Multi-attribute Evaluation of Materials for Shielding Enclosures Subjected to a Marine Environment

by

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Systems Engineering

(ABSTRACT)

The Naval Surface Warfare Center, Dahlgren Division (NSWCDD), has been tasked to design a shielded enclosure to be incorporated in an enclosed mast made of composite materials. This enclosure will house processing equipment which is known to be susceptible to electromagnetic energy. In addition to electromagnetic considerations, the design must accommodate the structural, fire prevention/control, signature, ballistics, and weight requirements which have been developed for the composite mast.

Some preliminary work has already been done by NSWCDD and other supporting organizations. Studies to determine the electromagnetic environment, lightning and electrostatic discharge requirements, and available shielding materials

are being conducted by NSWCDD and contractor personnel. Preliminary design requirements for the shielded room were developed based on these studies.

During this project, systems engineering principles were applied to selection of shielding materials for the shielded room. The previously developed requirements as well as system performance, cost, maintenance, and other life cycle issues were considered during the selection process.

FOREWORD

The Advanced Enclosed Mast/Sensor (AEM/S) System is an advanced technology development program sponsored by the Office of Naval Research (ONR). The Electromagnetic Environmental Effects portion of the AEM/S program is conducted at the Dahlgren Division of the Naval Surface Warfare Center (NSWCDD). The research necessary for this project was conducted under ONR and NSWCDD sponsorship.

Assistance was provided by all members of the AEM/S research team at NSWCDD and supporting contractor sites.

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Introduction

The Advanced Enclosed Mast/Sensor System (AEM/S) is an Advanced Technology Development (ATD) Program within the Department of the Navy. The purpose of the AEM/S is to enable the next generation of electronic sensors to perform as specified and to not significantly contribute to the electromagnetic (EM) signature of the ship. The AEM/S enables the next generation of electronic sensors to perform optimally by providing an environment which is relatively free of clutter, blockage, and intermodulation products. This is accomplished by the use of advanced multi-layered composites. Either phased array or rotating radars may be installed on/in the AEM/S. The phased array radars are surface mounted on the facets of the mast. The rotating radars are enclosed within frequency selective skins. These skins allow the radar frequency energy to pass while reflecting out-of-band energy. Figure 1, page 2, shows the AEM/S conceptual design.

Since the AEM/S encloses a large volume, it provides additional space for ship's equipments. In order for the equipments installed within the AEM/S to function properly, the appropriate EM environment (EME) must be provided. A

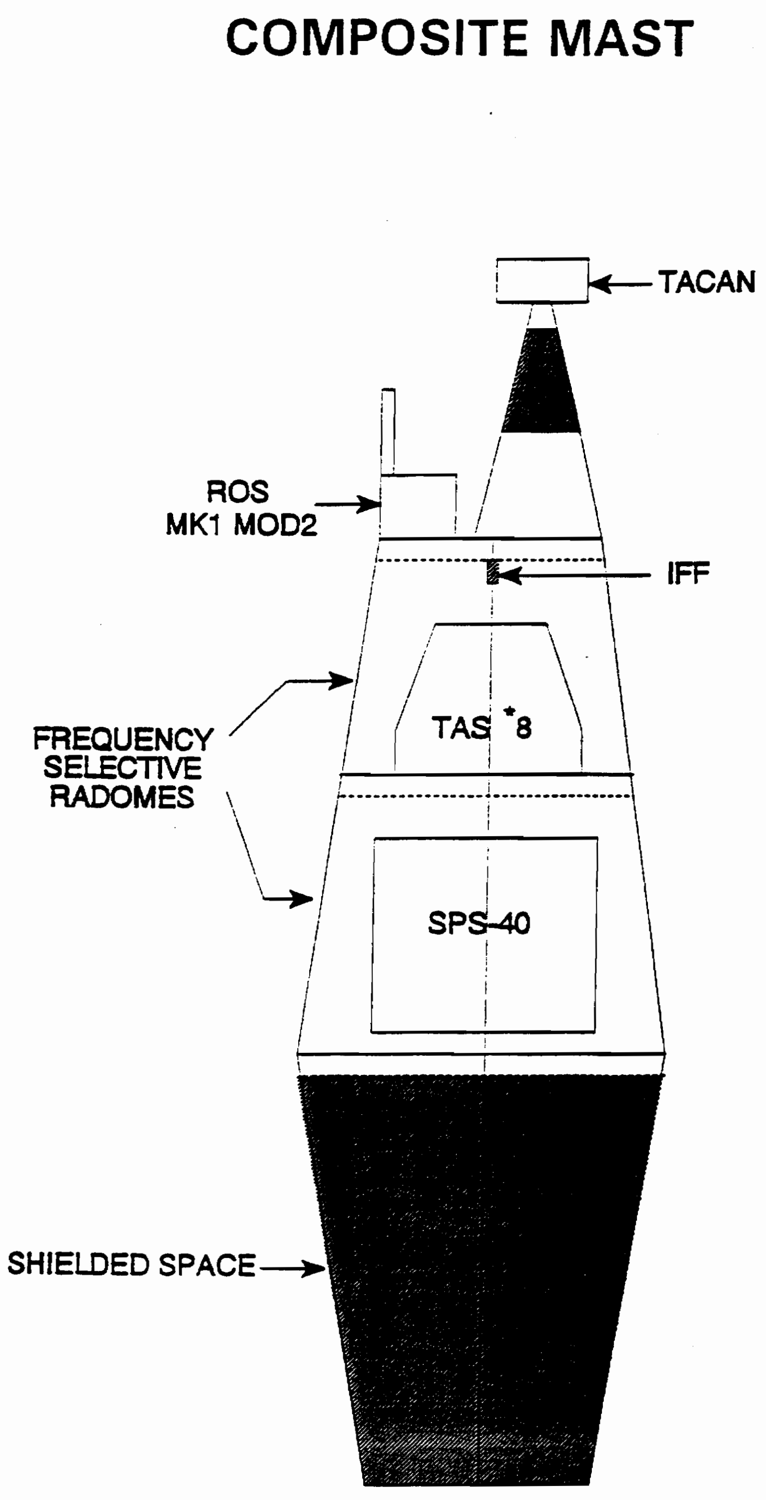


Figure 1: AEM/S Concept

metal ship provides this EME by attenuating the external EME through reflection and absorption. The composite materials used in the AEM/S are largely nonconductive. Nonconductive materials do not provide electromagnetic shielding. Therefore, shielding materials must be installed in the equipment spaces. The required shielding levels were developed by Reference (1). The shielding requirement is illustrated in figure 2, page 4.

In addition, a traditional metal mast acts as part of the return current path for unbalanced HF antennas. When the metal mast is replaced by the nonconductive composites, the HF antenna patterns are disrupted. The installation of the shielding materials replaces some of the lost conductive surface area, and thus mitigates the negative impact on the HF communications system.

Systems Background

The Navy has determined through several 6.1 Basic Research and 6.2 Applied Research programs that a decreased ship signature provides for greater survivability and tactical flexibility for a platform. During the 6.1 programs, different future battle scenarios were played to

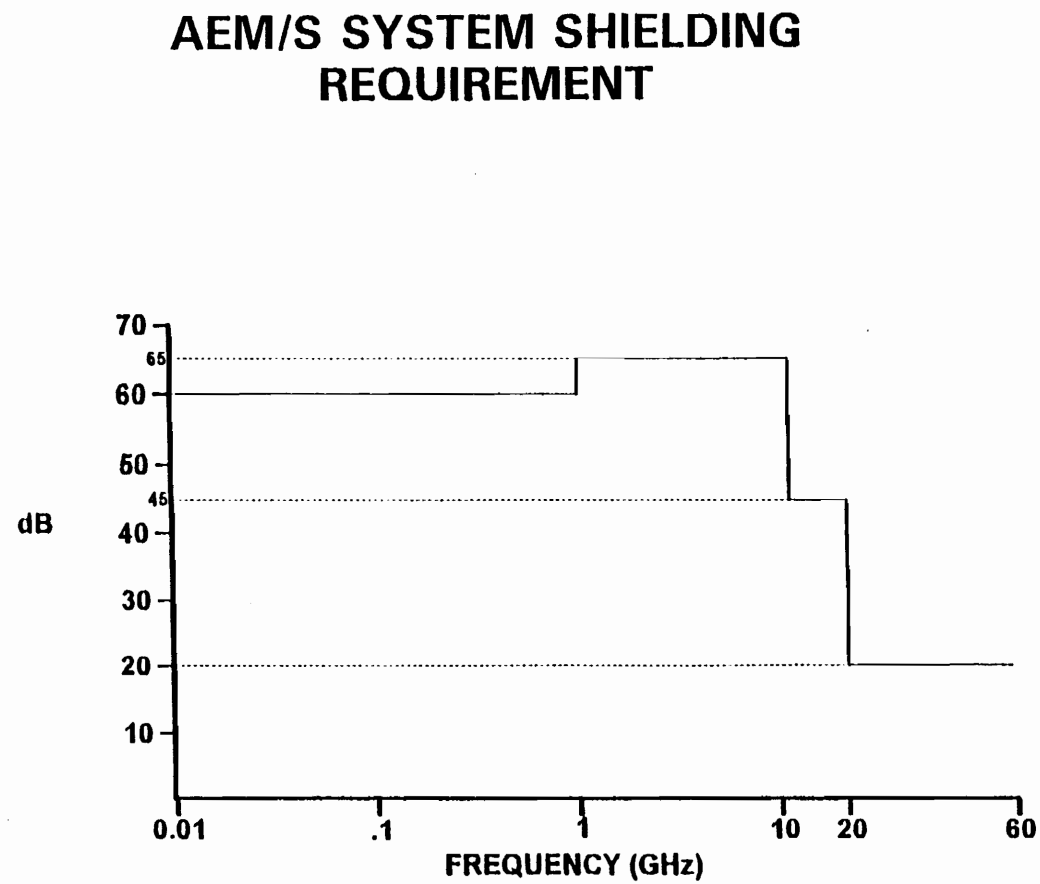
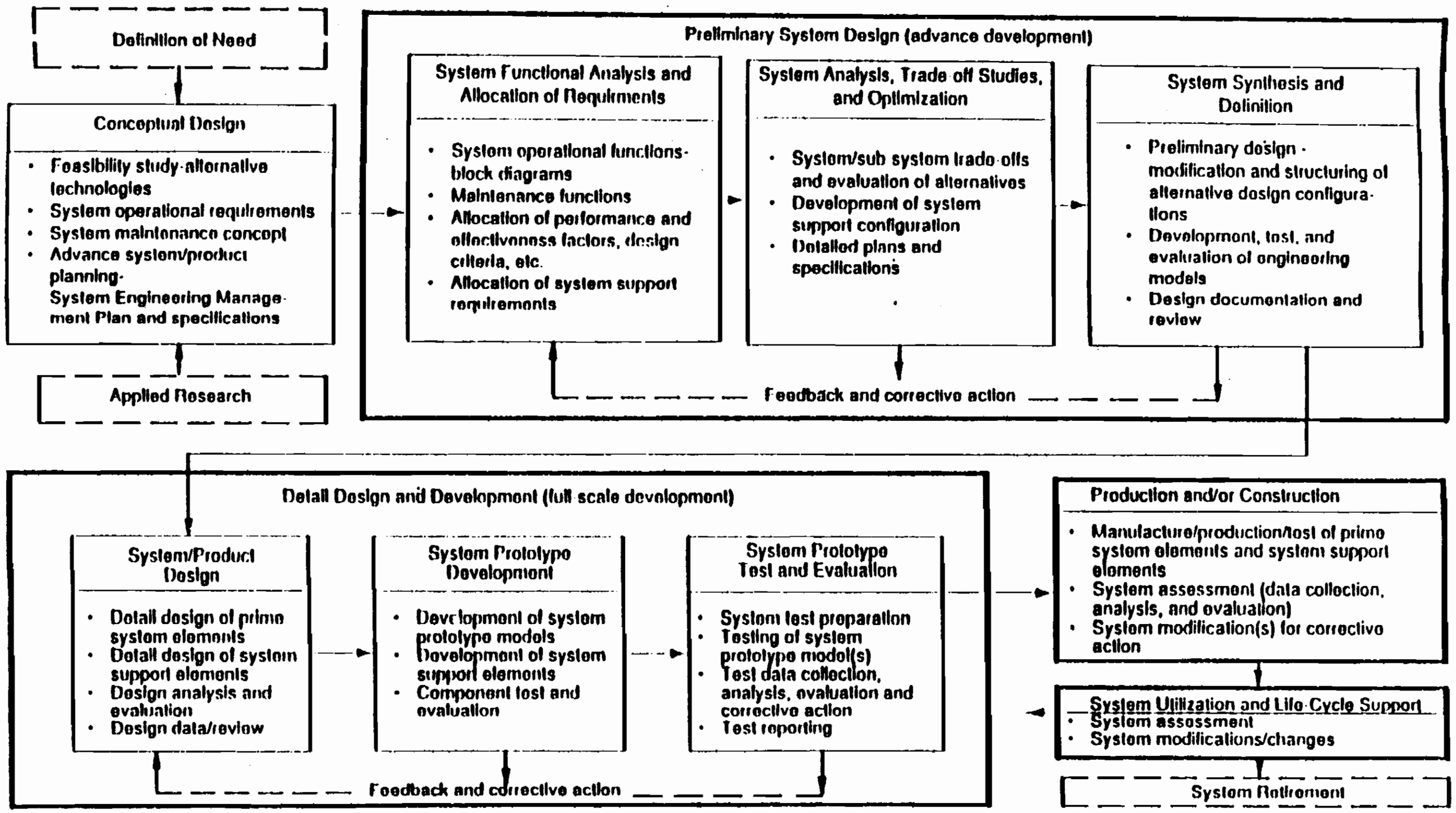


Figure 2: Shielding Requirement

determine which characteristics a future ship must have. Littoral warfare scenarios were prominent. These programs coincide with the definition of needs portion of Figure 3, Page 6.

The 6.2 phase of the research coincides with the Conceptual design process. During the 6.2 Research phase, it became apparent that the desired future ship characteristics could not be achieved with a typical low signature metallic mast design. The mast was blocking the radars, could not support phased array antenna systems gracefully, and was not meeting its allocated portion of the ship's signature goals. A new mast concept had to be developed based on the desired characteristics. After three years of 6.2 applied research, the conceptual design presented in Figure 2 was developed. The performance goals and requirements for the new composite mast system were clearly defined at the end of this phase.

The 6.3 Advanced Technology Development (ATD) program was funded for a FY95 start. The AEM/S ATD consists of the preliminary system design and detail design and development phases shown in figure 3 (Reference 2). This particular research and development project falls under the sub/system



The major steps of system design and development.

Figure 3: The major steps of system design and development

trade-offs portion of the preliminary system design. The shielding system is a critical subsystem of the composite mast. The efforts conducted herein are focused on selecting the optimum materials for shielding the required areas of the composite mast. In order to determine the characteristics required of the shielding system, the system operational requirements and performance goals must be determined. These requirements and goals were established by AEM/S tasking outside this project. The results of the outside tasks provided the critical performance categories and minimum acceptable performance levels used throughout this paper (see Appendix A).

Objective

The objective of this project is to select an appropriate candidate shielding material system for advanced development during the AEM/S ATD. The material system which is selected must provide adequate shielding for the electronics equipment, provide an adequate return current path for an embedded unbalanced HF antenna, and supply a grounding/bonding path for the installed electronic systems. These objectives must be accomplished while not negatively affecting the radar signature of the mast. The selected material must either be fire resistant or accept a surface treatment of fire insulation without sacrificing its shielding performance. The material system must also have an acceptable useful life and life cycle costs.

Approach

Multi-attribute performance evaluation of the candidate materials will be performed. The critical performance categories will be selected. Each material will be evaluated relative to each performance category. The critical performance categories to be considered are:

- signature impact
- corrosion resistance
- ability to be embedded
- bonding/grounding characteristics
- useful life
- fire resistance
- shielding performance
- performance bandwidth.

Appendix A contains the statements of work for the tasks which provide the performance levels for this project.

Material evaluations of typical shielding materials conducted by Carderock Division, Naval Surface Warfare

Center (CDNSWC), and Reference 3 determined that no available shielding materials other than solid metal sheets could provide any ballistic protection or structural strength. Metal sheets sufficiently thick to provide these attributes would have been too heavy for mast use. Therefore, ballistic protection and structural strength must be provided by other layers within the composite and cannot be considered as critical performance characteristics in this evaluation.

Current carrying capability is discussed in the introduction of this document as a performance characteristic. In reality, it is a measure of bonding and grounding performance level.

Materials

The materials selected for evaluation were:

M1 - Cu Nylon Ripstop: Material 1 consisted of a single layer of woven nylon ripstop material which was woven from copper coated threads.

M2 - Ag/Cu Nylon Ripstop: Material 2 consisted of a single layer of woven ripstop material which was woven from threads which were coated with a silver/copper alloy.

M3 - Silver/Copper Polyester Nonwoven: Material 3 consisted of a felt-like nonwoven material made of matted polyester fibers coated with a layer of silver/copper alloy.

M4 - Nickel/Copper Polyester Nonwoven: Material 4 consisted of felt-like nonwoven material made of matted polyester fibers coated with a nickel/copper alloy.

M5 - Copper Polyester Nonwoven: Material 5 consisted of a felt-like nonwoven material composed of matted copper coated polyester fibers.

M6 - Copper Wire Mesh: Material 6 was a 50x50 gauge copper wire mesh.

M7 - Brass Wire Mesh: Material 7 was a 40X40 gauge brass wire mesh.

M8 - Monel Wire Mesh: Material 8 was a 40X40 gauge monel wire mesh.

M9 - Stainless Steel Mesh: Material 9 was a 40x40 gauge stainless steel wire mesh.

M10 - Nickel/Carbon/Copper Shielded Paper: Material 10 was a nonwoven felt-like layer of nickel-coated carbon fibers on a copper foil sheet with a paper backing.

M11 - Copper Wire Mesh: Material 11 was a 24X24 gauge copper wire mesh.

In order to assess the useful life, shielding effectiveness, and corrosion resistance of the candidate shielding materials, a series of tests was conducted. First the materials were configured into test panels. Each of the materials was mounted on a KEVLAR panel using an environmentally stable contact adhesive. The adhesive was applied in a thin layer so that it did not soak through the materials. Shielding effectiveness testing was conducted on each panel.

The method selected for shielding effectiveness testing was the mode-stirred chamber. This method was selected for its excellent repeatability from test to test and facility to facility. MIL-STD-285 is the current Navy standard for shielding testing, but its repeatability is not sufficient for making material comparisons where materials must be tested over a period of time and then retested. Special fixtures to hold the test specimens were designed and built for this effort. The dimensions of the test fixture and test panels were selected to prevent resonances within the test band of interest. The test plans were developed by Tammy Campbell and Adrian Hellman. The mode-stirred chamber test setup is shown in Figure 4, page 13.

In order to determine if these materials could be used

MODE-STIRRED CHAMBER SE TEST SETUP

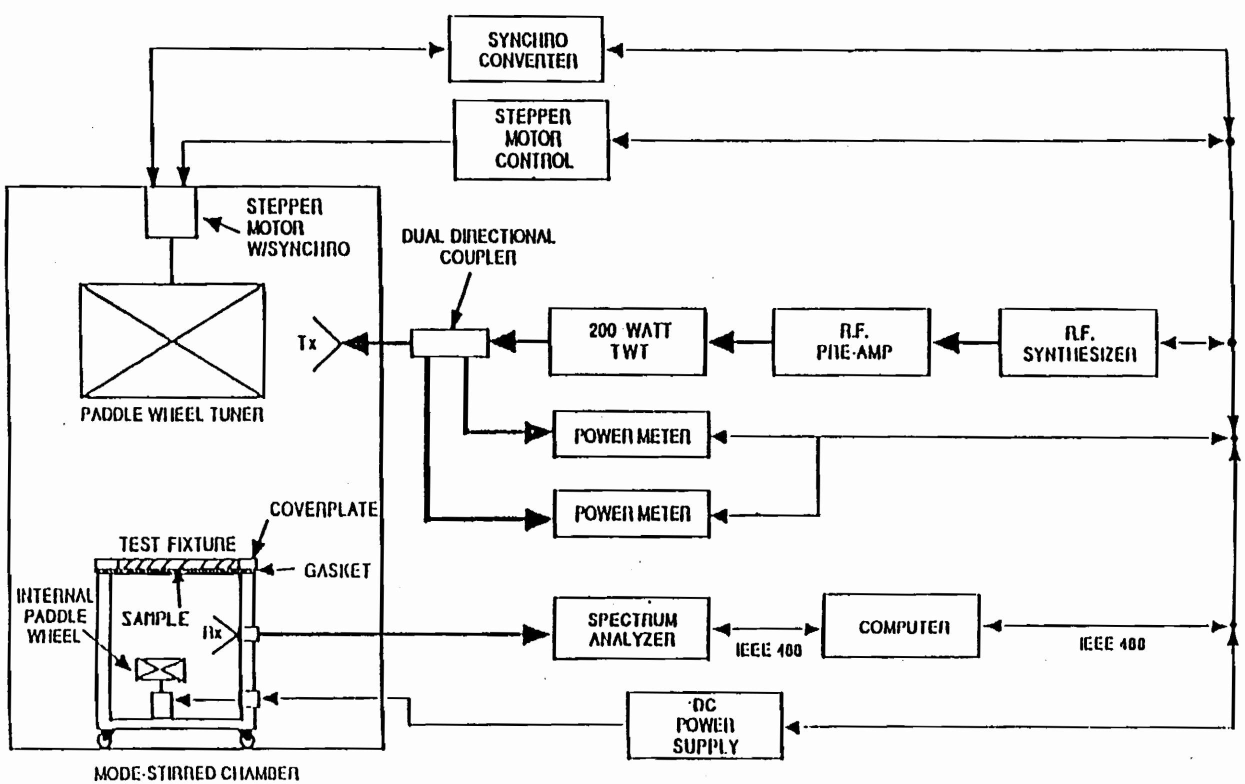


Figure 4: Mode-Stirred Chamber Test Setup

for a shielding material in a marine environment without a protective covering, accelerated aging was conducted on all 11 material sample panels. The panels were aged by the Carderock Division of the Naval Surface Warfare Center. The panels were put into an accelerated aging chamber where they were simultaneously subjected to salt fog, thermal changes, and UV radiation. After the equivalent of 15 years of service life (600 hours), the panels were removed, rinsed, and dried. The shielding effectiveness tests were repeated. The data is presented in Appendix B.

After aging, the materials were evaluated for multiple attributes. The most desirable materials were selected to be installed on 1/4 scale mast panels and evaluated for overall shielding performance. The highest rated material/material system will be selected for AEM/S installation.

Analysis

The first step to conducting a multi-attribute analysis of a system is to establish the attributes to be considered and their relative importance. Based on discussions with

Naval Sea Systems Command personnel and professional experience, the following list of attributes was established

- signature impact
- corrosion resistance
- ability to be embedded
- bonding/grounding characteristics
- useful life
- fire resistance
- performance bandwidth
- shielding performance.

Once the attributes are established, the minimum acceptable and preferred performance levels must be established. The performance level for each attribute is discussed below:

Signature Impact: Materials which provide a desirable signature return are either absorbing or have a smooth reflective surface. Materials with rough or inhomogeneous surfaces provide a less desirable signature return. The signature impact is rated as follows:

Absorptive	10
Smooth, Reflective	7

Minimal roughness, reflective	5
Significant surface roughness	below 5.

The minimum acceptable performance level for signature impact is 5.

Corrosion Resistance: Materials which corrode are a constant source of maintenance and performance problems within the fleet. The corrosion resistance ratings are as follows:

Totally Degraded	0
Significantly Degraded	3
Partially Degraded	5
Minimally degraded	7
No measurable degradation	10.

The minimum acceptable level for corrosion resistance is 5 for materials which cannot be embedded; 0 for materials which can be embedded.

Ability to be embedded: The ability of a material to be embedded impacts on the corrosion resistance, fire resistance, and useful life. The ratings for this category are:

Impractical	0
Very Difficult	3
Moderately Difficult	5
Relatively easy	7
No change in GRP layup required.	10

No minimum acceptable rating is necessary. However, the ability of the material to be embedded allows greater physical protection.

Bonding/Grounding Characteristics: The bonding/grounding capabilities of a shielding material determine if a bus bar system for electronic and/or safety grounds is necessary. The bonding/grounding ratings are as follows:

Not suitable for electronic or safety ground:	0
Suitable for electronic ground only	5
Suitable for both safety and electronic ground	10.

Useful Life: This category assesses the level of maintenance and/or physical protection needed by a material to last throughout a ships useful life. The Ratings are as follows:

Not suitable for marine use	0
Needs significant maintenance or physical protection	5
Low maintenance, little protection Required.	10

Fire Resistance: There are strict regulations regarding the use of flammable materials on ship. The fire resistance ratings were developed by the fire protection group at CDNSWC. The ratings are as follows:

Flashes on contact with flame	0
Flashes after prolonged exposure to flame	3
Flashes after prolonged exposure to flame, but self extinguishes upon flame removal	5
Does not burn, but melts/drips	7
Does not burn, melt, or drip under defined conditions.	10

The minimum acceptable fire performance level is 5 for materials which cannot be embedded; 0 for materials that can.

Shielding performance: Shielding performance is the required reduction of undesirable signals within a band. The ratings are as follows:

No shielding	0
Significantly below requirement	3
Below requirement	5
Very near requirement	7
Meets requirement	10.

The minimum rating for shielding performance is 5. If the shielding performance of a material is below 5, then the material is of very limited use even when used in conjunction with other materials.

Performance bandwidth: The performance bandwidth is the bandwidth over which the material provides the specified shielding performance. The RF performance levels were measured. The HF levels were taken from literature and skin depth assessments. See Reference (b). The performance bandwidth ratings are as follows:

No RF or HF shielding	0
RF or HF shielding	5
RF and HF shielding	10.

The materials were rated according to the above performance levels. Because weakness in any of the attributes can result in poor overall system performance, each of the attributes is equally important for the purposes of this evaluation. The material evaluation sheets for the materials are presented in Appendix C. A sample evaluation sheet is presented in Figure 2, below. Materials 7-11 were discarded for failing to meet various minimum acceptable levels. The remaining materials were ranked by summing the total of their ratings. Materials 3,5, and 6 received the highest total ratings. Material 3 had sufficient shielding over the desired frequency band to allow it to be used alone for the quarter scale blast panel test. Panels 5 and 6 had good performance in one frequency band each. They were

MATERIAL DESCRIPTION/RANKING SHEET

Material:
Description:

Signature Impact:
Corrosion Resistance:
Ability To Be Embedded:
Bonding/Grounding Characteristics:
Useful Life:
Fire Resistance:
Shielding Performance:
Performance Bandwidth:

Figure 5: Sample Multi-attribute Evaluation Sheet

paired to create a dual layer shield for the 1/4 scale Blast Panel Test.

The analytical results are consistent with those expected. Metallic meshes generally do not provide sufficient radar frequency (L-band and above) shielding effectiveness because only the heavy gauge meshes can be effectively installed in a shipyard environment. The fine gauge meshes cannot be soldered effectively because the rosin core solders will not flow through the mesh. Acid core solders cause corrosion problems after chemical exposure and therefore cannot be used. The metallized fabrics generally work well at L-band and above. However, they do not have sufficient skin depth to shield well in the HF, UHF, and VHF bands. The combination of copper and silver in Material 3 allowed for superior conductivity and therefore allowed a thin fabric to provide sufficient skin depth for wideband shielding applications.

Results

Based on the results of the performance analysis and the empirical data found in Reference 3, it was not surprising that one of the candidates was a dual layer shielding system. The probability that a single layer shielding material system will adequately meet the minimum acceptance criteria is generally considered low.

The following material systems were installed on the 1/4 scale blast panels and mode stirred chamber tested:

- Dual layer system consisting of 40x40 copper mesh and nonwoven copper fabric
- Single layer of silver/copper nonwoven fabric.

The dual layer system which contained the copper mesh and copper nonwoven fabric provided the best overall shielding performance. Its performance was either above the required shielding level or above the dynamic range of the measurement system at all times. The silver/copper nonwoven fabric performed inadequately across most of the frequency band. The measured results are contained in Appendix D.

Conclusions

Although there are many production and life cycle issues to be addressed, material systems which can meet the shielding requirements for the 21st century exist today. The challenge is to reduce the utilization/production costs of these materials and material systems. While the material systems measured provide significant shielding levels, their installation in a shipyard environment and maintenance at sea remain as future challenges.

Recommendations

Based on the above results/conclusions, it is recommended that the double layer shielding material system which consists of one layer of 24 gauge copper mesh and one layer of copper/polyester nonwoven Flectron embedded below a minimum of one layer of glass reinforced plastic be selected. The supporting rationale for this decision is that this material system provides acceptable performance at the initial installation and has a good probability of continuing to provide at least a minimal level of shielding effectiveness throughout the lifetime of the AEM/S.

References

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2. Blanchard, B.S., *System Engineering Management*, John Wiley & Sons, New York, 1991

3. Freyer, Dr. G., *Analysis of the Characteristics of Continuous Metal Sheets and Wire Meshes for Specified Composite Mast Requirements*, April 1993

Appendix A - Statements of Work

ELDYNE

APMS E^3 ENVIRONMENTAL SUPPORT

TITLE: ADVANCED PERFORMANCE MAST SYSTEM (APMS) E^3 TECHNICAL SUPPORT

1. Eldyne shall initiate efforts to determine the worst case external operational EM environment due to battlegroup emitters for the area surrounding the aft mast of a DD 963 Class ship. A report on the predicted EM environments shall be provided.

DELIVERABLES:

The deliverables prepared under this task statement shall include:

Technical Reports

- Report on operational EM environments for the mast

TASK STATEMENT FOR USI, INC. -

SHORT TERM COMPOSITE MAST SUPPORT

1. Based on shielding requirements, EM environments, and mast characteristics provided as GFI, the contractor shall calculate the required thicknesses of titanium, copper, steel, and aluminum to provide adequate shielding and to act as an adequate HF ground plane for the specified transmitters. In addition, the contractor shall determine the specifications (wire gauge, wire spacing) of monel, copper, brass, and aluminum mesh required to provide adequate shielding and to act as an adequate HF ground plane for the specified transmitters. A letter report, which provides the raw calculations and the tabulated results as well as conclusions and recommendations, is to be provided.

Deliverables:

- Letter report on material requirements

Funding: $7k

PROPOSAL FOR

EXPANDED ADVANCED ENCLOSED MAST/SENSOR

(AEM/S) E^3 VENTURES PROGRAM

1. The main goal of the Advanced Enclosed Mast/Sensor (AEM/S) System Advanced Technology Development (ATD) Program is to improve the self defense capabilities of future combatants by reducing the amount of sensor blockage by 80% and reducing the mast radar cross section to XX dbsm below that of today's best treated masts while providing a 20% weight savings over a conventional mast. In addition, the AEM/S is ideally suited for phased array, MIMIC, and conformal antenna systems. F54 is the E^3 lead for the AEM/S ATD and the AEM/S 6.2 program which is underway. Under the FY93 Ventures program, F54 and R34 have expanded their knowledge and capabilities in the field of composites while providing needed support to the Advanced Enclosed Mast/Sensor (AEM/S) 6.2 Project. FY94 Ventures funding will be used to support the expansion of the Ventures work already funded for FY93. New areas in which expertise will be gained include environmental aging effects on the electrical properties of frequency selective surfaces and

non-destructive evaluation (NDE) of electrical joints and bonds in composite structures such as the AEM/S.

2. During FY94 samples of frequency selective structure will be evaluated electrically, subjected to a simulated shipboard environment, and then re-evaluated. In addition, more shielded composite materials will be evaluated for shipboard use.

3. NSWCDD, F54 and R34, will jointly pursue techniques for composite material evaluation that will assist in the selection and ranking of joint design and fabrication methods for the AEM/S. These techniques include an innovative infrared imaging technique which can also be used for NDE. The method involves exposing the composite materials to electrical fields and/or injecting currents in the joints and monitoring the temperature changes within the joints using an infrared camera. Joints which are not electrically sound will heat under these conditions.

4. Although continuing the expansion of NSWCDD's electrical understanding of composites is low risk, it is a valuable learning exercise. The development of a reliable electrical

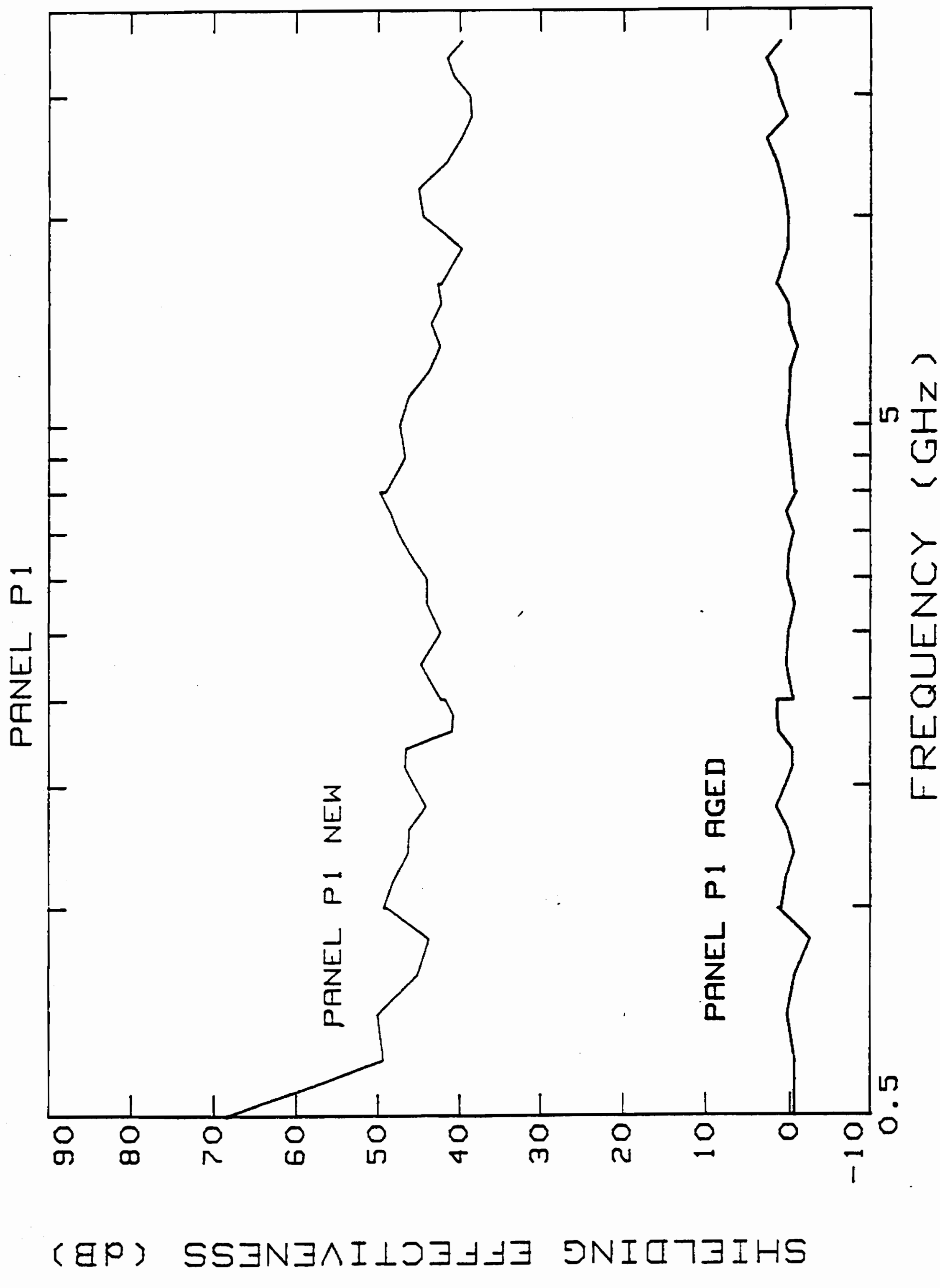
NDE technique will be technically challenging.

5. The AEM/S Ventures program is related to the AEM/S ATD, future composite mast programs for AEGIS Cruiser and Destroyer upgrades, and the 21st Century Destroyer program.

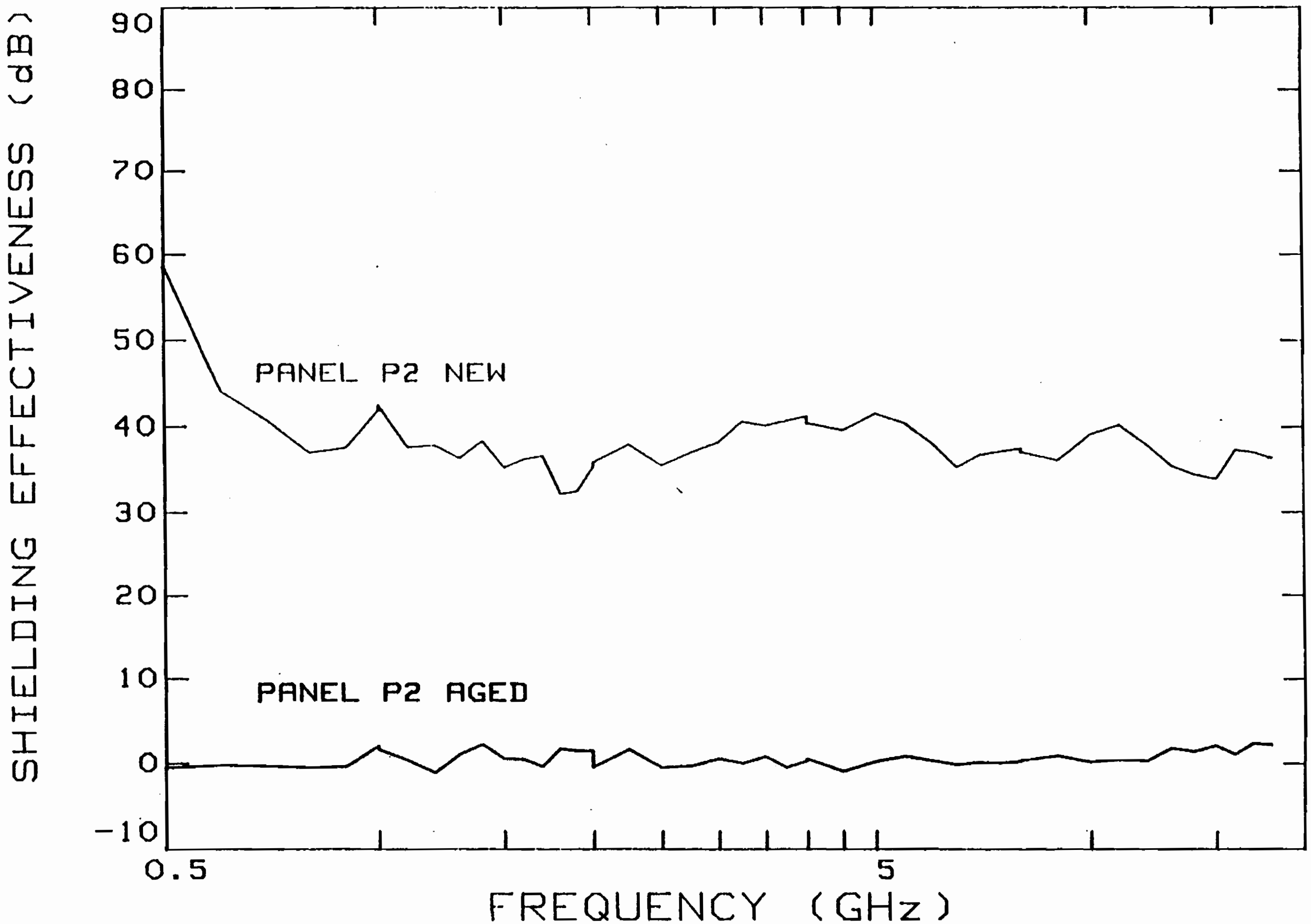
6. The team leaders will be Tammy Campbell (F54) and Dr. John Liu (R34). The team members will include several personnel from both branches.

7. F54 and R34 request $100k (F54 $40k, R34 $60K) of ventures funding to support the above efforts. Approval for the AEM/S ATD program looks promising. However, a FY94 6.2 budget short fall exists in the areas of environmental effects on the E^3 performance of shielded and/or frequency selective composites and the NDE of electrical joints and bonds. NSWCDD is scheduled to receive $1.1M in AEM/S ATD funding for FY95-FY97.

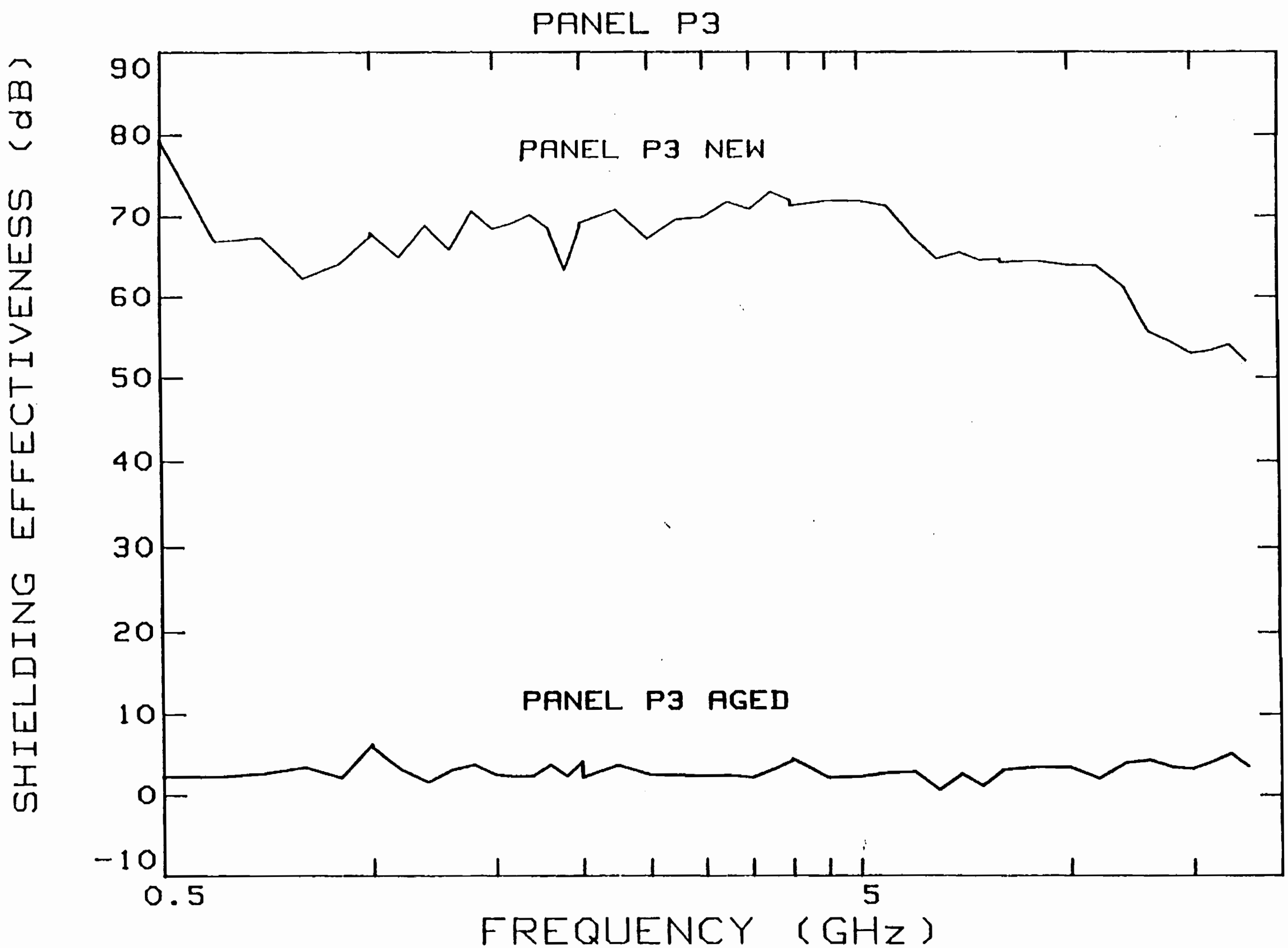
Appendix B - Shielding Effectiveness Data


PANEL P1
PANEL P1 NEW
PANEL P1 AGED
FREQUENCY (GHz)
0.5
5
SHIELDING EFFECTIVENESS (dB)
90
80
70
60
50
40
30
20
10
0
-10

PANEL P2



SHIELDING EFFECTIVENESS (dB)
90
80
70
60
50
40
30
20
10
0
−10
PANEL P2 NEW
PANEL P2 AGED
0.5
5
FREQUENCY (GHz)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PANEL P3 NEW
PANEL P3 AGED
SHIELDING EFFECTIVENESS (dB)
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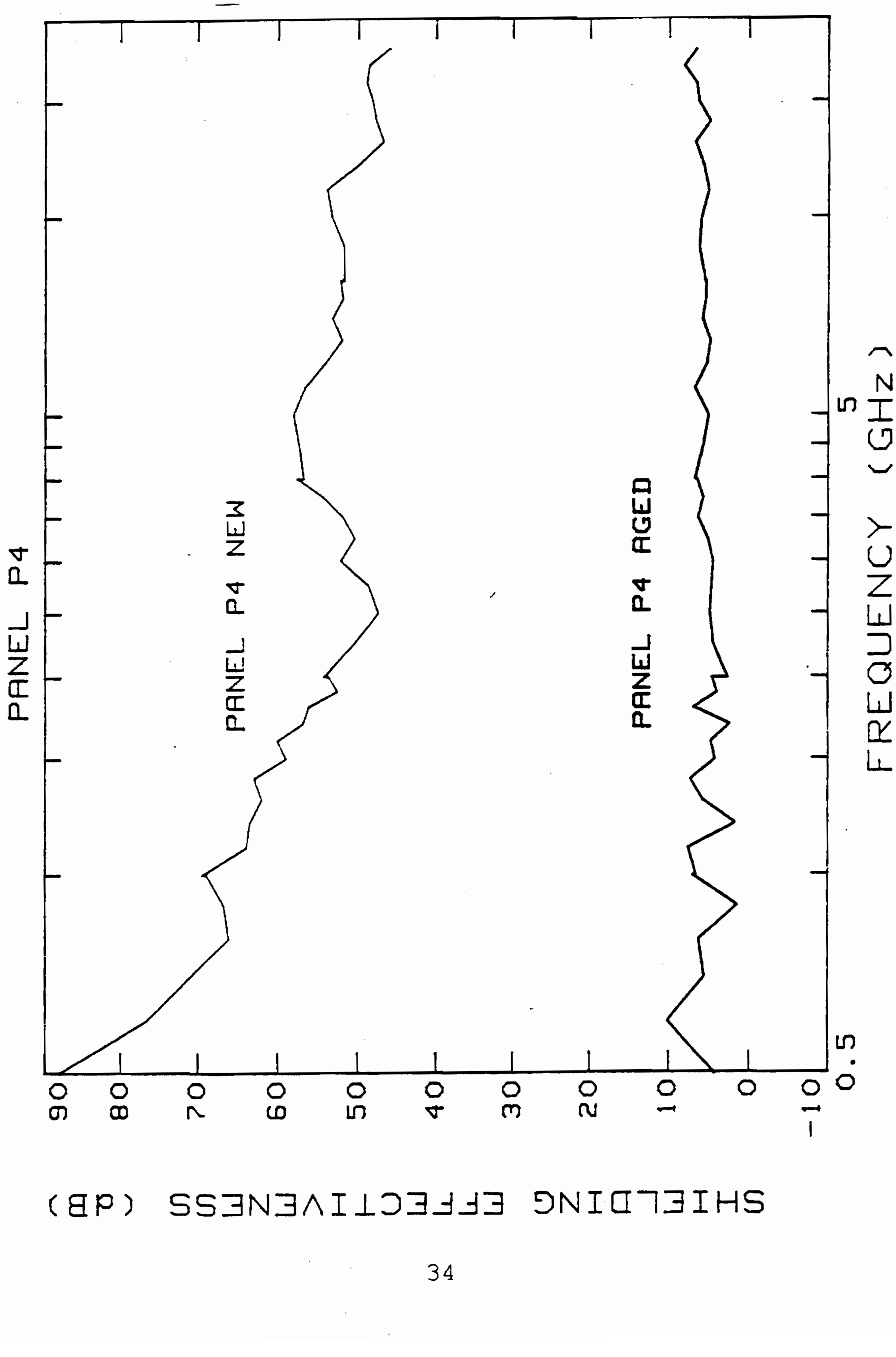
80
70
60
50
40
30
20
10
0
−10
0.5
5
FREQUENCY (GHz)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PANEL P4 NEW
PANEL P4 AGED
FREQUENCY (GHz)
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SHIELDING EFFECTIVENESS (dB)
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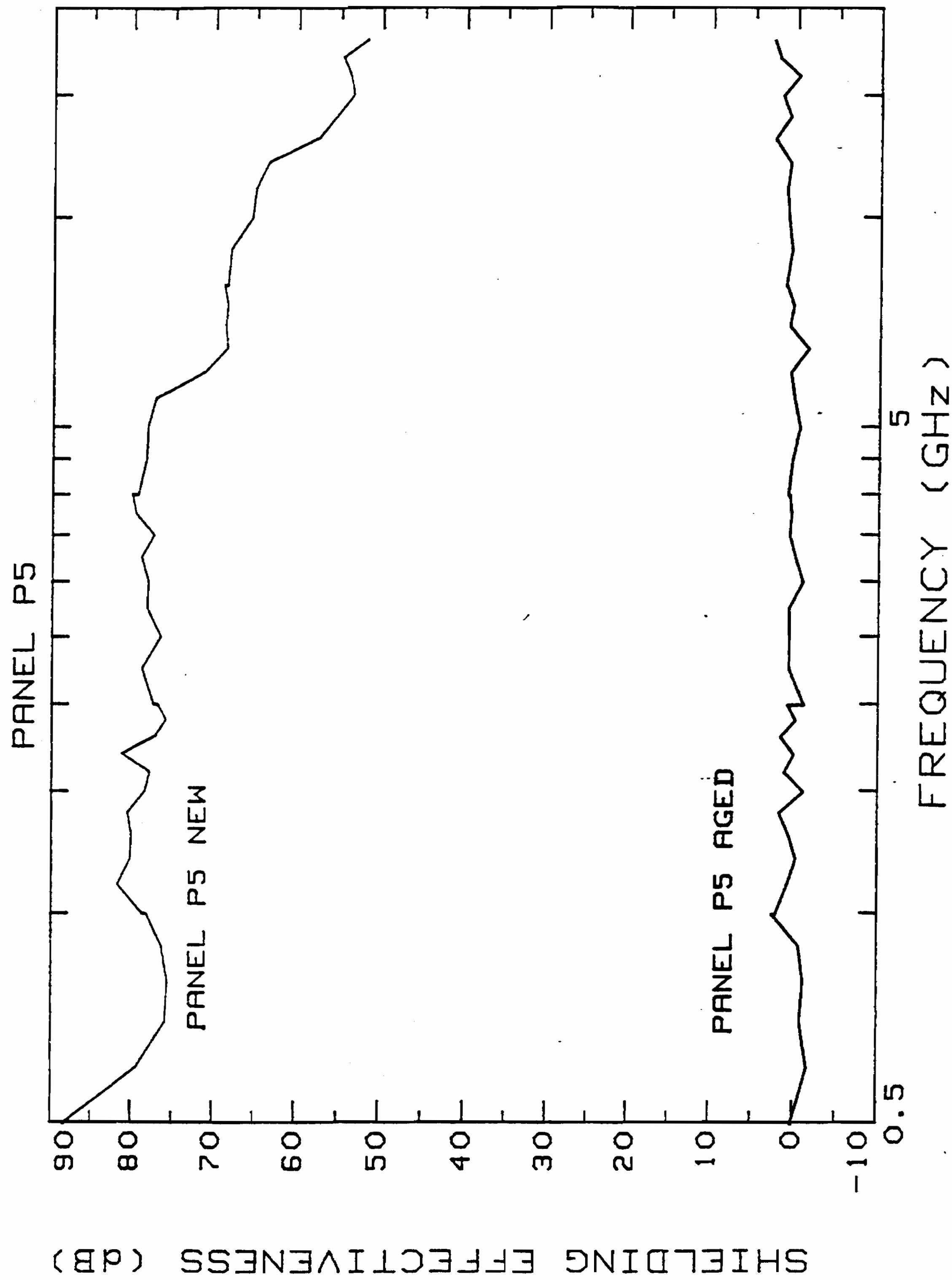
80
70
60
50
40
30
20
10
0
-10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PANEL P5 NEW
PANEL P5 AGED
FREQUENCY (GHz)
SHIELDING EFFECTIVENESS (dB)
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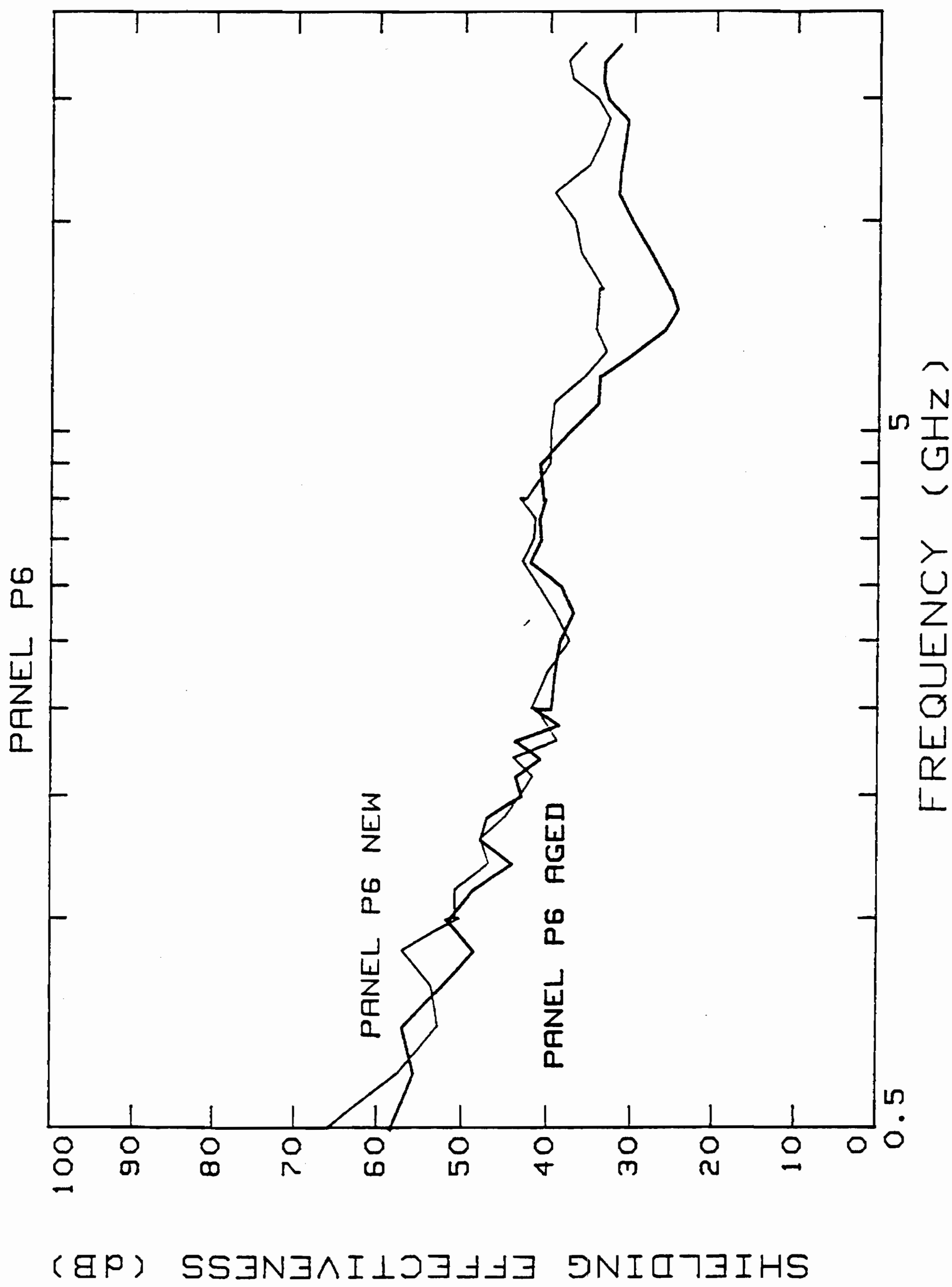
60
50
40
30
20
10
0
−10


PANEL P6
PANEL P6 NEW
PANEL P6 AGED
SHIELDING EFFECTIVENESS (dB)
FREQUENCY (GHz)
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80
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60
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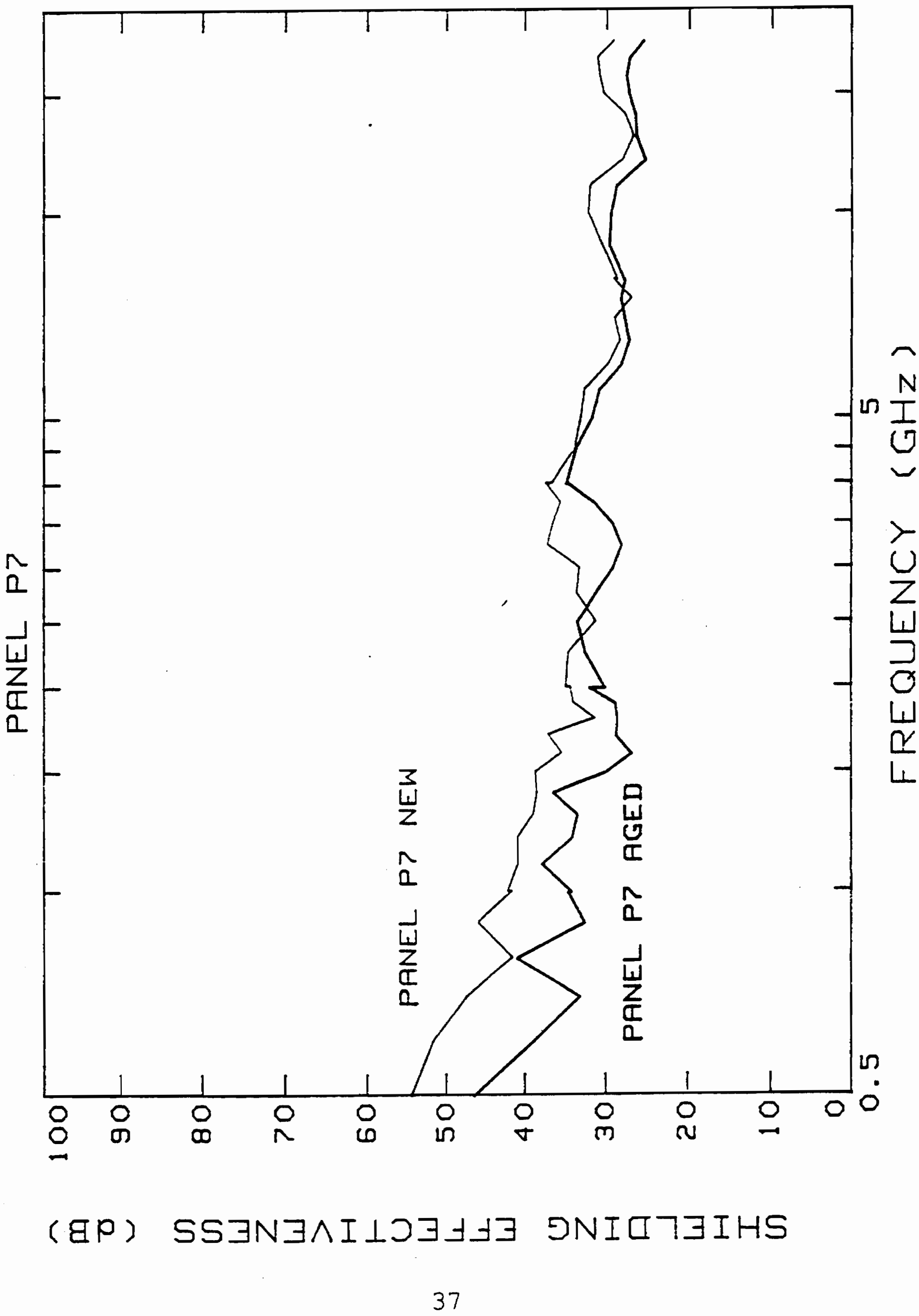
40
30
20
10
0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PANEL P7 AGED
SHIELDING EFFECTIVENESS (dB)
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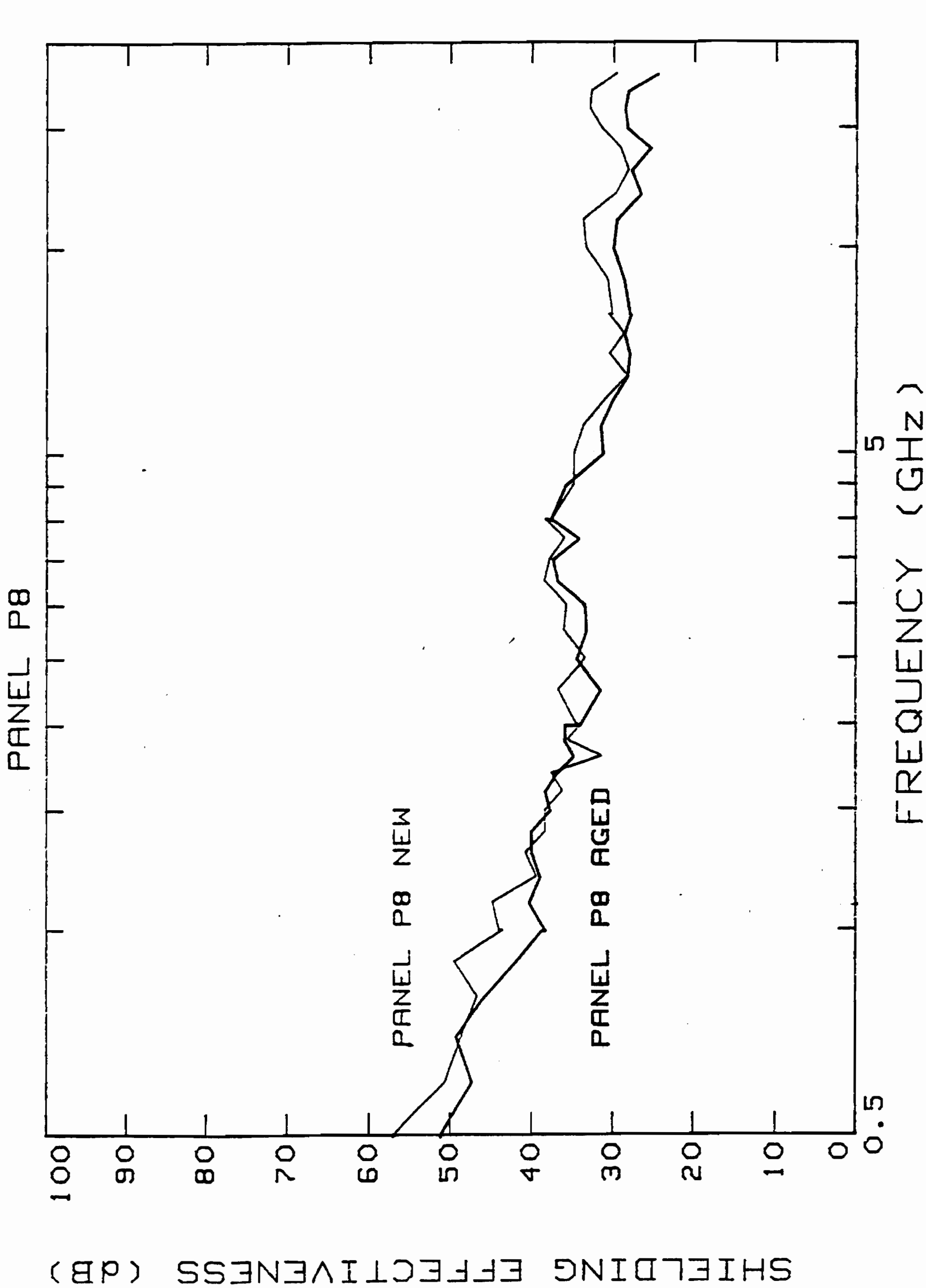
60
50
40
30
20
10
0
0.5
5
FREQUENCY (GHz)


PANEL P8
PANEL P8 NEW
PANEL P8 AGED
SHIELDING EFFECTIVENESS (dB)
FREQUENCY (GHz)
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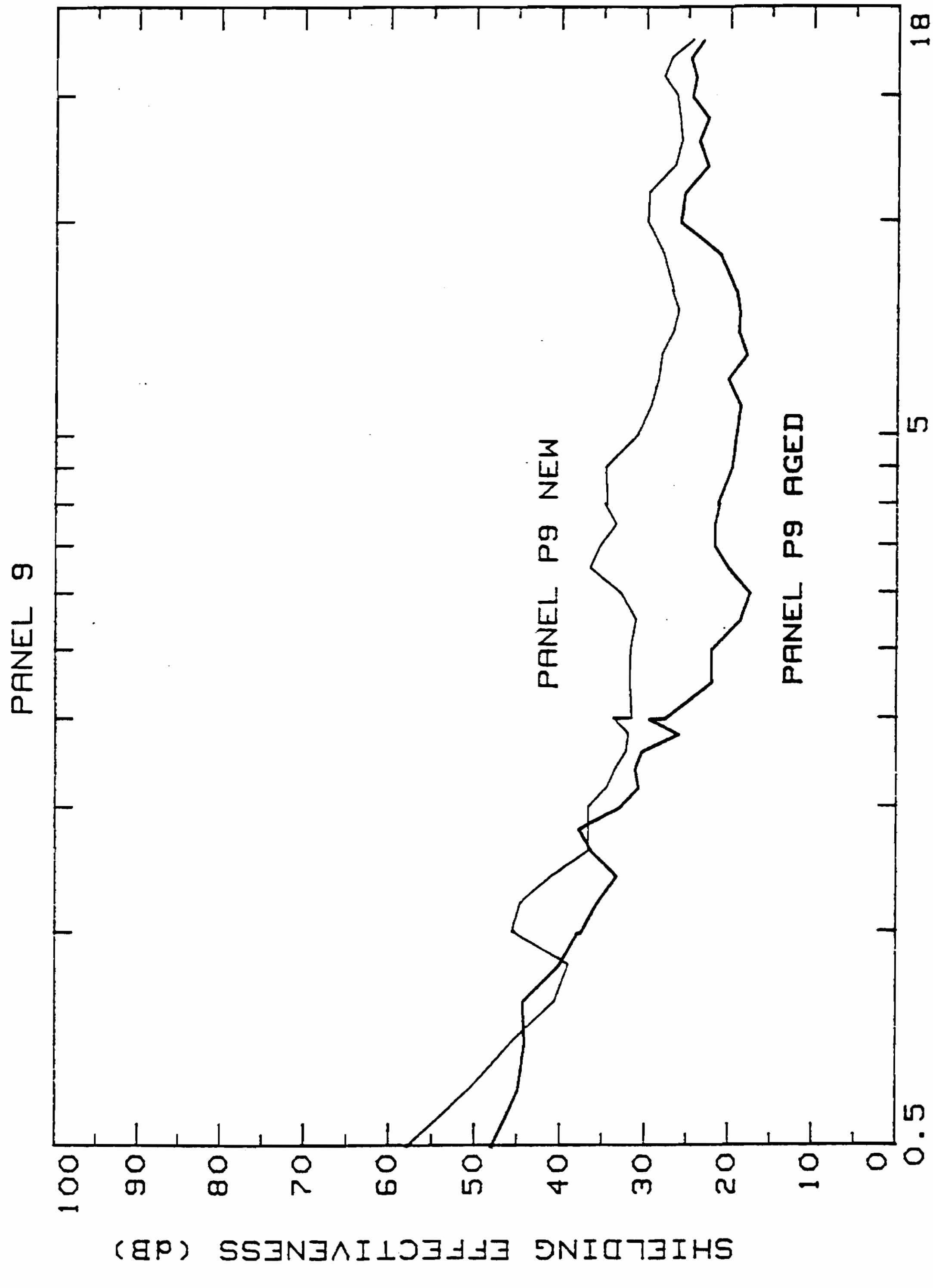
100
90
80
70
60
50
40
30
20
10
0


PANEL 9
PANEL P9 NEW
PANEL P9 AGED
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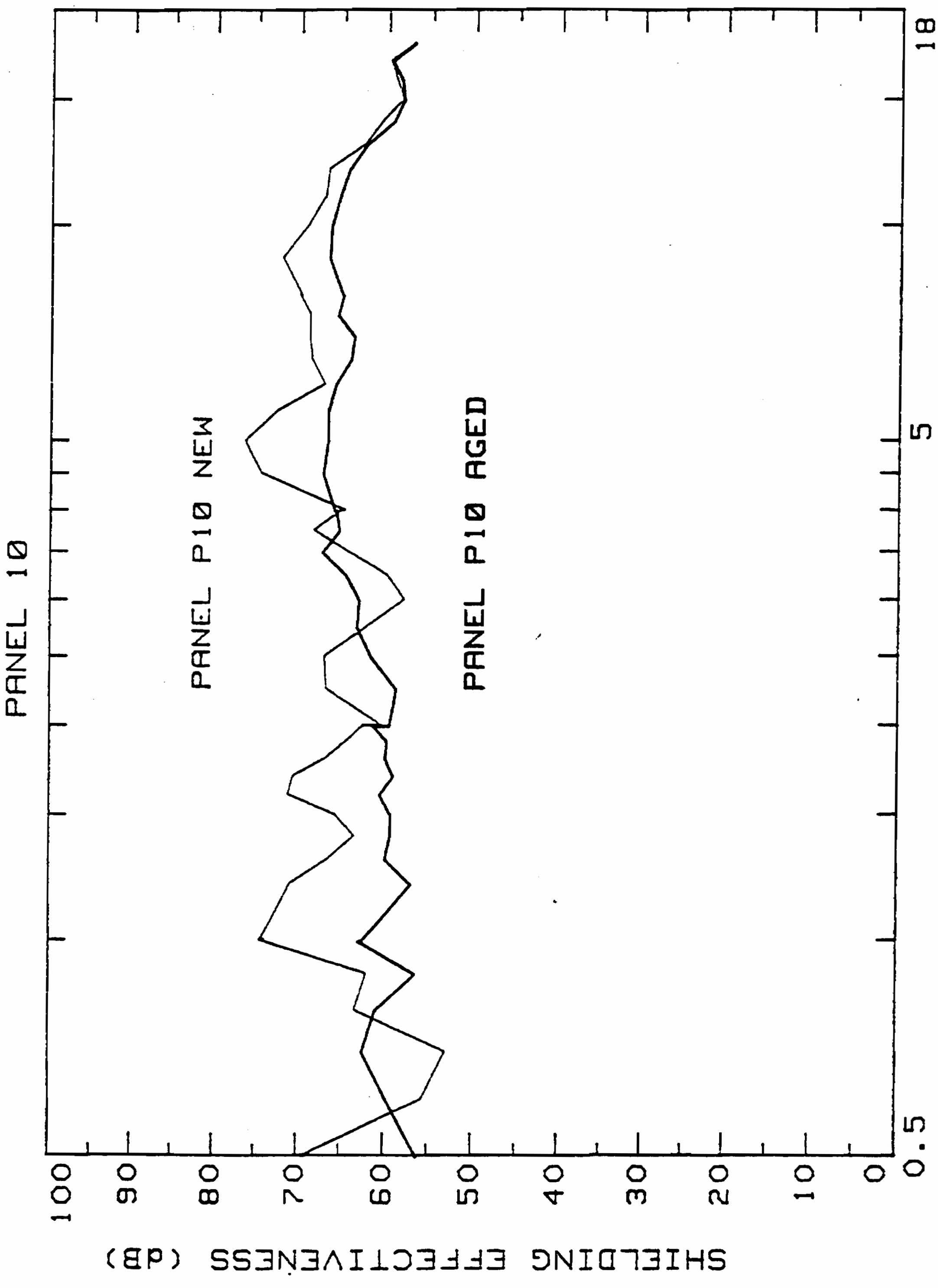
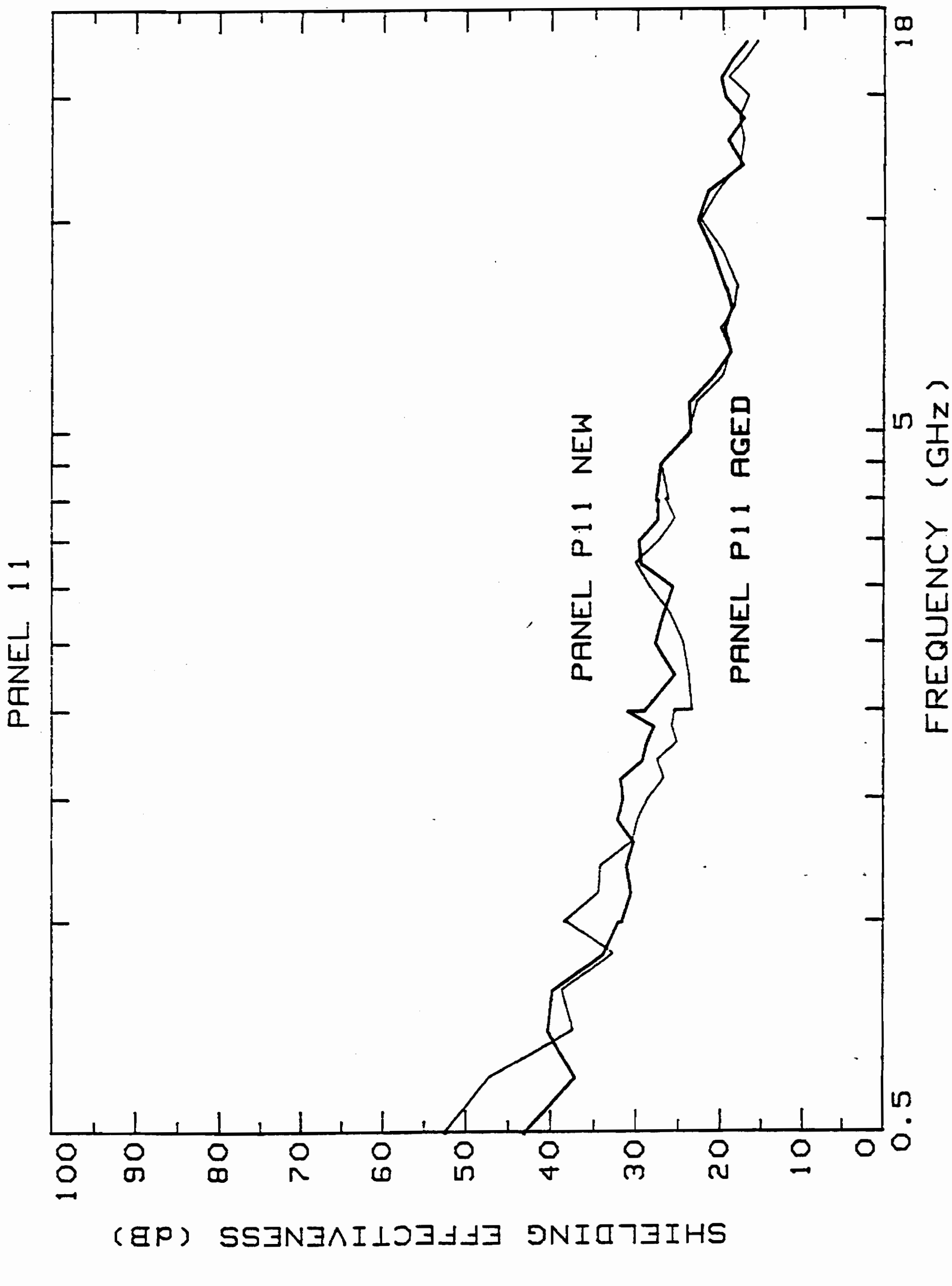
70
60
50
40
30
20
10
0
0.5
5
18


PANEL 10
PANEL P10 NEW
PANEL P10 AGED
SHIELDING EFFECTIVENESS (dB)
100
90
80
70
60
50
40
30
20
10
0
0.5
5
18


PANEL 11
PANEL P11 NEW
PANEL P11 AGED
SHIELDING EFFECTIVENESS (dB)
FREQUENCY (GHz)
0
10
20
30
40
50
60
70
80
90
100
0.5
5
18

Appendix C - Multi-Attribute Evaluation Sheets

MATERIAL DESCRIPTION/RANKING SHEET

Material: M1

Description: Copper Nylon Ripstop

Signature Impact:	7
Corrosion Resistance:	0
Ability To Be Embedded:	5
Bonding/Grounding Characteristics:	0
Useful Life:	5
Fire Resistance:	0
Shielding Performance:	7
Performance Bandwidth:	5
TOTAL	29

MATERIAL DESCRIPTION/RANKING SHEET

Material: M2

Description: Silver/Copper Nylon Ripstop

Signature Impact:	7
Corrosion Resistance:	0
Ability To Be Embedded:	5
Bonding/Grounding Characteristics:	0
Useful Life:	5
Fire Resistance:	0
Shielding Performance:	5
Performance Bandwidth:	5
TOTAL	27

MATERIAL DESCRIPTION/RANKING SHEET

Material: M3

Description: Silver/Copper Polyester Nonwoven

Signature Impact:	7
Corrosion Resistance:	0
Ability To Be Embedded:	7
Bonding/Grounding Characteristics:	0
Useful Life:	5
Fire Resistance:	0
Shielding Performance:	10
Performance Bandwidth:	10
TOTAL	39

MATERIAL DESCRIPTION/RANKING SHEET

Material: M4

Description: Nickel/Copper Polyester Woven

Signature Impact:	7
Corrosion Resistance:	0
Ability To Be Embedded:	5
Bonding/Grounding Characteristics:	0
Useful Life:	5
Fire Resistance:	0
Shielding Performance:	7
Performance Bandwidth:	5
TOTAL	29

MATERIAL DESCRIPTION/RANKING SHEET

Material: M5

Description: Copper Polyester Nonwoven

Signature Impact:	7
Corrosion Resistance:	0
Ability To Be Embedded:	7
Bonding/Grounding Characteristics:	0
Useful Life:	5
Fire Resistance:	0
Shielding Performance:	10
Performance Bandwidth:	5
TOTAL	34

MATERIAL DESCRIPTION/RANKING SHEET

Material: M6

Description: Copper Wire Mesh, 50 x 50

Signature Impact:	6
Corrosion Resistance:	10
Ability To Be Embedded:	3
Bonding/Grounding Characteristics:	10
Useful Life:	10
Fire Resistance:	7
Shielding Performance:	5
Performance Bandwidth:	5
TOTAL	56

MATERIAL DESCRIPTION/RANKING SHEET

Material: M7

Description: Brass Wire Mesh, 40 x 40

Signature Impact:	**5**	
Corrosion Resistance:	**10**	
Ability To Be Embedded:	**3**	
Bonding/Grounding Characteristics:	**10**	
Useful Life:	**10**	
Fire Resistance:	**7**	
Shielding Performance:	**3**	**(Rejected)**
Performance Bandwidth:	**5**	
TOTAL	**0**	

MATERIAL DESCRIPTION/RANKING SHEET

Material: M8

Description: Monel Wire Mesh, 40 x 40

Signature Impact:	5	
Corrosion Resistance:	10	
Ability To Be Embedded:	3	
Bonding/Grounding Characteristics:	5	
Useful Life:	10	
Fire Resistance:	7	
Shielding Performance:	3	(Rejected)
Performance Bandwidth:	5	
TOTAL	0	

MATERIAL DESCRIPTION/RANKING SHEET

Material: M9

Description: Stainless Steel Mesh, 40 x 40

Signature Impact:	5	
Corrosion Resistance:	10	
Ability To Be Embedded:	3	
Bonding/Grounding Characteristics:	0	
Useful Life:	10	
Fire Resistance:	10	
Shielding Performance:	2	(Rejected)
Performance Bandwidth:	5	
TOTAL	0	

MATERIAL DESCRIPTION/RANKING SHEET

Material: M10

Description: Nickel-Coated Carbon Fiber on a Copper Foil Backing on Paper

Signature Impact:	7	
Corrosion Resistance:	10	
Ability To Be Embedded:	0	
Bonding/Grounding Characteristics:	5	
Useful Life:	10	
Fire Resistance:	0	(Rejected)
Shielding Performance:	10	
Performance Bandwidth:	10	
TOTAL	0	

MATERIAL DESCRIPTION/RANKING SHEET

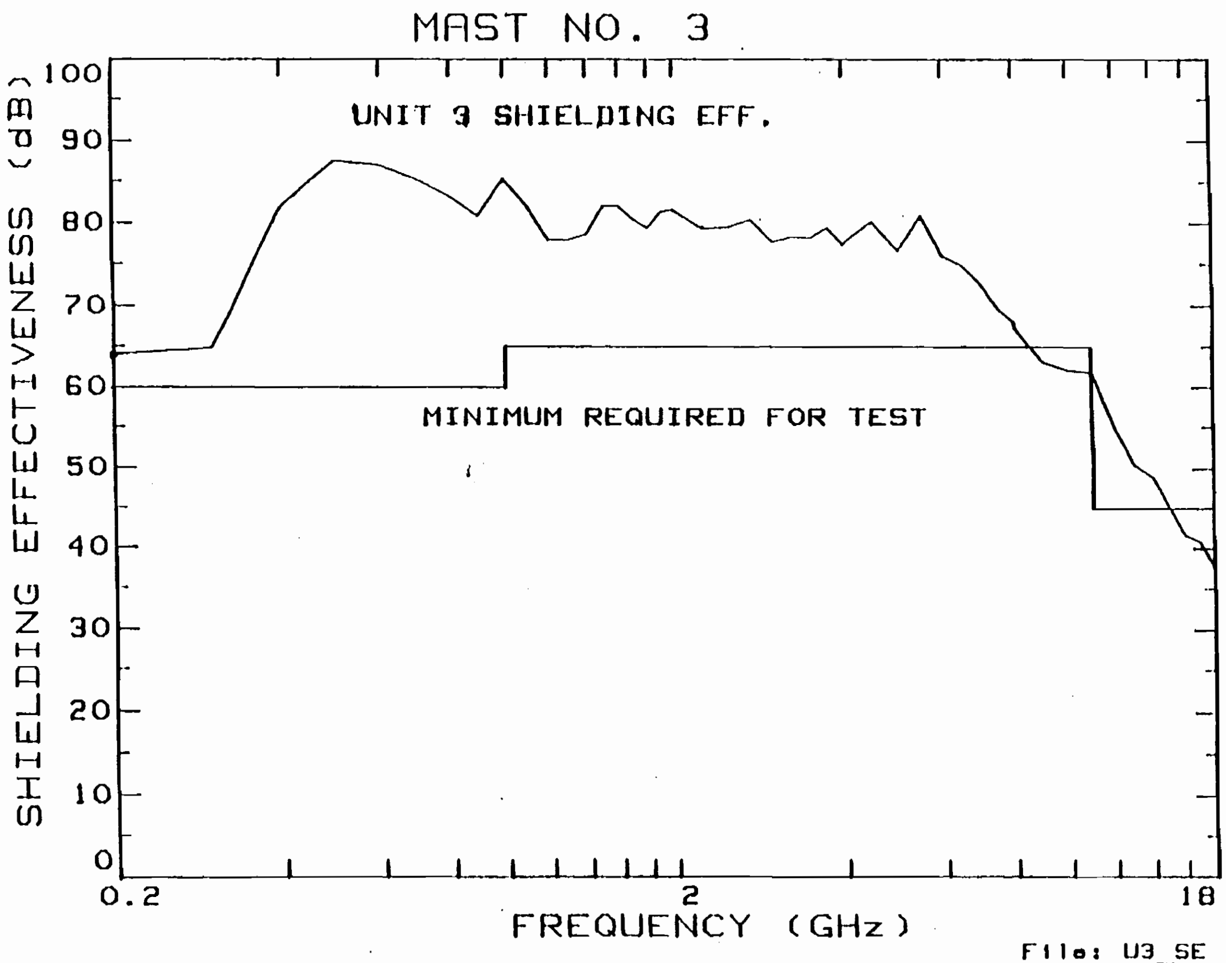
Material: M11

Description: Copper Wire Mesh, 24 x 24

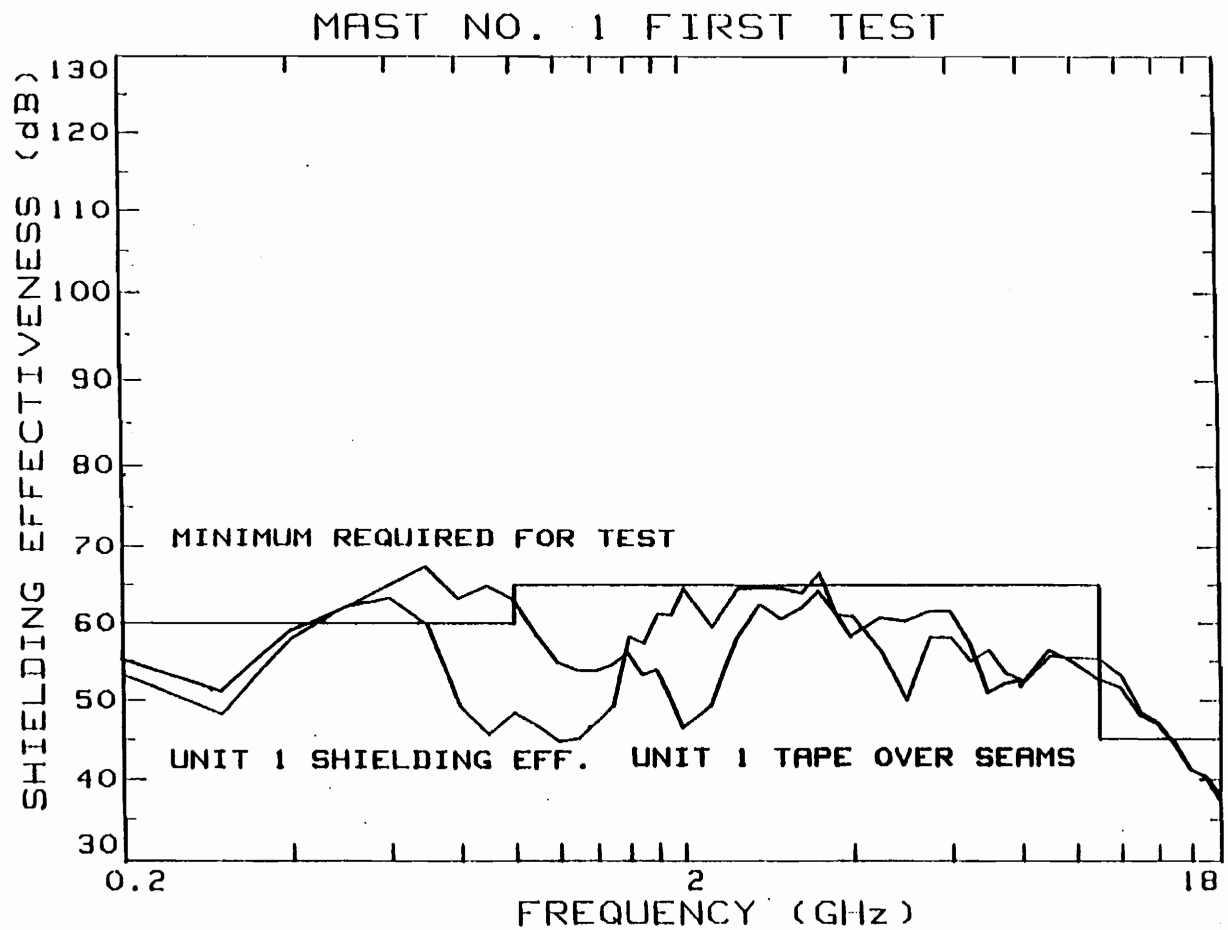
Signature Impact:	3	(Rejected)
Corrosion Resistance:	10	
Ability To Be Embedded:	3	
Bonding/Grounding Characteristics:	10	
Useful Life:	10	
Fire Resistance:	7	
Shielding Performance:	3	
Performance Bandwidth:	5	
TOTAL	0	

Appendix D - Results

COPPER MESH/COPPER FLECTRON SE TEST RESULTS



COPPER/SILVER FLECTRON SE TEST RESULTS



VITA

Tammy A. Campbell is a Systems/Composite Materials E^3 Project Engineer at the Naval Surface Warfare Center, Dahlgren Division. Ms. Campbell received her Bachelor of Science degree in Electrical Engineering from Tennessee Technological University in 1987. From 1987-1990, she was an E^3 engineer for the AEGIS Test Team. During this period, Ms. Campbell also acted as the E^3 Project Engineer for the Cooperative Engagement Program. She chaired the Tri-SYSCOM Composite Materials E^3 Working Group from 1990-1993. Currently, Ms. Campbell is a member of the NATO AC 141 SWG 10 Ad Hoc Working Group on Glass Reinforced Plastic (GRP) Ship Design and the composite materials representative to the Defense Exchange Agreement UK-RN-N-94-9522 on Naval Electromagnetic Environmental Effects. Ms. Campbell is the E^3 Project Manager for the AEM/S Program, the Surface Ship Technology Development Program, and Advanced Composites for Future Surface Ships Program.