ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN
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FINAL REPORT

ANALYSIS OF TEST DATA FILM GENERATED BY THE LUNAR SOUNDER (S-209)

FEBRUARY 1973

SUBMITTED BY
NORMAN MASSEY

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INTRODUCTION

This contract was issued by the NASA Manned Spacecraft Center to the Regents of The University of Michigan for the purpose of analyzing test data films generated by the Lunar Sounder Equipment (S-209). The Michigan facility was operated as an independent diagnostic center for the purposes of this program. The basic instrument used for these diagnoses was the Precision Optical Processor (POP).

The Lunar Sounder experiment was a part of the Apollo 17 scientific package and its goal was to examine the lunar surface at three different radar frequencies, VHF (2 meters), HF_1 (60 meters), and HF_2 (20 meters). In order to evaluate the design and to assess the readiness of the Apollo 17 radar equipment, a number of test films were made on the Lunar Sounder System over a ten month period. The final film was made only a few days before the launch. These films were analyzed at the Willow Run facility of the University of Michigan and a report on each film prepared and distributed upon completion of the analysis. These reports consisted of three basic parts. First was an introductory section used to outline the purpose of the test, list the descriptive information received with the film and detail the physical defects, if any, of the film when received. Next was the main body of the report which detailed the experiments used for the analysis. Each experiment was described and all results given, with all necessary supporting documentation. The third and final section gives the conculsions reached after analysis and the recommendations made for future work. In addition to issuing the report for each film, the important results and recommendations were presented via oral report to the key parties as test results became available.

TECHNICAL DISCUSSION

One or more optical tests were used on each film analyzed. The various available tests were:

1. Visual Examination:

Each test film was examined for gross physical defects, such as fogging, static discharge, mutilation, mottling, etc.

2. Exposure Level:

This test was used to determine the average bias level which was modulated by the incoming radar signal. This test measures the specular data film transmission and comparison is made to the incident data film light level so as to establish an amplitude transmission level. These levels were then compared to the previous results and the optimum levels as predicted by MSC computer predictions.

3. Diffraction Efficiency:

The amount of energy diffracted into a single sideband was measured and compared to the energy incident on the film. This is the diffraction efficiency of the film and is related to the modulation(signal amplitude) level of the signal and the system modulation transfer function(MTF). These tests were used to look for gain level changes or recorder defocusing which would effect MTF.

4. Sidelobe Measurements:

The objective of this test was to measure the sidelobe levels of the test signals after using $\text{sinc}^2(\ )$ weighting filters in the frequency plane. On some of the early films the desired weighting filters were not yet available and a triangular weighting was applied at the film plane. This gives a rough approximation to $\text{sinc}^2(\ )$ weighting in the frequency plane. This approximation technique was used with films number 100 and 101 and initially on film number 102. Beginning with film number 102, useable weighting filters became available and reports on later films include sidelobe scans of the weighted test signals when appropriate. This test was also used to evaluate the half power width of the central pulse. This measure gives a value for the RF or doppler bandwidth.

5. Visual Analysis of Test Signals within the Optical Processor:

By examining the compressed test signals through a microscope, it is often possible to see directly various recorder or radar problems, such as phase shifts, coherent noise patterns, improper triggering, film drive instability, etc.

6. Frequency Plane Analysis:

A single spherical lens was used to take a Fourier Transform of the film data so as to present a visual display of frequency and amplitude effects present on the signal film. Such effects as coherent noise, signal drive jitter, extraneous electronic signals, etc. were displayed and often photographed for insertion into the test reports. This analysis was performed with nearly all films.

7. PRF Scans:

A very useful method for analyzing the mechanical stability of the recorder film drive is examination of the PRF spectrum. With a perfect film drive, the grating formed by the sweep lines (PRF pulses) of the CRT trace will yield a diffraction limited spot after Fourier analysis in an optical system. Any deviation or errors in the film drive will cause this spot to spread or change position as a function of input film position. By scanning the PRF spot a qualitative judgement can be made about the quality of the film drive.

8. Harmonic Levels:

The harmonic level is the ratio of the energy in the second harmonic to that in the fundamental order. Depending on the form of the test signal, it was measured in one of two ways. For sine wave inputs it was possible to isolate and measure the fundamental and harmonic signals in the frequency plane. For chirped test signals, the undiffracted light and one side order was removed at the frequency plane and auxiliary optics were used to focus the fundamental and second harmonic. Where possible harmonic levels were normally measured for all three frequency channels (HF_1, HF_2 and VHF).

9. Noise Measurements:

Noise measurements were typically made using the appropriate bandwidths for each frequency channel. These are important measurements when comparing the effect of film noise for different recording films. Also the coherent noise present in the VHF channel was measured and estimates of its effect on the subsequent flight data were made

10. Linearity:

In order to maintain linearity through the Lunar Sounder System, it is necessary that the amplitude transmission of the output film be a linear function of input voltage. This was checked by inserting a constant voltage signal into the recorder and then changing the voltage in a stepwise manner. The result is a bias level step wedge on film. The amplitude transmission for each step on this film is then measured in the optical processor and plotted as a function of input voltage. These results were then used to determine the proper bias level setting and to determine the linear operating range of the recorder.

11. Dynamic Range:

The dynamic range is defined as the ratio of the strongest recorded linear signal to the weakest detectable signal. The weakest signal is usually limited by the film noise. These values can be measured in the optical processor and the linear dynamic range of the recording system determined. This was done with certain test films during this program.

12. Symmetry of Unweighted Test Signals:

The unweighted chirp pulse can be scanned to detect phase errors in the radiated signal form. This was frequently done early in the program in an attempt to get the chirp generation network improved and to achieve a more symmetric signal. Since the theoretical calculations for the results of applying $\text{sinc}^2(\ )$ weighting to the data assume no phase errors, it was felt that such asymmetry could be a source of potential difficulty.

13. Modulation Transfer Function:

The frequency plane of the optical processor can be scanned to determine the system modulation transfer function. The system transfer function shows graphically the amount of high frequency roll-off and is an excellent check on system response to various input frequencies.

The following section includes a list of the test films examined with a summary of the test purpose, a list of the optical tests performed as well as the conclusions and recommendations contained in the individual report issued for the film.

Film Number 100

This film, the first in the series, was received on 11 February 1972 and contained calibration and chirp test data signals on the HF_1, HF_2 and VHF channels with various video levels. Optical tests used for analysis included:

Visual Examination
Exposure Level
Diffraction Efficiency
Sidelobe Measurement (using a diamond aperture in the spatial plane)
Visual Analysis of Test Signals
Frequency Plane Analysis

The basic problem areas listed in the conclusions were in the areas of film handling and processing, spurious noise sources, film drive errors and a potential problem with high frequency roll-off in the HF_2 data.

Film Number 101 (12A/13A)

This film was received on 6 March 1972 but was accompanied by inadequate documentation. After some technical coordination it was determined that this film was only a preliminary test and the data format for subsequent tests had already been changed. Consequently only a minimal amount of testing was done. This included:

Visual Examination
Exposure Levels
Diffraction Efficiency
Visual Analysis of Test Signals

Frequency Plane Analysis

A copy film was analyzed simultaneously. Problem areas listed in the report were inadequate documentation, spurious noise sources, PRF fluctuations, film base transmission, and probable non-linearities in the duplication process.

Film Number 102 (Film No. 14A)

Film Number 102 was marked "Film No. 14A (equivalent to GACA Systems 10 film)" and received on 3 March 1972. It contained chirp test data signals and 5 MHz sinewave signals. It was analyzed with the aid of the following tests:

Visual Examination
Exposure Levels
Diffraction Efficiency
Noise Measurements
Sidelobe Measurements (using a diamond aperture in the spatial plane)
Sidelobe Measurements with $\text{sinc}^2(\ )$ weighting in the frequency plane
Dynamic Range
Visual Analysis of Test Signals
Modulation Transfer Function
Frequency Plane Analysis
Symmetry of Unweighted Test Signals

Since a $\text{sinc}^2(\ )$ weighting filter for HF_1 became available after the test report on this film was issued, these results were reported with the next test film. Problems were still being experienced with the film drive and with spurious noise signals. In addition, it was shown that the basic chirp test signal was asymmetric and a recommendation was made that the chirp generation network be adjusted.

Film Number 103 (GAC No. 10)

This film, received on 31 March 1972, contained calibration and chirp test signals and 0.625 MHz sine wave signals. It was analyzed by using:

Visual Examination

Exposure Level

Diffraction Efficiency

Sidelobe Measurements

Visual Analysis of Test Signals

Frequency Plane Analysis

Symmetry of Unweighted Test Signal

Modulation Transfer Function

The main problem pointed up by this film was the continuing asymmetry of the chirp test signal and the fact that the high frequency information contributed little to the pulse compression. However, it was shown that the sidelobes could be suppressed to at least -35 db. Other results were consistent with previous films.

Film Number 104 (Goodyear Film No. 1)

This was received on 30 May 1972 and contained a 32-step CRT bias run and sinusoidal test signals. The main purpose was to check linearity and harmonic levels. This was done by using the following tests:

Visual Examination

Harmonic Levels

Linearity

It was found that there was a non-linearity present in the film amplitude transmission versus CRT bias voltage curve. The second harmonic level was approximately -16 db. No other analysis was made and the film was returned to NASA/MSC.

Film Number 105 (TCP 0070)

Received on 10 July 1972, this film contained calibration and chirp test data signals at various video levels for all three channels. Tests employed were:

Visual Examination

Exposure Level

Diffraction Efficiency

Linearity

Harmonic Levels

Sidelobe Measurements (all three frequency channels)

Symmetry of Unweighted Test Signals

Visual Analysis of Test Signals

Frequency Plane Analysis

PRF Scans

Modulation Transfer Function

Harmonics were found to be excessively strong. The bias level shifted with a change in video strength. Chirp signals were still asymmetric indicating phase errors. Noise level was higher than desirable and there was severe azimuth modulation with a period of 12 cycles/mm. The PRF scans indicate problems with the recorder film drive. Most of these results were presented in an oral report in a meeting at Cape Kennedy.

Film Number 106 (KSC Test Film 8241)

This film was hand-carried by R. Kelly and received on 26 July 1972. It contained calibration signals, chirp test data signals, and sine wave signals. Tests used included:

Visual Examination

Exposure Efficiency

Linearity

Harmonic Levels

Dynamic Range

Sidelobe Measurements

Frequency Plane Analysis

Modulation Transfer Function

Several serious problems were still present in the Lunar Sounder recorder. Bias level changed with video level. The system was non-linear for strong video. Harmonic levels were very high (-7 to -10 db). It was recommended that all of these problems should receive high priority for correction. The technical data was given directly to R. Kelly about the first of August.

Film Number 107

This was generated by GAC and received on 22 August 1972. It

contained variable range frequencies at constant voltage, a constant range frequency at variable voltage, a non-synchronous azimuth sine wave and a bias level test. It was analyzed by using the following tests:

Visual Examination
Exposure Level
Linearity
Modulation Transfer Function
Diffraction Efficiency
Harmonic Levels
PRF Scans
Frequency Plane Analysis

This analysis showed that the recorder was still not operating properly. Bias level changed with video level. The modulation transfer function for VHF was very poor. Harmonic levels were about -10 db. Non-linearity was still a real problem. Corrective measures were urged.

Film Number 108 (TCP-K0005)

This test film, similar to test film number 105 (TCP-0070) except for increased system gain, was received on 21 September 1972. The film contained chirp test data signals of vary but unknown video levels. No data sheets were received with the film and it was necessary to make certain assumptions regarding content. The tests used to examine this film were:

Visual Examination
Harmonic Levels
Exposure Levels
Sidelobe Measurements
PRF Scans
Noise Measurements
Dynamic Range

The conclusion reached was that this film was very similar to TCP 0070 except for a higher absolute noise level, probably caused by the increased system gain. There was some fogging, probably chemical, on the film and also an overall mottled appearance to the background. The effect of this on the noise level could not be determined.

Film Number 109 (K0006)

This was the first test film examined from the replacement recorder. Received on 16 October 1972, it underwent immediate analysis and copies of the test results were delivered to R. Kelly on 18 October 1972. Tests used for the analysis were:

Visual Examination
Harmonic Levels
Exposure Levels
Sidelobe Measurements
Diffraction Efficiency
PRF Scans

The analysis of this film showed that the new recorder was a dramatic improvement over the previous one. It was adjudged to be adequate for the intended use. Harmonic levels were about -20 to -25 db and the weighted sidelobe levels were below - 35 db on the far range side. Problems were still being experienced with film mottling and an effort was underway to improve this situation.

Films Number 110 and 111

A test was run on the prototype recorder during September 1972 in an effort to find a solution to a severe film drive jitter problem. Two different film types were used. Film number 110 was SO-394 with a 2.5 mil Mylar base. Film number 111 was 2402 with a 4 mil base. Tests used to compare these films were:

PRF Scans
Frequency Plane Analysis

These tests showed the existence of a severe jitter problem when SO-394 film was used in the prototype recorder. Switching to the thicker 2402 film reduced the jitter by an order of magnitude. It was recommended that this film be used for future work with the prototype system.

Films Number 112 and 113 (KSC Sub Test)

These films were received on 29 October 1972. The purpose of this test was to determine the feasibility of replacing the previously used SO-394

with 3400 film, since previous experiments had shown SO-394 to be subject to severe mottling problems. A major impediment to accurate assessment was a loss of coherency in the trigger signal in the HF_1 portion of the 3400 film. Tests which were used included:

Visual Examination
Visual Analysis of Test Signals
Exposure Levels
Harmonic Levels
Diffraction Efficiency
Linearity
Noise Measurements
Sidelobe Measurements
Dynamic Range
PRF Scans

On the basis of this analysis a tentative recommendation was made that the 3400 film be used as a replacement. A slight increase in noise, 1.5 db, was seen but not felt to be a significant factor. After the basic testing was done on these films, some additonal examination of the 3400 film was done to help identify the source of the coherency problem. This was in direct response to specific requests from MSC and the results were immediately transmitted to MSC.

Film Number 114 (GSE Troubleshooting Test)

Because of an intermittent loss of coherency on the trigger signal experienced during the previous test, a special troubleshooting experiment was run. Film from this experiment was received on 9 November 1972 and analysis began immediately. Tests used were:

Visual Examination
Visual Analysis of Test Signals
Sidelobe Measurements

It was found that the coherency problem had been solved. The decision was made on the basis of this and the previous KSC Sub Test to switch to 3400

film in the Lunar Sounder recorder. This eliminates the mottling found previously. A strong coherent range noise problem was present in the VHF channel. This was to be pursued further but it was thought to be introduced electronically through the test signal equipment and was not an inherent feature of the radar system. Because of this coherent noise, VHF had a noise level of about -25 db relative to the strongest recorded signal. This noise made it impossible to measure the weighted sidelobe levels for VHF.

Film Number 115 (CDDT Test)

This was expected to be the final film in this series and was to show the readiness of the Lunar Sounder recorder prior to beginning the countdown procedure. As soon as the film was received on 19 November 1972, the following tests began:

Visual Examination
Exposure Levels
Sidelobe Measurements

The results suggested a severe problem in the recorder; one which especially affects the HF_2 channel. The low signal levels found could possibly be due to defocussing in the recorder. Other results were also in agreement with this hypothesis. The recommendation was made that the recorder be checked for focus problems.

Film Number 116 (Post CDDT Test)

It was learned that the recorder lens was out of focus and future evaluations were to disregard defocusing effects if possible. Film number 116 was received on 24 November 1972 and its purpose was again to assess the launch readiness of the Lunar Sounder recorder. The tests used were:

Visual Examination
Harmonic Levels
Exposure Levels
Sidelobe Measurements
PRF Scans

Data from Post CDDT test was substantially identical to that from CDDT test. It was felt that because of the focus problem no reliable assessment of equipment readiness could be made.

Film Number 117 (Pre-Launch Test)

A final readiness test was made on the Lunar Sounder recorder. Film from this test was received on 30 November 1972. Because of the need for immediate information, the analysis was completed on the same day. The film contained chirp test data signals at standard video levels for all three frequency channels. The analytic results were based on the following tests:

Visual Examination

Harmonic Levels

Sidelobe Measurements

PRF Scans

The conclusion was reached that no further corrections should be attempted in the limited time yet available to fulfill its purpose. There was still a large coherent noise pattern in the VHF channel, but it was hoped that this was being generated mainly by the ground test equipment and would not be present in actual lunar data.

This was the last of the eighteen films which were examined during this program. A report has been written and distributed covering in detail the analysis of each film.

CONCLUSIONS AND RECOMMENDATIONS

At the time of the launch the Lunar Sounder had the following characteristics:

1. Film Handling and Development:

   This was adjudged to be consistent and adequate.

2. Bias Levels:

   It is expected that for normal operating conditions and normal temperatures the amplitude transmission in the VHF channel will be about 44%; for the HF channels it will be about 37%.

3. Harmonic Levels:

   These should be -29 db or lower for even the strongest signals in all three channels.

4. Film Drive Stability:

   Based on the results of the Pre-Launch Test film drive stability

will not be a problem.

5. Dynamic Range:

The recorder dynamic range will be about 20 db for VHF, about 21 db for HF_2 and about 27 db for HF_1.

6. Linearity:

The recorder is adequately linear up to a maximum 6 volt peak to peak signal. The strongest signals expected to be encountered during the lunar mission will be about 4 volts.

7. Sidelobe Levels:

By using the present $\text{sinc}^2(\ )$ weighting filters when processing the data sidelobes should be below -35 db on the far range side for each frequency channel used. By careful alignment of the weighting filters these may go down another 5 db or more in some cases.

8. Coherent Noise:

This was the most serious remaining problem area prior to launch. Although the source could not be isolated, it was hoped that this was caused primarily by the ground-based test equipment. If it is still present in the lunar data, special data processing techniques will have to be developed to eliminate it.

Thus, at the time of launch it appears that the Lunar Sounder recorder is performing within specifications and should be expected to return useful data from its lunar mission.

H. Amble
2-12-73

Account Number: 011008
Account Name: NAS 9-12559 L. J. Porcello

Project Director: L. J. Porcello
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Expenditures

	Budget	Total Expended
Salaries & Wages	33,583.00	34,784.95
Fringe Benefits	4,030.00	2,922.46
Supplies	4,825.00	4,883.24
Travel	619.00	19.60
Direct Costs	43,057.00	42,610.25
Indirect Costs	21,253.00	21,719.47
Account Total	64,310.00	64,329.72

S-209 TEST FILM LOG

Date Received	Ident.	Length	Data	Condition	Tech. Coor.	Analysis	Misc.
2-11-72	100	28 ft.	Lunar Sounder test chirp pulse HF_1, HF_2, VHF 150 μs & 350 μs delay	Good except for crinkled on one edge and static discharge		2-14-72 POP WR ↓ 2-18-72	
3-6-72	101 & 101 Dupe	16 ft.	Lunar Sounder - Lab 12 / 13A	Good	Discussion with NASA and North American to try to certify the nature of each data run	3-13-72 Complete	We could not interpret thes data sheets. Time was los on interpretat
3-8-72	102	20 ft.	Lunar Sounder - 14A	Good		3-14-72 Start ↓ 4-12-72	This film didn have a good d sheet or photo reference material
3-31-72	103 GAC No. 10	15 ft.	Lunar Sounder - 10A	Good except cut into 25 pieces		4 24 72 ↓ Complete	We were pror ised the GAC sidelobe plots they didn't arrive with th film.

S-209 TEST FILM LOG

Date Received	Ident.	Length	Data	Condition	Tech. Coor.	Analysis	Misc.
5-30-72	104 Goodyr film No. 1		32 step wedge - 3.5 v to +3.5 v bias levels. Range sine waves at HF & VHF video levels of 1/2, 1, 3 & 7 V p-p and various frequencies	Good	N. Lamar	5-31-72 ↓	
7-10-72	105 TCP 0070	20'	Chirp signals at 6 video levels governed by AGC on each channel 21 step wedges copied before and after film exposure	Good		7-19-72	
7-26-72 Hand carried by Kelly	106 KSC test 8241		20 hz azimuth sine waves chirps on all 3 channels at .25, .5, 1, 2, 4, 7 V p-p video	Good	R. Kelly	8-2-72 Completed	
8-25-72	107 GAC No. 8	50' ?	Range sine wave HF & VHF Range variable voltage sine wave	Good	R. Kelly	8-28 -- ↓ 9-1	

S-209 TEST FILM LOG

Date Received	Ident.	Length	Data	Condition	Tech. Coor.	Analysis	Misc.
9-26-72	108 KSC 0005	30' ?	Chirps HF_1, HF_2, VHF Unknown video levels	Developer fogging	R. Kelly W. Panter	9-28-72 ↓ 10-4-72	No data shee Start of anal- ysis delayed, waiting for money & data
10-16-72 Hand carried by R. Kelly	109 KSC K0006	30' ?	Chirp Signals HF_1, HF_2, VHF New Recorder	OK	R. Kelly	10-16-72 ↓ 10-18-72	Rapid respons required
9-18-72	110 Proto- recorder SO-394		Bias level to check film drive jitter	OK		9-28-72 ↓ 9-29-72	
9-18-72	111 Proto- recorder 2402		Bias level to check film drive jitter	OK		9-28-72 ↓ 9-29-72	

S-209 TEST FILM LOG

Date Received	Ident.	Length	Data	Condition	Tech. Coor.	Analysis	Misc.
10-29-72 picked up at airport	112 Sub test	?	SO-394 film to compare with 3400 HF_1 & HF_2 chirp signals	OK	W. Panter	10-30-72 ↓ 11-1-72	
10-29-72 picked up at airport	113 Sub test	?	3400 film to compare with SO-394 HF_2 chirp signal HF_1 chirp loses coherency	OK perforated	W. Panter	10-30-72 ↓ 11-1-72	
11-9-72	114 GSE trouble-shooting 2nd batch 3400	40'	Chirp signals HF_1, HF_2, VHF	OK	G. Coultas	11-13-72 ↓ 11-14-72	
11-19-72	115 CDDT	20'	HF_1, HF_2, VHF Chirp pulse	OK some fogging	Dan Mangieri	11-19-72 ↓ 11-21-72	Hand carried by Alex March

S-209 TEST FILM LOG

Date Received	Ident.	Length	Data	Condition	Tech. Coor.	Analysis	Misc.
1-24-72	116 Post CDDT	40'	HF_1, HF_2, & VHF 2, 4, & 6 volt levels	OK	W. Panter	11-24-72	Hand carried by Larry Oliphant
1-30-72	117 Pre-Launch Test	60'	HF_1, HF_2, & VHF chirp signals Levels uncertain	OK Fogging by time marks - some other fogging	W. Panter	11-30-72	Hand carried by Albert Wells