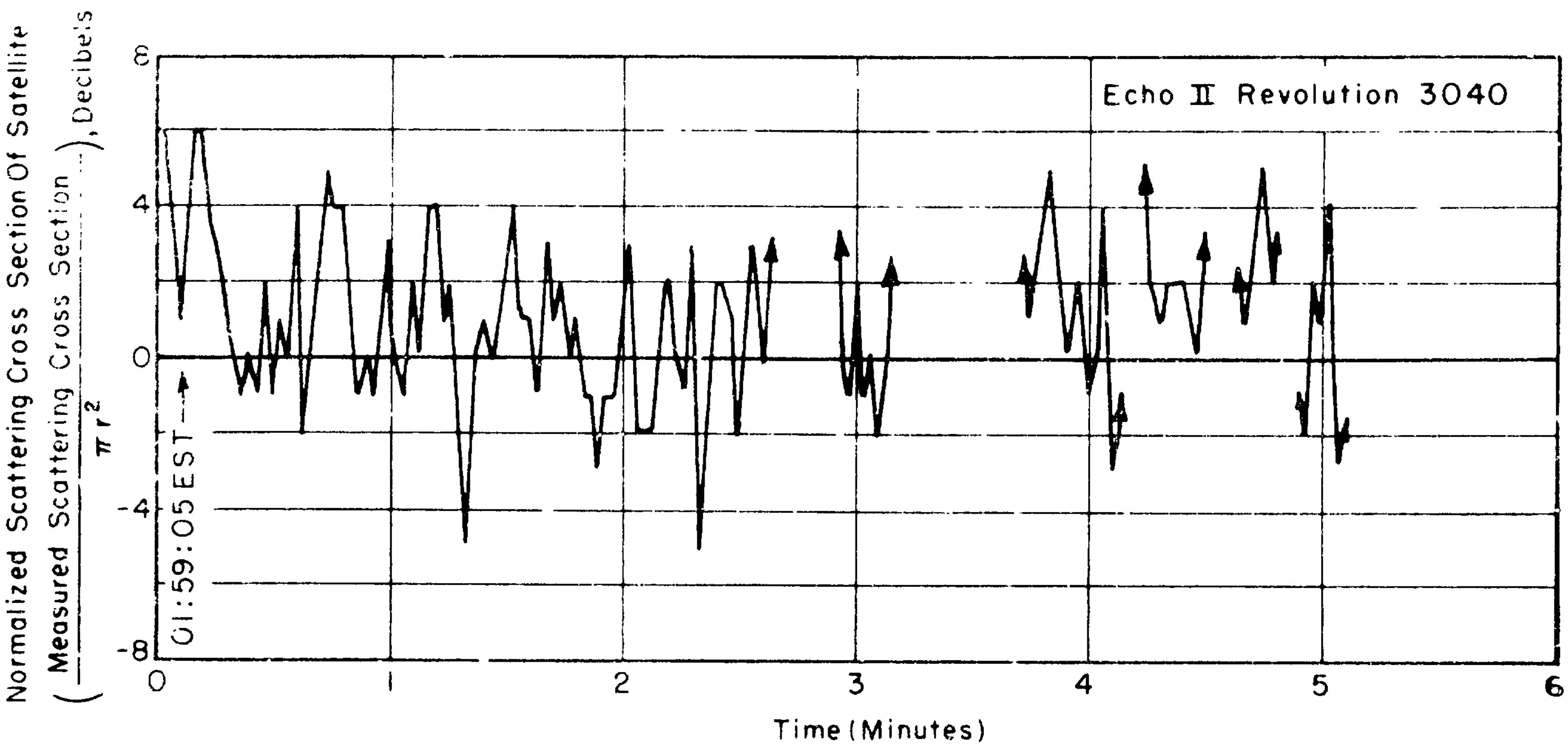

Fig. 5. Measured scattering cross section of Echo II, revolution 3040.

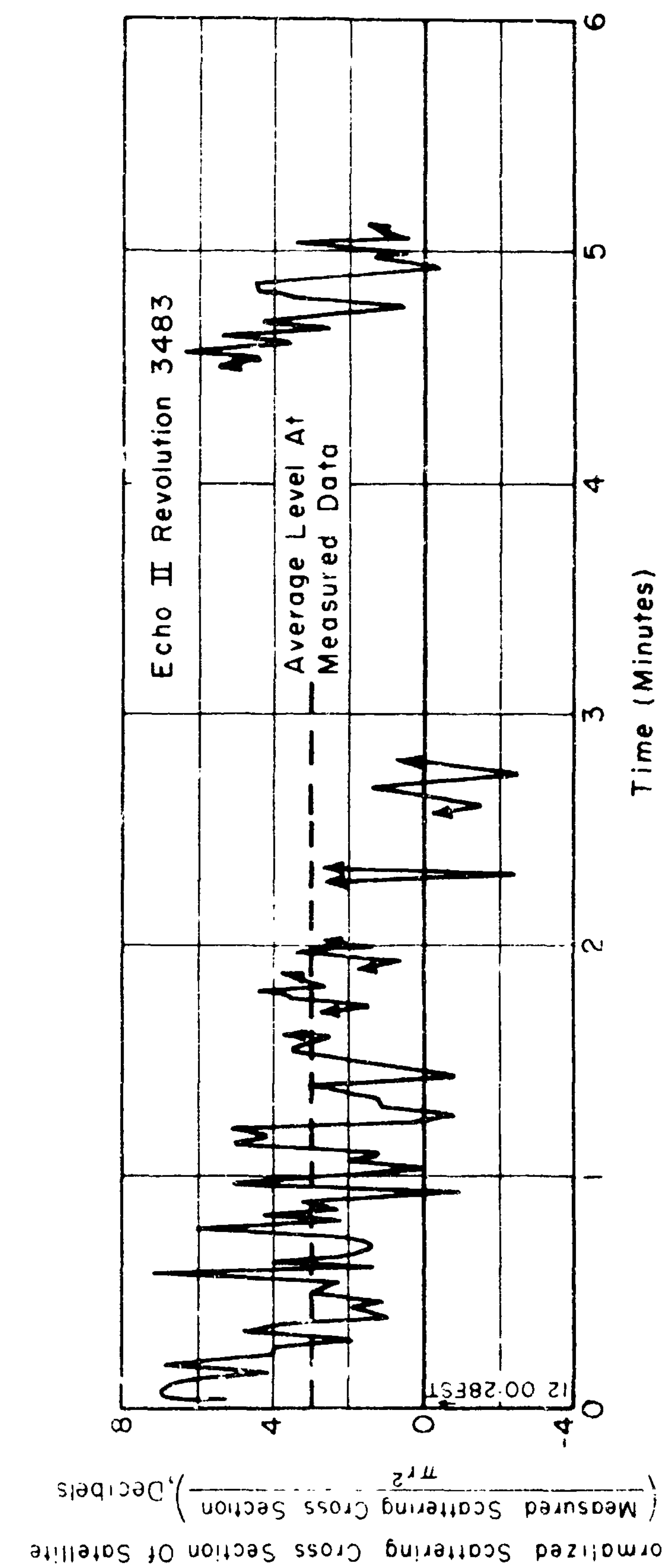

Fig. 6. Measured scattering cross section of Echo II, revolution 3483.

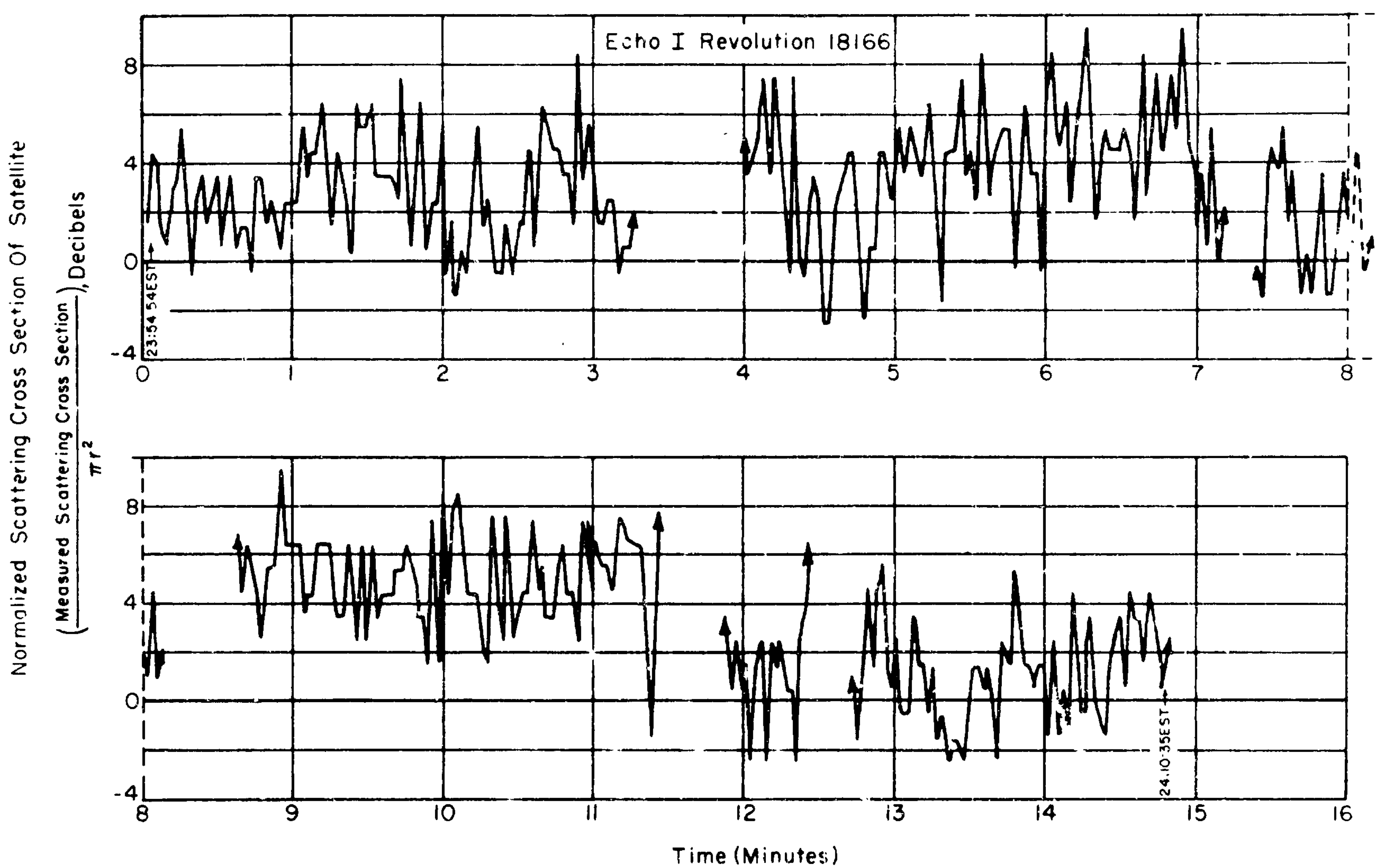

Fig. 7. Measured scattering cross section of Echo I, revolution 18, 166.

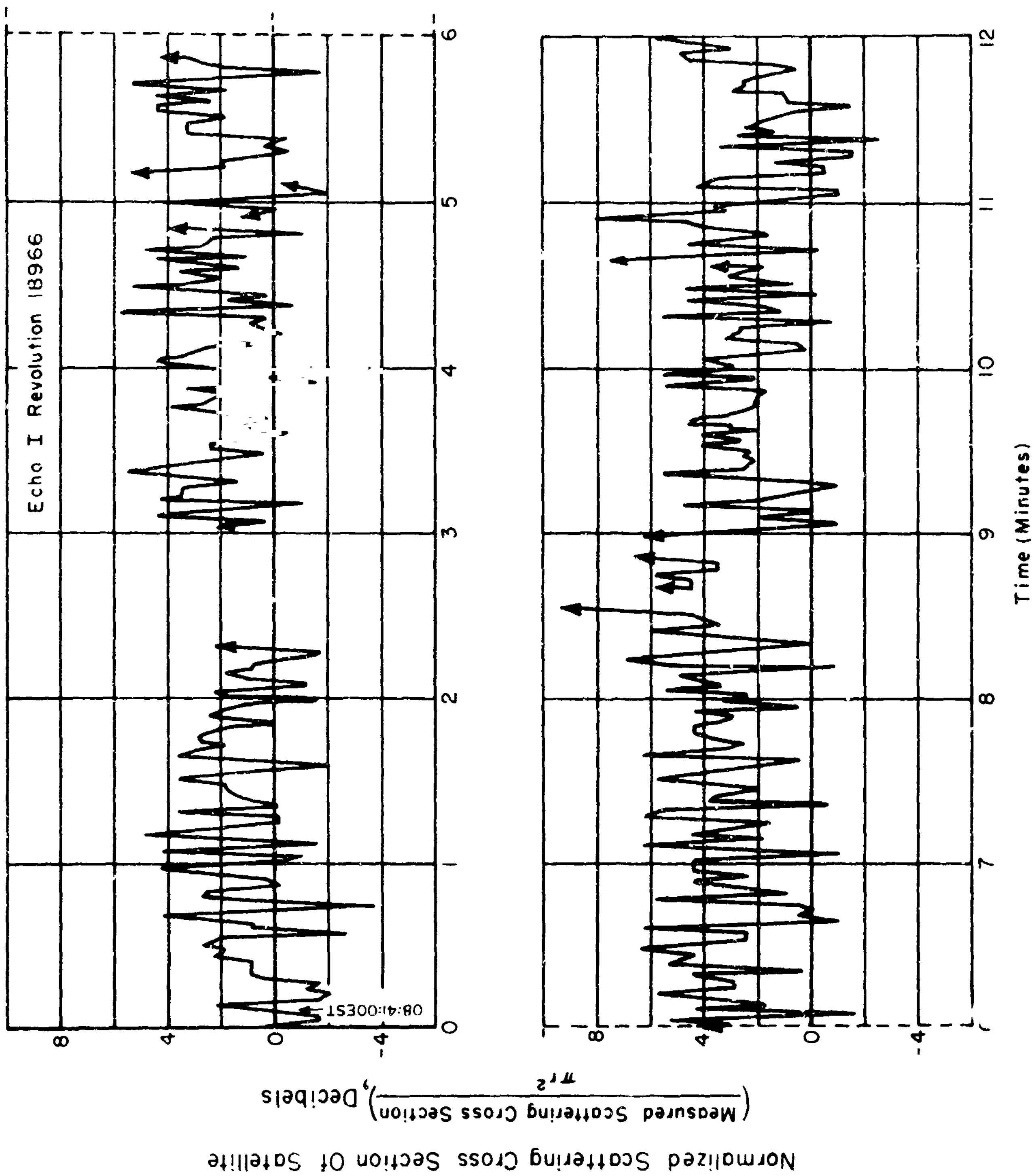

Fig. 8. Measured scattering cross section of Echo I, revolution 18,966.

measured data for both Echo I passes appears to be about 2-3 dbs above the calculated scattering cross section. This fact raises the interesting possibility that the apparent scattering cross section of the Echo satellites slowly increases as a function of time. This could be explained by postulating a flattening influence on the satellites after the internal gas pressure that maintained their spherical shapes is in equilibrium with the pressure of their surroundings. However, to ascertain whether the increase in the apparent scattering cross section is indeed present, the analysis of much more data with more accurately determined parameters is necessary.

From previous investigations based on the instantaneous power level it is known that the received signal level can fluctuate randomly between saturation and noise level. It is interesting to note that on the basis of these two second averages the maximum fluctuations are still 10 dbs. These are not necessarily the maximum scintillations that occurred. While the data were collected it was the practice to compensate for the approximately 20 db dynamic range of the receiver by inserting and removing attenuators in the first IF section of the receiver as the signal strength varied; hence the maximum observable peak of the scintillations should be on the order of 10 dbs.

Even after averaging the data for two seconds, the measured scattering cross section is varying from second to second. Because of the large and frequently occurring peaks it is difficult to estimate the extent of the scintillations. Perhaps a value on the order of 4 dbs peak-to-peak would be applicable to most of the data. During a one-second interval the satellite changes its orbital position by about five miles and rotates by some four degrees (a rotational period of 100 seconds is claimed for Echo II on the basis of telemetry data). It is suggested that the probable cause of these fluctuations can be found in surface irregularities and in their apparent motions relative to the tracking sites. This suggestion is apparently substantiated by the fact that a flat area of some 10 λ^2, suitably oriented relative to the tracking sites, yields a scattering cross section of about 13 dbs. A suitable oriented flat square area of four feet on a side would have approximately the same scattering cross-section as Echo II.

Figures 7 and 8 show the same data for Echo I as the preceding five figures show for Echo II. The variations in the scattering cross section of Echo I, based on these figures, are similar to the variations in the scattering cross section of Echo II.

V. SUMMARY

This report presents experimental data about the received signal strength on a Dallas-Echo-OSU link. The data are evaluated to display the scattering cross section of the satellite as a function of time on a two-second average basis. The calculated scattering cross section is πr^2, where r is the radius of the satellite; the result is 31.2 db for Echo II, and 28.6 for Echo I (1 m^2 = 0 db). The target gain introduced to compensate for the bistatic scattering is unity. The measured data are found to be practically never the same as the calculated value; discrepancies on the order of 10 db are quite common. The measurements of these discrepancies is limited by the maximum available signal and the dynamic range of the receiver; thus the actual peak scintillations could have been much greater, but they were at least 10 db. Discrepancies that exceed 3 dbs and prevail for periods of minutes are quite common. It is suggested that the origin of the scintillations is the surface irregularities of the satellites. The available data evaluated for Echo I show that the variations in the scattering cross section for this satellite are very similar to the variations experienced with Echo II. On the basis of these data and of previous measurements, it seems that the apparent average cross section of the Echo satellites increases as a function of time. An increase of 3 db over the calculated cross section has been observed during two Echo I revolutions and the same amount of increase has been noted for Echo II in at least one instance.

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