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ELECTRICAL NOISE PROBLEMS ASSOCIATED WITH CABLE AND GAGE FAILURE DURING EXPLOSIVE TESTING

by

F. P. Hanes, F. P. Leake, G. P. Bonner

Instrumentation Services Division
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Electrical noise and cross talk generated during explosive testing by gage and cable destruction were investigated. Results indicate that the primary instrumentation parameters affecting noise and cross talk levels are cable type, transducer bridge symmetry and its effects on signal conditioner common mode rejection ratio, and the degree of isolation between signal conditioner power circuits.

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PREFACE

The investigation reported herein was conducted by personnel of the Instrumentation Services Division (ISD), U. S. Army Engineer Waterways Experiment Station (WES), during the period February to March 1981.

The program was under the direct supervision of Mr. Francis P. Hanes, Chief, ISD. Mr. F. P. Leake conducted the experimental portion of the study. Messrs. Hanes, Leake, and G. P. Bonner, Chief, Special Services Branch, ISD, prepared the report.

LTC David C. Girardot, Jr., CE, was Acting Commander of WES during the course of this study. Mr. F. R. Brown was Acting Director.

CONTENTS

ELECTRICAL NOISE PROBLEMS ASSOCIATED WITH CABLE AND GAGE FAILURE DURING EXPLOSIVE TESTING

PART I: BACKGROUND

1. Elements of the Waterways Experiment Station (WES) have been involved in explosive testing for more than 25 years. During this time, an increase in interest has evolved in measurements approaching the ground-zero region. The requirement to locate instrumentation close to the explosion results in the destruction of some gages and cables, and the process sometimes produces extremely high noise levels on surviving data channels.

2. While some measurements on explosive tests have been made by other means, many WES measurements have employed a resistive or piezo-resistive strain gage bridge as a transductive element. All measurements referred to in this report are of this type.

3. The recently completed Silo Test Program (STP) produced noise problems on certain channels that were more severe than had been experienced previously by WES instrumentation engineers. During the data reduction phase of STPII, it became apparent that remedial action was indicated if future tests like the STPII event were to produce noise-free data. At this time, WES engineers began evaluating earlier field data with respect to the noise problem. Data from the events listed below were reexamined in this study.

- a. 1964-1974 (various experiments): Cross talk was noted between carrier and DC excited data channels. This cross talk was reduced to accepcable levels by separation of DC and carrier cables and signal conditioners.

- b. 1974 (ESSEX): Cross talk was noted between another experimenter's equipment and WES Bytrex HFG* pressure gages.

- c. 1976 (DICE THROW): Cross talk was noted on Bytrex HFG gages due to cable/gage destruction.

- d. 1976 (Post DICE THROW): Tests prove that 20-pair TSP cable is superior to telephone type 50-pair cable with respect to noise generated by gage/cable destruction. Excitation short to shield proved to be worst case fault.

* HFG gages were either used to afford compatibility with another experimenter's data or recorded for another agency.

e. 1980 (MIGHTY MACH): A short developed on a Kytrex HFG gage producing noise and cross talk similar to that associated with ESSEX data. This short was between excitation and shield.

f. 1980 (STFII Demonstration Shot): Cross talk was noted between surviving and destroyed channels.

g. 1980 (STFII Cal Shots): Cross talk was noted due to short between excitation and shield; some gages were affected more than others.

h. 1980 (STFII Main Event): More noise and cross talk due to destroyed gages was recorded on certain acceleration channels than on any prior WES test.

4. As a result of this reexamination, certain parameters were selected as probable contributors to the noise problem. These were (a) gage resistance and symmetry and their effects on signal conditioner common mode rejection ratio (CMRR*), (b) cable type, (c) gage excitation source, and (d) signal conditioner power source. As the experiment progressed, some attention was given to excitation voltage level, cable length, "common/ground" location, amplifier type, fault type, and cable termination.

5. Subsequent STI events are planned with more severe environments than those fielded previously and, without improvement, data quality from these events could be compromised by noise.

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*Common mode rejection ratio is defined as the ratio of differential gain to common mode gain:

$$CMRR = \frac{A}{A_{cm}}$$

Or in decibels: $CMR\ (db) = 20 \log CMRR$

For more details see "Operational Amplifiers Design and Applications", Tobey, Graeme, Huelsman; McGraw-Hill.

PART II: APPROACH

6. Postmortems on various events have shown evidence that much of the noise/cross talk recorded was due to cable or gage destruction that resulted in shorted cable elements. The shorting process probably was not a simple one and is not easily simulated. With this in mind, WES engineers set about shorting different pairs of data channel elements and noting the effects. It was found that a fault generated by shorting an excitation lead to cable shield (where the shield is electrically connected to excitation common or earth) produced 2:1 higher noise amplitudes than faults generated by shorting any other pairs. Unless otherwise noted, fault simulation was, therefore, limited to excitation/shield shorts for data taken during this investigation. It is recognized that there is conceivably a fault source that produces more noise than the excitation/shield short, but it would probably not be a singular event. One of the acknowledged deficiencies of this investigation was the inability to reproduce noise levels approaching those of STFII. There is reason to believe that these noise levels were the result of multiple, additive faults.

7. The Bytrex HFG pressure gage has been associated with noise/cross talk on several WES events. This gage is more asymmetrical with respect to signal - excitation bridge resistance than any other gage used by WES; thus, the hypothesis that gage asymmetry influences noise susceptibility by affecting the CMRR of the signal conditioner. The Bytrex gages owned by WES read about 400Ω between one signal lead and either excitation lead, and about 1500Ω between the other signal lead and either excitation lead. The typical WES Bytrex gage was simulated in this investigation with one percent resistors as shown in Figure 1.

8. The cable length used was 1500 ft. This length is the same as the cable runs for STFII and is typical of most recent WES field experiments.

9. The cable types investigated were (a) 50 twisted pair (telephone type), (b) 20 twisted, shielded pair furnished by the Defense Nuclear Agency (DNA), and (c) 4-conductor braid shielded similar to Belden Model 7869.

Two runs of 4-conductor cable were wound on a common reel to simulate a cable bundle as in a field cable trench. The majority of cable used by WES, except coaxial, for the past 20 years has been generally restricted to these three types.

10. The signal conditioners used for this investigation were built by WES, with one exception. This was the Ectron Model 776B on loan to WES from DNA Field Command. The Ectron has been used successfully on several events at the Nevada Test Site (NTS) and is considered state of the art by some members of the DNA community due to its high CMRR and fast recovery from input overload.

PART III: PROCEDURE

11. Most of the tests were conducted on the WES Model 103A signal conditioner. The 103A schematic is shown in Figure 2. Faults were simulated by connection of a signal generator (square wave) across fault pairs. The data channel that experienced the fault was called the transmitter. The data channel used to measure the effects of the fault was called the receiver. Both transmitter and receiver were connected to the 1500-ft cable lengths. The receiver input was fed by a 4-arm Wheatstone bridge consisting of one percent resistors. The signal conditioners were wired for either common or separate power and excitation or constant current excitation with common power. These three configurations ars shown in Figures 3-5.

12. The inputs of the Ectron 776B signal conditioners were substituted for and connected the same as the WES 103A. Specifications and details of the 776B may be obtained from the Ectron Corporation.*

13. The input to the transmitter was monitored by a Tektronix Model 214 oscilloscope (battery powered). The output of the receiver was monitored by a Tektronix Model 551 oscilloscope.

*Personal Communication, Earl Cunningham, Ectron Corporation, 8159 Engineer Road, San Diego, California (Telephone 714/278-0600).

PART IV: RESULTS

14. The results of this investigation are presented in Figure 6. The noise levels are referenced to the receiver input. In order to emphasize the significance of the noise figures, the reader is reminded that a single active arm strain gage bridge, excited at 10 Vdc, produces approximately 0.5 mV given a 100-microstrain input.* Background noise levels were 0.1-0.5 mV P-P. This noise was either white or multiples of 60Hz.

15. The CMR (db) for the WES 103A signal conditioner was reevaluated during this investigation for comparison with the Ectron 776b. At x 1000 gain, the 103A CMR (db) was 62.5 db from 100 Hz to 100 kHz. With input resistors trimmed for maximum CMR (db), 100 Hz to 10 kHz, the 103A achieved 80 db. The Ectron specifications claim a CMR (db) of 125 db at x 1000 gain from dc to 50 kHz and 105 db from 50 kHz to 500 kHz.

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* C. C. Perry and H. R. Lissner. 1962. "The Strain Gage Primer." 2nd Edition, McGraw-Hill.

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PART V: DISCUSSION AND CONCLUSIONS

16. At first glance, the reader may deduce from the data in Figure 6 that by symmetrizing a gage one may achieve virtually noise-free data (compare data line 3 with lines 4 and 5). True, this produces great improvement in CMRR compared to nonsymmetrical gages, but WES was already operating in the 2-5 mV noise range going into STP. Again, the 400Ω/1000Ω gage configuration is indicative of WES experience with the Bytrex HFG gage and is presented here as a worst case condition. The highest noise levels recorded on STP were produced by structural acceleration channels using Endevco Model 2264-C accelerometers. A random sample taken from WES stock during this investigation showed variations in 2264-C bridge lead resistances from 0.6 percent to 22 percent where the Bytrex sample showed variations on the order of 275 percent.

17. A comparison of data lines 3 with 13, 4 with 17, and 5 with 18 indicates that no advantage is gained by choosing 4-conductor shielded cable over 20 TSP. This conclusion should be reserved until a comparison is made between data lines 8 and 19, 9 and 16, and 11 and 21. Together these comparisons indicate that the advantage of one individual cable per channel is realized only when power and excitation sources are separated.

18. The Ectron 776B signal conditioner is an example of extreme circuit isolation. After the results of tests with the Ectron on 20 TSP and 4-conductor cables were evaluated, further efforts toward noise reduction with WES signal conditioners were concentrated on isolation of the power and excitation sources, assuming that individual 4-conductor cable is used. Further pursuit of higher CMRR for the WES 103A was foregone on the premise that the advantages held by the Ectron over the WES were probably attributable to circuit isolation rather than CMRR. Apparently the Ectron CMRR was not the complete solution to the noise problem associated with transducer and cable effects.

19. Some tests were run that produced data not shown on Figure 6. The conclusions drawn from these data included:

a. There is a nonlinear relationship between cable length and noise level received (x 15 length increase causes approximately x 2 noise level increase).

b. For excitation-shield faults, the noise frequency is inversely proportional to cable length (x 3 length increase = x 3 frequency decrease).

c. Excitation-shield fault produces higher frequency noise on a given cable length than excitation-excitation fault (for 1500-ft TSP cable: exc/sh fault - 50 kHz; exc/exc fault - 15 kHz).

d. Signal to noise ratio is reduced by termination resistance on receiver cable but is unaffected by termination resistance on transmitter cable.

20. The results of this investigation are presented as indicators of certain paths that are available to the experimenter in his efforts to reduce noise in measurement systems.

PART VI: RECOMMENDATIONS

21. Further noise testing at WES will include: (a) the comparison of constant current, separate and common excitation signal conditioners run on individual 4-conductor cables under controlled failure conditions in the field, (b) the development and testing of close-in signal conditioning, probably located at the junction box, (c) increasing the frequency response of the WES 103A signal conditioners, and (d) methods of protection from the effects of atmospheric and other noise sources external to the system. Until the results of these tests are in, it is recommended that:

a. Data channels with a high probability of destruction be excited with as low voltage/current level as practical and grouped and isolated from probable surviving channels with respect to cable bundles, junction boxes, signal conditioning racks, and recorders.

b. The survivor channels be excited at the highest possible voltage level so that gains may be minimized. All transducers should be selected so that their upper input limits are approached but not exceeded. Their bridge symmetry should be the best available.

c. Recording van, junction box, and transducer grounding schemes be evaluated in place and adjusted to produce the most noise-free configuration available.

d. At least one representative of each type transducer be isolated from all mechanical inputs, calibrated and recorded during the test. This will provide a means for the identification and subtraction of coincident noise from the data.

e. Total experimenter participation in full power-full frequency (FPFF) dry runs be imperative. No event should be fired until all data recorded on FPFF are acceptable.

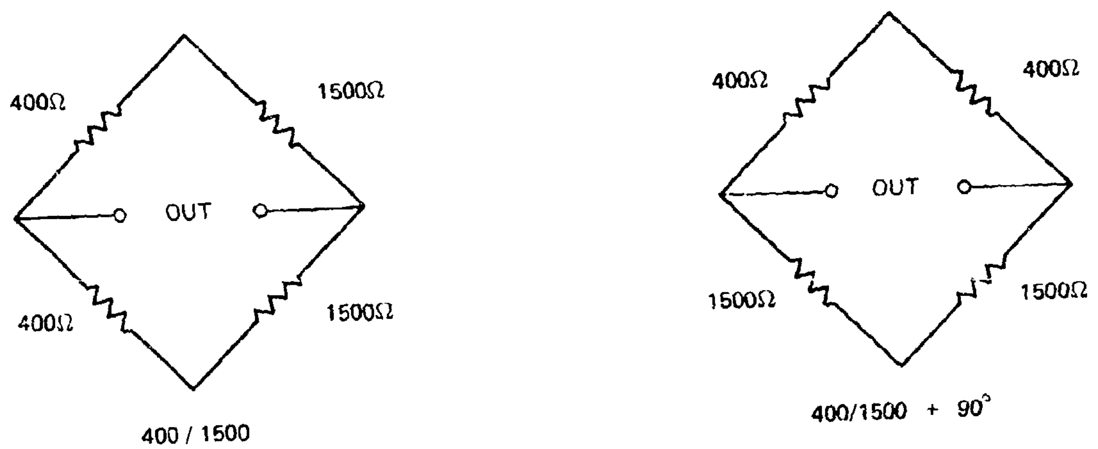


Figure 1. Bytrex HFG simulation

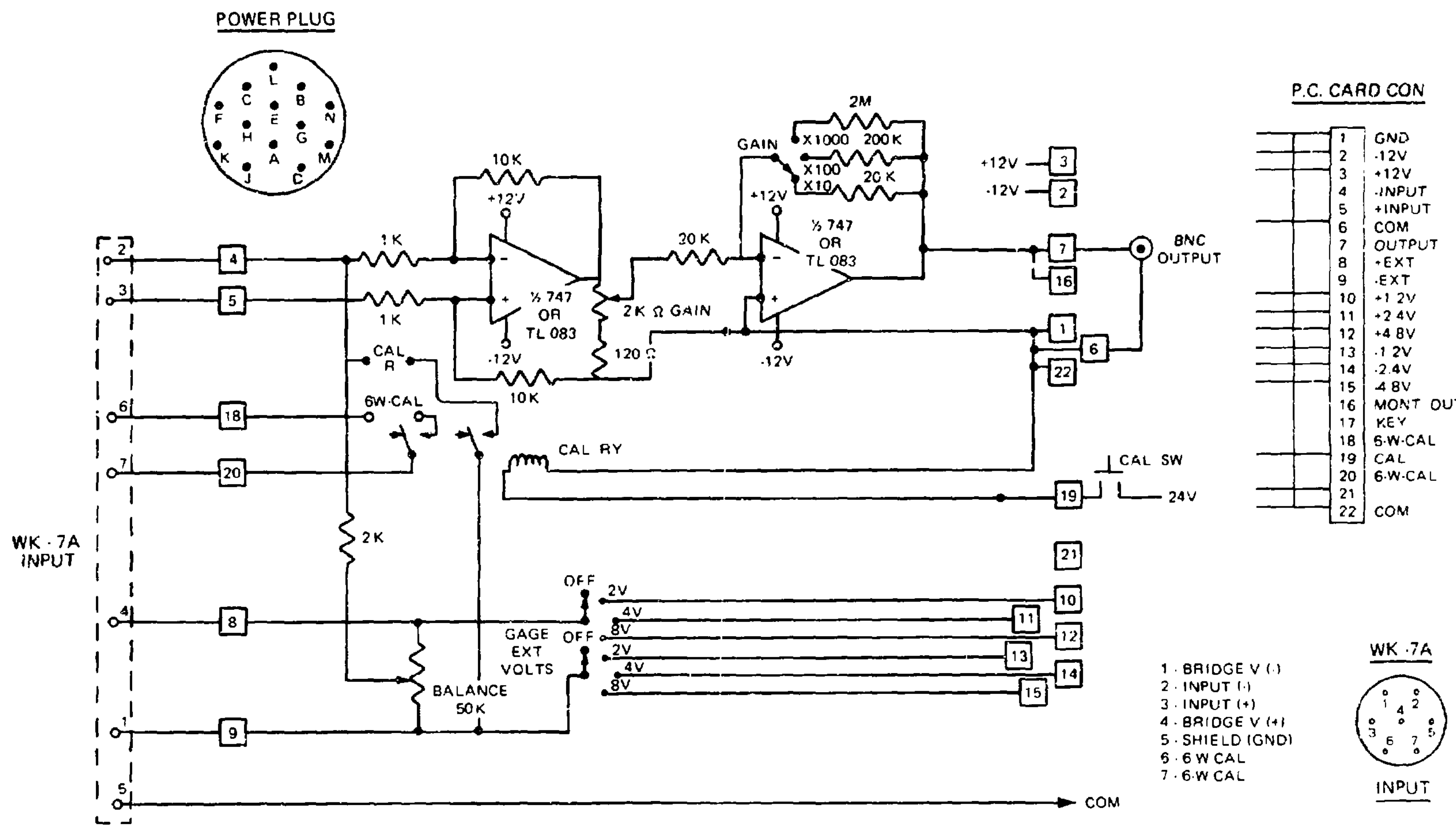


Figure 2. 103A amplifying and signal conditioning module

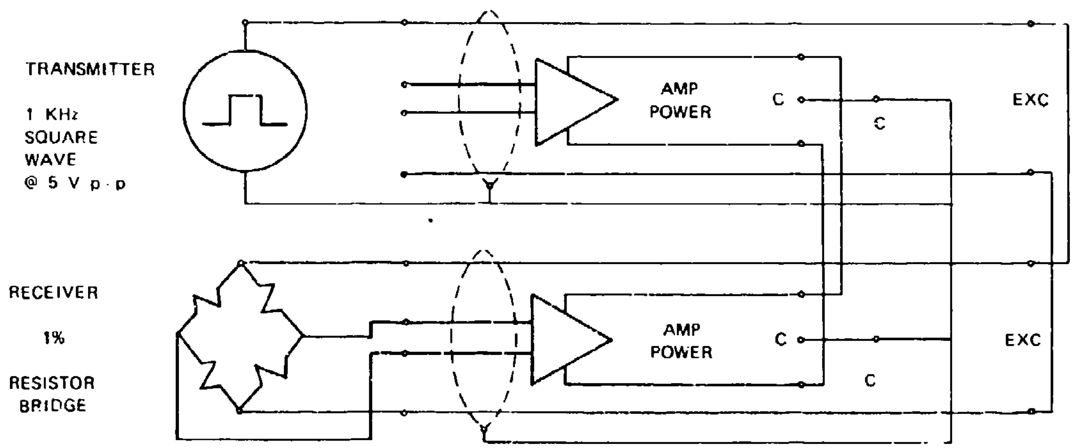


Figure 3. Test layout for common power and excitation

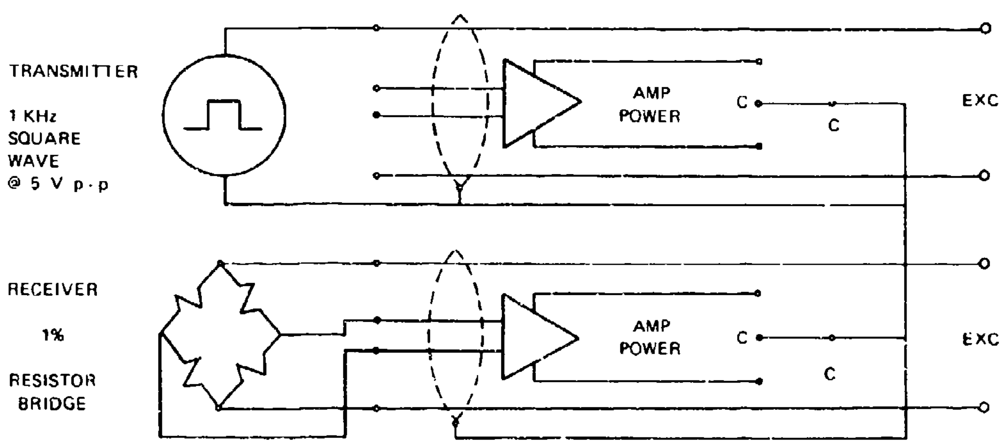
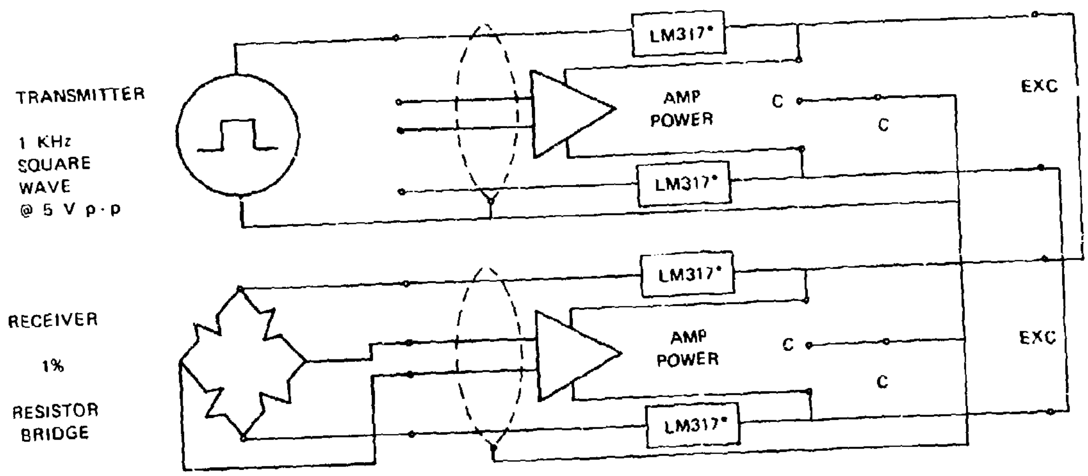


Figure 4. Test layout for separate power and excitation



*LM317 - 3-TERMINAL ADJUSTABLE REGULATOR - NATIONAL SEMICONDUCTOR

Figure 5. Test layout for common power and constant current excitation

	Bridge Configuration	Cable	Power	Excitation	Fault	Noise (MV P-P)
1	400/1500	50 pair	Common	Common	Exc-Shld	300
2	350/350	50 pair	Common	Common	Exc-Shld	30
3	400/1500	20 TSP	Common	Common	Exc-Shld	50
4	350/350	20 TSP	Common	Common	Exc-Shld	2
5	400/1500 + 90°	20 TSP	Common	Common	Exc-Shld	2
6	400/200	20 TSP	Common	Common	Exc-Shld	1.6
7	1500/1500	20 TSP	Common	Common	Exc-Shld	1.3
8	400/1500	20 TSP	Ectron 776B		Exc-Shld	50
9	400/1500	20 TSP	Separate	Separate	Exc-Shld	40
10	350/350	20 TSP	Separate	Separate	Exc-Shld	3
11	400/1500	20 TSP	Common	Constant Current	Exc-Shld	4.5
12	350/350	20 TSP	Common	Constant Current	Exc-Shld	1
13	400/1500	Belden 4 Cond.	Common	Common	Exc-Shld	50
14	400/1500	Belden 4 Cond.	Separate	Common	Exc-Shld	12.5
15	400/1500	Belden 4 Cond.	Common	Separate	Exc-Shld	5
16	400/1500	Belden 4 Cond.	Separate	Separate	Exc-Shld	3
17	350/350	Belden 4 Cond.	Common	Common	Exc-Shld	2
18	400/1500 + 90°	Belden 4 Cond.	Common	Common	Exc-Shld	2
19	400/1500	Belden 4 Cond.	Ectron 776B		Exc-Shld	1.5
20	400/1500	Belden 4 Cond.	Separate	Separate	No Common Ground	1
21	400/1500	Belden 4 Cond.	Common	Constant Current	Exc-Shld	0.5
22	400/1500	20 TSP	Common	Common	Exc-Sig	12.5
23	400/1500	20 TSP	Common	Common	Exc-Exc	5

Figure 6. Noise test results

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