System Level EMC Testing Of Spacecraft

Pablo Narvaez

Jet Propulsion Laboratory, California Institute of Technology

Electromagnetic Compatibility Group (5132)

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EMC Testing Of Spacecraft Systems Overview

- **Purpose Of EMC System Level Testing:**
  - Demonstrate total functional performance for self-compatibility of integrated system including interface cabling.
  - Demonstrate total functional performance for compatibility with intended environment of integrated system including transmitter sources.
  - Demonstrate functional performance of components and functions not tested in assembly level qualification testing.
  - Confirms self-compatibility of integrated system and compatibility with intended electromagnetic environment.
- **Advantages Of EMC System Level Testing:**
  - Representative qualification including cable interaction (effects of routing, bundling, and crosstalk), sensors, and distributed functions.
- **Disadvantages Of EMC System Level Testing:**
  - Testing too late to make design changes;
  - EMI solutions are often forced to band-aids only.
  - Demonstrating margins are often not realistic because higher test levels stress flight equipment.

EMC Testing Of Spacecraft Systems Concerns/Issues

- **CONCERNS AND ISSUES WITH SYSTEM LEVEL EMC TESTS**
  - **Thermocouples, accelerometer wiring and other non-flight cables may impact tests in system configuration**
    - **All non-flight cabling/ wiring will require shielding**
    - **Represents worst-case scenario**
  - **Live pyros are required for radiated susceptibility tests**
    - **Should make plans to install them for test**
  - **Tests may uncover susceptibilities that may be too late to make design changes**
    - **Interference problems require immediate solutions that may impact schedules.**
    - **Problems may require operational work-arounds**
      - **Initial EMC system testing should be scheduled prior to rework periods**
  - **Demonstrating margins is often not realistic because higher test levels may stress flight equipment.**
    - **More true for component level conducted susceptibility, than system level testing**
  - **Solar arrays should be installed during system EMC tests.**
    - **Compatibility with transmitters is demonstrated.**

EMC System Level Testing
Mars Exploration Rover Overview

JPL

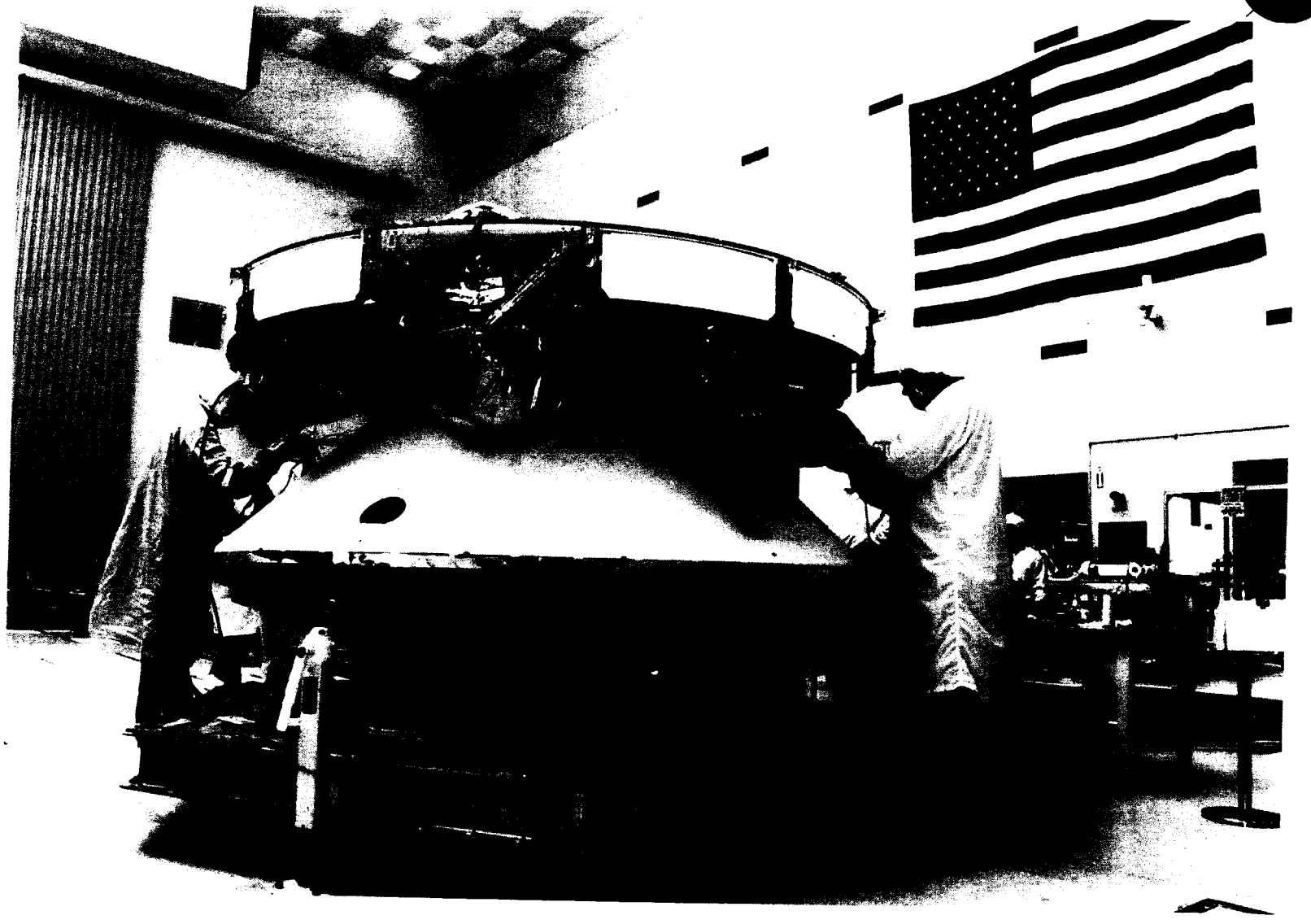
NASA

- **EMC Testing Of The Mars Exploration Rover**
- **MER mission will consist of the following mission phases:**

  Launch
  Earth to Mars Cruise
  Mars Approach
  Mars Entry, Descent, and Landing
  Mars Surface Operations

  – **Three mission phases selected for three system EMC tests;**
    - **Launch/Cruise**
    - **Descent or EDL (entry, descent, landing**
    - **Rover Surface Operations.**
  – **The MER system level tests were a combination of EMC tests and a limited functional self-compatibility test.**
  – **A functional self-compatibility test exercises each function independently while monitoring every other function for possible effects due to interference coupling.**

MER Launch/Cruise Configuration

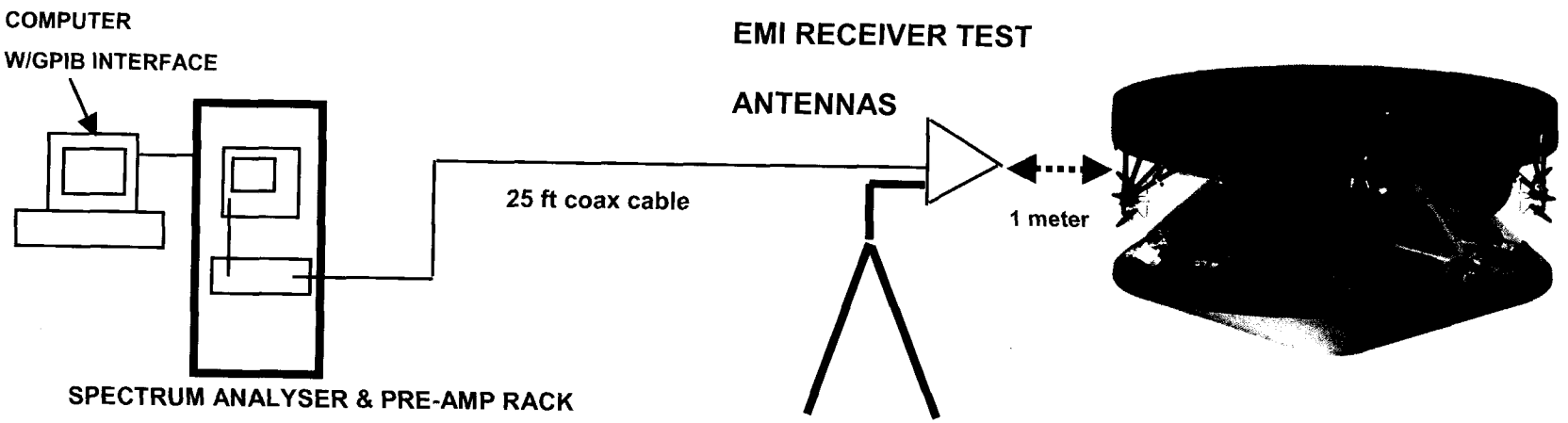


Launch/Cruise Phase EMC Tests, Objectives

- **Test Objectives For Launch/Cruise Configuration**
  - **Perform Radiated Emission (RE) measurements. Confirm system is compatible with launch vehicle receivers and launch site receivers.**
  - **Perform Radiated Susceptibility (RS) test. Confirm that MER pyro-devices will tolerate the effects of launch site transmitters and confirm that MER launch configuration is functionally tolerant of KSC launch site transmitters.**
  - **Verify proper pyro-device operation before and after RF stimulation. Both RS and RE tests will be performed in the same configuration.**
  - **Establish RF link and KSC RF environment. At appropriate times, pull umbilical and fire squibs.**

Launch/Cruise Phase EMC Tests

Test Configuration For Radiated Emissions



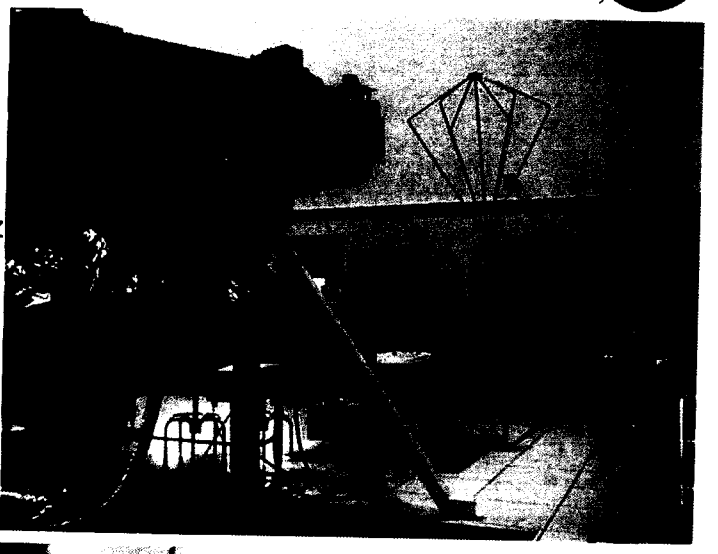
EMI TEST GSE EQUIPMENT

MER IN LAUNCH/CRUISE CONFIGURATION

Launch/Cruise Phase EMC Tests, Configuration

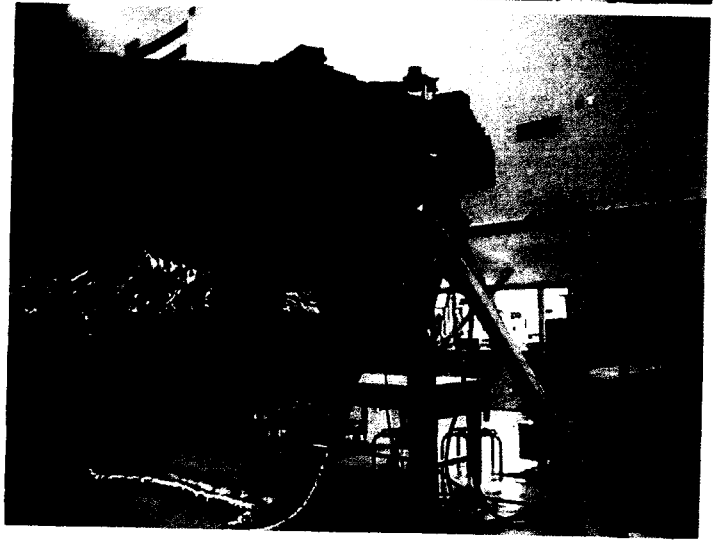
14kHz
to 40MHz

40 MHz
to 200 MHz



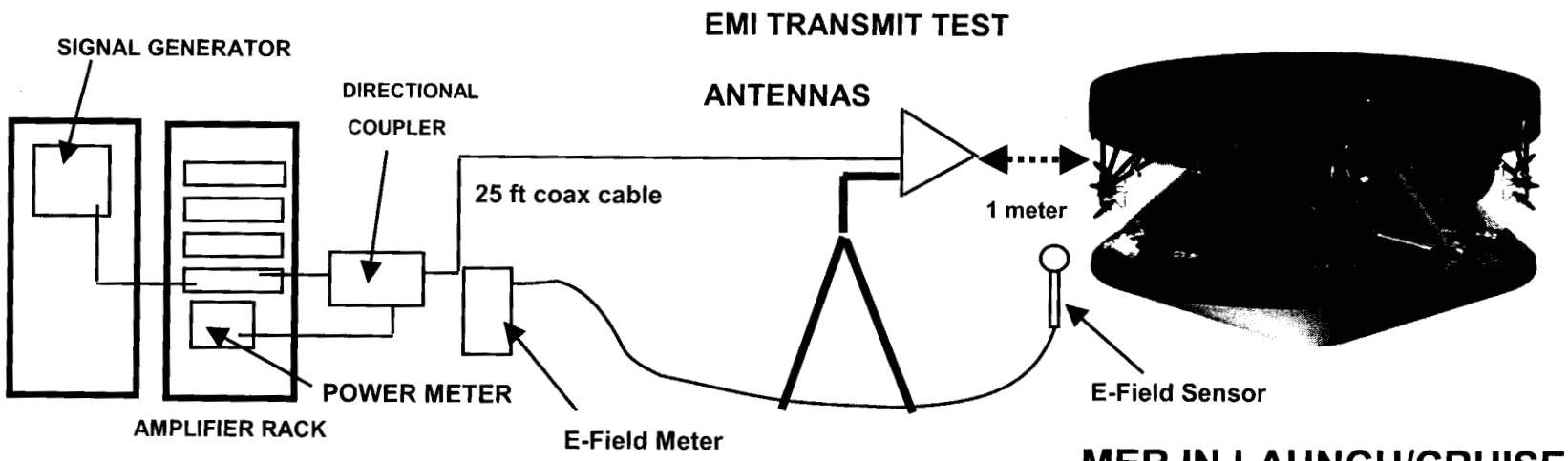
200 MHz
to 1 GHz

1 GHz
to 10 GHz



Test Configuration For Radiated Emissions
+Xs/c & -Xs/c Sides

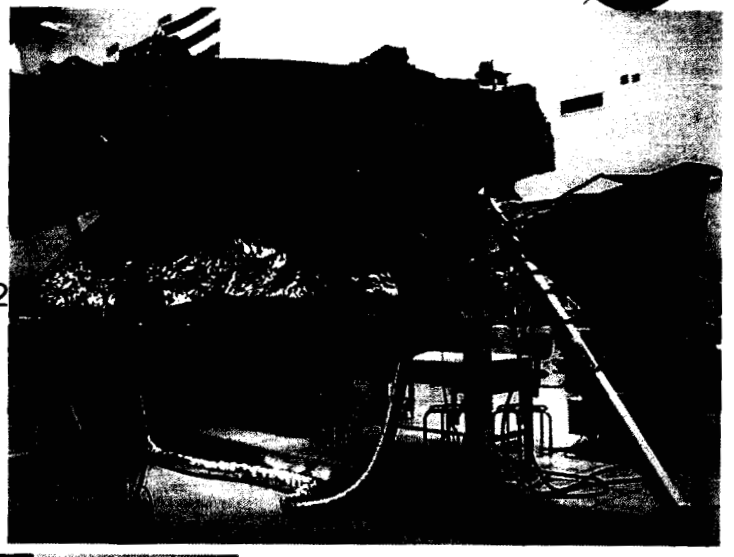
Test Configuration For Radiated Susceptibility



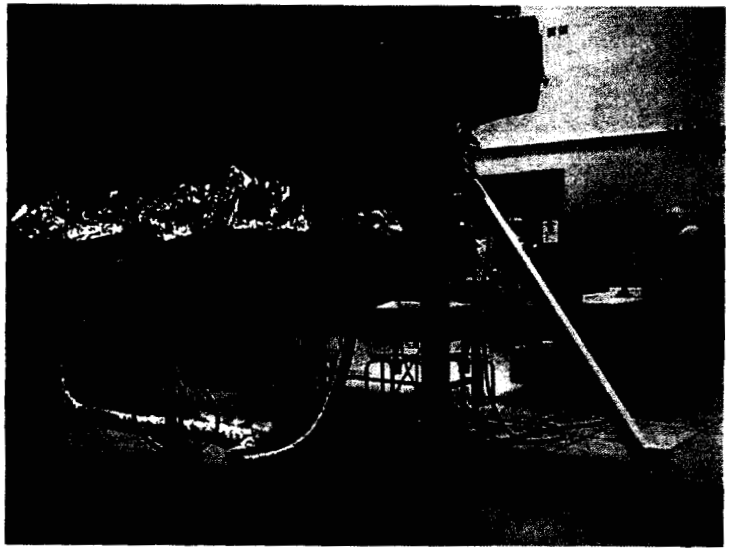
Launch/Cruise Phase EMC Tests, Configuration

14 kHz to 300 MHz Test Config. #1

300 MHz to 1 GHz Test Config. #2

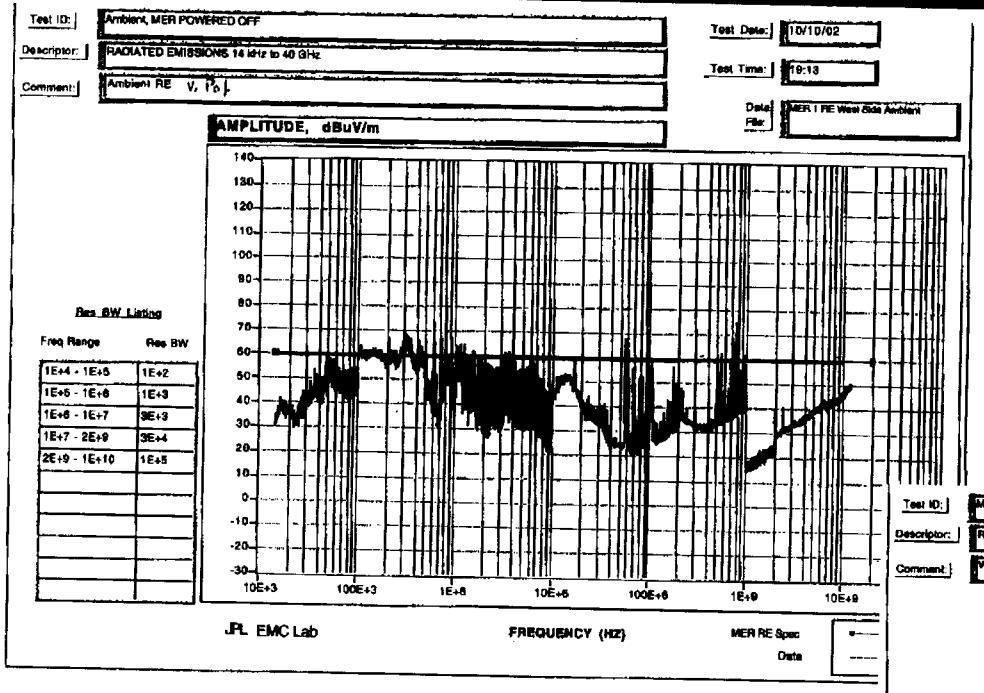


1 GHz to 10 GHz Test Config. #3



Test Configuration For Radiated Susceptibility

Launch/Cruise Phase EMC Tests, Typical Results



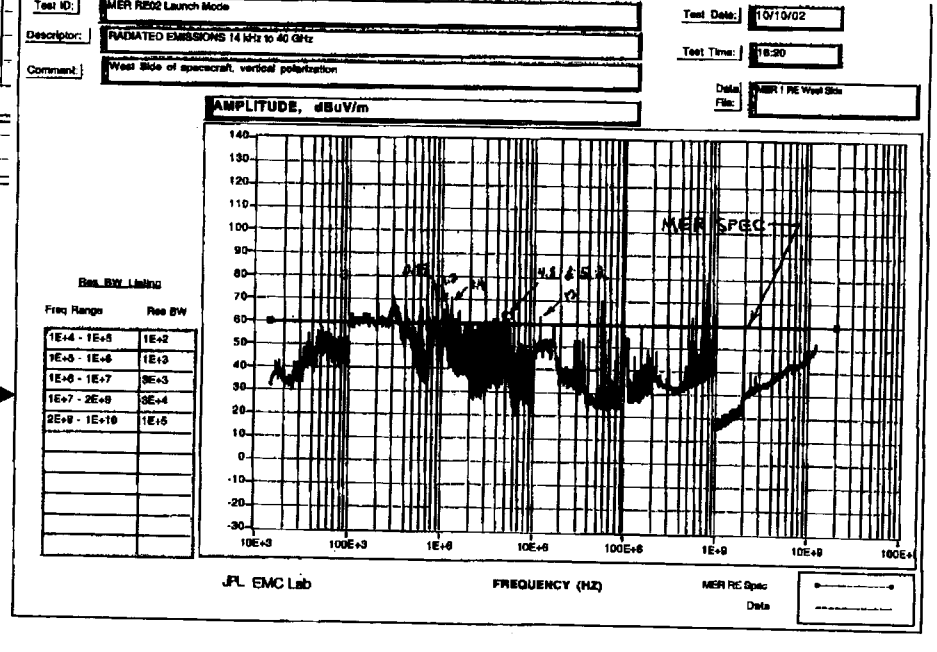
Radiated Emissions

Ambient, S/C OFF

Radiated Emissions

MER S/C ON

Launch/Cruise Mode



Launch/Cruise Phase EMC Tests, Results

RADIATED EMISSONS TEST RESULTS

1) MER 1 was tested for RE02 radiated emission spectra at 1 meter from the +Xs/c and -Xs/c sides in the vertical polarization and horizontal polarizations.
2) There were very minor, over-spec emissions on the +Xs/c side and only in the vertical polarization as indicated by the arrows in the previous figure 1. Over-Spec emissions occurred at 0.82 MHZ, 1.2 MHz, 1.4 MHz, 4.8 MHz, 5.2 MHz and 12 MHz. None of these pose a threat to Launch Vehicle receivers.
3) There were no over spec emissions in the -Xs/c (vertical and horizontal polarizations) nor were there over-spec emissions on the +Xs/c side in the horizontal polarization.

Launch/Cruise Phase EMC Tests, Results Summary

MER 1 RADIATED SUSCEPTIBILITY TEST RESULTS, GENERAL RF FIELDS

FREQUENCY RANGE	ANTENNA POLARIZATION	FIELD STRENGTH	TEST RESULT	COMMENTS
14 kHz to 300 MHz Test Configuration #1	VERTICAL	5 V/m	PASS	NO ANOMALIES
300 MHz to 1 GHz	VERTICAL	5 V/m	PASS	NO ANOMALIES
Test Configuration #2	HORIZONTAL	5 V/m	PASS	NO ANOMALIES
1 GHz MHz to 10 GHz	VERTICAL	5 V/m	PASS	NO ANOMALIES
Test Configuration #3	HORIZONTAL	5 V/m	PASS	NO ANOMALIES

Launch/Cruise Phase EMC Tests, Results Summary

RADIATED SUSCEPTIBILITY TEST RESULTS, KSC & S/C TRANSMITTERS

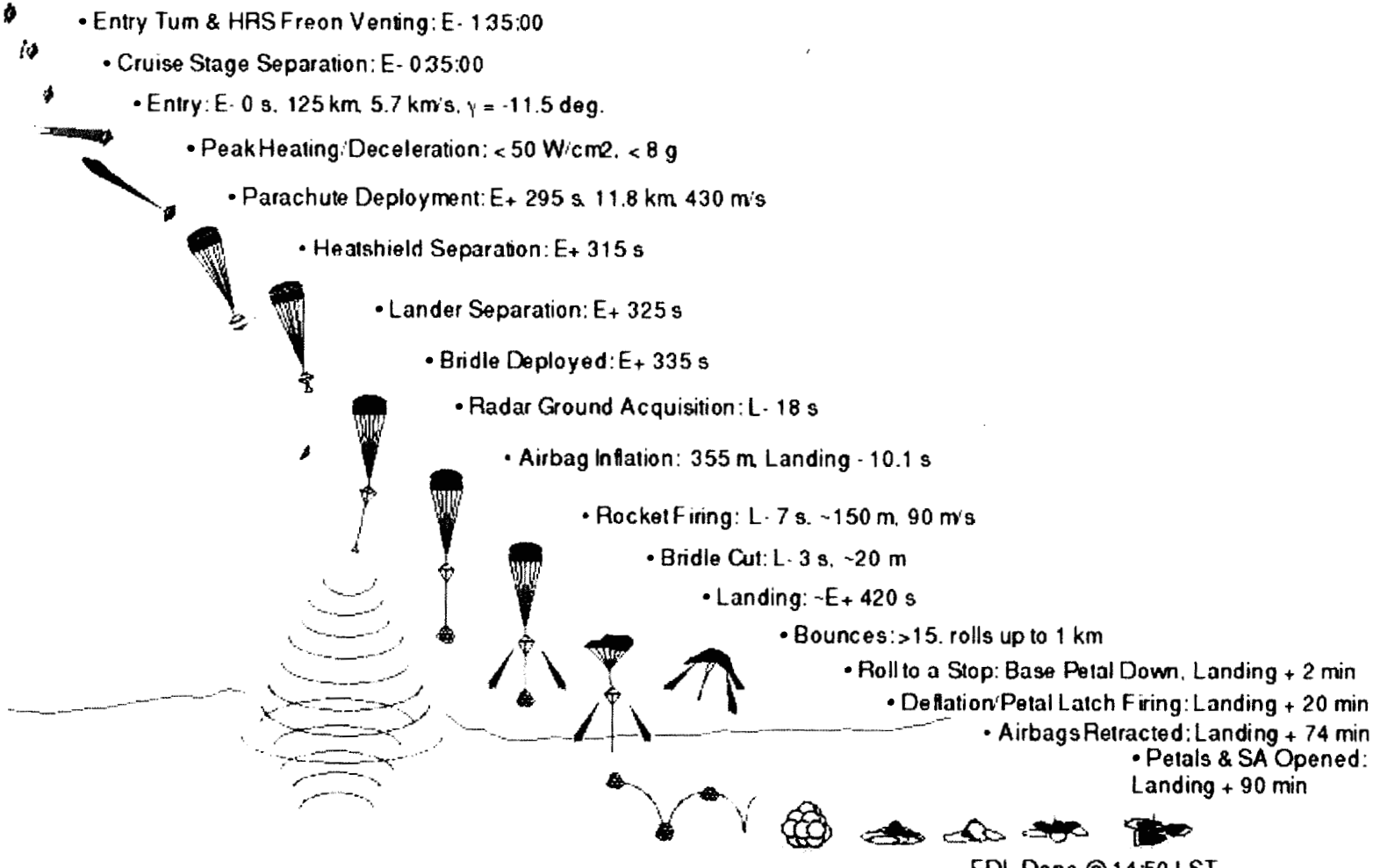
FREQUENCY RANGE	TEST ANTENNA POLARIZATION	FIELD STRENGTH	TEST RESULT	COMMENTS
2.2 GHz – 2.3 GHz	VERTICAL HORIZONTAL	50 V/m	PASS	NO ANOMALIES
2.75 GHz- 2.84 GHz	VERTICAL HORIZONTAL	18 V/m	PASS	NO ANOMALIES
2.865 GHz	VERTICAL HORIZONTAL	36 V/m	PASS	NO ANOMALIES
2.9 GHz-3.1 GHz	VERTICAL HORIZONTAL	40 V/m	PASS	NO ANOMALIES (Small Glitch)
5.625 GHz–5.768 GHz	VERTICAL HORIZONTAL	60 V/m	PASS	NO ANOMALIES
8.43 GHz-8.445 GHz	VERTICAL HORIZONTAL	85 V/m	PASS	NO ANOMALIES

MER 1 RADIATED SUSCEPTIBILITY TEST RESULTS, GENERAL RF FIELDS

1) The MER 1 S/C was irradiated in the vertical polarization from 14 kHz to 300 MHz and in both the vertical and horizontal polarizations from 300 MHz to 10 GHz.
2) The Small Deep Space Transponder was powered on and placed in the receive mode via the Cruise Low Gain Antenna (CLGA) during the radiated susceptibility testing. The antenna hats were removed and the X-Band receiver was left unlocked and the key parameters were monitored by the RFS team for possible anomalous or off-nominal readings.
3) During 5 V/m radiated susceptibility test, slight jumps in the Wideband AGC and Narrowband AGC were observed by the RFS team as the radiating frequency scanned across the 3rd and 2nd sub-harmonics of the 7.1 GHz – 7.2 GHz receive frequency (2.39 GHz and 3.59 GHz). This behavior was due to harmonics of the EMC signal generator and antenna. The SDST did not lock due to the signal strength and sweep rate.

MER Entry Descent & Landing

EDL Process



EDL Done @ 14:50 LST
Earth Set @ 15:20 LST

Descent/EDL Phase EMC Test Objectives

Test Objectives With MER in Descent/EDL Configuration

- A functional self-compatibility test that confirms that the Lander's Radar Altimeter System is unaffected by UHF transmitter and other operating functions while in descent configuration.
- Demonstrate that Descent Camera is not affected by Radar Altimeter
- Demonstrate that the backshell and rover Inertial Measurement Units are unaffected by UHF and X-Band transmitters via direct or indirect RF coupling on bridle cable
- Demonstrate that the X-Band patch (lander) antenna transmits properly
- Demonstrate plugs out compatibility
- Simulate deadface, i.e. cable cutter actions

Descent/EDL Phase EMC Test Configuration

TEST CONFIGURATION FOR EDL TESTS

1) Backshell was suspended above lander. RF absorber was placed on floor to attenuate RAS return signal.

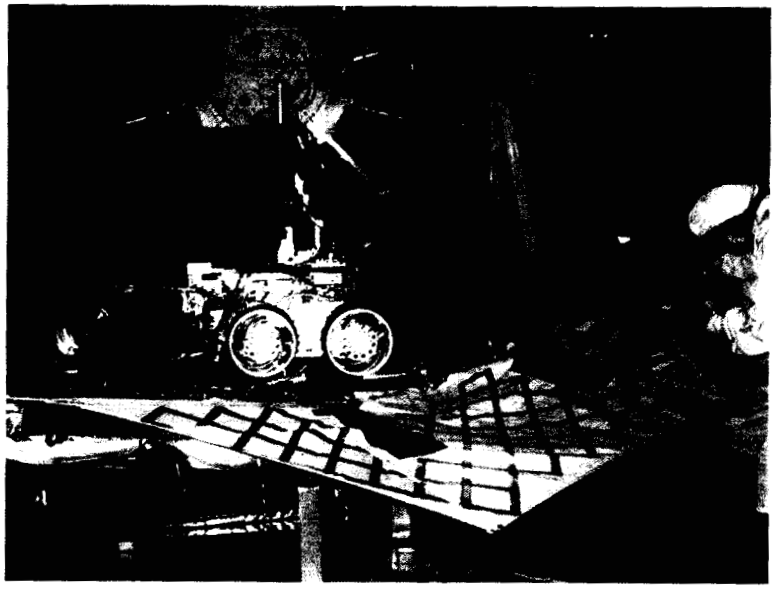
2) UHF and X-Band air- links established with EMC test antennas. Test confirmed compatibility of RF links with each other and with MER system.

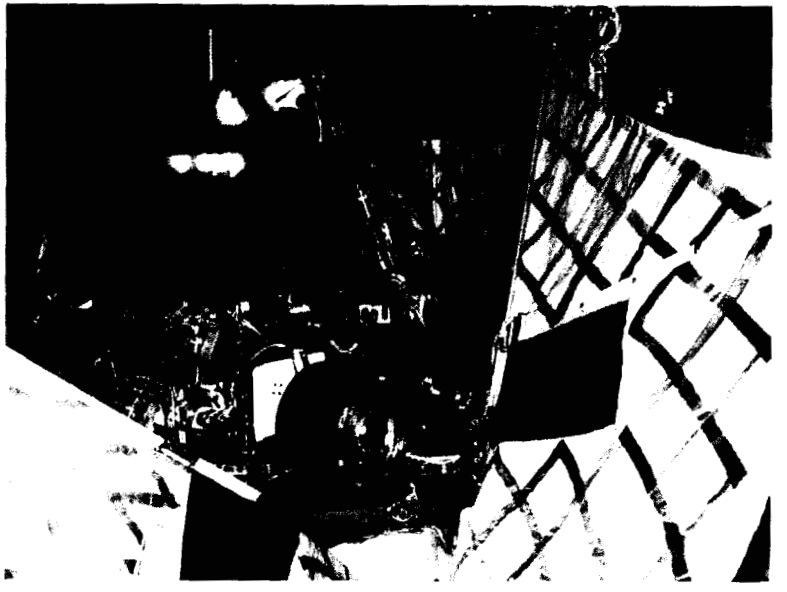
– Several tests performed in this configuration:

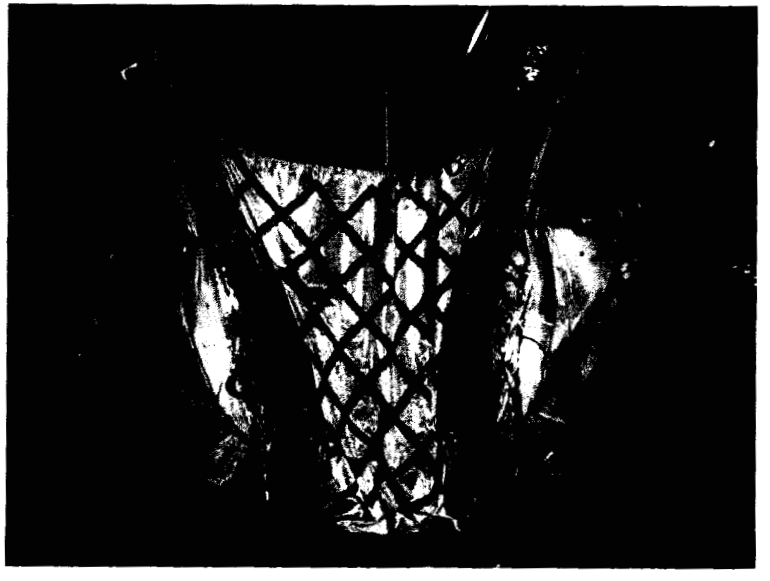
- a) Self-compatibility tests during the descent phase
  - › Radiate from the Lander Low Gain Antenna (LGA), Ultra High Frequency (UHF) monopole antenna, and Radar Altimeter antenna.
  - › At least one EDL simulation run will be performed
  - › Monitor IMUs, record results

3) Radiating via the X-Band patch antenna into EMC test antenna positioned below lander.

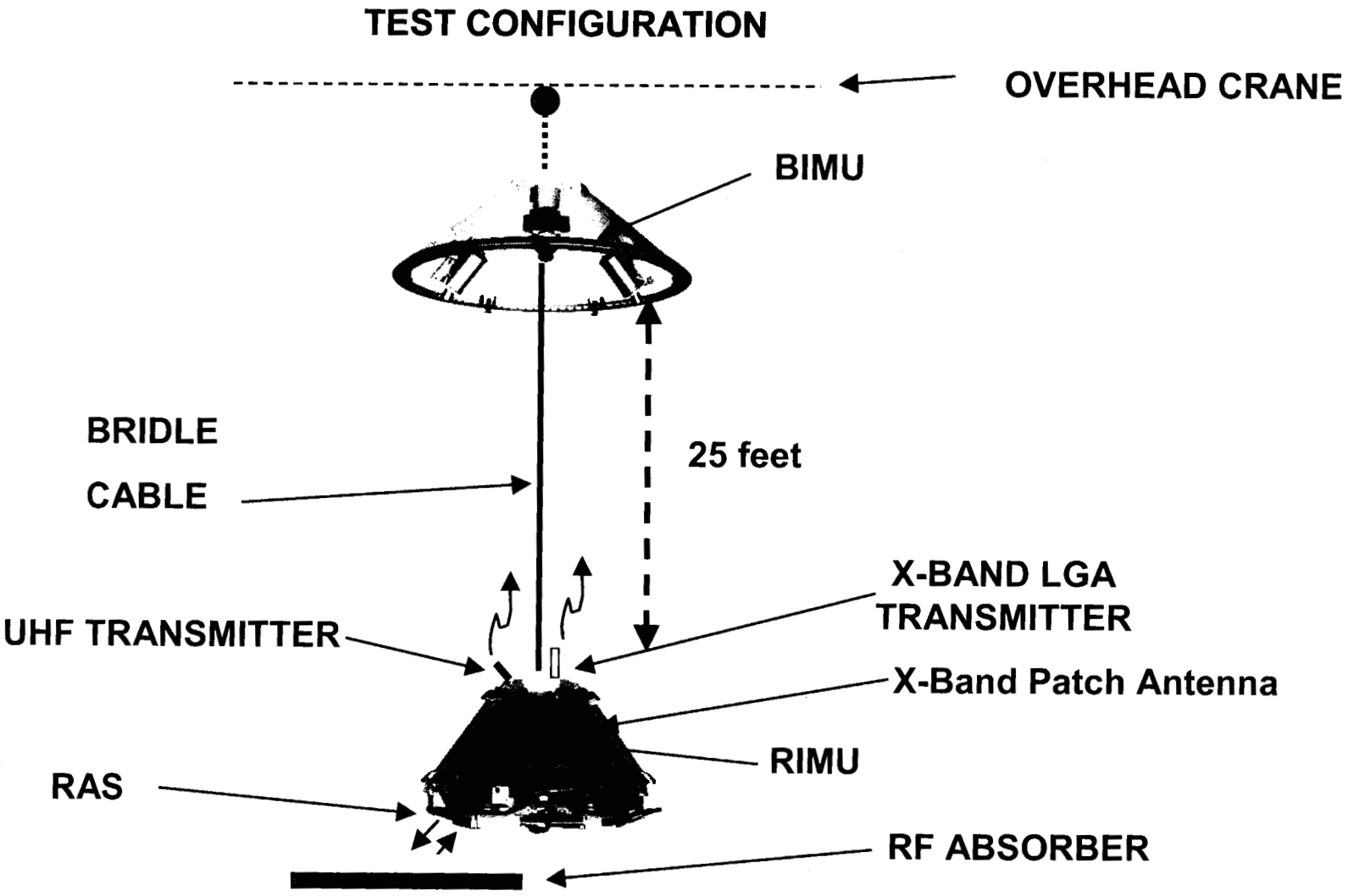
Descent/EDL Phase EMC Test Configuration



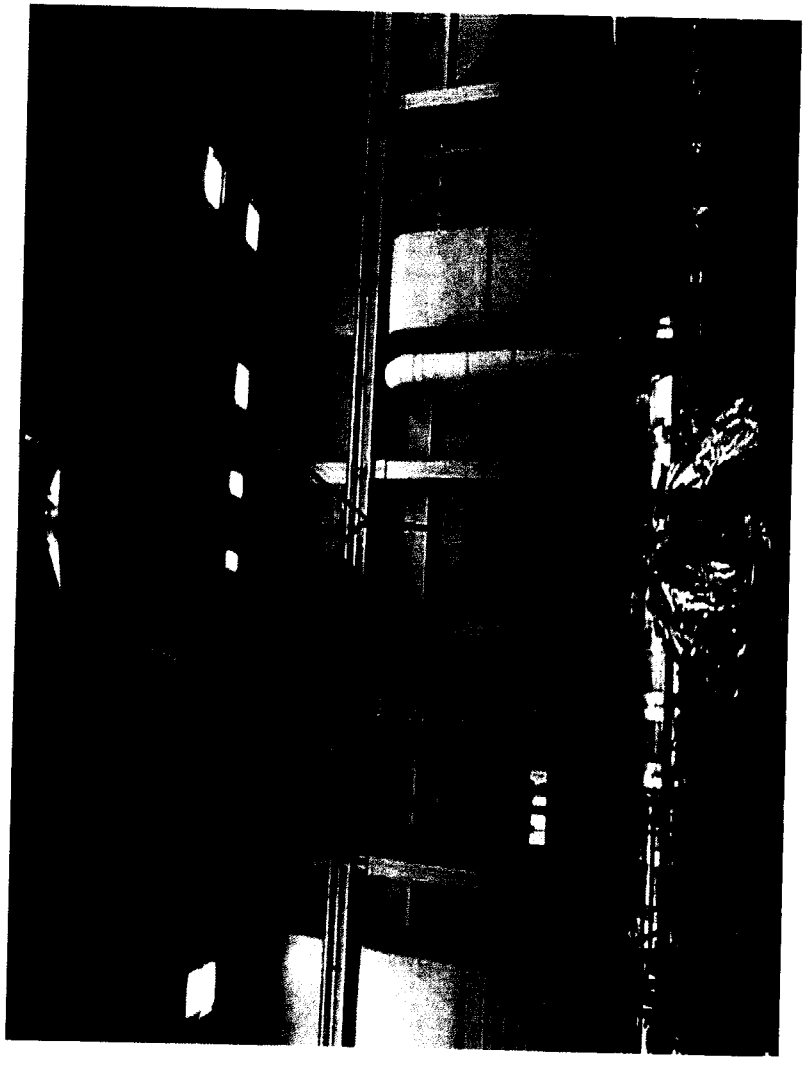




Descent/EDL Phase EMC Test Configuration - 1



Descent/EDL Phase EMC Test Configuration - 2



Descent/EDL Phase EMC Test Configuration - 3

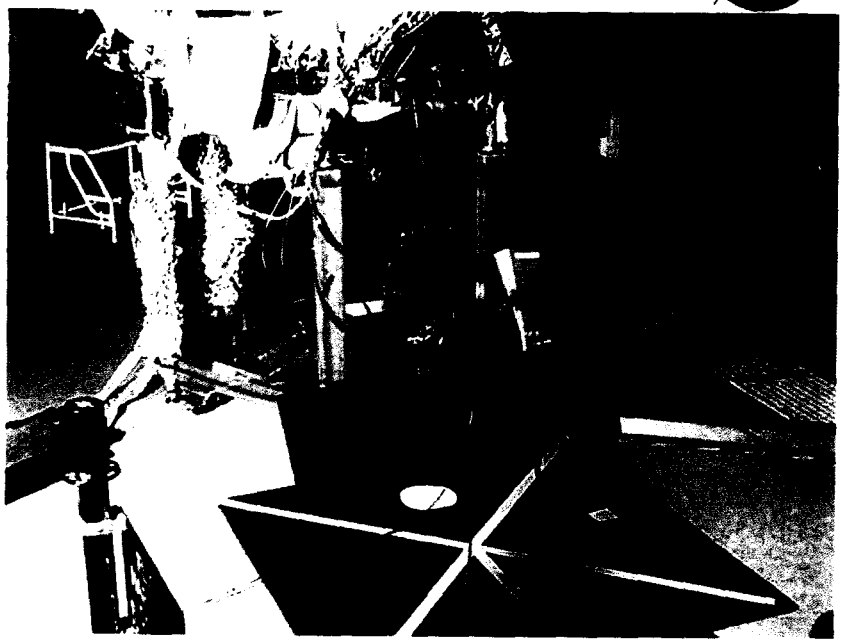
X-Band Test Horn Antenna And

UHF Spiral Antenna Used For

Air-Link Test

Lander Included Air Bags

To Simulate Attenuated Signals

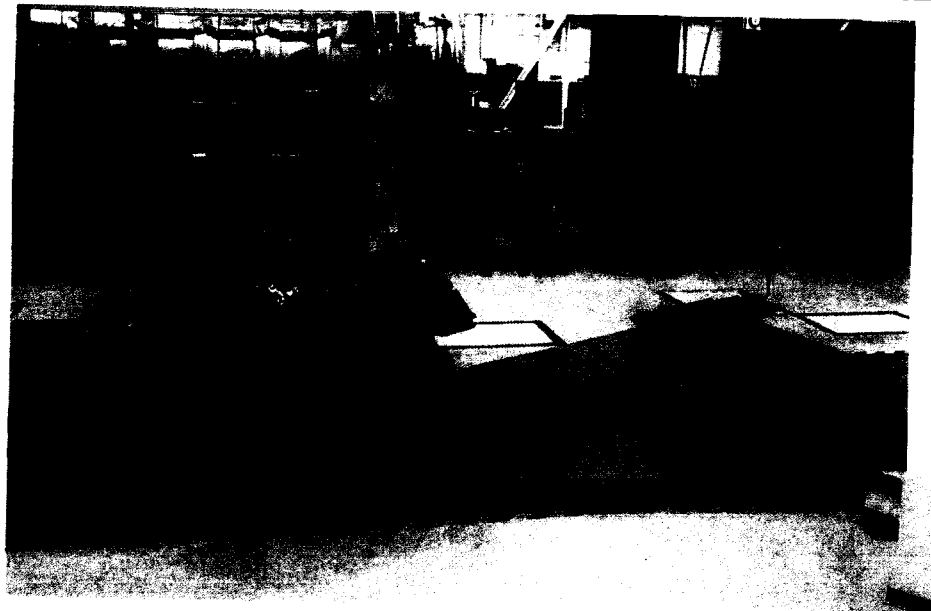


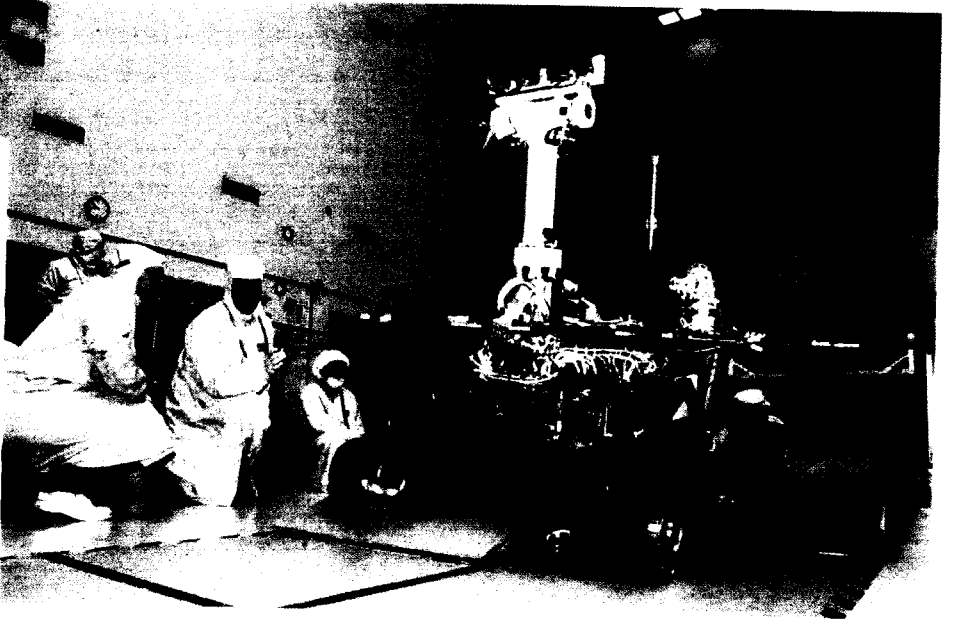
Ferrite Absorber Laid On Floor

Image Cross Pattern Included For

Dimes Camera

Rover Surface EMC Testing





Rover EMC Tests, Surface Phase Objectives

Test Objectives

- To uncover interferences between UHF and X-Band RF transmitters with other Rover functions
- To uncover interference between Rover subsystems and X-Band/UHF communication receivers
- To ensure compatibility of RF links with each other and with MER system including with articulated HGA
- To demonstrate total functional performance for self-compatibility of integrated Rover system including all flight interface cabling.
  - Representative cable interactions (effects of routing, bundling, and crosstalk), sensors, and distributed functions.
- To demonstrate functional performance of components and functions not tested in assembly level EMC qualification testing.

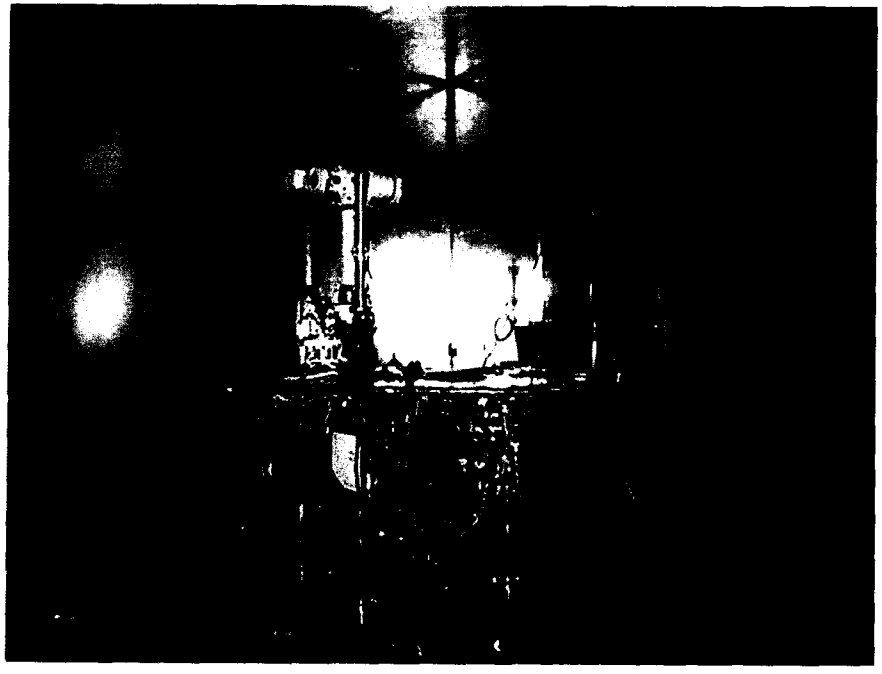
Rover EMC Tests, Surface Phase Objectives

Pre-Test Planning, System Level Compatibility Matrix

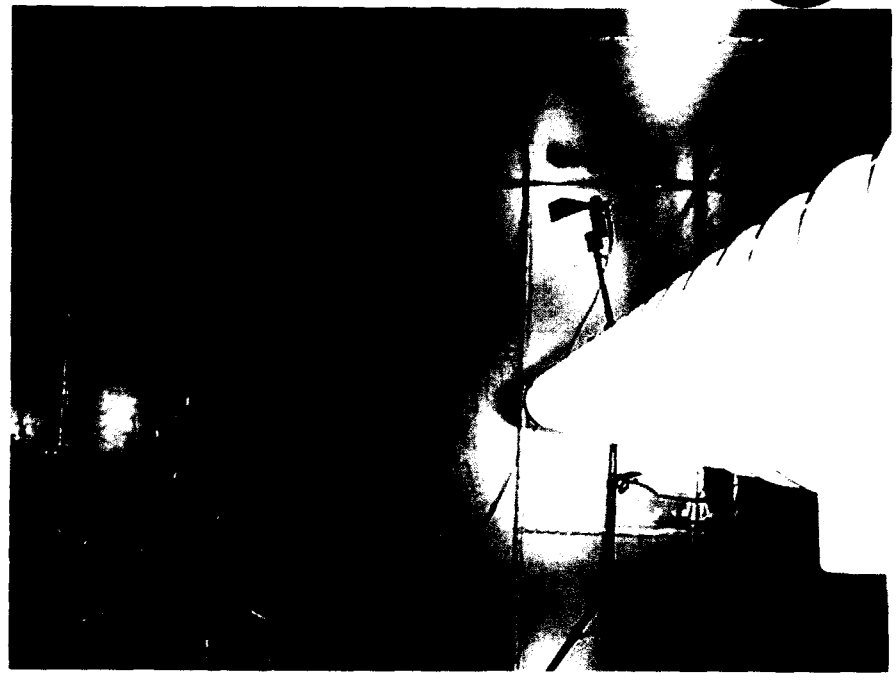
Victims \ Sources	X-Band Rx	X-Band Tx	UHF Rx	UHF Tx	AvPower	IMU	APXS	Mossbauer	Mini-TES	PanCams	Micro-Imager	HazCams	NavCams	IDD	RAT	wheels	steering
X-Band Rx			4														
X-Band Tx			4					4			4	4	4		4	4	2
UHF Rx	4													2	4		2
UHF Tx	4						4	4							4		2
AvPower		2	4			4	4	4	4	4	4	4	4	4	4	4	2
IMU		2	4		2		4	4	4	4	4	4	4	4	4		2
APXS		4			2				2					4			2
Mossbauer		2			2												2
Mini-TES		2			2		2							2			2
PanCams		2		2	2									2			2
Micro-Imager		2		2	2									4	4		
HazCams		2		2	2											2	2
NavCams		2		2	2											4	4
IDD		2	4	2	2		2		4								
RAT		4	4	4	2												
wheels		4			2							2	2				2
steering		4			2							2	2			2	
HGA Gimbal		4			2	4	2							2			
PMA		4	4		2									2			
Filter wheel		4	4		2												
MI cover		4	4	4	2									4			

Most vulnerable or worst case	
Mid	2
Least vulnerable	
Valid combination, not an EMI issue	4
Not a valid combination or EMI resolved in ass'y testing	
Not valid, same victim/source	

Rover EMC Tests, Surface Phase Configuration



X-Band Air Link



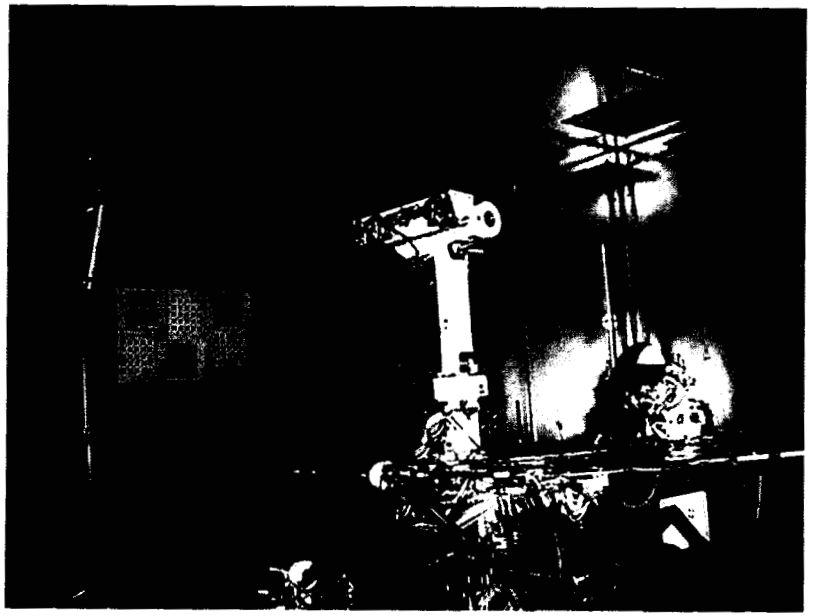
UHF Air Link

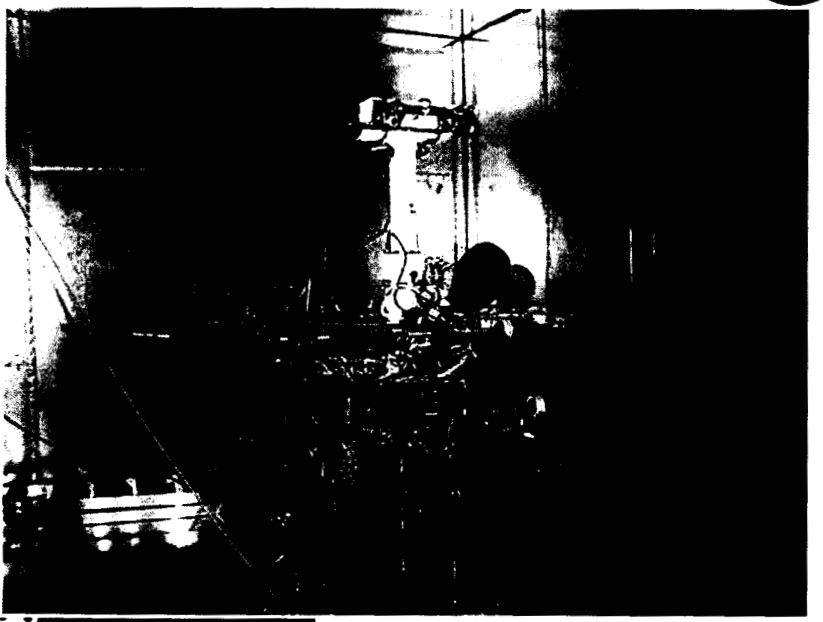
MER 1&2: X-Band Air Link And UHF Air Link

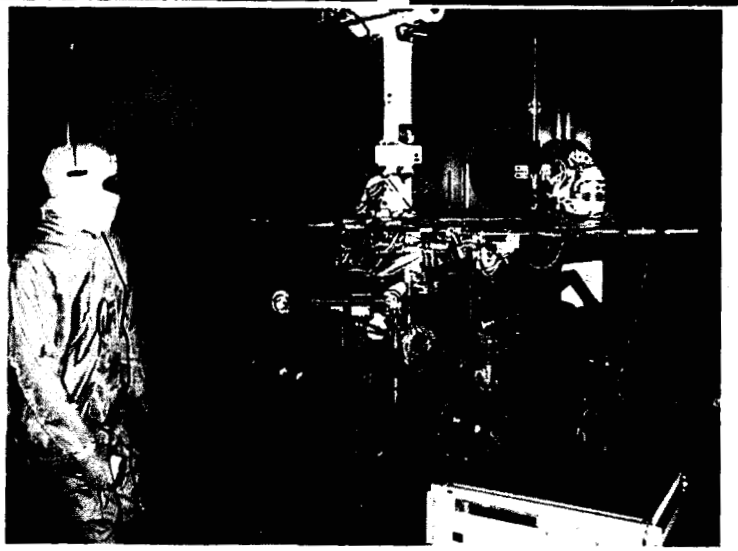
MER 2: GSE Cables Attached

MER 1: Totally Plugs Out, On Batteries Only

Rover EMC Tests, Surface Phase Configuration





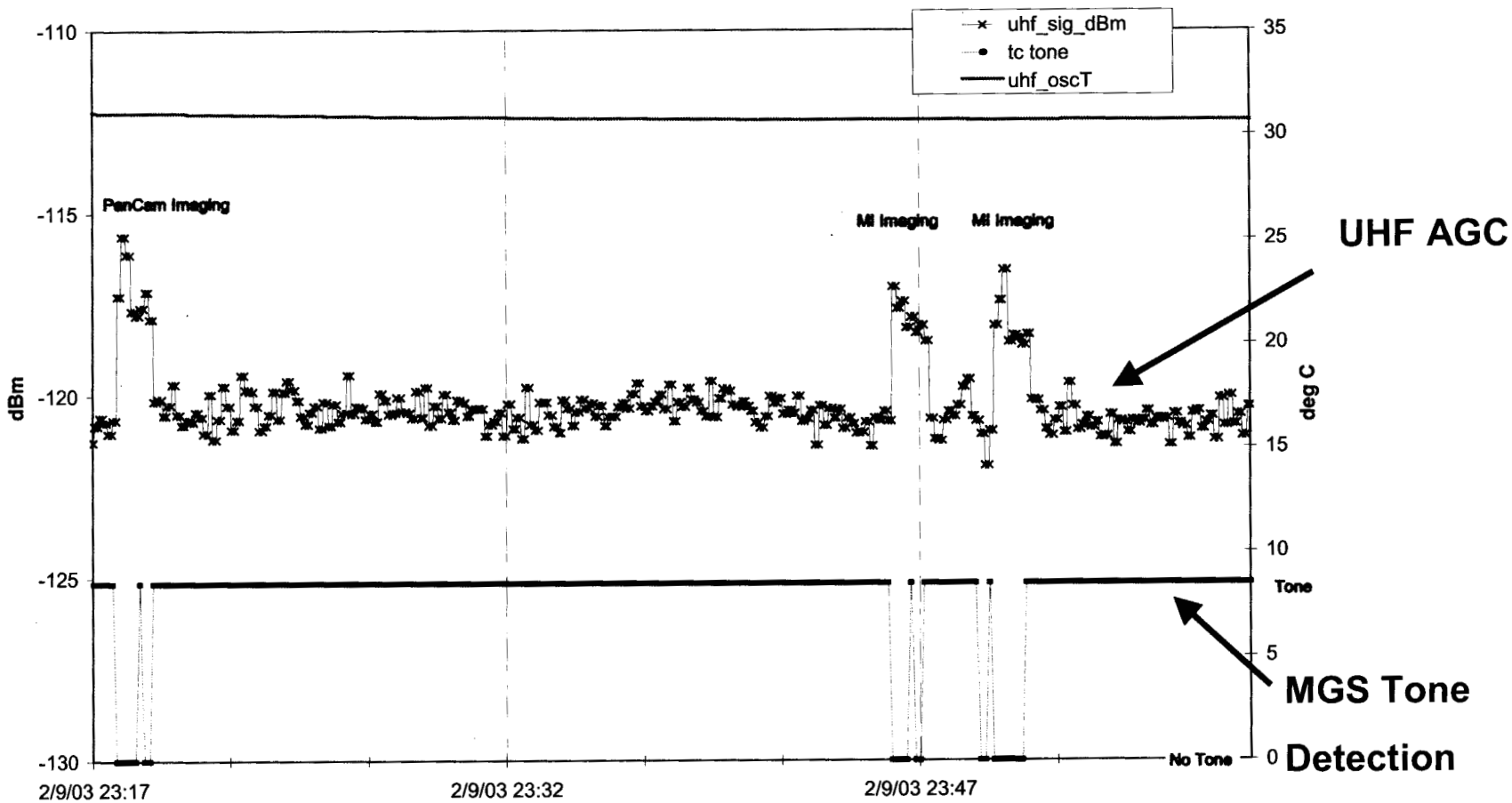


Fully Plugs Out, No Cables Test

All Telecom Via Air Link

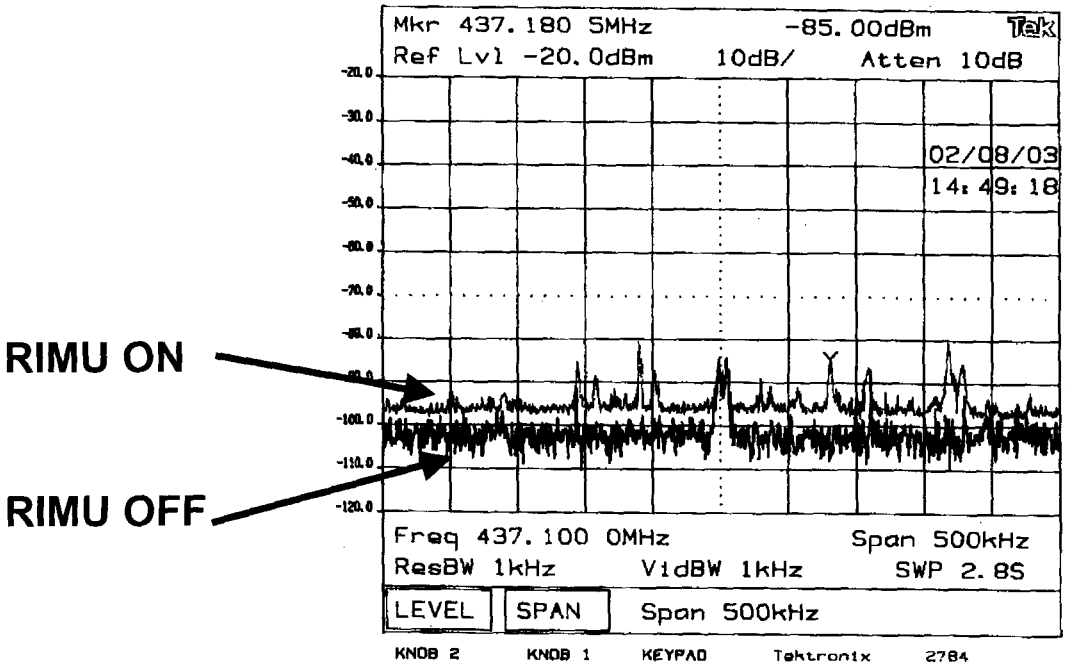
Rover On Batteries

Rover EMC Tests, Surface Phase
Example UHF Results



- Rover 1 UHF Receiver In MGS Tone Detection Mode.
- Loss Of Tones Due To Pan Cam And MicroImager Operations

Rover EMC Tests, Surface Phase Results

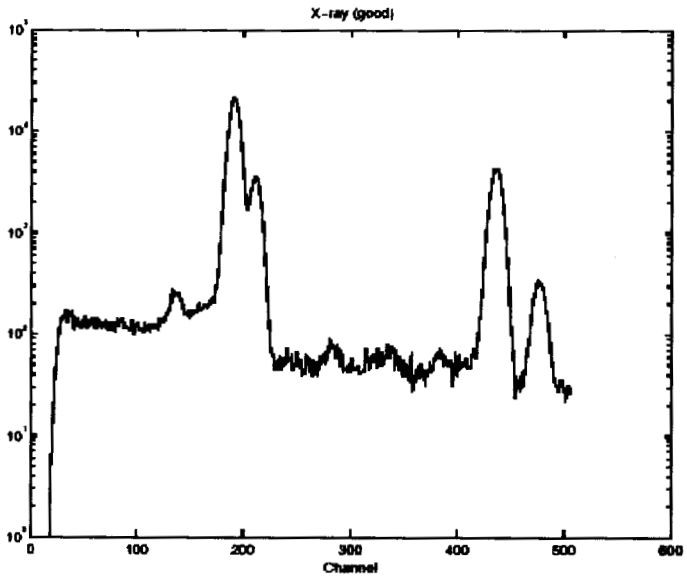


-Rover 1 UHF Emissions, UHF Tone Detection Mode, UHF Receiver Goes In and Out Of Lock With RIMU Powered ON,

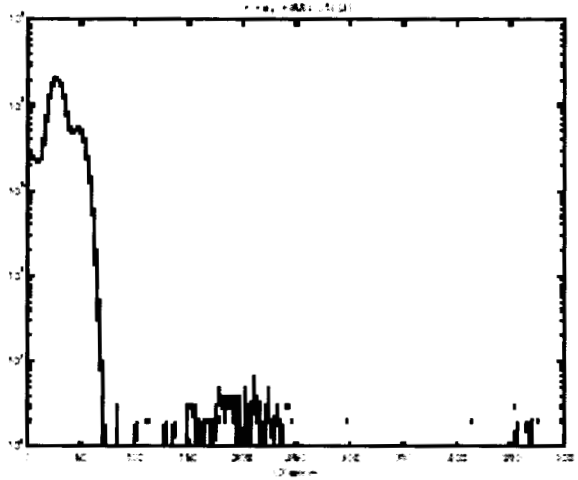
- When Powered OFF UHF Does Not Go In and Out Of Lock,

-Degradation in MGS Tone Detection sensitivity – Noise close to 437.1 MHZ at 437.180 kHz Is Cause Of Receiver Degradation,

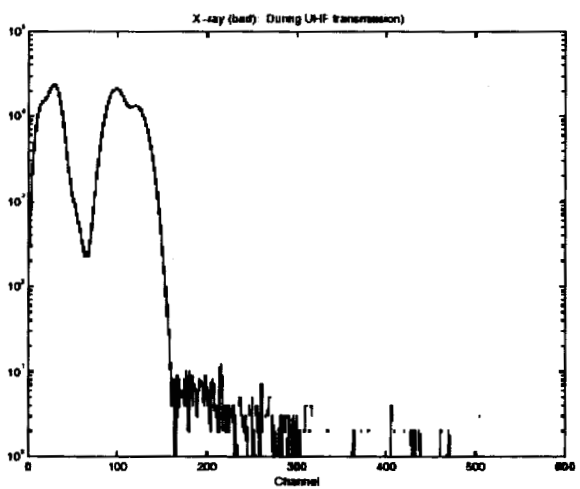
Rover EMC Tests, Surface Phase Results



GOOD ALPHA PARTICLE X-RAY SPECTROMETER DATA SET (UHF Tx OFF, RIMU OFF)

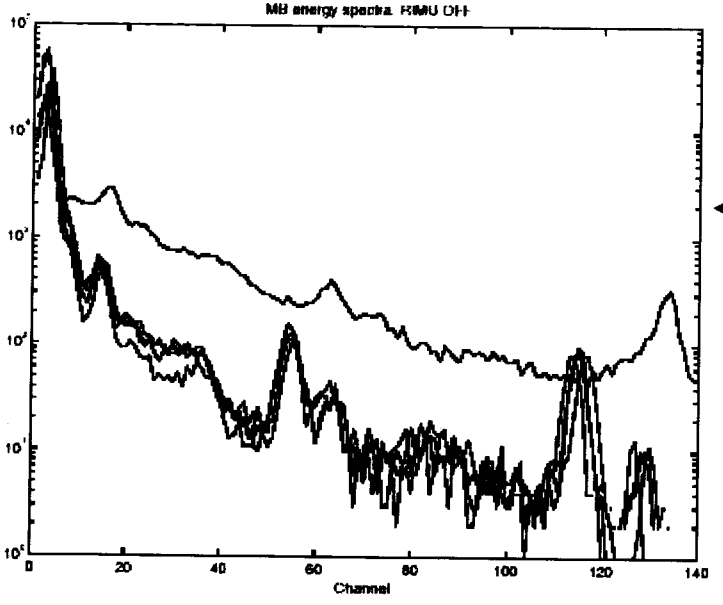


APXS X-RAY DATA CORRUPTED BY RIMU



APXS X-RAY DATA CORRUPTED BY UHF RF TRANSMITTER EMISSIONS

Rover EMC Tests, Surface Phase Results



MÖSSBAUER Energy Spectra

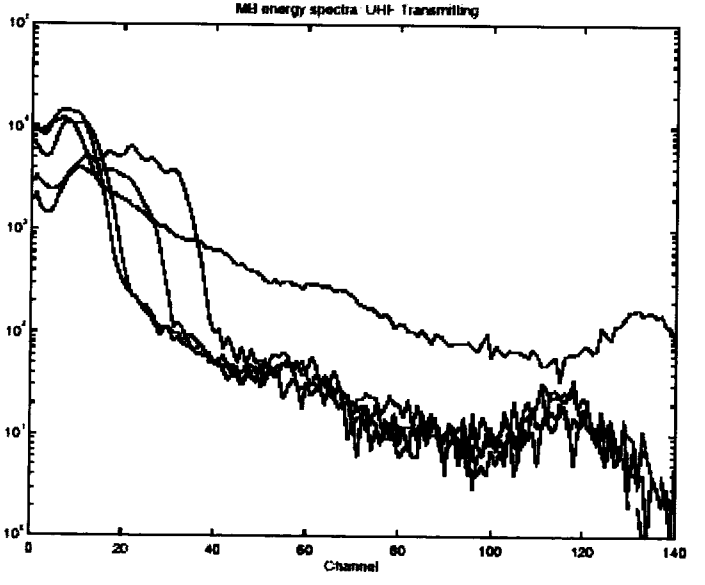
With UHF Transmitter OFF

GOOD DATA

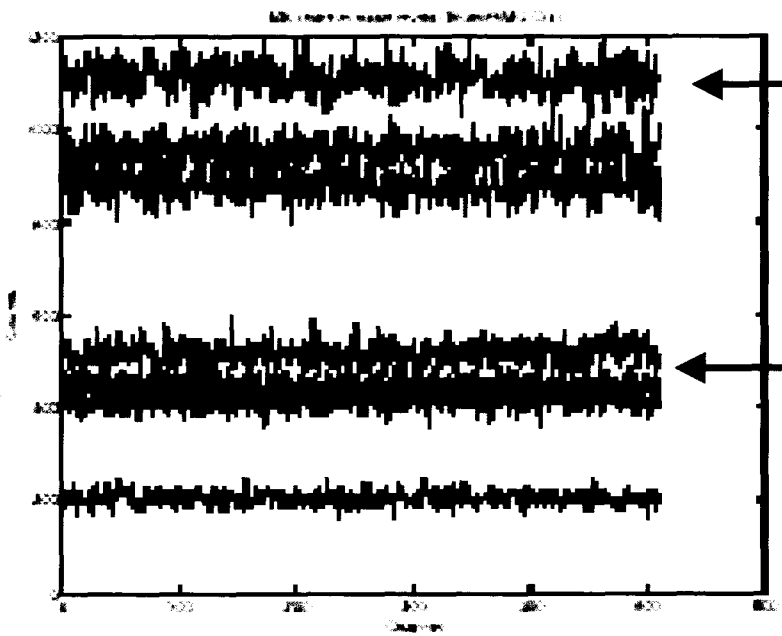
MÖSSBAUER Energy Spectra

With UHF Transmitter ON

DATA UNUSABLE



Rover EMC Tests, Surface Phase Results



HIGHER NOISE COUNT RATE WITH RIMU ON

NORMAL NOISE COUNT RATES WITH RIMU OFF

MÖSSBAUER Sensitivity To RIMU:

-Noise count rates in the main detector channels are substantially higher with RIMU ON (BLUE) as compared to RIMU OFF (RED)

Rover EMC Tests, Surface Phase Results

Rover System Level Compatibility Test Results

VICTIMS \ SOURCES	X-Band Rx	X-Band Tx	UHF Rx	UHF Tx	AvPower	IMU	APXS	Mossbauer	Mini-TES	PanCams	Micro-Imager	HazCams	NavCams	IDD	RAT	wheels	steering	HGA Gimbal	PMA	Filter wheel
X-Band Rx	O																			
X-Band Tx		O																		
UHF Rx			O																	
UHF Tx				O																
AvPower					0															
IMU						O														
APXS							O	0		0	0	0	0	0	0	0	0	0	0	0
Mossbauer							0	O	0	0	0	0	0	0	0	0	0	0	0	0
Mini-TES								0	O	0	0	0	0		0	0	0	0	0	0
PanCams							0	0	0	0	0	0	0		0	0	0	0	0	0
Micro-Imager							0	0	0	0	O	0	0	0	0	0	0	0	0	0
HazCams							0	0	0	0	0	O	0	0	0	0	0	0	0	0
NavCams							0	0	0	0	0	0	O	0	0	0	0	0	0	0
IDD								0			0	0	0	0	0	0	0	0	0	0
RAT							0	0	0	0	0	0	0	0	O	0	0	0	0	0
wheels				0			0	0	0	0	0			0	0	O	0	0	0	0
steering				0			0	0	0	0	0			0	0	0	O	0	0	0
HGA Gimbal								0			0	0	0		0	0	0	O	0	0
PMA							0	0			0	0	0	0	0	0	0	0	O	0
Filter wheel							0	0	0		0	0	0	0	0	0	0	0	0	O

2 - MEDIUM EMI CONCERN

0 - Not Applicable/Not Tested

Rover EMC Tests, Surface Phase Results

Post System Level Resolutions Of Incompatibilities

VICTIMS \ SOURCES	X-Band Rx	X-Band Tx	UHF Rx	UHF Tx	Av/Power	IMU	APXS	Mossbauer	Mini-TES	PanCams	Micro-Imager	HazCams	NavCams	IDD	RAT	wheels	steering	HGA Gimbal	PMA	Filter wheel
X-Band Rx	O																			
X-Band Tx		O																		
UHF Rx			O																	
UHF Tx				O																
Av/Power					0															
IMU						O														
APXS							O	0		0	0	0	0	0	0	0	0	0	0	0
Mossbauer							0	O	0	0	0	0	0	0	0	0	0	0	0	0
Mini-TES								0	O	0	0	0	0		0	0	0	0	0	0
PanCams							0	0	0	0	0	0	0		0	0	0	0	0	0
Micro-Imager							0	0	0	0	O	0	0	0	0	0	0	0	0	0
HazCams							0	0	0	0	0	O	0	0	0	0	0	0	0	0
NavCams							0	0	0	0	0	0	O	0	0	0	0	0	0	0
IDD								0			0	0	0	0	0	0	0	0	0	0
RAT							0	0	0	0	0	0	0	0	O	0	0	0	0	0
wheels				0			0	0	0	0	0			0	0	O	0	0	0	0
steering				0			0	0	0	0	0			0	0	0	O	0	0	0
HGA Gimbal								0			0	0	0		0	0	0	O	0	0
PMA							0	0			0	0	0	0	0	0	0	0	O	0
Filter wheel							0	0	0		0	0	0	0	0	0	0	0	0	O

0 - Not Applicable/Not Tested