NELC/REPORT 1546

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COMBINED-ENVIRONMENT TESTING OF SHIPBOARD ELECTRONIC EQUIPMENT

Second of a series

Additional test data are presented, and a regression equation is derived which verifies the contribution of synergistic (interacting) effects to deterioration in performance by relating output power to environmental factors

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Research and Development Report

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PROBLEM

Verify the occurrence of synergistic (interacting) effects in combined-environment testing and show their contribution to the deterioration in performance of a shipboard electronic module.

RESULT

The test revealed that synergistic effects occurred and contributed to the degradation in performance of an intermediate-frequency, amplitude-modulation (if/am) amplifier module. This specific module is used in the signal converter which is part of the AN/SRC-16.

RECOMMENDATIONS

1. Conduct a conventional environmental test according to MIL-E-16400E (NAVY)* and a combined-environment test on a shipboard electronic module and compare the results.

2. Continue assessment of the effect of combined environments on shipboard electronic equipment with various types of shipboard electronic modules.

3. Continue work to develop a ''standard'' combined-environment test procedure.

ADMINISTRATIVE INFORMATION

This report covers work from October 1907 to January 1968 and was approved for publication 18 March 1968. The work was performed under the SEEDS program, SF 013 14 04, Task 5788 (NELC R114), by the Equipments Effectiveness Division.

Thanks are extended to C. J. Van Vliet, of the Mathematical Division, for preparing the computer programs in conjunction with the derivation of the regression equations.

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*Department of the Navy Military Specification MIL-E-16400E (NAVY), *Electronic Equipment, Naval Ship and Shore, General Specification*, 15 June 1962.

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INTRODUCTION

The reliability of operational shipboard electronic equipment has not improved appreciably over the past few years. Failure rates of electronic equipment are still high and means to lower them should be ascertained. In many instances, equipment which has been subjected to environmental testing in the laboratory fails once it is installed and operating in its actual shipboard environment. Indications are that the present test methods have inherent deficiencies in that they do not produce these potential failure modes and effectively simulate field failures during laboratory testing. Scrutiny of the test method for subjecting electronic equipment to environments in a sequential manner reveals two obvious discrepancies: (1) the test method does not simulate the actual environmental conditions in which the equipment is to operate, and (2) it does not subject the equipment to the synergistic (interacting) effects of the true environments.

If the reliability of shipboard electronic equipment is to improve in the future, then, the potential failure modes and problem areas must be detected prior to mass production of the equipment. This may be accomplished through simulating the total effects of the actual shipboard environment. In other words, the equipment should be exposed to the synergistic effects as well as to the main effects in an environmental test. These combined effects have a detrimental effect on the performance and failure rate of shipboard electronic equipment, as prior tests have revealed. *

The purpose of this report is to show the occurrence of the synergistic effects in combined environments and their contribution to the degradation in performance of shipboard electronic equipment.

Subsequent sections will describe the test procedures and the verification of synergistic effects in combined environments.

The test facilities and instrumentation are described in the appendix.

THE TEST PROGRAM

Test Specimen

The intermediate-frequency, amplitude-modulation (if/am) amplifier module was chosen for this particular test because of availability and susceptibility to the environments as demonstrated in a previous combined-environment test. The active components in the module are all solid-state devices. The module receives a 500 (±3)-kHz intermediate-frequency signal, demodulates and amplifies the audio signal superimposed on it, and provides automatic-gain-control bias.

The module contains four major circuits: (1) four-stage intermediate-frequency amplifier, (2) mixer-detector, (3) two-stage audio amplifier, and (4) automatic-gain-control amplifier.

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* Navy Electronics Laboratory Report 1292, *Environmental Test for Electronic Equipment for Southern Cross*, by W. R. Beye, 8 June 1965; and

Navy Electronics Laboratory Report 1366, *Combined-Environment Testing of Shipboard Electronic Equipment,* by F. Robinson, 7 April 1966

Operating Conditions

The if/am amplifier modules were operated with an input signal level of 1000 microvolts and a carrier frequency of 500(±3) kHz, modulated 30 percent with a 1000-Hz tone. The supply voltages to the modules were held at +27 Vdc and -27 Vdc by two regulated power supplies. The modules were adjusted for 1 milliwatt of output power across a 600-ohm balanced load and the volume control was locked to prevent alteration as a result of vibration.

Performance Measurements

Performance measurements were recorded for each of the 27 treatments that were applied to the test specimens. These measurements consisted of the voltage at three test jacks, output power, and distortion. Prior to each run, a set of initial readings was taken at room ambient condition for each of the three test specimens.

Test Conditions

A three-factor, three-level, full-factorial test which consisted of 27 combinations of temperature, humidity, and vibration was applied six different times to each test specimen. Each of the 27 treatments was allowed to stabilize for 1 hour to expedite the complete test. Stabilization was verified by monitoring wet- and dry-bulb charts and by monitoring the internal temperature of each module with thermocouples. After the elapse of an hour, performance measurements were recorded for each specific treatment. In the interest of repeatability, the temperatures and humidity levels were programmed from two cams. The 27 treatments along with levels of the three environments are shown in table 1.

VERIFICATION OF SYNERGISTIC EFFECTS

The presence of the various interacting effects of combined environments and their contribution to the overall degradation in performance of an if/am amplifier module were verified by subjecting three if/am amplifier modules to a 3x3x3 full-factorial test.

The regression equation which relates the output power of the if/am amplifier module to the environmental factors will be derived for the test data.

Tables 2 through 7 show the levels of the environments along with the output power of each module. The enormous number of data involved necessitated the use of a computer to facilitate calculations in the derivation of the regression equation.

In the 3x3x3 full-factorial test, the general regression equation contains 26 terms and takes the form shown below.

$$P = b_0 + b_1T + b_2H + b_3V + b_4T^2 + b_5H^2 + b_6V^2 + b_7TH + b_8HV + b_9VT$$

$$+ b_{10}TH^2 + b_{11}T^2H + b_{12}HV^2 + b_{13}H^2V + b_{14}VT^2 + b_{15}V^2T$$

$$+ b_{16}T^2H^2 + b_{17}H^2V^2 + b_{18}V^2T^2 + b_{19}THV + b_{20}THV^2 + b_{21}TH^2V$$

$$+ b_{22}T^2HV + b_{23}TH^2V^2 + b_{24}T^2HV^2 + b_{25}T^2H^2V + b_{26}T^2H^2V^2$$

However, to facilitate the derivation of the response equation, only the first nine of the 26 terms were considered in the regression equation, since these terms included the main effects as well as the two-factor interacting effects.

The regression equation which was derived took the following form:

$$P = b_0 + b_1T + b_2H + b_3V + b_4T^2 + b_5H^2 + b_6V^2 + b_7TH + b_8HV + b_9VT$$

The coefficients of the above regression equation have the following values:

$b_0 = 1.1117$

$b_1 = 0.0013594$

$b_2 = -0.0014441$

$b_3 = 0.063866$

$b_4 = -0.000045701$

$b_5 = 0.000015696$

$b_6 = -0.0025789$

$b_7 = -0.000020144$

$b_8 = -0.00039512$

$b_9 = -0.00047497$

TABLE 1. VARIOUS APPLIED TREATMENTS.

Treatment	Level		
	Vibration, *g*	Temperature, °F	Humidity, %
1	0.50	50	35
2	1.25	50	35
3	2.00	50	35
4	0.50	86	35
5	1.25	86	35
6	2.00	86	35
7	0.50	122	35
8	1.25	122	35
9	2.00	122	35
10	0.50	50	65
11	1.25	50	65
12	2.00	50	65
13	0.50	86	65
14	1.25	86	65
15	2.00	86	65
16	0.50	122	65
17	1.25	122	65
18	2.00	122	65
19	0.50	50	93
20	1.25	50	93
21	2.00	50	93
22	0.50	86	93
23	1.25	86	93
24	2.00	86	93
25	0.50	122	93
26	1.25	122	93
27	2.00	122	93

TABLE 2. TEST DATA OF THREE IF/AM AMPLIFIER MODULES, RUN NO. 1.

Output Power, mW			Vibration,	Temperature,	Humidity,
Module					
1	2	3	g	° F	%
1.12	1.09	1.14	0.50	50	35
1.38	1.12	1.29	1.25	50	35
1.20	1.09	1.29	2.00	50	35
0.96	1.00	0.98	2.00	86	35
0.91	0.96	0.93	1.25	86	35
0.85	0.96	0.96	0.50	86	35
0.50	0.17	0.46	0.50	122	93
0.50	0.14	0.40	1.25	122	93
0.35	0.13	0.35	2.00	122	93
0.62	0.16	0.48	2.00	86	93
0.86	0.15	0.81	1.25	86	93
0.93	0.88	0.88	0.50	86	93
0.93	1.04	1.04	0.50	50	93
1.09	1.06	1.14	1.25	50	93
0.98	1.06	1.14	2.00	50	93
0.52	0.60	0.56	2.00	122	35
0.58	0.54	0.60	0.50	122	35
0.50	0.56	0.56	1.25	122	35
0.97	1.04	1.04	1.25	50	65
1.06	1.14	1.14	2.00	50	65
1.06	1.14	1.17	0.50	50	65
0.86	0.93	0.91	0.50	86	65
0.79	0.86	0.86	1.25	86	65
0.81	0.84	0.86	2.00	86	65
0.50	0.50	0.50	2.00	122	65
0.45	0.50	0.40	1.25	122	65
0.43	0.50	0.38	0.50	122	65

TABLE 3. TEST DATA OF THREE IF/AM AMPLIFIER MODULES, RUN NO. 2.

Output Power, mW Module 1	2	3	Vibration, g	Temperature, °F	Humidity, %
0.41	0.50	0.29	0.50	122	93
0.40	0.48	0.26	1.25	122	93
0.40	0.46	0.24	2.00	122	93
1.01	1.06	1.06	2.00	50	35
0.96	1.04	1.06	1.25	50	35
0.88	1.03	0.91	0.50	50	35
0.72	0.79	0.81	0.50	86	35
0.70	0.72	0.74	1.25	86	35
0.68	0.70	0.72	2.00	86	35
0.45	0.54	0.48	0.50	122	35
0.38	0.54	0.35	1.25	122	35
0.36	0.52	0.33	2.00	122	35
0.66	0.72	0.70	2.00	50	65
0.86	0.88	0.98	1.25	50	65
0.96	0.96	1.06	0.50	50	65
0.66	0.79	0.81	0.50	86	65
0.74	0.79	0.81	1.25	86	65
0.74	0.77	0.80	2.00	86	65
0.45	0.58	0.48	2.00	122	65
0.41	0.48	0.41	1.25	122	65
0.36	0.50	0.33	0.50	122	65
0.96	1.01	1.04	2.00	50	93
1.04	1.04	1.06	1.25	50	93
1.04	1.04	1.12	0.50	50	93
0.70	0.74	0.81	0.50	86	93
0.70	0.74	0.79	1.25	86	93
0.72	0.72	0.79	2.00	86	93

TABLE 4. TEST DATA OF THREE IF/AM AMPLIFIER MODULES, RUN NO. 3.

Output Power, mW			Vibration, g	Temperature, °F	Humidity, %
Module					
1	2	3			
0.26	0.41	0.32	2.00	122	93
0.36	0.45	0.29	1.25	122	93
0.36	0.45	0.24	0.50	122	93
0.66	0.66	0.68	0.50	86	93
0.70	0.68	0.72	1.25	86	93
0.70	0.68	0.72	2.00	86	93
0.91	0.93	0.96	2.00	50	93
0.93	1.06	1.06	1.25	50	93
0.96	1.06	1.09	0.50	50	93
0.54	0.58	0.43	0.50	122	65
0.46	0.46	0.22	1.25	122	65
0.43	0.56	0.17	2.00	122	65
0.68	0.70	0.64	2.00	86	65
0.66	0.70	0.68	1.25	86	65
0.72	0.72	0.70	0.50	86	65
0.91	0.96	1.01	0.50	50	65
1.01	1.01	1.01	1.25	50	65
0.91	1.01	1.01	2.00	50	65
0.98	1.09	1.12	0.50	50	35
1.06	1.12	1.09	1.25	50	35
1.09	1.04	1.09	2.00	50	35
0.84	0.91	0.84	2.00	86	35
0.79	0.84	0.81	1.25	86	35
0.79	0.84	0.81	0.50	86	35
0.54	0.62	0.43	0.50	122	35
0.56	0.62	0.48	1.25	122	35
0.46	0.62	0.41	2.00	122	35

TABLE 5. TEST DATA OF THREE IF/AM AMPLIFIER MODULES, RUN NO. 4.

Output Power, mW			Vibration,	Temperature,	Humidity,
Module					
1	2	3	g	°F	%
0.40	0.54	0.38	2.00	122	35
0.38	0.50	0.36	1.25	122	35
0.68	0.91	0.91	2.00	50	35
0.96	0.91	1.01	1.25	50	35
1.04	1.12	1.06	1.25	50	65
1.06	1.14	1.14	2.00	50	65
0.79	0.79	0.84	2.00	86	65
0.79	0.81	0.81	1.25	86	65
0.45	0.45	0.38	1.25	122	65
0.38	0.48	0.32	2.00	122	65
0.96	0.93	1.04	2.00	50	93
0.96	1.04	1.04	1.25	50	93
0.70	0.74	0.74	1.25	86	93
0.66	0.72	0.74	2.00	86	93
0.40	0.43	0.32	2.00	122	93
0.35	0.41	0.26	1.25	122	93
1.06	1.06	1.12	0.50	50	35
0.74	0.81	0.81	0.50	86	35
0.74	0.79	0.79	1.25	86	35
0.48	0.62	0.45	0.50	122	35
0.56	0.86	0.96	0.50	50	65
0.72	0.79	0.77	0.50	86	65
0.45	0.54	0.48	0.50	122	65
0.84	0.88	0.98	0.50	50	93
0.68	0.72	0.72	0.50	86	93
0.36	0.43	0.28	0.50	122	93
0.79	0.86	0.81	2.00	86	35

TABLE 6. TEST DATA OF THREE IF/AM AMPLIFIER MODULES, RUN NO. 5.

Output Power, mW			Vibration,	Temperature,	Humidity,
Module					
1	2	3	g	° F	%
0.91	1.04	1.04	2.00	50	65
0.86	1.04	0.98	1.25	50	65
0.88	1.04	0.98	0.50	50	65
0.70	0.81	0.66	0.50	86	65
0.64	0.74	0.60	1.25	86	65
0.60	0.64	0.58	2.00	86	65
0.40	0.54	0.08	0.50	122	65
0.33	0.58	0.07	1.25	122	65
0.33	0.54	0.06	2.00	122	65
0.72	0.91	0.88	2.00	50	93
0.77	0.93	0.96	1.25	50	93
0.86	1.04	0.98	0.50	50	93
0.62	0.77	0.64	0.50	86	93
0.68	0.79	0.70	1.25	86	93
0.66	0.79	0.68	2.00	86	93
0.30	0.29	0.10	2.00	122	93
0.29	0.46	0.05	1.25	122	93
0.28	0.46	0.04	0.50	122	93
0.74	0.93	0.93	0.50	50	35
0.84	1.01	1.04	1.25	50	35
0.96	1.09	1.09	2.00	50	35
0.77	0.88	0.72	2.00	86	35
0.72	0.77	0.70	1.25	86	35
0.72	0.79	0.68	0.50	86	35
0.41	0.66	0.14	0.50	122	35
0.33	0.48	0.10	1.25	122	35
0.32	0.56	0.10	2.00	122	35

TABLE 7. TEST DATA OF THREE IF/AM AMPLIFIER MODULES, RUN NO. 6.

Output Power, mW			Vibration,	Temperature,	Humidity,
Module					
1	2	3	g	°F	%
0.91	1.14	0.96	2.00	50	35
0.96	1.17	1.12	1.25	50	35
0.96	1.06	1.12	0.50	50	35
0.72	0.93	0.80	0.50	86	35
0.68	0.79	0.79	1.25	86	35
0.68	0.84	0.79	2.00	86	35
0.36	0.64	0.30	2.00	122	35
0.41	0.41	0.30	1.25	122	35
0.35	0.62	0.20	0.50	122	35
0.66	0.52	0.88	0.50	50	65
0.79	1.01	0.88	1.25	50	65
0.86	1.06	1.04	2.00	50	65
0.68	0.84	0.79	2.00	86	65
0.56	0.70	0.74	1.25	86	65
0.64	0.79	0.74	0.50	86	65
0.33	0.46	0.28	0.50	122	65
0.29	0.38	0.21	1.25	122	65
0.28	0.36	0.19	2.00	122	65
0.81	0.93	1.04	0.50	50	93
0.88	1.12	1.12	1.25	50	93
0.91	0.91	1.09	2.00	50	93
0.62	0.79	0.81	2.00	86	93
0.58	0.77	0.77	1.25	86	93
0.64	0.77	0.79	0.50	86	93
0.15	0.28	0.22	2.00	122	93
0.25	0.20	0.20	1.25	122	93
0.28	0.29	0.18	0.50	122	93

The regression equation for the three-factor test of temperature, humidity, and vibration becomes now

$$
\begin{aligned}
P = {} & 1.1117 + 0.0013594T - 0.0014441H + 0.063866V - 0.000045701T^2 \\
& + 0.000015696H^2 - 0.0025789V^2 - 0.000020144TH - 0.00039512HV \\
& - 0.00047497VT
\end{aligned}
$$

where

P = output power in milliwatts

T = temperature environmental factor

H = humidity environmental factor

V = vibration environmental factor

TH = temperature-humidity-interaction factor

HV = humidity-vibration-interaction factor

VT = vibration-temperature-interaction factor

The coefficient of correlation that was computed for the regression equation had a value of 0.906. This high value of correlation is indicative of the closeness of fit between the regression equation and the true-response equation. This was substantiated by several estimations of the output power using the regression equation. The estimations are shown in table 8.

From the above regression equation, one observes that synergistic effects do occur and have a detrimental effect on electronic equipment operating in combined environments. It is these additional interacting effects acting in conjunction with the main effects that influence the failure rate and performance of shipboard electronic equipment.

The contribution of each environmental factor may be obtained from the regression equation. If a unit change is assumed for each environmental factor, then, the magnitudes of the coefficients of the various factors represent the degrees of contribution. After the scrutiny of the interacting terms, one notices that the humidity-vibration and the vibration-temperature interactions contributed about equally to the degradation in output power of the if/am amplifier module. However, the temperature-humidity interaction contributed approximately one-tenth less to the degradation in output power than the other two interactions.

During a particular combined-environment test, the significance or insignificance of the different main and interaction terms will depend to a large degree on the type of electronic equipment being tested. The susceptibility of electronic equipment to the different environments and their interactions will definitely vary as a result of the variety of components which go to make up different equipments. For instance, one type of electronic equipment may contain components that are susceptible to all the environmental factors; however, another type may contain components which are susceptible only to vibration-temperature and temperature-humidity interactions and insusceptible to the humidity-vibration interaction. This should not be construed to imply that the interaction of humidity and vibration is not essential in combined-environment testing, nor should any environmental factor be discounted because it did not affect a piece of electronic equipment during a specific combined-environment test.

The important point is that these additional detrimental effects are present in combined environments and they have an opportunity to influence the failure rate and performance of shipboard electronic equipment.

In summary, synergistic effects have been shown to exist in combined environments and to have contributed to the degradation in output power of an if/am amplifier module. Furthermore, it is quite apparent that synergistic effects are essential to environmental testing of shipboard electronic equipment and should be seriously considered in it.

TABLE 8. ESTIMATES OF OUTPUT POWER FROM REGRESSION EQUATION.

Temperature, °F	Relative Humidity, %	Vibration, g	Observed Output, mW	Estimated Output, mW	Difference, mW
50	93	2.00	1.14	0.97	0.17
50	93	0.50	1.04	0.97	0.07
50	35	1.25	1.12	1.03	0.09
86	65	1.25	0.79	0.74	0.05
122	65	1.25	0.45	0.38	0.07
122	35	2.00	0.52	0.45	0.07
122	93	1.25	0.40	0.33	0.07
86	93	0.50	0.88	0.72	0.16
86	35	0.50	0.85	0.80	0.05
50	65	1.25	0.98	0.99	–0.01
86	65	2.00	0.77	0.73	0.04
122	65	0.50	0.36	0.40	–0.04

CONCLUSION

Synergistic (interacting) effects of combined environments were shown to exist and to have contributed to the degradation in output power response of an if/am amplifier module.

RECOMMENDATIONS

1. Conduct a conventional environmental test according to MIL-E-16400E (NAVY) and a combined-environment test on a shipboard electronic module and compare the results.

2. Continue assessment of the effects of combined environments on shipboard electronic equipment with various types of shipboard electronic modules.

3. Continue work to develop a ''standard'' combined-environment test procedure.

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APPENDIX: TEST FACILITIES AND INSTRUMENTATION

Environmental Test Facilities

The environmental test facilities used to perform the test are shown in figures A1 through A4.

The vibrator (figs. A1 and A2) was designed to vibrate a maximum load of 1000 pounds at a maximum acceleration level of 10 *g*.

The table top of the vibrator may be rotated 90°, without the removal and remounting of the test specimens, to permit horizontal vibration in either the fore-and-aft or lateral axis. Vibration in the vertical axis is accomplished by positioning two phase-locking pins at the rear of the vibrator. Acceleration levels of the vibrator table are maintained within ±5 percent of the set *g* level over a frequency range of 14 to 60 Hz by a closed-loop feedback system.

The vibrator may be withdrawn from beneath the chamber to facilitate the accessibility and installation of large test specimens. The vibrator can be remotely operated in two different modes; namely, constant amplitude with variable acceleration, and constant acceleration with variable amplitude. Automatic changeover from constant acceleration to constant amplitude is accomplished at any desired frequency by presetting the upper and lower transition points on the vibrator control panel. The vibrator has built-in safety factors that enable it to be operated unattended for long periods of time.

Temperature and humidity are controlled by the two racks of instrumentation and controls on the right of the environmental chamber (fig. A2).

The control console (fig. A3) consists of the vibrator control panel, six channels of acceleration readout, and a multichannel oscilloscope for simultaneous display of acceleration, velocity, and displacement.

Test Instrumentation

The test instrumentation shown in figure A4 was used to operate and monitor the performance of the test specimens. The instrumentation consisted of a potentiometer pyrometer which was used to monitor the internal temperatures of the test specimens, one rack of excitation and control equipment, one rack of readout and monitoring equipment, and an electric counter.

A block diagram of the instrumentation is shown in figure A5.

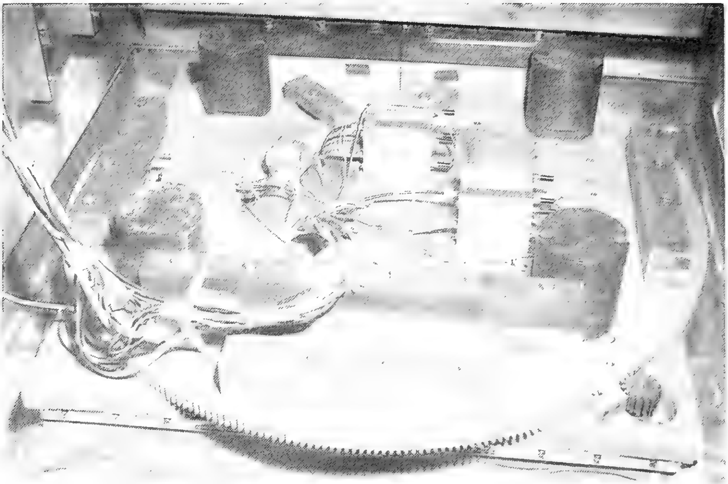

Figure A1. Internal view of environmental chamber and vibrator, with test specimens mounted.

Figure A2. Environmental chamber and vibrator with temperature and humidity control instrumentation.

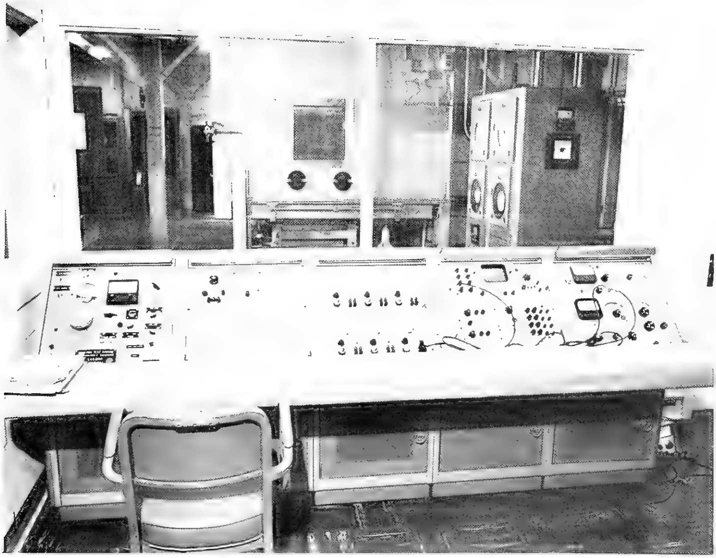

Figure A3. Control console with vibrator control panel and monitoring instrumentation.

Figure A4. Instrumentation used in operating and monitoring the test specimens.

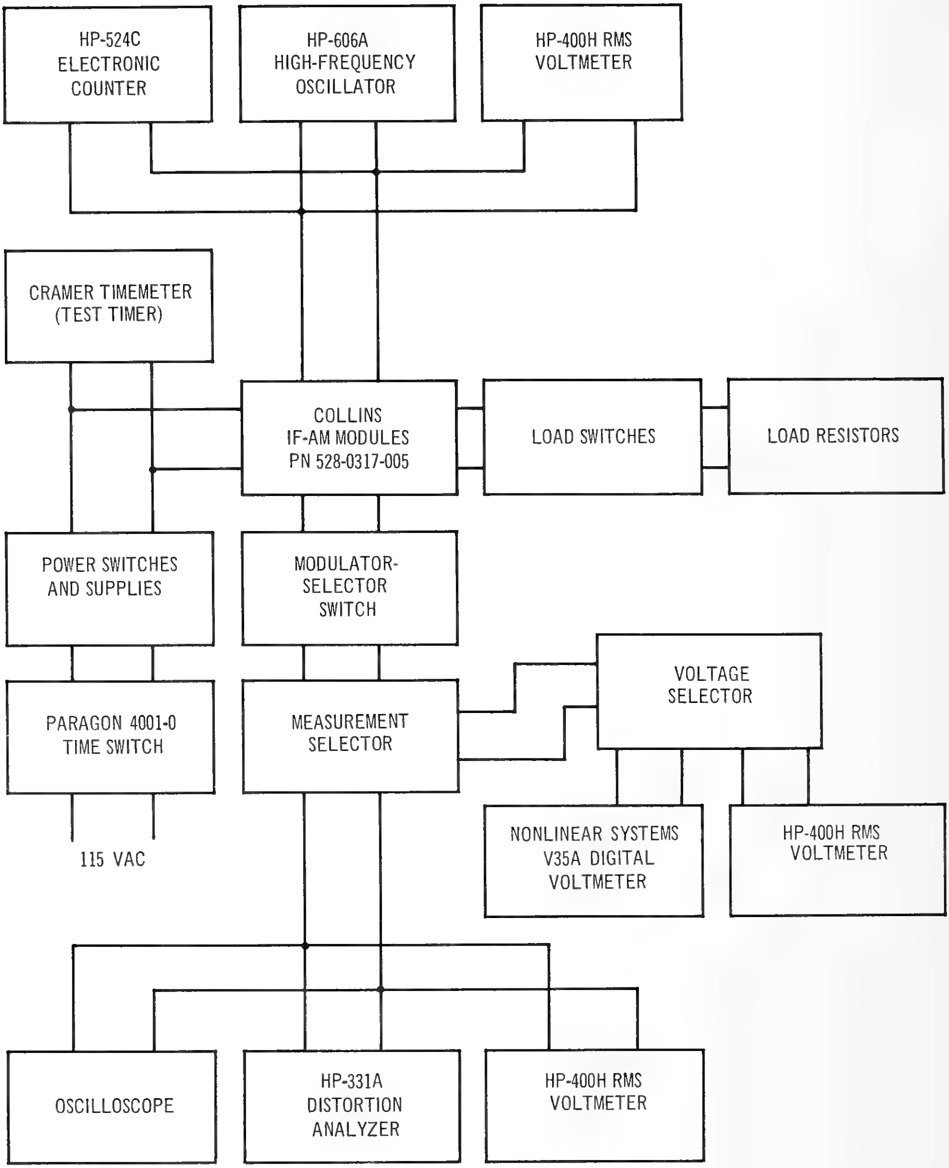

Figure A5. Block diagram of if/am module test instrumentation.

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13. ABSTRACT

Lack of improvement in reliability of operational shipboard electronic equipment over some years has led to an investigation of present test methods. This report shows that the method presently used for subjecting electronic equipment to environments in sequence fails to simulate actual environmental conditions and to subject the equipment to the synergistic (interacting) effects of the environment.

A combined-environment test consisting of 27 combinations of temperature, humidity, and vibration is applied to several specimens of an if/am amplifier module to verify the presence of synergistic effects, and these effects are shown to contribute to deterioration in performance.

The development of a standard combined-environment test procedure is recommended.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Environmental tests						
Electronic equipment - Reliability						

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