EE332: Analog and Mixed Signals
Project Proposal

1. Introduction:

In a world dominated by digital microprocessors that rely on binary logic, this project delves into the principles of analog computing by designing and constructing a functional analog calculator. The core of the calculator is built around operational amplifiers (op-amps) configured with specific feedback networks of resistors, capacitors, and diodes. By selecting op-amp topologies whose closed-loop transfer functions–precisely set by negative feedback–implement the desired math, the calculator can perform a variety of operations directly in hardware. These functions include **addition, subtraction, multiplication, division, differentiation, integration, logarithmic functions, modulus-like magnitude operations, and other mathematical operations**. Ultimately, this project serves as a hands-on exploration of the fundamental building blocks of analog signal processing, offering a practical demonstration of how mathematical functions are realised in circuits.

2. Problem Statement:

The central problem is to design and construct a self-contained, purely analog calculator capable of performing fundamental arithmetic and calculus operations, including addition, subtraction, multiplication, integration, and differentiation. The scope of this project requires representing numerical inputs as variable DC voltages or AC signals, nominally within a 0.01V to 14V range, and producing a corresponding output DC voltage that accurately reflects the calculated result, which can be measured with a standard multimeter. The significance of this project lies in its practical application of analog circuit design principles. The potential impact of a successful implementation is a tangible, educational demonstration of analog computation–a paradigm that remains highly relevant in niche, high-speed applications where the instantaneous processing of real-world, continuous signals is paramount.

The solution will be realized by implementing various operational amplifier (op-amp) configurations. Summing amplifiers will perform addition, inverting buffers will manipulate signal polarity for subtraction, and a combination of logarithmic and exponential amplifiers will achieve multiplication. Furthermore, low and high-pass filters will be integrated to serve as analog integrators and differentiators, respectively. Solving this problem is critical as it demands a

comprehensive understanding of these op-amp topologies, alongside practical skills in power supply design and signal scaling, to ensure the calculator's accuracy and functionality.

3. **Proposed Approach:**

a) Overview of Approach

Our comprehensive approach is to build a multifunctional analog computer using the LM358 Operational Amplifier on a high-voltage, dual-rail ±30V power supply, which establishes a true 0V ground reference for all operations. This fundamental change eliminates the need for a virtual ground and allows for more straightforward, high-performance circuit designs using op-amplifier LM358

The system is designed to accept inputs directly from external laboratory equipment. A DC power supply will provide variable voltage levels for arithmetic operations, while a function generator will supply AC signals (sine, square, triangle waves) for testing the calculus blocks. Each mathematical function is implemented in a dedicated modular circuit, and all signals are processed symmetrically around 0V, enabling true bipolar operation.

The calculator will be capable of performing:

- Arithmetic: Addition, Subtraction, Multiplication, and Division.
- Calculus: Integration and Differentiation.
- Non-linear Functions: Logarithm, Anti-logarithm (Exponential), and a Modulus-like magnitude (Absolute Value) function.

The core principles remain the same: summing amplifiers for addition, and logarithmic amplifiers for multiplication ($\ln(A \times B) = \ln(A) + \ln(B)$ and division ($\ln(A / B) = \ln(A) - \ln(B)$). A precision rectifier will handle the absolute value, and active filters will perform calculus operations.

b) Components and Blocks

The system is designed with seven distinct functional blocks integrated onto a single PCB, all optimized for single-supply operation. A multi-position switch will allow the user to select the desired function and route the appropriate signals to the output.

System Block Breakdown:

	Block	Function
1.	Power Supply & Bias	Generates stable 30V DC and a virtual ground.
2.	Buffered Input Stage	Provides high-impedance inputs for external sources.
3.	Adder/Subtractor	Performs addition or subtraction on inputs A and B.
4.	Multiplier/Divider	Multiplies or divides A and B using log principles.
5.	Log and Anti-Log	Outputs the logarithm or anti-logarithm of an input.
6.	Modulus (Absolute Value)	Computes the absolute value of an input.
7.	Integrator and Differentiator	Performs calculus operations.
8.	Square root	Performs the square root of function

Note: We may add some other blocks as well for other mathematical operations

Block Descriptions:

1. Dual-Rail Power Supply Block

Function: This block is the foundation of the system. It will convert an AC input from a center-tapped transformer into three stable DC outputs: +30V, -30V, and Ground. This will be achieved using a bridge rectifier, large smoothing capacitors, and adjustable voltage regulators like the LM317 (for +30V) and LM337 (for -30V) to ensure a clean, regulated supply.

Expected Outcome: A robust power source providing symmetric positive and negative rails for optimal op-amp performance

2. Buffered Input Stage
   ○ Function: This block replaces the potentiometers. It consists of input terminals (e.g., BNC connectors) for sources 'A' and 'B'. Each input is immediately fed into an op-amp configured as a voltage follower. This presents a very high impedance to the external equipment, preventing our calculator from loading down the source, and provides a low-impedance signal to the internal computational blocks.
   ○ Expected Outcome: Two perfectly buffered signals that faithfully replicate the external inputs for use in the rest of the system.

3. Adder/Subtractor Block
   ○ Function: This block is now a standard textbook implementation of an inverting summing amplifier and a difference amplifier. Since the reference is true ground, the circuit design is significantly simplified, requiring only the op-amp and precision resistors.
   ○ Expected Outcome: An output voltage V_out that is the sum $V\_out = -(A+B)$ or difference ($V\_out = B-A$) of the input voltages.

4. Multiplier/Divider Block
   ○ Function: These blocks are also simplified. The logarithmic, anti-logarithmic, and precision rectifier circuits will be implemented using standard dual-supply topologies. This removes all the biasing complexity required for the single-supply design, leading to more accurate and predictable performance.
   ○ Expected Outcome: Clean, accurate output signals for multiplication, division, log, anti-log, and absolute value functions without any DC offset.

5. Log/Anti-Log Block
   ○ Function: This block provides direct access to the non-linear functions. A switch configures an op-amp circuit to either function as a logarithmic amplifier (taking

input A and outputting ln(A)) or as an anti-logarithmic amplifier (taking input A and outputting e^A).
- ○ Expected Outcome: A voltage representing the natural logarithm or the exponential of the input voltage.
6. Modulus (Absolute Value) Block
    - ○ Function: This block implements a precision full-wave rectifier. This circuit uses two op-amps and diodes to output the absolute magnitude of an input signal.
    - ○ Expected Outcome: A positive output voltage representing the absolute value of the input signal.
7. Integrator/Differentiator Block
    - ○ Function: This block will shine when connected to a function generator. It will perform real-time integration and differentiation on incoming AC waveforms. For example, a sine wave input to the differentiator will produce a cosine wave output, and a square wave input to the integrator will produce a triangle wave output.
    - ○ Expected Outcome: A direct, visual demonstration of calculus operations on dynamic signals.
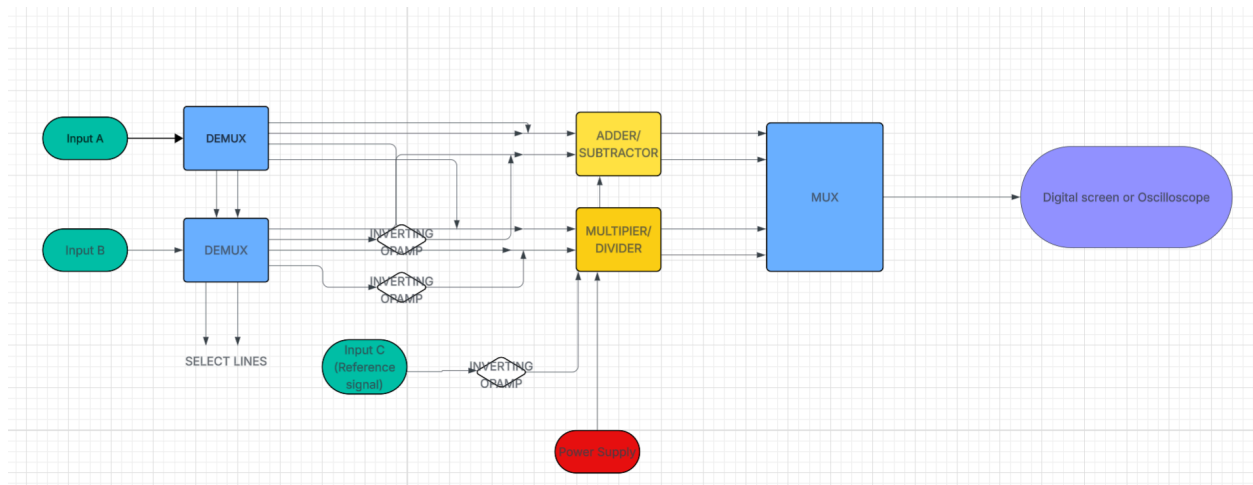
c) Advantages of the Proposed Approach

This enhanced design significantly improves the project's scope and utility:

- Functional Versatility : The calculator is now a comprehensive analog signal processing unit, capable of handling a wide range of linear, non-linear, and calculus-based operations, making it a far more powerful and versatile educational tool.
- Simplified Power Supply : The single-supply design using the LM358 eliminates the complexity of a dual-rail power supply, reducing component count and simplifying the PCB layout.
- Improved Noise Immunity : Placing capacitors in the feedback loops of the op-amps is a practical and effective technique for reducing high-frequency noise and preventing oscillations, leading to more stable and reliable results.
- Deep Educational Value : This project provides direct, hands-on experience with a wide array of fundamental analog circuits, from basic adders to complex log/anti-log multipliers and precision rectifiers, all within the practical constraints of a single-supply system.
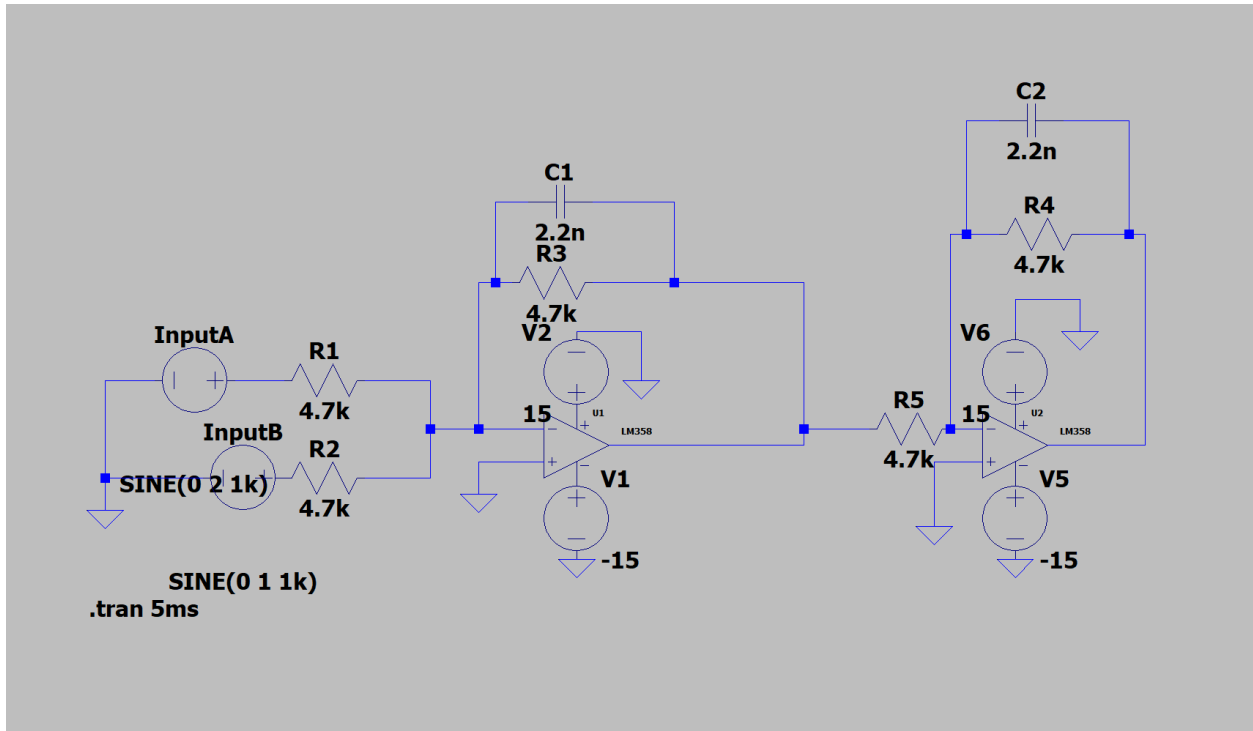
Working of the circuit:

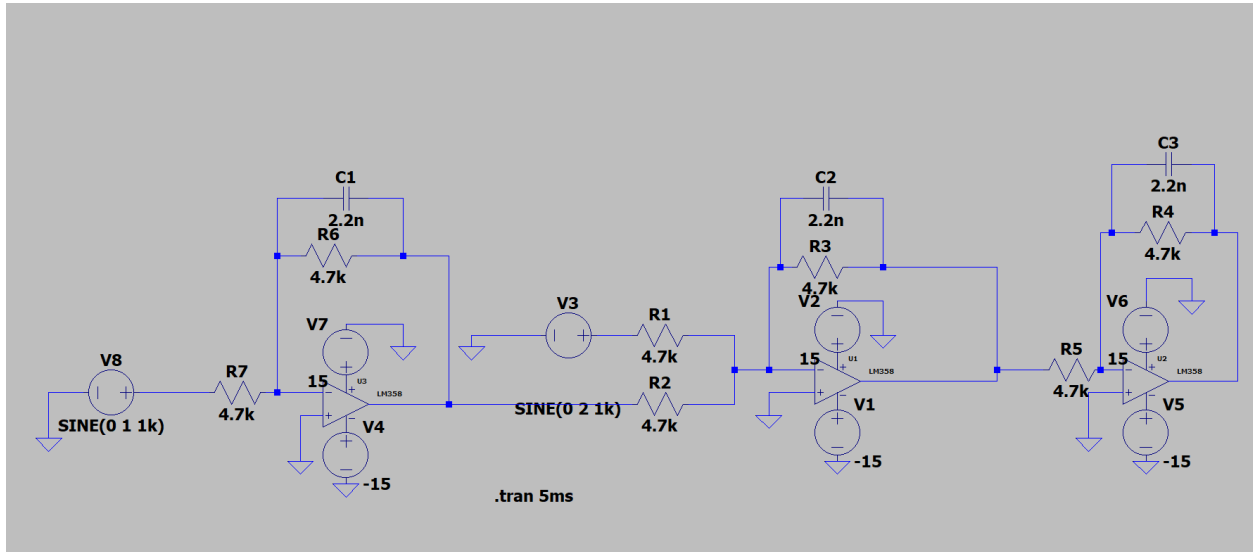## a) Basic Circuit Diagram/Basic Block Diagram

This figure illustrates a simplified block diagram of an analog calculator. This version is limited to four fundamental arithmetic operations to demonstrate the core concept, whereas a full-featured implementation would include a broader range of mathematical functions.
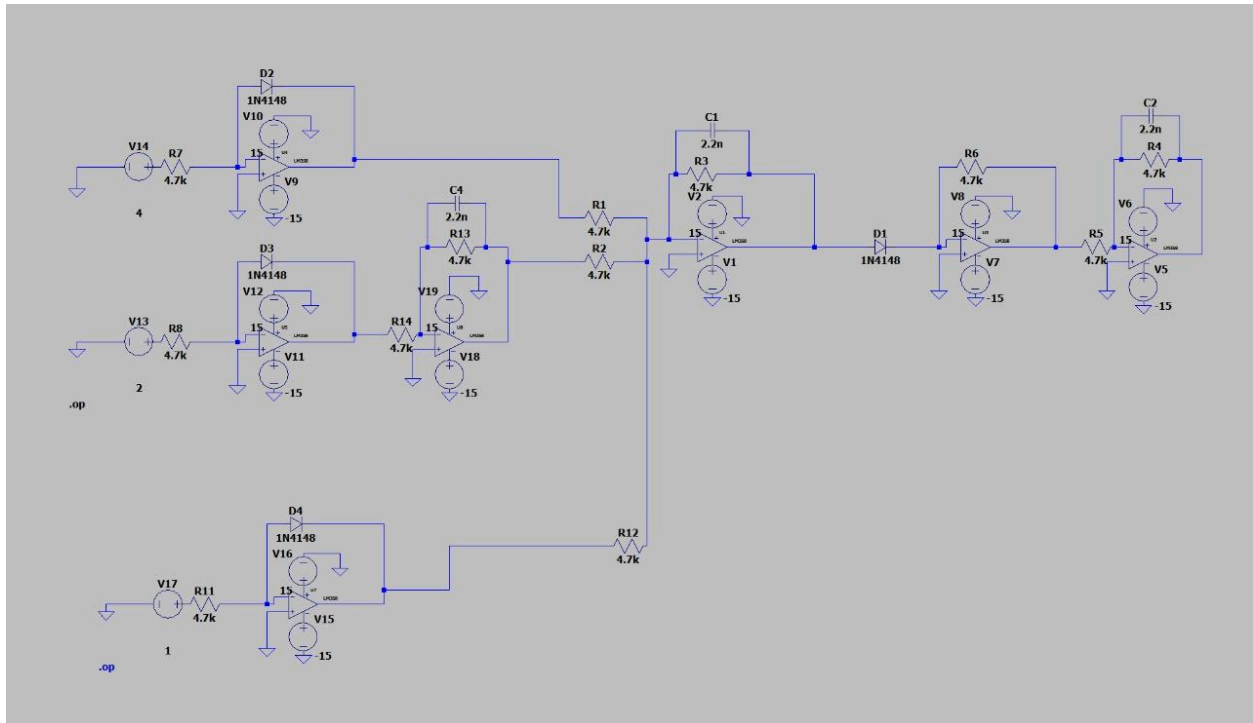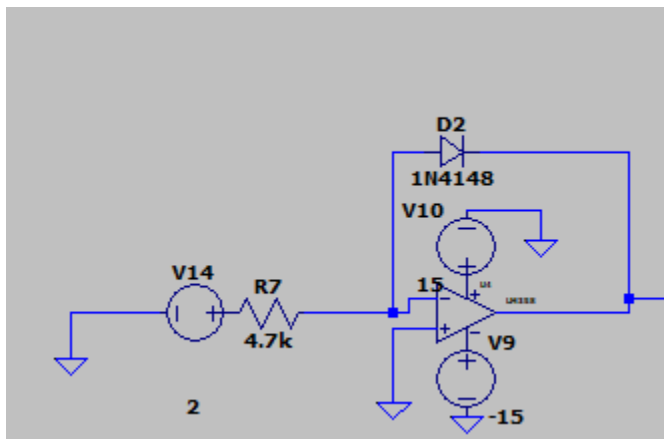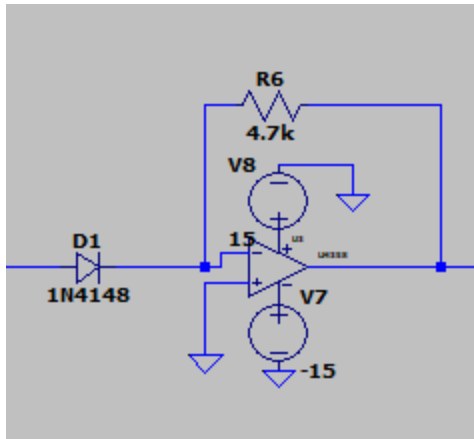
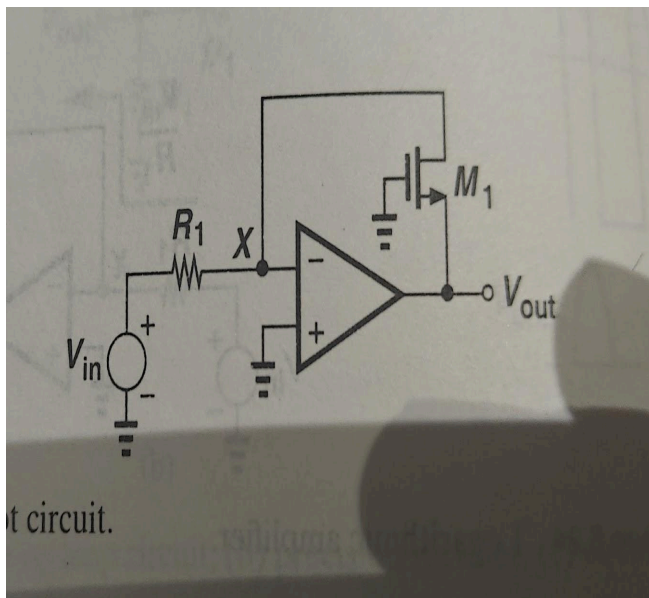**1.ADDER**

2. Subtractor

3. Multiplier

4. Divider

5.log

6. Antilog

7. Square root

t circuit.
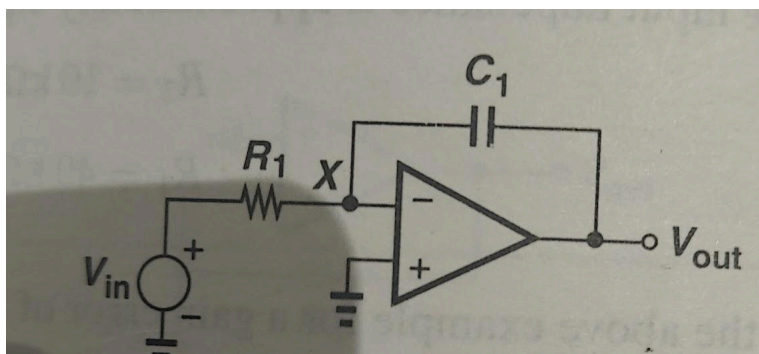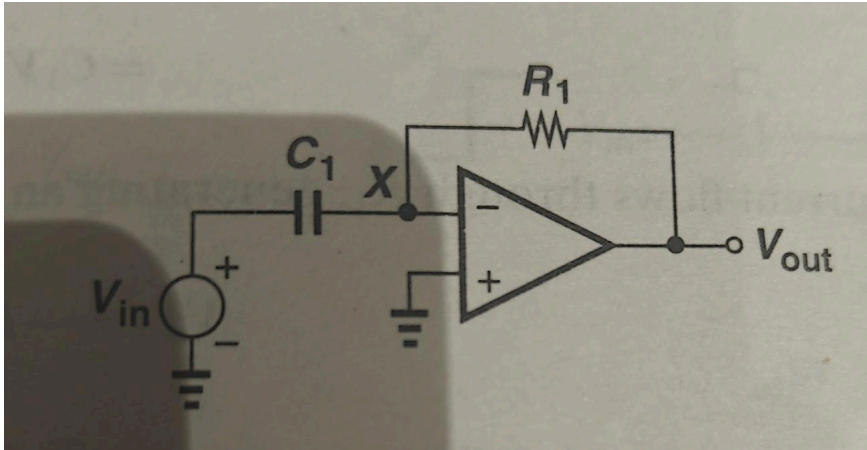
8. Integrator

9. differentiator

System Architecture and Signal Flow

The calculator's architecture is designed for modularity and clarity. It operates as a parallel processing system where all calculations happen simultaneously, and the user simply selects which result to view.

The step-by-step signal flow is as follows:

1. Input Stage: Two variable signals, Input A and Input B, are provided by external laboratory equipment (a DC power supply for numbers or a function generator for waveforms). These inputs are immediately fed into high-impedance buffer amplifiers (op-amps in a voltage follower configuration). This crucial first step ensures that our calculator doesn't draw any significant current from the source, preventing measurement errors.

2. Parallel Computation: The buffered A and B signals are routed to the inputs of all nine computational blocks at the same time. This means the adder block is always calculating A+B, the multiplier block is always calculating A×B, the integrator is always integrating A, and so on. This parallel, instantaneous computation is a hallmark of analog computing.

3. Operation Selection: The user selects the desired mathematical operation using a multi-position rotary switch. Each position on the switch corresponds to one of the computational blocks (Add, Subtract, Multiply, etc.).

4. Output Multiplexing: The rotary switch controls the select lines of an analog multiplexer (Mux). The Mux has multiple input channels, each connected to the output of one of the computational blocks. Based on the switch's position, the Mux selects only one of these inputs and passes it to the final output terminal. This method is critical because it

prevents multiple circuit outputs from conflicting with each other and ensures a single, clean result.

5. Output Display: The final, selected voltage is sent to an output BNC or banana jack terminal, ready to be measured by a Digital Voltmeter for a numerical answer or an Oscilloscope to view the resulting waveform.

Noise Reduction: A key design feature across all blocks is the placement of a small capacitor (a few nanofarads) in parallel with the op-amp's feedback resistor. This forms a simple low-pass filter that shunts high-frequency noise to the ground and improves the stability of the circuit, preventing unwanted oscillations.

b) Explaination

The analog calculator will contain 4 components: an adder, subtractor, multiplicator and a divisor.

Each of the following circuits is designed to operate on the ±30V dual-rail supply, using a true 0V ground as a reference.

1. Adder (Inverting Summing Amplifier)
    o This is one of the most fundamental op-amp circuits. The input signals A and B are each fed through an input resistor to the inverting (-) terminal of the op-amp. The output voltage is the inverted sum of the inputs, scaled by the ratio of the feedback resistor (R_f) to the input resistors (R_in).

    o **Formula:** $V_{out} = -R_f\left(\frac{V_A}{R_{inA}} + \frac{V_B}{R_{inB}}\right)$

    o And then an inverting opamp is used in order to get the output in the actual configuration as in the adder stage, a phase of 180 degrees is added.
        o **V_out= (V_A + V_B)**
    o If all resistors are equal (R_f = R_inA= R_inB), the output is simply V_out= (V_A + V_B).

2. Subtractor (Difference Amplifier)

- This circuit uses a single op-amp to find the difference between two signals. It combines the principles of both inverting and non-inverting amplifiers.

    Formula: $V_{out} = -R_f\left(\frac{V_A}{R_{inA}} + \frac{V_B}{R_{inB}}\right).$

- In this we only just inverted a signal and rest same as adder will lead to -(V_A-V_B)
    And then a inverting opamp is used tp get V_A - V_B

    - **V_out= (VA - V_B)**

- For this circuit to work accurately, the resistor ratios must be precisely matched R_f/R_in on the inverting side must equal the ratio of the resistors on the non-inverting side). When all resistors are equal, the output is simply V_{out} = VA-VB.

3. Multiplier

- Multiplication is achieved using the logarithmic identity: ln(V1\times V2) = ln(V1) + ln(V2) - ln(Vr).
- The three voltages are then fed into an inverting adder and then a non-inverting exponential amplifier. All reference voltages are to be tuned with a until output readings are accurate
- The circuit consists of three stages:
    1. Log Stage: Two logarithmic amplifiers take the natural log of the positive input voltages A and B.
    2. Summing Stage: An adder circuit sums the two logarithmic outputs.
    3. Anti-Log Stage: An anti-log (exponential) amplifier takes the output of the adder and performs the inverse operation (e^x), yielding the final product.
    4. And then an inverting opamp
- The result is a voltage is (V1 * V2)/Vr.

    $$V_{out} = \frac{V_1 V_2}{V_R}.$$

4. Divider

- Division uses a similar principle: ln(V1 / V2) = ln(V1) - ln(V2) + ln(Vr).
- The circuit is almost identical to the multiplier, but the summing stage is replaced with a subtraction (difference) stage. The log of B is subtracted from the log of A, and also the reference in this is in original configuration, that means the

reference voltage is been multiplied by the output the result is then fed to the anti-log amplifier. And then finally a inverting opamp.

- **Vout = (V1/V2)*Vr**

'

5. Logarithmic Amplifier

- This circuit produces an output voltage that is proportional to the natural logarithm of the input voltage. It uses the exponential current-voltage relationship of a semiconductor diode or a BJT placed in the op-amp's feedback path. And an inverting opamp is used to get desired output.
- Function: V_out is proportional to logVin

6. Anti-Log (Exponential) Amplifier

- This is the inverse of the log amp. The diode or BJT is placed at the input of the op-amp. It produces an output voltage that is an exponential function of the input.And an inverting opamp is used to get desired output.
- Function: V_out is proportional to e^Vin

7. Square Root Amplifier

- This clever circuit uses a nmos mosfet in the feedback loop of an op-amp. The op-amp's output V_out is proportional to root of the input.
- Function: V_out is proportional to sq.rt of V_in

8. Integrator

- An op-amp with a resistor at its input and a capacitor in its feedback loop. It produces an output voltage proportional to the integral of the input voltage over time.
- **Formula:** $V_{out}(t) = -\frac{1}{RC} \int V_{in}(t)dt.$
- When fed a square wave from a function generator, this circuit will output a triangle wave.

9. Differentiator

- ○ The inverse of the integrator, with a capacitor at the input and a resistor in the feedback loop. It produces an output proportional to the rate of change of the input voltage.
- ○ **Formula:** $V_{out}(t) = -RC\frac{dV_{in}(t)}{dt}$.
- ○ When fed a triangle wave, this circuit will output a square wave. It's highly sensitive to high-frequency noise, so a small series resistor is often added to the input capacitor to limit its bandwidth.

---

c) Step-by-Step Build Plan

This project will follow a rigorous, modular build-and-test methodology to ensure success.

1. **Simulation :**
   - ○ Design and simulate every single block (power supply, adder, multiplier, integrator, etc.) individually in LTspice or a similar SPICE program.
   - ○ Verify correct DC operating points, AC frequency response, and transient behavior. This virtual testing phase is critical for catching design flaws and finalizing component values before touching any hardware.
2. **Modular Breadboard Prototyping :**
   - ○ Power Supply First: Build and test the ±30V dual-rail power supply on a breadboard. Confirm the outputs are stable, accurate, and have minimal ripple under load. This is the foundation for the entire project.
   - ○ One Block at a Time: Build and test each computational block individually. Start with the simplest (e.g., the adder) and move to the most complex (e.g., the multiplier).
   - ○ Test Rigorously: Use a lab DC power supply for inputs and a DMM to verify the adder and subtractor. Use a function generator and an oscilloscope to test the integrator and differentiator, confirming the expected waveform conversions.
3. **Full System Breadboard Integration:**
   - ○ Once all individual blocks are confirmed working, connect them on a larger breadboard.
   - ○ Implement the input buffering and the output multiplexer/switch system.
   - ○ Conduct a full system test, switching between all functions to ensure they work correctly in an integrated environment and debug any issues that arise from block interactions.
4. **PCB Design :**

- After the breadboard prototype is fully functional, design a schematic and a 2-layer PCB layout using software like KiCad.
- Best Practices: Pay close attention to the layout. Use a star-grounding scheme, place the power supply section away from sensitive analog traces, use wide traces for power delivery, and keep feedback paths short.

5. **Assembly and Soldering :**
   - Solder all components onto the fabricated PCB, starting with the shortest components (resistors, diodes) and finishing with the tallest (capacitors, IC sockets, terminals). Double-check component orientations.

6. **Final Testing and Calibration :**
   - Power up the final PCB and perform a complete functional test of all operations.
   - For the most sensitive circuits, like the multiplier and divider, use multi-turn trimpots in place of fixed resistors for key scaling factors. Calibrate these circuits using a precision voltage source and DMM to achieve the highest possible accuracy.

7. **Expectation:**

The expected output will be correct according to input and used operations as long as the output is in the range of the supplied power of the opamp, and we expect an error of up to 1-5 percent, and the input range is 10mV to 14V.

References:

- **Fundamental of microelectronics behzad razavi chapter 8**
- **https://www.ti.com/lit/ds/symlink/sn74ls138.pdf?ts=1760712740425&ref_url=https%253A%252F%252Fen.wikipedia.org%252F [DeMUX datasheet]**
- **https://www.ti.com/lit/ds/symlink/sn54ls151.pdf?ts=1760789050503&ref_url=https%253A%252F%252Fwww.google.com%252F [MUX Datasheet]**
- **https://www.ti.com/lit/ds/symlink/lm358.pdf?ts=1760749751390&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM358 [LM358 data sheet]**

- **DESIGN WITH OPERATIONAL AMPLIFIERS AND ANALOG INTEGRATED CIRCUITS by sergio franco chapter 1**

- ***Op-Amps for Everyone*** by Ron Mancini, Texas Instruments.
- ***The Art of Electronics*** by Paul Horowitz and Winfield Hill.