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SEMI-ANNUAL STATUS REPORT II

on

The Influence of Polarization on Millimeter Wave Propagation through Rain

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PROJECT PERSONNEL

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1. Introduction

This report describes the second six months of a continuing program for the measurement and analysis of the depolarization and attenuation that occur when millimeter wave radio signals propagate through rain. Technical details covered in the previous report are repeated only as necessary for clarity.

2. Narrative Summary of the Report Period

2.1 July

The antennas were installed on July 6 and fully aligned by July 10. After alignment the residual cross polarization level on both receiver channels was -51dB.

On July 15, lightning struck the local telephone exchange and damaged the receiver, the PB-440 computer, and the remote system-status indicator. The last two were repaired within a few days, but some latent undetected receiver damage persisted until August and replacement mixer diodes for the +45° polarized channel were not available from the distributor until mid-September. Nevertheless, the receiver was put into a temporarily acceptable (i.e. with a slightly degraded + channel noise level) operating condition by the end of the month. To prevent future lightning damage, protective circuits were installed between the receiver and the telephone lines.

2.2 August

The system began taking data on August 4 with one receiver channel and two rain gauges. Operations had been delayed by a receiver power supply failure on August 1 which burned out the local oscillator (LO) and damaged several transistors. The LO was returned to the manufacturer for repairs and replaced by its backup unit: a Hewlett Packard (HP) sweep oscillator loaned by NASA.

Also on August 1, the transmitter power monitor failed and was returned to the manufacturer for repair under warranty. In the interim, another instrument was used to set and spot-check the transmitter output, but it was insufficiently stable for on-line monitoring.

Two-channel operation began on August 10 and the first dual-polarization data were taken on August 17. Shortly thereafter, a drought began, and no rain fell from August 20 until September 14.

2.3 September

The LO returned on September 4 and was placed in service. The drought ended on September 14, but a momentary interruption of the 60 Hz power main disabled the analog-to-digital converter and the received signal levels were not recorded. This was the last thunderstorm of 1972. All subsequent autumn rains were covered, but the digital system will be modified before the 1973 thunderstorm season to make it immune to power line transients.

On September 19, the transmitter failed and went back to the manufacturer for warranty repair. Once again the faithful HP sweeper was

pressed into service for the two weeks that the transmitter was absent. It was noted that the residual cross polarization level of the antenna system was higher with the sweeper transmitting than with the usual transmitter. The probable cause was a spurious signal in the sweeper output, down 30 or 40 dB from the main signal level. If such a spurious output should lie outside the normal (and narrow) operating bandwidth of the transmitting antenna feed, it might be transmitted with an improper polarization and raise the apparent cross polarization level at the receiver.

The installation of rain gauges #2, #3, #4 was delayed until the telephone company could provide the necessary lines, but #3 and #4 were connected to the system on September 20. They were followed on September 27 by wind sensor #1 (at the transmitter site). Since September 27, no significant wind velocities have been recorded, so a quantitative assessment of the role of wind in rain depolarization must await future thunderstorms.

2.4 October

The transmitter returned to service on October 5.

On October 6, the residual cross polarization level fluctuated erratically for about 30 minutes and then stabilized at -3dB. An intensive search began for the cause; after about 20 man-days of work a common housefly was discovered dead inside the transmitting antenna feed! The fly had crawled into an open waveguide while the transmitter was disconnected and made its way unerringly (obeying all of Murphy's laws) to the most sensitive part of the feed before expiring.

Sometime after the fly was removed, some difficulty in maintaining long-term antenna alignment was experienced - i.e. after the antennas were set the residual cross polarization level would slowly deterioriate with time. This problem - thought to be mechanical - did not restrict data collection, but it remains a nuisance to be corrected before spring.

After a minor power supply transient on October 11, the LO failed again. It was returned to the manufacturer for evaluation, but the repair cost approached the price of a new unit. A more rugged LO of a different design will be purchased in 1973.

Rain gauge #3 began operation on October 15, completing the planned rain gauge network.

2.5 November

Wind sensor #3 was installed on November 1 and its velocity transducer was connected to the digital system. The direction indicator awaits the installation of a special power supply, but none of the rains since November 1 have been accompanied by significant wind, so no important wind direction data have been missed. The mid-path wind sensor (#2) will be added before the next thunderstorm season.

During November, the receiver and transmitter were disassembled, carried to the laboratory and tested. Except for a minor problem with a loose attenuator card in the receiver (repaired when discovered) all components were within specifications and were returned to the field.

At the suggestion of our NASA colleagues, the instantaneous behavior of our received signals was examined and an effort was made to relate observed mechanical vibrations of the receiving antenna to noise in the receiver output. These investigations are continuing and will be

described elsewhere in this report.

With the onset of extreme cold weather, the transmitter waveguide switches frequently froze overnight. Initial attempts to heat the transmitter house failed, as electrical noise generated by the heater interfered with the transmitter control unit. Heat tape wrapped around the waveguide switches generated no noise, but its heat output was too low. Accordingly, the transmitter control unit was redesigned to improve its noise immunity.

2.6 December

In December, our data processing programs advanced to the point where time-averages could be calculated for any data from any storm and plotted on a digital plotter. These programs are summarized later in the report.

On December 21, the modified transmitter control unit was installed, permitting continuous heating of the transmitter house and eliminating the problem of frozen waveguide switches.

3. Computer Data Processing and Experiment Control

3.1 Introduction

A Raytheon PB-440 computer assisted by a special-purpose controller operates the experiment, acquires data, and does some preliminary processing before storing the results on paper tape. Information from the paper tape is transcribed to magnetic tape and then read into an IBM 370/155 system for high level processing. This chapter outlines the progress of the 440 system since the last report and describes the

present status of the 370 effort.

3.2 The Raytheon PB-440 System

3.2.1 Introduction

The previous report described the design philosophy and most of the operating hardware in the PB-440 system. This section describes three important programs now running which control the experiment, compress the incoming data, and convert the data to a decimal form (with the proper units) acceptable to the 370.

3.2.2 Experimental Control

The experimental control program maintains the system in the proper operating mode for current weather conditions and signal behavior. It operates as follows:

The clear weather operating mode is called mode 0, and in it the +45° transmitter channel operates continuously while the computer monitors the + to - cross polarization level and the +45° direct attenuation. Both receiver channels are sampled at 10 second intervals while wind velocity and transmitter power are sampled every 100 seconds. If the cross polarization level (in dB) changes by more than 2% or if one of the rain gauges reports precipitation, the system begins operating in mode 1. During mode 1 operation, transmission is sequenced at 4 second intervals from the + channel to the - channel and then to both channels. Receiver sampling occurs at 1 second intervals and wind velocity is sampled every 4 seconds. Mode 1 operation continues until the precipitation rate falls below 6 mm/hr or until the cross polarization level stabilizes. At this time, mode 2 operation is begun with transmitter switching at 10 second intervals and receiver and

wind sampling at 2 and 10 second intervals respectively. Mode 2 operation continues until the precipitation rate falls below 3 mm/hr. The system then enters mode 3 with transmitter switching at 100 second intervals and receiver and wind sampling at 10 and 100 second intervals respectively. When the precipitation rate falls below 2 mm/hr, the system reenters mode 0 operation.

3.2.3 Data Compression

When a new data point enters the computer, the program locates the last two values stored for that input. If the new value and the last value differ by more than 1% (this value can be changed by the programmer) the new value is stored. If the difference between the new value and the last value is less than 1%, the new value is compared with the next to last value. If these differ by more than 1%, the new value is stored in a new location; if the difference is less than 1%, the last value is discarded and the new value take its place. Under typical operating conditions this scheme provides a 20:1 compression of stored data.

3.2.4 Data Conversion

For all quantities except rain rate, data conversion is done by linear interpolation using calibration curves for the input in question. Each table contains 32 entries and the tables are updated each time the system is recalibrated. Rain rates are computed directly from the time intervals between trips and are accurate to within 3%.

3.3 IBM 370 Operations

3.3.1 Introduction

An IBM 370/155 computer program has been developed which processes, analyzes, and plots the accumulated data from a number of selected storms. These data are rain rates from each gauge plus quasi-instantaneous (i.e. short integration time) samples of the analog signals coming in during a storm. The latter are stored at essentially regular times while the intervals between successive rain gauge trips are random. Before data from different inputs can be compared the computer must generate a time-function representation for each data variable. These time functions can be averaged over appropriate time intervals to generate the average signal levels, rain rates, etc., required by steady-state theory.

3.3.2 Time-Function Generation

The computer constructs a table of values and entry times for each data input active during a given storm. For a given input channel we will call the times of entry t_i (where $t_i < t_{i+1}$) and the corresponding data points v_i. The computer must build a time function v(t) which will give the value of v at any time t.

Our current algorithm makes a simple step-function fit to the tabulated data points. For signal representation this method is not as accurate as a piecewise linear approximation, but it simplifies the numerical averaging that follows. Since the most frequently considered signal parameter in this report is a 15-second time average (to which about 15 data points contribute) the errors introduced by the step-function fit are minor. Later programs will incorporate a piecewise-

linear approximation for all data but rain rates; these are presumed constant between rain gauge trips.

To generate a value for v(t), the computer searches the data table for t_j such that $t_j \leq t < t_{j+1}$. If successful it makes $v(t) = v(t_j)$. If $t < t_1$ (the first data point in the table) the computer returns a zero for v(t). (This happens infrequently in the processing of anything but rain gauge data; for rain gauge data, the rate is zero before the first recorded trip). If t is greater than the last entry time, t_n, then the returned value is the last in the table, v_n.

3.3.3 Time Averaging

Time averages are generated by numerically averaging the time function values over a specified interval. The program in use will average for arbitrary starting and ending times; 1,5,15,30,60, and 120-second running averages around successive reference points one second apart are calculated routinely.

4. Data Presentation and Analysis

4.1 Introduction

During the period of this report data were collected for 19 storms. Of these 19, the 6 with the highest rain rates are discussed in the paragraphs which follow. Table 1 lists the dates of all observed storms and identifies with asterisks those to be analyzed. Table 2 lists the important parameters of the selected group.

The discussion which follows will deal almost exclusively with 15-second running averages of both rain rates and signal levels.

Table 1. Summary of Data for This Report Period

Storm	Date	Discussed Here
1	4 August 1972	*
2	17 August 1972	
3	17 August 1972	*
4	18 August 1972	
5	19 August 1972	
6	14 September 1972	
7	26 September 1972	
8	27 September 1972	
9	27 September 1972	
10	27 September 1972	
11	28 September 1972	
12	29 September 1972	
13	29 September 1972	*
14	4 October 1972	
15	5 October 1972	
16	24 October 1972	
17	27 October 1972	*
18	13 November 1972	*
19	14 November 1972	*

Table 2. Summary of Storms Discussed in This Report

Date	Local Starting Time	Local Ending Time	Storm Duration, Seconds	Peak Rain Rate Between Trips for any 1 Gauge	Peak 15-second Averaged Path Rain Rate, mm/hr.	Total Rain Accumulation, mm					Number of Retained Data Points										
						RG #1	RG #2	RG #3	RG #4	RG #5	RG #1	RG #2	RG #3	RG #4	RG #5	R + T +	R + T −	R + T ±	R − T +	R − T −	R − T ±
Aug. 4	15:42:13.4	16:04:13.0	1319.6	63.4	37.3	3.81	–	–	–	3.05	15	–	–	–	12	68	110	90	–	–	–
Aug. 17	19:46:56.0	20:50:31.2	3815.2	152.3	104.2	6.35	–	–	–	9.1	25	–	–	–	36	15	28	21	20	18	18
Sept. 29	22:54:46.2	23:55:36.8	3650.6	78.7	45.5	4.57	–	4.32	4.32	4.57	18	–	17	17	18	44	116	62	58	41	37
Oct. 27	22:30:11.8	22:41:38.8	687.0	38.7	26.0	1.52	1.27	1.78	1.78	1.52	6	5	7	7	6	12	55	117	59	132	6
Nov. 13	22:20:54.8	23:03:43.0	2568.2	26.4	16.6	2.03	2.03	2.29	2.29	1.78	8	8	9	9	7	7	79	27	155	26	2
Nov. 14	00:20:13.4	00:55:34.6	2121.2	40.8	32.7	8.11	8.88	8.37	9.14	7.61	32	35	33	36	30	2	112	11	50	5	3

Measurements must be averaged before they can be compared with present steady-state theory, but if the averaging time is too short, random fluctuations will be overemphasized and if it is too long, significant time variations will be suppressed. A preliminary screening of the data indicates that 15-second averaging times provide reasonable correlation between theory and experiment, so 15-second running averages were adopted for this report. The influence of averaging times on experimental results will be reconsidered later in the project.

4.2 Expected Behavior of the Data

The present model for predicting cross polarization levels has been presented in several forms (Oguchi, 1964) (Saunders, 1971) (Thomas, 1971), but basically it depends upon polarization-dependent attenuation of waves propagating through a population of non-spherical rain drops. The exact attenuation values are known only at a few frequencies, so theoretical predictions at most frequencies (ours included) involve extrapolation and interpolation.

If for our path and frequency we adopt Thomas's model of depolarization and Oguchi's attenuation values (interpolated to 17.65 GHz), we would expect depolarization to vary with rain rate as shown in Figure 1. This curve assumes +45° or -45° transmitted polarization incident on uncanted drops; canted drops would produce smaller but unequal cross polarization levels for the +45° and -45° cases. The waves with the direction of polarization toward which the minor axes of the drops are canted should depolarize the most.

Rainfall rate enters the differential attenuation model through

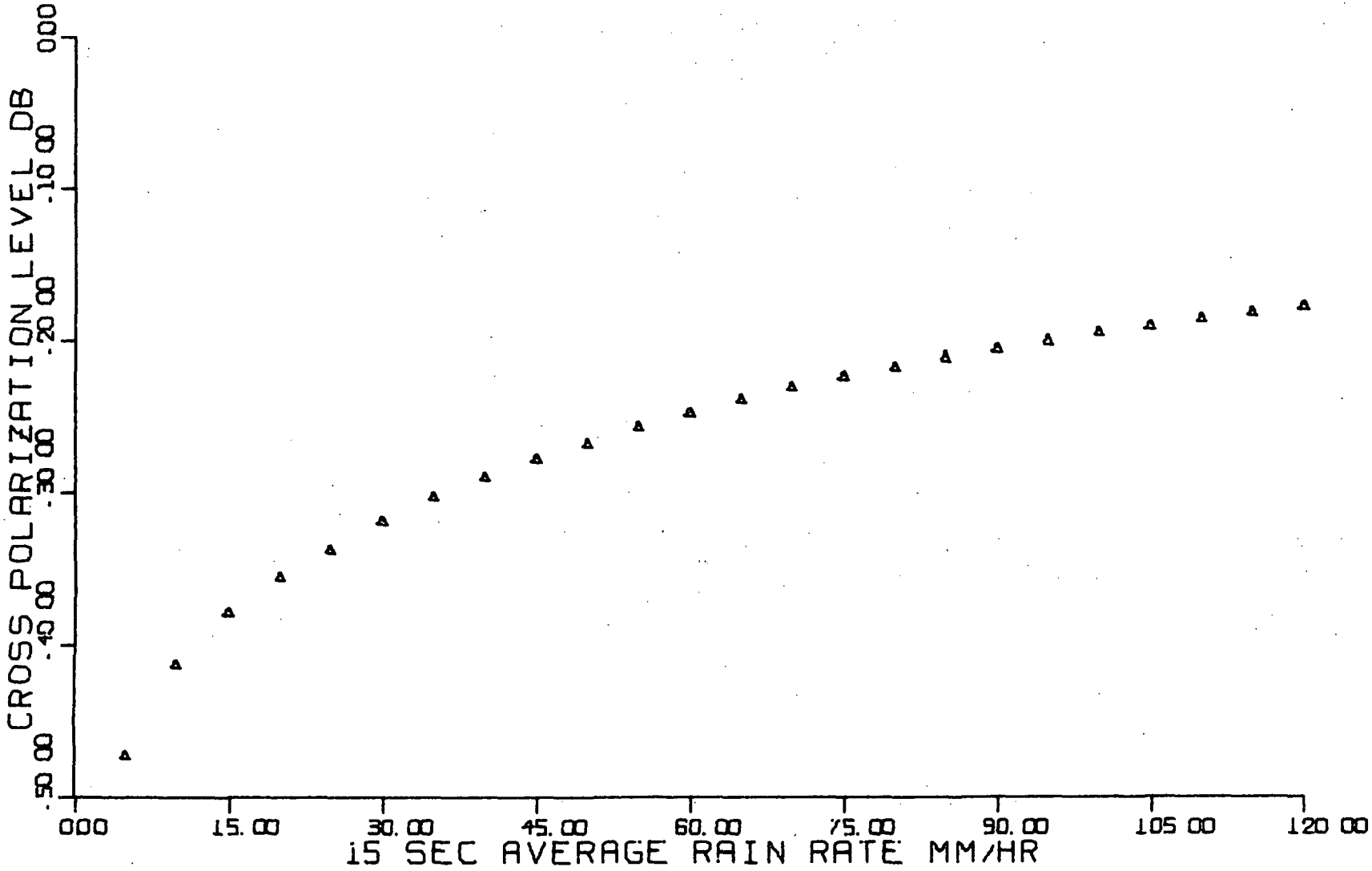

Figure 1. Theoretical depolarization for a 1.43 km path at 17.65 GHz.

the ratio of horizontal (for uncanted drops) to vertical attenuation, A_H/A_V. (The rainfall rate and the wind velocity do determine the average canting angle of a given drop population, but the mathematical dependence is unknown and will be ignored in this discussion.) If the attenuation coefficients for horizontal and vertical polarization are α_H and α_V dB/km respectively, then

$$A_H = e^{-\alpha_H L} \tag{1}$$

and

$$A_V = e^{-\alpha_V L} \tag{2}$$

where L is the path length in km.

For drops with canting angle ϕ (measured between the minor axis and the vertical) and waves polarized at an angle θ from the vertical, the cross polarization level in dB is given by

$$\mathrm{XPOL} = 20 \log_{10} \left| \frac{\sin(\theta-\phi)\cos(\theta-\phi)\left(\frac{A_H}{A_V} - 1\right)}{1 + \sin^2(\theta-\phi)\left(\frac{A_H}{A_V} - 1\right)} \right| \tag{3}$$

If the drops are uncanted (ϕ=0) and the incident waves have $\pm 45°$ polarization, the cross polarization level becomes

$$\mathrm{XPOL} = 20 \log_{10} \left| \frac{0.5\left(\frac{A_H}{A_V} - 1\right)}{1 + 0.5\left(\frac{A_H}{A_V} - 1\right)} \right| \tag{4}$$

As A_H/A_V approaches 1.0 (i.e. at low rain rates), the cross polarization level is quite sensitive to small changes in A_H/A_V, while for large A_H/A_V (high rain rates) the sensitivity is greatly reduced. For example, at R (rain rate) = 12.5 mm/hour, Oguchi's value of A_H/A_V is 1.02 and XPOL = -40.09 dB. A 1% decrease is A_H/A_V changes XPOL to -46.06 dB (a 5.97 dB decrease) while a 1% increase in A_H/A_V changes XPOL to -36.61 dB (a 3.48 dB increase). Thus if Oguchi's A_H/A_V were

correct to $\pm 1\%$ at R = 12.5 mm/hour, one could measure cross polarization levels anywhere from 5.97 dB below to 3.48 dB above the theoretical value. For a $\pm 2\%$ uncertainty in A_H/A_V, the R = 12.5 mm/hour cross polarization levels range from $-\infty$ dB ($A_H/A_V = 1.0$) to -34.07 dB ($A_H/A_V = 1.04$); measured values could lie anywhere below the theoretical curve and up to 6.02 dB above it. Since Oguchi's A_H/A_V values almost certainly are not accurate to $\pm 2\%$ for any rainfall rate and since the rainfall along a propagation path would almost never be homogeneous to within $\pm 2\%$, one should find considerable scatter in cross polarization measurements at low rain rates. Our data bear this out.

The situation improves at higher rain rates. For R = 100 mm/hour Oguchi's value of A_H/A_V is 1.24 and the corresponding cross polarization level is -19.40 dB. A $\pm 2\%$ uncertainty in A_H/A_V varies the cross polarization level from -20.25 dB to -18.64 dB, a spread of only -1.61 dB. This reduction in scatter at the higher rain rates is obvious both in our data and in that of other investigators. For further emphasis, Figure 2 displays the expected spread in predicted cross polarization levels versus rain rate for a $\pm 2\%$ uncertainty in A_H/A_V.

Some scatter in the experimental values is expected - particularly at low rain rates - and if the experience of other experimenters (Shimba and Morita, 1972) is typical, the trend of the measured cross polarization levels should be toward higher values than the theory predicts. Whether this is because Oguchi's attenuation values are low - as Thomas thinks (private communication) - remains to be seen. As the next section illustrates, our measured cross polarization levels are higher than expected.

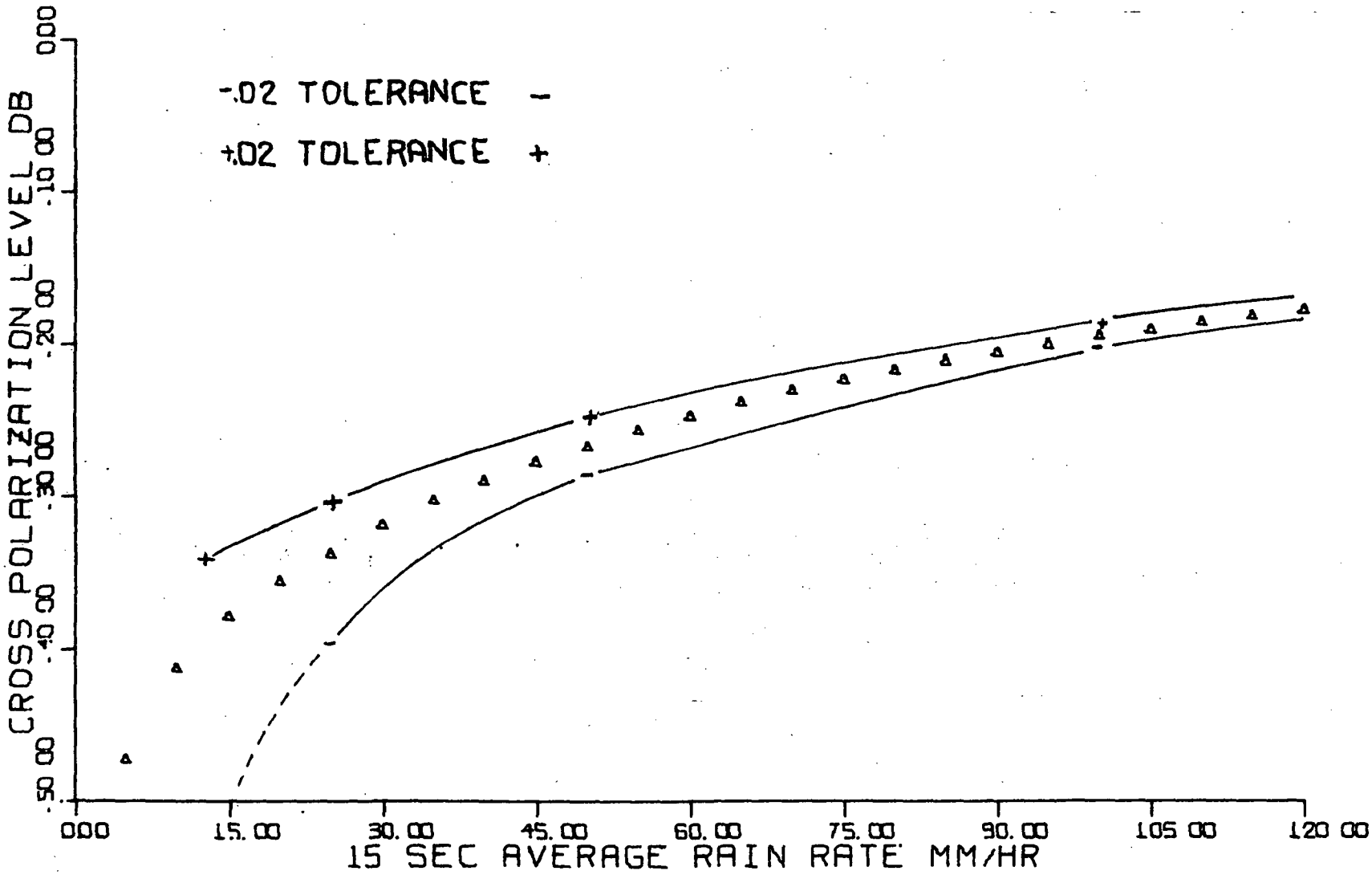

Figure 2. Variation of theoretical depolarization for a ±2% uncertainty in the ratio of horizontal to vertical attenuation.

4.3 Experimental Results

4.3.1 Storm of August 4, 1972

This storm was the first that we observed. Unfortunately the -45° polarized receiver channel was not working, so only data on +45° attenuation and on -45° to +45° cross polarization were taken. Rain rates were measured by two gauges, one at each end of the path. Figure 3 presents the results in terms of a time history of the storm. (All points plotted in this and subsequent curves represent 15-second running averages.) Some correlation between cross polarization level and rain rate is evident but the attenuation seems to be little affected by rain rate.

Figure 4 is a scatter plot of the cross polarization level versus rain rate. The points indicated by a triangle are the Oguchi predictions for our path. The plotted points are 15-second running averages taken at one second intervals. Since the expected scatter at low rain rates is large and since low tipping-bucket rain rates are not representative of the instantaneous rain rate, measured values for rain rates less than 10 mm/hour have been deleted from all scatter plots in this report.

The agreement between experimental and theoretical values in Figure 4 is remarkably close, particularly in view of the scatter predicted for a hypothetical $\pm 2\%$ uncertainty in Oguchi's theoretical A_H/A_V values. With only two rain gauges operating, the inaccuracy in the measured rain rates alone almost certainly exceeds $\pm 2\%$.

In Figure 5 the experimental cross polarization values falling within each 1 mm/hour increment of rain rate have been averaged and plotted to display the average results for the storm. Most points lie close to the theoretical curve.

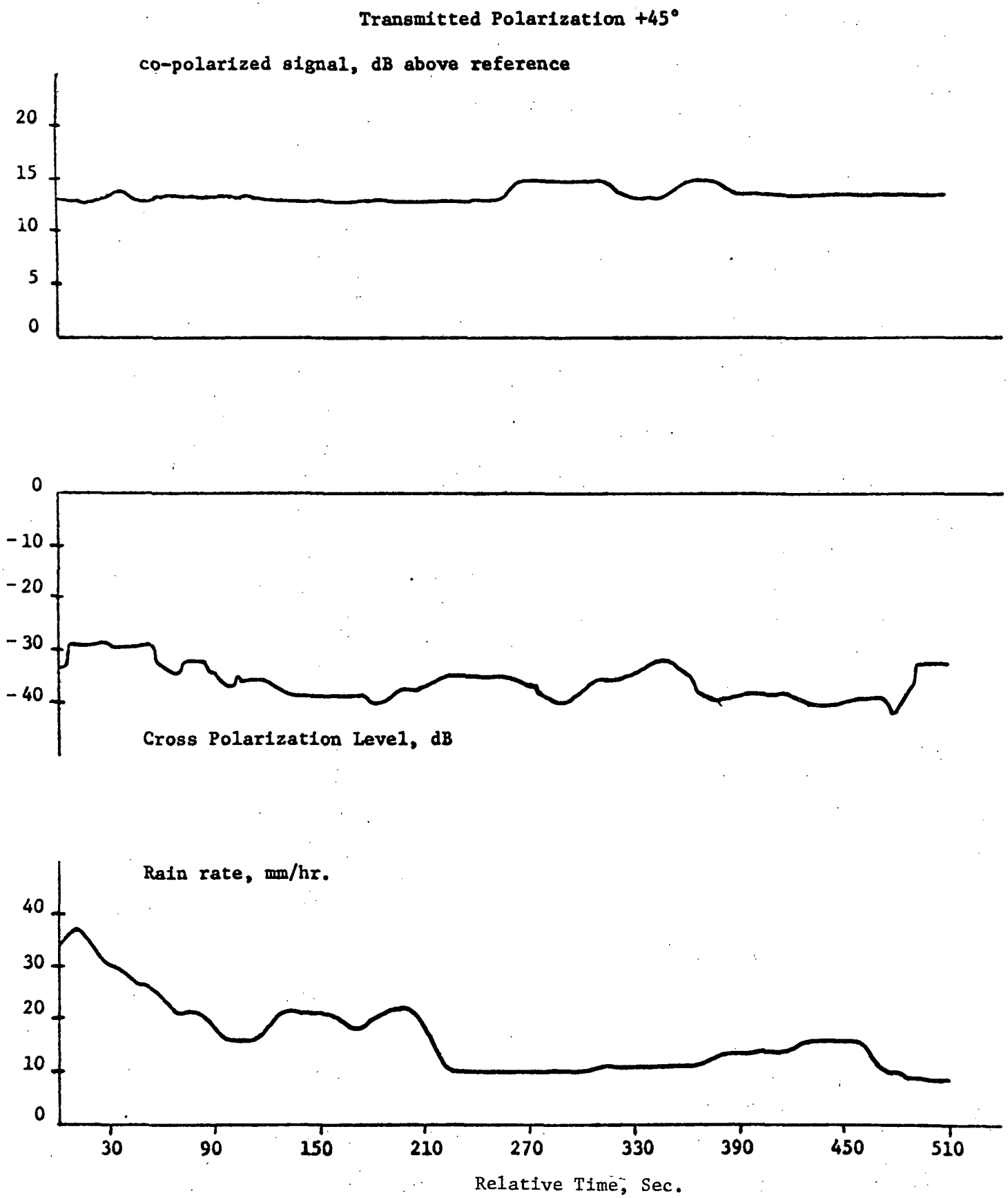

Figure 3. August 4, 1972, storm time history.

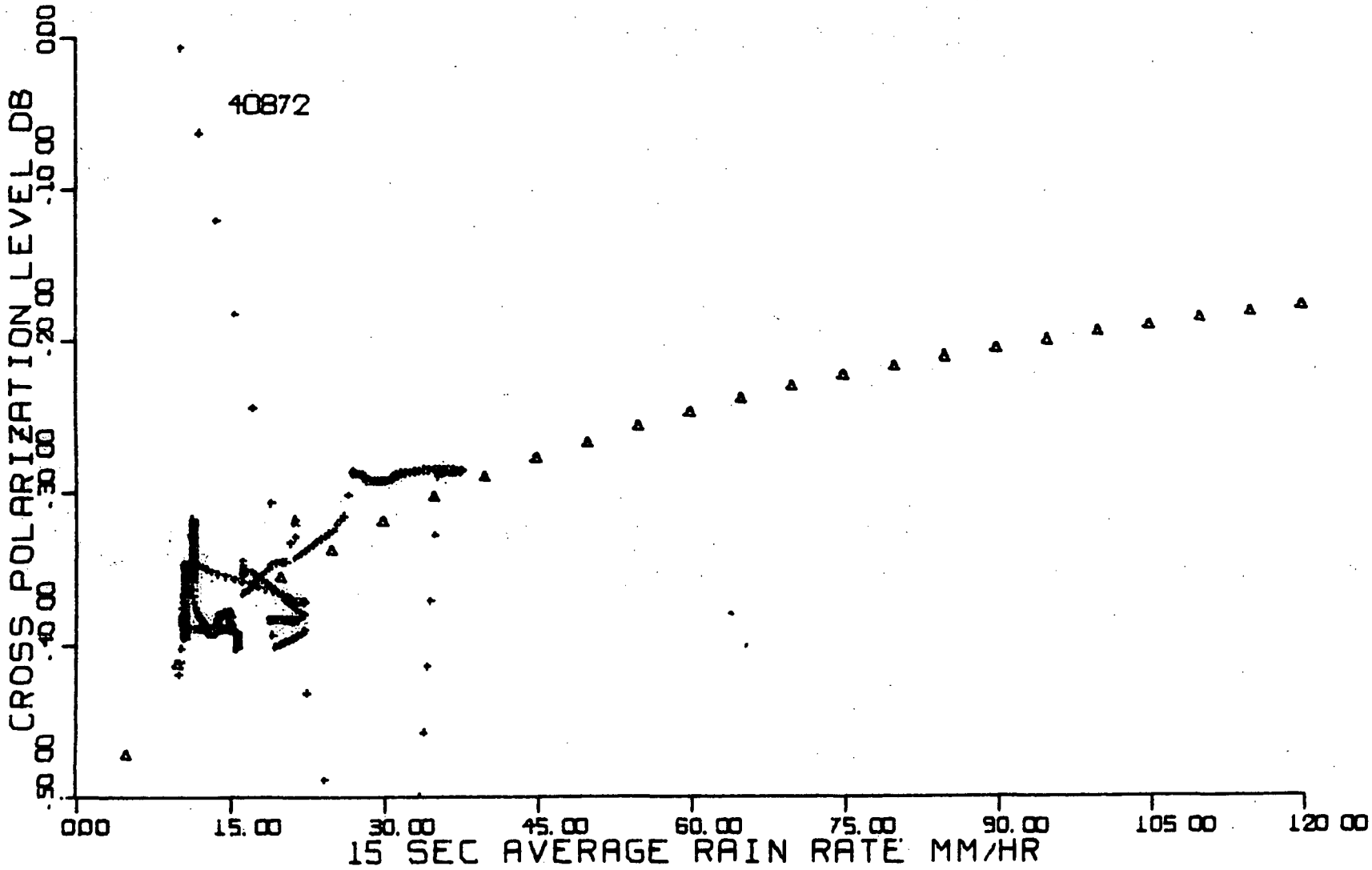

Figure 4. August 4, 1972, cross polarization scatter plot.

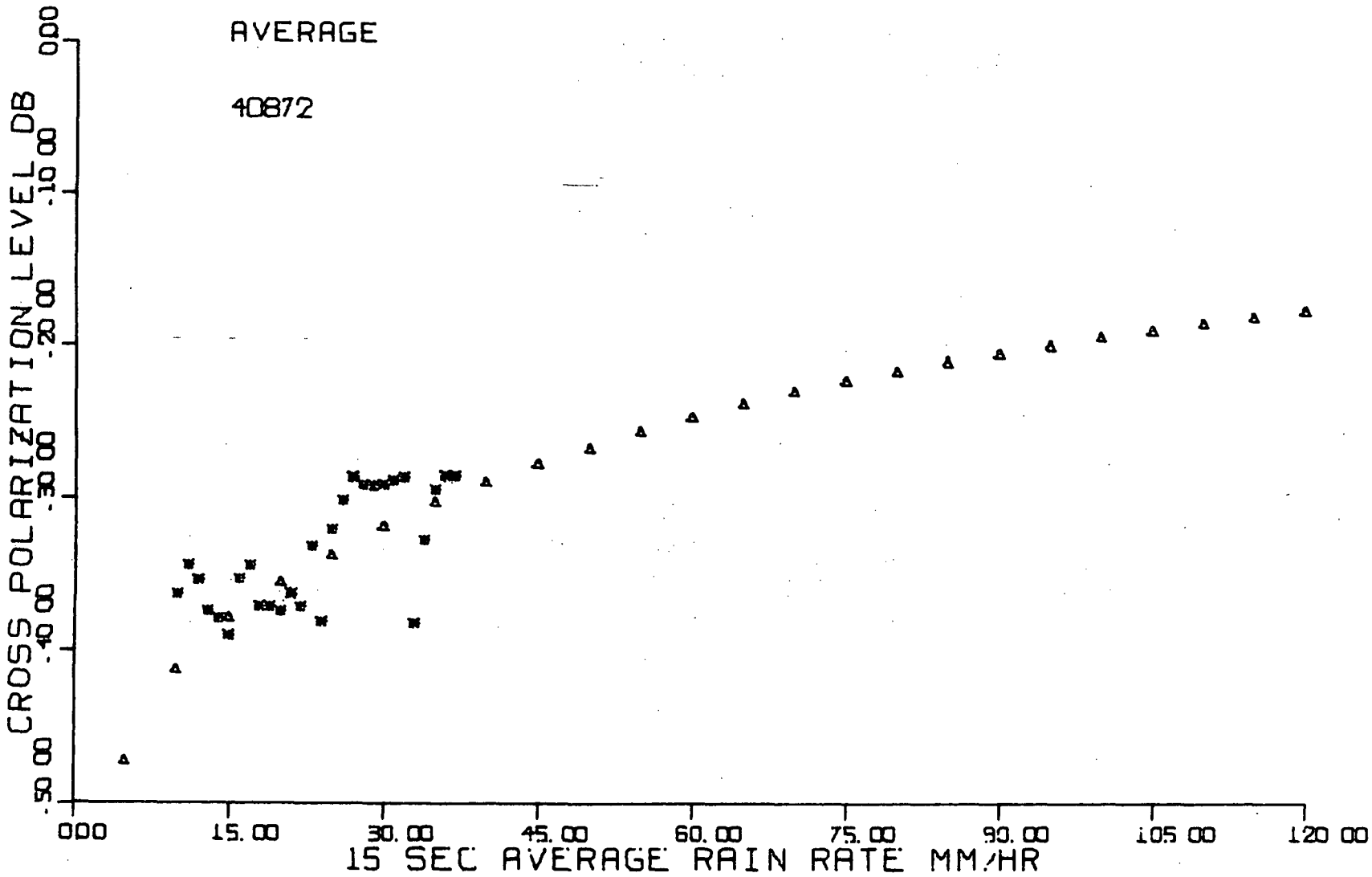

Figure 5. August 4, 1972, average cross polarization levels.

4.3.2 Storm of August 17, 1972

The second storm on this date provided more data than any other storm discussed in this report. Figure 6 displays the time history of the storm and indicates that the peak rain rate occurred about 5 minutes after the storm began. Both receiver channels were operating and the difference in rain attenuation for +45° and -45° polarization is evident. The identity of the strongest (less attenuated) polarization changed about 7 times during the storm, and there were several periods when the attenuation on one channel was about 1 dB less than on the other. This effect holds the promise of improving satellite system performance through polarization switching, but the degree of improvement to be expected on a satellite path cannot yet be predicted.

For most of the storm the +45° to -45° ("+ to -") and -45° to +45° ("- to +") cross polarization levels were unequal. This indicates that the drops were canted and that by current theory the canting was generally toward the +45° direction. Note that this effect is not reflected in the measured attenuations; a need for further refinement of the theory may be inferred.

Figure 7 is a one-point-per-second scatter plot of the depolarization level as a function of rain rate with + to - conversion shown as a | and - to + conversion shown as a +. Note the reduced scatter at high rain rates. The correlation between theory and experiment is more marked in Figure 8 where the points in the previous figure are averaged for each integer rain rate value.

4.3.3 Storm of September 29, 1972

This storm provided considerable cross polarization data, as

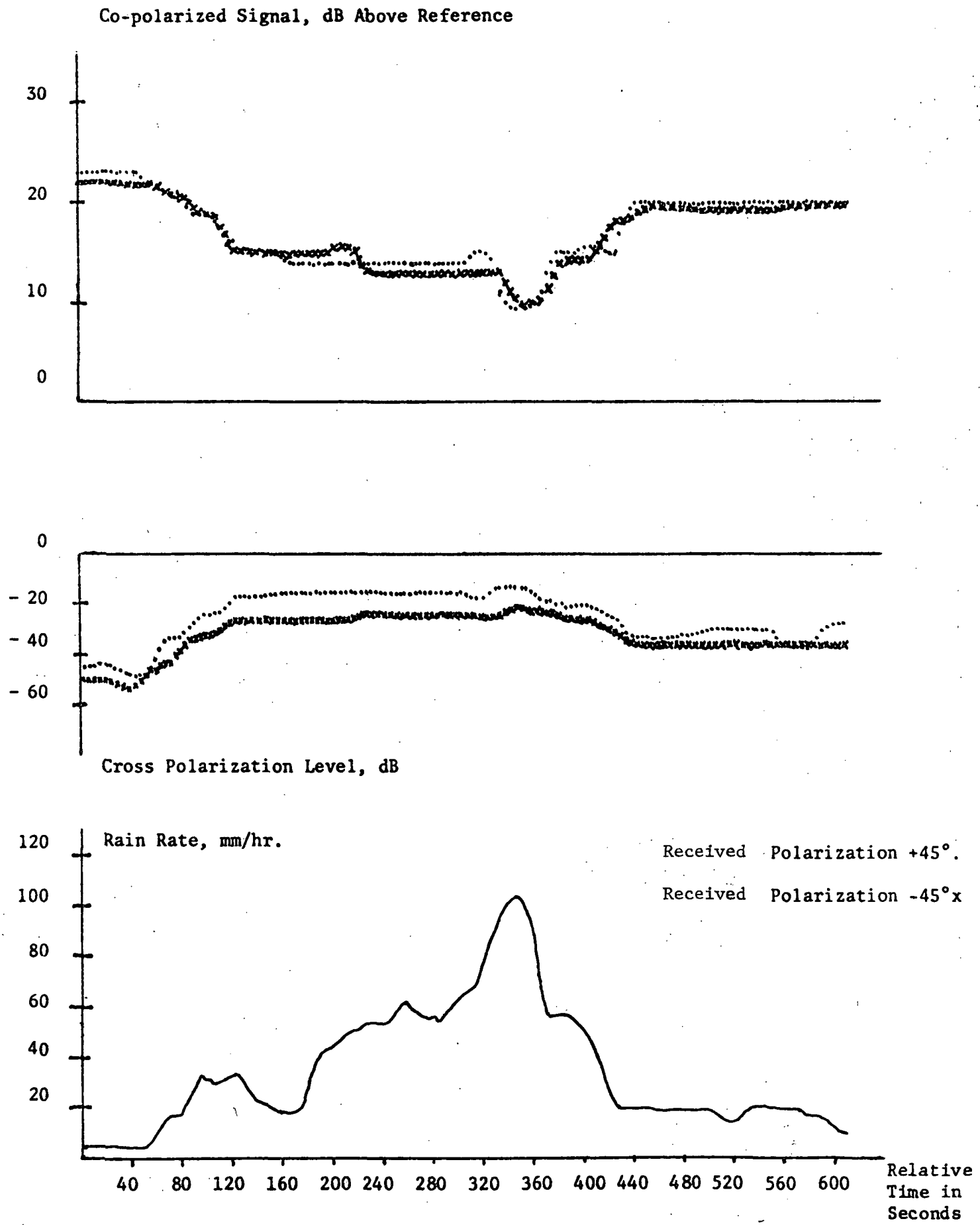

Figure 6. August 17, 1972, time history.

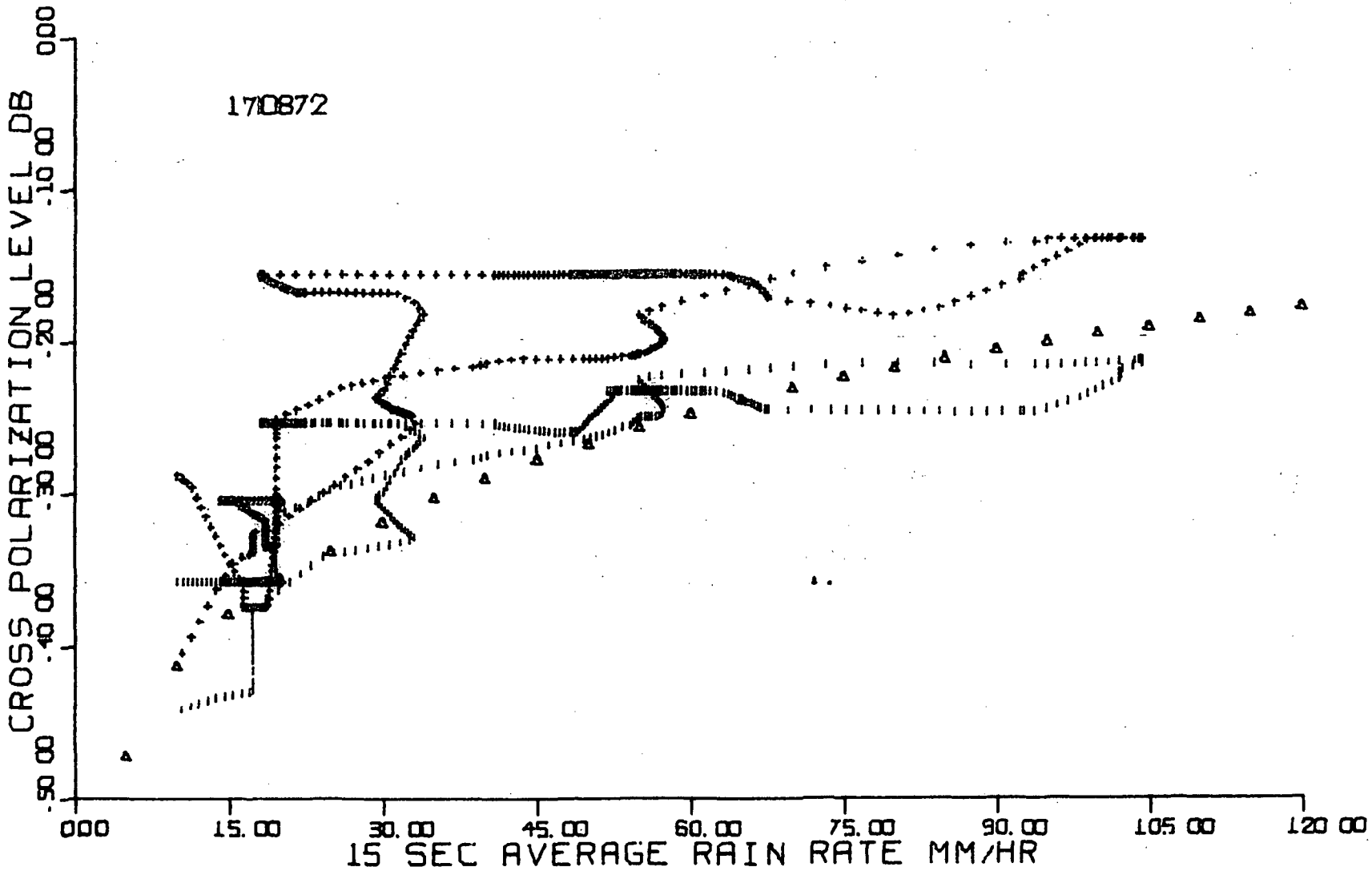

Figure 7. August 17, 1972, cross polarization scatter plot.

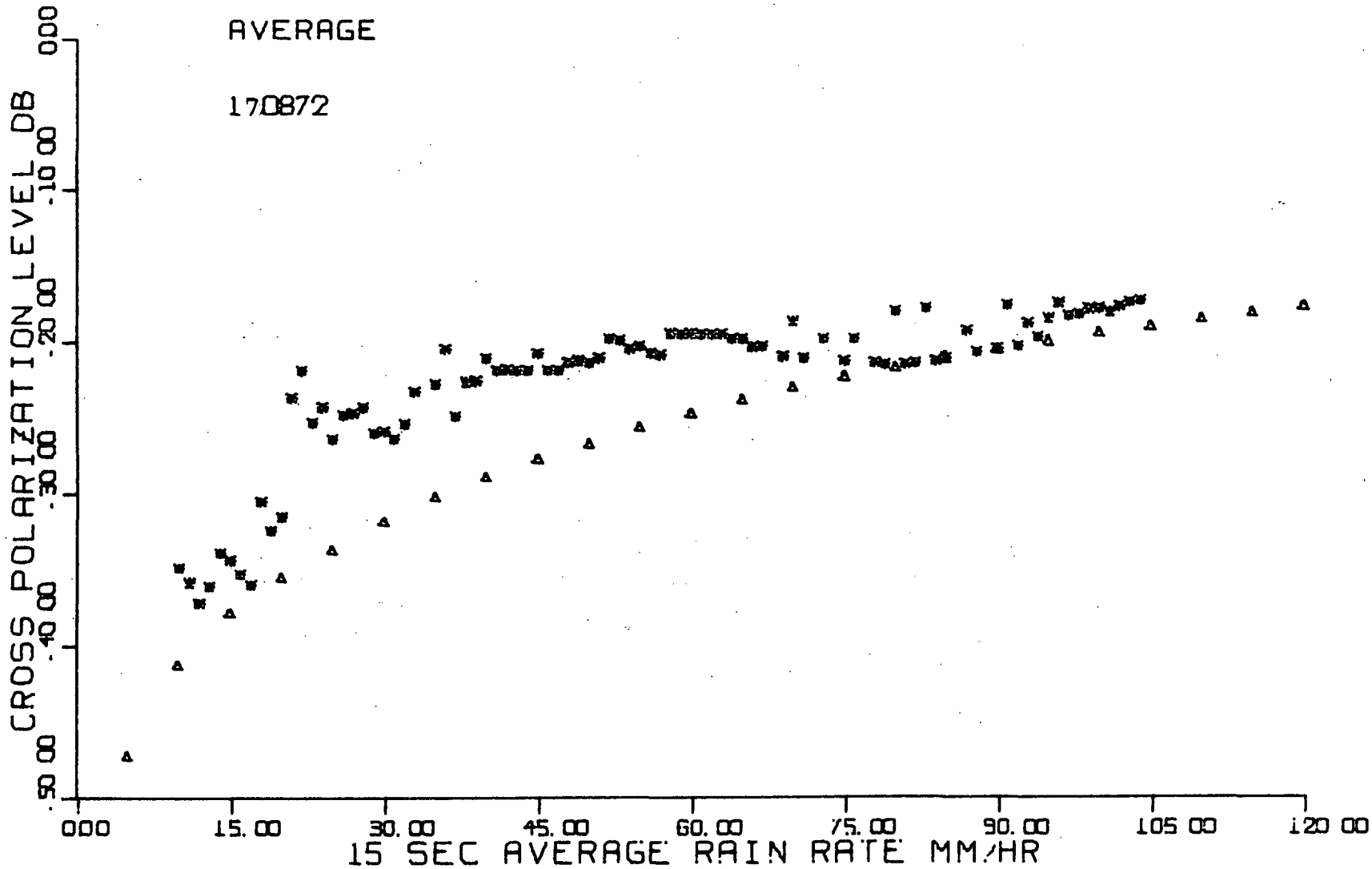

Figure 8. August 17, 1972, average cross polarization levels.

indicated on the scatter plot of Figure 9. The difference between the +45° and -45° cross polarization levels is striking and would seem to indicate rather pronounced canting. Note that the average depolarization as shown in Figure 10 generally agrees with the theoretical predictions.

4.3.4 Storm of October 27, 1972

This storm produced some rather surprising data; see Figure 11 for its time history. A period of intense rain came about 25 minutes after the start of the storm and was accompanied by extreme increases in cross polarization level and attenuation on both channels. These effects were displaced somewhat in time. Unfortunately the IBM 370 program halted prematurely and scheduling problems have precluded completing the curve in time for this report. Of considerable interest are the levels to which the direct and cross polarized signals returned at the end of the rain.

With no other information than the direct signal level, one might wonder if the equipment were operating correctly. The behavior of the cross polarization levels in the scatter plot of Figure 12 and the average plot of Figure 13 indicates that it was functioning normally, as the measured cross polarization levels agree well with those of the other storms presented. The time variation of attenuation during this storm remains to be explained.

4.3.5 Storm of November 13, 1972

Figures 14 and 15 show the scatter and the average values of cross polarization level as a function of rain rate.

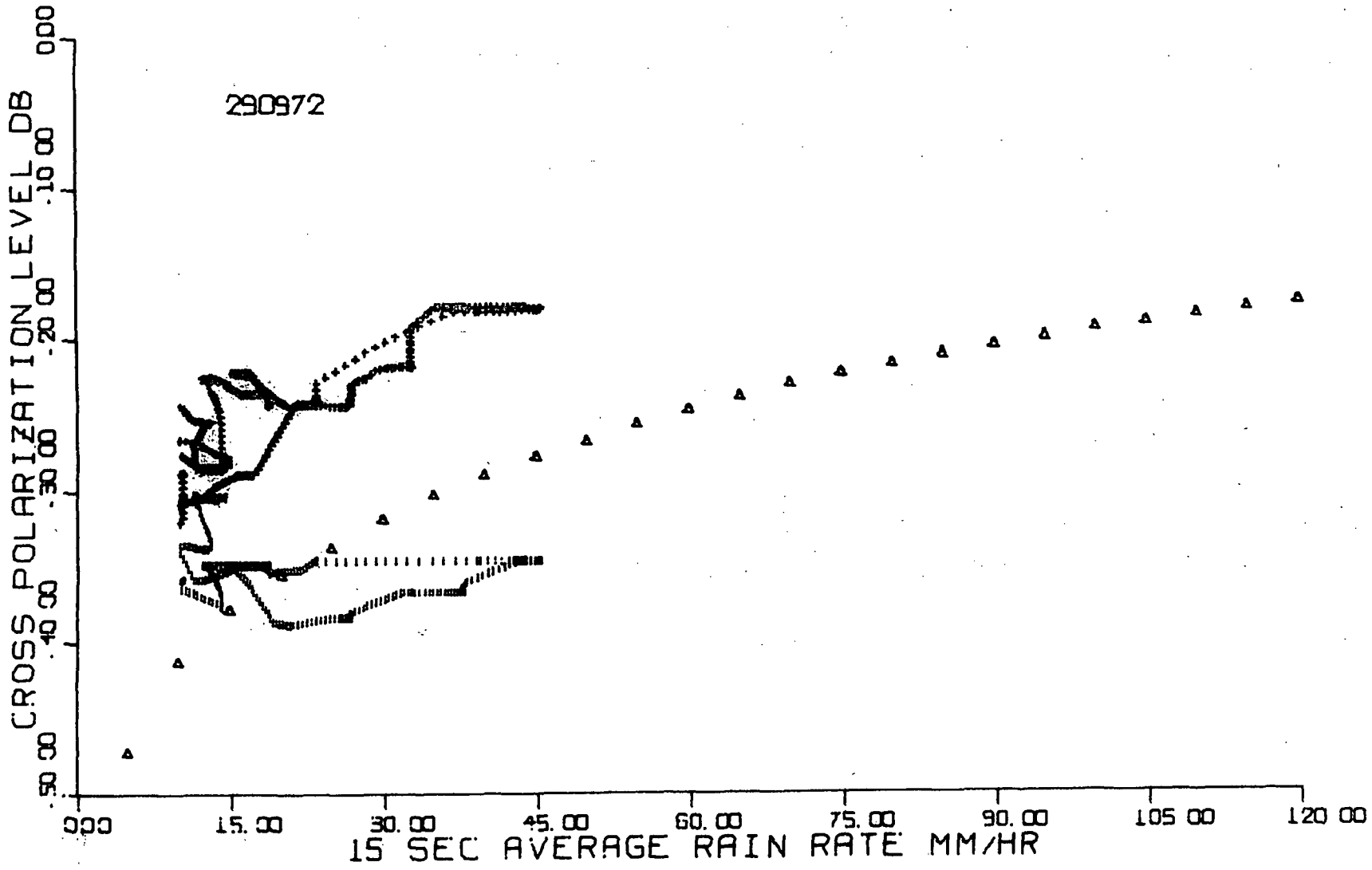

Figure 9. September 29, 1972, cross polarization scatter plot.

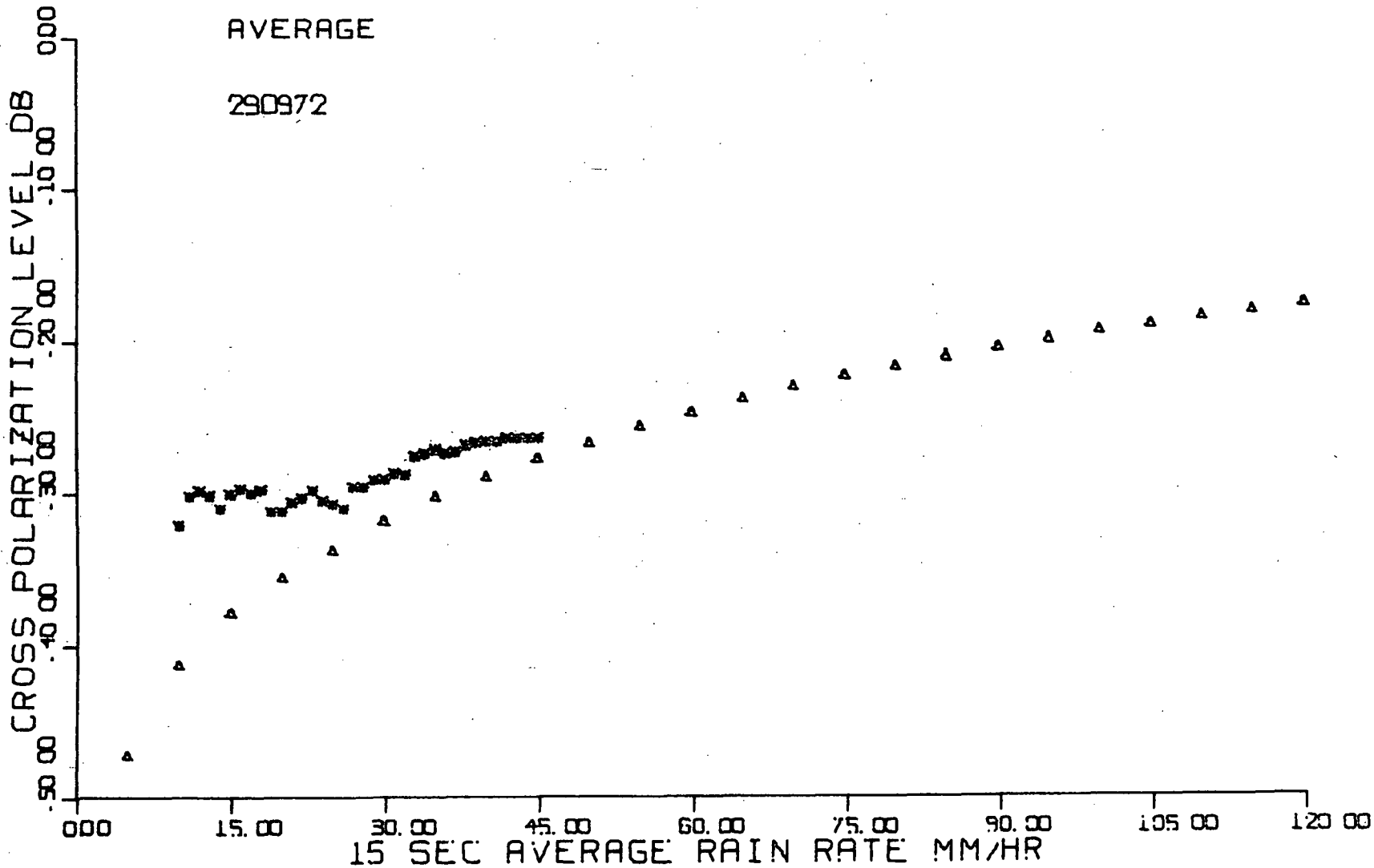

Figure 10. September 29, 1972, average cross polarization levels.

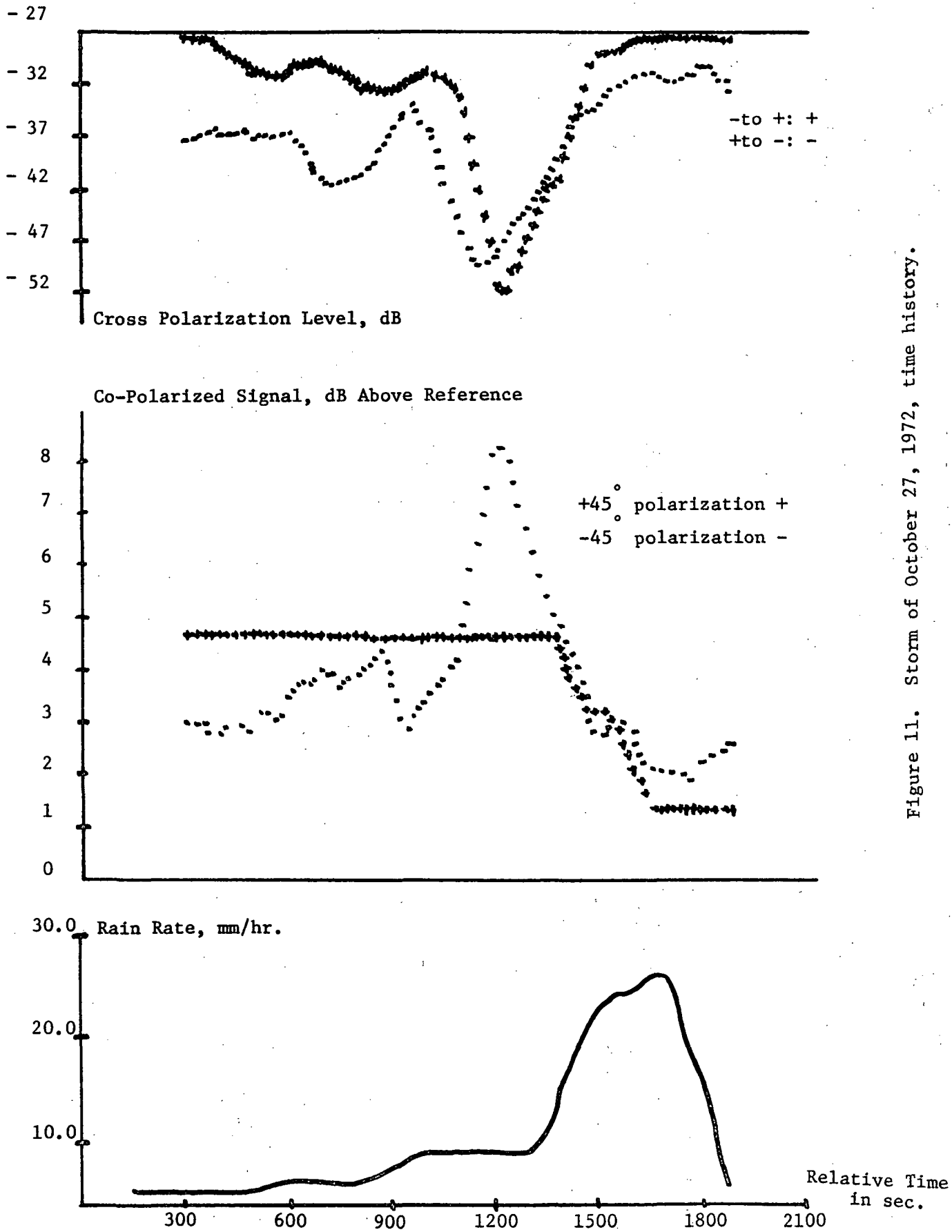

Figure 11. Storm of October 27, 1972, time history.

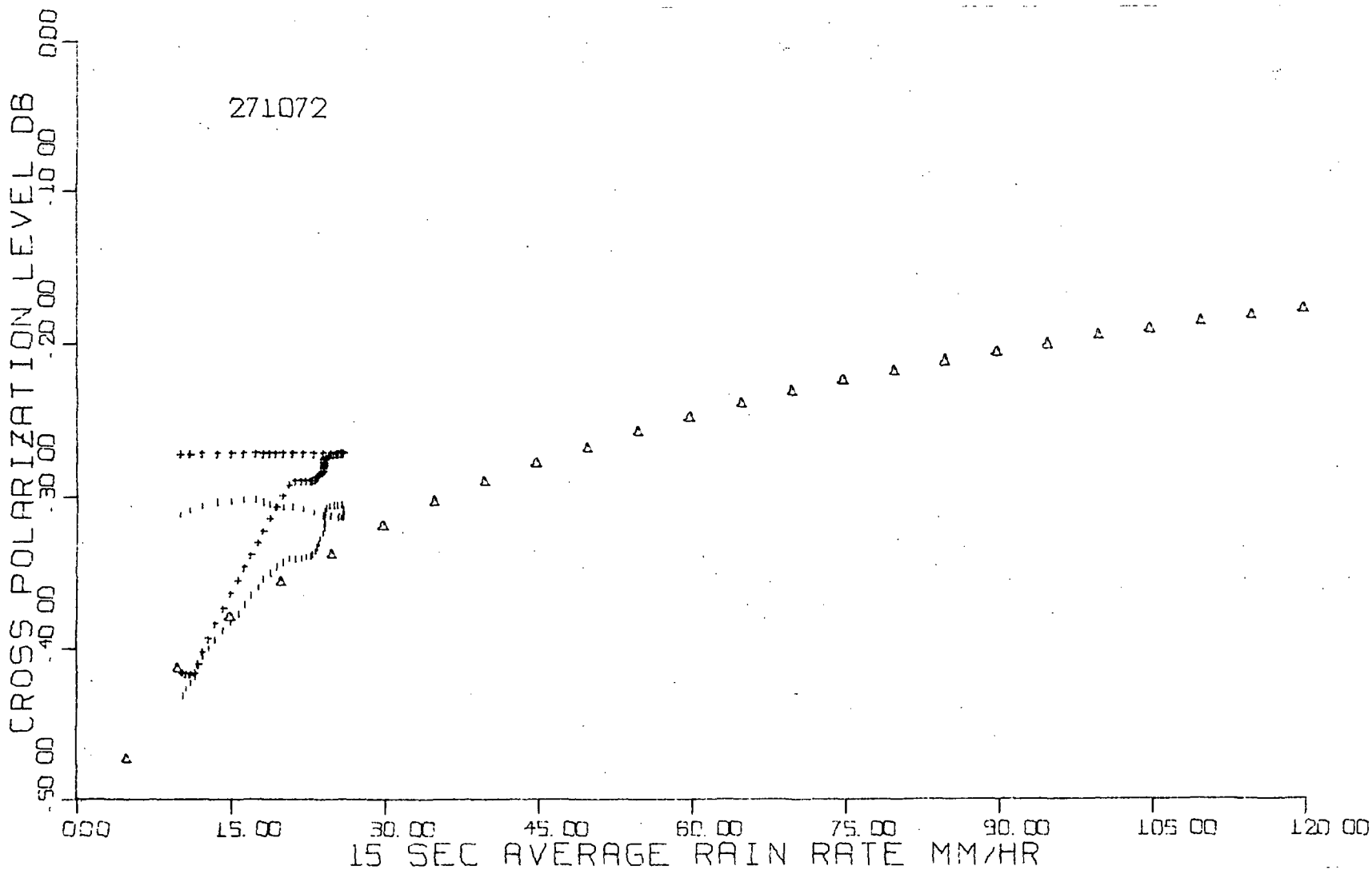

Figure 12. October 27, 1972, cross polarization scatter plot.

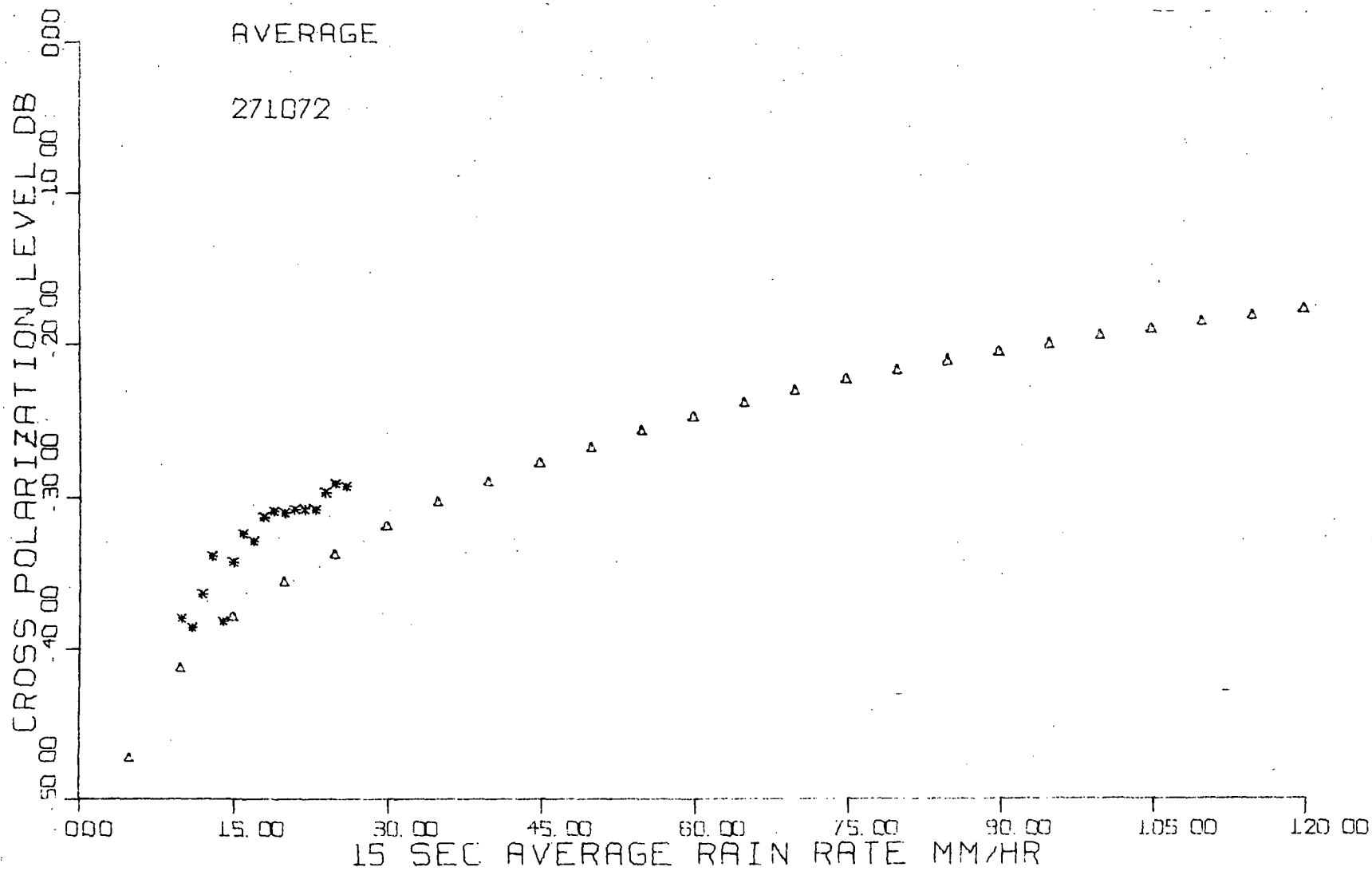

Figure 13. October 27, 1972, average cross polarization levels.

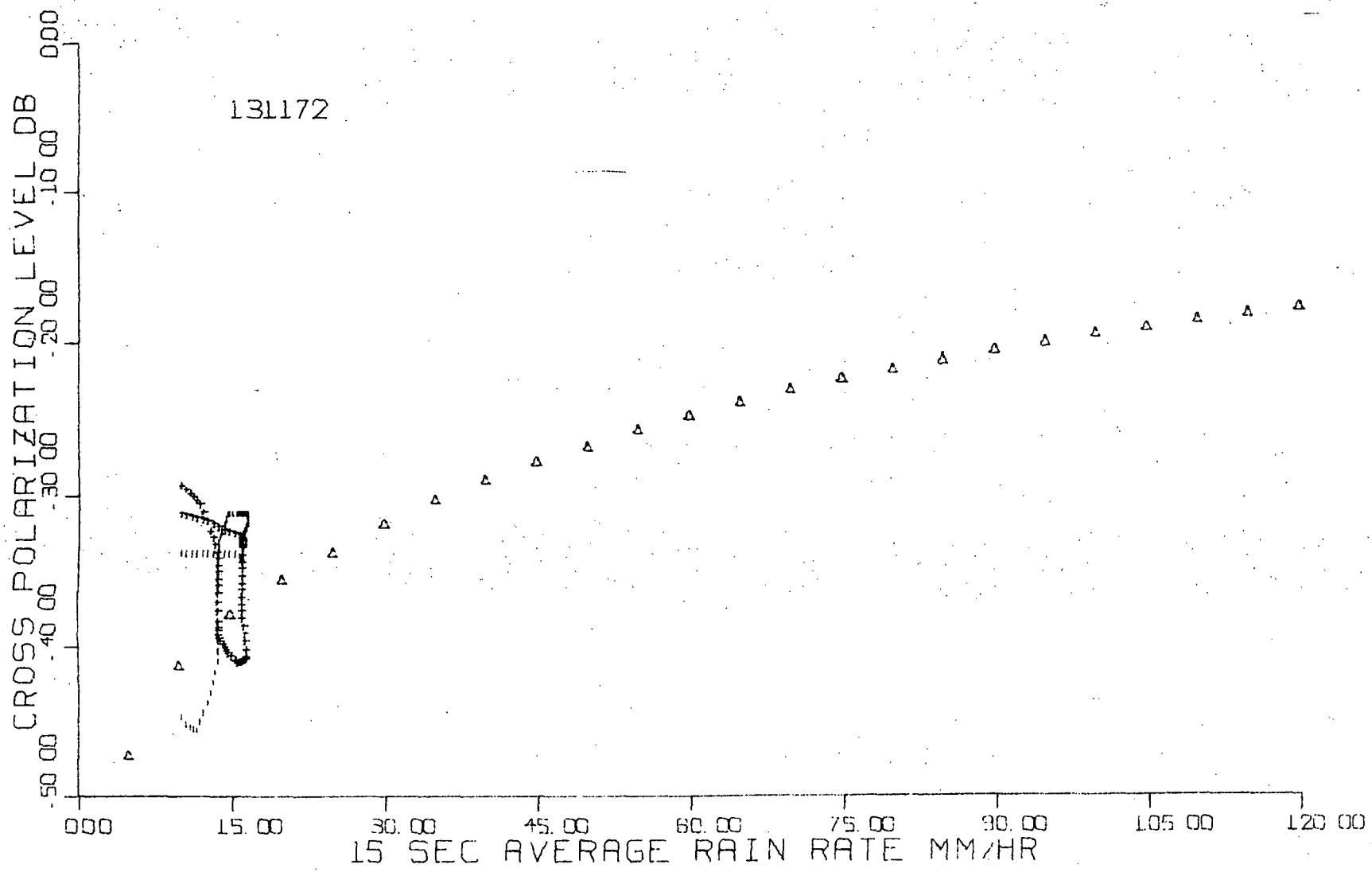

Figure 14. November 13, 1972, cross polarization scatter plot.

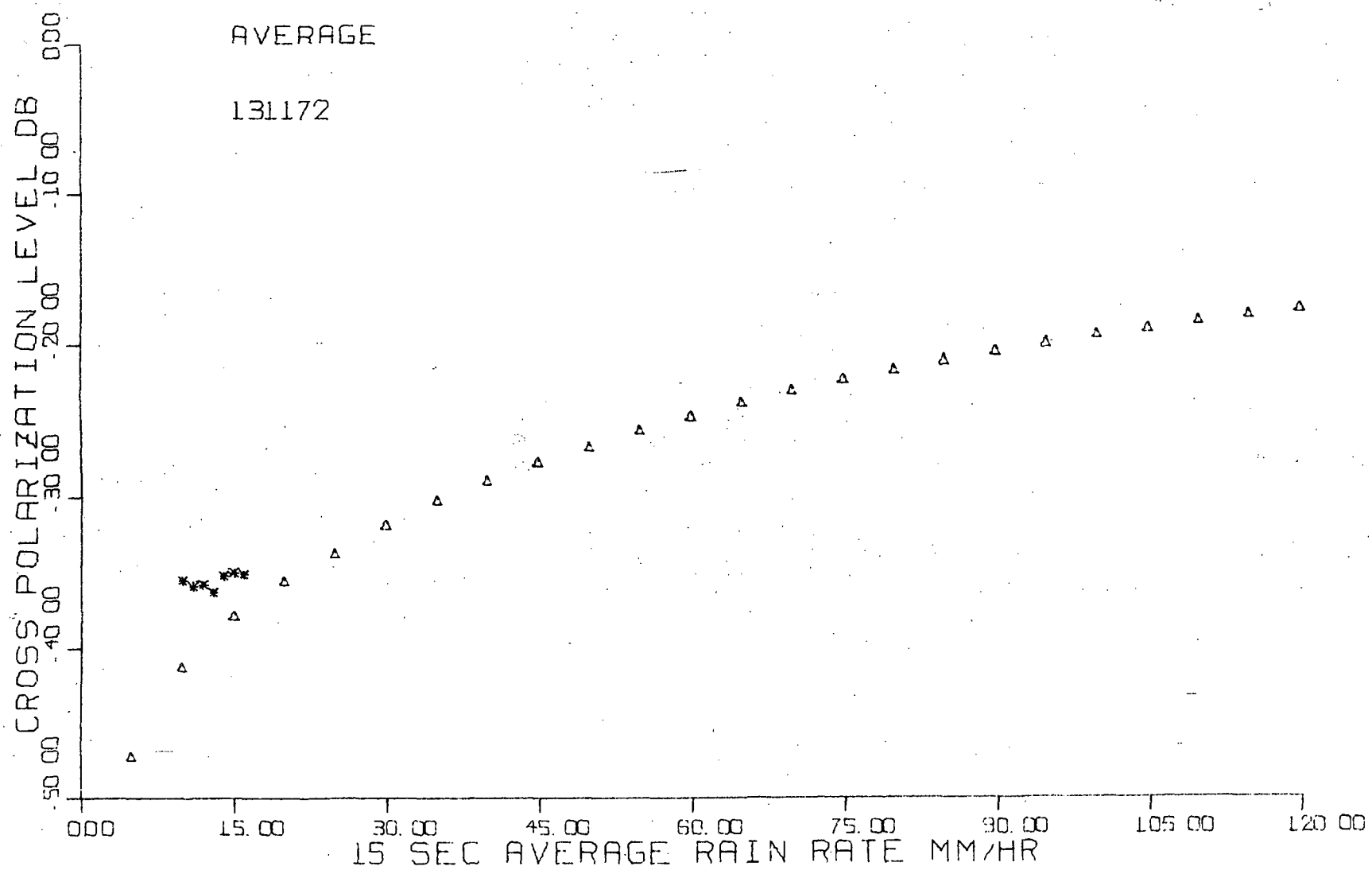

Figure 15. November 13, 1972, average cross polarization levels.

4.3.6 Storm of November 14, 1972

Data from this storm are displayed in Figures 16 and 17.

4.4 Conclusions

Figure 18 is a composite scatter plot which includes all of the cross polarization levels presented in this report. Figure 19 shows 6 storm average - to + depolarization for each integer rain rate and Figure 20 is a similar plot lumping - to + and + to - levels. The values in Figure 20 are heavily biased by the storm of November 14 (see page 5). The agreement with theory is generally good, but particularly at low rain rates the theory predicts values which are too low. This is significant, because an operating communications system will encounter low rain rates much more frequently than very high ones. The need for further experimentation and more exact theory is obvious.

5. Theoretical Investigation

The experimental results presented in the previous chapter underscore the need for an accurate theoretical model to predict the amount of depolarization at a given rain rate. The model must include both frequency and wind effects and to be most useful it should be applicable to signals scattered in any direction.

There are two approaches to the problem - the stochastic and the deterministic - and both are under investigation. The deterministic model first requires the solution for scattering by a single raindrop; this is really the problem of a plane wave incident on a lossy dielectric oblate spheroid, and it has never been solved exactly. The low-frequency approximation available in the literature (Stevenson, 1953)

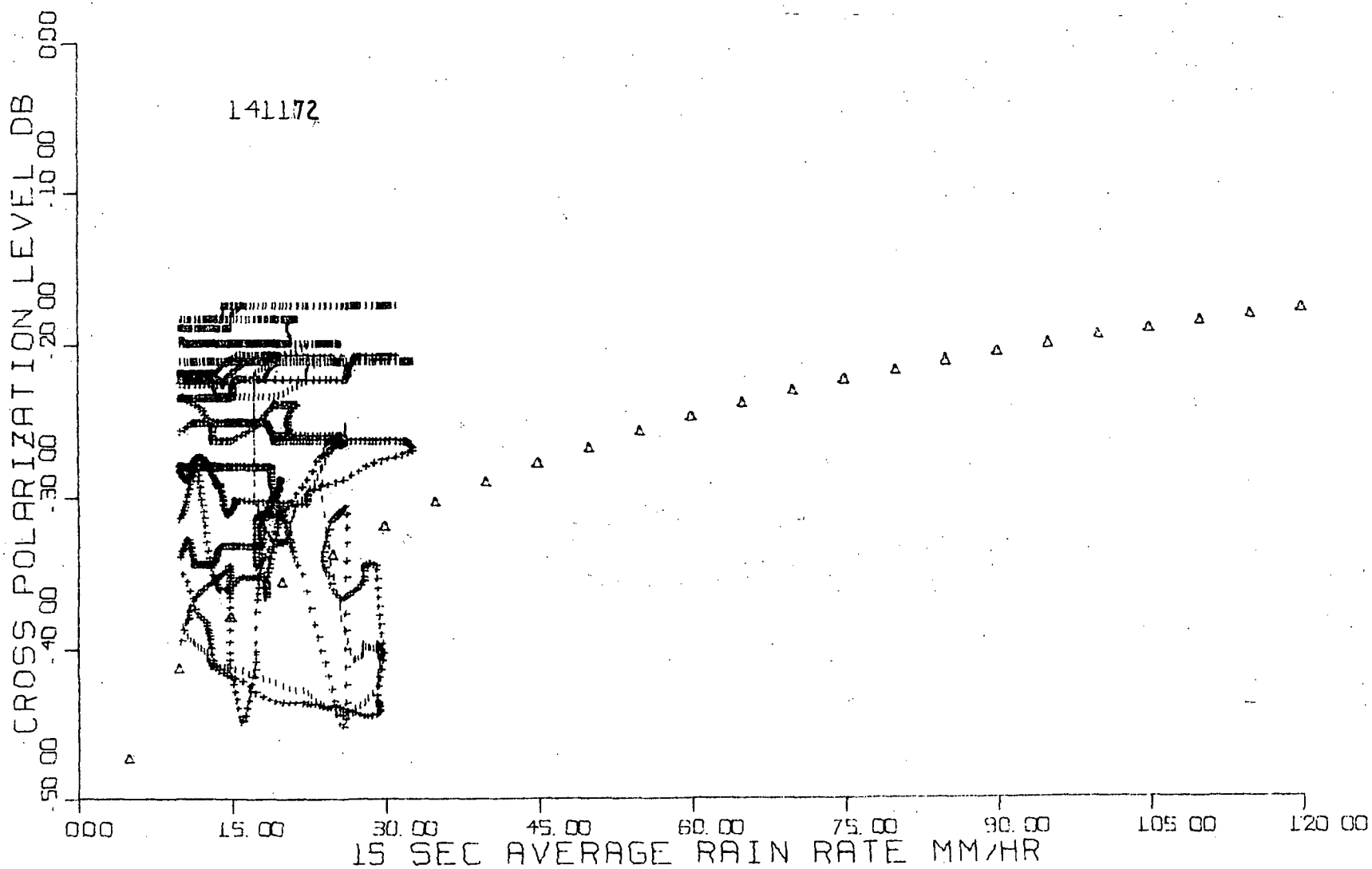

Figure 16. November 14, 1972, cross polarization scatter plot.

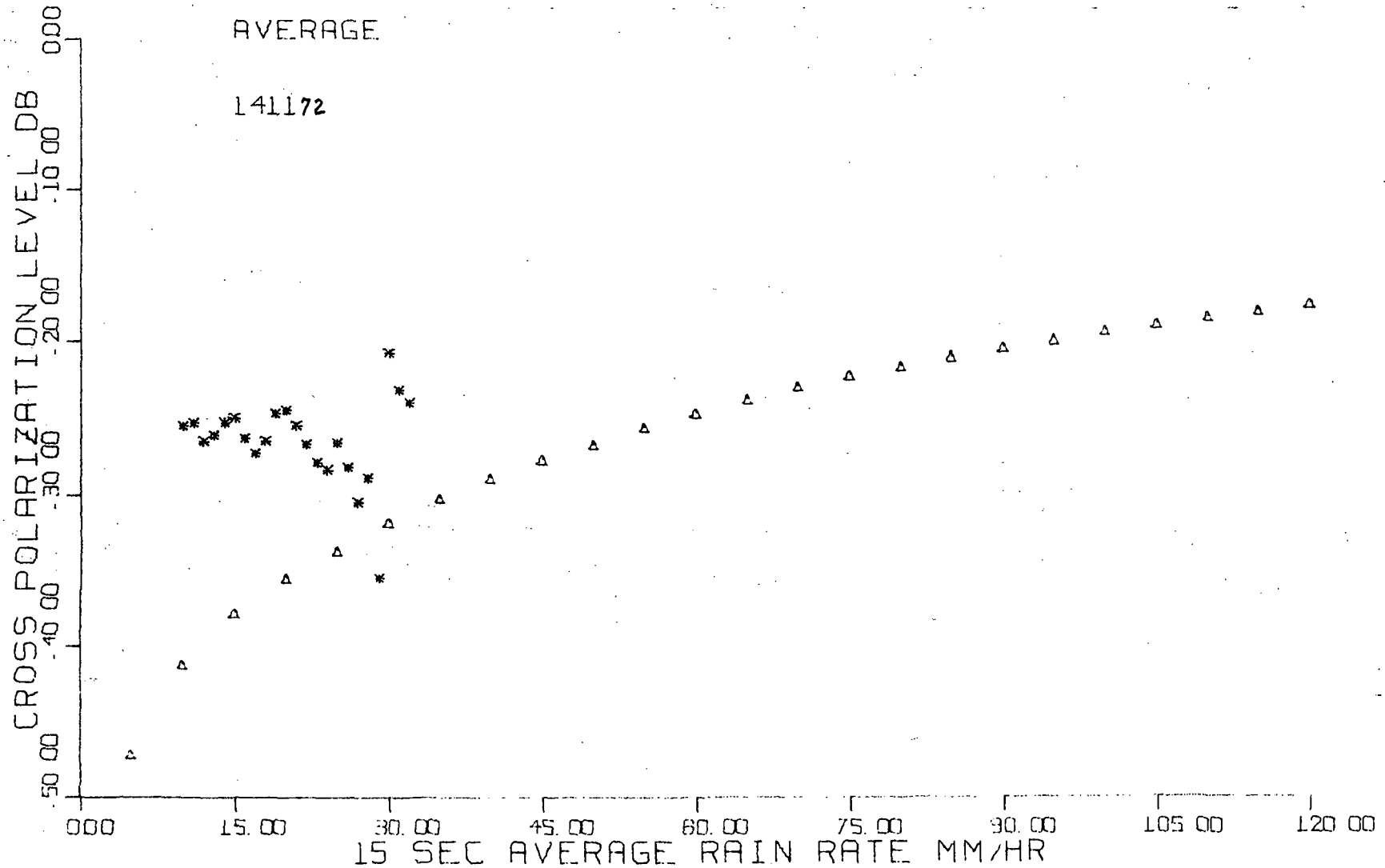

Figure 17. November 14, 1972, average cross polarization levels.

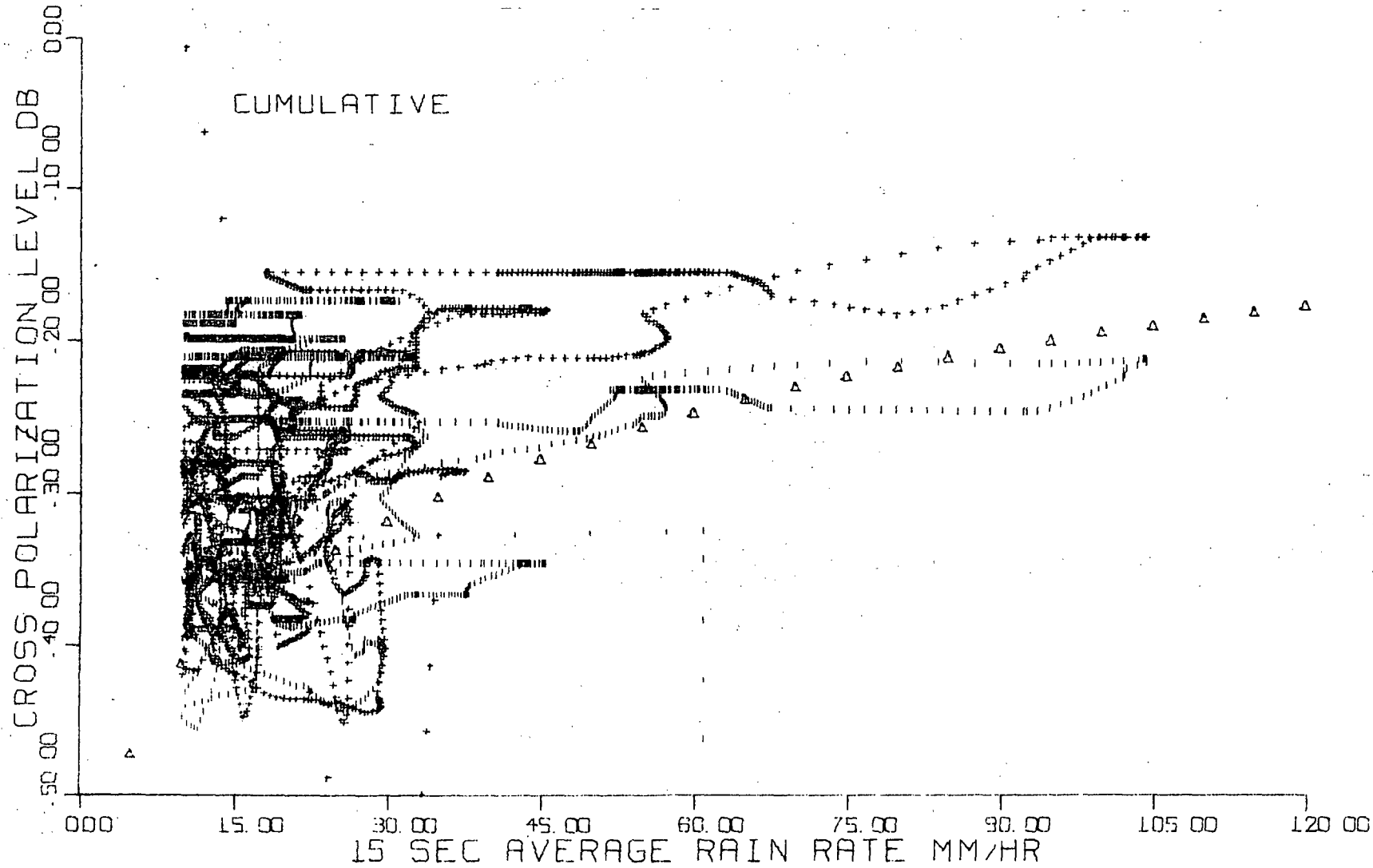

Figure 18. Composite cross polarization scatter plot.

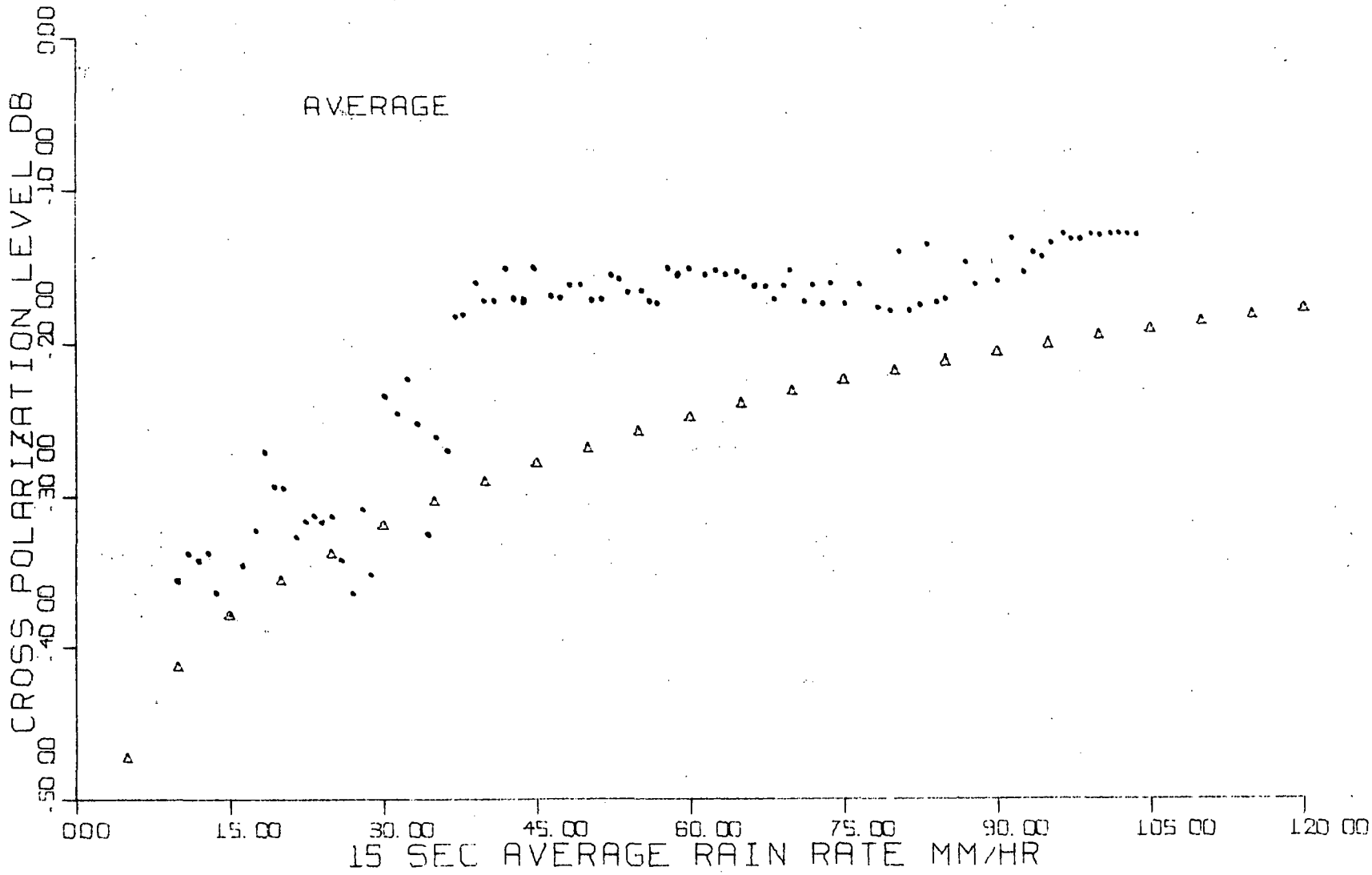

Figure19. Average - to + cross polarization levels for the 6 storms reported.

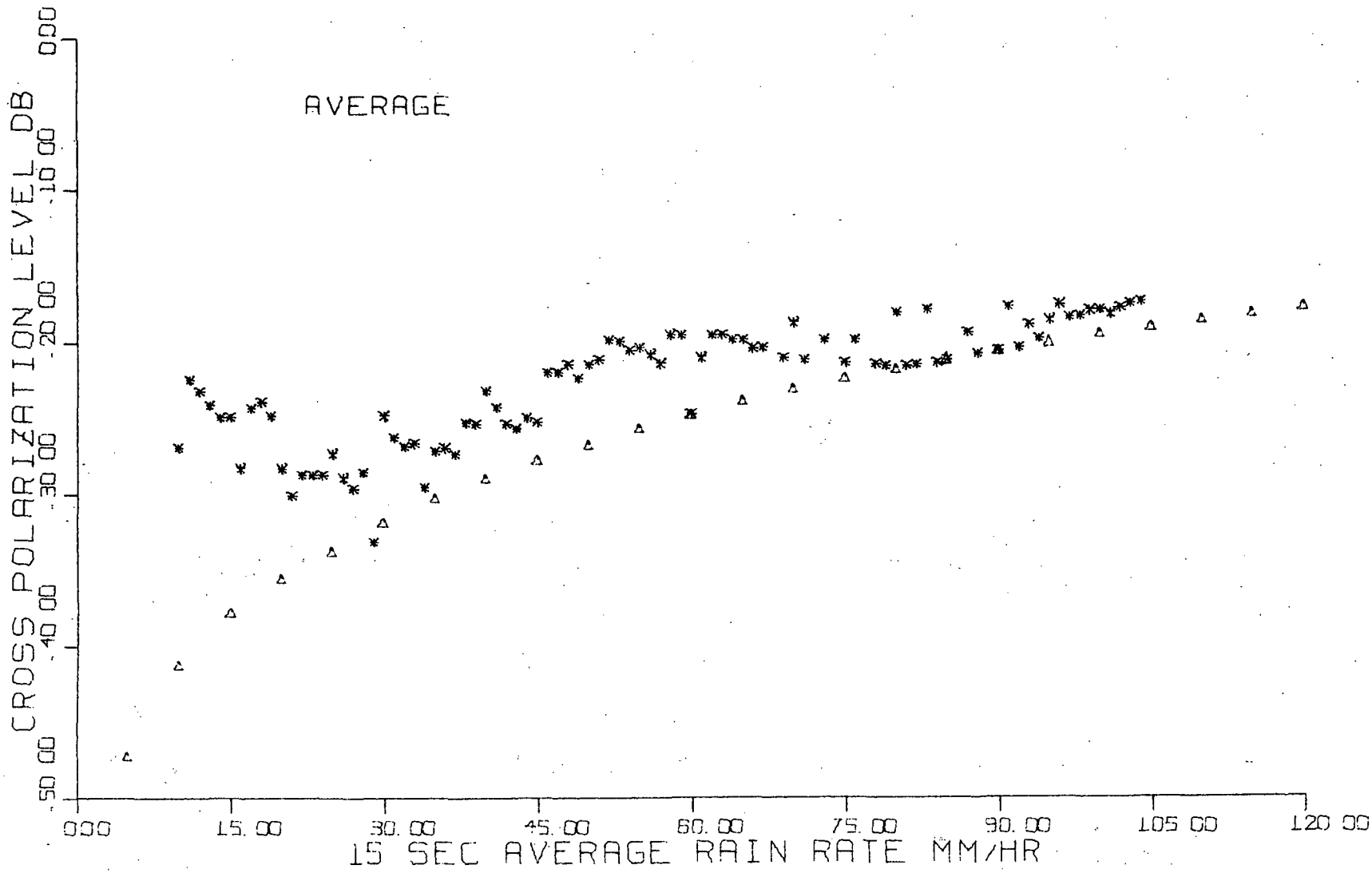

Figure 20. Overall average + to - and - to + cross polarization levels for the 6 storms reported.

involves a two term series representation with each term requiring many calculations. The first term gives Rayleigh-type scattering and is sufficient to approximate the scattered field amplitude. The phase of the scattered field is very important in attenuation calculations, but the phase given by the first term alone is highly inaccurate. We are currently investigating the effect of including the second term. After the single-drop problem is solved the real rain situation - an ensemble of drops - must be attacked.

A stochastic solution is also possible and may be pursued. This treats rain as a random medium and seeks the expected values of the scattered fields.

6. Antenna Vibrations and Signal Fluctuations

Nearby machinery causes the wall on which our receiving antenna is mounted to vibrate, and we are investigating the influence that these vibrations may have on our data. A time-domain study has been completed and a comparison of the antenna vibration frequency spectrum with the frequency spectra of the receiver outputs is planned.

Both receiver outputs are taken from identical logarithmic video amplifiers which pass undistorted all signals with rise times of 0.1 microseconds or less. These circuits normally drive the analog to digital converter through a voice-grade telephone line and a .04 second RC integrator; the telephone lines and the integrator suppress some of the scintillations in the received signal.

To make a worst-case analysis of the existing situation, we removed the telephone lines and connected a 2 kHz bandwidth Honeywell Visicorder to the receiver output. To eliminate DC saturation of the

Visicorder a 200 microfarad blocking capacitor was placed in series with the instrument. The co-polarized and cross-polarized receiver signals were both recorded at chart speeds of 50 and 10 inches per second. The original records were forwarded to NASA; since their low contrast precludes Xerox reproduction, they do not appear in this report.

The principal features of the cross polarized signal were a 120 Hz component modulated by a 15 Hz signal, the composite waveform having a peak-to-peak swing of about 0.025 volts. Our nominal cross polarized signal level is about 1 volt, so that in the worst case noise represents about 2.5% of the unfiltered cross polarized signal level.

The co-polarized signal exhibited a 60 Hz ripple of about 0.009 volts superimposed on a nominal 2.5 volt signal level. Hence the noise component of the unfiltered co-polarized signal is about .0036%.

Whether the noise observed in the receiver output represents antenna vibrations, transmitter or receiver power supply hum, or extraneous 60 Hz pickup somewhere in the receiver is at present unknown. We intend to attach an accelerometer to the receiving antenna and compare a spectral analysis of its output voltage to the receiver output spectrum. This will confirm or eliminate the antenna vibrations as a noise source. Whatever the source of the residual noise in the receiving system, the noise at worst represents less than ±2.5% of the recorded signal levels and this is well within the expected accuracy of the overall experiment. Under clear-weather conditions our data compression program (see page 7) indicates that after filtering cross polarized signal fluctuations in excess of 1% are infrequent.

7. Literature Cited

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