CSE 210
Computer Architecture Sessional

Assignment-2: 32-bit Floating Point Adder Simulation

Section – C2
Group – 07

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1 Introduction

A computer representation of a real number with a fixed number of digits before and after the decimal point (or radix point in a more general sense) is called a floating point number. A floating point adder is a digital circuit that works with floating point numbers to add and subtract. Numbers that are too large or too small to be accurately represented by integer representations can be represented using this method.

Three fields make up the floating point representation of a number: the sign bit, the exponent field, and the mantissa field. The sign bit represents the sign, either positive or negative. To express a wide range of values, the exponent field permits the significand to be multiplied by a power of the base using a fixed amount of bits in a biased form. The bias needs to be deducted from the stored bits in order to get the real exponent. The fractional portion of the number, or mantissa, is made up of the digits that come after the decimal point. The sign bit, exponent field, and mantissa in this implementation use 1, 9, and 22 bits, respectively. Thus, the exponent bias for our problem would be $2^{9-1} - 1 = 255$.

In order to add two numbers, a floating point adder first aligns their decimal points before adding their mantissas. After necessary shifts and related modifications (increment/decrement), the result's exponent is fixed. Normalization and rounding are performed afterwards. The signs of the two integers being added determine the sign of the outcome.

Applications for floating point adders include financial modeling, computer graphics, and calculations in science and engineering. Because co-processors can be computationally demanding, it is utilized in them to do quick, hardware-accelerated floating point arithmetic. These calculations can be completed far more quickly by a specialized floating point adder than by the main processor. Applications requiring high-precision floating point calculations, such as data analysis and scientific simulations, may find this to be especially crucial.

1.1 Floating Point Representation

According to IEEE 754 standard, a floating-point number is delineated by a trio of elements: a sign bit, an exponent, and a fraction (alternatively termed mantissa or significand). The general structure adheres to the formula:

$$(-1)^{\text{sign}} \times (1 + \text{fraction}) \times 2^{\text{exponent}-\text{bias}}$$

In our assignment,we have exponents of 9 bits and mantissa of 22 bits.

Bit Number	Portion
31	Sign (S)
30–22	Exponent
21–0	Fraction/Mantissa

Table 1: Bit Ranges of Floating-Point Number

Each component holds specific significance:

- Sign bit: Denoting the sign of the number, with 0 for positive and 1 for negative.

- Exponent: Denoting the exponent of 2 by which the fraction undergoes multiplication.
- Fraction: Representing the actual fractional segment of the number, often normalized to commence with a leading 1.

The normalized significand, residing in the range $1.0 \leq |\text{significand}| < 2.0$, consistently incorporates a leading pre-binary-point 1 bit. This obviates the need for explicit representation, commonly denoted as the hidden bit. The normalized significand is essentially synonymous with the fraction, featuring the restored "1." at its forefront.

The bias, a constant, is incorporated to facilitate the representation of the exponent using a signed integer, thereby accommodating both positive and negative exponents.Here the bias is 255.

1.2 Range

- Extremely small numbers, in proximity to zero, manifest with a diminished exponent and a fraction featuring leading zeros.
- Extremely large numbers are portrayed with an elevated exponent.

In a floating-point adder with a 22-bit mantissa and an 9-bit exponent, the largest and smallest representable positive normalized numbers are determined by the range of exponents and the precision of the mantissa.

For the largest positive number, the exponent is set to its maximum value of 255, and the mantissa is the maximum value for a 22-bit representation. The binary representation is $1.11111111111111111111 \times 2^{255}$. In approximate decimal form, this represents a number of approximately $3.402823466 \times 10^{76}$.

For the smallest positive normalized number, the exponent is set to its minimum value of -254, and the mantissa is the minimum value (just the implicit leading bit). The binary representation is $1.00000000000000000000 \times 2^{-254}$, approximately equal to $5.562684646268003 \times 10^{-77}$ in decimal.

These values encapsulate the range of positive normalized numbers that can be precisely represented by your floating-point adder with a 22-bit mantissa and an 9-bit exponent. It's crucial to note that these approximations are subject to the inherent limitations of representing real numbers in a finite binary format.

1.3 EEE 754 encoding of floating point numbers

Exponent	Fraction	Object Represented
0	0	0
0	Non Zero	± Denormalized Number
1–510	Anything	± Floating Point Number
511	0	± Infinity
511	Nonzero	NaN (Not a Number)

Table 2: EEE 754 Encoding

1.4 Denormalized Number

The denormalized numbers in IEEE 754 floating-point representation are a special category of values that are smaller than normal numbers. They are used to allow for gradual underflow, where numbers get extremely close to zero with diminishing precision. Denormalized numbers have an exponent of all zeros and a hidden bit set to zero. The formula for denormalized numbers is:

$$\text{Denormalized Number} = (-1)^{\text{sign}} \times (0 + \text{Fraction}) \times 2^{-\text{exponent}_{\text{min}}}$$

Where: – sign is the sign bit (either 0 or 1), – Fraction is the fractional part of the number (including the hidden bit, which is 0 for denormalized numbers), – $\text{exponent}_{\text{min}}$ is the minimum representable exponent value.

Denormalized numbers have a smaller exponent range compared to normalized numbers, and they allow for a smooth transition to zero, ensuring that precision degrades gradually as the numbers get smaller.

For example, in single-precision format, the smallest denormalized number is represented as:

$$0.\underbrace{00000000000000000000001}_{\text{Fraction}} \times 2^{-254}$$

Which is equivalent to 1.0×2^{-276}. This is considerably smaller than the smallest positive normalized number, which is $1.00000000000000000000000 \times 2^{-254}$. Denormalized numbers play a crucial role in maintaining precision for very small values close to zero in floating-point arithmetic.

1.5 Floating Point Number Addition

Performing floating-point addition involves several steps:

Example: Consider two normalized numbers in IEEE 754 single-precision format:

$$A = (-1)^0 \times 1.011 \times 2^3 \quad \text{and} \quad B = (-1)^1 \times 1.101 \times 2^2$$

Step 1: Aligning Exponents Let us Identify the number with the smaller exponent and adjust its mantissa and exponent to match the larger one. Since B has a smaller exponent, we need to align it with A. We shift the mantissa of B to the right and decrease its exponent by 1:

$$A = (-1)^0 \times 1.011 \times 2^3 \quad \text{and} \quad B = (-1)^1 \times 0.1101 \times 2^3$$

We need exponent comparator and Right shifter for this.

Step 2: Adding Mantissas Let us add the mantissas:

$$\text{Sum of Mantissas} = 1.011 + (-1)^1 \times 0.1101 = 0.1001$$

This step is performed using ALU (Arithmetic Logic Unit)

Step 3: Normalizing Result If the output is not normalised,we have to Normalize the result by adjusting the exponent and shifting the mantissa to have a leading 1:

$$\text{Normalized Result} = 1.001 \times 2^4$$

This normalization is performed either by shifting right and incrementing the exponent or shifting left and decrementing the exponent.

Step 4: Checking for Overflow or Underflow We have to check for overflow or underflow.If either occurs, it indicates an exception. In this case, there's no overflow or underflow.

Step 5: Rounding Result We have to the result based on the precision required.A rounder circuit can be designed Guard and round digits and sticky bits.A rounder module can be implemented for this purpose.

Step 6: Normalizing Rounded Result If the output is not in normalised form,we have to Normalize the result by adjusting the exponent and shifting the mantissa to have a leading 1

Step 7: Handle Special Cases In the realm of floating-point representation, some noteworthy cases deserve attention: denormalized numbers, infinity, and NaN. There are no special cases in this example.

Moreover, The sign of the result is determined based on the signs of the original numbers. So, after aligning exponents, adding mantissas, normalizing, and finalizing the result, the sum of A and B is approximately:

$$\text{Result} = 1.001 \times 2^4$$

This process ensures correct addition of floating-point numbers while considering the alignment of exponents, mantissa addition, normalization, rounding, and handling special cases.

2 Problem Specification

The task involves creating a circuit for a floating point adder that accepts two floating points as inputs, adds their sum, and outputs another floating point. Every floating point will have a length of 32 bits and be represented as follows:

Sign	**Exponent**	**Fraction**
1 bit	9 bits	22 bits

Table 3: Problem Specification

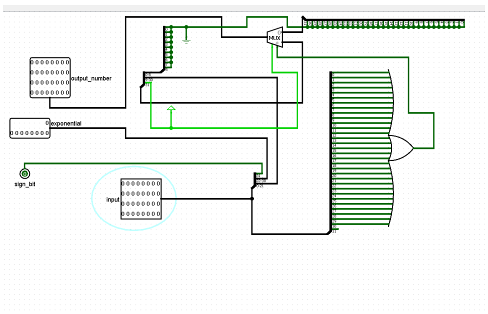
3 Description and Circuit Diagram of Modules

In order to maintain modularity in the floating point adder design, multiple libraries have been built and implemented. Descriptions and usages of the libraries are given below:

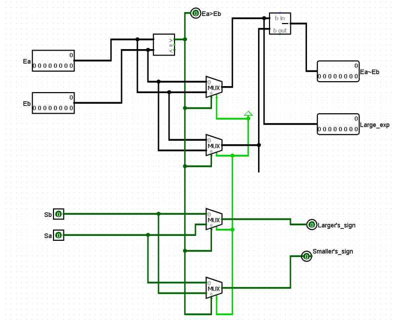
3.1 Processing the Input

This module (`InputHandler.circ`) processes the input for further operations in the floating-point adder. It contains:

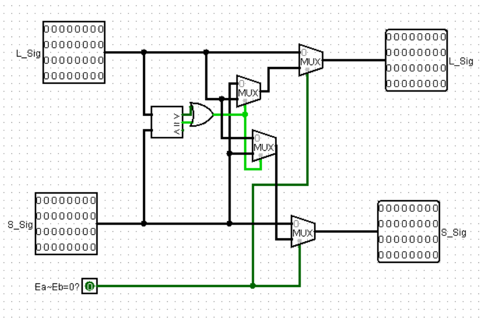
- A circuit that splits the 32-bit floating-point number into an 9-bit exponent and a 22-bit significand,later makes that 22 bit into 32 bit significand.Additionally here is checking if all bit except sign bit is 0,then the significand will be all 0,otherwise with the logic implemented. `[Input Processor]`.
- An exponent differentiator that calculates the difference between the exponents of two inputs `[Exponent Differentiator]`.
- A circuit that determines which significant is greater and identifies the greater and smaller significant `[Significant comparator]`
- This circuit determines the sign of the larger value between two floating-point numbers. It first compares the exponents; the number with the larger exponent has the dominant sign. If the exponents are equal, the circuit compares the significant, selecting the sign of the number with the larger significant `[Sign comparator]`.
- A circuit that determines which input is greater, identifies the greater exponent, calculates the exponent difference, etc., for control decisions `[Input Handler]`.



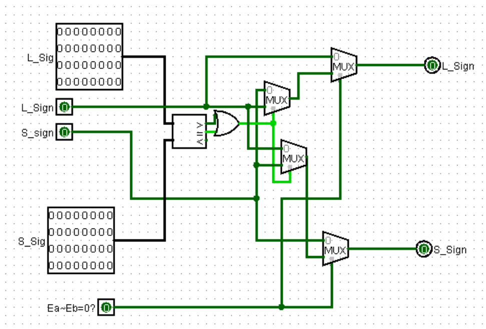
(a) Input Processor



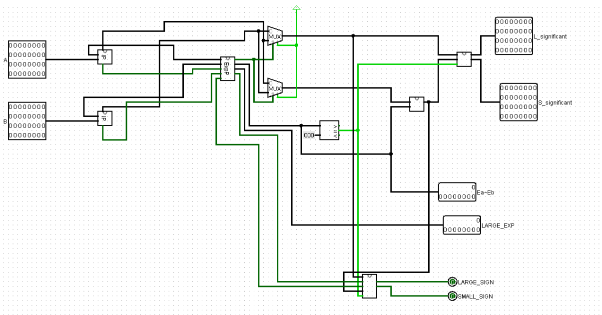
(b) Exponent Differentiator



(c) Signifacant comparator



(d) Sign comparator



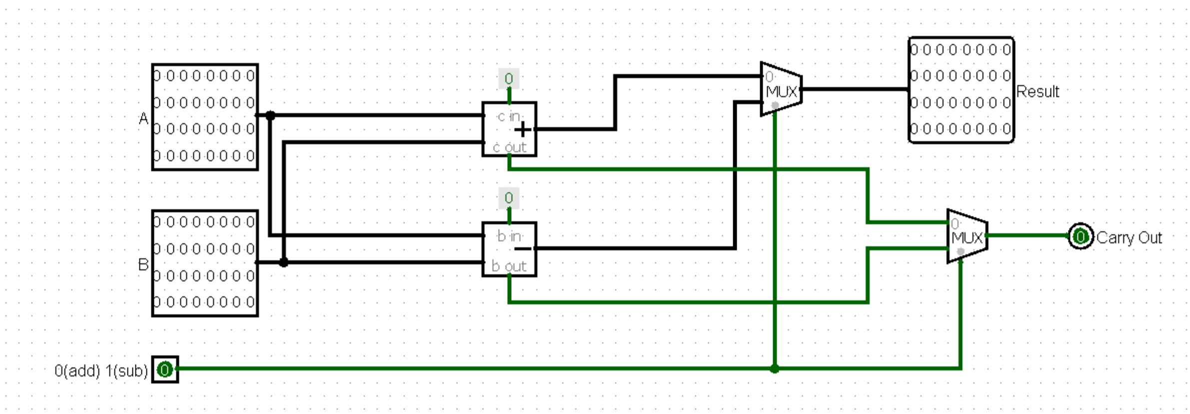
(e) Input Handler

Figure 1: Input Operator Modules

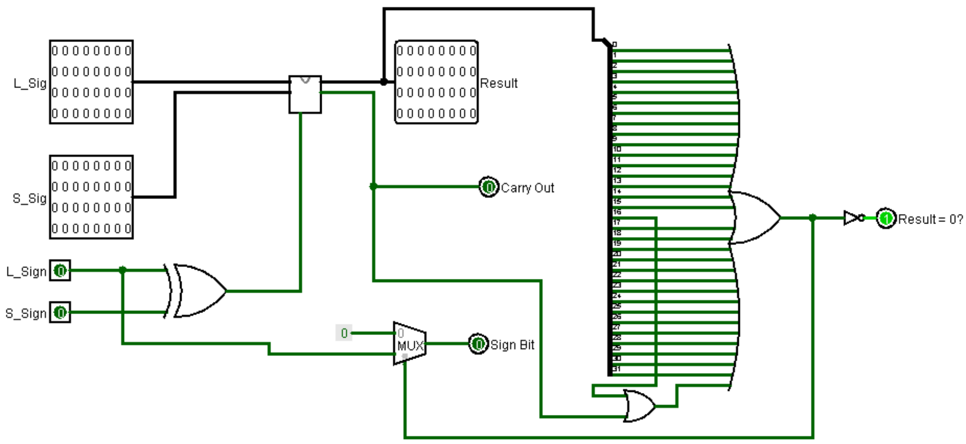
3.2 Adder Library

The adder library contains circuits essential for performing floating-point addition (FPA), including the following:

- **32-Bit ALU:** A core component that performs addition or subtraction on the significands of two input floating-point numbers. It uses a control signal to toggle between addition (0) and subtraction (1) modes.
- **Significand Adder:** This unit manages the input significands, determining the operation type based on the signs of the inputs. Additionally, if the resulting significand is zero, it sets the output sign to zero.



(a) 32-Bit ALU

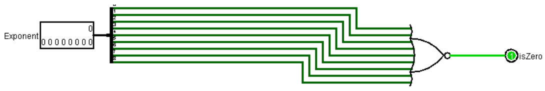


(b) Significant Adder

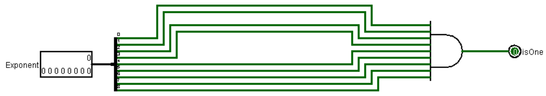
Figure 2: Adder Library

3.3 Checker Library

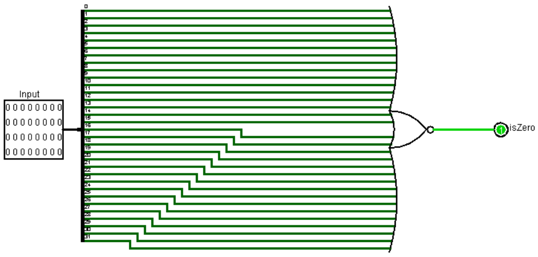
The 9 bit Zero Checker (`0_checker.circ`) checks whether the Exponent's all 9 bits are zero or not. Same for the 9 bit One Checker (`1_checker.circ`) whether the Exponent's all 9 bits are one or not. The 32 bit Zero Checker (`32bit_0_checker.circ`) checks whether the significand's all 32 bits are zero or not.



(a) 9 bit Zero Checker



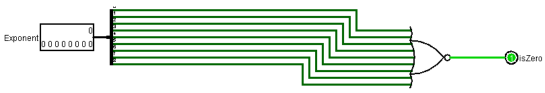
(b) 9 bit One Checker



(c) 32 bit Zero Checker

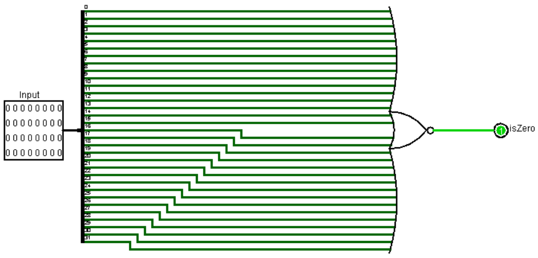
Figure 3: Checker Library

The 9 bit Zero Checker[0_checker.circ] checks whether the Exponent's all 9 bits are zero or not. Same for the 9 bit One Checker[1_checker.circ] whether the Exponent's all 9 bits are one or not.The 32 bit Zero Checker[32bit_0_checker.circ] checks whether the significand's all 32 bits are zero or not.



(a) 9 bit Zero Checker

(b) 9 bit One Checker



(c) 32 bit Zero Checker

Figure 4: Checker Library

3.4 Shifter Library

Left Shifters:Liberty The left shifters can shift bits by 1, 2, 4, 8, or 16 positions:

- `1 LeftShift` - Shifts left by 1 bit
- `2 LeftShift` - Shifts left by 2 bits
- `4 LeftShift` - Shifts left by 4 bits
- `8 LeftShift` - Shifts left by 8 bits
- `16 LeftShift` - Shifts left by 16 bits

Right Shifters: The right shifters can shift bits by 1, 2, 4, 8, or 16 positions:

- `1 RightShift` - Shifts right by 1 bit

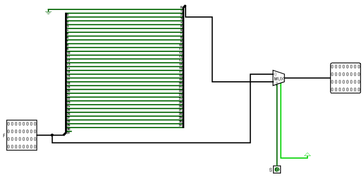
- `2 RightShift` - Shifts right by 2 bits
- `4 RightShift` - Shifts right by 4 bits
- `8 RightShift` - Shifts right by 8 bits
- `16 RightShift` - Shifts right by 16 bits

Arbitrary Shifters: These shifters can shift by any number of bits up to 31 bits:

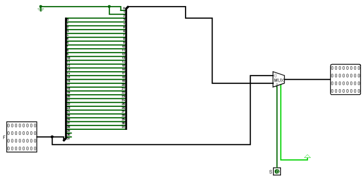
- `Arbitary LeftShift` - Shifts left by an arbitrary number of bits (up to 31)
- `Arbitary RightShift` - Shifts right by an arbitrary number of bits (up to 31)

Right Shifter with Empty: This shifter sets all bits to 0 if the shift amount exceeds 31 bits:

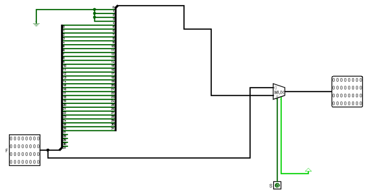
- `Right Shift With Empty` - Right shifts up to 31 bits, or sets all bits to 0 if more than 31 bits



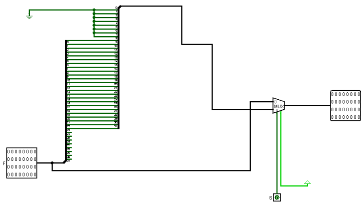
(a) 1 bit left shifter



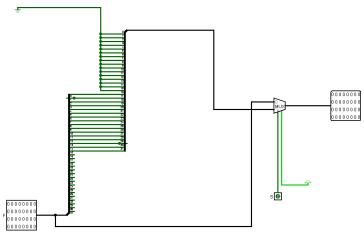
(b) 2 bit left shifter



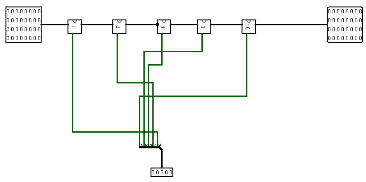
(c) 4 bit left shifter



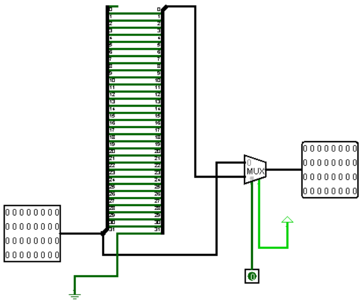
(d) 8 bit left shifter



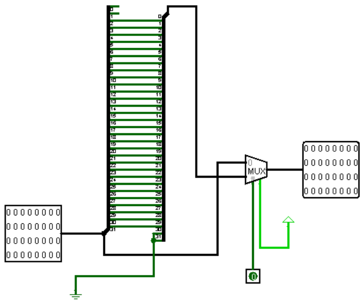
(e) 16 bit left shifter



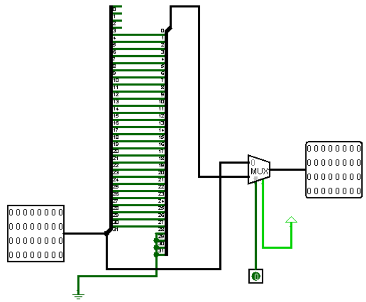
(f) Arbitary left shifter



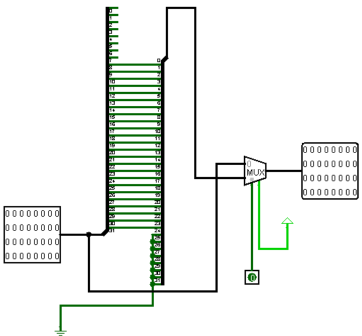
(g) 1 bit right shifter



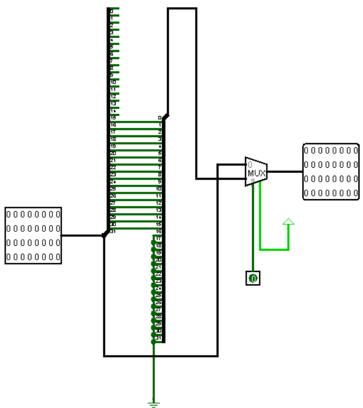
(h) 2 bit right shifter



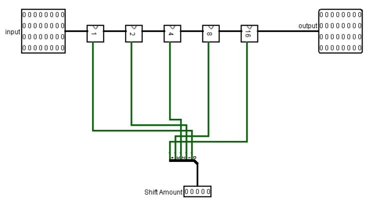
(i) 4 bit right shifter



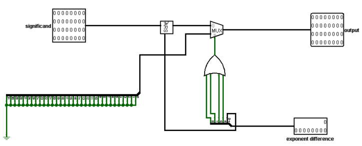
(j) 8 bit right shifter



(k) 16 bit right shifter



(l) Arbitary Right Shifter

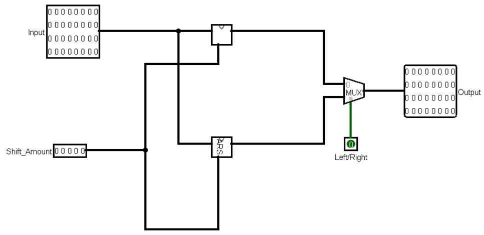


(m) Right Shift with empty

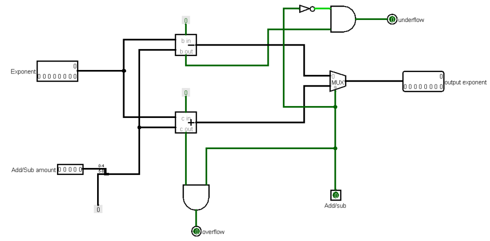
Figure 5: Shifter Circuits

3.5 Normalizer Library

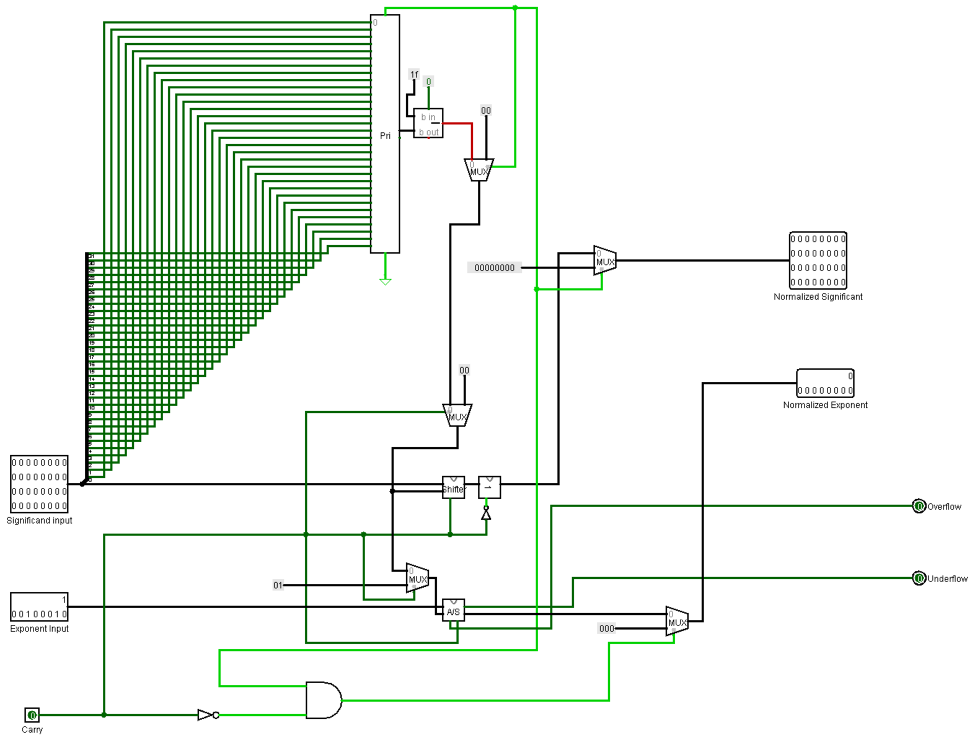
This library contains 3 circuits. a 32 bit shifter, an 9 bit ALU(for addition and subtraction) and a normalizer.



(a) 32 bit shifter



(b) 9 bit ALU



(c) Normalizer

Figure 6: Normalizer Library

3.6 Rounder

The name of the Module is Rounder.circ. It contains two OR gate,one AND gate and a full Adder and does the rounding of the mantissa.

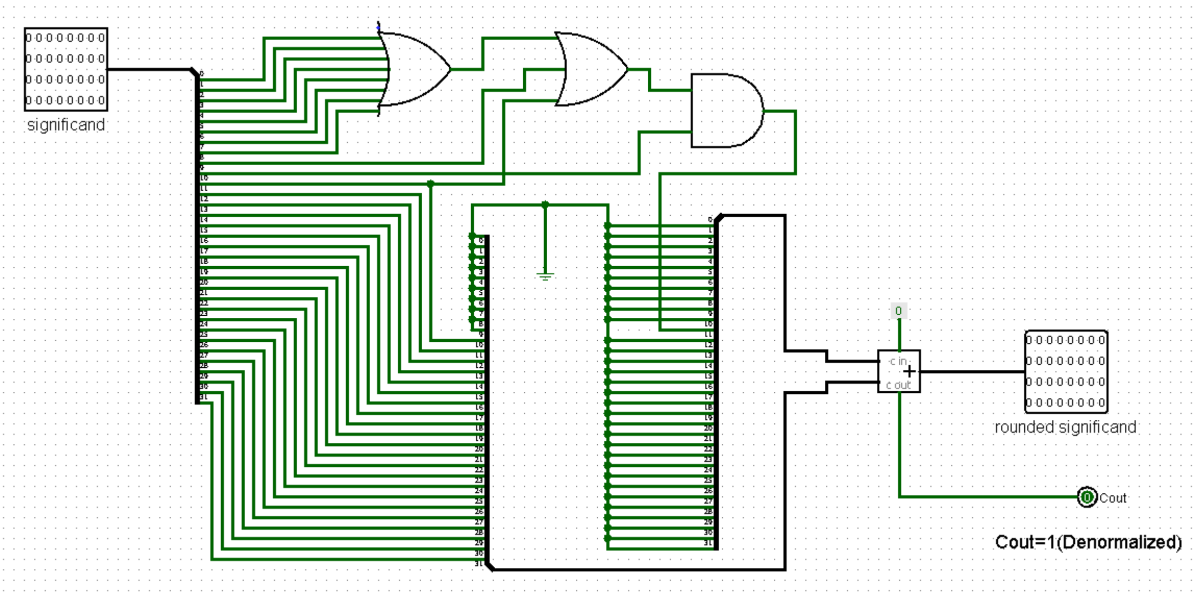


Figure 7: Rounder Circuit

3.7 Rounded Normalizer

Circuit to check whether the output from Rounder is normalized or not. If not, it normalizes the result and also checks for overflow and normalization.

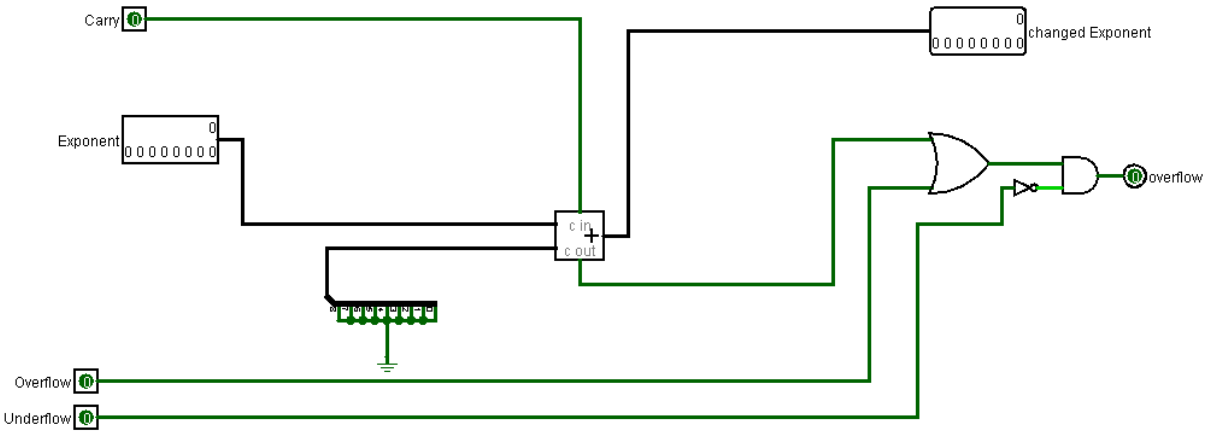


Figure 8: Rounded Normalizer

3.8 Flag Checker

The flag checker[Flag.circ] checks the properties of the result whether the result is denormalized or underflow or overflow or NaN or INF.

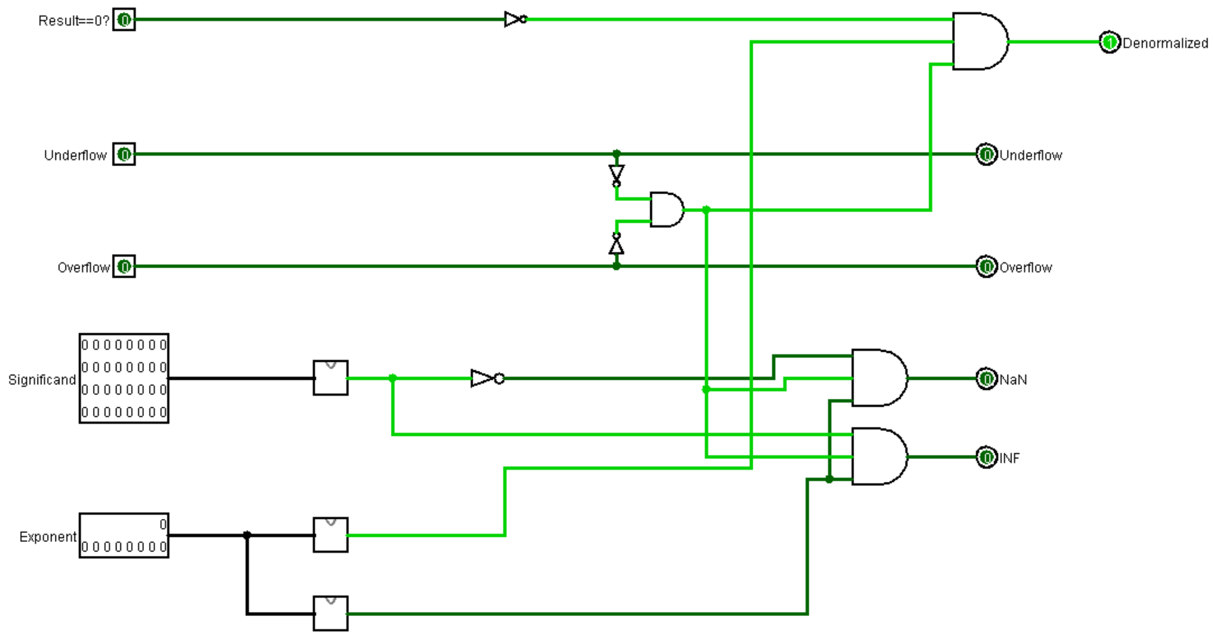


Figure 9: Flag Checker

3.9 Output Presenter

THis circuit is responsible for formatting the final output of a floating-point computation. It takes as input a 1-bit sign, a 9-bit exponent, and a 32-bit significand. The circuit combines these inputs by preserving the 1 sign bit, 9 exponent bits, and selecting the 22 most significant bits from the 32-bit significand to create a standardized 32-bit output. This ensures the output aligns with the desired floating-point format, effectively rounding the significand to fit the 32-bit structure.

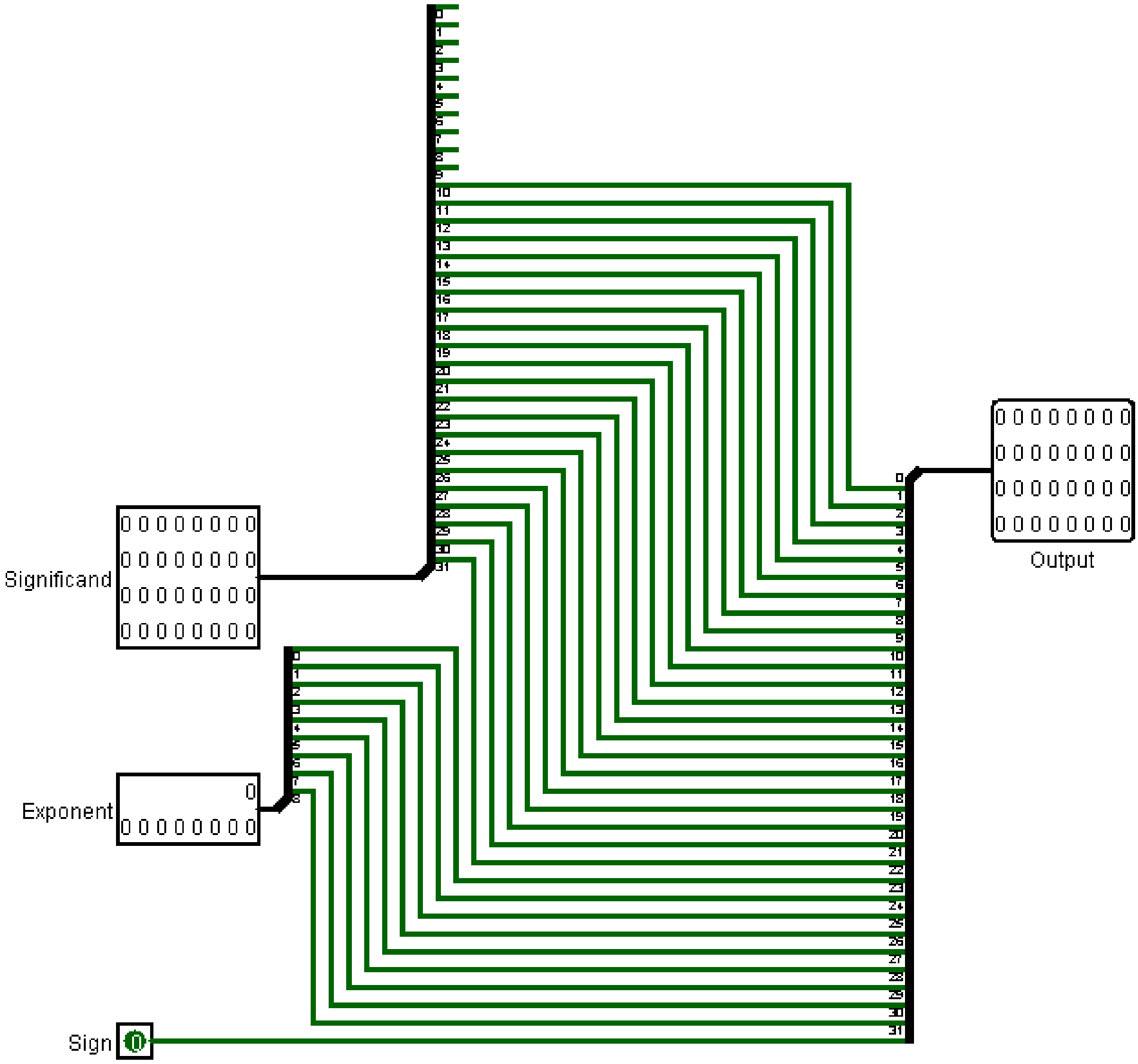


Figure 10: Output Processor of the Result

4 Floating Point Adder

The last module, called FPA.circ, uses the libraries and other modules to fully create a floating point adder. It has the real floating point adder, or circuit FPA. The output processor circuit that merges the sign, exponent, and significand of the result is also included in this module.

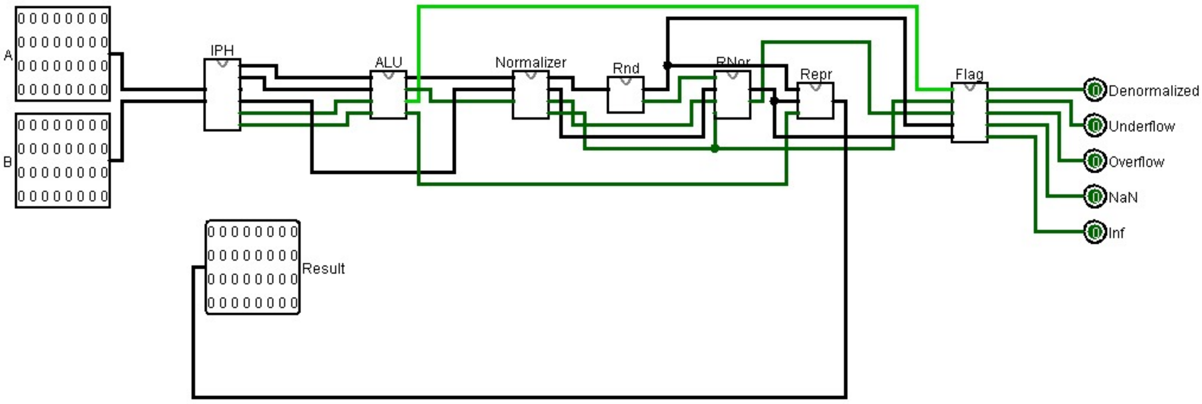


Figure 11: The FPA

5 Flowchart of the Addition/Subtraction Algorithm

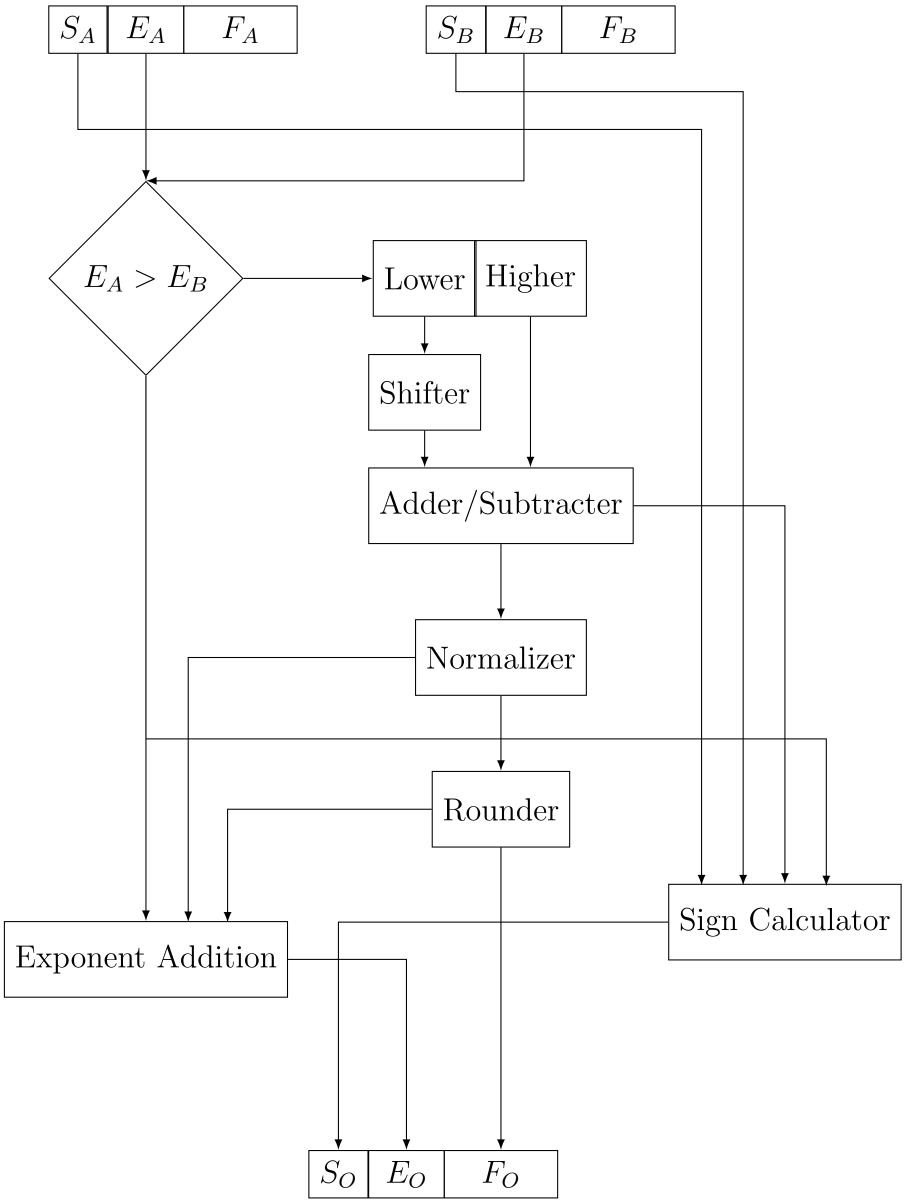


Figure 12: Flow chart of the addition/substraction algorithm

6 Comprehensive Design Description

6.1 Comparing the Exponents and Aligning Radix Point

The radix points need to be lined up in order to add two floating-point values. To align the input with the larger input, this is usually accomplished by moving the input with the smaller exponent to the right. We have computed the difference between the two inputs using a 9-bit subtractor and compared their exponents using a comparator.

6.2 Shifting

All shifting operations have been carried out using shifters based on multiplexers. We have employed five 32-bit multiplexers to obtain bit shifts of any arbitrary value up to 31. The multiplexers have the ability to shift 1, 2, 4, 8, and 16 bits in turn. Combining them yields shifts of any length up to 31, as 3f and 3l illustrate. It could take more than 31 shifts to align two fractions, in which case all bits would be 0. Furthermore, the exponent difference ought to be the shifter circuit's input. Thus, after all seven of the higher bits are clear, the lower five bits are used for shifting. The shift amount does not exceed $31(2^5 - 1)$ just in that scenario. Otherwise, the fraction will be 0(all bits cleared), which is done in 3m.

6.3 Normalization

First we find out the location of first set bit using priority encoder. Then subtract the location from from 32 to get the shift amount. We shift the significand by the shift amount to the left and also decrease the exponent by the shift amount. If we have carry from adder, we simply increase the exponent by 1 and shift the significand by 1 to the left.

6.4 Rounding

We used a 32-bit adder to add and subtract the mantissas. However, we occasionally need to round the result because we can only hold 22 bits. The 23st bit is regarded as the *guard bit*, and the 24nd as the *round bit*. The *sticky bit* will be set if any of the bits to the right of the round bit are set; otherwise, it remains unset.

19th bit	G	R	S	Action
$\times$	0	$\times$	$\times$	Truncate
1	1	$\times$	$\times$	Round up
0	1	0	0	Truncate
$\times$	1	1	$\times$	Round up
$\times$	1	$\times$	1	Round up

Actually, $X100$ is the case for round-to-even. So, if the 22th bit is 0, we need to do nothing, hence truncation. Otherwise, we will round up. For simplification, we will use a K-map. (22th bit $= M$)

$MG \backslash RS$	00	01	11	10
00	0	0	0	0
01	0	1	1	1
11	1	1	1	1
10	0	0	0	0

$$\text{flag} = GS + GR + MG = G(M + R + S)$$

If the flag is set, 1 is added at the 22th position. Otherwise, the bits beyond the 23st position are truncated.

6.5 Rounded Normalization

This circuit adjusts the exponent of a floating-point number when a carry is generated from the rounding process. If the rounding operation results in a carry, this circuit increments the exponent by 1. Additionally, it includes overflow detection to ensure that the incremented exponent does not exceed its maximum value. If an overflow condition is detected, the circuit outputs a signal to indicate the overflow, ensuring accurate handling of the floating-point result within the specified range.

6.6 Flag Checking

The Flag Checking process is responsible for determining the status of the floating-point result based on various conditions. It evaluates specific flags such as Underflow, Overflow, Significand, and Exponent, to identify special cases in floating-point arithmetic. Depending on these inputs, it assigns a flag indicating one of several possible outcomes: $Denormalized, INF$(Infinity), NaN(Not a Number), $Underflow$ or $Overflow$. This mechanism ensures proper categorization of edge cases, providing clarity in scenarios where the result deviates from a normalized floating-point value.

Input					Flag
Result=0?	Underflow	Overflow	Significand	Exponent	
0	×	×	0	0	Denormalized
×	1	×	Not Zero	0	Demornalized
×	×	×	0	511	INF
×	×	×	Not Zero	511	NaN
×	1	×	Not Zero	0 to 510	Underflow
×	×	1	Not Zero	0 to 510	Overflow

Table 4: Flag Checking

7 ICs Used with Count as a Chart

IC Number	Quantity
IC 74157	183
IC 7432	43
IC 7408	15
IC 7483	72
Comparator	4
IC 7402	3
IC 7404	4
IC 74148	4

Table 5: IC count

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8 Simulator used Along with the Version Number

$logisim - generic - 2.7.1$ has been used for simulating the floating point adder circuit.

9 Discussion

In our project, we aimed to implement a novel design of a Floating Point Adder (FPA). Rather than designing the entire circuit from scratch, we opted for a modular approach, building separate components first and then integrating them to create a functional circuit. This strategy not only simplified the process but also allowed us to distribute the workload effectively.

We encountered several challenges along the way. The first significant challenge was designing a shifter capable of shifting by any arbitrary amount. To achieve this, we combined 1, 2, 4, 8, and 16-bit shifters in a serial configuration, where each shifter corresponded to one of the bits in the shift amount.

The next challenge we faced to detect underflow and overflow. We checked for underflow and overflow in our normalizer part. But for accurate output we again had to check for overflow in our rounded normalizer part.

The toughest part of FPA was normalizer. Designing and testing the normalizer took most of our time. But at last we made it and it works fine.

To ensure a minimal yet fully functional design, we used a combination of built-in circuits from the Logisim library and our own custom circuits.

Overall, designing and implementing the floating-point adder was a rewarding experience that deepened our understanding of its inner workings.