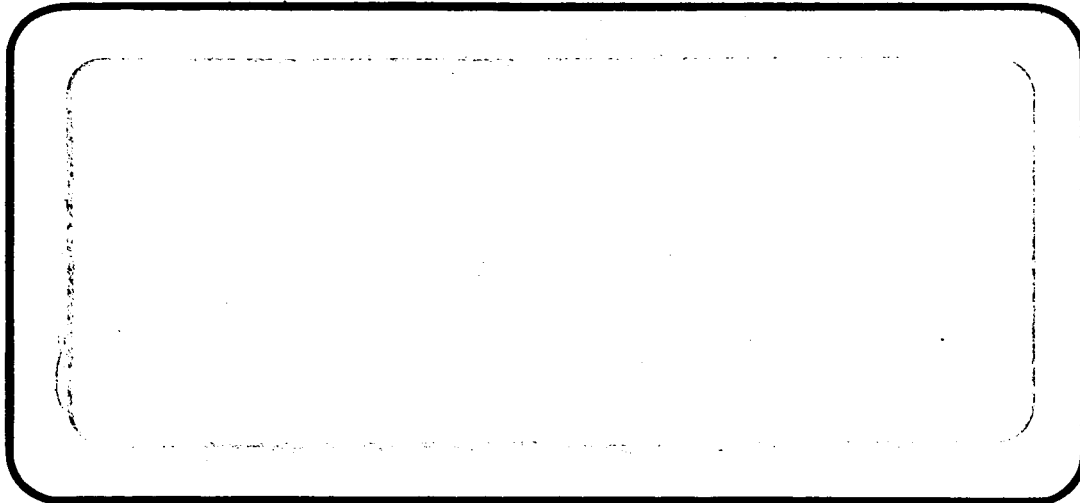




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DEVELOPMENT OF A SPACE VEHICLE ELECTROMAGNETIC
INTERFERENCE/COMPATIBILITY SPECIFICATION

NASA CONTRACT NUMBER 9-7305

28 JUNE 1968

VOLUME III

SYSTEM SPECIFICATION
TRW DOCUMENT NUMBER 08900-6001-T002

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1.0 INTRODUCTION

This specification represents a new approach to controlling electromagnetic interference. In this approach the system integration contractor will be responsible for the development of discrete specification limits to be utilized on the program to which this specification is applied. The specification limits imposed upon subsystem contractors will be developed by the use of a computer program, available from the procuring agency, which is designed to consider the total system electromagnetic environment in the computation of these limits. The integration contractor will be required to mathematically model those circuits which represent required emitters and receptors of electromagnetic energy on the space vehicle. There are contained herein, a list of available computer models into which must be inserted particular parameters of the spacecraft subsystems. These functional models, when inserted into the computer program, will develop discrete specification limits based upon the requirements of the particular system modelled.

2.0 SCOPE

This specification is intended to be applied to the integration contractor responsible for the overall system operation. Since it is the system integration contractor who defines the requirements of the subsystems to be utilized on the spacecraft, it is intended that this knowledge of the requirements be utilized to develop unique specification limits, which are realistic for the particular spacecraft modeled.

3.0 PURPOSE

It is the purpose of this specification to insure overall electromagnetic compatibility between all subsystems of the integrated spacecraft. Differences between spacecraft require different specification limits to achieve the desired overall system compatibility. Therefore, this system specification allows the spacecraft integration contractor the maximum degree of freedom in imposing only realistically developed specification limits on subcontractors.

4.0 DESIGN GUIDELINES

4.1 Structure Bonding

- 4.1.1 The conductivity of the spacecraft should be as high as possible. Aluminum is considered sufficient. Magnesium, while lighter, has only about one-half the conductivity of aluminum and is more difficult to protect with conductive finishes.
- 4.1.2 Protective finishes must be electrically conductive. Painting and anodizing of mating surfaces is always to be avoided. Gold, silver, and tin are good plating materials for aluminum and copper, while alodine 1000, irdite 14 and 18p, and oakite 36 are acceptable chemical film finishes for aluminum.
- 4.1.3 The most acceptable method of fastening structural members together is by welding. When this is not practical, members should be bolted with a sufficient number of bolts to assure a high contact pressure (at least 20 psi) across the entire mating surface.
- 4.1.4 If bond straps must be used, their length to width ratio should be low and they should be at least 2 skin depths* thick at the lowest frequency of interest. However, at very low frequencies, this would result in very thick straps (52 mils at 10 kHz). It is, therefore, necessary to temper this requirement with the practicalities imposed by mechanical constraints.
- 4.1.5 The DC bonding resistance between any two bonded members should not exceed 5 milliohms.

4.2 Grounding

- 4.2.1 In most cases it will be found that a hybrid ground system is the most satisfactory for EMC control. A hybrid ground system may be defined as one in which singly grounded circuits and shields and multiply grounded circuits and shields are both used, according to the particular requirements of the circuits under consideration.

*
$$\delta = \sqrt{\frac{\rho}{\pi \mu f}},$$

where: δ = skin depth in meters
 ρ = resistivity in ohms-meters
 f = frequency in Hertz
 μ = magnetic permeability (for non-magnetic materials,
 $\mu = 4\pi \times 10^{-7}$)

- 4.2.2 Circuits which are to be single point grounded should not share a common return to a ground point. An exception may be made to this rule if the circuits sharing the common return are mutually compatible.
- 4.2.3 Regardless of whether a shield is single point or multipoint grounded, shield grounds will be made directly to the structure, and the ground wire will be as short as possible. In no case will shields be connected to a common wire and grounded at some remote point. Shields may be commoned at a halo ring or some other type of standard shield termination device which is directly bonded to structure.
- 4.2.4 Shields which are intended to reduce magnetic field coupling must be grounded at both ends.
- 4.2.5 A shield which is intended to reduce electric field coupling may be grounded at one end provided the shield is shorter than $\lambda/5$ at the highest frequency of interest.
- 4.2.6 If a shield is longer than $\lambda/5$ at the highest frequency to be shielded, it should be grounded at intermediate points so as to eliminate resonant modes.
- 4.2.7 The return wire of a twisted pair will not be grounded at both ends.
- 4.2.8 If a twisted pair circuit is to be shielded for E-fields, the E-field shield should be floated at the end of the circuit which is not grounded, and grounded at the other end. If both ends of the circuit are floating, the shield may be grounded at either end, but preferably at the source end in a noise generating circuit and at the high field end in a susceptible circuit.
- 4.2.9 Coaxial cable shields will be grounded at both ends and at all intermediate interfaces.
- 4.3 Harnesses and Wiring
- 4.3.1 Wires should be assigned to different harnesses according to their signal classification. Five general classifications are:

4.3.1 (continued)

1. Power Lines
 - a. Direct Current
 - b. Alternating Current
2. Command Lines
3. Digital Data Lines
4. Analog Signal Lines
 - a. Less than 100 MV
 - b. 100 MV to 1 volt
 - c. More than 1 volt
5. RF Signal Lines
 - a. Transmitter Outputs
 - b. Receiver Inputs

4.3.2 The distance between different classes and subclasses of harnesses should be the maximum possible, especially between classes 1 and 4 and between classes 3 and 5.

4.3.3 Harnesses should be positioned as close to the structure as possible. This is especially true for harnesses carrying signals using the structure as the return.

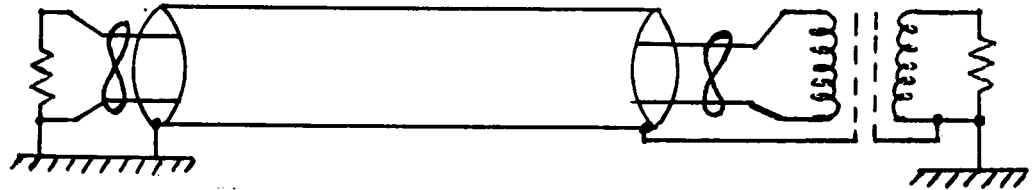
4.3.4 Wires between equipments or subsystems should follow the most direct route. Interference coupling is a direct function of length.

4.3.5 Twisted pair wiring should be used for balanced or quasi-balanced circuits to reduce magnetic field coupling. However, care must be taken to assure that the distance between the twisted pairs to be isolated is at least 1.5 times the twist length, where the twist length is the reciprocal of the number of full twists per inch. This usually requires that separate harnesses be used. If the distance cannot be increased, this criterion can be met by increasing the number of twists per inch, thereby reducing the twist length.

- 4.3.6 Balanced circuits with center tap grounds should be used for sensitive low frequency circuits.
- 4.4 Shielding
- 4.4.1 High voltage circuits are likely to be E-field generators and should be shielded.
- 4.4.2 Sensitive circuits having low current inputs are likely to be susceptible to E-fields and should be shielded.
- 4.4.3 Sensitive circuits having low voltage inputs at medium and high frequencies should be shielded to protect them from H-fields.
- 4.4.4. Circuits which carry large currents at high frequencies are likely to be H-field generators and should be shielded.
- 4.4.5 Grounding of shields is discussed in the section on grounding, but in general E-field shields may be floated at one end while H-field shields must be grounded at both ends.
- 4.4.6 Shield continuity should be maintained over the entire length of the shield.
- 4.4.7 Shielded wires passing through junction boxes should be shielded inside the J-box.
- 4.4.8 Unshielded segments of shielded wires should be kept to an absolute minimum length. Peripheral shield termination hardware or conductive epoxy potted back shells can be used to obtain this objective.
- 4.4.9 Shielding against magnetic fields below 10 kHz usually requires the use of shields made of high permeability materials or very thick copper shields.
- 4.4.10 If a circuit must be shielded against both E and H-fields over a wide frequency range, a double isolated shield may be required. In this case, the inner shield should be grounded at the grounded end of the circuit while the outer shield should be grounded at the opposite end.
- 4.4.11 When circuits are transformer coupled, common mode noise can be reduced by using transformers with shielded primary and

4.4.11 (continued)

secondary windings. The transformer shields should be connected as shown below.



4.4.12 Coaxial cable should be used for all circuits which are intended to operate at radio frequencies.

4.4.13 Shielding effectiveness is a positive function of a shield's thickness, conductivity, and percent coverage.

5.0 SYSTEM COMPATIBILITY TEST

5.1 General Test Requirements

The purpose of the system compatibility test is to demonstrate that every unit in the system operates in accordance with its specified performance parameters while the system is fully exercised in each of its probable modes of operation, and to determine the compatibility margin of the system. The margin is the difference between the known sensitivity and the measured noise with all parts of the system in operation, except that wire being measured.

This test may be integrated into the normal system verification test. A complete functional test shall be conducted on a fully integrated system. Provision shall be made for sampling the various critical circuits as part of this test. Maximum use shall be made of previous test results in determining critical circuits. Signal levels on these critical circuits shall be compared with those previously found in the earlier testing and with the computer predictions.

The system shall be operated in all modes of operation while the system is being monitored for malfunction or for undesirable responses. The data taken during this test can also be used to check the computer model.

For compatibility testing the spacecraft should be configured as nearly as possible to the actual spacecraft configuration during flight. Care should be taken to control ground reflections which represent an abnormal condition. Maximum utilization of RF links to command control the spacecraft during system testing will tend to minimize the effects of Ground Support Equipment interference.

5.2 General Measurement Requirements

5.2.1 Breakout Boxes

If breakout boxes are to be used, they must be designed and fabricated so as to maintain the wiring and shielding characteristics of each wire in the harness. Only those wires to be monitored should be brought out to test points, and all others should just pass through the box. This may require a different breakout box for each harness containing a critical wire.

5.2.2 Measuring Instruments

If current probes are to be used, their transfer functions must be known over the entire frequency range of interest. The passband of the measuring instrument must be limited to the passband of the critical circuit if integrating type instruments are used. Wideband voltmeters and oscilloscopes are typical of integrating type instruments. The characteristics of the passband shaping filters must be accurately determined. The use of frequency selective narrowband instruments is discouraged for measuring noise into a wideband receptor because of the great amount of time required for each sequence of measurements. However, in the case of very sensitive wideband receptors, it may be necessary to use this method because of the relative insensitivity of wideband test instruments.

5.3 Test Plan Requirements

5.3.1 General

The system integration contractor will submit to NASA, for approval, a detailed test plan which will include criteria for unacceptable responses and malfunctions. This plan must be submitted at least 30 days prior to the scheduled start of testing. Unless otherwise specified, the supplier shall be responsible for the performance of all inspections related to these tests. However, the contracting agency reserves the right to monitor these tests when deemed necessary.

5.3.2 Critical Points

The detailed test plan must identify those critical points in the system which will be monitored to determine the ratio between normal sensitivity and existing system noise. The plan must include, as appendices, the analyses upon which the selection of critical points is based, and the sensitivity of those points. The number of critical points to be monitored is not fixed, but must be representative of the different types of possible interference receptors in the system.

5.3.3 Measurement Techniques

The procedure must describe the measurement technique to be used for each critical point.

5.4 Compatibility Criteria

Compliance with this specification shall be demonstrated when the system completes a full functional test sequence without unacceptable responses or malfunctions.

6.0 CONTROL PLAN REQUIREMENTS

The System Control Plan is a two part document. Part I is a management plan and must be included in the contract proposal. Part II is the technical plan and must be submitted after the contract is awarded. The number of days, after the award of contract, that the technical plan must be submitted will be determined by the contracting agency. The control plan must be responsive to all of the items listed below.

6.1 Management Plan

- 6.1.1 Organizational responsibility of the EMC Control group including lines of authority and control.
- 6.1.2 EMC implementation plan including milestones.
 - a. Development of subsystem EMC specification.
 - b. Development of frequency allocation plan that will assure interference between transmitters and receivers at their defined frequencies.
 - c. Preliminary and critical EMC design reviews.
- 6.1.3 Submit a flow chart showing the entire EMC control program and how it interfaces with the rest of the program plan.
- 6.1.4 Subcontractor Control
 - a. How will EMC control of subcontractors be implemented?
 - b. Delineate the subcontractor surveillance plan that will reveal problems that could result in failure to meet EMC requirements.
 - c. Method of enforcing the subcontractor's EMC control plan.
 - c. What assurances are there that subcontractors failing to meet test requirements will have sufficient time to fix the units so as not to cause a program schedule slip?
- 6.1.5 EMC Control Group
 - a. What is the EMC experience of the people responsible for the EMI control program?
 - b. Submit resumes of those working on the contract.
 - c. EMC facility description.

6.2 Technical Plan

6.2.1 Structure

- a. Of what metal is the structure to be made?
- b. Are any members to be made of a different material? If yes, what?
- c. Finish to be used.
- d. Will any areas use a different finish? If yes, where and what?
- e. Methods of fastening the various members of the structure together.
- f. Bonding plan to assure that the structure is a low impedance plane.
- g. What is being done to eliminate structural dimensions that are resonant at primary source frequencies.
- h. General bonding plan including structure to structure and unit to structure bonding.
 - (1) Bonding tests.
 - (2) Location and dimensions of bond straps and reasons that contact bonding is not implementable.

6.2.2 Power System

- a. Describe the power system wiring configuration.
- b. Number and locations of power system ground points.
- c. Minimization of power bus impedance.
- d. Number of secondary power supplies (converters and inverters).
 - (1) Are they synchronized?
 - (2) What are their primary frequencies?
 - (3) Control of converter and inverter EMI.
- e. Functional Description of Power System

6.2.3 Harnesses and Wiring

- a. Number of harnesses.
- b. Lengths of each (Approximate).
- c. Diameters of each (Approximate).
- d. Number of wires in each.

6.2.3 Continued

- e. Types of signals in each.
- f. Maximum and minimum distances between any two harnesses (Approximate).
- g. Method of holding the harness near ground.
- h. Maximum and minimum distances from the center of each harness to ground (approximate).
- i. Location of boxes to minimize cable lengths.
- j. Are any harnesses longer than $\lambda/5$ at the highest signal frequency to be carried in that harness? If yes, will intermediate shield terminations be used to eliminate resonant effects on the shields?

6.2.4 J-Boxes

- a. Subcontractor type EMI controls are to be imposed on J-boxes and any other units made by the system integration contractor.
- b. Show sketches of proposed J-box wiring and assembly.
- c. Are any J-boxes to be used for different types of signals? If yes, what control methods inside the boxes are being imposed to assure the isolation integrity set by shields outside the box?

6.2.5 Connectors

- a. Type of signal connectors.
- b. How will signal separation be maintained?

6.2.6 Shielding

- a. How and where will shields be terminated?
- b. Types of signal wires to be shielded.
- c. Types of shields to be used.
- d. Shield continuity.

6.2.7 Grounding

- a. Describe in detail and submit a detailed sketch of the system grounding plan.
- b. What measures will be taken to assure that there will be no unintentional grounds?

7.0 SUBSYSTEM SPECIFICATION LIMITS

7.1 Integration Contractor Requirements

It shall be the responsibility of the Integration Contractor to develop the Interference and Susceptibility limits for use in the Subsystem Specification.

The limits will be developed using the computer program described in paragraph 3.0 of TRW document 08900-6001-T000 "Development of a Space Vehicle Interference/Compatibility Specification" "Final Engineering Report.

The computer program will develop specification limits for interference generation and susceptibility based on a modelled spacecraft system. The modelling requirements and computer program operation are described in the above named document.

7.2 Computer Program

The NASA Contracting Agency will provide to the Integration Contractor the Computer Program for a Univac 1108 in either punched cards or program tape form.