FAST-SPEC-012
REVISION A

Small Explorer-Fast Auroral Snapshot

"SMEX-FAST"

Magnetic Contamination and EMI/EMC
Control and Implementation Plan

17 SEPTEMBER 93

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1.0 INTRODUCTION

This document establishes the Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), electrostatic cleanliness, and magnetic cleanliness details for the Small Explorer-Fast Auroral Snapshot (SMEX-FAST) mission being developed by the Goddard Space Flight Center (GSFC) and the University of California-Berkeley (UCB). These details consist of the project management plan, performance requirements, design guidelines, and quality assurance requirements needed to assure that the SMEX-FAST spacecraft will be electromagnetically, electrostatically, and magnetically compatible with its environment, the Pegasus launch vehicle, and itself throughout all phases of the mission.

2.0 APPLICABLE DOCUMENTS

2.1 Referenced documents

The documents listed here are applicable to the extent as specified herein. In cases of a conflict in requirements, this document shall have precedence over the referenced documents.

GEVS-SE January 1990	General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components
MIL-STD-461C 4 August 1986	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462 Notice 6 (USAF) 15 October 1987	Electromagnetic Interference Characteristics, Measurement of
MIL-B-5087B Interim Amendment 3 (USAF) 24 December 1984	Bonding, Electrical, and Lightning Protection, for Aerospace Systems
FAST-SPEC-005 28 April 1992	Requirements Document for SMEX Fast Auroral Snapshot (FAST) Mission
FAST-SPEC-013 (Prelim) 19 December 1991	Mission Unique Electronics (MUE) Requirements Document
OSC A70055 20 February 1992	Pegasus-TOMS Interface Control Document

2.2 Background documents

In addition to the above referenced documents, the documents listed below were used in the development of this document. This list is provided solely for the benefit of the reader who desires a deeper understanding of the driving factors behind this document.

Background Specifications and Standards:

MIL-STD-463A 1 June 1977	Definitions and Systems of Units, Electromagnetic Interference and Electromagnetic Compatibility Technology
MIL-STD-1541A (USAF) 30 December 1987	Electromagnetic Compatibility Requirements for Space Systems
MIL-E-6051D Notice 1 26 February 1988	Electromagnetic Compatibility Requirements, System
FAST-SPEC-005 28 April 1992	Requirements Document for SMEX Fast Auroral Snapshot Explorer (FAST) Mission
FAST-SPEC-013 (Prelim) 19 December 1991	Mission Unique Electronics (MUE) Requirements Document

Other sources:

"Global Geospace Science (GGS) Mission EMC/EMI Design and Implementation Requirements", CDRL 315, Contract No. NAS5-30503, 29 April 1991.

"Global Geospace Science (GGS) Mission ESC Design and Implementation Requirements", CDRL 319, Contract No. NAS5-30503, 22 May 1991.

"Optimum Electrical Systems Design with Regard to EMI and EMC as Applied to ISTP", Robert G. Martin (Swales) memorandum, 30 May 1990.

"Spacecraft EMI Design Recommendations", Robert G. Martin (Swales) memorandum, 7 August 1990.

"Noise Reduction Techniques in Electronics Systems", Henry W. Ott, John Wiley & Sons, 1976, ISBN 0-471-65726-3.

"Grounding and Shielding Techniques in Instrumentation", Ralph Morrison, John Wiley & Sons, 1977, ISBN 0-471-02992-0.

"Electromagnetic Interference and Compatibility, Volume 1: Electrical Noise and EMI Specifications", Donald R.J. White, Don White Consultants, 1971.

"Electromagnetic Compatibility Handbook", J.L. Norman Violette and Michael Violette, Van Nostrand Reinhold, 1987.

3.0 ORGANIZATIONAL RESPONSIBILITIES

3.1 Electrical systems engineer responsibilities

The electrical systems engineer shall be responsible for developing the EMI Control and Implementation Plan, providing technical advice to the design engineers, reviewing the designs for compliance to EMI requirements, developing the EMI test plans and procedures, monitoring the EMI tests, and writing the EMI test reports.

3.2 Design engineer responsibilities

The various design engineers shall develop designs that are in compliance with the requirements stated herein, provide pertinent design data when required for EMI design reviews, assist in developing EMI test plans and reports, and correct any problems that are uncovered during EMI testing of their designs.

4.0 TECHNICAL DISCUSSION

Details describing the mission requirements and spacecraft configuration may be found in FAST-SPEC-005.

4.1 EMI Philosophy

The goal of this EMI control and implementation plan is to assure that the SMEX-FAST spacecraft is compatible with its environment, the Pegasus launch vehicle, and itself consistent with constraints on spacecraft weight, power, and cost. First and foremost, since this mission measures low-level magnetic and electric fields and small charged particles, any option considered must provide for adequate science and spacecraft performance. Due to programmatic constraints, this plan will accept the transponder and Pegasus interfaces and EMI performance as given and will make recommendations on the rest of the spacecraft to correct any shortcomings.

4.2 Operational considerations

From the EMI point of view, there are two major operational factors that must be considered. The first is that the spacecraft must be able to transmit real-time telemetry while taking accurate science data simultaneously. The second is that the ACS will not drive the spin coil and precession coil while science data is being taken.

4.3 Electromagnetic compatibility

The spacecraft contains many different types of scientific instruments and electronic circuits. Inadvertent radiation to or from these circuits (either intersystem or intrasystem) can corrupt science and/or housekeeping data, cause improper operation of the spacecraft and/or launch vehicle. This plan will make recommendations to develop an electromagnetically-compatible spacecraft that avoids these problems.

4.4 Potential emitter and receptor characteristics

A frequency mapping of potential emitters and receptors is shown in Figure 4.4-1. The exact frequencies are shown in Table 4.4-1.

4.5 Electrostatic cleanliness

Any spacecraft orbiting through space plasma is susceptible to differential charging if improperly designed. Any significant differential charge on the spacecraft can distort the science data and even cause damaging arcing if large enough. This plan will make recommendations to develop an "electrostatically-clean" spacecraft that avoids the differential charging problem.

4.6 Magnetic cleanliness

Any significant permanent or current-induced magnetic dipole moments generated by the spacecraft bus can distort the science data. This plan will make recommendations to develop an "magnetically-clean" spacecraft that avoids this problem.

5.0 EMI REQUIREMENTS

5.1 Basis for EMI requirements

GEVS-SE and MIL-STD-461C (for Class A2a equipment) are used as the sources of EMI requirements with modifications provided by UCB and OSC.

5.2 Specific EMI requirements

The various EMI requirements and verification procedures shall be applied to the spacecraft and its boxes as shown in Table 5.2-1. Details of the requirements and verifications are contained in the following subparagraphs. For EMI purposes, the spacecraft has only two levels of assembly: individual boxes and the assembled spacecraft itself. A box is defined to be an enclosure with self-contained electronics and wiring where the enclosure is mounted to the spacecraft structure.

5.2.1 Conducted emissions

5.2.1.1 DC Power Leads (Low Frequency)

For all spacecraft power and power-return leads (including switched power and Pegasus interface power), the narrowband emissions shall be limited to the levels shown in Figure 5.2.1.1-1. Testing shall be in accordance with MIL-STD-461 and MIL-STD-462, test method CE01, with limits shown in Figure 5.2.1.1-1.

5.2.1.2 DC Power Leads (High Frequency)

For all spacecraft power and power-return leads (including switched power and Pegasus interface power), the narrowband emissions shall be limited to the levels shown in Figure 5.2.1.2-1, and the broadband emissions shall be limited to the levels shown in Figure 5.2.1.2-2. Testing shall be in accordance with MIL-STD-461 and MIL-STD-462, test method CE03, with limits shown in Figure 5.2.1.2-1 and Figure 5.2.1.2-2.

5.2.1.3 Antenna Terminal

Conducted emissions on the transponder RF port shall not exceed 34 dBμV for narrowband emissions and 40 dBμV/MHz for broadband emissions with the receiver on and the transmitter off. Harmonics and all other spurious emissions from the RF port while the transmitter on shall not exceed -55 dBW. Testing shall be in accordance with MIL-STD-462, test method CE06. CE06 testing shall be performed before the transponder is integrated with its antenna system.

5.2.2 Conducted susceptibility

5.2.2.1 DC Power Leads (Low Frequency)

The test sample shall not exhibit any malfunction, degradation of performance, or deviation from specified indications (beyond the normal tolerances) when electromagnetic radiation whose magnitude is no greater than the limits shown in Figure 5.2.2.1-1 is injected into the spacecraft power leads (including switched power and Pegasus interface power). The applicable frequency interval shall be 30 Hz to 50 KHz. Testing shall be in accordance with MIL-STD-462, test method CS01.

5.2.2.2 DC Power Leads (High Frequency)

The test sample shall not exhibit any malfunction, degradation of performance, or deviation from specified indications (beyond the normal tolerances) when electromagnetic radiation whose magnitude is no greater than 1 Volt from a 50 Ω source is injected into the spacecraft power leads (including switched power and Pegasus interface power). The applicable frequency interval shall be 50 KHz to 400 MHz. Testing shall be in accordance with MIL-STD-462, test method CS02.

5.2.2.3 Intermodulation

a. Signal generator #1 is set to 66 dB above the level required to obtain the standard reference output (as specified in MIL-STD-462) but shall not exceed 10 dBm.

b. Signal generator #2 is set to 66 dB above the level required to obtain the standard reference output (as specified in MIL-STD-462), but the generator output level shall not exceed 10 dBm.

Testing shall be in accordance with MIL-STD-462, test method CS03 and shall be applied to the transponder.

5.2.2.4 **Spurious Rejection**

The transponder receiver shall not exhibit any undesired response when subjected to spurious signal whose limits are shown in Figure 5.2.2.4-1. Testing shall be in accordance with MIL-STD-462, test method CS04, and shall be applied at the box level.

5.2.2.5 **Cross Modulation**

The transponder receiver shall not exhibit, due to cross modulation, any malfunction, degradation of performance, or deviation from specified indications (beyond the normal tolerances) when subjected to the following from signal generator #2: a signal 66 dB above the level required to obtain the standard reference output (as specified in MIL-STD-462), but not to exceed a power output level of 10 dBm. Testing shall be in accordance with MIL-STD-462, test method CS05, and shall be applied to the transponder at the box level.

5.2.2.6 **DC Power Spikes**

The test sample shall not exhibit any malfunction, degradation of performance, or deviation from specified indications (beyond the normal tolerances) when spikes having the waveform shown in Figure 5.2.2.6-1 into the spacecraft power leads (including switched power and Pegasus interface power). Testing shall be in accordance with MIL-STD-462, test method CS06.

5.2.3 **Radiated Emissions**

5.2.3.1 **Electric Fields**

Unintentional electric fields radiated by the spacecraft and its individual boxes shall not exceed the limits shown in Figures 5.2.3.1-1 and 5.2.3.1-2 for narrowband emissions and Figures 5.2.3.1-3 and 5.2.3.1-4 for broadband emissions. Testing shall be in accordance with MIL-STD-462, test method RE02 with the revised test frequency range and limits shown in Figures 5.2.3.1-1, 5.2.3.1-2, 5.2.3.1-3, and 5.2.3.1-4.

5.2.3.2 **Magnetic Fields**

The magnetic field radiated emissions test will measure power in the specified bandwidth. Unintentional magnetic fields radiated by the spacecraft and its individual boxes shall not exceed the limits shown in Figure 5.2.3.2-1 over the frequency interval 20 Hz to 1 MHz. The test shall be performed at 1 meter. Should additional sensitivity be required, the test may be performed at 30 cm, with 15 dB added to the specified levels. The search-coil magnetometer sensitivity shown in Figure 5.2.3.2-2 demands a tight specification for radiated magnetic fields. This test replaces RE04 and will probably require a search-coil magnetometer.

5.2.4 Radiated Susceptibility-Electric Fields

The test sample shall not exhibit permanent malfunction, degradation of performance, or deviation from specified indications (beyond the normal tolerances) when subjected to the radiated electric fields specified herein. Units that are mounted external to the spacecraft structure (i.e. outside of the volume defined by the solar array substrate, the instrument deck, and the radiation shield) shall use the following levels:

Frequency Range	Launch Mode	Normal Mode
14 KHz to 2 GHz	10 V/m	10 V/m
2 GHz to 18 GHz	10 V/m	10 V/m
5 GHz to 6 GHz	100 V/m *	N/A

* 2600 Hz pulse repetition frequency with a 10% duty cycle.

Units that are located entirely within the spacecraft structure shall use levels that are a tenth of (20 dB below) the above limits. Intentional electric field sensors that operate within the frequency range of the test shall be removed or disabled without otherwise disabling the spacecraft during test. Testing shall be in accordance with MIL-STD-462, test method RS03.

5.2.5 DC magnetics requirements

The maximum magnetic fields generated by individual boxes shall be as shown in Table 5.2.5-1. The maximum DC magnetic field generated by the spacecraft shall be no greater than 1 nT at the fluxgate magnetometer. These requirements will be tested by making measurements of the magnetic fields generated by the spacecraft while operating in the magnetic test facility located at GSFC.

5.3 Pegasus and Carrier Aircraft RF environment

During the captive carry and launch phases of the mission, the spacecraft shall not exhibit permanent malfunction, degradation of performance, or deviation from specified indications (beyond the normal tolerances) when subjected to the RF environment shown in the Table 5.3-1 for the Pegasus RF environment and Table 5.3-2 for the Carrier Aircraft RF environment (requirements taken from OSC A70055). The requirements of the paragraph are verified by performance of the tests specified in 5.2.4.

6.0 DESIGN GUIDELINES

6.1 Grounding and power/signal distribution

The spacecraft grounding and power distribution system shall be as described in paragraph 3.8.1 of FAST-SPEC-005.

6.1.1 Primary power wiring

Primary power is defined to be the spacecraft power bus generated by the power subsystem and consists functionally of two wires: +28 Vdc and +28 Vdc Return.

It includes connections to the power subsystems (including relayed power) and the primary side of all DC-DC converters used in the science instrumentation and other spacecraft bus subsystems. Primary power shall be carried on twisted pair wiring to reduce normal mode magnetic dipole moments. Power is typically carried on multiple pairs of wires for redundancy; all of the power wires should be twisted together. As a guide, roughly 20 turns per foot will be effective for wire twisting. At the DC-DC converters, both the +28 Vdc and +28 Vdc Return wires shall be DC-isolated from the converter chassis by at least 1 Megohm. The power subsystem shall tie all +28 Vdc Return wires together and to spacecraft chassis at a common point within the MUE that is as close to the battery as possible. The common return point and DC-isolation at the converters will prevent converter noise currents from contaminating the spacecraft chassis.

6.1.2 Electrical bonding

Electrical bonding of boxes and spacecraft chassis members to each other is critical to maintaining low impedance to return current flow. Bonding between the conductive parts of spacecraft chassis, box enclosures, connectors mounted on the enclosures/spacecraft chassis, and cable shields shall be in accordance with MIL-B-5087, Classes R, C, S, and H.

6.1.3 Bundle shields and connectors

If bundle shields are used, they shall be terminated to the shells of all connectors through as low an impedance path as possible. Mated connectors shall have a dc resistance of no greater than 2.5 milliohms from the shell of one connector to the shell of the other. The bundle shields will reduce electrostatic coupling between wires internal and external to the shields.

6.1.4 Signal distribution

6.1.4.1 Signals between spacecraft enclosures

Requirements on signal distribution between the spacecraft enclosures are described in FAST-SPEC-013.

6.1.4.2 Ground Support Equipment (GSE) interface signals

6.1.4.2.1 Twisted-shielded pair wiring

GSE interface signals and power shall be carried on twisted-shielded pair wire. The wire twisting will reduce normal mode magnetic dipole moments. As a guide, roughly 20 turns per foot will be effective for wire twisting.

6.1.4.2.2 Shield terminations

Shields for GSE interface signal pairs whose frequency is less than 1 MHz shall be connected to chassis at the transmitter only and shall be continued through any intervening connectors. Shields for GSE interface signal pairs whose frequency is greater than 1 MHz shall be connected to chassis at both the transmitter and the receiver and shall be continued through any intervening connectors. Daisy-chaining of shield terminations at connectors shall be minimized to the maximum extent consistent with weight and cost constraints. If daisy-chaining of grounds at intermediate connectors must be used, no more than 5 shields may be daisy-chained at a connector. Daisy-chaining shall be consistent if used at more than one location in the signal path. The shields will reduce electrostatic coupling between wires internal and external to the shields. All shields present at connectors mounted on an enclosure shall be terminated to the exterior of the enclosure.

6.1.4.2.3 Differential signal transmission

Standard interface signals shall be differentially transmitted and received to reduce common mode electromagnetic coupling between the signal and other wires. Each differential transmitter shall be source-terminated to the characteristic impedance of its transmission line and shall be DC-isolated from its enclosure by at least 1 Megohm. Each differential receiver shall provide DC-isolation of at least 1 Megohm between each wire of the differential pair to each other and the enclosure chassis. The isolation requirements will prevent signal currents from contaminating the ground plane. The timing skew between the signal edges of any pair shall be no greater than 6 ns. The timing skew requirement will reduce unintentional radiation from the signal pair.

6.1.3.4 Pegasus launch vehicle interface signals

The SMEX-FAST interface to the Pegasus launch vehicle is the standard interface offered by Orbital Sciences Corporation (OSC). This interface shall be in accordance with the Interface Control Document section of FAST-SPEC-013.

6.1.4 PC board and motherboard requirements

Power distribution on multilayer PC boards and motherboards shall use at least one layer as a ground plane and at least one layer for supply voltages. It is recommended that PC boards and motherboards using multiple supply voltages should distribute these voltages on separate layers if practical, or as a minimum, use separate layers to distribute power for digital and analog circuits. The recommendations on power distribution will help to minimize the series impedance in the power circuit, leading to reduction in common impedance coupling of interference. All PC boards shall use bypass capacitors located as near to the power point of entry to the board as practical. Each integrated circuit shall have bypass capacitors located near the power pins of its package. It is recommended that long, closely-spaced signal tracks be avoided if practical to minimize coupling effects. Single-ended transmission of signals from PC board to PC board is allowed. If necessary, sensitive signals may be shielded from on-board interference by sandwiching the signal tracks between 2 ground planes. Sensitive signals may also be shielded at the PC board connector by surrounding the signal pin by grounded pins, if practical. It is strongly recommended that potential EMI emitters and receptors be identified and separated and/or shielded from each other in the motherboard.

6.2 Wire harness requirements

6.2.1 Power and signal classes

To the maximum extent possible, wires in the following classes shall not be run in bundles containing wires of another class.

6.2.1.1 Class 1 wires

The following wires are defined to be Class 1 wires:

a. DC circuit wiring carrying steady-state or transient currents above 1 A,
b. relay and solenoid wiring, and
c. all primary power wiring.

6.2.1.2 Class 2 wires

The following wires are defined to be Class 2 wires:

a. wires carrying currents between 50 Ma and 1 A, and
b. wires carrying digital signals.

6.2.1.3 Class 3 wires

The following wires are defined to be Class 3 wires:

a. wires carrying signals to sensitive instruments,
b. wires carrying signals to sensitive circuits, and
c. instrumentation wiring.

6.2.1.4 Class 4 wires

Cables carrying transmitted and received RF between the transponder and antennae are defined to be Class 4 wires.

6.2.1.5 Class 5 wires

Meltwire and electro-explosive device (EED) wires are defined to be Class 5 wires.

6.2.2 Wire harness mechanical requirements

All wire harness runs shall be routed as close to the spacecraft structure as possible to reduce magnetic dipole moments. All wire harness runs shall be clamped to the structure at frequent intervals to minimize generation of fields caused by relative motion between the harness and the structure. Parallel runs of bundles of differing class shall be avoided to the maximum extent possible.

6.3 DC-DC converter requirements

DC-DC converters shall meet the requirements defined in paragraph 3.8.3 of FAST-SPEC-005.

6.4 Switched inductive load spike suppression

Switched inductive loads, such as relay coils and the like, shall be bypassed with a parallel, reversed-biased diodes to suppress high-voltage inductive spikes caused when current flow in interrupted.

6.5 Open collectors

In those cases where single-ended signals are used between enclosures, driving a pulled-up load with an open-collector or similar device shall be avoided to the maximum extent possible. Doing so will avoid conduction of power bus noise into the enclosure and avoid a possible safety hazard due to inadvertent grounding of the signal line causing activation of the pulled-up load. Recommended practice is to drive the high side of the load and ground the low side.

6.6 Signal rise and fall times

Consistent with adequate performance and cost, signal rise and fall times shall be slowed to reduced the radiated noise spectrum. If R-C filtering is used to control the rise and fall time, the filter shall be located at the transmitting end.

6.7 Resistivity of spacecraft surface materials

The resistivity of spacecraft surface materials shall be in accordance with paragraph 2.1.4.8.1.2 of FAST-SPEC-005.

6.8 Magnetic materials

Magnetic shielding of spacecraft circuitry shall be avoided, if possible. Diamagnetic and paramagnetic materials are preferred for spacecraft use, since they have no easily perceptible magnetic properties unless contaminated during fabrication. Examples of diamagnetic materials are aluminum, copper, titanium, beryllium copper, silver, lead, magnesium, tin, and most glasses. Ferromagnetic, ferrimagnetic, and superparamagnetic materials shall be avoided to the maximum extent possible because of their strong and/or unstable magnetic properties. Examples of these materials include iron and iron alloys, nickel and nickel alloys, cobalt and cobalt alloys, steel, Invar, and ferrites. Tools used during all phases of the project either shall be made of non-magnetic materials or shall be demagnetized prior to use on the spacecraft. These requirements will reduce the build-up of permanent magnetic dipole moments. Use of any magnetic material greater than 10 grams must be approved by the systems engineer.

6.9 Solar array wiring

Solar array wiring shall be in accordance with paragraph 3.9.7 of FAST-SPEC-005.

6.10 Filtered-pin connectors

Filtered pin connectors shall be considered as one option to prevent conducted EMI from entering into and escaping from an enclosure.

7.0 QUALITY ASSURANCE

7.1 Test philosophy

The system, subsystems, and components shall meet the applicable portions of MIL-STD-461 and MIL-STD-462 as interpreted by this document. The spacecraft shall operate without undesirable EMI interactions with the Pegasus launch vehicle. Test plans shall be developed and tests performed by electrical systems engineer subject to the review of OSC to assure spacecraft/Pegasus compatibility. Tests shall be performed on subsystems and components to show compliance to the applicable requirements and to provide information that would enhance the compatible integration of the subsystem/component into the overall spacecraft. Modifications and changes to component design after EMI testing shall be reviewed by the electrical systems engineer to determine the need for additional testing.

7.2 Test plans

An EMI test plan shall be prepared for the spacecraft and each component/subsystem in accordance with Table 5.2-1. As a minimum, the plans shall include the following details:

a. the means of implementation and application of the needed test procedures,
b. nomenclature, description, and mode of operation of the test sample,
c. description and RF ambient profile of the test site (open space,anechoic, and/or shielded enclosure),
d. test frequencies including modulations, and computations to indicate frequencies of which extraneous outputs, susceptibilities, and intermodulation products may be expected,
e. considerations and regulations regarding the operation of the test sample and measuring equipment in unshielded areas (eg. FCC or FAA regulations),
f. personnel required, including GSFC, UCB, and OSC representatives and performance personnel,
g. readout and detector functions to be used in measuring equipment, where applicable,
h. dummy loads, filters, dummy antennae, signal samplers, and similar items to be used and their description (eg. VSWR, isolation, and loss) in the range of interest,
i. method of loading and triggering the test sample during tests,

j. method and criteria for determining malfunction or degradation of performance during susceptibility tests,
k. expected overall accuracy of measurements and external influencing conditions, and
l. detailed list of test equipment.

7.3 Test procedure

The spacecraft EMI test procedure shall be prepared by the electrical systems engineer. An EMI test procedure shall be prepared for each subsystem and component test by the responsible lead engineer and approved by the electrical systems engineer. The test procedure shall contain the detailed method of testing including but not limited to the following:

a. detailed step-by-step procedures and test set-ups with maximum use of photographs, drawings, and diagrams,
b. nomenclature, serial numbers, and general characteristics of test equipment (eg. transfer impedance of current probes and effective lengths of antennae), and
c. methods and dates of last calibration of interference measuring equipment and calculations to show expected accuracy of each where required.

7.4 Test fixture

The test fixture used to support the spacecraft shall be constructed such that significant RF potential differences shall not exist within the structure. The fixture shall be bonded to the shielded enclosure by a maximum DC resistance of 2.5 milliohms. The test fixture shall make provisions for the bonding of the spacecraft to the fixture in accordance with the bonding requirements of this document.

8.0 NOTES

8.1 Acronyms

ACS	Attitude Control Subsystem
dB	deciBel
DC	Direct Current
EED	Electro-Explosive Device
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
FAA	Federal Aviation Administration
FAST	Fast Auroral SnapshoT
FCC	Federal Communications Commission
GSFC	Goddard Space Flight Center
MUE	Mission Unique Electronics
OSC	Orbital Sciences Corporation
PC	Printed Circuit
R-C	Resistor-Capacitor
RF	Radio Frequency
SMEX	SMall EXplorer
UCB	University of California at Berkeley
VSWR	Voltage Standing Wave Ratio

8.2 EMI checklists

These checklists have been provided as a helpful reminder of good EMI control practices. A "yes" or "not applicable" answer to any question requires no further thought. A "no" answer requires careful consideration of the potential EMI impact and should be resolved by discussion with the electrical systems engineer.

8.2.1 Checklist A: circuits to be shielded and filtered

a. Have chopper, converter, relay, motor, clock or timing circuits with fast rise time or high PRF, and similar circuits been filtered using filters selected for their attenuation characteristics at the noise frequencies?

b. Has the DC-DC converter transformer been electrostatically-shielded?

c. Has bandpass filtering been used on transmitter outputs or receiver inputs?

d. Is the shielding material suitable for the frequency range of interest?

e. Have decoupling capacitors been used on internal power connections?

f. Have shielded subassemblies been used in the equipment?

g. Have RF chokes and inductors been used to confine the RF energy to the desired circuits?

h. Have low-level or susceptible circuits been physically separated from EMI producing circuits within an enclosure?

i. Have toroids been used to minimize the leakage field of inductors and have inductors been cross-oriented to minimize coupling?

j. What effect do vent holes have on the box's radiated emissions?

8.2.2 **Checklist B: elimination of spurious responses**

a. Have short lead lengths been used for all circuits, especially capacitors in RF circuits?

b. Has damping been used in circuits capable of oscillation?

c. Have critical dimensions been avoided, considering the enclosure as an RF cavity?

d. Have all feedback loops been designed to prevent oscillation under worst-case conditions?

e. Have high-power and low-power stages of units been isolated?

f. Is the proposed enclosure bonding adequate at the known critical radio frequencies?

g. Have components that are not self-resonant in the intended frequency range been used except when required by the circuit functionality?

h. Have special circuits that discriminate against spurious resonances been used?

8.2.3 **Checklist C: selection of components**

a. Are diodes or other suppression components being used across relay coils?

b. Are R-C circuits being used across relay contacts?

c. Are capacitors being used directly across DC motor brushes?

d. Are toroids or other low-leakage inductors being used?

e. Are separate connectors being used for sensitive and EMI-producing circuits?

f. Is twisted-pair and/or shielded wiring being used?

g. Is balanced-circuit design being used?

8.2.4 Checklist D: electro-explosive devices

a. Has the EED been bonded to the structure per MIL-B-5087?

b. Have firing circuit conductors been routed as twisted-shielded pairs?

c. Have bundle shields been circumferentially-terminated?

d. Have EED cables been isolated in accordance with the wire harness separation classifications?

f. Internal to components, has EED wiring been isolated from all other wires?

g. Have separate connectors been provided for EED wiring?

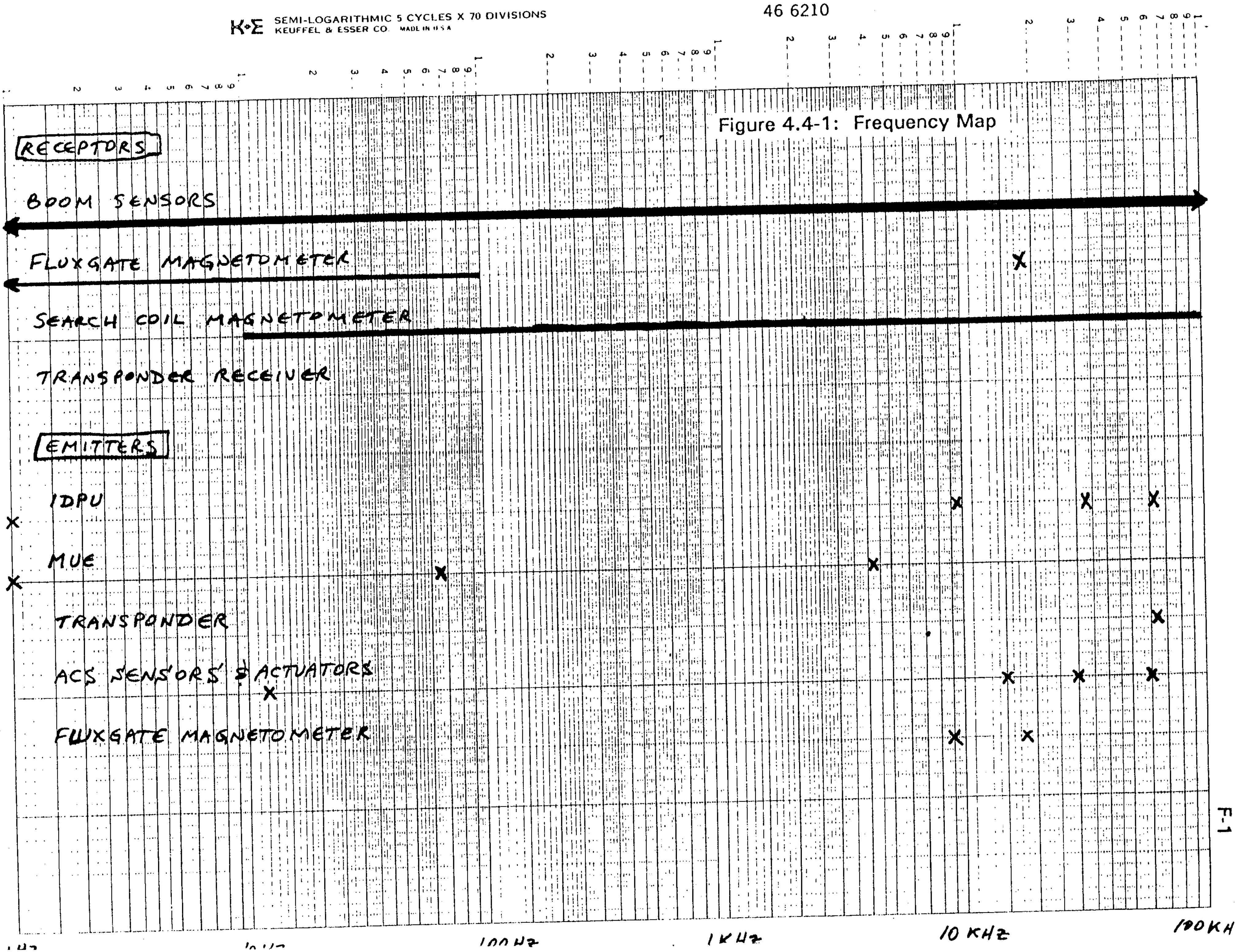


Figure 4.4-1: Frequency Map

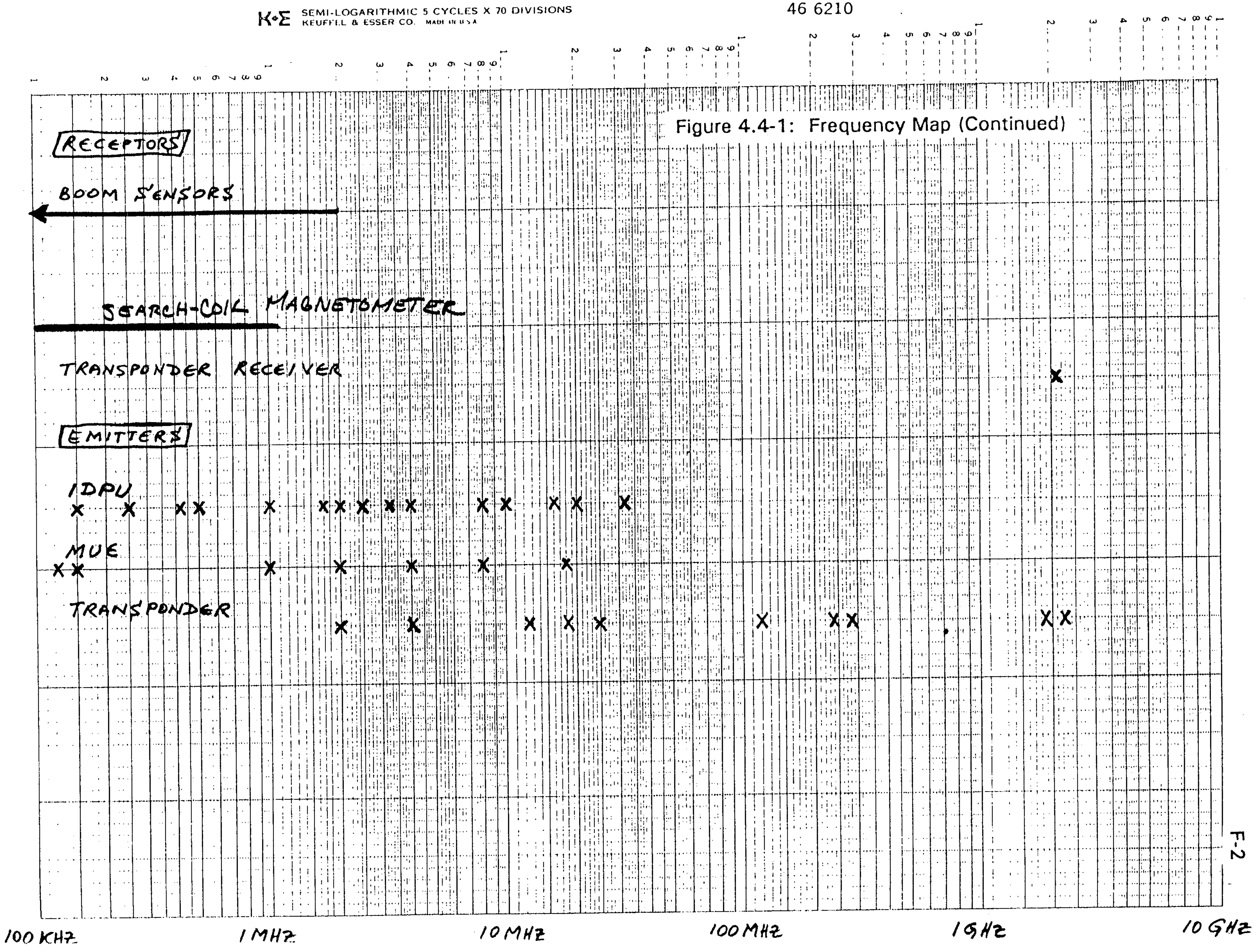


Figure 4.4-1: Frequency Map (Continued)

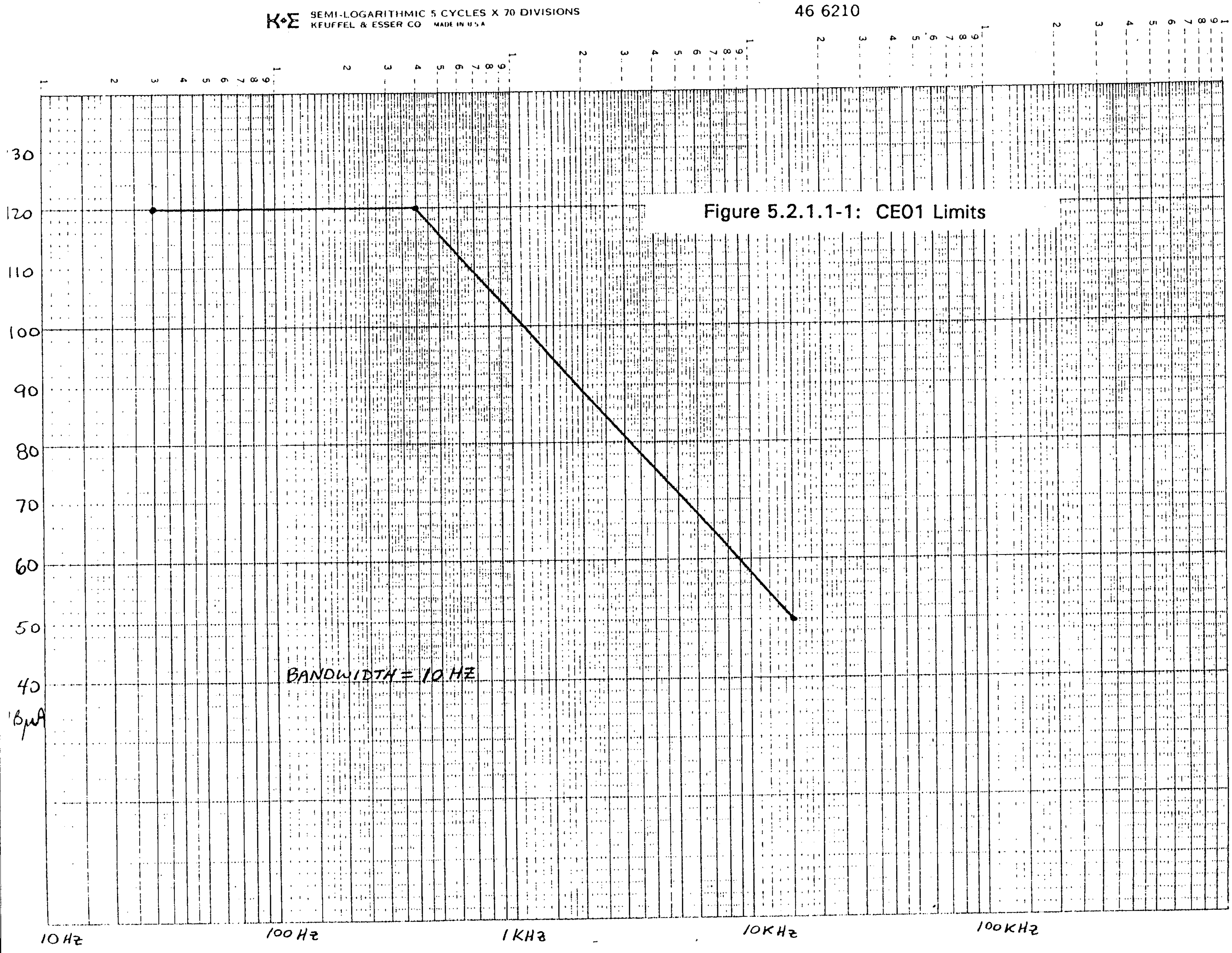


Figure 5.2.1.1-1: CE01 Limits

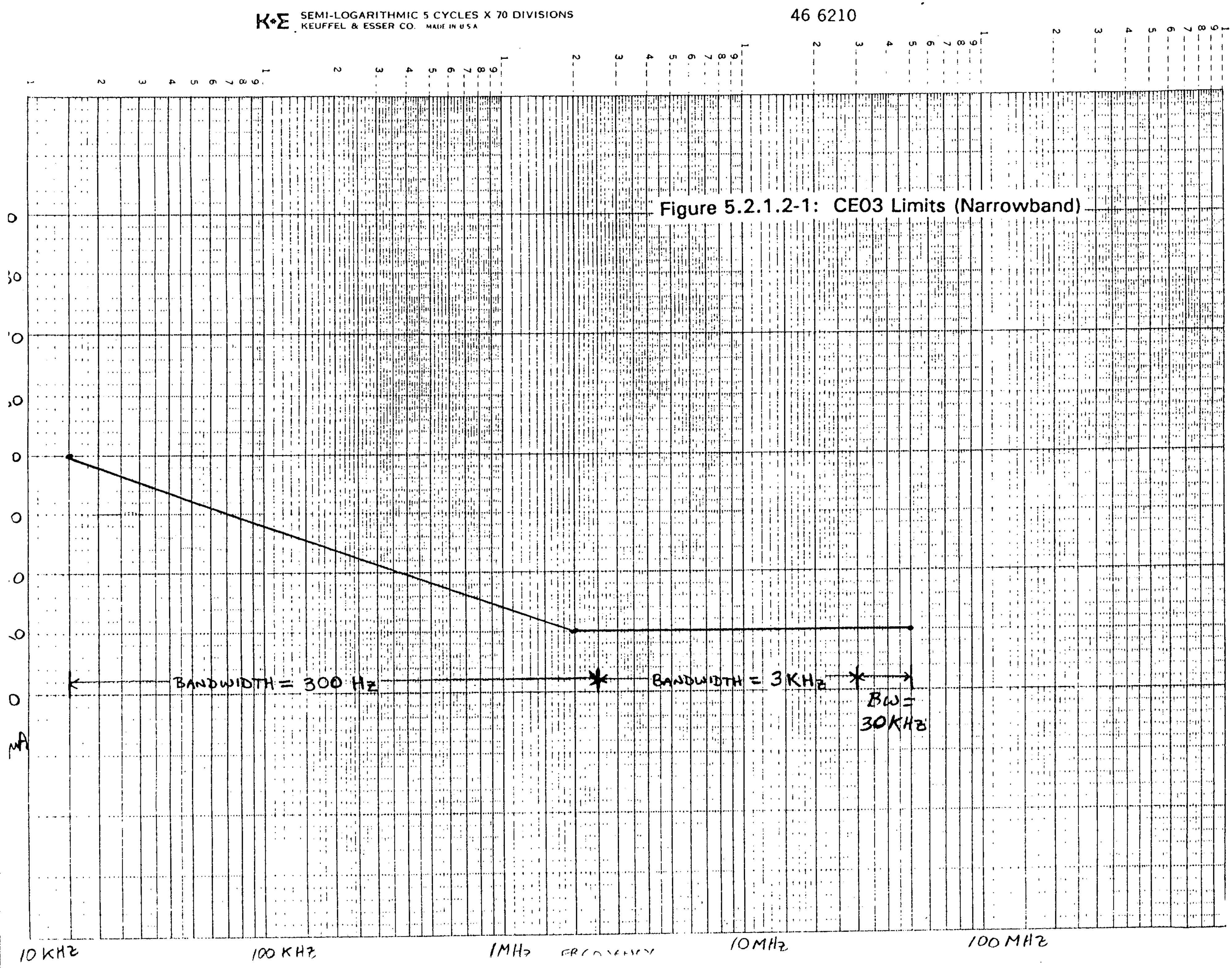


Figure 5.2.1.2-1: CE03 Limits (Narrowband)

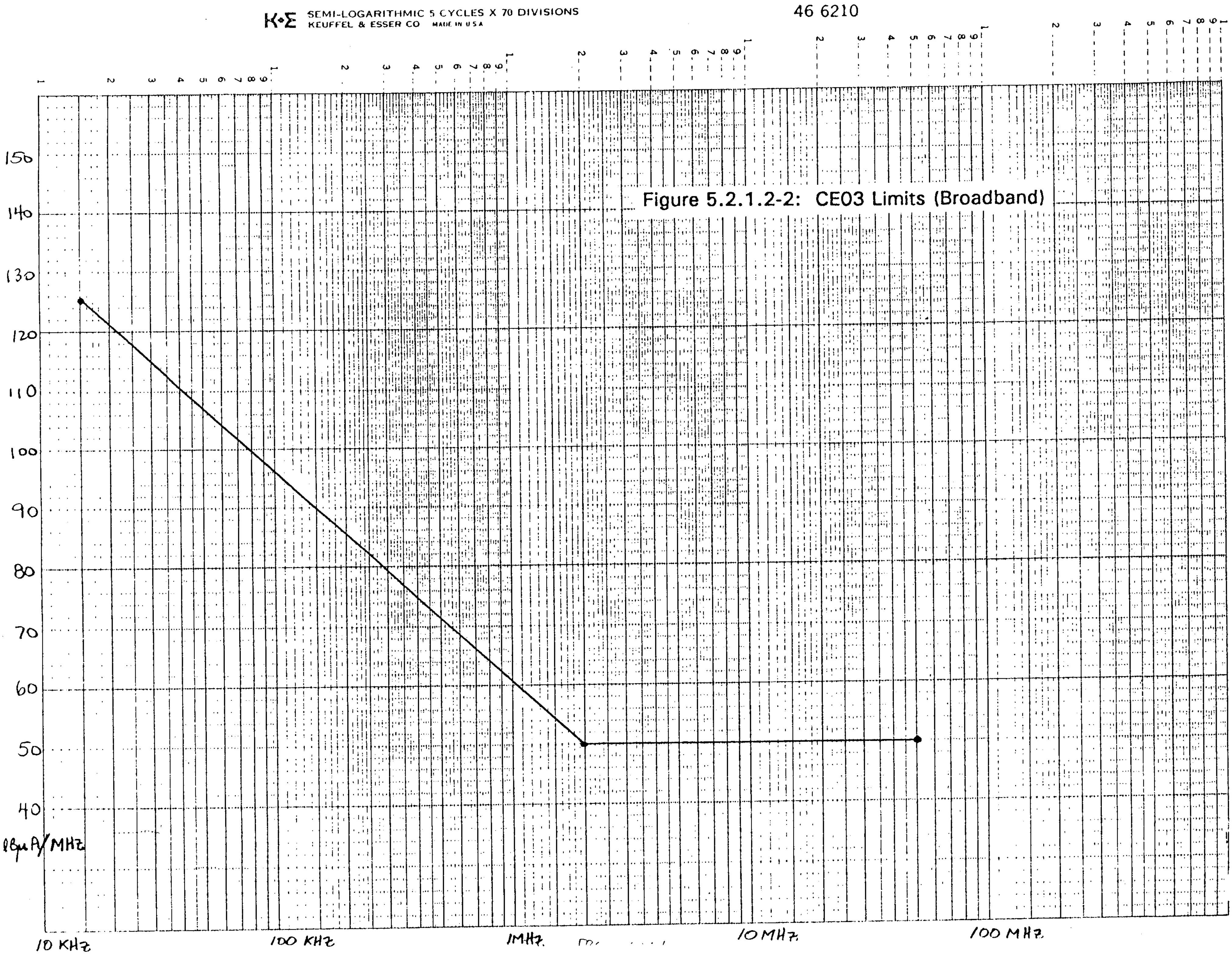


Figure 5.2.1.2-2: CE03 Limits (Broadband)

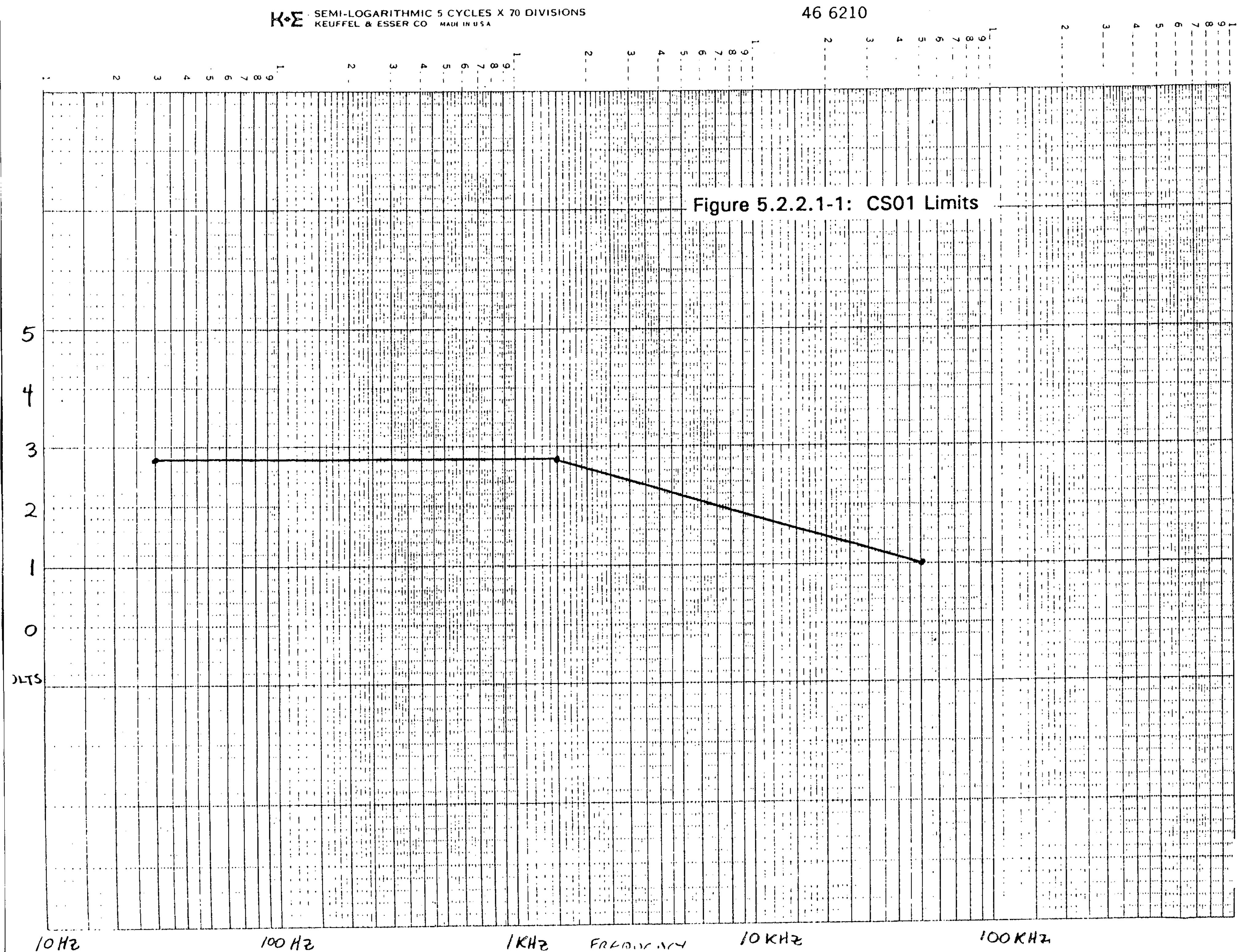
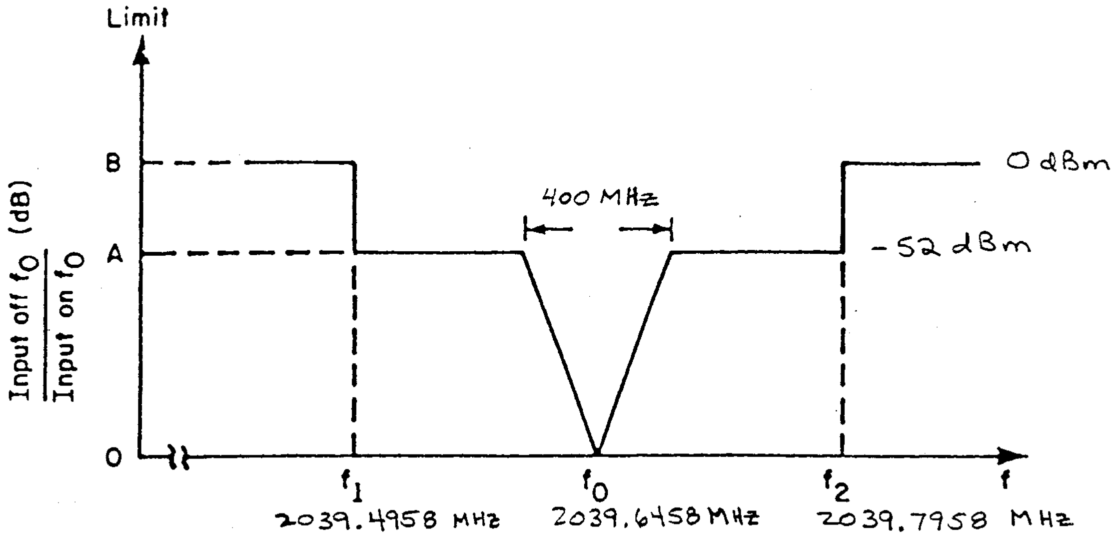


Figure 5.2.2.1-1: CS01 Limits



f_0 = Receiver tuned frequency or band center for amplifiers.

f_1 = Lowest tunable frequency of receiver band in use or the lowest frequency of amplifier passband.

f_2 = Highest tunable frequency of receiver band in use or the highest frequency of amplifier passband.

W = Bandwidth between the 60 dB points of the receiver selectivity curve as defined in the test sample's technical requirements or the control plan.

<u>Limits</u>:

1. The limit at A is 60 dB above the input level required to produce the standard reference output. The standard reference output is based on a -112 dBm input.
2. The limit at B shall be set as follows:
   a. Receivers: 0 dBm applied directly to the receiver input terminals.
   b. Amplifiers: The limit shall be as specified in the test sample's technical requirement or control plan. If no limit is defined in the above documents, the 0 dBm value shall be used.

Figure 5.2.2.4-1: CS04 Limits

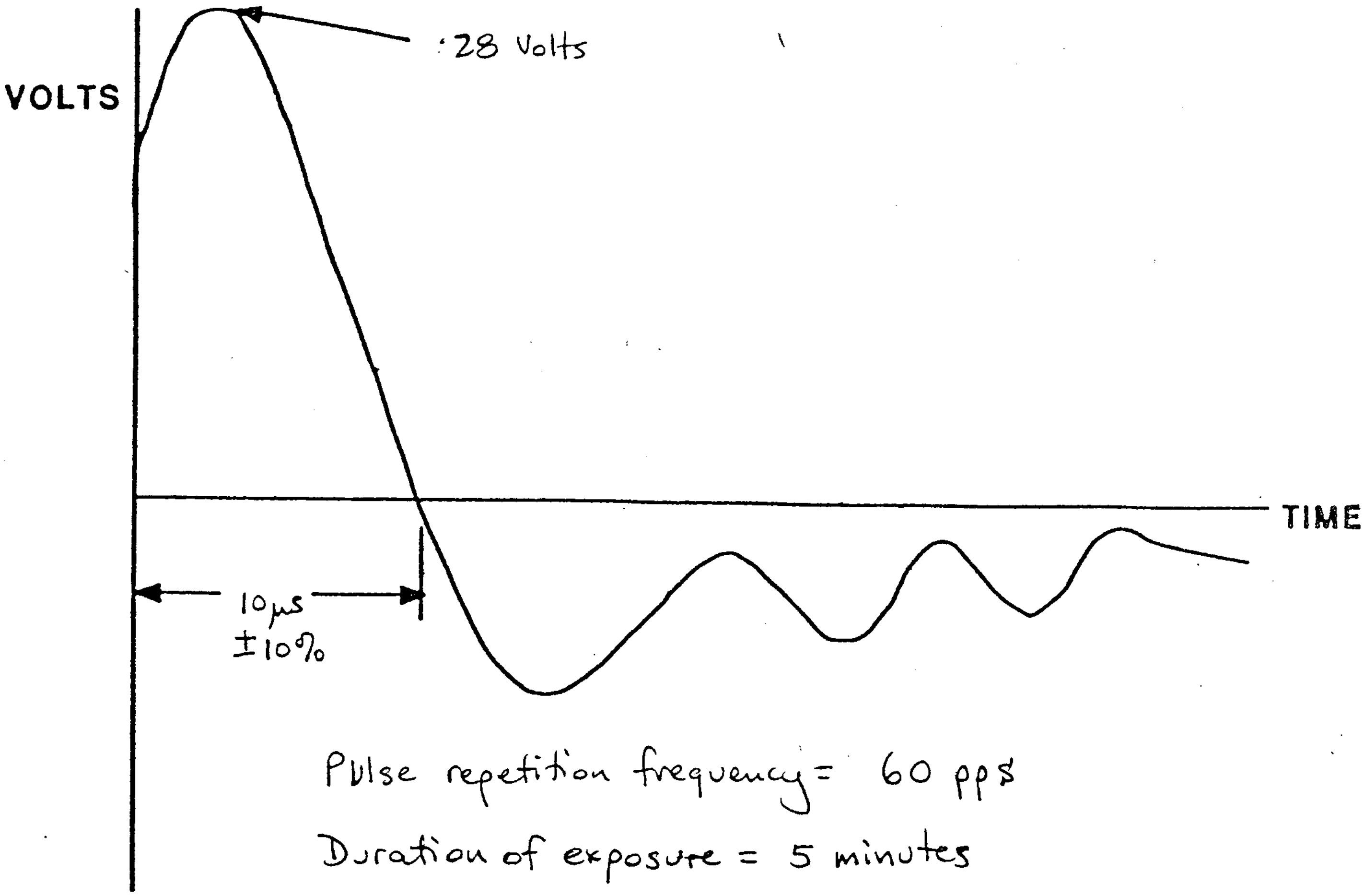
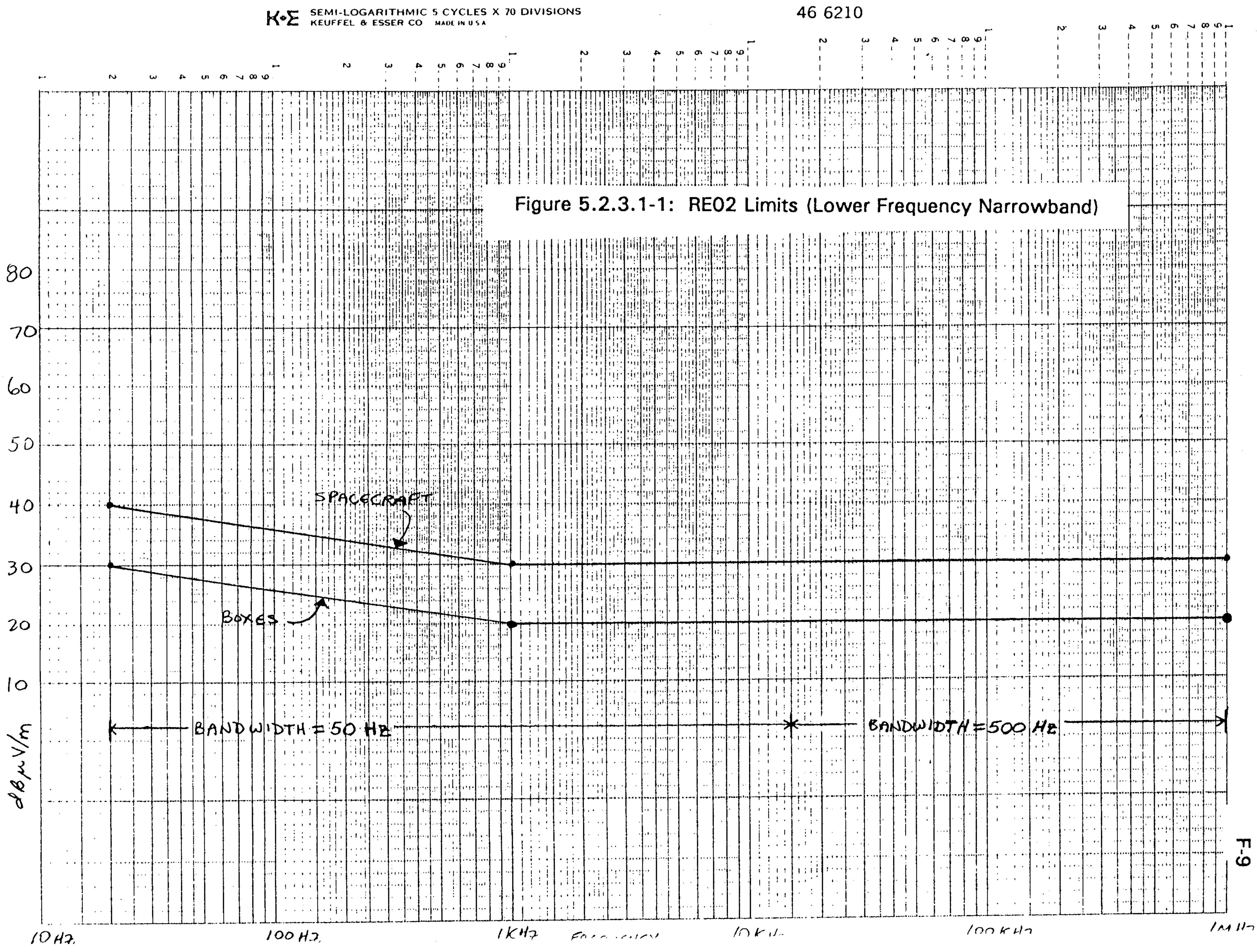


Figure 5.2.2.6-1: CS06 Limits

Figure 5.2.3.1-1: RE02 Limits (Lower Frequency Narrowband)



K•Σ SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO MADE IN U.S.A.

46 6210

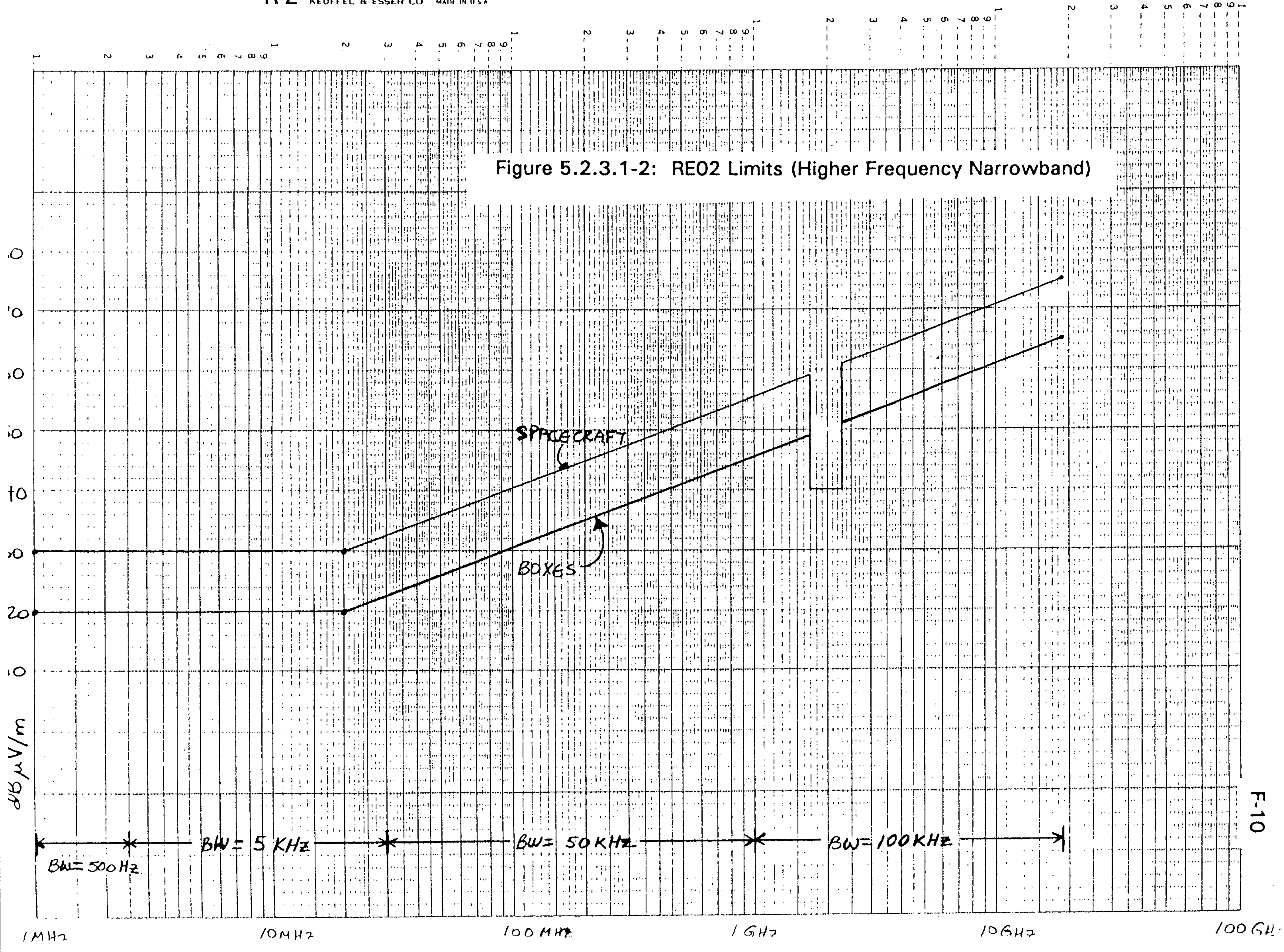


Figure 5.2.3.1-2: RE02 Limits (Higher Frequency Narrowband)

K•E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS KEUFFEL & ESSER CO. MADE IN U.S.A. 46 6210

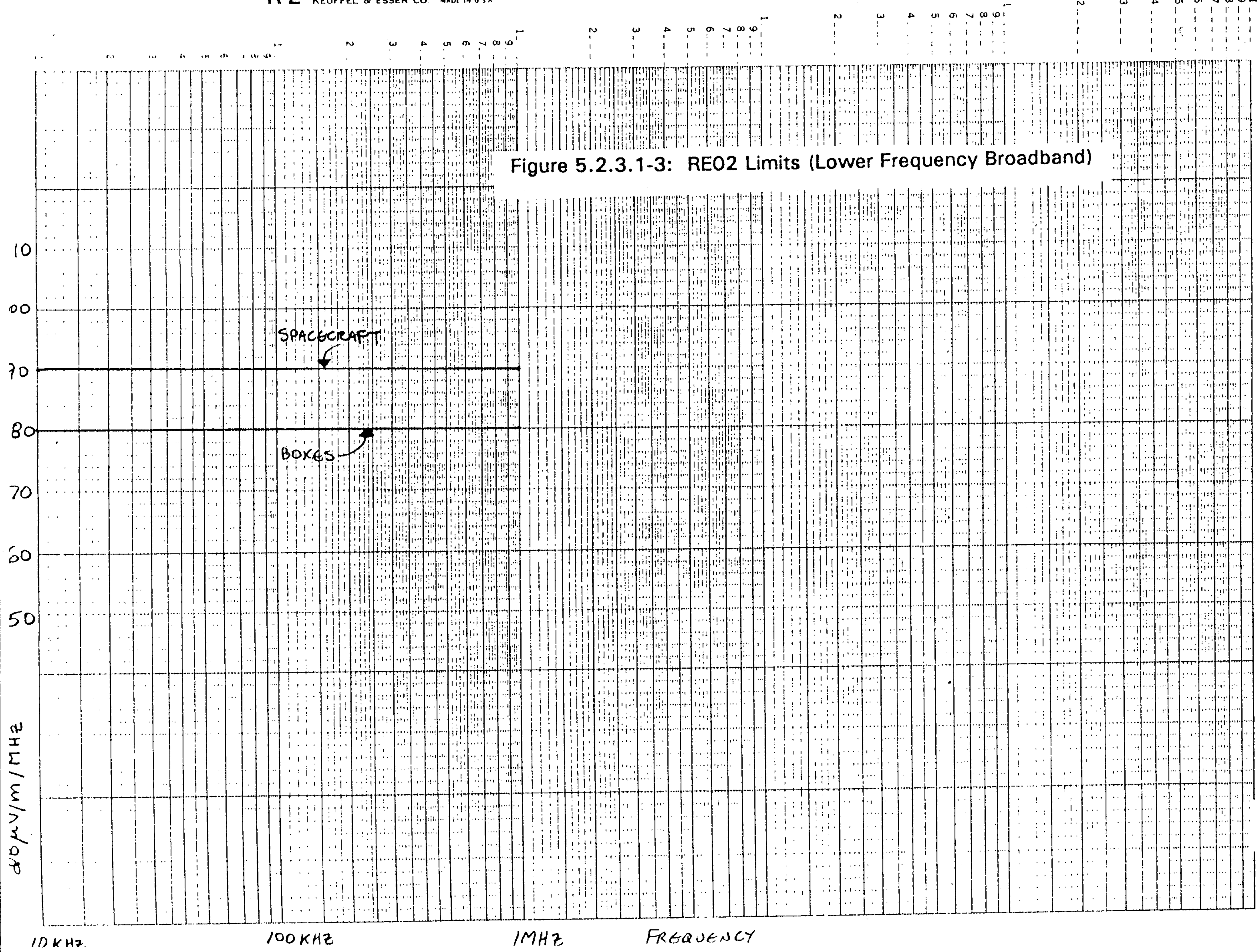


Figure 5.2.3.1-3: RE02 Limits (Lower Frequency Broadband)

K•E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 6210

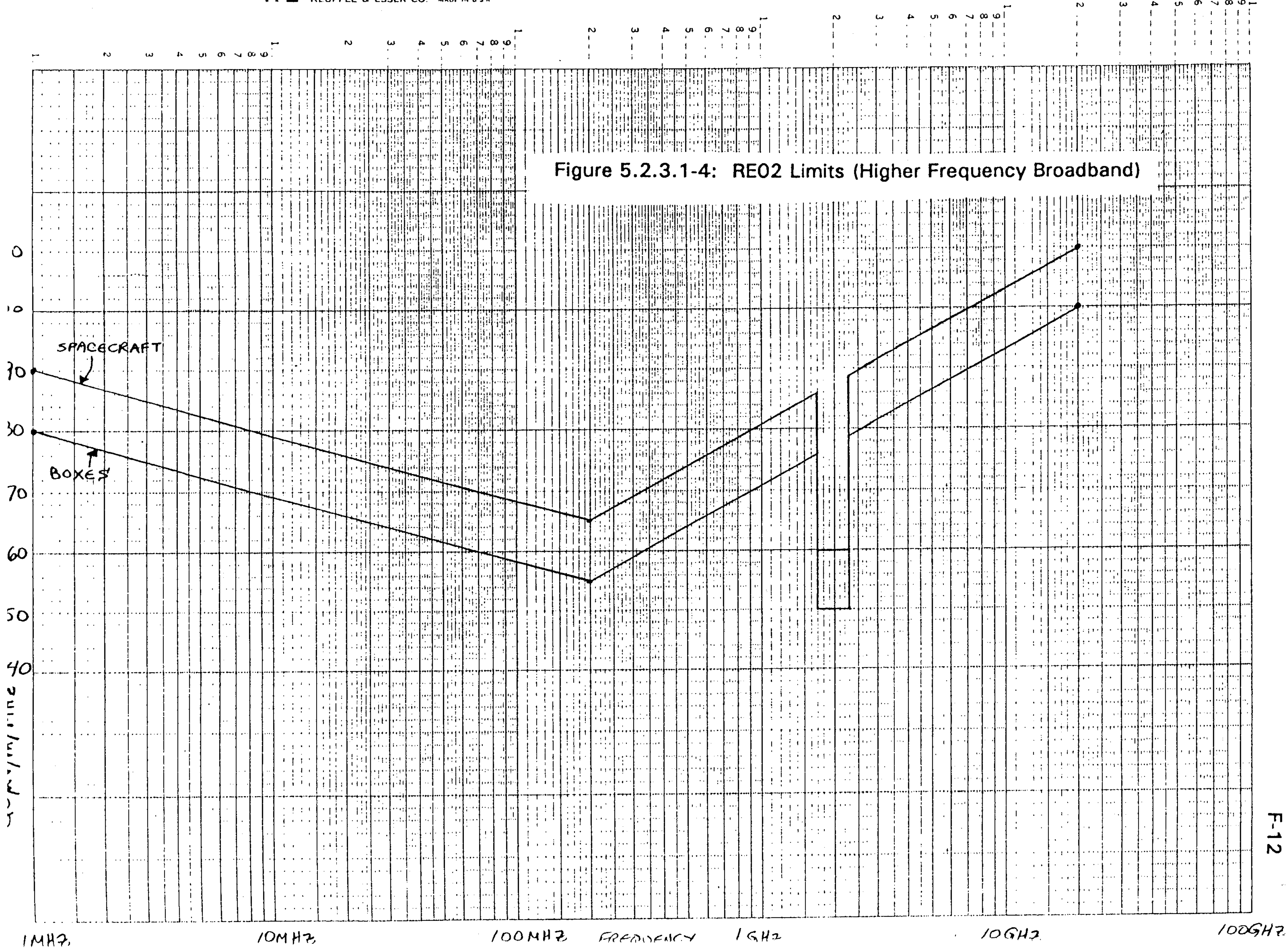


Figure 5.2.3.1-4: RE02 Limits (Higher Frequency Broadband)

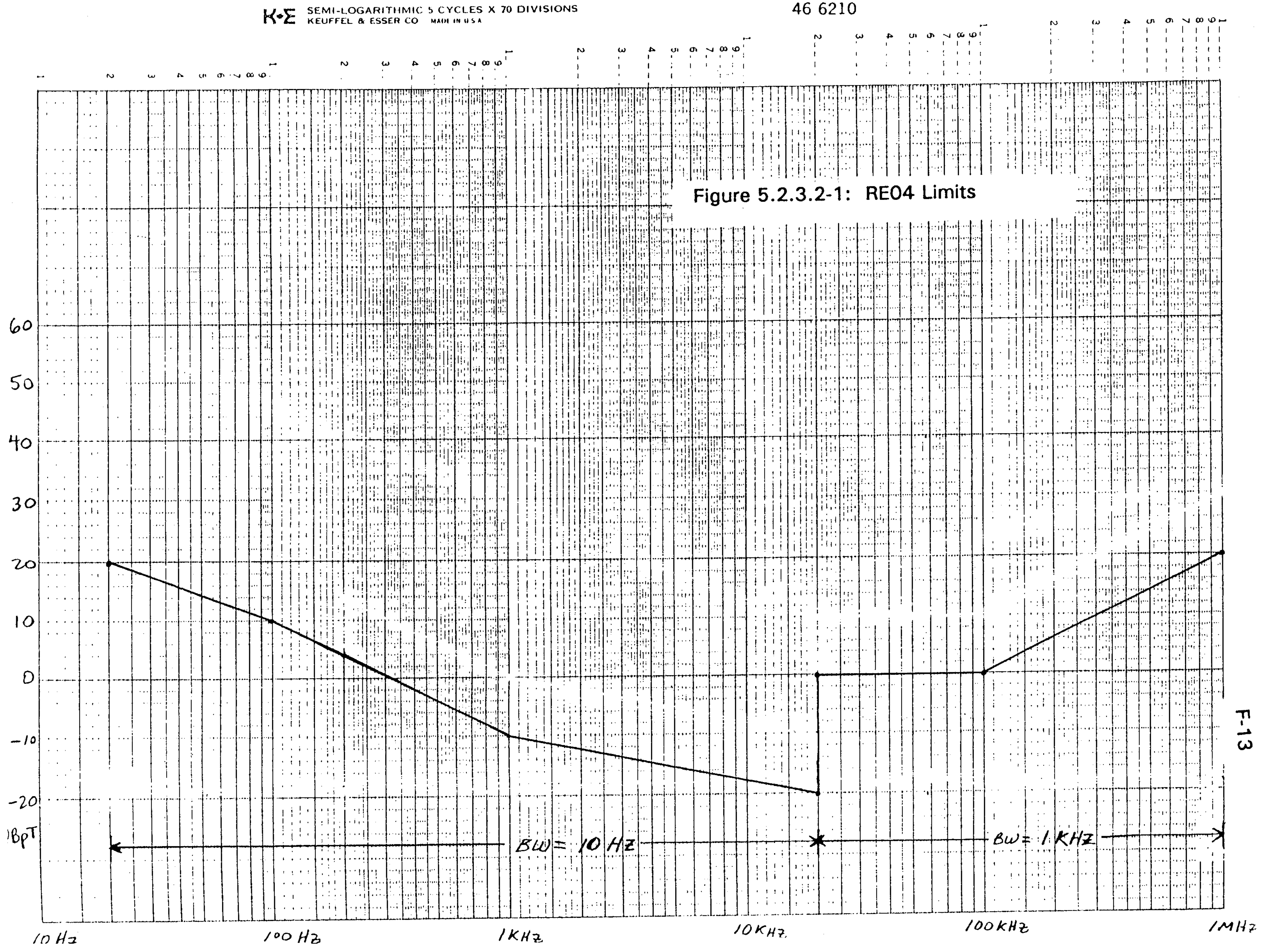


Figure 5.2.3.2-1: RE04 Limits

Table 4.4-1: FAST Frequencies

Unit	Signal Type	Frequency
IDPU	Processor Oscillator	20.0000 MHz
	Processor Clock	10.0000 MHz
	Processor Primary Cycle A	2.5000 MHz
	Processor Primary Cycle B	2.0000 MHz
	Processor Primary Cycle C	1.6667 MHz
	UART Oscillator	153.8462 KHz
	UART Clock	9.6154 KHz
	S/C Clock	4.1943 MHz
	S/C Sync Pulse	1.0000 Hz
	Memory Interface Clock	4.1943 MHz
	Memory Cycle Rate	419.4304 KHz
	ADC Sample Rate	32.7680 KHz
	ADC Clock	2.6214 MHz
	ESA Shift Clock	1048.5760 KHz
	Spin Phase Clock	3276.8000 KHz nominal
	DSP System Clock	32.0000 MHz
	DSP Serial Shift Clock	16.0000 MHz
	DSP Parallel Input Clock	8.0000 MHz
	Wave-Particle Correlator System Clock	16.0000 MHz
	H/S Burst Memory System Clock	4.0000 MHz
	H/S Burst Memory Sample Clock A	2.0000 MHz
	H/S Burst Memory Sample Clock B	1.0000 MHz
	H/S Burst Memory Sample Clock C	500.0000 KHz
	H/S Burst Memory Sample Clock D	250.0000 KHz
	IDPU and Instrument DC-DC Converters	62.0000 KHz nominal

Table 4.4-1: FAST Frequencies (Continued)

UNIT	SIGNAL TYPE	FREQUENCY
Transponder	Transmit	2214.9999 MHz
	Receive	2039.6458 MHz
	$2F_1$	18,458,333 Hz
	$13F_1$	119,979,166 Hz
	$26F_1$	239,958,333 Hz
	$30F_1$	276,875,000 Hz
	$208F_1$	1,919,666,667 Hz
	F_2	12.25 MHz
	$2F_2$	24.5 MHz
	F_{osc}	4.096 MHz
	$F_{osc}/2$	2.048 MHz
	Transponder DC-DC Converter	62.5 KHz
MUE	Processor Card Oscillator	8 MHz
	S/C Clock, Up/downlink	18 MHz
	S/C Clock	4,194,304 Hz
	Coil Driver Converter, MUE DC-DC Converter	125 KHz
	RS-422 Clock	151 KHz
	Other	1 Hz
	Other	64 Hz
	Other	4.096 KHz
	Other	1 MHz
	Other	2 MHz
	Other	4 MHz

Table 4.4-1: FAST Frequencies (Continued)

UNIT	SIGNAL TYPE	FREQUENCY
ACS Sensor/Actuators	Spin Coil PRF	12 Hz
	Sun Sensor DC-DC Converter	6 KHz
	ACS Magnetometer Drive Frequency 2ND Harmonic	 15 KHz 30 KHz
Science Instruments	Wire & Axial Boom Sensors	DC to 2 MHz
	Search Coil Magnetometer	10 Hz to 1 MHz
	Fluxgate Magnetometer Received Passband Drive Frequency 2ND Harmonic	 DC to 100 Hz 9 KHz 18 KHz

Table 5.2-1: EMI Requirements/Verifications per Level of Assembly

Requirement	MIL-STD-462 Test Method	Reference Paragraph Number	Level of Assembly	
			Spacecraft	Box
DC Power Leads (Lo Freq)	CE01	5.2.1.1	N	A
DC Power Leads (Hi Freq)	CE03	5.2.1.2	N	A
Antenna Terminal	CE06	5.2.1.3	N	B
DC Power Leads (Lo Freq)	CS01	5.2.2.1	N	A
DC Power Leads (Hi Freq)	CS02	5.2.2.2	N	A
Intermodulation	CS03	5.2.2.3	N	B
Spurious Rejection	CS04	5.2.2.4	N	B
Cross Modulation	CS05	5.2.2.5	N	B
DC Power Spikes	CS06	5.2.2.6	N	A
Electric Fields	RE02	5.2.3.1	S	C
Magnetic Fields	RE04	5.2.3.2	S	C
Electric Fields	RS03	5.2.4	S	C
DC Magnetic Properties	N/A	5.2.5	S	C

LEGEND:
A = Test performed on all units interfacing to spacecraft power, including switched power and Pegasus interface power (Solar Arrays, Batteries, MUE, IDPU, Shunt Boxes)
B = Test Performed on Transponder
C = Test Performed on all Boxes
N = No Test Performed at this Level
S = Test Performed on Spacecraft

CE = Conducted Emissions
CS = Conducted Susceptibility
RE = Radiated Emissions
RS = Radiated Susceptibility

Table 5.2.5-1: Magnetization Requirements

Type	Background Magnetization (Tesla)	Maximum Magnetic Field (nT)	
		at 50 cm	at 100 cm
Initial Permanent Magnetization	0	32	4
After Exposure to 0.0015 Tesla Magnetizing Field	0	64	8
After Exposure to 0.005 Tesla Demagnetizing Field	0	16	2
Induced Magnetization	3×10^{-5}	16	2
Stray Fields			
DC	0	16	2
0.01 - 0.1 Hz	0	8	1
0.1 - 1.0 Hz	0	8	1

Table 5.3-1: Pegasus RF Environment

Source	1	2	3	4	5
Function	Command Destruct	Tracking Transponder	Tracking Transponder	Alternate Telemetry	Booster Telemetry
Role	Receive	Transmit	Receive	Transmit	Transmit
Band	UHF	C-Band	C-Band	S-Band	S-Band
Frequency (MHz)	416.5	5765	5690	2269.5	2288.5
Bandwidth	180 Khz	N/A	14 MHz @ 3 dB	TBD	315 KHz @ 3 dB
Power Output	N/A	400 W Peak	N/A	5 W	5 W
Sensitivity	-107 dBm	N/A	-70 dBm	N/A	N/A
Modulation	FM	Pulse Code	Pulse Code	FM	PCM/FM

Table 5.3-2: Carrier Aircraft RF Environment

Source	1	2	3	4	5
Function	Comm	Comm	Telemetry	Video Telemetry	Video Telemetry
Role	Receive-Transmit	Receive-Transmit	Transmit	Transmit	Transmit
Band	UHF	UHF	L-Band	C-Band	S-Band
Frequency (MHz)	268.1	286.8	1435-1525	4583	1727
Bandwidth	Standard A/C Radio	Standard A/C Radio	1 MHz @ 60 dB	6 MHz @ 60 dB	6 MHz @ 60 dB
Power Output	Standard A/C Radio	Standard A/C Radio	5 W	10 W	10 W
Sensitivit y	Standard A/C Radio	Standard A/C Radio	N/A	N/A	N/A
Modulation	Standard A/C Radio	Standard A/C Radio	FM	FM	FM