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ELECTROMAGNETIC COMPATIBILITY REVIEW
OF THE
NASA GEMINI PROJECT

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TABLE OF CONTENTS

	Page
1.0 INTRODUCTION	1
2.0 GEMINI EMC PROGRAM BACKGROUND	2
2.1 Program Description	2
3.0 GEMINI SYSTEM EMC PROBLEMS	4
3.1 General	4
3.2 Representative EMC Problems	4
3.2.1 Computer Malfunction Caused by Antenna Motor	4
3.2.2 Computer Malfunction Caused by AGE Coaxial Switch	13
3.2.3 Glitches Caused Spurious Radar Commands To Augmented Target Docking Adapter	14
3.2.4 Inadvertent Keying of Spacecraft UHF Communications Transmitter	14
3.2.5 Tracking-Beacon Transponder Interrogated by Airport Radar	15
3.2.6 Experiment Transmitter Emitted Spurious Radiations	17
3.2.7 Experiment Package Interfered with Measurement of Bio-Med Parameters	17
3.2.8 ECS Solenoid Valve Glitches Interfered with Telemetry System	18
3.2.9 Coolant-Valve Solenoid Glitches Reset Telemetry Multiplexer	18
3.2.10 Glitches Caused AGE Power Supply Output to Fluctuate	20
3.2.11 Common Impedance Grounding System Caused Noisy Accelerometer	21
3.2.12 Excessive Noise on Low-Level Multiplexer Channels	21
3.2.13 Excessive Noise on Gimbal Stabilization Signal Monitoring Lines	23
3.3 EMC During Gemini Mission	23
4.0 SUMMARY OF NASA GEMINI PROBLEMS	24
5.0 GENERAL GEMINI IMPROVEMENTS	24
5.1 Design Improvements	24
5.2 Program Improvements	25

APPENDIX

	Page
Some Additional Discussion of EMI Problems	27

LIST OF TABLES AND FIGURES

Tables	Title	Page
3-1	Tabulation of Gemini System-Level EMC Problems	5
4-1	EMC Problem Summary	26

Figures	Title	Page
3-1	Reduction of EMI by Twisting the Signal Wire With its Return	16
3-2	Solenoid Valve Interference	19
3-3	Accelerometer Grounding Configurations	22

1.0 INTRODUCTION - This analysis is written under the requirements of SAFSL-12006, as a part of the Gemini B contract, and summarizes a review of the electromagnetic interference (EMI) problems experienced on the NASA Gemini Program.

To clarify the EMC philosophy of the Gemini project a background of its EMC program has been presented in Section 2. The EMC problems encountered on the NASA Gemini program at the system level have been tabulated in Section 3, Table 3.1. This is followed by a presentation of 13 representative case histories. (Additional EMI problems are briefly discussed in the Appendix.)

2.0 GEMINI EMC PROGRAM BACKGROUND

2.1 Program Description - McDonnell's EMC responsibility to the NASA on the Gemini program was to design and develop a vehicle which would carry out its intended mission without comprimise from EMI. NASA placed no specific EMI requirements on any McDonnell hardware, other than where it interfaced with other contractors' equipment. Implicit in the definition of McDonnell's responsibility was the responsibility to fix, or rectify, any EMI problem that might be encountered.

McDonnell did not choose to impose EMI specifications on vendor supplied equipment as a compliance requirement. MIL-I-26600 was applied only as a design goal and test requirement. There is evidence that some of the vendors were conscientious, and did in fact use this military specification as a design goal. The EMI activity on the part of other vendors was obviously tempered by the fact that there were no compliance requirements.

The Genistron Corporation was given a contract by McDonnell to assist in the control of EMI on the Gemini program. The joint McDonnell and Genistron effort consisted of:

(1) writing the EMI Control Plan;

(2) writing EMC Design Notes;

(3) reviewing spacecraft (S/C) shielding and grounding techniques;

(4) review vendor test procedures;

(5) reviewing vendor test results;

(6) recommending corrective action where vendor tests indicated a potential problem at the system level;

(7) recommending corrective action where problems were encountered during Electronic System Test Unit (ESTU) tests, at the McDonnell-St. Louis facility;

(8) monitoring interfaces with associate contractors for compliance with EMI requirements.

This activity not only prevented many EMI problems, but resolved others which arose during ESTU tests. A good example of EMC problem prevention was the effort involved in the redesign of the Agena acquisition lights. The results of EMI tests performed by the vendor indicated a strong possibility that the broadband noise generated by the acquisition lights would interfere with the C-band radar beacon and rendezvous radar transponder. Tests utilizing the questionable components verified this suspicion as fact. A coordinated assult on the problem by McDonnell, the vendor and the customer resulted in a redesigned acquisition light and the addition of a power filter. This made the visual acquisition and radar system compatible as verified by ground test as well as flight performance.

Much EMC activity, problem prevention, and problem resolution did in fact occur on the Gemini Program prior to system tests. However, in spite of this activity, 100 separate problems caused by EMI were recorded on the Gemini program during system level tests at St. Louis and Cape. These are the problems which are described in this study.

Whereas this report emphasizes the problems which were encountered during the system-level tests, due credit is given to the EMC activity which prevented numerous other problems from remaining unsolved until final predelivery test of flight spacecraft.

3.0 GEMINI SYSTEM EMC PROBLEMS

3.1 General - All EMC problems investigated in this study have been tabulated in Table 3-1. The problems have been noted in the right-hand colums as due to glitches, steady state EMI, or RF environment. Problems due to glitches are those that occurred as a result of switching activity initiated by test personnel, or the astronauts. Problems due to steady state EMI are those that occurred as a result of the steady state operation of the S/C systems, and not as the result of switching activity. Problems due to RF environment are those that occurred as a result of the operation of the S/C in its deliberate RF environment. A deliberate RF environment is defined here as an RF environment due to deliberately generated signals from intended sources. There was no program schedule impact resulting from the problems discussed herein because the problems were resolved at the system level rather than redesigning flight equipment.

3.2 Representative EMC Problems - The 100 EMC problems are listed in Table 3-1. A group of detailed "case history" presentations of the more interesting and educational problems are presented below. Each of these accounts describes the problem, then discusses the present Gemini B status of corrective action, if any. Some additional EMC problems have been discussed briefly in Appendix A.

3.2.1 Computer Malfunction Caused by Antenna Motor - During tests, glitches generated by the spacecraft HF communications antenna extend/retract motor caused the computer "malfunction" light to illuminate. (Ref. MRR #56AUG163 vs H431-11, St. Louis.)

3.2.1.1 Investigation - An examination of the test sequence and events which occurred at the time of the malfunction, indicated that the antenna motor was the probable cause. During the subsequent troubleshooting, transients of -40 to +90 volts (peak to peak) were observed on the motor power lines whenever the antenna motor was turned off or on. However, the troubleshooting effort failed to actually duplicate the anomaly in that the computer malfunction light did not illuminate.

TABLE 3-1

TABULATION OF GEMINI SYSTEM-LEVEL EMC PROBLEMS

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environment
1.	Computer Malfunction	Transients generated by coaxial switches in Erector Tower white-room	S/C 9 FRR-9A SEDR H468-9	X		
2.	Computer yaw-ladder signal interference	Noisy IGS power supply	S/C 7 DR#210		X	
3.	Computer halt	Unshielded computer halt line picking up noise	S/C 2 FRR		X	
4.	Computer malfunction	Extraneous wire on computer PIA test point picking up noise			X	
5.	Computer malfunction	Noise generated by HF communications antenna motor	MRR 56AUG163 vs H431-11		X	
6.	Computer malfunction	Caused by Building 103 ambient electro-magnetic noise	IDR#45 vs. H383-5			X
7.	Computer halt	Unshielded computer halt line picking up EMI of unknown source	IDR#33 vs. H434-5		X	
8.	Computer malfunction	High voltage transients on rate gyro power lines	IDR#3 vs H432-6		X	
9.	Z channel of IVI drove to zero	Extra wire on ATM Mode switch picking up switching glitches	IDR#5 vs H431-10	X		
10.	Z channel of IVI one count high	Unshielded IVI signal ground picking up EMI of unknown source	IDR#7 vs H431-7		X	
11.	Computer halt	EMI of unknown source	IDR#77 vs H383-4		X	
12.	Computer halt	EMI of unknown source	IDR#19 vs H371-3		X	
13.	Computer halt	EMI of unknown source	IDR#42 vs H371-3		X	

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environment
14.	Multiplexer (low-level) noise	Excessive EMI on instrumentation power line	IDR#1 vs J435-10 S/C DR#043		X	
15.	Multiplexer resets	Caused by pick-up from various spacecraft switching transients	IDR#3 vs D331-3 IDR#9 vs D385-3 S/C 3 DR#225	X		
16.	Noisy TM Parameter Readouts	Transients from evaporator and radiator valve solenoids	IDR#6 vs H385-3 S/C 3 MP#391 MPS#136 EO#D89637 vs DWG NO. 52-79393	X		
17.	Loss of sync on TM ground test station.	Transients from floor polisher in white room.	SEDR D321-3			X
18.	Noisy bio-med parameter readouts	RFI from spacecraft HF communications transmitter	IDR#1 vs H345-3			X
19.	Loss of sync on TM ground test station	TM AGE coaxial cable near UHF rescue beacon antenna	IDR#54 vs H431-2		X	
20.	Noisy TM parameter readouts	EMI from rate gyro power supply	IDR#29 vs H431-8		X	
21.	Noisy TM parameter readouts	EMI from spacecraft low-light-level television camera advance mechanism			X	
22.	Noisy TM parameter readouts	EMI from rate gyro package	IDR#11 vs H434-2R		X	
23.	Noisy TM parameter readouts	EMI from D-4 and D-7 experiments	Memo GSO-1671		X	
24.	Multiplexer resets	EMI from ECS valve solenoid transients	IDR#9 vs D385-3 IDR#3 vs D331-3 IDR#71 vs H431-4	X		

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environ-ment
25.	Multiplexer resets	Switching MDIU-ON		X		
26.	Multiplexer resets	Switching computer light - OFF		X		
27.	Multiplexer resets	Switching Bio-med Recorder - ON		X		
28.	Multiplexer resets	Switching D-14 Experiment - EXTEND BOOM		X		
29.	Multiplexer resets	Switching Platform Mode - CAGE SEF		X		
30.	Multiplexer resets	Switching A/C Power - OFF		X		
31.	Multiplexer resets	Switching Radar - OFF		X		
32.	Multiplexer resets	Switching C-Band Beacon - ON (via DCS)		X		
33.	Multiplexer resets	Switching Tape Playback - CONTINUOUS		X		
34.	Multiplexer resets	Switching H/F Whip Antenna - EXTEND		X		
35.	Multiplexer resets	Switching TM Control (TM) - R/T AND ACQ		X		
36.	Multiplexer resets	Switching Acme Logic Switches - PRI		X		
37.	Multiplexer resets	Switching Computer - ON		X		
38.	Multiplexer resets	Switching Platform Mode - FREE		X		
39.	Multiplexer resets	Switching TAPE DUMP via DCS Command		X		
40.	Multiplexer resets	Switching T/M Control (STBY) - OFF		X		
41.	Multiplexer resets	Switching Platform Mode - BEF		X		
42.	Multiplexer resets	Switching Bio-med Inst. C/B - ON		X		
43.	Multiplexer resets	Switching Platform Mode - CAGE BEF		X		

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environment
44.	Multiplexer resets	Switching Manual O_2 - HI RATE		X		
45.	Multiplexer resets	Switching Suit Fan - ON or OFF		X		
46.	Multiplexer resets	Switching Seq. Inst. C/B - OFF		X		
47.	Multiplexer resets	Switching Att. Control C/B - OFF		X		
48.	Noisy TM parameter readouts	RFI from spacecraft TM transmitter	IDR#40 vs H495-2			X
49.	Multiplexer (low-level) noise	EMI from nearby spacecraft power line	IDR#2 vs H432-6 EO#D121367 vs 52-99426 EO#D121366 vs 52-79501 EO#D123705 vs 52-79501		X	
50.	Noise on remote TM ground test station readouts	EMI picked up on extension cables to remote ground station			X	
51.	Noisy bio-med parameter readouts	EMI from defective ground station recorder motor	IDR#3 vs H434-10			X
52.	Noisy TM parameter readouts	RFI from spacecraft HF communications transmitter	IDR#49 vs H431-4			X
53.	Noise spikes on bio-med parameter readouts	Source unknown	IDR#24 vs H431-8		X	
54.	Noisy TM data channels	RFI from launch vehicle TM transmitter into multiplexer	DR#1550 vs H457-3			X
55.	Noisy TM data channels	Poor grounding and shielding of multiplexer	IDR#3 vs H453-3 S/C 3 DR#1484 Memo PGCK-1773		X	

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environment
56.	Noisy TM parameter readouts	RFI from spacecraft HF communications transmitter	S/C 3 DR#1333			X
57.	Noisy TM parameter readouts	RFI from spacecraft UHF communications transmitter	SEDR H456-7 S/C 6 Plan X test report; S/C 2 FRR			X
58.	Noisy TM parameter ECO2	RFI from spacecraft UHF beacon transmitter	IDR#7 vs H453-6			X
59.	Noisy bio-med parameter	EMI from S-3 experiment DC-DC converter	MRR 125ARG129 vs H383-8 EO#D124201 vs DWG. NO. 52T060232-297		X	
60.	Inadvertent VOX operation during EVA tests	Audio coupling within the 100 foot tether for S/C 8	IDR#12 vs H383-8 Memos GSO-1809 GSO-1914 S/C 9 STR-9513		X	
61.	Spacecraft intercom noise	Source located within ELSS chest-pack	MRR 46ATG121 vs H383-10 MPS S-63, S-66		X	
62.	Inadvertent S-band beacon interrogation	RFI from airport radar systems	Memo GSO-915			X
63.	Noise in spacecraft intercom	EMI from an AGE 28VDC power supply	IDR#22 vs H383-10		X	
64.	Noise in control room (St. Louis) intercom	EMI from C-band beacon				X
65.	DCS messages were erroneous	DCS ground station (St. Louis) susceptible to EMI	MRR 105AWG10 vs H431-8		X	
66.	Inadvertent VOX operation during EVA tests	Audio coupling within the EVA tether for S/C 9	Memos GSO-1809 GSO-1914 GSO-2293 S/C 9 STR-9513		X	

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environment
67.	ATDA C-beacon replied when S/C 9 C-beacons were interrogated	S/C interrogate and reply signals combined to meet ATDA interrogate code.	Memo GSO-1914		X	
68.	Noise in spacecraft intercom when EVA tether was connected	Audio feedback within EVA communications system	Memo GSO-1809		X	
69.	Noise in spacecraft intercom when ELSS chest-pack heaters were on "emergency"	Electrical noise generated by the emergency oxygen heaters			X	
70.	Noise in spacecraft intercom	EMI from erector white-room automatic photographic camera			X	
71.	Interference on spacecraft-to-block house UHF link	RFI from Miami Airport	S/C 2 FRR			X
72.	"Cross-talk" on spacecraft intercom	Audio coupling within the AGE ground-to-spacecraft intercom cable	S/C 4 FRR		X	
73.	Interference on Cape DCS link	RFI from "Range" transmissions				X
74.	IMU Malfunction indication	Malfunction detector energized by EMI from various switching activities	IDR#32 vs H431-2 S/C 2 DR#276	X		
75.	Ripple on IMU dither voltage	System was susceptible to EMI because of an ineffective shielding configuration.	IDR#43 & 54 vs H453-2 IDR#2 vs H462-2 IDR#7 vs H453-7 S/C 2 MPS's 05-767, 05-824, 05-833			

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environ-ment
76.	Noisy G&C recordings	Thruster solenoid transients on monitor lines	IDR#54 vs H453-2	X		
77.	IMU Malfunction indication	EMI from switching activity	IDR#42 vs H371-2	X		
78.	Inadvertent activation of Roll jets	EMI from rate gyro package	IDR#61 vs H431-4		X	
79.	Noise on G&C ladder signals	EMI from Primary O_2 heater	S/C 9 FRR		X	
80.	Horizon scanner loss-of-track	AGE cable picking up EMI	IDR#29 vs H431-4 AGE MRR 35AWG39		X	
81.	Horizon scanner interference	Extraneous wire in AGE acting as antenna and picking up EMI	IDR#12 vs C371-4		X	
82.	Horizon scanner loss-of-track	EMI from spacecraft HF antenna motor	IDR#18 vs H431-11		X	
83.	Horizon scanner loss-of-track	Susceptible to EMI from various sources	IDR#8 & 11 vs H495-3 S/C 2 DR#1314		X	
84.	Horizon scanner loss-of-track	EMI picked up on AGE cabling	IDR#29 vs H431-4 AGE MRR 45AWG5		X	
85.	Horizon scanner improper operation	System susceptibility due to poor spacecraft grounding and shielding configuration	IDR#33 vs H431-3 S/C 3 MPS's 05-275, 05-285, 05-292, 05-295		X	
86.	Inadvertent ATDA commands	ATDA L-band radar susceptible to various forms of EMI	ATDA SEDR M453 Memos GSO-1901 GSO-2001		X	
87.	Erroneous radar readouts	EMI from many different AGE sources			X	

TABLE 3-1 Continued

Item #	Problem	Cause	Documents	Glitches	Steady State EMI	RF Environment
88.	Erroneous radar readouts	EMI from Agena acquisition light			X	
89.	Interference on spacecraft radar	RFI from Patrick AFB radar	SEDR H466-8 Memo PGCK-2881			X
90.	EMI source in TDA	Unsuppressed mooring drive motor	McDonnell Report 052-066.67		X	
91.	EMI source in TDA	Unsuppressed latch release motor	McDonnell Report 052-066.66		X	
92.	Power Supply (28VDC) fluctuations	Sensing lines picking up transients generated by spacecraft coaxial switch	IDR#28 vs H434-12	X		
93.	Power supply fluctuations	Sensing lines picking up transients present on adjacent wires in complex		X		
94.	Noisy accelerometer outputs	Due to "common impedance" grounding configuration	IDR#50 vs J435-6		X	
95.	Inadvertent OAMS thruster firing	Transients generated by adjacent OAMS thrusters	MRR 75APG121 vs H383-6		X	
96.	Spurious RF emissions in vicinity of spacecraft	Emitted from D-14 experiment package	MRR 26ASG84		X	
97.	Spurious oscilliations in MMU	EMI introduced via AGE test box	Memo GSO-1914		X	
98.	Interference on FDI	EMI from D-12 (AMU) experiment	Memo GSO-1827 MRR 16ASG7 vs S/C 9		X	
99.	Noise on D-10 experiment electrometers from ambient EMI	High input impedance to electrometers	IDR#22 vs H434-10 MRR 36ATG8 EO#D114662 vs DWG. NO. 52-79505		X	
100.	Low-light-level television susceptibility to EMI	Characteristic of design	IDR#43 vs H434-8 Memo GSO-1812		X	

3.2.1.2 Corrective Action - The flight plan was amended to enable the computer to be turned off whenever either of the two HF communications antennas were being extended or retracted.

3.2.1.3 Gemini B Status - The present flight plan is such that only one HF antenna is used, which will be extended after touchdown. During this time the computer will not be on. Also, tests will be performed on the antenna motor to determine if suppression devices on the motor would be desirable for out-of-sequence testing during SST.

This case illustrates a characteristic frequently encountered in EMC problems, namely that of nonrepeatability, or random occurrence. The account also indicates the application of flight plan logic as an alternative to hardware redesign.

For a tabulation of computer system EMC-related problems, see Table 3-1, Items 1 through 13.

3.2.2 Computer Malfunction Caused by AGE-Coaxial Switch - During tests at Cape Kennedy the computer "malfunction" light illuminated whenever either of two Aerospace Ground Equipment (AGE) coaxial switches, used to sequence antennas, were actuated. (Ref. IDR#1 vs H468-9; FRR-9A, Cape.)

3.2.2.1 Investigation - Two motor driven coaxial switches, located at the top of the erector and controlled from the blockhouse, were powered by wires routed in proximity to many other lines between the spacecraft and blockhouse. The switching transients were coupled into adjacent computer lines along the one throusand foot run to the spacecraft, resulting in the computer malfunction.

3.2.2.2 Corrective Action - One of the switches was replaced by a manually operated switch, and the other by a hybrid ring coupler.

3.2.2.3 Gemini B Status - A switching transient occuring in a wire, one thousand feet long, could be expected to cause problems in nearby sensitive systems. Whenever control by means of switched power must be managed at a remote point (as in this case), 3.2.2.3 Continued

a low current, low voltage control system should be used. To further guard against the coupling of magnetic and electric fields into other circuits, the control wire should be twisted with its return, and the pair shielded. If it is impossible to route the two leads together, they should be kept away from sensitive signal lines, making sure that any electromechanical devices which they operate (such as relays, etc.) are properly suppressed. These precautions will be followed on Gemini B.

3.2.3 Glitches Caused Spurious Radar Commands to Augmented Target Docking Adapter (ATDA) - Several ATDA functional operations were generating transients which, when coupled into the L-band radar command link, caused the docking cone to change from the rigidized to the unrigidized state, or vice versa. (Ref. ATDA SEDR M453; Memos GSO-1901, Cape.)

3.2.3.1 Investigation - The two main sources of interference were: (1) transients on the ATDA power busses caused by on-board equipment being turned on and off, and (2) transients generated within the L-band transponder itself.

3.2.3.2 Corrective Action - The incorporated solutions consisted of (1) the addition of in-line power filters, (2) improvement (from an EMC standpoint) of the wiring configuration, (3) the addition of an external suppression circuit to the transponder, and (4) the reconfiguration of the RCS thruster solenoid suppression diodes.

3.2.3.3 Gemini B Status - The ATDA is not included in the Gemini B configuration.

3.2.4 Inadvertent Keying of Spacecraft UHF Communications Transmitter - During altitude chamber tests, the extravehicular activity (EVA) communications system did not perform properly due to audio coupling within the astronaut's one hundred foot tether cable. (Ref. Memos GSO-1809, GSO-1914; STR 9513; IDR#12 vs. H383-8, St. Louis.)

3.2.4.1 Investigation - Audio signals from the EVA headset wires were coupled into the EVA microphone lines. This audio coupling was a result of a deviation from the following EMC design principle: Each audio "signal" wire should be tightly twisted

3.2.4.1 Continued

with its "return" wire to cancel the magnetic fields present around each of the individual wires. The deviation occurred when one wire of each pair was diverted to a relay in the astronaut's EVA Life Support Package or "back-pack". Therefore, for a short distance (about three feet), the magnetic fields around the wires were not cancelled, and inductive coupling resulted. These audio signals were then sent into the spacecraft Voice Control Center (VCC) where they activated the automatic, voice operated communications transmitter keying circuit (VOX). When the transmitter is keyed, the communications receiver is disabled. Thus, when the ground station transmitted to the spacecraft receiver, the resultant audio would immediately disable the receiver and momentarily disrupt reception in the spacecraft.

An interesting test conducted by the Boeing Company demonstrates the effectiveness of twisting the signal wire with its return, in order to reduce EMI (See Figure 3-1). Although this test called for a signal to be induced into the test cable, the reciprocal nature of electromagnetic field effects allows the results of the test to indicate the relative amounts of signal that would be radiated from the various cable configurations.

3.2.4.2 Corrective Action - The flight plan was altered to eliminate the VOX mode of operation in the space-to-ground communications link during EVA.

3.2.4.3 Gemini B Status - The EVA Life Support Package (back-pack) is not included in the Gemini B configuration.

3.2.5 Tracking-Beacon Transponder Interrogated by Airport Radar - During the Spacecraft No. 3 vibration tests, the S-band tracking-beacon transponder replied intermittently to "interrogations" from the combined signal of a U.S. Weather Bureau radar and a FAA approach control radar, both about one mile from the McDonnell spacecraft facilities. (Ref. Memo GSO-915, St. Louis).

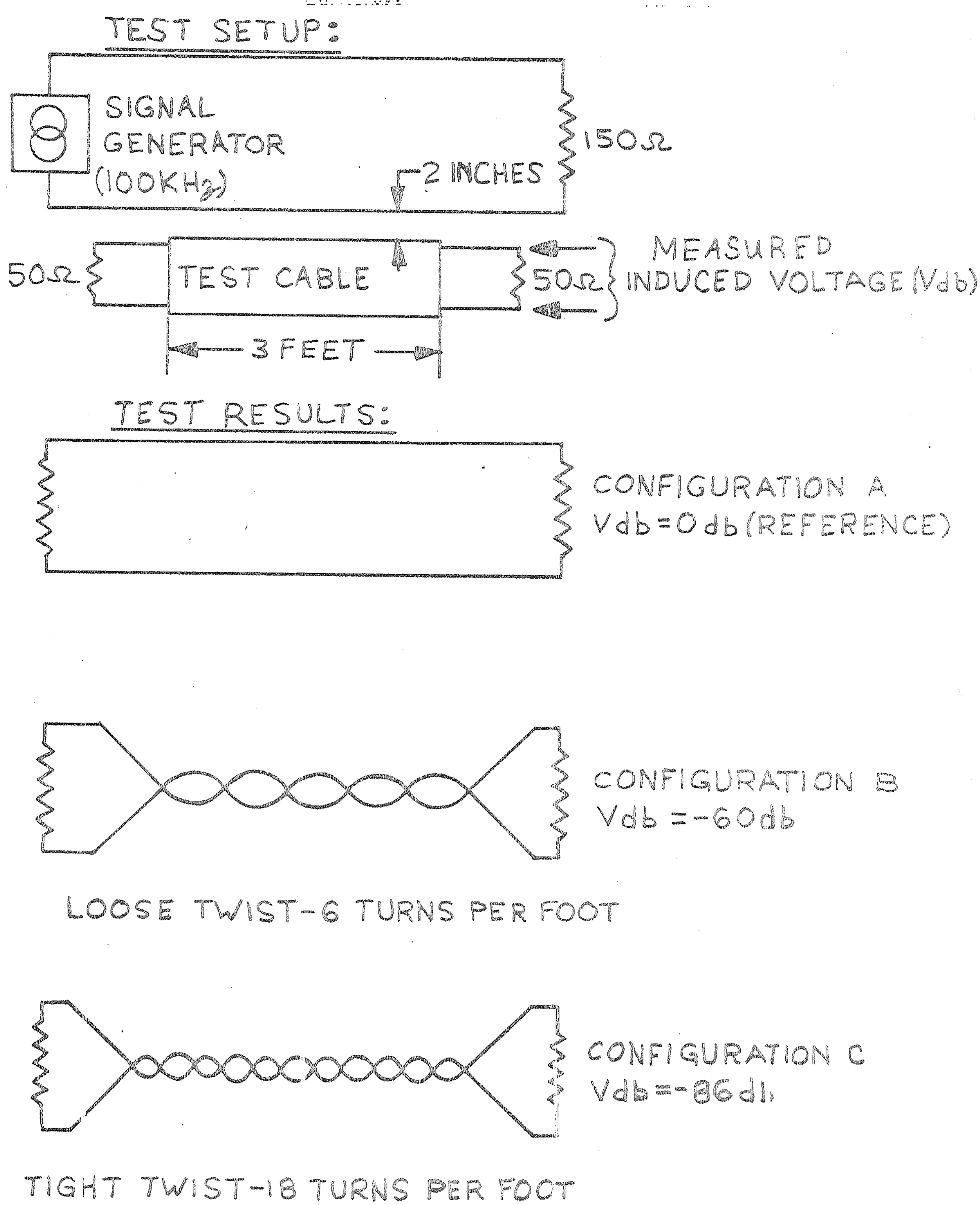


FIGURE 3-1 REDUCTION OF EMI BY TWISTING THE SIGNAL WIRE WITH ITS RETURN

3.2.5.1 Investigation - The coding requirement for successful interrogation of the transponder (i.e. to obtain a beacon reply) called for a pair of pulses whose leading edges were separated by 6.5 μsec., $\pm$ 1.8 μsec. The interrogation frequency was 2840 MHz and the receiver bandwidth at 30 db was specified to be no more than 40 MHz. The FAA radar transmitted a single pulse at 2820 MHz, and the Weather Bureau radar transmitted a single pulse at 2881 MHz. The rotating radar antennas allowed the pulses to periodically combine into pairs which met the beacon receiver coding and input frequency/amplitude requirements.

3.2.5.2 Corrective Action - No corrective action was taken.

3.2.5.3 Gemini B Status - The S-band tracking beacon transponder is not included in the Gemini B configuration.

3.2.6 Experiment Transmitter Emitted Spurious Radiations - A GFE supplied special purpose spacecraft transmitter (Experiment No. D-14) was found to be radiating many spurious frequencies during prelaunch tests at Cape Kennedy. (Ref. MRR#26ASG84, Cap.)

3.2.6.1 Investigation - The D-14 experiment consisted of a dual frequency, low power, CW transmitting system, designed to assist in the study of the Faraday Rotation effect. The spurious radiations were detected with a ground test station spectrum analyzer during routine spectrum surveillance.

3.2.6.2 Corrective Action - The transmitter was retuned by the experimenter (Navel Research Labs) which eliminated the spurious radiations.

3.2.6.3 Gemini B Status - The D-14 experiment is not included in the Gemini B configuration.

3.2.7 Experiment Package Interferred with Measurement of Bio-Med Parameters - The electrocardiogram and respiration rate telemetry parameters from both astronauts were being interferred with by a spacecraft GFE experiment package (Experiment S-3). (Ref. MRR#125ARG129 vs. H383-8, St. Louis.)

3.2.7.1 Investigation - The S-3 experiment consisted of two identical packages which were designed to provide data for the study of the effect of an outer space environment on the growth of frog eggs. The interference was generated in a small DC-DC converter within each package, and was coupled into the astronaut's bio-med parameter monitoring system.

3.2.7.2 Corrective Action - The wire harness leading to the packages was redesigned to incorporate shielded wire and EMI filters.

3.2.7.3 Gemini B Status - The S-3 experiment is not included in the Gemini B configuration.

3.2.8 ECS Solenoid Valve Glitches Interferred with Telemetry System - Transients generated by the spacecraft evaporator and radiator valves caused loss of syncronization of the telemetry system during tests. (Ref. IDR#6 vs. H385-3; S/C 3 MPS#91 and MPS#136 St. Louis.)

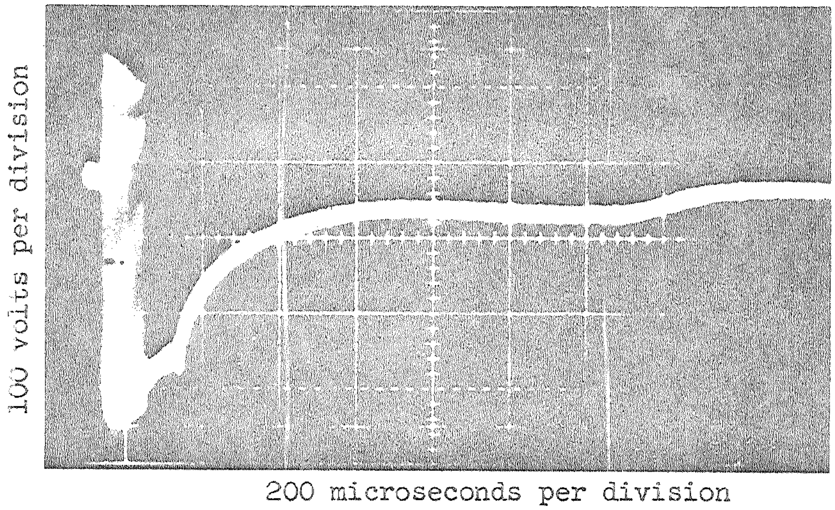
3.2.8.1 Investigation - The transient spikes (from 50 to 70 volts in amplitude) were observed on the solenoid power lines, but disappeared when suppression diodes were installed on the solenoid power plug.

3.2.8.2 Corrective Action - Since the actual solenoid terminals were inaccessible, the potting at the electrical connector to the valve was cut away, the diodes soldered to the exposed pins, and the connector was repotted. (See EO#D89637 vs. Dwg. No. 52-79393.)

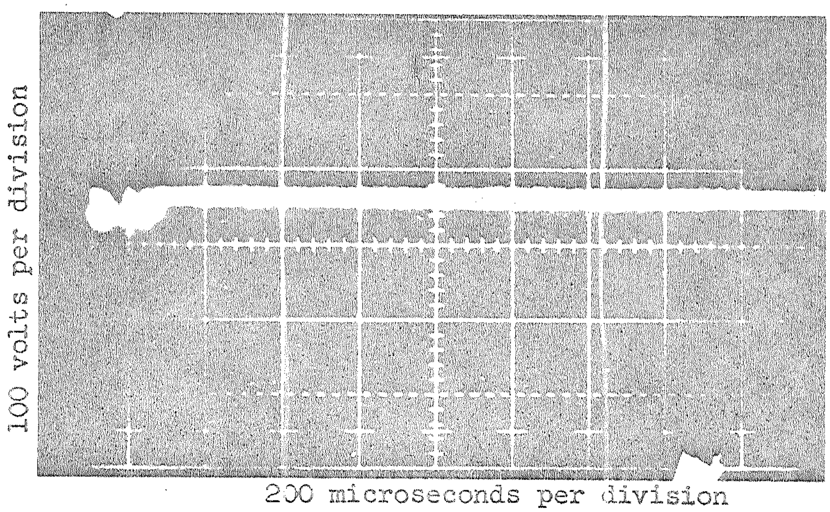
Figure 3-2 shows typical interference characteristics (500 volt, peak-to-peak glitch) of an unsuppressed solenoid. Also shown, for comparison, is the reduced interference level after a simple diode suppressor was added across the solenoid.

3.2.8.3 Gemini B Status - All solenoids on the Gemini B will be diode suppressed.

3.2.9 Coolant-Valve Solenoid Glitches Reset Telemetry Multiplexer - The spacecraft adapter-section telemetry multiplexer was repeatedly "reset" by high voltage transients from the coolant-valve solenoids. (Ref. S/C 3 DR#225; IDR#3 vs. D331-3; IRD#9 vs. D385-3, St. Louis,)



UNSUPPRESSED TRANSIENT (500V)



DIODE SUPPRESSED TRANSIENT (25V)

Figure 3-2. Solenoid Valve Interference.

3.2.9.1 Investigation - It was found that the coolant-valve solenoids generated transients, 300 to 500 volts in amplitude and of short (millisecond) duration, whenever the valves were actuated.

3.2.9.2 Corrective Action - The problem was solved by adding suppression devices to the solenoids. It should be noted that the coolant system was not alone in its ability to initiate a reset of the multiplexer. Some of the other spacecraft switching functions that have been known to cause multiplexer resets during the NASA Gemini program are:

1. MDIU - ON
2. Computer - ON
3. Computer Light - OFF
4. Platform Mode - FREE
5. Platform Mode - BEF
6. Platform Mode - CAGE BEF
7. Platform Mode - CAGE SEF
8. Platform Mode - OFF
9. DCS Command - TAPE DUMP
10. TM Control (STBY) - OFF
11. TM Control (TM) - R/T AND ACQ
12. Bio-Med Inst. G/B - ON
13. Bio-Med Recorder - ON
14. Manual O_2 - HI RATE
15. Suit Fan - ON or OFF
16. Att. Control C/B - OFF
17. Seq. Inst. C/B - OFF
18. ACME Logic Switches - PRI
19. A/C Power - OFF
20. Tape Playback - CONTINUOUS
21. C-Band Beacon - ON (via DCS)
22. Radar - OFF
23. D-14 Experiment - EXTEND BOOM
24. HF Whip Antenna - EXTEND

3.2.9.3 Gemini B Status - All solenoids will be diode suppressed on the Gemini B. The multiplexers are normally reset every 2.4 seconds to insure syncronization. A false reset therefore causes an abnormal situation for less than 2.4 seconds. Since this interruption will not degrade the mission objectives or flight safety of the crew, it was agreed by both McDonnell and Aerospace that no redesign of the multiplexer reset circuits is required for Gemini B. (Ref. Minutes of Preliminary Design Review for Gemini B PCM System McDonnell Company, St. Louis, Mo., held on 6 October 1966).

3.2.10 Glitches Caused AGE Power Supply Output to Fluctuate - Transients, generated by a spacecraft coaxial switch, appeared on the voltage sensing leads of an AGE power supply causing the output of the power supply to vary between 0 and 28 volts. (Ref. IDR#28 vs H434-12, St. Louis.)

3.2.10.1 Investigation - During EVA tests, a special purpose, spacecraft telemetry receiving system was used to receive transmissions from a low power telemetry transmitter located in the Astronaut Maneuvering Unit (AMU). A coaxial switch in the spacecraft, energized by a "signal seeking" circuit in the receiver, cycled the input of the receiver between two antennas, once every second, until a usable RF level was found.

High-amplitude, positive voltage transients, generated by the coaxial switch, were sent back to the AGE power supply via its sensing lines and were interpreted by the supply as momentary over-voltages. As a result, the power supply output voltage would drop to zero for about twenty milliseconds every time the coaxial switch was cycled. The energy stored by a 100,000 microfarad capacitor in the AGE power system maintained the actual spacecraft bus voltage at the proper level while the power supply was off.

3.2.10.2 Corrective Action - Suggestions for improvement of the AGE supply system which were considered, (but not incorporated) included: (1) a more judicious selection of the voltage sensing point, and (2) filtering of the sensing leads to prevent sensing-circuit response to transient voltages.

3.2.10.3 Gemini B Status - The special purpose, telemetry receiving system is not included in the Gemini B configuration. To prevent this type of problem from occurring on Gemini B, an R-C network is included in the voltage lines for sensing as close as possible to the spacecraft. Improved shielding is also incorporated for the Gemini B configuration.

3.2.11 Common Impedance Grounding System Caused Noisy Accelerometer Outputs - The ground test station telemetry readouts of the X, Y, and Z accelerometer outputs were unacceptably noisy. (Ref. S/C 6 DR#50 vs J435-6, Cape.)

3.2.11.1 Investigation - The noise was being imposed on the accelerometers via the common impedance of a ground path shared by the accelerometers and the instrumentation system's DC-DC converters. (See Figure 3-3).

3.2.11.2 Corrective Action - A separate ground path was provided (dotted line of Figure 3-3) for the accelerometer returns.

3.2.11.3 Gemini B Status - A separate ground path for the accelerometer returns will be provided on the Gemini B.

3.2.12 Excessive Noise on Low-Level Multiplexer Channels - The adapter-section low-level multiplexer outputs contained an unacceptably high noise level. (Ref. IDR#1 vs J435-10; S/C 10 DR#043, Cape.)

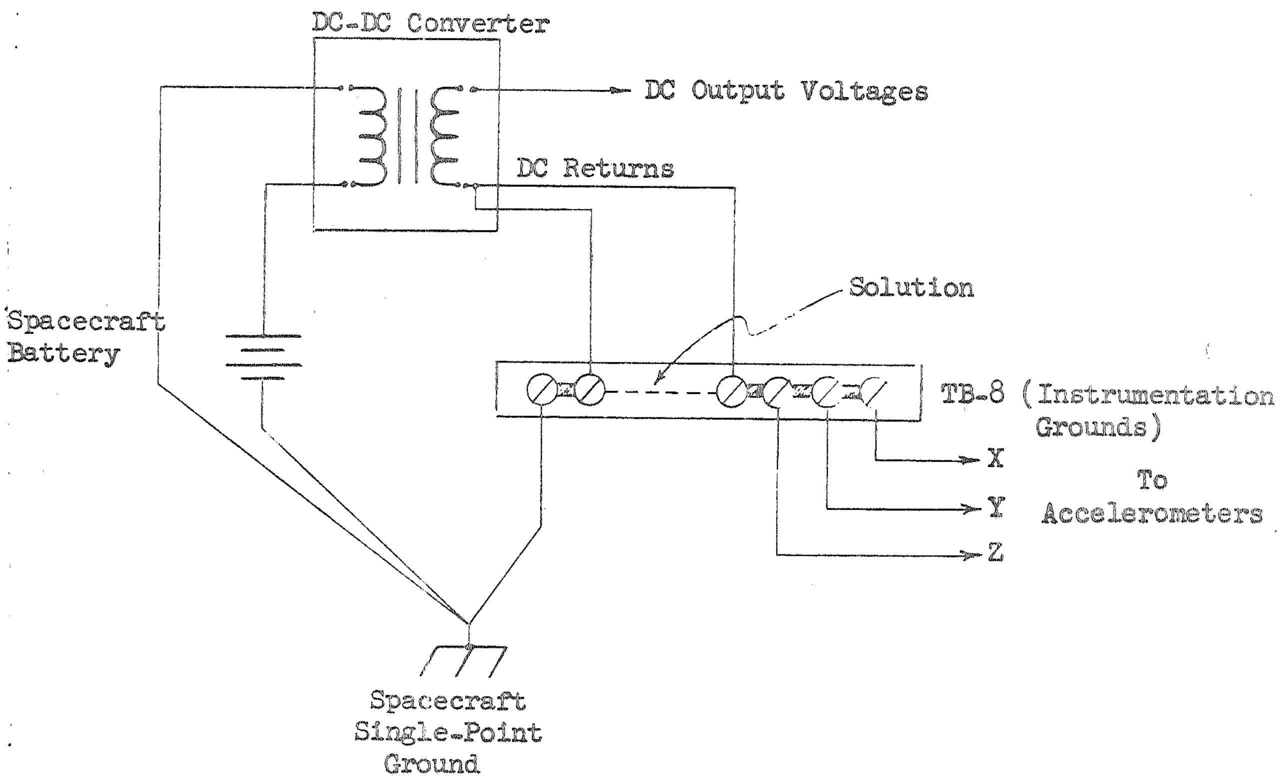


Figure 3-3. Accelerometer Grounding Configurations

3.2.12.1 Investigation - Electromagnetic noise (about 400 millivolts peak) observed on the instrumentation system's 24 volt main power line, was induced into the nearby multiplexer subsystem power wires.

3.2.12.2 Corrective Action - The instrumentation system's power line was rerouted away from the multiplexer power line.

3.2.12.3 Gemini B Status - Wire routing in the Gemini B adapter is in general much different from the wire routing in NASA Gemini, and it is not anticipated that this problem will reoccur. Tests will be conducted on the electronic systems test unit (ESTU) to insure that this condition is not present.

3.2.13 Excessive Noise on Gimbal Stabilization Signal Monitoring Lines - The guidance and control recordings of the gimbal stabilization signals were noisy when the RCS or OAMS jets were fired during tests. (Ref. IDR#54 vs. H453-2, Cape.)

3.2.13.1 Investigation - Transient spikes, about three volts in amplitude and 0.02 milliseconds in duration, were present on a one throusand foot-long jet-actuator monitoring line, and were coupled into the nearby gimbal stabilization signal monitoring cable.

3.2.13.2 Corrective Action - The jet-actuator monitoring lines were left disconnected, except when required for troubleshooting.

3.2.13.3 Gemini B Status - Since lines monitoring an electromechanical actuation are potential sources of EMI, their shielding and routing will be given special attention.

3.3 EMC During Gemini Mission - With the exception of the momentary loss of data due to multiplexer resets, the Gemini spacecraft was electromagnetically compatible during the mission as evidenced by the fact that there were no mission problems attributable to EMI. However, it should be remembered that in order to attain this EMC during the mission, a few flight constraints were imposed (example - Paragraph 3.2.1.2).

4.0 SUMMARY OF NASA GEMINI PROBLEMS - The Gemini System-level problems that were documented have been summarized in Table 4-1. Since NASA agreed that the multiplexer reset problems represented an acceptable design characteristic, (Ref. Inter-Office Memo No. 465-G1170, Minutes of MAC/NASA Policy Meeting held on 15 April 1965), not all multiplexer reset problems were documented. Of the subsystems having a sufficient number of EMC problems to rate special mention, the TM subsystem is the most significant, with 46% of the total. However, more than one-half of these TM problems involved the multiplexer reset function (see Paragraph 3.2.9), and were caused by glitches which could all have been avoided with either improved circuit design, or suppression measures. Excluding these. 22 EMC problems would have been related to the TM system. Since the other subsystems listed in Table 4-1 average 13 problems each, a total of 22 for the TM subsystem is not surprising considering its complexity, its vast cabling network, and the fact that it interfaces with all other spacecraft subsystems.

5.0 GENERAL GEMINI IMPROVEMENTS - During the NASA Gemini program, many EMI problems were encountered during production spacecraft testing. In order to reduce the EMI problems encountered on Gemini B, improvements have been made in the design of the spacecraft system, and more comprehensive EMC tests have been planned for the purpose of finding probable EMI problem areas before actual spacecraft production begins.

5.1 Design Improvements - Specific design improvements are given in this design note in the discussions of the Gemini B status of corrective action for the EMI problems encountered during NASA Gemini. General design improvements incorporated for Gemini B include additional shielding for computer wires and AGE cables, suppression of solenoids by the use of diodes, separation of wire categories in the adapter, wire routing improvements (from an EMC standpoint) in the re-entry section, low impedance paths between pyrotechnic initiators and structure, and SSD Exhibit 64-4 compliance on new equipments and interfacing equipments. These design improvements will not only eliminate the specific problems that occurred on NASA Gemini, but will also prevent the occurrance of the same type of problems on Gemini B.

5.2 Program Improvements - In addition to the design improvements for the Gemini B, the EMC test program has been improved in order to find probable EMI problem areas at an early state of the program.

During the NASA Gemini program, the ESTU and the compatibility test unit (CTU) were used to verify compatibility between systems. The NASA ESTU was used to determine if the electronic systems (Communications, Guidance and Control, and Instrumentation) would operate together. The CTU was used to determine if all electrical and electronic systems and associated AGE would operate together. Both of these units were helpful in eliminating EMI problems in the production spacecraft.

The Gemini B ESTU is similar to the NASA CTU in that it contains both the electrical and electronic systems, it utilizes a wiring configuration representative of flight vehicles, and it utilizes SST AGE and associated cabling. The NASA CTU did not completely achieve its objective because extensive wiring design changes took place that could not be reflected in the CTU because of schedule. It is anticipated that the extent of Gemini B design changes occurring too late to be reflected in ESTU will be much less than on NASA Gemini.

Formal EMC tests were not performed on either of the NASA test units. On the Gemini B, formal EMC tests will be performed on the ESTU. These formal EMC tests include:

Critical Point Safety Martin Test

Power Bus noise tests for each sub-system

Interfacing circuits noise tests with sophisticated interface simulations.

It is anticipated that this type of test will bring to light probable EMI problem areas, and will eliminate many of the NASA Gemini type problems before production testing.

TABLE 4-1

EMC PROBLEM SUMMARY

Related Subsystem	Quantity of Problems Encountered: Glitches	Steady State EMI	RF Environment	Totals
Computer	2	10	1	13
[illegible] Subsystem	27	10	9	46
Communications Subsystem	0	10	4	14
Guidance & Control Subsystem	3	9	0	12
Miscellaneous	2	12	1	15
TOTALS	34	51	15	100

Average system-level EMC problem per S/C = 8-1/2

APPENDIX A

SOME ADDITIONAL DISCUSSION OF EMI PROBLEMS

1.0 Loss of Telemetry Synchronization - Electromagnetic noise on the high-level multiplexer resulted in an intermittent loss of sync on the telemetry ground station. During the course of troubleshooting, it was noticed that resets would occur whenever a nearby maintenance man in the white room turned his floor polisher on or off. Solution: Filtering was added to the reset line, and the floors were polished between tests. (Ref.: SEDR ID321-5, St. Louis.) Gemini B Status: No redesign of this circuitry has been incorporated on Gemini B.

2.0 Audio Hum in Pilot's Headset - Considerable audio hum was being introduced into the pilot's lightweight headset by an AC powered DC supply located in an AGE console containing intercom audio circuitry. Solution: External batteries were used instead of the AGE power supply. (Ref.: IDR#22 vs. H383-10, St. Louis.) Gemini B Status: If this problem occurs during the Gemini B Program, the same solution will be incorporated.

3.0 Computer Malfunction Indication - During the manned altitude testing of Spacecraft Five, the computer malfunction light illuminated as a result of the high intensity, ambient electromagnetic interference in the vicinity of the Building 103 altitude chamber. Solution: No corrective action has been taken. (Ref.: IDR#45 vs. H383-5, St. Louis.) Gemini B Status: No improvements are expected in the ambient interference in Building 103. However, the computer malfunction light wire will be shielded in Gemini B.

4.0 DCS Ground Test Station EMI - The DCS ground station prepunched tape messages did not always agree with the messages actually sent to the spacecraft from the ground station. Also, the tape reader would stop occasionally at random messages, or start up by itself. The general concensus is that the cables and circuits interconnecting the various DCS ground station racks have shielding problems. Solution:

AC MRR #6 AWG3 - Shielding problem ... [illegible]
Corrected by EO 703186 # 52D190217

4.0 Continued

These interfaces received a great deal of attention, but no one acquainted with the system is certain that the problem was completely corrected. Gemini B Status: The DCS ground station is not used for the Gemini B.

5.0 Interference on IVI's - The Z channel of the IVI drove to zero because of an extraneous, open-ended wire connected to an unused position of the ATM mode switch. This wire was acting as an antenna which radiated transients, caused by the switch operation, into the IVI's. Solution: The wire was removed. (Ref.: IDR#5 vs. H431-10, St. Louis.) Gemini B Status: The wire which acted as an antenna will not be included in the Gemini B configuration.

6.0 Computer Malfunction Indication - Transients in excess of 150 volts were present on the rate gyro power lines, and caused a computer malfunction whenever the rate gyros were turned on. Solution: Zener diodes were placed across the rate gyros for transient suppression. (Ref.: IDR#3 vs. H432-6, St. Louis.) Gemini B Status: The Zener diode method of suppression will be incorporated on Gemini B.

7.0 Computer Halt Initiated by EMI - A computer halt signal was generated by EMI from an unknown source. The susceptibility was due to (1) an unshielded halt signal line, (2) the high impedance of the computer halt circuitry, and (3) the fast-rise-time characteristics of the transients. Solution: A filter capacitor was placed between the halt line and the computer signal ground. Other occasions on which computer halt signals have been generated by EMI are described in the following documents: IDR#77 vs. H383-4 (St. Louis altitude chamber), IDR#19 vs. H371-3, and IDR#42 vs. H371-3. (Ref.: IDR#33 vs. H434-5, St. Louis.) Gemini B Status: The halt circuitry has been redesigned to have a peak noise immunity of 5.2 volts and has been shielded. The NASA Gemini halt circuit would trigger when a 3 volt, 10 microsecond signal was on the HALT line.

8.0 <u>Telemetry Interfered with by HF Transmitter</u> - Throughout the entire NASA Gemini program, whenever the spacecraft HF transmitter was keyed, various telemetry parameters became noisy. It has been demonstrated many times that the situation is somewhat improved when the hatches are closed and all shingles are in place. Solution: No feasible solution has been proposed to this problem. However, every flight plan was written to insure that the HF communications system was not normally used during EVA (hatch open) exercises, since during this time both the interference, and the necessity for "clean" bio-med telemetry parameters, would be at their maximum. (Ref.: IDR#25 vs. H431-7, St. Louis.) Gemini B Status: The HF communications will not be used during the flight mission except during recovery. During this time no telemetry will be transmitted.

9.0 <u>Telemetry Interfered with by UHF Rescue Beacon</u> - The telemetry signal from the spacecraft to the ground test station became noisy and caused the ground station to lose sync whenever the UHF rescue beacon was turned on. The rescue beacon is a relatively high power UHF transmitter, and is pulse group modulated. It was designed in this way to permit receivers in rescue vessels to easily acquire the resultant signal. However, inadvertent acquisition by other systems is also possible, and occurred in this case because the coaxial cable carrying the telemetry signal to the ground station was routed so as to pass close by the rescue beacon antenna. Solution: The telemetry cable was rerouted. (Ref.: IDR#54 vs. H431-2, St. Louis.) Gemini B Status: The rescue beacon will not be operated at the same time the telemetry is transmitted. Also, the Gemini B uses a low power (3 watt) cw transmitter and is not expected to create a problem of this nature.