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TESTS OF CROSS COUPLING BETWEEN DIAGNOSTIC TRANSDUCER CIRCUITS.

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CROSS COUPLING TESTS BETWEEN TRANSDUCER CIRCUITS

1.0 Scope

The diagnostic instruments to be used in the NRX tests were tested under the actual conditions to be found during test in the NRX reactors. In addition to qualifying each transducer to survive under the environmental conditions found in NRX, the transducer should be tested under conditions which include identical cables and cable length, preamplifier, signal conditioning equipment, amplifiers, grounding techniques, and proximity to other transducer circuits. By duplicating the data system, grounding techniques and proximity to other transducers, it will be possible to locate and solve problems which would otherwise not be brought to the surface until the instruments were tied into the data system at the test site.

The first area to be investigated, is the possiblity of cross coupling between transducer circuits due to these circuits being located in close proximity. The LVDT's (linear velocity displacement transducers) and variable reluctance pressure transducer was a 5 volt rms, 3 kilocycle per second carrier signal. It is felt that if cross coupling is to be a problem, it will exist with this high level, high frequency signal.

2.0 Tests Conducted

In order to determine the amount of cross coupling between transducer circuits, a series of tests were conducted. In these tests, a LVDT circuit and another transducer circuit were located in close proximity and the signal carrying leads were run parallel for a distance of ten feet. The LVDT circuit was energized with a 15 volt peak-to-peak, 3 kc signal and the voltage induced in the transducer circuit measured. The transducer circuits tested with the LVDT circuit were:

Strain Gages
Thermocouples
Accelerometers
Pressure Transducers, Strain Gage Type

The cross coupling tests between LVDT circuits and strain gage circuits were conducted first and were the most complete tests. In the strain gage tests the following parameters were varied: type of cables, cable separation, LVDT carrier frequency and LVDT carrier voltage. The results of these tests apply to most of the transducer circuits; therefore, the remaining transducer tests were conducted using the cables and LVDT carrier frequency and voltage conditions to be found in the NRX-A-1 tests.

2.1 Strain Gage Tests

The block diagram of the strain gage cross coupling tests is shown in Figure 1 and a picture of the physical set-up is shown in Figure 2.

The first tests conducted were to determine the effect of LVDT carrier frequency and cable type. The type cables tested were No. 22 Alpha Wire, plastic insulation; No. 16 Raychem type SSF3K, three wire shielded; and 0.062" O.D. magnesium oxide insulation, three wire, stainless steel sheath. These three cables were tested in five configurations:

1. LVDT circuit with No. 22 Alpha wire, plastic insulated and strain gage circuit with No. 22 Alpha wire, plastic insulation.
2. LVDT circuit with No. 22 Alpha wire, plastic insulation and strain gage circuit with No. 16 Raychem type SSF3K, three wire shielded.
3. LVDT circuit with No. 16 Raychem type SSF3K, three wire shielded and strain gage circuit with No. 16 Raychem type SSF3K, three wire shielded.
4. LVDT circuit with No. 16 Raychem type SSF3K, three wire shielded and strain gage circuit with 0.062" O.D. magnesium oxide insulation, three wire, stainless steel sheathed.
5. LVDT circuit with 0.062" O.D. magnesium oxide insulation, three wire, stainless steel sheathed and strain gage circuit with 0.062" O.D. magnesium oxide, three wire, stainless steel sheathed.

The input to the LVDT circuit was a 15 volt peak-to-peak signal whose frequency was varied from 1 to 10 kc. In the cases where shielded or sheathed cables were used, the shield or sheath was not grounded. The test circuit was placed on a wooden board to prevent unwanted ground paths through the supporting structure.

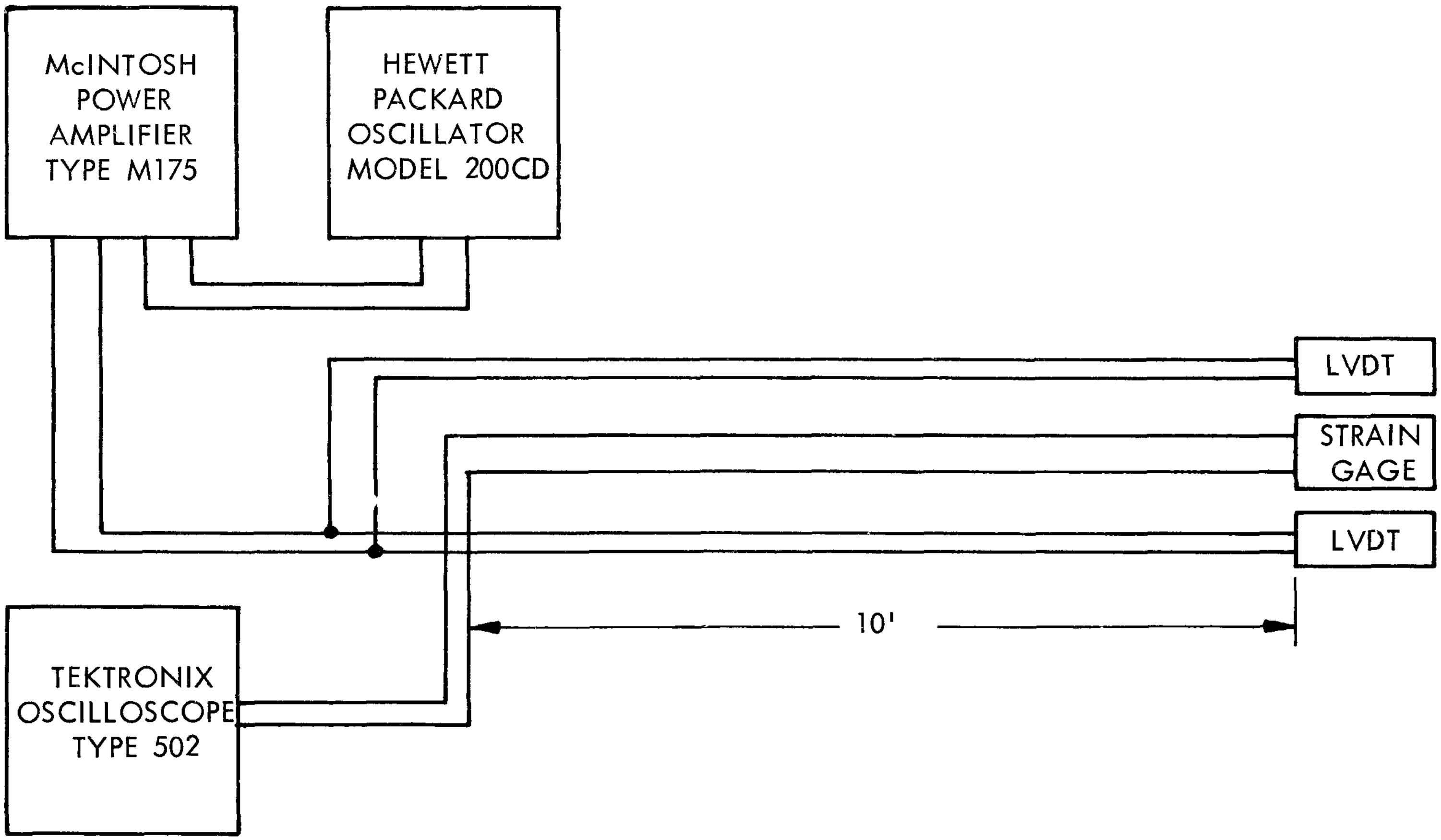

FIGURE 1 BLOCK DIAGRAM OF STRAIN GAGE TESTS

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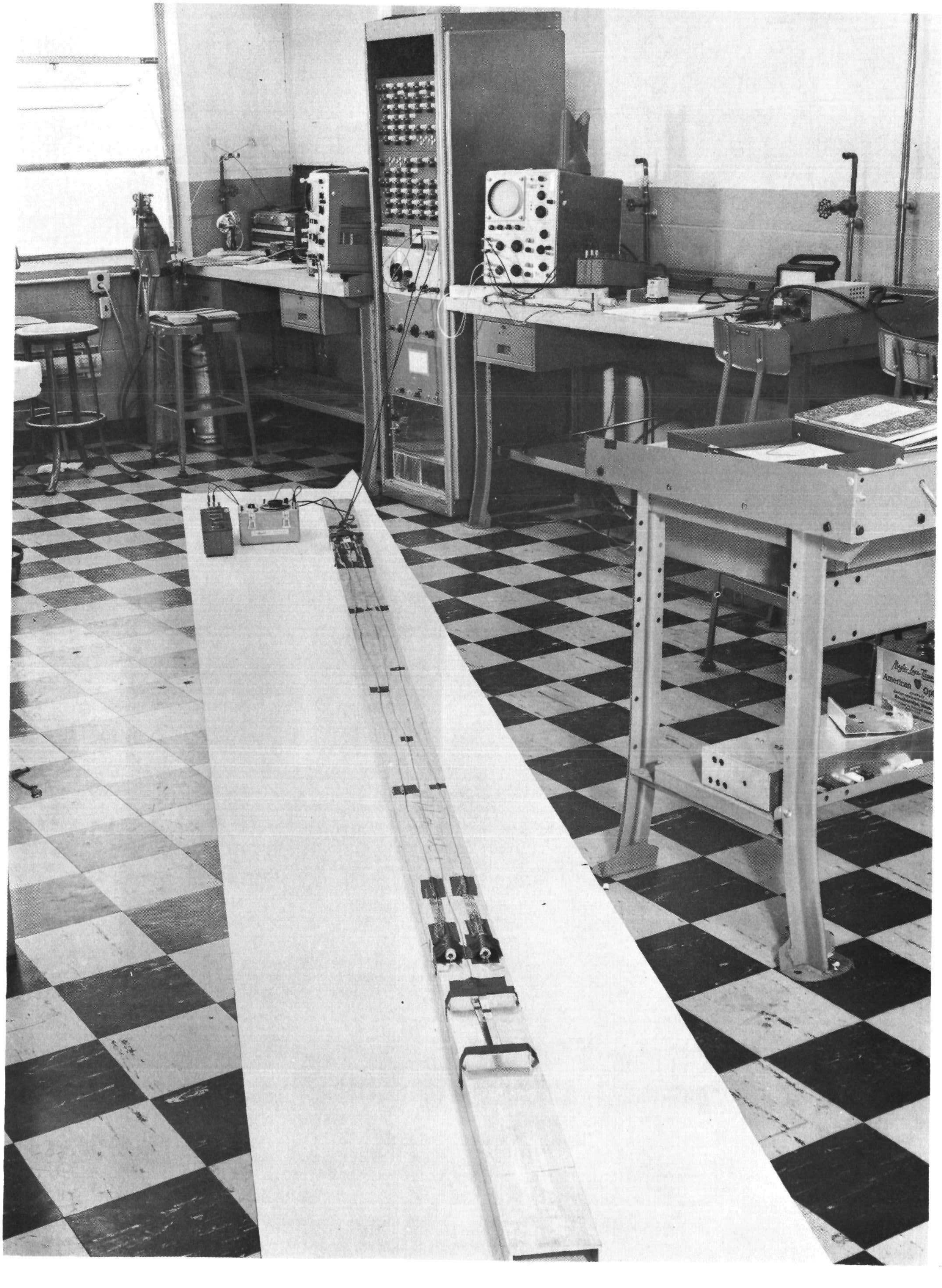

Figure 2 Test Set-Up

The results of this test are shown in Table 1 and Figure 3. The results show that the sheathed cable provides the best protection against cross-coupling. The amount of cross coupling varies linearly with LVDT carrier frequency. The voltage induced in the strain circuits at 3 kc and using sheathed cables in 0.20 millivolts.

During these tests, trouble was encountered due to pickup of 60 cps radiation present in the test area. This room radiation pickup was cured by grounding and shielding the circuit as shown in Figure 4. By maintaining a common ground between coax cables, sheath cables and all test equipment, no pickup was observed with the oscilloscope in its most sensitivity position, 100 microvolts per centimeter.

A test was conducted to determine the effect of LVDT carrier frequency relative to voltage and cable separation. The block diagram of the test setup was the same as that used for the preceding test and the circuit was grounded and shielded as shown in Figure 4. Two LVDT circuits were used with the strain gage circuit located midway between the cables of the LVDT circuit. The cable separation is the distance from the strain gage cable to one of the LVDT cables. The results of this test are shown in Table 2. The voltage induced in the strain gage circuit increased with increasing frequency and voltage and decreased separation between cables.

The above test was repeated with all junction points shielded with aluminum foil and the foil grounded. This was done to try to prevent the small cross coupling present in the preceding test. The results of this test is shown in Table 3. A comparison of Tables 2 and 3 shows very little improvement in the cross coupling by shielding the cable junction points. The induced voltage with the LVDT carrier at 3 kc and 15 volts peak-topeak was always less than 15 microvolts peak to peak.

The same test was repeated a third time with the LVDT and strain gage circuits mounted on an aluminum beam. The aluminum beam was grounded

TABLE I: VOLTAGE INDUCED IN STAIN GAGE CIRCUIT AS A FUNCTION OF FREQUENCY AND CABLE TYPE

FREQ. (KC)	INDUCED VOLTAGE (MILLIVOLTS P-P)				
	1	2	3	4	5
1	0.44	0.40	0.28	0.24	0.10
2	1.00	0.80	0.56	0.54	0.15
3	1.50	1.20	0.80	0.90	0.20
5	2.40	2.00	1.40	1.24	0.25
10	4.70	3.80	2.80	2.60	0.60

TEST CABLES

1. LVDT - No. 22 Alpha wire, plastic insulated strain gage - No. 22 Alpha wire, plastic insulated
2. LVDT - No. 22 Alpha wire, plastic insulated strain gage - Raychem No. 16 type SSF3K, shielded
3. LVDT - Raychem No. 16 type SSF3K, shielded strain gage - Raychem No. 16 type SSF3K, shielded
4. LVDT - Raychem No. 16 type SSF3K, shielded strain gage - 0.062 inches sheathed cable
5. LVDT - 0.062 inches sheathed cable strain gage - 0.062 inches sheathed cable

1 LVDT - PLASTIC INSULATION
STRAIN GAGE - PLASTIC INSULATION

2 LVDT - PLASTIC INSULATION
STRAIN GAGE - SHIELDED

3 LVDT - SHIELDED
STRAIN GAGE - SHIELDED

4 LVDT - SHIELDED
STRAIN GAGE - SHEATHED

5 LVDT - SHEATHED
STRAIN GAGE - SHEATHED

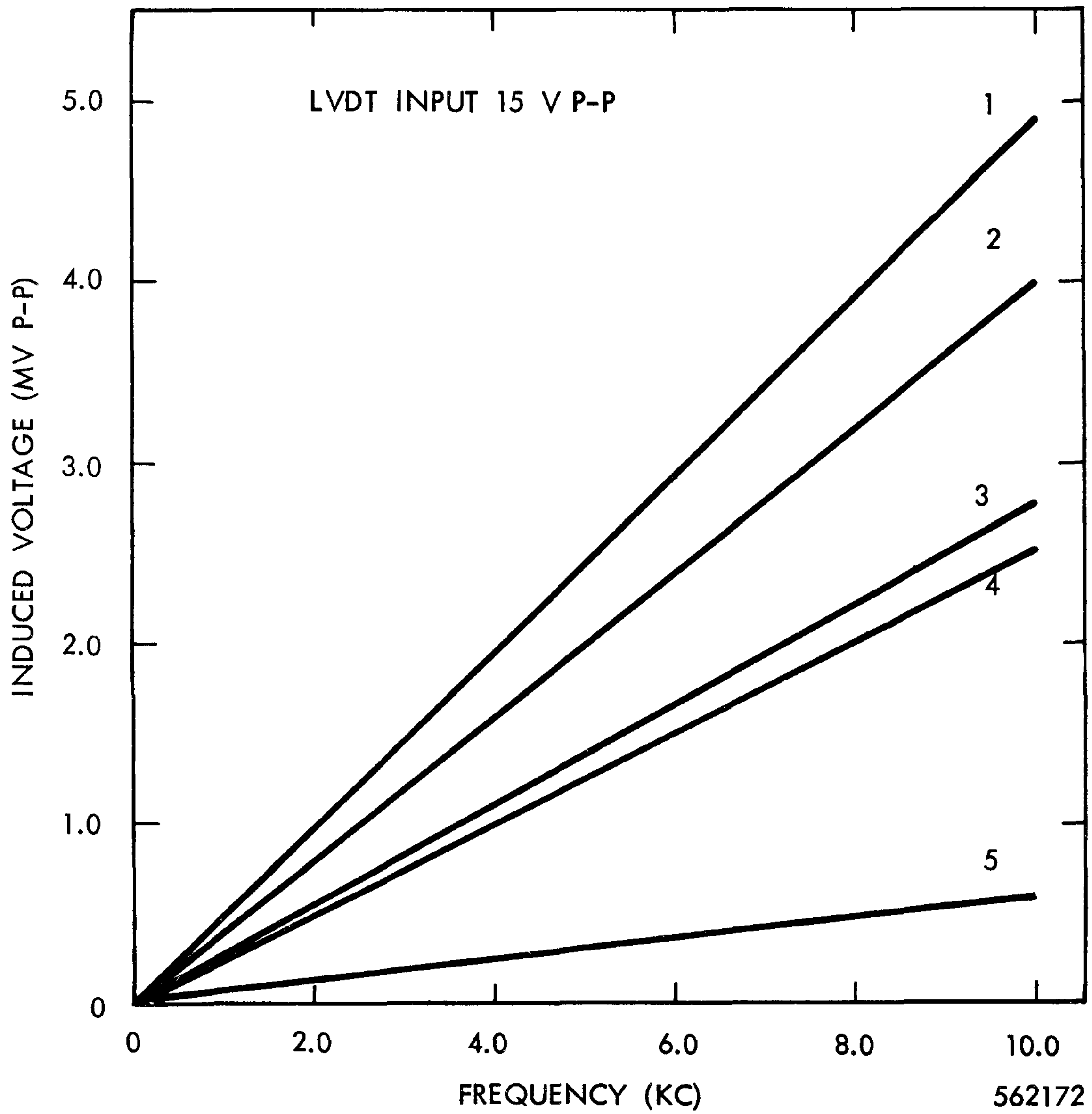

FIGURE 3 VOLTAGE INDUCED STRAIN GAGE CIRCUIT AS A FUNCTION OF FREQUENCY AND CABLE TYPE

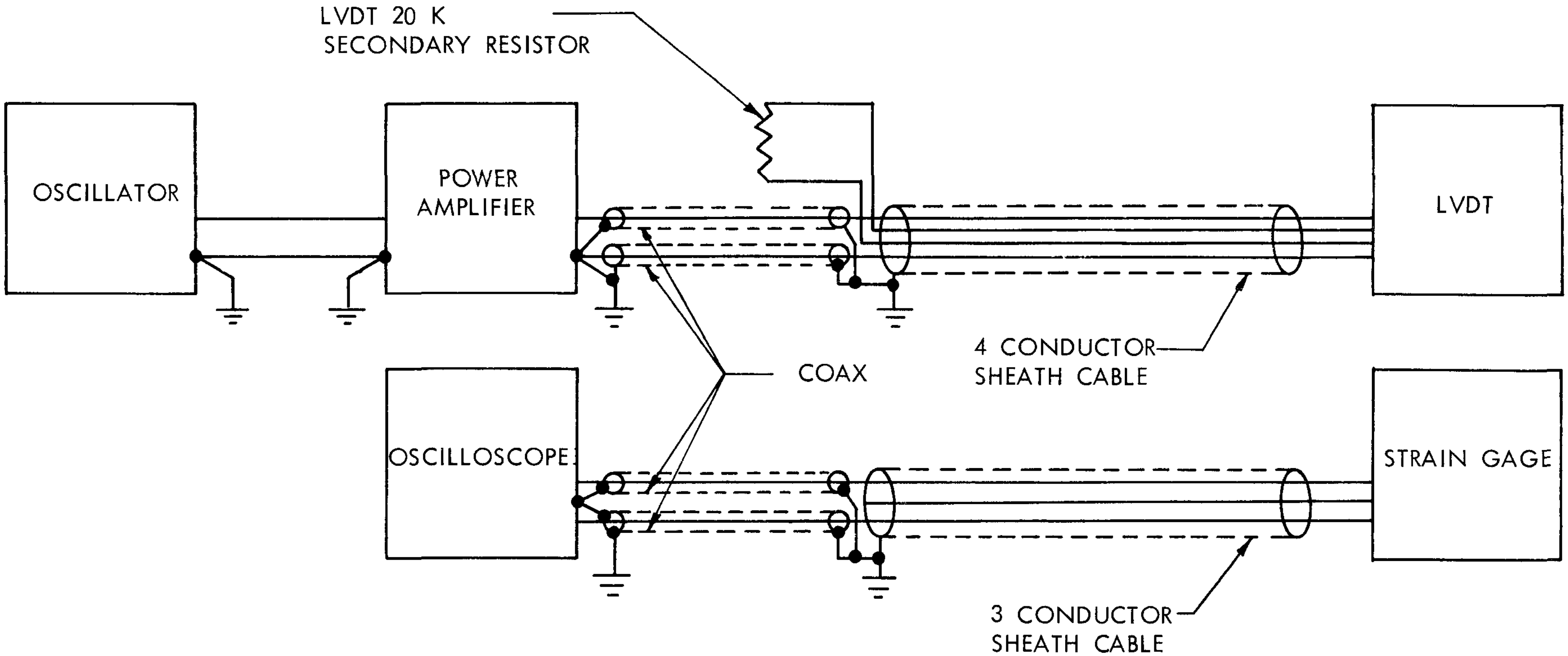

FIGURE 4 BLOCK DIAGRAM OF STRAIN GAGE TESTS SHOWING GROUNDING AND SHIELDING TO PREVENT PICK-UP OF ROOM RADIATION

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TABLE 2: VOLTAGE INDUCED IN STRAIN GAGE CIRCUIT AS A FUNCTION OF LVDT CARRIER FREQUENCY AND VOLTAGE & CABLE SEPARATION

LVDT CARRIER		INDUCTED VOLTAGE (MILLIVOLTS P-P)			
FREQUENCY KC	VOLTAGE VOLTS P-P	SEPARATION 3 INCHES	SEPARATION 2 INCHES	SEPARATION 1 INCH	SEPARATION 0 INCH
0.5	5	0.01	0.01	0.01	0.01
0.5	15	0.01	0.01	0.01	0.01
0.5	50	0.01	0.01	0.01	0.01
3	5	0.01	0.01	0.01	0.01
3	15	0.01	0.01	0.015	0.01
3	50	0.01	0.01	0.020	0.03
10	5	0.01	0.01	0.01	0.01
10	15	0.01	0.01	0.01	0.01
10	50	0.01	0.02	0.02	0.02
30	5	0.01	0.01	0.01	0.01
30	15	0.01	0.01	0.01	0.03
30	50	0.03	0.02	0.03	0.06
60	5	0.01	0.01	0.01	0.01
60	15	0.015	0.015	0.02	0.06
60	50	0.04	0.04	0.035	0.15
100	5	0.01	0.01	0.01	0.01
100	15	0.01	0.20	0.01	0.10
100	50	0.017	0.40	0.02	0.30

TABLE 3: VOLTAGE INDUCED IN STRAIN GAGE CIRCUIT AFTER SHIELDING ALL JUNCTION POINTS

LVDT CARRIER		INDUCER VOLTAGE (MILLIVOLTS P-P)			
Frequency (KC)	Voltage (Volts P-P)	Separation 3 inches	Separation 2 inches	Separation 1 inch	Separation 0 inches
0.5	5	0.01	0.01	0.01	0.01
0.5	15	0.01	0.01	0.01	0.01
0.5	50	0.01	0.01	0.01	0.01
3	5	0.01	0.01	0.01	0.01
3	15	0.01	0.01	0.01	0.01
3	50	0.01	0.01	0.01	0.01
10	5	0.01	0.01	0.01	0.01
10	15	0.01	0.01	0.01	0.01
10	50	0.01	0.01	0.01	0.01
30	5	0.01	0.01	0.01	0.01
30	15	0.01	0.01	0.01	0.02
30	50	0.05	0.05	0.05	0.06
60	5	0.01	0.01	0.01	0.02
60	15	0.04	0.04	0.04	0.06
60	50	0.09	0.08	0.10	0.15
100	5	0.04	0.02	0.02	0.04
100	15	0.07	0.08	0.06	0.10
100	50	0.35	0.40	0.38	0.40

to the circuit. Results of this test are shown in Table 4. The test results show no variation between the circuits mounted on a conducting aluminum beam or a non-conducting wooden board.

The oscilloscope used to measure the magnitude of the induced voltage was replaced by a Baldwin-Lime-Hamilton Strain Indicator, and a preset strain was set on the strain gage. With this setup, the effects of any cross coupling on the actual strain reading could be obtained. A block diagram of the test setup is shown in Figure 5 which illustrates the ground and cable shielding used. The test was conducted under three conditions:

1. Sheath cables used in LVDT and strain gage circuits. Strain gage cable shields at equipment ground, LVDT cable shield not grounded.
2. Sheath cables used in LVDT and strain gage circuits. Strain gage and LVDT cable shields at equipment ground.
3. Sheath cables replaced by plastic insulated cables. Shields of connecting coax cables at equipment ground.

Table 5 shows the results of the tests under condition 1. The maximum strain error was found to be 45 microinches per inch when the LVDT carrier frequency was 3 kc and voltage was 25 volts p-p.

The LVDT cable shields were then grounded and the test rerun, test condition 2. The results of this test is shown in Table 6. With the strain gage circuit, LVDT circuit and all cable shields at a common ground, no cross coupling effects could be found. The Baldwin-Lima-Hamilton Strain Indicator was replaced with a Budd Strain Indicator, Model HW1 and again no effect of cross coupling could be found.

The sheath cables were replaced by plastic insulated cables and the cross coupling test repeated. The results are shown in Table 7. The largest strain error of 46 microinches/inch at a LVDT carrier frequency of 10 kc and voltage of 25 volts peak-to-peak.

TABLE 4: VOLTAGE INDUCED IN STRAIN GAGE CIRCUIT WITH LVDT AND STRAIN GAGE CIRCUITS MOUNTED ON ALUMINUM BEAM

LVDT CARRIER		INDUCED VOLTAGE (MILLIVOLTS P-P)		
Frequency KC	Voltage (Volts P-P)	Separation 2 inches	Separation 1 inch	Separation 0 inch
0.5	5	0.01	0.01	0.01
0.5	15	0.01	0.01	0.01
0.5	50	0.01	0.01	0.01
3	5	0.01	0.01	0.01
3	15	0.01	0.01	0.01
3	50	0.01	0.01	0.01
10	5	0.01	0.01	0.01
10	15	0.01	0.01	0.01
10	50	0.01	0.01	0.03
30	5	0.01	0.01	0.01
30	15	0.01	0.02	0.03
30	50	0.04	0.05	0.05
60	5	0.01	0.02	0.03
60	15	0.03	0.05	0.06
60	50	0.08	0.10	0.10
100	5	0.03	0.03	0.04
100	15	0.05	0.06	0.08
100	50	0.32	0.36	0.38

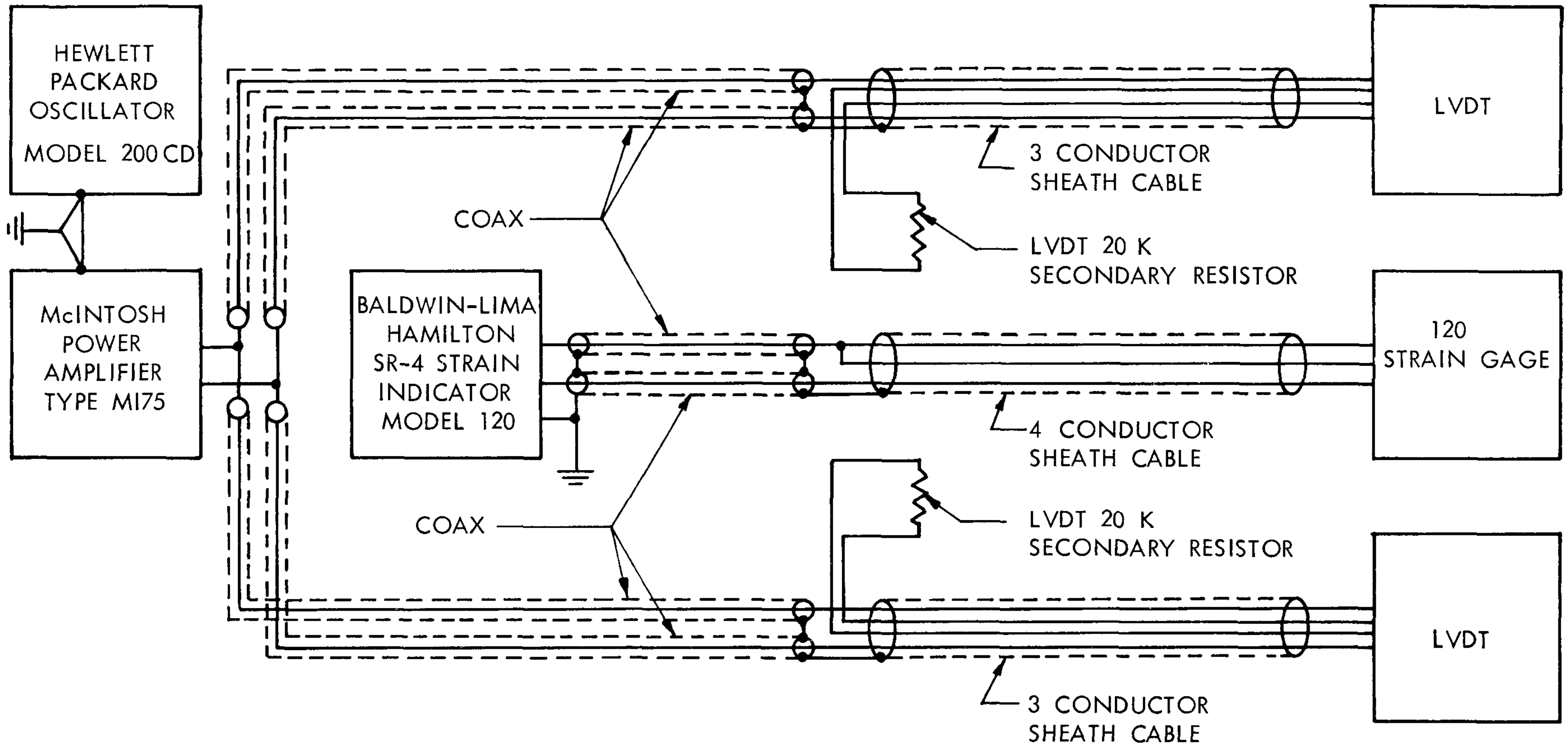

FIGURE 5 BLOCK DIAGRAM OF TEST SETUP FOR EFFECT OF CROSS COUPLING ON STRAIN READING

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TABLE 5: STRAIN ERROR DUE TO CROSS COUPLING; SHEATH CABLES; LVDT CABLE SHIELD NOT GROUNDED; STRAIN GAGE SHIELD GROUNDED

LVDT CARRIER		INITIAL STRAIN LVDT CKT OFF Micro-inch/inch	STRAIN LVDT CKT ON Micro-inch/inch	Δ STRAIN Micro-inch/inch
FREQUENCY (KC)	VOLTAGE (Volt P-P)			
0.5	5	30572	30576	4
0.5	15	30572	30585	13
0.5	25	30572	30586	14
3.	5	30566	30588	22
3.	10	30566	30606	40
3.	15	30566	30608	42
3.	20	30566	30609	43
3.	25	30566	30611	45
10.	5	30587	30610	23
10.	15	30587	30630	43
10.	25	30587	30631	44
30.	5	30584	30609	25
30.	15	30584	30590	6
30.	25	30584	30623	39
60.	5	30586	30587	1
60.	15	30586	30598	12
60.	25	30586	30509	23
100.	5	30588	30588	0
100.	15	30588	30588	0
100.	25	30588	30588	0

TABLE 6: STRAIN ERROR DUE TO CROSS COUPLING; SHEATH CABLE; CABLE SHIELDS AT EQUIPMENT GROUND

LVDT CARRIER		INITIAL STRAIN	STRAIN	Δ STRAIN
FREQUENCY (KC)	VOLTAGE (Volts P-P)	LVDT CKT OFF Micro-inch/inch	LVDT CKT ON Micro-inch/inch	Micro-inch/inch
0.5	5	30628	30628	0
0.5	15	30628	30628	0
0.5	25	30628	30628	0
3	5	30630	30630	0
3	10	30630	30630	0
3	15	30630	30630	0
3	20	30630	30630	0
3	25	30630	30630	0
10	5	30630	30630	0
10	15	30630	30630	0
10	25	30630	30630	0
30	5	30628	30628	0
30	15	30628	30628	0
30	25	30628	30628	0
60	5	30626	30626	0
60	15	30626	30626	0
60	25	30626	30626	0
100	5	30628	30628	0
100	15	30628	30628	0
100	25	30628	30628	0

TABLE 7: STRAIN ERROR DUE TO CROSS COUPLING PLASTIC INSULATED CABLES

LVDT CARRIER		Initial Strain	Strain	Δ Strain
Frequency (KC)	Voltage Volts P-P)	Lvdt CKT off Microinch/ in.	Lvdt CKT on Microinch/ in.	Microinch/ in.
0.5	5	5008	5008	0
0.5	15	5008	5006	2
0.5	25	5008	5005	3
3	5	5008	5008	0
3	15	5008	5005	3
3	25	5008	5008	5
10	5	5008	5005	3
10	15	5008	4970	38
10	25	5008	4962	46
30	5	5005	5005	0
30	15	5005	5004	1
30	25	5005	4980	25
60	5	5005	5005	0
60	15	5005	5005	0
60	25	5005	5005	0
100	5	5005	5005	0
100	15	5005	5005	0
100	25	5005	5005	0

In all cases in the above tests, the LVDT circuit was disconnected and the oscillator turned off. The oscillator was then turned on to insure the strain indicator was not effected by the oscillator and power amplifiers themselves. No effect on strain indication due to the oscillator or amplifier, themselves, could be found.

The tests on cross coupling between LVDT circuits and strain gage circuits indicate that no cross coupling problems will occur if proper grounding methods are used. The cable sheaths and all equipment must be connected to a common ground.

2.2 Thermocouple Tests

Thermocouples were tested to determine if any cross coupling would be present due to LVDT circuits. The block diagram of the thermocouple test setup is shown in Figure 6. The sheath cables of the LVDT circuits and the sheath thermocouple were run parallel for 10 feet, cable separation 0.5 inches. The thermocouple was terminated in a 300 k resistor since this is the approximate input impedance of the amplifier in the signal conditioning equipment.

A chromel/alumel, full sheathed, grounded junction thermocouple was placed in the test setup with the sheath connected to equipment ground. The LVDT circuits were energized with a carrier frequency of 3 kc and a carrier voltage of 15 volts peak-to-peak, the values to be used in the NRX tests. No induced voltage could be detected. The thermocouple sheath was then removed from equipment ground and the test repeated. Again, no pickup could be detected in the thermocouple circuit.

A copper/constantan, sheathed, exposed junction thermocouple (junction no grounded to sheath) was then placed in the test circuit. The sheath was connected to equipment ground. The LVDT circuits were energized and the pickup measured. No induced voltage could be detected in the thermocouple circuit. The sheath was then removed from equipment ground and the test repeated. Again no induced voltage could be detected

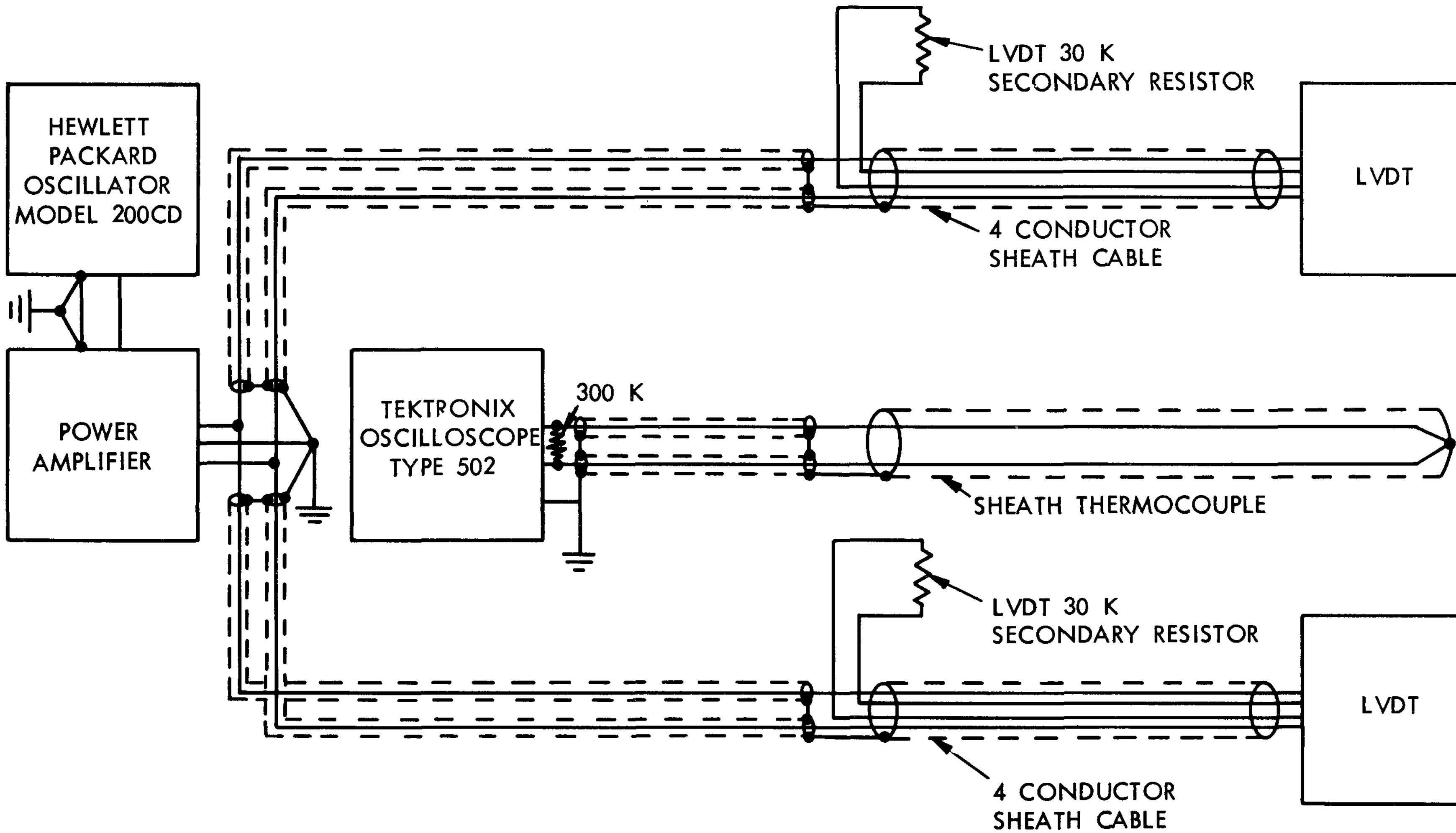

FIGURE 6 BLOCK DIAGRAM OF THERMOCOUPLE TEST SETUP

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in the thermocouple circuit due to cross coupling from the LVDT circuits.

Further tests were conducted on thermocouples to determine if temperature differences between thermocouple sheath ground points could cause a change in thermocouple output. Any change of output would be due to a thermo-electric effect between the dissimilar metals of the sheath, ground and thermocouple wires.

The test setup is shown in Figure 7. A copper ground wire was connected to the thermocouple sheath at both end points and midpoint. The midpoint ground connection was heated and the temperature of the sheath-ground connection was monitored with an auxiliary thermocouple. The test was conducted with the ground wire connected and the thermocouple output read without heat and with heat applied. The ground connection was then disconnected and the test repeated.

The test was conducted using a fully sheathed chromel/alumel thermocouple. The test results are shown in Table 8. The test results show that the difference in thermocouple output when heat is applied is the same when the ground wire is connected or disconnected. This indicates the change in thermocouple output is due to the thermocouple wire not being perfectly homogeneous and not due to thermoelectric effects between the dissimilar metals of the sheath and ground wire.

The test were repeated using a fully sheathed copper/constantan thermocouple. The test results are shown in Table 9. The test shows no difference in thermocouple output when heat is applied to the sheath.

2.3 Accelerometer

Accelerometers were next tested to determine if there would be any cross coupling between accelerometer circuits and LVDT circuits. The block diagram of the test setup is shown in Figure 8. The accelerometer used was a Gulton Glennite Model AA20404. The voltage amplifier uses a triaxial input cable and drives the inner shield by positive feedback of the input signal to reduce the effective capacitance of the cable.

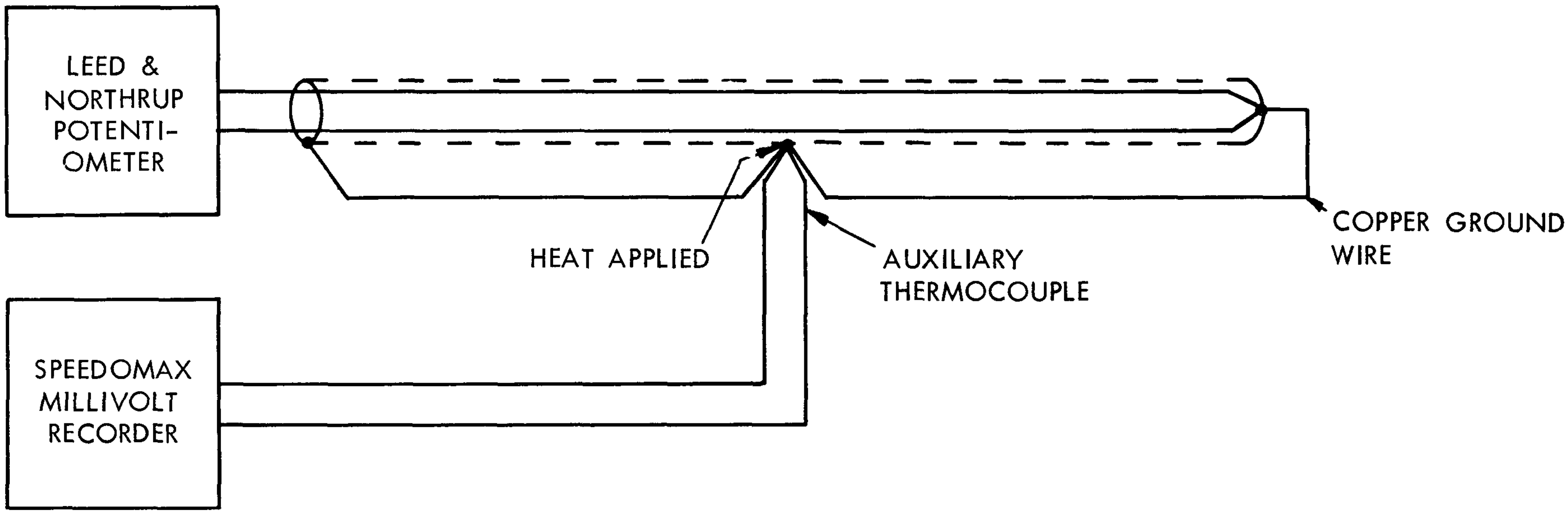

Figure 7 TEST SETUP TO DETERMINE EFFECT OF TEMPERATURE DIFFERENCE BETWEEN SHEATH GROUND POINTS

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TABLE 8

EFFECT OF TEMPERATURE DIFFERENCE BETWEEN SHEATH GROUND POINTS CHROMEL/ALUMEL THERMOCOUPLE

TEST NO.	T/C OUTPUT NO HEAT (MILLIVOLTS)	T/C OUTPUT HEAT (MILLIVOLTS)	Δ T/C OUTPUT (MILLIVOLTS)	SHEATH TEMPERATURE °F
GROUND WIRE CONNECTED				
1	1.10	1.13	0.03	1120
2	1.06	1.14	0.08	1600
3	1.06	1.12	0.06	1600
4	1.06	1.12	0.06	1600
5	1.06	1.13	0.06	1600
GROUND WIRE NOT CONNECTED				
6	1.08	1.13	0.05	1600
7	1.08	1.14	0.06	1600
8	1.08	1.14	0.06	1600
9	1.08	1.14	0.06	1600
10	1.08	1.14	0.06	1600

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TABLE 9

EFFECT OF TEMPERATURE DIFFERENCE BETWEEN SHEATH GROUND POINTS COPPER/CONSTANTAN THERMOCOUPLE

TEST NO.	T/C OUTPUT NO HEAT (MILLIVOLTS)	T/C OUTPUT HEAT (MILLIVOLTS)	Δ T/C OUTPUT (MILLIVOLTS)	SHEATH TEMPERATURE °F
GROUND WIRE CONNECTED				
11	1.04	1.04	0.00	1100
12	1.04	1.04	0.00	1100
13	1.04	1.04	0.00	1100
14	1.04	1.04	0.00	1100
15	1.04	1.04	0.00	1100
GROUND WIRE NOT CONNECTED				
16	1.04	1.04	0.00	1100
17	1.04	1.04	0.00	1100
18	1.04	1.04	0.00	1100
19	1.04	1.04	0.00	1100
20	1.04	1.04	0.00	1100

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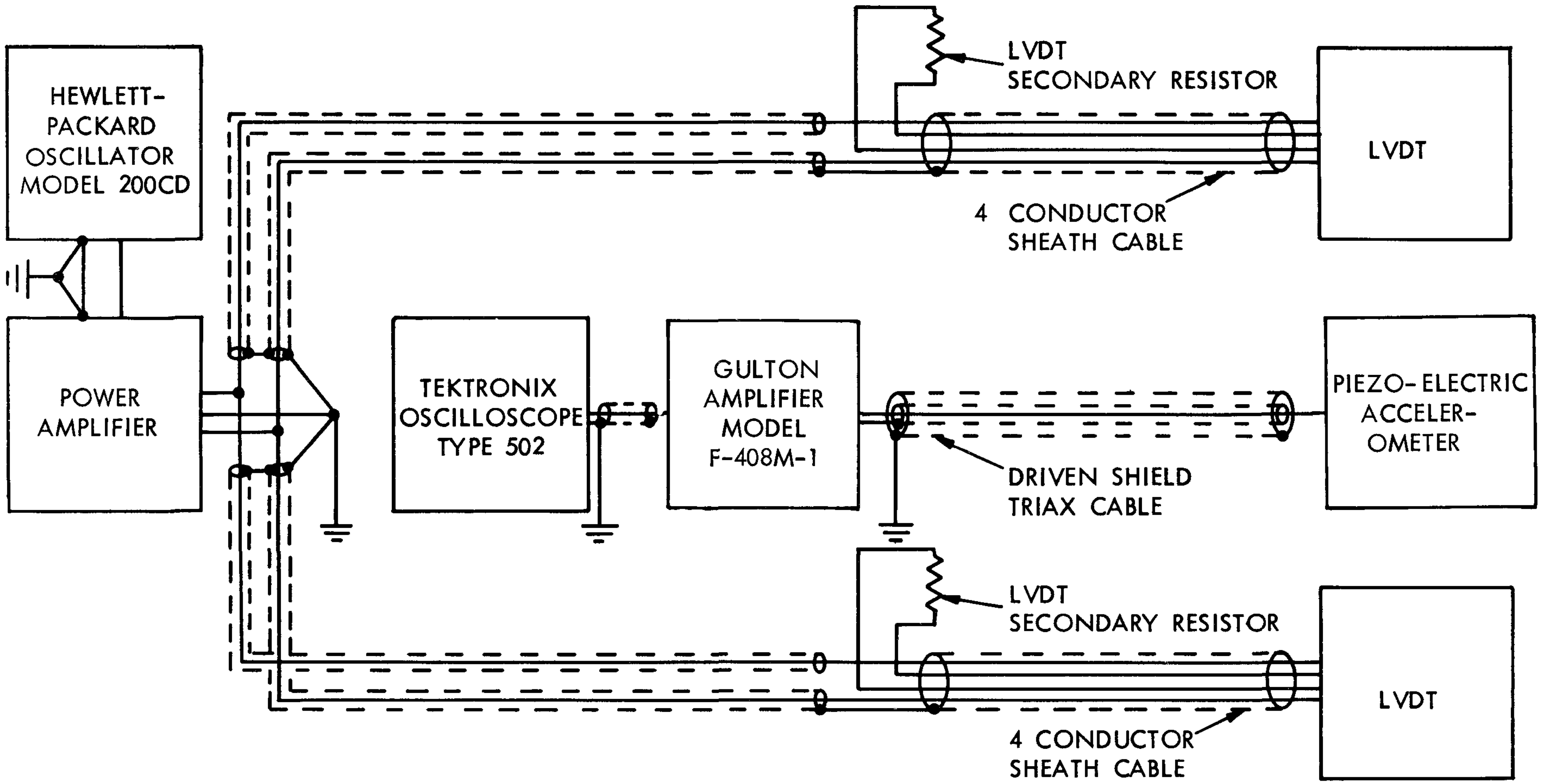

Figure 8 BLOCK DIAGRAM OF ACCELEROMETER TEST SETUP

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The LVDT circuits were then energized with a 3 kc carrier frequency and 15 volt peak-to-peak carrier voltage. No induced voltage could be detected in the accelerometer circuit.

2.4 Pressure Transducers

The final transducer tested for cross coupling with LVDT circuits was a pressure transducer, strain gage type. The block diagram of the test setup is shown in Figure 9. The pressure transducer used was a Statham 596.

The LVDT circuits were energized with a carrier frequency of 3 kc and voltage of 15 volts peak-topeak. Examination of the pressure transducer output showed a large 60 cps signal with a small 3 kc signal superimposed upon it. The 60 cps signal was due to pickup of radiation present in the test area. It was impossible to measure the amplitude of the 3 kc signal present from cross coupling from the LVDT circuit. The pressure transducer circuit grounds were reworked and the negative side of the pressure transducer input voltage was grounded. The output was examined again and no induced voltage could be detected.

3.0 Conclusion

Tests have been conducted to determine if any cross coupling will occur between LVDT circuits and other transducer circuits. The results of these tests conducted with strain gage, thermocouples, accelerometers, and pressure transducers indicate that no cross coupling can be expected if proper grounds are maintained. All cable sheaths and shields and signal conditioning equipment should be maintained at common ground potential.

4.0 Plans for Future Work

Attempts are being made to obtain signal conditions and amplifiers which are identical to those used at the test site. If this equipment cannot be obtained, duplicates will be built in the laboratory. Once the signal conditioning equipment

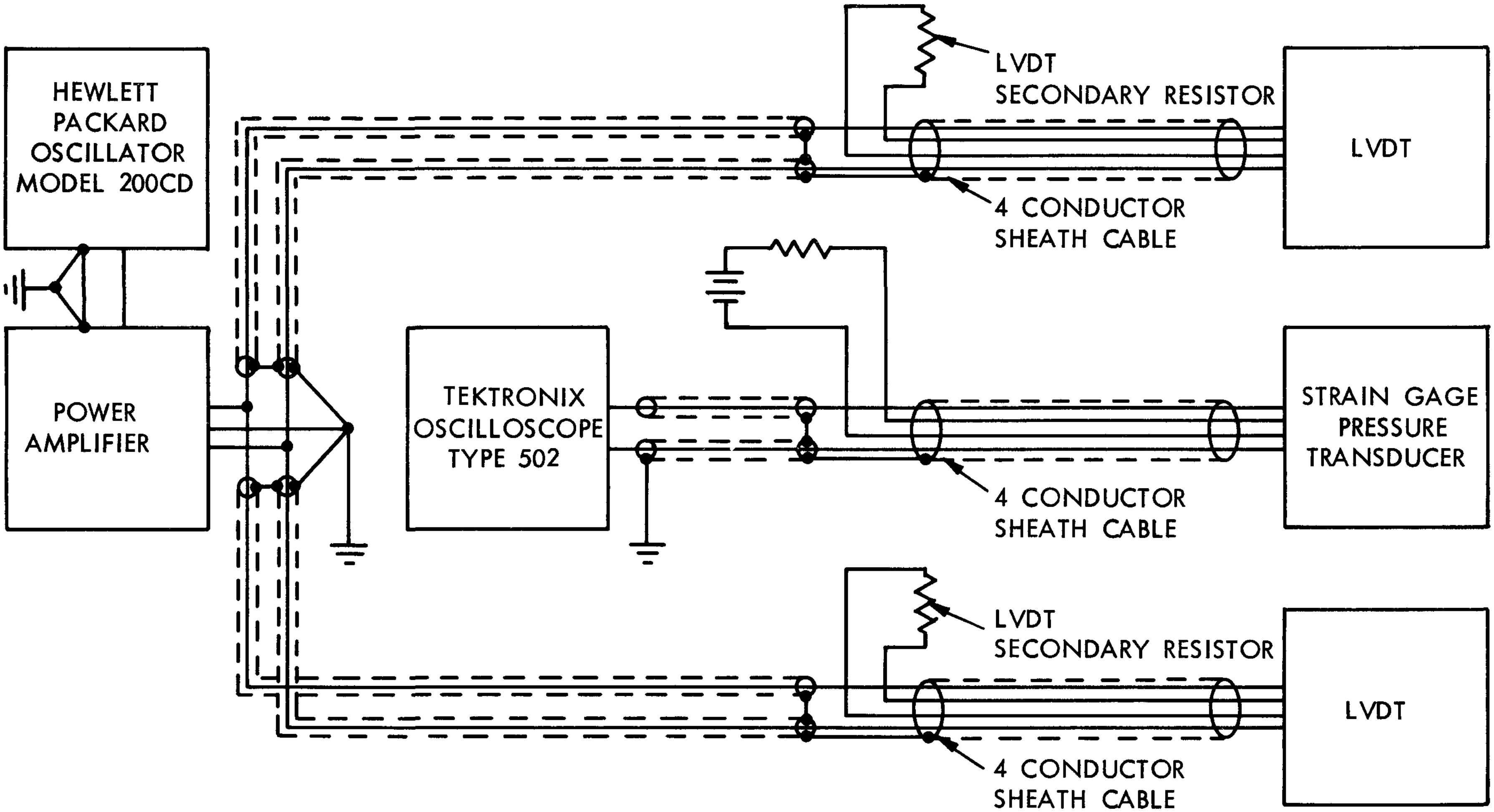

FIGURE 9 BLOCK DIAGRAM OF PRESSURE TRANSDUCER TEST SET-UP

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is obtained, tests will be conducted on all transducers with the appropriate cables and signal conditioners. These tests will determine any change in transducer calibration due to cables and signal conditioners.

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