IN 221 (AUG) 3:0
Sensors and Transducers
Electromagnetic Sensors and Transducers
Lecture 3

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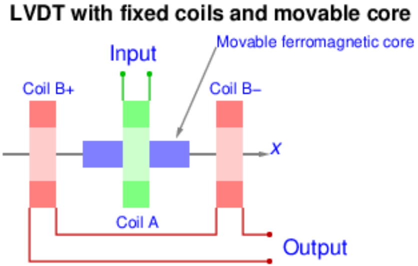
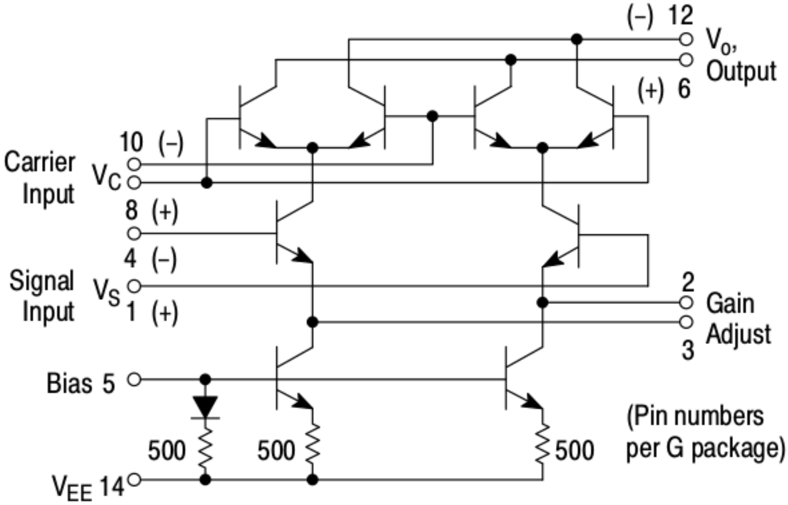
LVDT with fixed coils and movable core



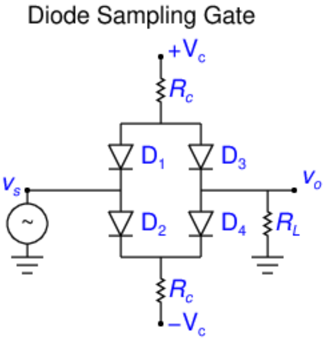
- Coils A, B$+$, and B$-$ are fixed.
- Fields due to B$+$ and B$-$ are in opposition.
- Many modern LVDTs are of this type.

Circuit for multiplication: Gilbert Cell



Gilbert cell used in MC1496

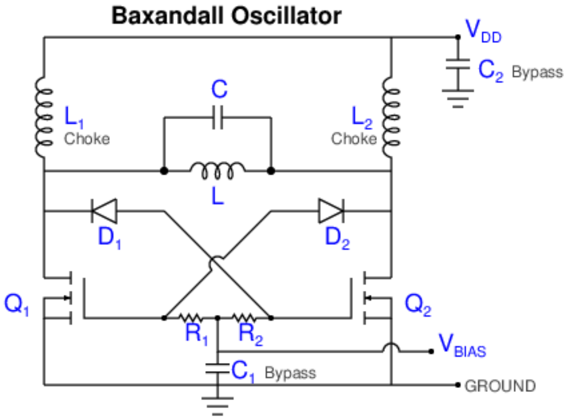
Circuit for multiplication: Sampling Gate



Diode sampling gate circuit: $v_o = v_s$, if V_c is able to turn the diodes on, otherwise $v_o = 0$.

If v_s and V_c are both sinusoids of the same frequency and V_c is large in amplitude, then v_o is proportional to the component of v_s along V_c.

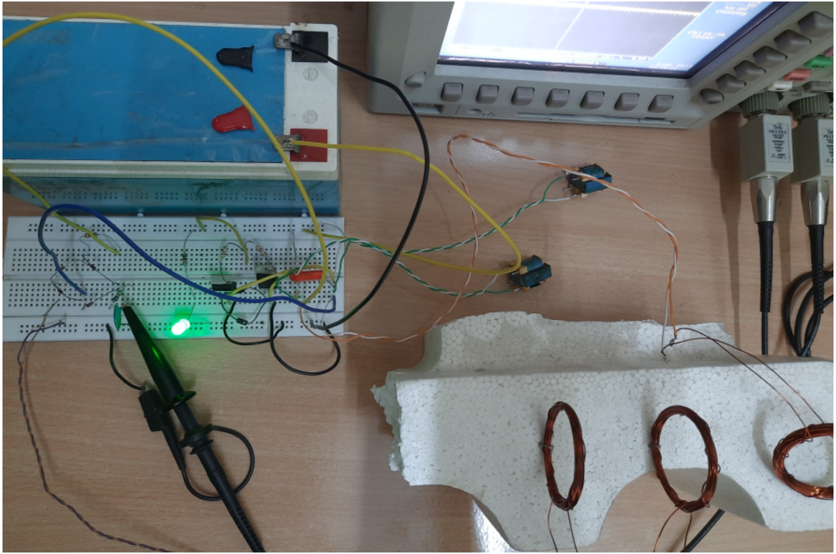
Baxandall Oscillator



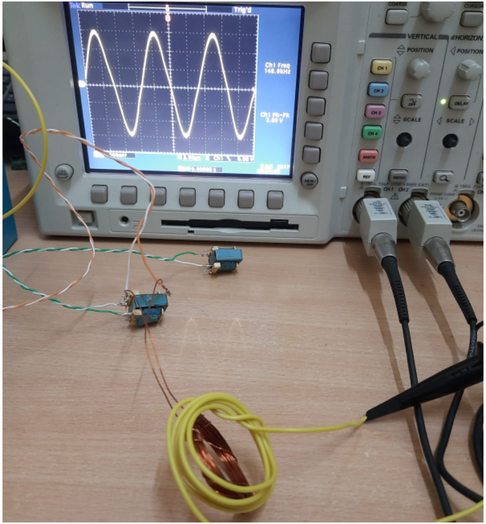
Baxandall Oscillator Parts

- Field coil $L = 97\,\mu\mathrm{H}$
- $C = 10.29\,\mathrm{nF}$
- MOSFETs: ST55NF06L or IRF540N
- Diodes: 1N4007
- $R_1 = R_2 = 470\,\Omega$
- Chokes: $L_1 = L_2 = 1\,\mathrm{mH}$
- Bypass capacitors C_1, C_2 not used.
- $V_{\mathrm{DD}} = V_{\mathrm{BIAS}} = 12.0\,\mathrm{V}$

LVDT Demo: System

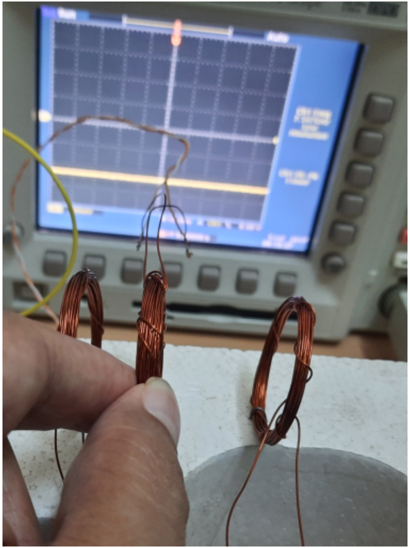


LVDT Demo: Oscillation

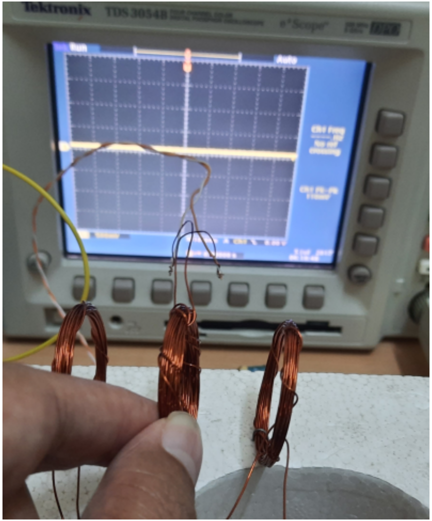


Frequency of oscillation: $f = 148.6\,\text{kHz}$.

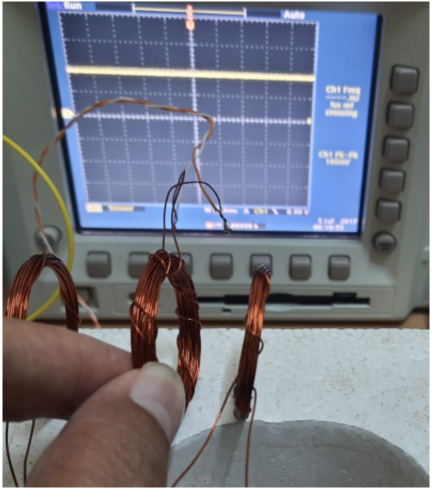
LVDT Demo: Coil moved left



LVDT Demo: Coil close to centre



LVDT Demo: Coil moved right



Temperature Sensors

- Thermistor
- Thermocouple
- Resistance Thermometer
- Silicon Bandgap Temperature Sensor
- Infrared Temperature Sensor

Thermistor

- Resistor whose resistance changes with temperature.
- Usually made of semiconductors.
- Change of resistance is more than that in metal resistors.
- Usually nonlinear.
- Limited range of use: -90 ℃ to 130 ℃
- Two types: NTC and PTC
- NTC: Negative Temperature Coefficient, resistance decreases with increase in temperature
- PTC: Positive Temperature Coefficient, resistance increases with increase in temperature
- NTC type is more commonly used.
- Can be quite sensitive, but not as accurate as other types of temperature sensors.
- Also used to limit starting current.

Thermocouple

- Involves junctions of two different metals.
- Generates a small voltage that is roughly proportional to the temperature difference of the two junctions.
- Based on Seebeck effect
- Many types available: Types K, J, N, R, S, B, T, E, and others.
- Advantage: Wide range (from -270 ℃ to 1700 ℃)
- Advantage: Requires no external power
- Disadvantage: Output is quite small, usually requires amplification
- Disadvantage: Amplification can be challenging

Resistance Thermometer

Resistance Temperature Detector (RTD)

- The resistivity of metals is a linear function of temperature over a wide range of temperatures.
- Usually a very pure form of the metal is used.
- A resistor made of the metal is enclosed in some form of protective housing.
- Commonly used metals: Platinum, Copper, Nickel
- Platinum can work till 600 ℃.

Temperature Coefficient of Resistance (TCR)

Let the resistance of a resistor be R_{ref} at temperature T_{ref} and R at temperature T. Then for metal resistors over a wide range of temperatures,

$$R = R_{\mathrm{ref}}[1 + \alpha(T - T_{\mathrm{ref}})] \tag{1}$$

where α is called the temperature coefficient of resistance (TCR).
T_{ref} is usually 20 ℃.

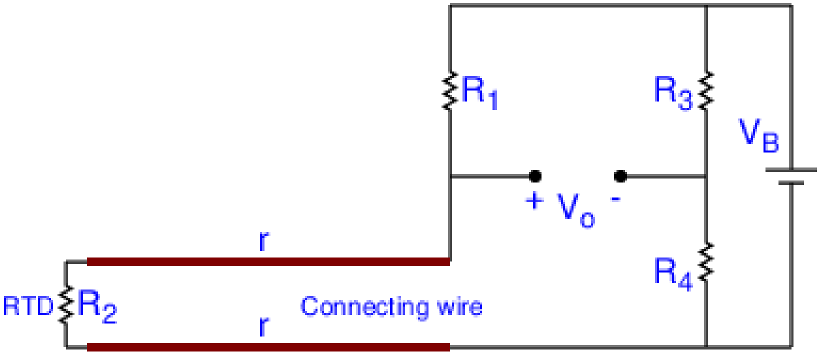
$$\alpha = \frac{R - R_{\mathrm{ref}}}{R_{\mathrm{ref}}(T - T_{\mathrm{ref}})} = \frac{\Delta R}{R_{\mathrm{ref}}\Delta T} \tag{2}$$

Units: per ℃

TCR of Commonly Used Metals

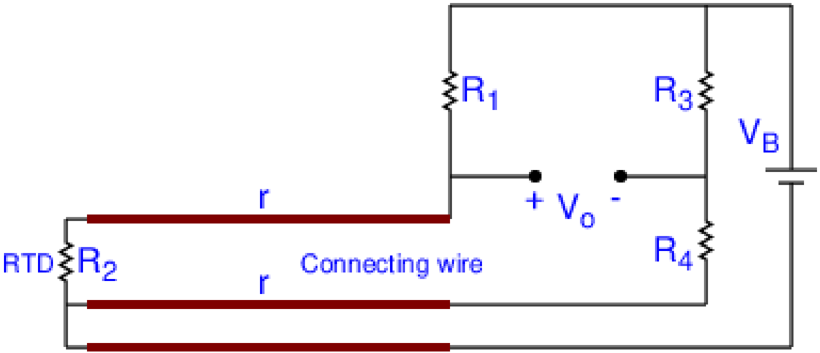
Metal	α
Platinum	3.925×10^{-3} °C^{-1}
Copper	3.9×10^{-3} °C^{-1}
Aluminium	3.9×10^{-3} °C^{-1}
Gold	3.4×10^{-3} °C^{-1}
Silver	3.8×10^{-3} °C^{-1}
Tungsten	4.5×10^{-3} °C^{-1}
Iron	5.0×10^{-3} °C^{-1}
Nickel	6.0×10^{-3} °C^{-1}
Tin	4.5×10^{-3} °C^{-1}
Lead	3.9×10^{-3} °C^{-1}

Two-wire Configuration



Disadvantage: r depends on the length of the connecting wire and only affects R_2.

Three-wire Configuration



Advantage: r affects both R_2 and R_4 equally.

Silicon Bandgap Temperature Sensor

The difference in voltage drop across two identical diodes or base to emitter junctions:

$$\Delta V_{\mathrm{BE}} = \frac{kT}{q} \ln\left(\frac{I_{\mathrm{C1}}}{I_{\mathrm{C2}}}\right) \tag{3}$$

Here I_{C1} and I_{C2} are the diode or the collector currents.

- Can be part of an integrated circuit
- Reasonably accurate
- Inexpensive
- Example: LM35 temperature sensor IC

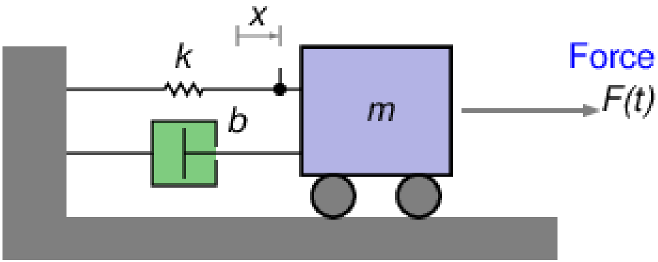
Practice Problems

1. The electrodes of a parallel plate capacitor are circular discs, each having a radius of 10 cm. If the electrodes are separated by an air gap of 1 mm, calculate the capacitance neglecting fringing fields.
2. A sine wave signal having peak voltage 20 V and frequency 10 MHz is applied across a 1 nF capacitor. Calculate the peak current in the capacitor.
3. A circular coil has 10 turns of wire with radius 10 cm. Calculate the magnitude of B on the axis of the coil at a distance 5 cm from the centre of the loop due to a 10 A current in the coil. Assume that there are no magnetic materials near the coil.
4. A resistor constructed using platinum wire has resistance 100 Ω at 20 °C. What will be its resistance at 10 °C?
5. In the Wheatstone bridge shown on Slide 20 of Lecture 1, $V_B = 10\,\mathrm{V}$, $R_1 = R_4 = 100\,\Omega$, and $R_2 = R_3 = 96\,\Omega$. Calculate V_0.

Answers to Practice Problems

1. 278.157 pF
2. 1.256 64 A
3. 44.9588 μT
4. 96.075 Ω
5. −204.082 mV

Spring-Mass-Dashpot System: Modelling



x: Displacement of the mass from its equilibrium position

$$m\ddot{x} + b\dot{x} + kx = F \tag{4}$$

F: Force
$v = \dot{x}$: Velocity
Relationship between force and velocity:

$$m\ddot{v} + b\dot{v} + kv = \dot{F} \tag{5}$$

Tension in the Dashpot

- Here the applied force $F(t)$ is the input.
- We could consider the velocity $v(t)$ as the output.
- A better choice is to consider the tension in the dashpot, $F_d(t) = bv(t)$, as the output.
- $F_d(t)$ is the force endured by the dashpot.
- Having both input and output as forces makes the mathematics neater.

Relationship between $F(t)$ and $F_d(t)$:

$$m\ddot{F}_d + b\dot{F}_d + kF_d = b\dot{F} \tag{6}$$