Bendix

Aerospace Systems Division

EMI TEST RESULTS AND MARGIN OF COMPATIBILITY FOR ALSEP ARRAY E

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ABSTRACT

This ATM provides an overall assessment of the EMI characteristics of the Flight 6 ALSEP System and summarizes the results of the Flight and Qualification Test Programs relative to EMI capability.

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1.0 SUMMARY

ALSEP Flight System is free of all EMI problems within itself and in relation to other Apollo equipment. This is attributable to an improved grounding system and comprehensive early EMI tests which allowed corrective action to be taken.

Although not considered a problem, it should be noted that Lunar operating procedures must caution against performing the LSG mass change function until adequate reserve power is available. Operation of the LSG mass change motor at very low reserve power may cause temporary uplink loss, however mass change will occur only once during the first lunar day initialization when at least 30 watts of reserve power is available.

2.0 EMI SPECIFICATION

The mandatory requirements as listed in AL770000 under paragraph 1.4 are:

A. Short duration deviations.

B. Radiated interference above 150 MHz only, with the acceptable level above 150 MHz increased by 10 dB (above the limits of MIL-I-26600. SEP frequencies were added by SCN #3 at levels which guarantee that the interference will be 10 dB below SEP receiver sensitivity at a range of 30 feet.

C. Antenna conducted spurious emanations above 150 MHz only, with acceptable levels above 150 MHz increased by 10 dB (above the levels of MIL-I-26600).

D. Susceptibility, radio frequency radiated above 150 MHz only, with acceptable level above 150 MHz relaxed by 10 dB (compared to MIL-I-26600).

E. Receiver front end rejection. Measured under antenna conducted susceptibility tests.

F. Electro explosive device compatibility.

G. Systems functional test for compatibility as in MIL-6051D and crosstalk as part of System Thermal Vacuum Test.

3.0 LUNAR RECEIVERS AND SIGNAL SOURCES

Table 1 tabulates all known receiving equipment which is potentially susceptible to radiated EMI and corresponding sources which can emit interfering signals.

TABLE I
LUNAR RECEIVERS AND SIGNAL SOURCES

Frequency (MHz)	Signal Source	Receiver Site	AL 770000 Limits (NB) Susceptibility	Interference (Rad)
1.0			+102 dbμV @ 1 ft	52 dbμV (ant. ind.)
2.1				46
4.0	SEP	SEP		41
8.1	Transmitter	Receiver		37
16.0				35
32.0				48
5.00 - 5.33				31
15.0 -- 16.6	CSM Sounder	CSM Sounder		27.5
150.0 - 166.0				38
259.7	EVCS	EVCS		41.5
279.0	EVA-1, EVA-2,	(EVA-1, EVA-2		42
296.8	LCRU, LM, CSM)	LCRU, LM, CSM)	+102dbμV @ 1ft	42.5 dbμV (ant. ind.)
2101.8	MSFN	LCRU, LM	+102dbμV @ 3 ft	70dbμV/M
2106.4	MSFN	CSM		
2119.0	MSFN	All ALSEP's		
*2265.5	LCRU	MSFN		
2272.5	CSM (FM)	MSFN		70dbμV/M
2275.5	ALSEP Array E	MSFN		N/A
2276.0	ALSEP Array D	MSFN		70dbμV/M
2278.0	ALSEP Array A-2	MSFN		
2278.5	ALSEP Array A	MSFN		
2282.5	LM, P&F Subsatellite	MSFN		
2287.5	CSM (PM)	MSFN	+102dbμV @ 3 ft	70 dbμV/M

41.2MHz Transmitter for LSP is operated after other Apollo equipment has left.

* See Special Test

4.0 ALSEP SUSCEPTIBILITY

Central Station and system EMI tests have demonstrated that ALSEP performance will be unaffected by other Apollo equipment. A problem did occur with LEAM during a special radiated susceptibility test (DR AC 5547) but subsequent to a fix and retest was completely satisfactory.

DR AC 5547- Noise hits were noticed during the LEAM section of System EMI. Little variation occurred with test antenna output or frequency but unreeling the flat cable caused substantial changes. The ground system was revised, redefining "case" as "chassis" and the problem was eliminated.

5.0 INTERFERENCE FROM ALSEP

Central Station EMI testing revealed several harmonics of the Data Processor crystal oscillator were above MIL-I-26600 limits (DR AC 4893). No other out of limits interference was observed.

DR AC 4893 - At Flight Central Station EMI several frequencies in the SEP range were found to be above spec levels. SCN #3 was added to the ALSEP EMI spec to define acceptability in this range. At Flight system EMI test the new limits were used and passed satisfactorily, demonstrating compatibility between ALSEP interference and the SEP receiver at 30 feet.

6.0 EMI TEST RESULTS OF OTHER MODELS

MSC directed a full EMI test on the Design Verification central station and Prototype experiments. A very comprehensive test to MIL-461 was performed revealing several defects.

6.1 LSP Transmitter had excessive spurious outputs at second and third harmonics.

6.2 Both Data Processor 2MHz crystal oscillators gave some above limits outputs although they were in general 15-25 db less than Array D. The LSPE 16 Channel MUX oscillator is not operating in the presence of other Apollo equipment or during ALSEP normal data processing. The C/S data processor alone gave a few insignificant points, the greatest of which was -85 dbm at 62MHz.

6.3 Experiment turn-on transients and current noise were excessive for LSG if the slave heater was left enabled at turn off. Noise due to the mass change motor is shown later.

6.4 Oscillation in LSG heater box circuit causing radiated EMI at 38MHz.

6.5 Interaction between LSP and 90 channel multiplexers occurred on shared channels (Due to loading, not EMI).

6.6 A large number of other points were plotted during these tests; some were attributable to experiment test sets and were not plotted if they disappeared when the test set was turned off or were radiated points that did not show on system test.

All the listed defects were corrected by hardware change except the LSG mass change motor current.

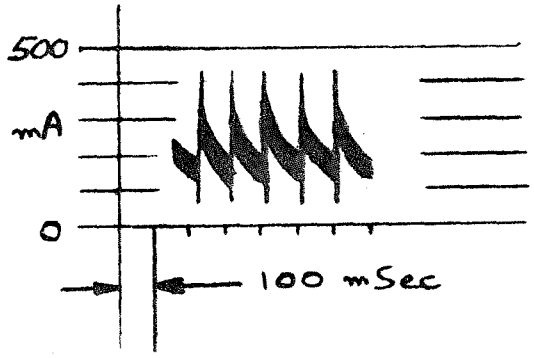
7.0 LOW FREQUENCY NOISE CURRENT

The 29 Volt line current ripple was measured for each experiment under normal operating condition with the following results:

		Specified Limit
LMS	30 mA peak to peak	60 mA peak to peak
LEAM	3 mA peak to peak	60 mA peak to peak
HFE	14 mA peak to peak	60 mA peak to peak
LSG	40 mA peak to peak	60 mA peak to peak
LSP	10 mA peak to peak	60 mA peak to peak

These results indicate very adequate suppression of current noise.

A measurement was also made of the LSG 29 Volt line current noise with the mass change motor operating in its end-stop hunt with the result shown below:



7.0 (Continued)

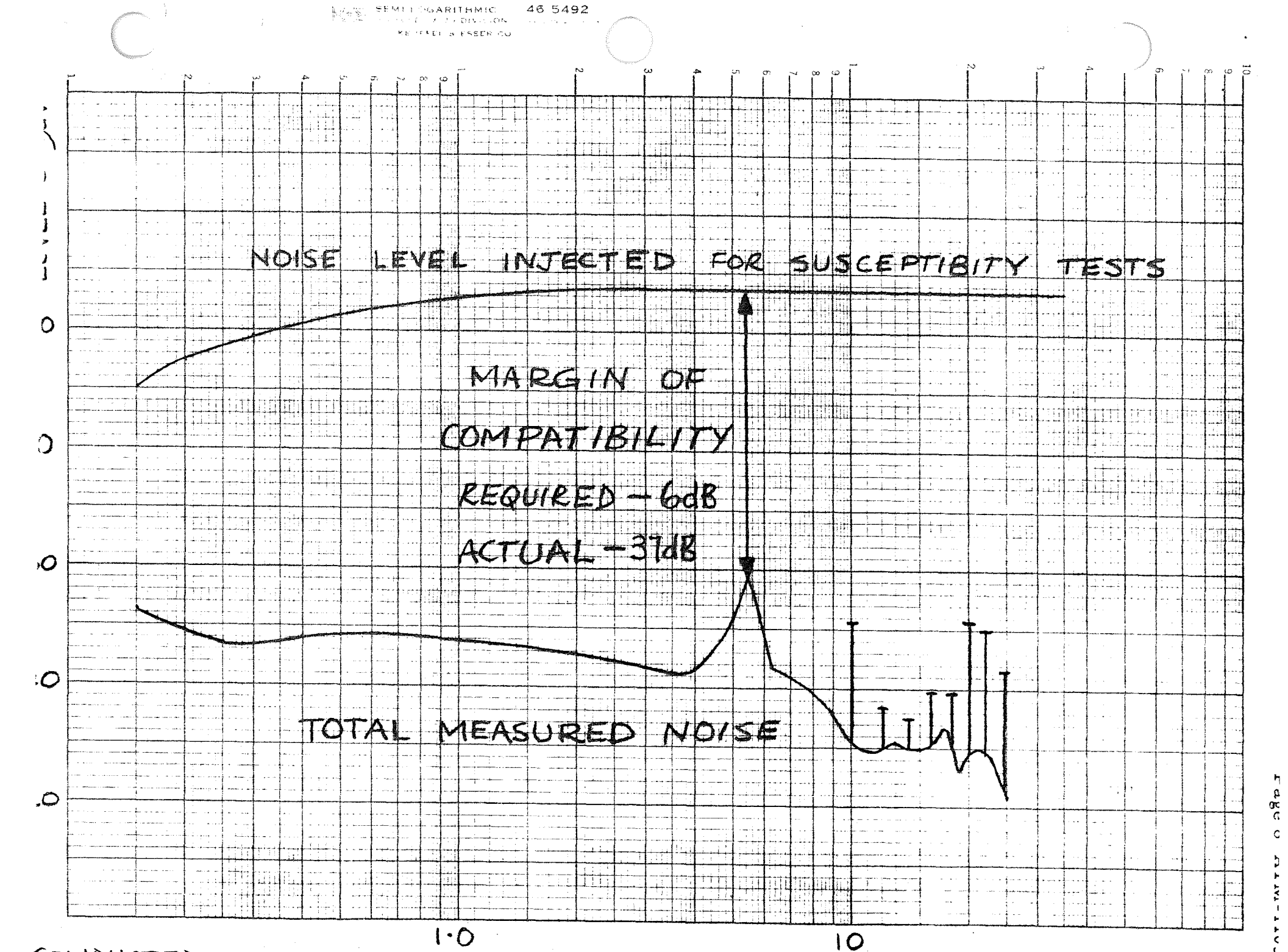
Provided sufficient reserve power is available (approx. 14 watts), this ripple has no effect on any part of ALSEP. The mass change motor is only actuated in the initial setting up of LSG during the first lunar day, and the Operations Plan ensures that adequate reserve power will be available at this time. If the LSG mass change motor should be inadvertently operated at low reserve power, the uplink could be affected. Repeated transmissions of commands would be necessary since the probability of acceptance by Array E would drop to about 10% - 20%. Complete and continuous lock-out is unlikely.

8.0 CONDUCTED AND RADIATED COMPATIBILITY BETWEEN ALSEP SUBSYSTEMS

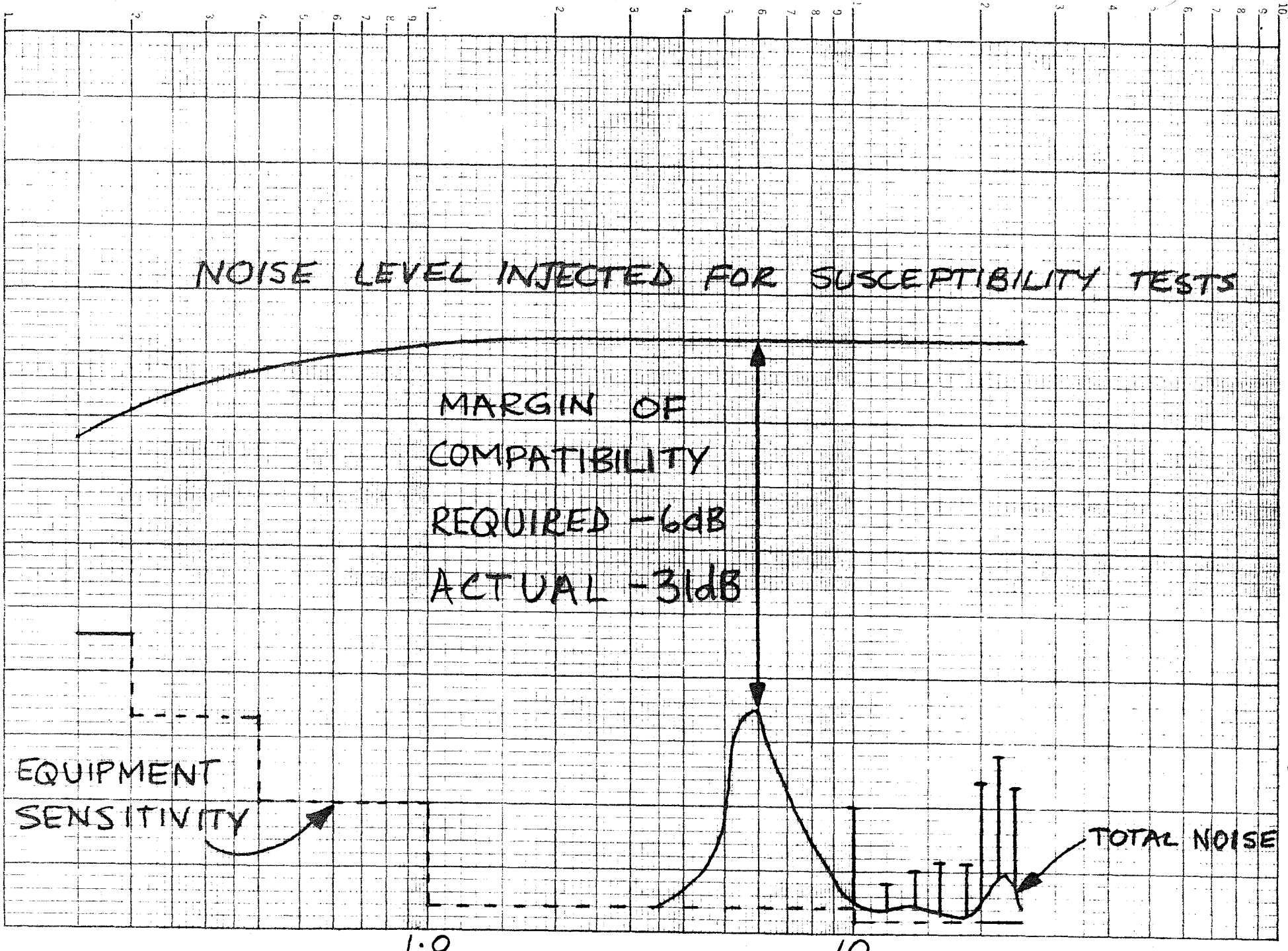
After the design changes necessary to correct the discrepancies in paragraph 6, out of limits performance was compared with conducted susceptibility in Figures 1 and 2. It can be seen that the 6 db margin of compatibility required by MIL-6051D is easily attained.

Figure 3 compares the radiated interference and susceptibility again demonstrating an adequate margin.

Letter 9713-558 "LSP Transmitter/ALSEP Integrated System Test Results" indicates pickup by LEAM but anticipates no problem in operation. Further tests were run to finalize the investigation of the LSP transmitter/ geophone problem.



CONDUCTED COMPATIBILITY – STAB.NET FIGURE 1 FREQUENCY – MEGAHERTZ



CONDUCTED COMPATIBILITY - CURRENT PROBE FIG. 2. FREQUENCY MEGAHERTZ

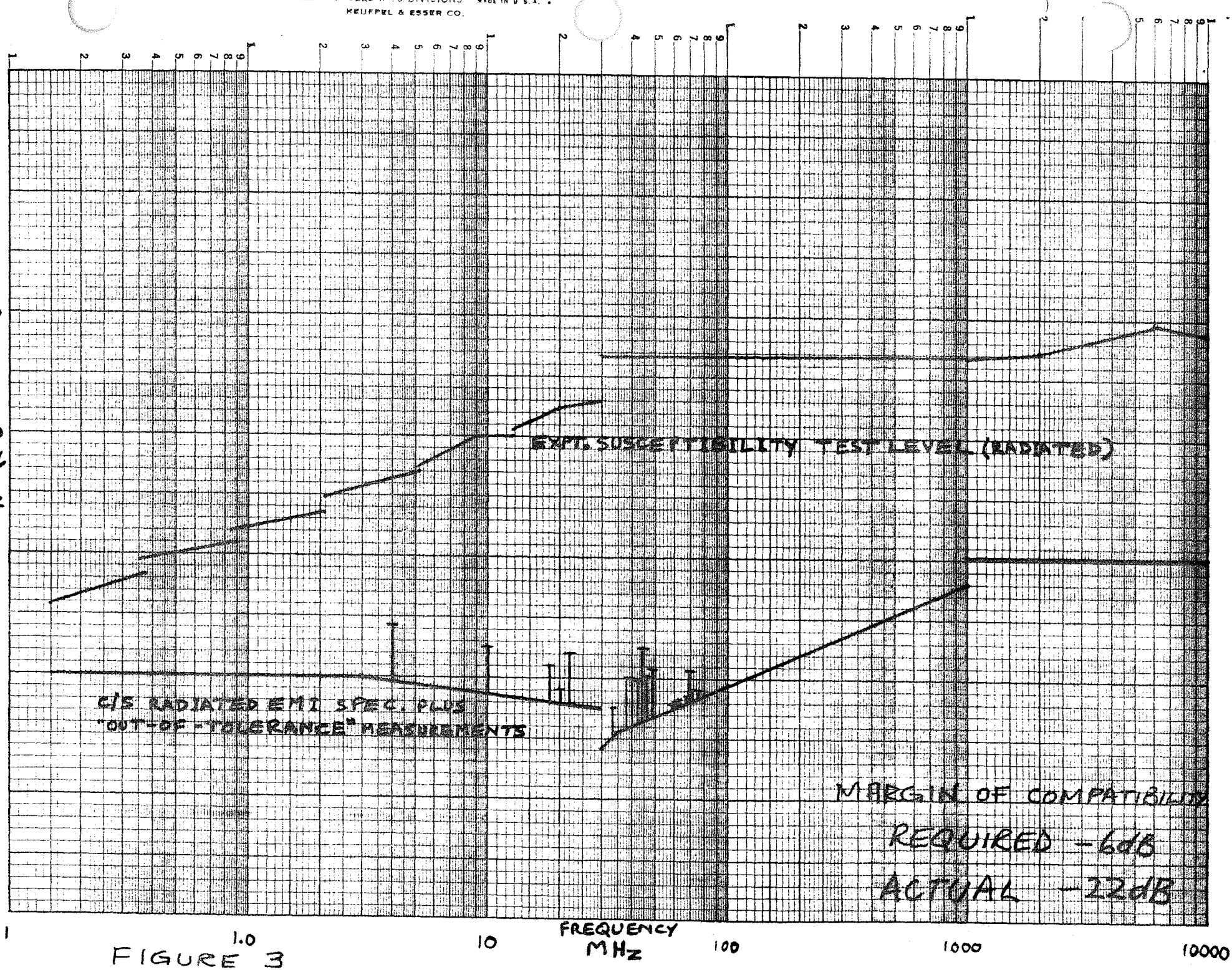

K&E SEMI-LOGARITHMIC 46 6213
5 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.
EXPT. SUSCEPTIBILITY TEST LEVEL (RADIATED)
C/S RADIATED EMI SPEC. PLUS "OUT-OF-TOLERANCE" MEASUREMENTS
MARGIN OF COMPATIBILITY
REQUIRED -6dB
ACTUAL -22dB
0.1
1.0
10
100
1000
10000
FREQUENCY MHz

FIGURE 3

9.0 EXPERIMENT EMI MEASUREMENTS

EMI measurements on the LEAM, LSG, and LMS operating from their individual test sets have been performed as part of the Array E program. EMI tests for the HFE were performed prior to integration with earlier ALSEP Arrays. The LSP EMI tests are performed in conjunction with the C/S EMI tests. For the purpose of EMI tests the LSP C/S electronics are considered a part of the C/S.

Great care must be taken in interpreting the results of experiment EMI tests run with their individual test sets. It has been found that the source of out of tolerance EMI is often the test set rather than the experiment. In some cases, particularly those of narrow band conducted and radiated interference, it is easily shown out of tolerance EMI is harmonically related to oscillators within the test set. In other cases, where it is not possible to show such relationships, measurements made at the system level do not show out of tolerance EMI. Where measurements are made at both the experiment and system level, system level results are considered the more valid because test set EMI does not affect the results.

Radiated EMI and radiated susceptibility are measured at the system level as well as at the experiment and C/S level. The results of tests at either level can be used for demonstrating system compatibility. The system level tests are somewhat superior for this purpose because the interconnecting flat cables are deployed. Conducted interference and conducted susceptibility however, are measured only at experiment and C/S level. Therefore system compatibility, at least for narrow band conducted EMI, must be based on the results of these individual tests. In the case of broad band conducted EMI, the measurements of noise on the interconnecting lines made during DVM system integration are superior for proving compatibility because they are not affected by test set EMI and the measured peak to peak voltages are directly relatable to circuit noise margins. The validity of using DVM test results for the Qual and Flight models is demonstrated in ATM 1100.

9.1 LEAM EMI TEST TP2365515

The LEAM EMI test was run on the prototype model.

Broad Band Conducted Interference

Out of tolerance broad band conducted interference was measured at 12 frequencies in the frequency range from 0.86 MHz to 12.2 MHz. The ambient EMI level measured with the LEAM OFF and the test set ON, was 25 to 55 dB above the sensitivity of the measuring receiver. This is not conclusive proof that the test set is the source of the measured EMI; however, it does render the results inconclusive. It is for this reason that peak to peak noise measurements are used to demonstrate compatibility.

Narrow Band Conducted Interference

All out of tolerance narrow band conducted EMI is directly relatable to the test set.

Broad Band Radiated EMI

Out of limits broad band radiated interference was measured at several frequencies in the range from 17kHz to 5MHz. The source of this EMI was traced to the squib lines. Subsequently the squib lines were filtered and the squib monitor channels modified to read a ratio of filtered 5V DC rather than unfiltered 3V AC. It was established with these changes broad band radiated EMI was within tolerance.

Narrow Band Radiated EMI

With the exception of narrow band components at 19 and 26 MHz, out of tolerance narrow band radiated interference orginated from the 2 MHz clock in the test set. This fact was proven by turning OFF the test set, 2MHz clock.

Radiated Susceptibility

The radiated susceptiblity test was successfully passed.

9.1 (Continued)

Conducted Susceptibility

The conducted susceptibility tests were successfully passed.

Transient Susceptibility

The transient susceptibility test was successfully passed.

Power, Data and Command Line Noise

Noise voltages were in tolerance with the exception of Command Lines 1, 2, 3 and 4 where the peak to peak noise voltages measured were 130 mV, 150mV, 130mV and 180mV respectively. However, during system integration measurements these noise voltages were measured at less than 100mV, the tolerance level.

Although out of tolerance EMI was measured in several cases none of these reduce the margin of compatibility below 6dB or violate the mandatory EMI requirements.

9.2 LMS EMI TESTS TP2365505

EMI tests were run on the prototype LMS with the original design and with the Multimode format modification.

Conducted Interference Broad Band

Out of tolerance broad band conducted interference was measured at 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0 and 10.0 MHz. It should be noted that the ambient level, with the experiment OFF was 35 to 50 dB above the test receiver sensitivity indicating that the test set was probably the source of out of tolerance EMI.

Conducted Interference, Narrow Band

No out of tolerance narrow band interference was measured except that harmonically related to the test set 678 kHz oscillator.

9.2 (Continued)

Radiated Interference

No out of tolerance narrow band or broad band radiated interference was measured.

Conducted Susceptibility

The conducted susceptibility test was successfully passed.

Radiated Susceptibility

The radiated susceptibility test was successfully passed.

Transient Susceptibility

The transient susceptibility test was successfully passed.

Power, Data and Command Line Noise

All power, data, and command line noise was measured within tolerance (150 mV for the 29 volt line and 100 mV for other lines).

The only out of tolerance EMI measured for the LMS that is not definitely due to the test set is the broad band conducted interference. However, the noise measured on the power line on a peak to peak basis was well within tolerance, therefore the margin of compatibility is not adversely affected.

9.3 LSG EMI TESTS, TP2365534 and TP2365536

EMI tests have been run on the Engineering and Qual Models LSG. Qual model testing was required to prove a change made to the LSG to prevent an oscillation in the heater box circuitry. This oscillation had been a source of out of tolerance narrow band radiated EMI.

Conducted Interference

Out of tolerance broad band conducted interference was measured at 7MHz. All out of tolerance narrow band conducted EMI measured was due to the test set.

9.3 (Continued)

Radiated Interference

Out of tolerance radiated interference, not related to the test set, was measured at 38 MHz for the Engineering Model. A subsequent circuit change was effective in removing the source of the EMI, as demonstrated in Qual Model EMI tests.

Conducted Susceptibility and Transient Susceptibility Test

LSG successfully passed the condutted susceptibility and transient susceptibility tests.

10.0 SPECIAL TESTS

During the Array E program special tests have been performed that yield valuable data for proving compatibility.

10.1 DVM SYSTEM INTEGRATION TESTS

During DVM system integration, as each of the experiments was integrated with the C/S, each of the lines interconnecting the C/S and the experiment was brought out through a break out box and the noise on these lines measured. In each case it was verified that peak to peak noise did not exceed 150 mV on the 29 volt line and 100mV on the data and control lines.

10.2 ALSEP/LCRU COMPATIBILITY TESTS

The calculated field strength at ALSEP due to LCRU radiated signals under certain conditions, exceeds the ALSEP radiated susceptibility test level. Therefore a test was performed using the MSFN model ALSEP to determine if ALSEP would be adversely affected for the case of the LCRU high gain antenna aimed directly at ALSEP. The significant result of this test was that no adverse effects were noted for signal strength at ALSEP equivalent to the LCRU operating at a distance of 20 feet with its high gain antenna directed at ALSEP. Although many design changes were introduced in Array E, the similarity of this Array to the MSFN model at the interconnecting flat cable interface and RF input/output makes it possible to extend the results to Array E. Thus, even under worst case conditions, the test results show ALSEP Array E will not be adversely affected by LCRU radiated signal.

10.3 LSP/ALSEP SYSTEM COMPATIBILITY TESTS

A series of tests have been run to determine the effects of the LSP radiated signal upon system operation. First tests were conducted to determine the level of voltages induced on flat conductor cables to insure that they were below thelevel at which damage to circuits could occur. When it was determined that potentially damaging voltages were not coupled to the flat cables, a test was run with the experiments deployed and operating and the LSP transmitting at full power. This test was run in the ALSEP lab. Field strength measurements at the C/S and each experiment location showed that the fields were as great or greater than will be encountered in lunar operation. The only adverse affect of LSP transmitted signal was interference with LEAM data. Analysis of the LEAM data indicates that the LSP transmitted signal affects the operation of the LEAM detectors and associated amplifier circuits. This is significant, for if the interfering signal affected logic circuit operation, the possibility of false commands or in the worst case circuit damage for all experiments and the C/S would require consideration. However, with the point of interference isolated to the LEAM sensors and considering the fact that LEAM is not operated during the period that LSP is transmitting, this interference with LEAM data is not a system incompatibility. Hence, the results of tests at reduced deployment distances prove the compatibility of the ALSEP system with the LSP transmitted signals.

10.4 DEPLOYED SYSTEM FIELD TEST FOR GEOPHONE NOISE

During the thermal-vacuum test of the Qualification model it was determined that the LSP geophone channels exhibited noise when the LSP transmitter was on. The amount of noise was related to the proximity of the LSP RF cable to the geophone cables and to other configurational changes. During troubleshooting using both DVM and Qual hardware, it was determined that the noise was coupled primarily in cabling external to the Central Station and that the addition of wires connecting the geophone channel shields to the thermal plate ground significantly reduced the amount of noise.

It was difficult to obtain meaningful quantitative measurements because the coupling was so strongly dependent on the arrangement of the cables external to the station. A design change was incorporated into both qualification and flight stations which grounded the geophone shields near the point of penetration to the thermal bag. The effectiveness of the change was determined by establishing a baseline configuration of geophone and RF cables and measuring the noise before and after the shields were grounded.

10.4 (Continued)

It was then decided to perform a deployed system test in the field to determine whether the noise would be present in a fully deployed configuration and if so to define requirements for any noise reduction programs which might be required to process geophone data. This test was performed at the end of the formal qualification test sequence.

The field test consisted of deploying the qualification system (some non-qual experiments were used) on a grassy slope between Plant 1 and Plant 2. The RF command and data link was established by locating an S-Band antenna on the roof of Plant 2, which was connected to the STS located in the Systems Lab, and by pointing the station S-Band antenna at the roof antenna. D.C. power was provided from three automobile batteries through a suitable resistor, all located to simulate an RTG. The system was deployed in the lunar surface configuration with the experiments and geophones located at the proper distance and direction from the Central Station. The test consisted of accomplishing the following events:

a. The station was turned on.
b. The RF link was established.
c. Proper station performance was verified.
d. The LEAM, HFE, LSG and LMS were turned on and proper performance was verified.
e. The LSP was turned on and the high data rate was established.
f. Geophone data was displayed on an eight channel analog recorder.
g. The LSP transmitter was turned on and it was determined that there was no change in the geophone analog recordings.
h. The LSP transmitter was turned off and the LSP antenna was moved to a location along a line from the Central Station thru the LSG.
i. The LSP transmitter was turned on and again there was no evidence of AGC pulse noise on the geophone data.

As a "worst case" condition the LSP antenna was located along the line from the Central Station through the geophone module. In this set-up the RF cable was located directly adjacent to the four geophone lines in the path from the Central Station to the geophone module which was thirty feet from the station. In this case the AGC pulses coupled into the four low signal channels at an amplitude which varied from 2.5 volts p-p on geophone #2 to 10 volts p-p (full scale) on geophones #3 and #4. The greater coupling on these two channels could have been because the RF cable to the antenna extended an additional seven feet along these cables to these geophones.

10.4 (Continued)

The Station was then returned to the normal data rate and the status of the other experiments was checked. It was determined that there was no change in status of any of the experiments or in the Central Station, resulting from LSP transmitter operation.

The conclusions of the test are that there will be no noticable coupling between the LSP transmitted energy and the geophone array as long as the LSP antenna is located in the area North of the Central Station and if the two cables are not wound together in some manner. These conditions will be easily satisfied in a normal deployment as planned for Apollo 17. It can be further concluded that the LSP transmitted energy will have no effect on the operation of the other experiments.

11.0 ALSEP - SEP INTERFACE DATA

Several harmonics of the 90 channel and LSP multiplexer oscillators appeared close to SEP frequencies. Criteria were carefully derived to prove that the SEP could safely be brought within 30 feet of ALSEP Central Station. These were incorporated by SCN #3 to AL 770000 and satisfactorily verified at Flight System EMI test. However, it is not recommended that the SEP receiver should be closer than 30 feet.

12.0 SOUNDER

The low levels of radiation from ALSEP are unlikely to bother the sounder except during LSP transmitter operation when power at sounder may be as great as -60 dBm. Similarly the LSP explosive package receiver could be affected by the 8th harmonic of sounder if harmonic suppression at 41.2 MHz was less than 40 dB below carrier.

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LCRU/ALSEP EMI Measurements	Letter No. 9713-327
LSP Transmitter/ALSEP Integrated System Test Results	Letter No. 9713-558
SEP/ALSEP EMI Interface	ATM 1092
Investigation of Array E Experiment EMI Test Validity	ATM 1100