Introduction:

The circuit shown in Figure 2 of the EGR222 Lab 2 exercise is sufficient for use in the lab but it is not satisfactory for use in an industrial environment where there can be large temperature variations. LVDT's (Linear Variable Differential Transformers) have one primary winding, P, and two secondary windings, S, as shown in Figure 1 of the Lab 2 exercise. These windings each have many turns of fine copper wire. This means each winding has significant resistance as well as inductance. From Ampère's Law the magnetic flux in the LVDT is generated by the magnitude of the current in the primary winding. The voltage developed in the secondary winding depends on the rate of change of the magnetic flux. If you apply a DC voltage to the primary winding of a transformer (including LVDT's) you will create a magnetic flux but it will not be varying and there will be no voltage developed in the secondary windings. That's why you cannot use transformers to pass DC voltages.

The Problems:

There are two problems with the simple circuit shown in Figure 2 of the EGR222 Lab 2 exercise when it is used in an industrial environment.

- When the LVDT primary winding is driven by a voltage source the primary current is determined by the impedance of the primary winding which consists of the wire resistance and inductance. But the wire resistance changes value as the temperature changes and this resistance variation changes the primary current and therefore the secondary winding voltage.
- When there is a significant load resistance connected to the secondary winding the secondary winding wire resistance (which also changes with temperature) will cause the secondary voltage, as seen by the load resistance, to change with temperature.

The Ideal Solutions:

The solution to the first problem is to drive the LVDT primary winding with a constant AC current that does not vary with temperature. This means the magnetic flux will also not vary with temperature. The solution to the second problem is to have a very large impedance connected to the secondary windings. Therefore any secondary winding resistance change will not affect the secondary winding output voltage.

The Engineering Solutions:

The solutions to the temperature problem are resolved by the use of operational amplifiers (op amps) as shown in Figure A. A constant AC LVDT primary winding current is provided by means of a general purpose op amp, U1, and resistor, RSET. The resistor, RSET, can be obtained with a very low temperature coefficient (i.e. the resistance value does not vary with temperature). From op amp theory the voltage **<u>between</u>** the inverting and noninverting op amp inputs is zero and these inputs are a very high impedance (i.e. they do not either source or sink current). Pin 3 of U1 (U1-3) is grounded therefore U1-2 is also at zero volts (but not grounded). This is called a "virtual" ground. The current in RSET is therefore

$$I_{RSET} = \frac{V_{IN}}{RSET}$$

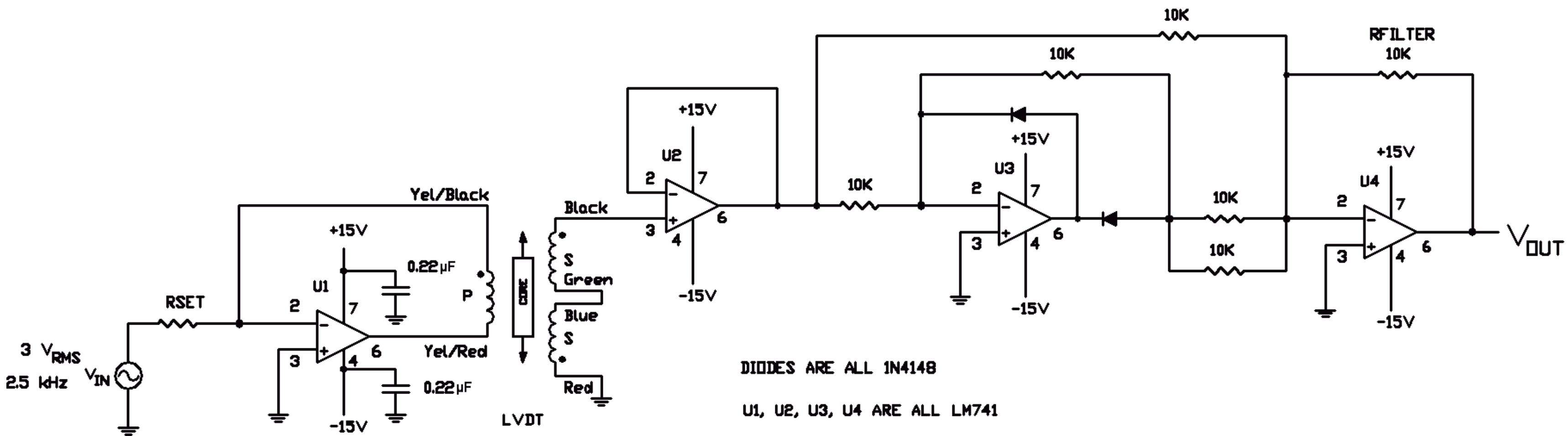
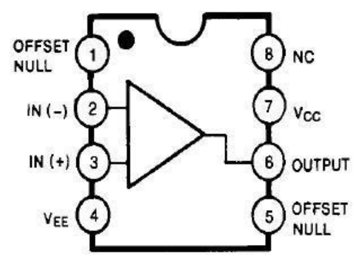
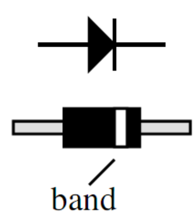


Figure A
LVDT Conditioning Circuit



LM741 (Top View)



1N4148 Diode

If V_{IN} is an AC voltage, I_{RSET} will be an AC current. Since the U1 inputs cannot sink or source current the current, I_{RSET}, must flow in the LVDT primary winding. The output of U1 will adjust its output voltage to satisfy this condition even if the primary winding resistance changes.

The second problem is solved by connecting the LVDT secondary windings to a source follower consisting of op amp U2 configured as a unity gain noninverting amplifier. U2-3 is a very high impedance and therefore does not cause any LVDT secondary winding voltage variation with temperature. The output of U2, U2-6, provides a very low impedance to drive the full wave rectifier (FWR) circuits consisting of op amps U3 and U4 and the associated circuitry. The operation of the FWR circuit is very interesting – see if you can figure out how it operates before coming to the lab. If you can't figure it out simulate it on LTspice or PSpice. If you use LTspice use a LT1014 op amp which is a good substitute for the LM741.

Setup:

Don't try and build the entire circuit at one time. First build the current source, U1, and make sure it works then build the source follower, U2 and make sure the output of U2, U2-6, is the same as the LVDT secondary voltage. Finally build the FWR circuit. The 0.22µF capacitors on the U1 power pins don't affect the LVDT operation – they only prevent the op amps from oscillating due to the long leads from the power supply to the breadboard.

Each lab station will use a different LVDT model. They vary in the amount of linear travel allowed for the LVDT core. When you get the LVDT look for the model number etched on the side of the LVDT – it should be three or four digits followed by the letters HR. At the back of this addendum is a catalog for the LVDT's. Find your model number and check the length of the core (the B dimension) to be sure you have the correct core for your LVDT.

From the LVDT catalog you will see that the nominal LVDT primary voltage is $3V_{RMS}$ and the primary impedance is specified at 2.5kHz (the same frequency that we will be using in this lab). Using the 1000HR LVDT as an example we can see the primary impedance is 460 ohms at 2.5kHz. If we set the value of RSET to the nearest standard resistance value equal to the primary impedance value the LVDT primary voltage as seen at U1-6 should be approximately $3V_{RMS}$. In this case RSET would be 470 ohms (the nearest standard value). Remember that the function generator output voltage setting is only correct if you have a 50 ohm load. In our case we have a 470 ohm load so the actual function generator voltage will be close to twice the voltage setting so to get a $3V_{RMS}$ input voltage to our circuit set the function generator output voltage to $1.5V_{RMS}$.

Be sure to observe the correct color coding of the LVDT secondary windings. In this configuration when the core is centered in the center of the LVDT the two secondary voltages will cancel out and there will be zero volts at U2-3. Moving the core in either direction will generate an AC voltage at U2-3.

When you have observed the correct full wave rectifier waveform at V_{OUT} (U4-6) you can filter the waveform by adding a 0.22µF capacitor <u>across</u> resistor, RFILTER. You can now record V_{OUT} as a function of displacement using the DMM set to DC Volts.

HR Series

General Purpose LVDT

The high reliability HR Series of LVDTs is suitable for most general applications. The HR Series features a large core-to-bore clearance, high output voltage over a broad range of excitation frequencies, and a magnetic stainless steel case for electromagnetic and electrostatic shielding.

Features

- ***Optimum performance for a majority of applications***
- ***Large 1/16 inch radial core-to-bore clearance***
- ***Calibration certificate supplied with all models***
- ***Compatible with all Schaevitz® signal conditioners***
- ***High temperature (220°C) and high pressure (vented case) available – consult factory***

Applications

- ***General***

Options

- ***5.0 kHz excitation frequency testing****
- ***Metric thread core***
- ***Guided core***
- ***Small diameter/low mass core***
- ***Mild radiation resistance (withstands 10^{12} NVT total integrated flux; 10^{7} rads Gamma)***

** Performance and electrical specifications for alternative frequencies will differ from the standard specifications listed below which are based on a 2.5 kHz excitation frequency. Consult factory for further information.*

Specifications

Input Voltage .... 3 V rms (nominal)
Frequency Range .... 400 Hz to 5 kHz
Operating Temperature Range ... -65°F to 300°F (-55°C to 150°C)
Null Voltage .... <0.5% full scale output
Shock Survival .... 1,000 *g* for 11 msec
Vibration Tolerance .... 20 *g* up to 2 kHz
Coil Form Material .... High density, glass-filled polymer
Housing Material .... AISI 400 series stainless steel
Lead Wires .... 28 AWG, stranded copper, Teflon-insulated, 12 inches (300 mm) long (nominal)

Performance and Electrical Specifications @ 2.5 kHz[1]

HR Series Model Number	Nominal Linear Range		Linearity (±% full range)				Sensitivity mV out/V in Per		Impedance Ohms		Phase Shift Degrees
	inches	mm	50	100	125	150	0.001 in	mm	Pri	Sec	
050 HR	±0.050	±1.27	0.10	0.25	0.25	0.50	5.8	230	430	4000	-1
100 HR	±0.100	±2.54	0.10	0.25	0.25	0.50	4.2	165	1070	5000	-5
200 HR	±0.200	±5.08	0.10	0.25	0.25	0.50	2.5	91	1150	4000	-4
300 HR	±0.300	±7.62	0.10	0.25	0.35	0.50	1.3	51	1100	2700	-11
500 HR	±0.500	±12.70	0.15	0.25	0.35	0.75	0.7	25.6	460	375	-1
1000 HR	±1.00	±25.4	0.15	0.25	1.00	1.30*	0.39	14.2	460	320	-3
2000 HR	±2.00	±50.8	0.15	0.25	0.50*	1.00*	0.23	8.3	330	330	+5
3000 HR	±3.00	±76.2	0.15	0.25	0.50*	1.00*	0.25	9.1	315	830	+11
4000 HR	±4.00	±101.6	0.15	0.25	0.50*	1.00*	0.20	7.1	275	550	+1
5000 HR	±5.00	±127.0	0.15	0.25	1.00*	n/r	0.14	5.5	310	400	+3
7500 HR	Now available — Contact factory for details										
10000 HR	±10.0	±254	0.15	0.25	1.00*	n/r	0.07	2.8	550	750	-5

[1] All calibration is performed at room ambient temperature.
** Requires special reduced core length.*

HR Series LVDT
High Reliability
Large Core-to-Bore Clearance
AC-Operated

How to Order

Specify the HR Model followed by the desired option number(s) added together.

Ordering Example:
Model Number 050 HR-018 is an HR Series LVDT with a ±0.05” range (050 HR), with 5 kHz testing (002), Metric thread core (006), and a guided core (010).

HR Model

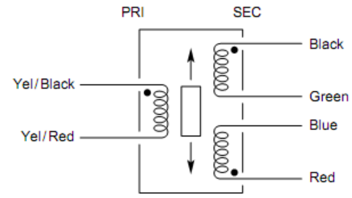
050 HR
100 HR
200 HR
300 HR
500 HR
1000 HR
2000 HR
3000 HR
4000 HR
5000 HR
10000 HR

Options

Number	Description
002	5.0 kHz Linearity Test[1]
006	Metric Thread Core
010	Guided Core[2]
020	Small Diameter/Low Mass Core[3]
080	Radiation Resistance[2]

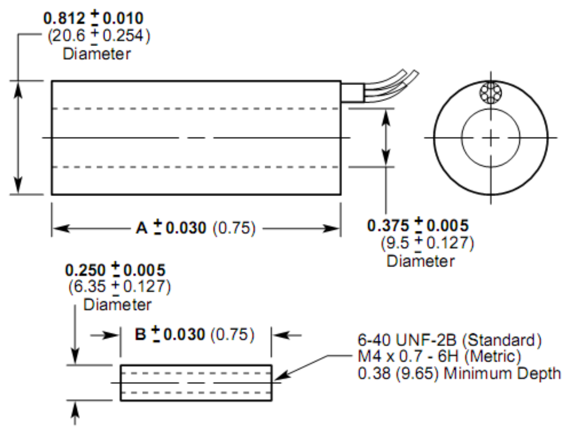
[1]Available on models 050 HR, 100 HR, 200 HR, and 500 HR only.
[2]Guided core and radiation resistance options cannot be ordered together.
[3]Available on models 050 HR - 500 HR only. Consult factory for mass, dimensions and thread size.

Wiring



Connect Green to Blue for differential output

Dimensions in (mm)



Mechanical Specifications

HR Series	Weight				Dimensions			
Model	Body		Core		A (Body)		B (Core)	
Number	oz	gm	oz	gm	in	mm	in	mm
050 HR	1.13	32	0.41	4	1.13	28.7	0.80	20.3
100 HR	1.69	48	0.21	6	1.81	46.0	1.30	33.0
200 HR	1.93	60	0.28	8	2.50	63.5	1.65	41.9
300 HR	2.72	77	0.35	10	3.22	81.8	1.95	49.5
500 HR	3.85	109	0.64	18	5.50	139.7	3.45	87.6
1000 HR	4.45	126	0.74	21	6.63	168.4	4.00	101.6
2000 HR	5.93	168	0.95	27	10.00	254.0	5.30	134.6
3000 HR	7.94	225	0.99	28	12.81	325.4	5.60	142.2
4000 HR	10.41	295	1.27	36	15.64	397.3	7.00	177.8
5000 HR	11.99	340	1.27	36	17.88	454.2	7.00	177.8
10000 HR	20.56	580	1.52	43	30.84	783.3	8.50	215.9