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PROJECT SPACE SHUTTLE

DATA BUS EVALUATION LABORATORY TEST REPORT

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PROJECT SPACE SHUTTLE

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1.0 INTRODUCTION

A Data Bus Evaluation Laboratory (DBEL) facility has been established within the Data Systems Branch to test and evaluate Space Shuttle data bus hardware. This test report describes performance testing conducted on an in-house developed multiplex interface adapter (MIA) for the purpose of evaluating DBEL test procedures, test hardware, and test software in a realistic test environment.

The test parameter limits on which the tests in this report are based were obtained from the North American Rockwell Specification for the Multiplex Interface Adapter (MIA) Unit, MC615-0010.

1.1 TEST PHILOSOPHY

The North American Rockwell Specification defines a Bit Error Rate as the figure of merit for a MIA. This figure is computed by the following formula:

$$\text{Bit Error Rate} = \frac{\text{Bit Errors}}{\text{No. of Bits Transmitted}}$$

The Manchester to NRZ decoder used in the MIA developed for the DPS subsystems is of the type that detects a phase change to define a "one" or "zero". With this type decoder, if a phase transition is not detected, the bit associated with that phase change will be decoded incorrectly and subsequent bits will also be wrong. The only way for the system to recover is for a second phase change to be undetected. For this reason, the figures of merit thought to be appropriate are:

a) Probability of an Unsuccessful Transmission =

$$\frac{\text{Total No. of Incorrectly Received Words}}{\text{No. of Transmissions}}$$

b) Probability of Undetected Word Errors =

$$\frac{\text{No. of Undetected Word Errors}}{\text{No. of Word Transmissions}}$$

1.2 TEST EQUIPMENT USED

The equipment used to perform tests on a data bus system fall into one of two categories. These categories are 1) the equipment necessary to control and correlate data on the data bus, and 2) the equipment necessary to observe and perturb the data bus signals. A Universal Bus Exerciser (UBE) has been developed that will control the data being transmitted on the data bus and verify the integrity of the data received by a MIA acting as a data bus receiver. This UBE (see Figure 1) is composed of a Data General Corporation NOVA 1200 mini-computer with teletypewriter, high speed paper tape reader and punch, and line printer, a Test Controller, Word Comparator, and Noise Controller.

In operation, the Test Controller takes data from the computer, converts it to serial NRZ format and outputs the data to the transmitting MIA and to the Word Comparator. The Test Controller also receives information from the computer to control the Noise Controller. The Word Comparator

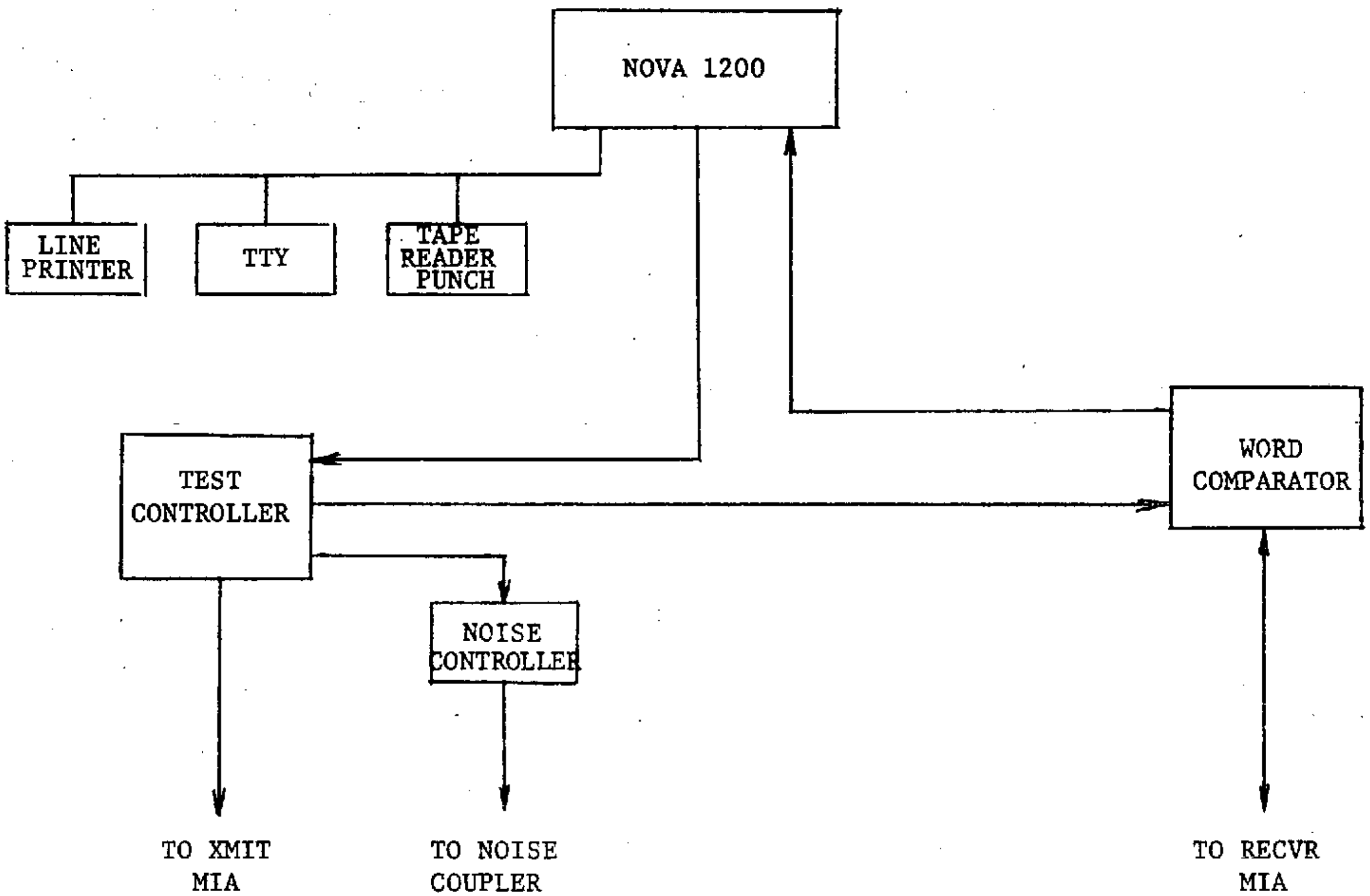

FIGURE 1

UNIVERSAL BUS EXERCISER BLOCK DIAGRAM

compares the data received from the receiver MIA with the data received from the Word Comparator on a bit by bit basis. If there is a bit error, an interrupt is sent to the computer. The computer then reads the error word (exclusive OR of the transmitted and received word) and error type information, i.e., parity error, invalid Manchester or word length from the Word Comparator. All this transmission error information is compiled by the computer and printed out at the end of the test. Other developed equipment used in the DBEL include various transformers for injecting common mode noise and thirty-two Data Bus Couplers (DBC) used to couple a MIA to the data bus or to simulate a MIA load on the data bus. A schematic drawing of the DBC is shown in Figure 2.

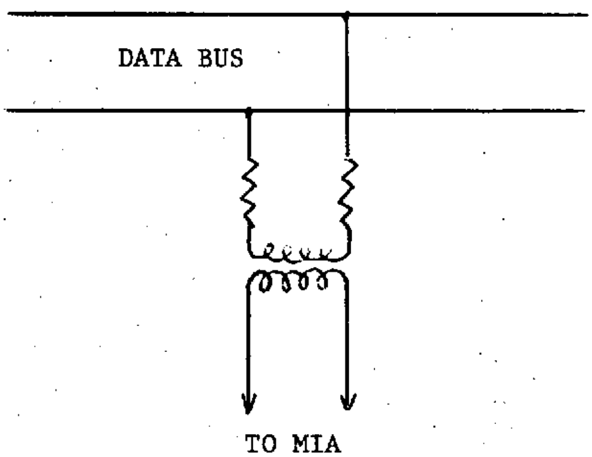

FIGURE 2
SCHEMATIC OF DATA BUS COUPLER

The remainder of the test equipment used in the DBEL include the following:

1) Hewlett Packard Model 3400 RMS Voltmeter
2) Elgenco, Inc. Model 603A Gaussian Noise Generator
3) Hewlett Packard Model 651A Test Oscillator
4) Tektronic Model 547 Oscilloscope
5) Olektron Corp. No. TX-HJ-3-215 Mixer/Attenuator
6) Miscellaneous power supplies and test probes

1.3 TEST SOFTWARE

A detailed description of the test software is contained in Lockheed Document No. LEC-1839, Bisector Program Specifications. In general, program Bisector provides an interface between the human operator and the test hardware. This interface will, 1) provide for selection of test configuration; 2) provide performance monitoring of the test hardware; 3) provide for the display of test result data as well as indications of catastrophic failures. In the configuration used in tests for this report, the computer outputs a predetermined sequence of data words and inputs from the Word Comparator transmission error information. The number of transmissions is selectable and was chosen to be $2^{23}-1$ or $5(2^{23}-1)$. The tests were programmed to halt if 500 word errors were detected. This number was arbitrarily chosen and is assumed to be so large as to never be encountered in normal operation.

2.0 OUTPUT DRIVE CAPABILITY TESTS

This test was conducted in three parts. The first part determined the maximum cable length drive capability of the

MIA; the second part determined the maximum line load (MIA stations on bus) drive capability with maximum specified bus cable length, and the third part determined the maximum number of line load faults that the system will tolerate with maximum specified cable length and line load conditions.

2.1 CABLE LENGTH DRIVE TEST

2.1.1 Objective

The purpose of this test was to determine the data bus cable length limit at which point the undetected word error rate becomes excessive.

2.1.2 Test Description

The hardware was set up as shown in Figure 3. A transmitting MIA controlled by the UBE was connected to a receiving MIA via a data bus cable terminated at each end by a 70 ohm resistor. The receiving MIA was always connected at the approximate middle of the data bus cable. It was anticipated that the signal distortion due to reflections would be near maximum at this point. The data bus cable length was then varied from approximately 160 ft. to a maximum length where failure rate became excessive.

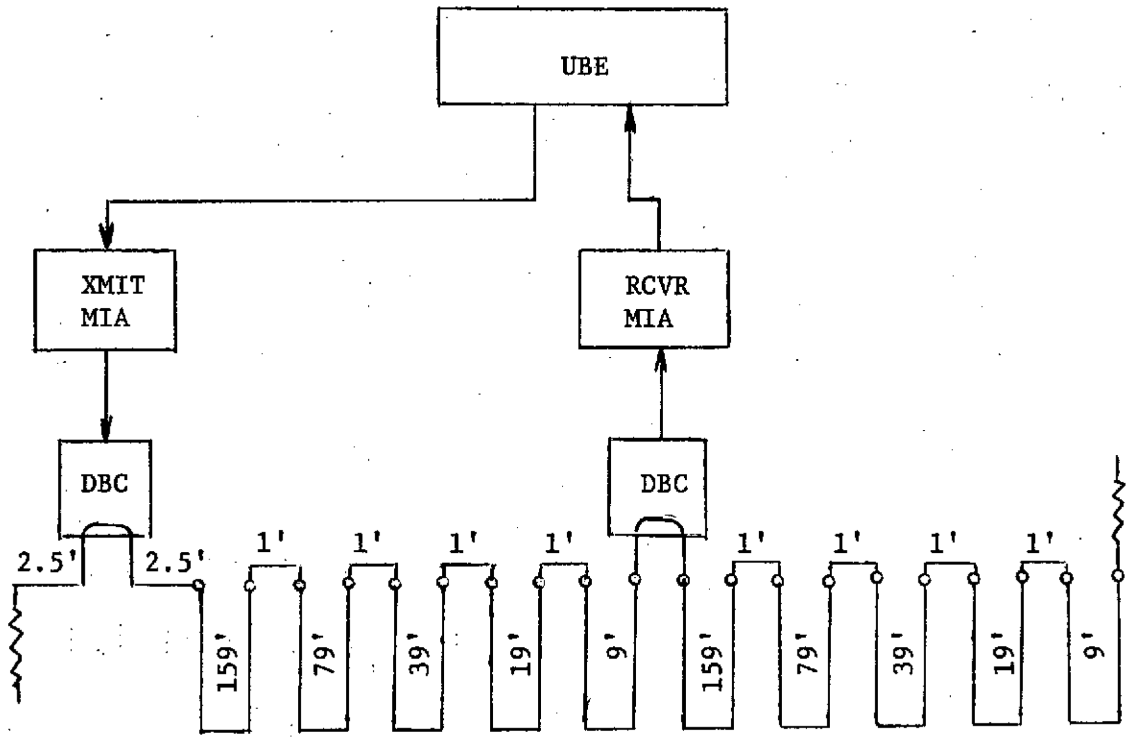

FIGURE 3

HARDWARE CONFIGURATION FOR CABLE LENGTH DRIVE TEST

2.1.3 Cable Length Test Results

The following table summarizes the results of the cable length test.

Distance to MIA	No. of Words	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
160	5592405	0	0	$<1.79 \times 10^{-7}$	
240	5592405	1	1	1.788×10^{-7}	
310	5592405	0	0	$<1.79 \times 10^{-7}$	
310	28027561	6	3	2.141×10^{-6}	1.07×10^{-6}
320	5592405	4	2	7.153×10^{-7}	3.58×10^{-7}
320	28027561	10	4	3.57×10^{-6}	2.14×10^{-6}
340	28027561	154	43	5.49×10^{-6}	3.96×10^{-6}
360	3089411	500	183	1.62×10^{-4}	1.03×10^{-4}
390	1399102	500	0	3.57×10^{-4}	3.57×10^{-4}
470	1399180	500	0	3.57×10^{-4}	3.57×10^{-4}

TABLE I

SUMMARY OF CABLE LENGTH TEST RESULTS

2.1.4 Conclusion

The maximum distance between the transmitting MIA and the receiving MIA should be no more than 320 ft.

2.2 LINE LOAD DRIVE TEST

2.2.1 Objective

The purpose of this test was to determine the line load limit, i.e., the number of MIA stations on the bus, at which point the system failure rate becomes excessive.

2.2.2 Test Description

The hardware configuration for this test was as shown in Figure 4. A transmitting MIA controlled by the UBE was connected to the receiving MIA, with the receiving MIA being in the approximate center of the test setup. The load coupler terminations were connected to the load couplers via cable stubs of 10 ft. and 30 ft. lengths. Thirty feet has been established as the maximum length a subsystem may be from its load coupler. Loads (via load couplers) were added to the system until the undetected word failure rate became excessive.

2.2.3 Test Results

The distortion of the bus signal caused by the addition of a single load coupler is much more than anticipated. For this reason, the failure rate change associated with the

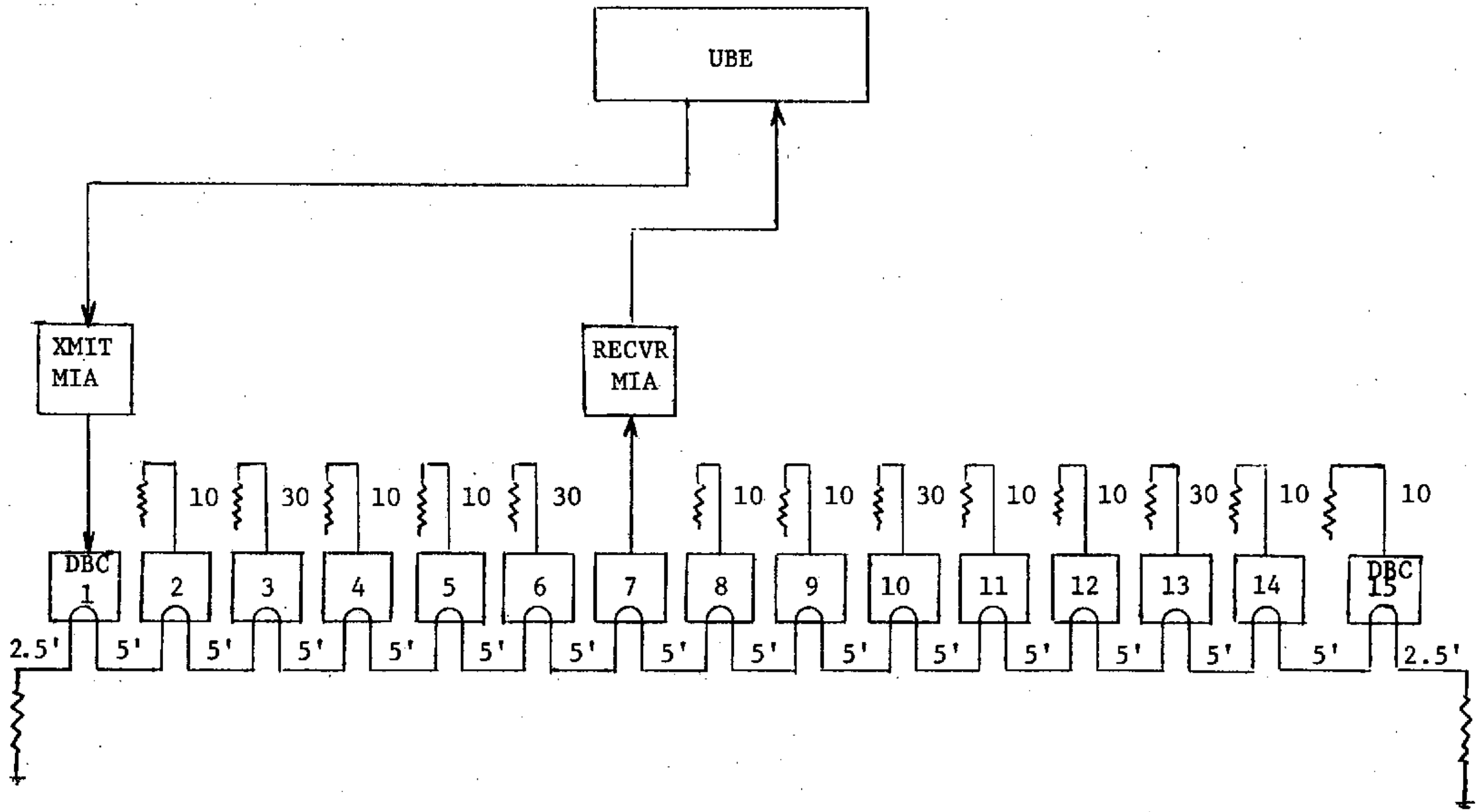

FIGURE 4

HARDWARE CONFIGURATION FOR LINE LOAD DRIVE TEST addition of a single load beyond a maximum number is extreme. For example, there were no failures with 15 loads over a 15 minute interval but 16 loads produced errors on almost every transmission. Therefore, the maximum number of loads on a given bus cable cannot exceed 15.

2.3 LINE LOAD FAULT TEST

2.3.1 Test Objective

The purpose of this test was to determine the maximum number of worst case load faults that may occur at which point the system failure rate becomes excessive.

2.3.2 Test Description

The hardware configuration for this test was the same as used in the Line Load Drive Test (Figure 4). Fifteen line loads were coupled to the bus via load couplers at equal distances along the bus. Each load consisted of a 6.8K ohm resistor connected across the transformer primary at the end of the cable stub.

Load faults were then introduced by shorting out the primary winding at the load. This represents an expected worst case fault. Load faults were placed at random locations along the bus until the failure rate became excessive.

2.3.3 Test Results

With 15 loads on the bus, no faults could be tolerated. With 14 loads four faults could be tolerated. As with Line

Load Drive Test, the point about which the system worked well or not at all was clearly defined. The results are summarized in Table II.

No. of Faults	No. of Transmissions	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
1	5592405	0		$< 1.79 \times 10^{-7}$	
2	5592405	0		$< 1.79 \times 10^{-7}$	
3	5592405	0		$< 1.79 \times 10^{-7}$	
4	5592405	0		$< 1.79 \times 10^{-7}$	
5	36680	500	220	1.36×10^{-2}	7.6×10^{-3}
6	7243	500	206	6.9×10^{-2}	4.06×10^{-2}
7	18320	500	236	2.7×10^{-2}	1.44×10^{-2}

TABLE II

SUMMARY OF LINE LOAD FAULT TEST (14 LOADS)

2.3.4 Conclusion

With the maximum number of loads on the data bus, no faults can be tolerated. With one less than the maximum number of loads, four faults can be tolerated.

2.4 COMMON MODE NOISE REJECTION TEST

2.4.1 Test Objective

The purpose of this test was to determine the MIA common mode noise rejection limit at which point the common mode signal causes receiver operation.

2.4.2 Test Configuration

The hardware configuration for this test was as shown in Figure 5. The transmitting MIA was connected to the receiving MIA by a short cable. Common mode noise was transformer coupled to the bus cable between the shield and each leg of the twisted pair as shown. The common mode signal was measured with an oscilloscope at the bus terminal connections of the receiving MIA.

2.4.3 Test Description

With the equipment connected as shown in Figure 3, a common mode signal was injected at frequencies of 60, 400, 1K, 10K, 100K, 1M, and 2MHz. At each of these frequencies, the signal amplitude varied from 10V to 80V in increments of 10V.

2.4.4 Test Results

The MIA's were insensitive to common mode noise at frequencies below 100KHz. The following tables summarize the results with common mode frequencies above 100KHz and voltage levels above 20Vp-p.

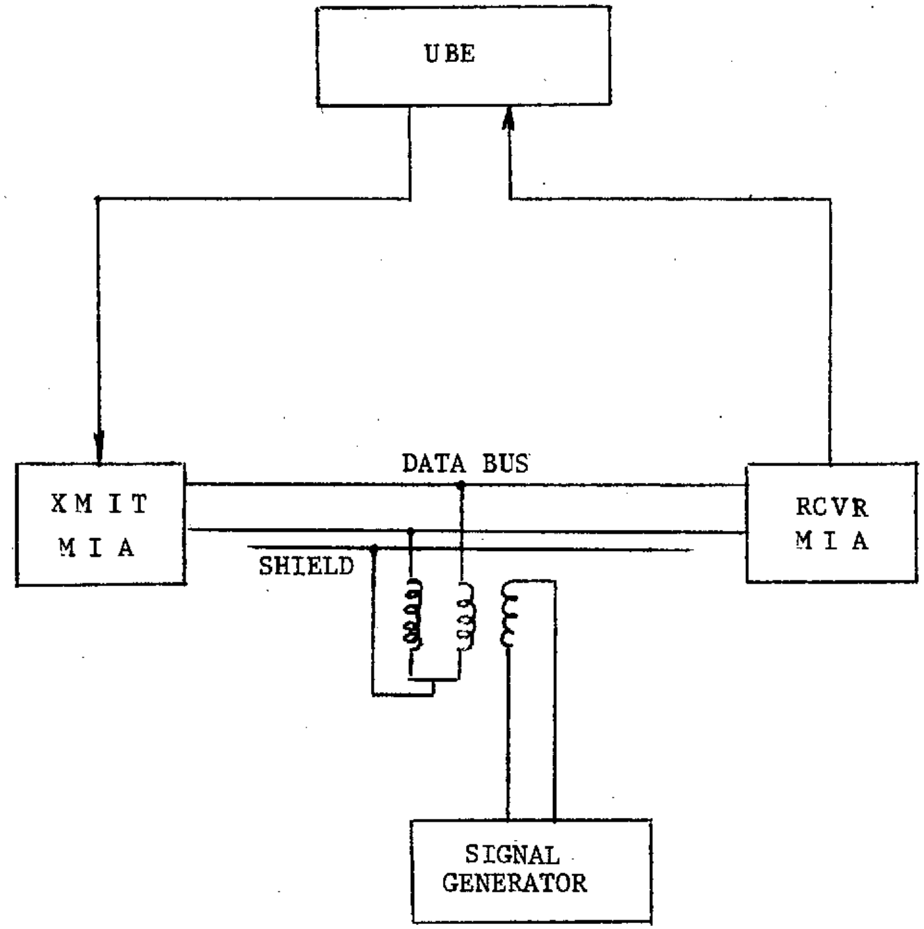

FIGURE 5
HARDWARE CONFIGURATION FOR COMMON MODE NOISE TESTS

Common Mode Volts	No. of Transmissions	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
20	28027561	12	8	4.28×10^{-7}	1.43×10^{-7}
30	28027561	177	95	6.31×10^{-6}	2.93×10^{-6}
40	11079460	500	245	4.51×10^{-5}	2.39×10^{-5}
50	4757503	500	255	1.05×10^{-4}	5.15×10^{-5}
60	1421163	500	267	3.52×10^{-4}	1.64×10^{-4}
70	812342	500	254	6.15×10^{-4}	3.03×10^{-4}
80	414308	500	263	1.21×10^{-3}	5.72×10^{-4}

TABLE III

RESULTS OF COMMON MODE NOISE TEST AT 100KHz

Common Mode Volts	No. of Transmissions	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
30	28027561	0	0	$< 3.57 \times 10^{-8}$	
40	28027561	10	5	3.57×10^{-7}	1.78×10^{-7}
50	28027561	4	1	1.43×10^{-7}	1.07×10^{-7}
60	28027561	3	2	1.07×10^{-7}	3.57×10^{-8}
70	28027561	54	29	1.93×10^{-6}	8.92×10^{-7}
80	22058451	500	233	2.27×10^{-5}	1.21×10^{-5}

TABLE IV

RESULTS OF COMMON MODE NOISE TEST AT 1MHz

Common Mode Volts	No. of Transmissions	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
30	28027561	0	0	$< 3.57 \times 10^{-8}$	
40	28027561	1	1	3.57×10^{-8}	
50	28027561	0	0	$< 3.57 \times 10^{-8}$	
60	28027561	51	28	1.82×10^{-6}	8.21×10^{-7}
70	28027561	175	88	6.24×10^{-6}	3.10×10^{-6}
80	28027561	59	30	2.01×10^{-6}	1.03×10^{-6}

TABLE V

RESULTS OF COMMON MODE NOISE TEST AT 2MHz

2.4.5 Conclusions

The DPS MIA's are relatively immune to common mode noise at any frequency other than the basic bit rate frequency. The susceptibility at this frequency is probably due more to an unbalance in the receiver test fixture than the receiver transformer.

2.5 DIFFERENTIAL NOISE SENSITIVITY TESTS

2.5.1 Test Objective

The differential noise sensitivity tests were conducted in four parts. They were intended to determine the following parameters.

1) The minimum signal/noise ratio at which point the receiving MIA fails to detect the sync pattern,

2) The minimum signal/noise ratio that results in an excessive error rate assuming the MIA did receive a valid sync pattern,

3) The minimum signal/noise ratio at which point the receiving MIA error rate becomes excessive with the noise injected continuously, and

4) An extended differential noise test whereby the minimum signal-to-noise ratio that results in an excessive error rate with the transmitting and receiving MIA operating in a simulated realistic environment is determined.

2.5.2 Sync Signal Recognition Test

2.5.2.1 Test Configuration

The hardware configuration for this test was as shown in Figure 6. A transmitting MIA controlled by the UBE was connected to a receiving MIA via a DBC and the mixer/attenuator. Band limited white noise with an upper frequency of 5MHz was injected on the data bus via the noise controller and the mixer/attenuator.

2.5.2.2 Test Description

With the hardware in the configuration shown in Figure 6, and with the noise generator off, the signal level was measured with an RMS voltmeter at the receiving MIA input terminals. This voltage was modified to account for the "dead" time between bus words. This modified voltage was the one used to compute the noise level for a specified signal/noise ratio. The noise level was adjusted with the transmitting MIA power on but in a quiescent state.

2.5.2.3 Results of Sync Pattern Recognition Test

In this test, the noise was injected during the sync period only. The following table summarizes the results of this test.

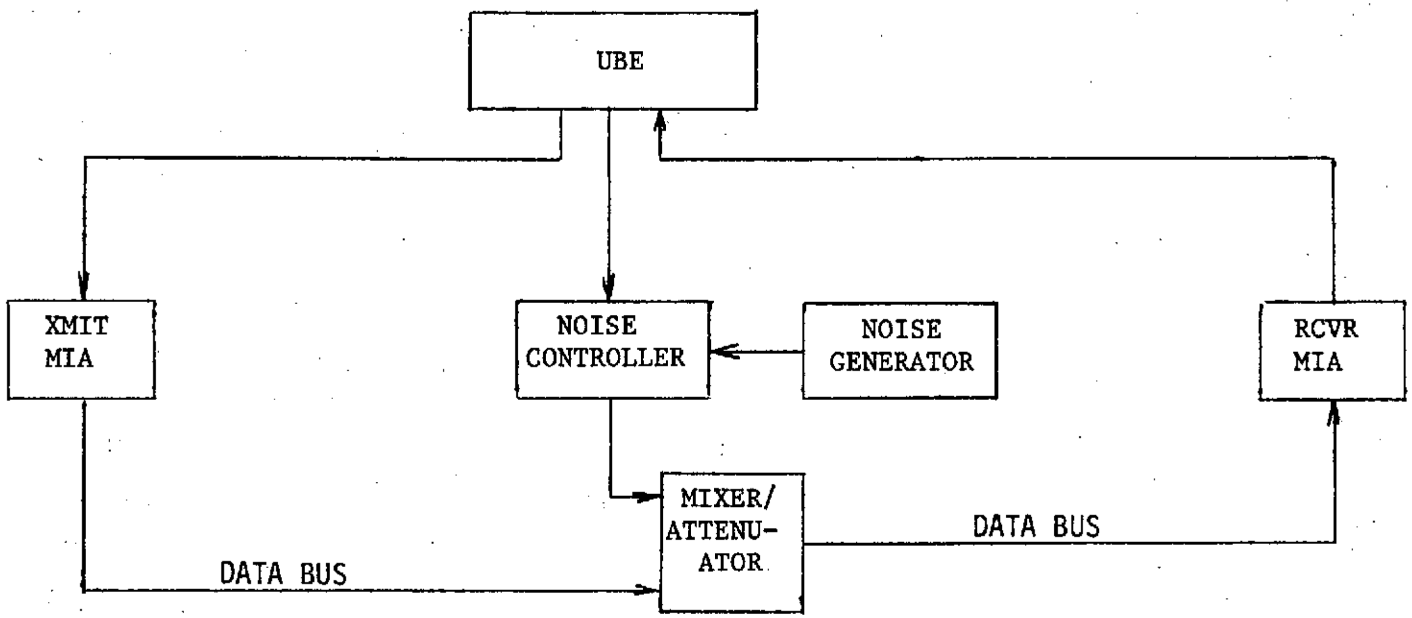

FIGURE 6

HARDWARE CONFIGURATION FOR
DIFFERENTIAL NOISE SUSCEPTABILITY TESTS

(S/N) db	No. of Transmissions	* Unsuccessful Transmissions	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
20	28027561	0	0	$<3.58\times10^{-8}$	
19	28027561	4	0	1.43×10^{-7}	1.43×10^{-7}
18	28027561	40	21	1.43×10^{-6}	6.78×10^{-7}
17	28027561	77	44	2.75×10^{-6}	1.18×10^{-6}
16	28027561	282	139	1.01×10^{-5}	5.10×10^{-6}
15	8913503	500	251	5.61×10^{-5}	2.79×10^{-5}
14	4334615	500	244	1.15×10^{-4}	5.68×10^{-5}

TABLE VI

SUMMARY OF SYNC PATTERN RECOGNITION TEST

*Refer to conclusion of this test for interpretation of this parameter.

2.5.2.4 Conclusions from Sync Pattern Recognition Test

It is very difficult to draw a meaningful conclusion from the data presented in Table VI. This is because the UBE will not record an error if the receiving MIA does not detect a valid sync. The UBE is designed in such a way as to detect bit errors only. All the errors recorded in the above table are from errors in the first one or two data bit positions. This implies that sync was received. Therefore the correct number of unsuccessful transmissions is larger (probably by a factor of at least two) than the number recorded in the data. With this limitation of the data considered, the minimum signal/noise ratio that can be tolerated is probably no more than 18 db. A solution to this limitation is discussed in paragraph 3.0.

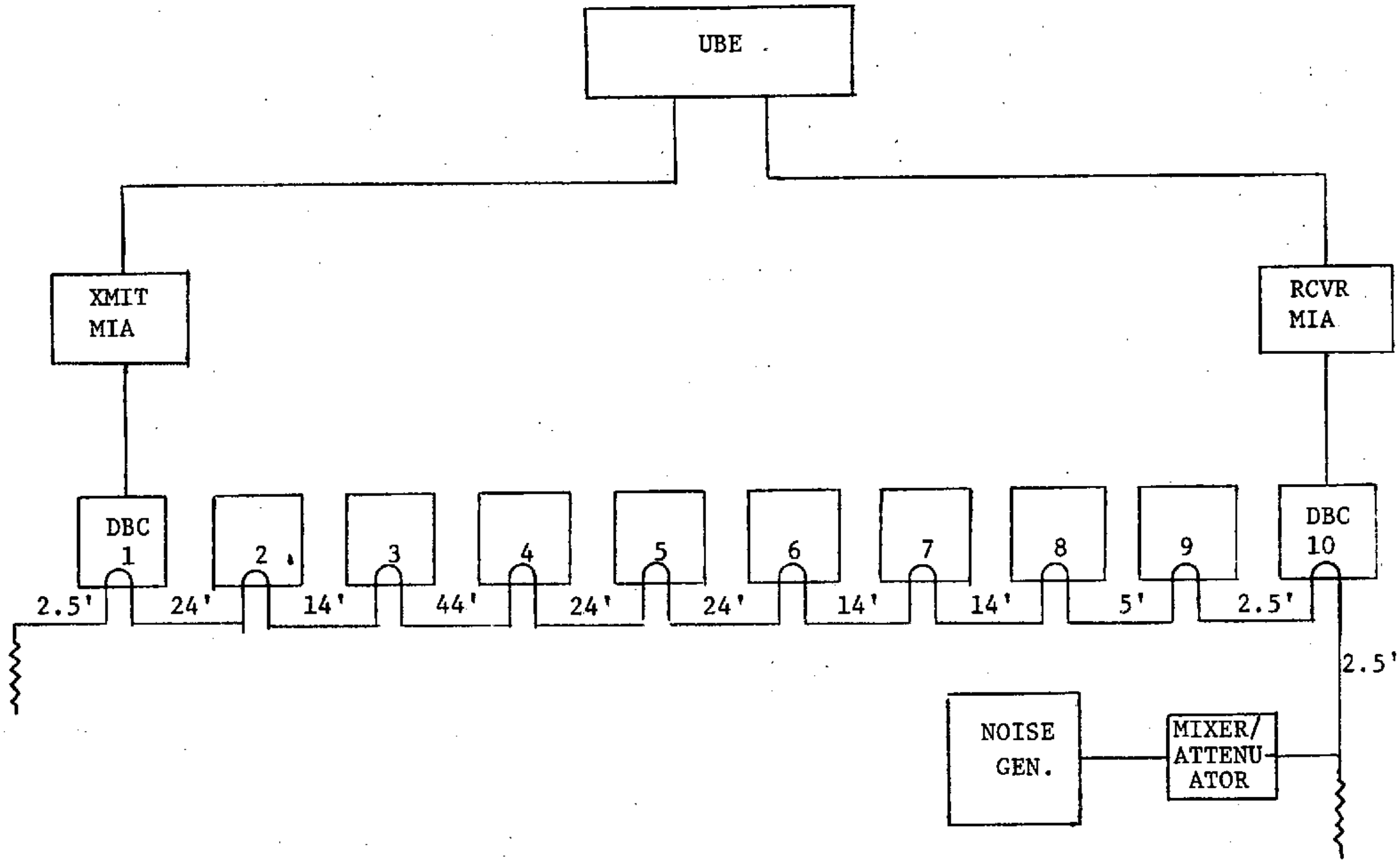

FIGURE 7

HARDWARE CONFIGURATION FOR
EXTENDED DIFFERENTIAL NOISE TESTS

2.5.3 Results of Bit Pattern Recognition Test

The voltages and noise levels for this test were established in the same manner as for the Sync Pattern Recognition Test. The only difference in the test was that the noise was injected at all times except during the sync period. The results of this test are summarized in the following table.

(S/N) db	No. of Transmissions	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
20	26260827	500	229	1.90×10^{-5}	1.03×10^{-5}
19	8450314	500	247	5.92×10^{-5}	3.01×10^{-5}
18	3334133	500	237	1.50×10^{-4}	7.89×10^{-5}
17	1935700	500	260	2.58×10^{-4}	1.24×10^{-4}
16	505120	500	248	9.90×10^{-4}	4.99×10^{-4}
15	204698	500	258	2.44×10^{-3}	1.18×10^{-3}
14	106454	500	261	4.70×10^{-3}	2.24×10^{-3}

TABLE VII

SUMMARY OF BIT PATTERN RECOGNITION TEST

2.5.3.1 Conclusion of Bit Pattern Recognition Test

An examination of the above table reveals that the MIA's under test were extremely sensitive to noise and that any noise level of 20 db or greater will result in an excessive error rate.

2.5.4 Results of Continuous Noise Test

The voltages and noise levels for this test were established in the same manner as in the Sync Pattern Recognition Test and the Bit Pattern Recognition Test. All the test conditions are the same except that the noise was injected continuously. The results of this test are summarized in the following table.

(S/N) db	No. of Transmissions	Total Word Errors	Detected Errors	Prob. of Unsuccessful Transmission	Prob. of Undetected Error
20	9019236	500	220	5.54×10^{-5}	3.10×10^{-5}
19	4088414	500	249	1.22×10^{-4}	6.14×10^{-5}
18	3122582	500	245	1.60×10^{-4}	8.17×10^{-5}
17	1729523	500	273	2.89×10^{-4}	1.31×10^{-4}
16	222983	500	227	2.24×10^{-3}	1.22×10^{-3}

TABLE III
SUMMARY OF CONTINUOUS NOISE TEST

2.5.4.1 Conclusion of Continuous Noise Test

The above data is consistent with the data taken in the two prior tests. Any differential noise level of 20 db or greater will cause excessive error rates.

2.5.5 Extended Differential Noise Test

In this test the hardware was configured as shown in Fig. 7. Its intent was to determine the feasibility of using the DPS MIA's in a realistic environment. The number of sub-station and the length of bus cable were chosen to simulate the conditions under which a MIA might be used.

2.5.5.1 Results of Extended Differential Noise Test

The results of this test are summarized in the following table.

Additional test capabilities will be added to the laboratory as time and manpower permit. These will include the following:

a. Shield room isolation

b. Temperature testing

c. Performance as a function of impulse noise

d. Extension of CW differencial and common mode noise generation capabilities to 20 MHZ.

e. Cable and connector pin crosstalk tests

f. A greater selection of techniques for inserting noise onto the data bus

g. A data bus signal generator test set which will provide adjustable signal parameters for signal amplitude, use and fall times, bit rate and bit-bit jitter, off-set, word-word jitter, and invalid manchester coding.

Data bus hardware presently in-house or on order which will be subjected to evaluation and off-limits performance testing include:

a. Multiplex Interface Units (MIU's) and Data Bus Couplers (DBC) from the B-1 electrical multiplex (E-MUX) system.

b. Teledyne Command Decoder Units being developed under Contracts NAS9-13565 and NAS9-13813.

c. Space Shuttle data bus hardware. This includes breadboard, prototype and flight multiplex interface adapters (MIA's) and data bus couplers (DBC's) being procured from Singer under Contract NAS9-13025.