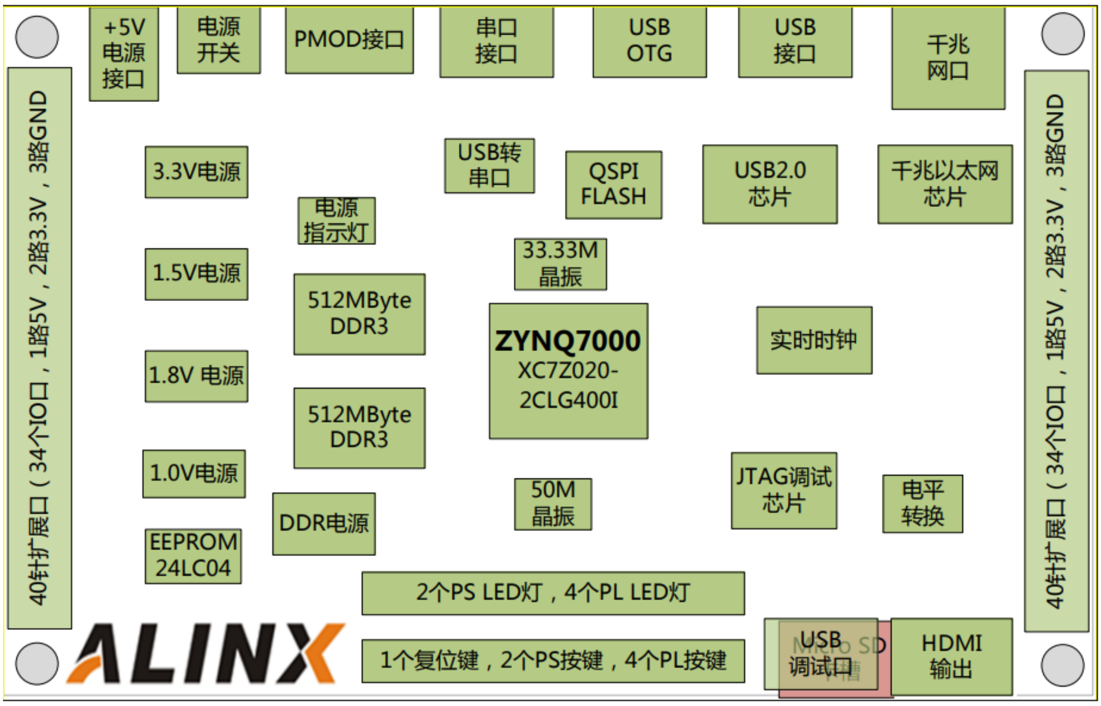
2024-3-31

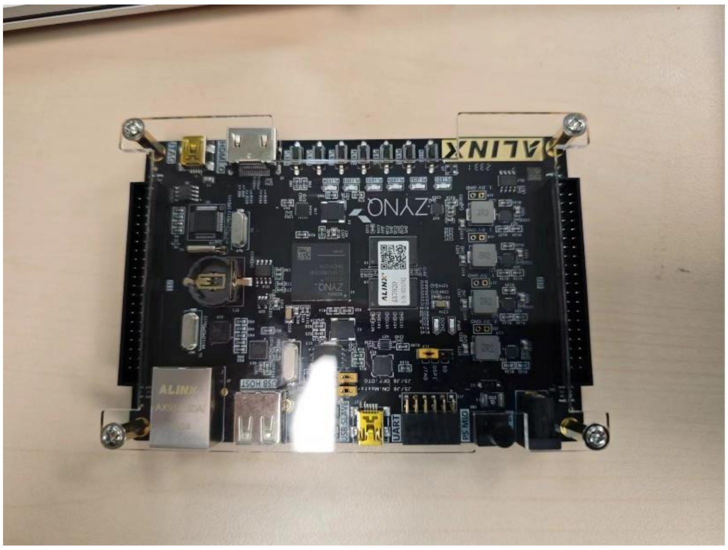
MSD 加法与电子加法计算时间对比实验

1 实验用具

针对此次试验我们采用 Alinx7020，此款开发板使用的是 Xilinx 公司的 Zynq7000 系列的芯片，型号为 XC7Z020-2CLG400I， 400 个引脚的 FBGA 封装。ZYNQ7000 芯片可分成处理器系统部分 Processor System（PS） 和可编程逻辑部分 Programmable Logic（PL）。在 AX7020 开发板上，ZYNQ7000 的 PS 部分和 PL 部分都搭载了丰富的外部接口和设备，方便用户的使用和功能验证。另外开发板上 集成了 Xilinx USB Cable 下载器电路，用户只要用一个 USB 线就可以对开发板进行下载和调 试。图 1 为整个 AX7020 整个系统的结构示意图:



通过这个示意图，我们可以看到，我们这个开发平台所能含有的接口和功能。下面是实物展示：



实验目的

针对两种电子加法器的性能测试以及对比，我们将使用 XC7Z020-2CLG400I 型 FPGA 开发板上的资源。首先，我们会利用该板上的双核 ARM Cortex-A9 中的传统加法器，该加法器为 32 位，代表第一种加法器。接着，我们将利用可编程逻辑单元阵列（PL）在同一开发板上构建多个 33 位的最高有效位（MSD）加法器，以代表第二种加法器。

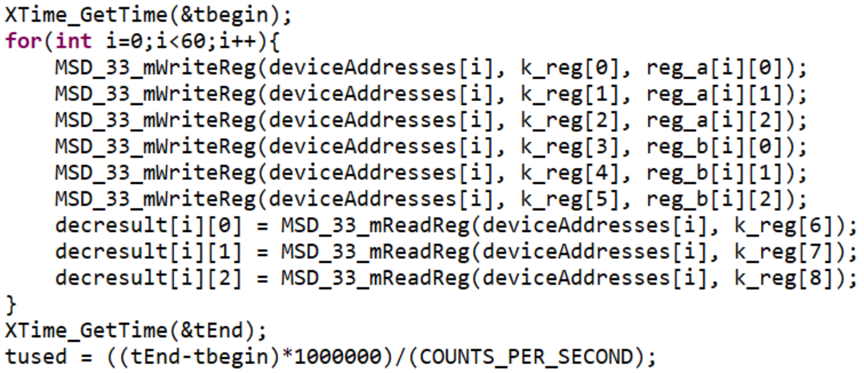
在测试过程中，我们将记录并比较两种加法器的计算用时。对于第一种加法器，我们将测试其处理一个 32 位数据的加法所需的时间。而对于第二种加法器，我们会测试其处理多个 33 位数据的加法所需的时间，并且注意到由于其并行处理的特性，其计算时间可能会显著减少。

通过这些测试，我们将能够直观地评估两种加法器的性能优劣，进而了解到是否值得投资于构建更复杂但性能更优异的 MSD 加法器。

期望的实验结果：第 2 种加法器的工作用时短。即：第 2 种加法器快。

实验准备

1. **时间计算：**在 Xilinx 提供的库中，`xtime_l.h` 是与时间管理相关的一个头文件，用于处理时间和延时功能。XTime_GetTime(XTime Xtime) 获取当前时间，结果存储在 Xtime 中。通过计算时间差再乘以时钟周期获取到准确时间。Alinx 的频率为 50Mhz 对应时钟周期是 20ns。



```
XTime_GetTime(&tbegin);
for(int i=0;i<60;i++){
    MSD_33_mWriteReg(deviceAddresses[i], k_reg[0], reg_a[i][0]);
    MSD_33_mWriteReg(deviceAddresses[i], k_reg[1], reg_a[i][1]);
    MSD_33_mWriteReg(deviceAddresses[i], k_reg[2], reg_a[i][2]);
    MSD_33_mWriteReg(deviceAddresses[i], k_reg[3], reg_b[i][0]);
    MSD_33_mWriteReg(deviceAddresses[i], k_reg[4], reg_b[i][1]);
    MSD_33_mWriteReg(deviceAddresses[i], k_reg[5], reg_b[i][2]);
    decresult[i][0] = MSD_33_mReadReg(deviceAddresses[i], k_reg[6]);
    decresult[i][1] = MSD_33_mReadReg(deviceAddresses[i], k_reg[7]);
    decresult[i][2] = MSD_33_mReadReg(deviceAddresses[i], k_reg[8]);
}
XTime_GetTime(&tEnd);
tused = ((tEnd-tbegin)*1000000)/(COUNTS_PER_SECOND);
```

2. **MSD 加法器并行原理：**在可编程逻辑 (PL) 端，我们采用信号机制来协调多个运算单元的操作。具体来说，当 60 个多位数数字 (MSD) 加法器完成填充操作后，系统会通过一个同步信号触发所有加法器并行开始计算。这

种方式确保了所有加法器同时进行运算，提高了整体计算效率。最终，所有加法器的计算结果会统一返回，确保数据处理的一致性和同步性。

实验策略

1. 利用第二种加法器的“可重构出任意大小加法器”的特性，我们构建了一个 33 位的最高有效位（MSD）加法器。这样，我们可以直接对 33 位数据进行加法运算，而第一种加法器则需要两次计算才能完成一个加法运算：首先计算低 32 位，然后计算高 32 位（尽管实验数据中仅有一位）。相比之下，第二种加法器只需一次计算就能完成 33 位数据的加法。
2. 利用第二种加法器的“可重构出多个加法器”的优势，我们构建了 60 个 33 位的 MSD 加法器，并使它们能够并行工作。这意味着我们可以一次性计算 60 个 33 位数的加法，而第一种加法器则只能逐个计算 33 位数的加法（每次加法还需要两次计算）

实验过程

第一步：数据准备。我们将 60 对原始数据送入内存。数据范围是 2^32-2^33，范围从 4294967295 到 8589934591

```
data_a= [
    6163550658, 6413109763, 4493162740, 4459676060, 6148214032,
    5439006107, 4433876780, 5861763895, 5221972308, 4935524470,
    5389687797, 4354296534, 4790236573, 6306732821, 5654945182,
    6069373681, 4870013515, 6180308189, 6221500578, 6329734393,
    5090246305, 5522595258, 5387336040, 4360315825, 5515023509,
    5973410702, 5784501258, 5232857401, 6019818661, 4846029805,
    5046807674, 6106273973, 4637160715, 5392211615, 5555725575,
    5791996815, 5837229290, 5778789187, 5203953563, 4309582241,
    6168520261, 5470611017, 4386111010, 6026674767, 5689423199,
    4785091805, 4964832056, 5654890046, 4737018386, 5437568557,
```

6000280530, 6126097812, 5537764560, 6096738408, 5350641731,
5545828808, 6339368421, 6375512686, 6240230742, 5127674579]

data_b= [
5670367407, 5412345023, 5914847405, 6128327586, 4587896338,
5026686114, 4935222256, 4760041748, 4614409077, 4377978840,
5175819138, 5634001496, 5947783309, 4908543247, 5960452096,
5591331536, 4727949047, 5955264796, 5970133931, 6321056983,
6073297128, 4455663635, 4521584003, 6273163952, 5632439975,
6265859821, 6278962862, 5399591672, 6238104244, 6005097228,
5727386570, 6035573062, 4814809633, 5901575191, 4373607691,
4403649190, 6153957194, 6109318345, 4673901860, 4906714130,
4635253234, 5761701894, 6103554071, 5135616837, 4835360414,
5610035924, 5553855281, 5663039910, 4390156807, 6134636813,
4409012067, 5272496534, 5612425667, 4960474159, 4752740764,
5935161763, 6080424745, 5902262331, 4863341116, 5603599112]

第二步：加法运算。在第一种加法器上，需要重复执行 60 次加法指令。而在第二种加法器上，由于其并行处理能力，我们只需重复执行 1 次加法指令（运算），每次同时计算 60 对位数据。

1. **第一种加法器：**

```
for (int i = 0; i < NUM_BINARIES; i++)
{
        binary_add(bin_nums_a, bin_nums_b, bin_result, i);
}
```

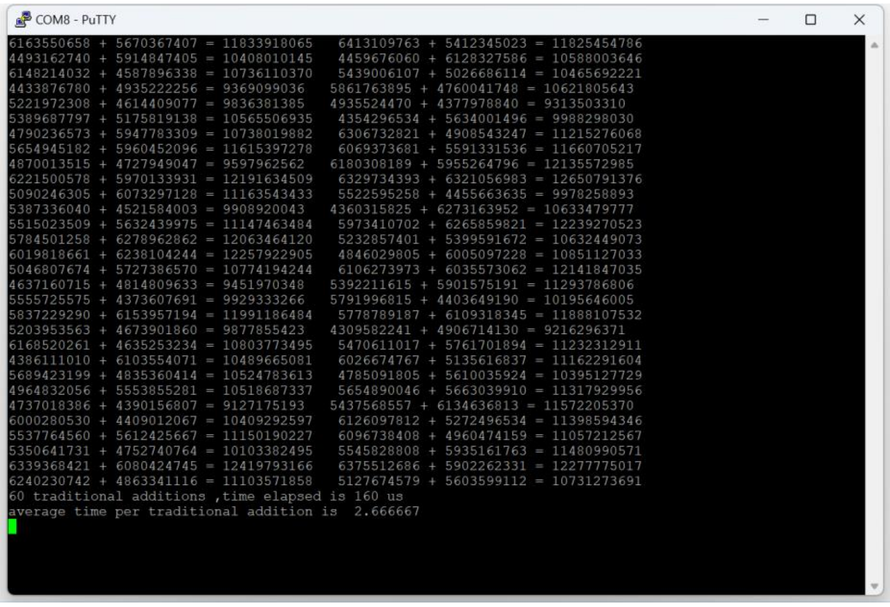
2. **第二种加法器：**

```
MSD_33_mWriteReg(deviceAddresses[i], k_reg[0], reg_a[i][0]);
MSD_33_mWriteReg(deviceAddresses[i], k_reg[1], reg_a[i][1]);
MSD_33_mWriteReg(deviceAddresses[i], k_reg[2], reg_a[i][2]);
MSD_33_mWriteReg(deviceAddresses[i], k_reg[3], reg_b[i][0]);
MSD_33_mWriteReg(deviceAddresses[i], k_reg[4], reg_b[i][1]);
MSD_33_mWriteReg(deviceAddresses[i], k_reg[5], reg_b[i][2]);
decresult[i][0] = MSD_33_mReadReg(deviceAddresses[i],
k_reg[6]);
```

```
    decresult[i][1] = MSD_33_mReadReg(deviceAddresses[i],
    k_reg[7]);
    decresult[i][2] = MSD_33_mReadReg(deviceAddresses[i],
    k_reg[8]);
```

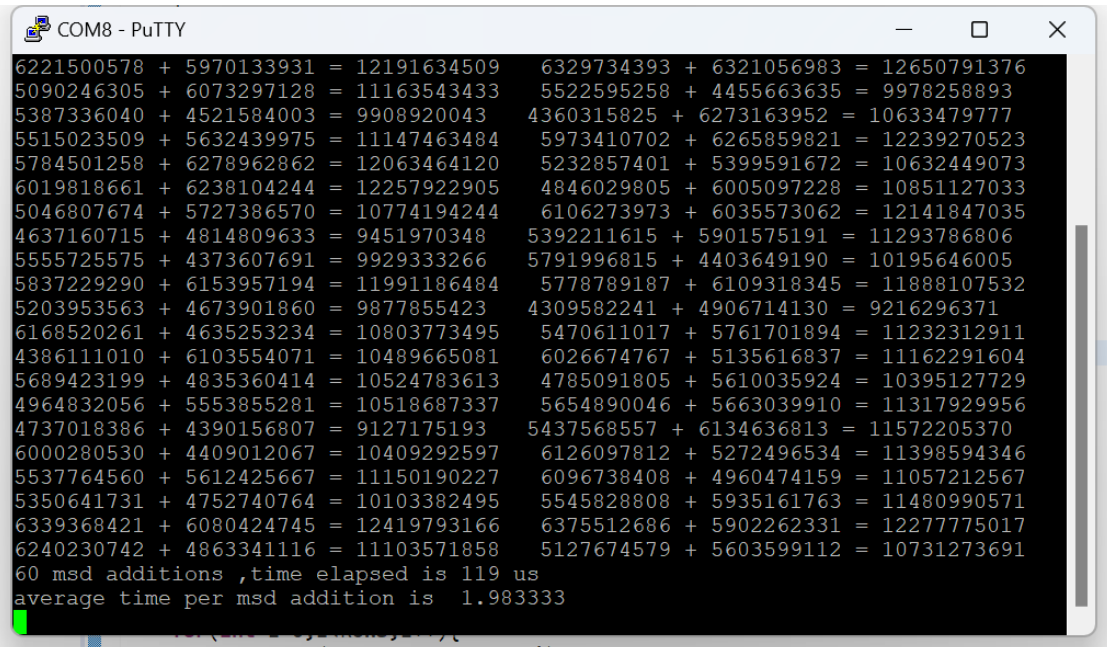
第三步：显示运算结果。第二步的运算结果会先存储在内存中。当 60 个数据计算完毕后，再执行第三步。屏幕将显示如下信息：

第一种加法器实验结果：



```
6163550658 + 5670367407 = 11833918065   6413109763 + 5412345023 = 11825454786
4493162740 + 5914847405 = 10408010145   4459676060 + 6128327586 = 10588003646
6148214032 + 4587896338 = 10736110370   5439006107 + 5026686114 = 10465692221
4433876780 + 4935222256 = 9369099036   5861763895 + 4760041748 = 10621805643
5221972308 + 4614409077 = 9836381385   4935524470 + 4377978840 = 9313503310
5389687797 + 5175819138 = 10565506935   4354296534 + 5634001496 = 9988298030
4790236573 + 5947783309 = 10738019882   6306732821 + 4908543247 = 11215276068
5654945182 + 5960452096 = 11615397278   6069373681 + 5591331536 = 11660705217
4870013515 + 4727949047 = 9597962562   6180308189 + 5955264796 = 12135572985
6221500578 + 5970133931 = 12191634509   6329734393 + 6321056983 = 12650791376
5090246305 + 6073297128 = 11163543433   5522595258 + 4455663635 = 9978258893
5387336040 + 4521584003 = 9908920043   4360315825 + 6273163952 = 10633479777
5515023509 + 5632439975 = 11147463484   5973410702 + 6265859821 = 12239270523
5784501258 + 6278962862 = 12063464120   5232857401 + 5399591672 = 10632449073
6019818661 + 6238104244 = 12257922905   4846029805 + 6005097228 = 10851127033
5046807674 + 5727386570 = 10774194244   6106273973 + 6035573062 = 12141847035
4637160715 + 4814809633 = 9451970348   5392211615 + 5901575191 = 11293786806
5555725575 + 4373607691 = 9929333266   5791996815 + 4403649190 = 10195646005
5837229290 + 6153957194 = 11991186484   5778789187 + 6109318345 = 11888107532
5203953563 + 4673901860 = 9877855423   4309582241 + 4906714130 = 9216296371
6168520261 + 4635253234 = 10803773495   5470611017 + 5761701894 = 11232312911
4386111010 + 6103554071 = 10489665081   6026674767 + 5135616837 = 11162291604
5689423199 + 4835360414 = 10524783613   4785091805 + 5610035924 = 10395127729
4964832056 + 5553855281 = 10518687337   5654890046 + 5663039910 = 11317929956
4737018386 + 4390156807 = 9127175193   5437568557 + 6134636813 = 11572205370
6000280530 + 4409012067 = 10409292597   6126097812 + 5272496534 = 11398594346
5537764560 + 5612425667 = 11150190227   6096738408 + 4960474159 = 11057212567
5350641731 + 4752740764 = 10103382495   5545828808 + 5935161763 = 11480990571
6339368421 + 6080424745 = 12419793166   6375512686 + 5902262331 = 12277775017
6240230742 + 4863341116 = 11103571858   5127674579 + 5603599112 = 10731273691
60 traditional additions ,time elapsed is 160 us
average time per traditional addition is  2.666667
```

第二种加法器：



```
6221500578 + 5970133931 = 12191634509   6329734393 + 6321056983 = 12650791376
5090246305 + 6073297128 = 11163543433   5522595258 + 4455663635 = 9978258893
5387336040 + 4521584003 = 9908920043   4360315825 + 6273163952 = 10633479777
5515023509 + 5632439975 = 11147463484   5973410702 + 6265859821 = 12239270523
5784501258 + 6278962862 = 12063464120   5232857401 + 5399591672 = 10632449073
6019818661 + 6238104244 = 12257922905   4846029805 + 6005097228 = 10851127033
5046807674 + 5727386570 = 10774194244   6106273973 + 6035573062 = 12141847035
4637160715 + 4814809633 = 9451970348   5392211615 + 5901575191 = 11293786806
5555725575 + 4373607691 = 9929333266   5791996815 + 4403649190 = 10195646005
5837229290 + 6153957194 = 11991186484   5778789187 + 6109318345 = 11888107532
5203953563 + 4673901860 = 9877855423   4309582241 + 4906714130 = 9216296371
6168520261 + 4635253234 = 10803773495   5470611017 + 5761701894 = 11232312911
4386111010 + 6103554071 = 10489665081   6026674767 + 5135616837 = 11162291604
5689423199 + 4835360414 = 10524783613   4785091805 + 5610035924 = 10395127729
4964832056 + 5553855281 = 10518687337   5654890046 + 5663039910 = 11317929956
4737018386 + 4390156807 = 9127175193   5437568557 + 6134636813 = 11572205370
6000280530 + 4409012067 = 10409292597   6126097812 + 5272496534 = 11398594346
5537764560 + 5612425667 = 11150190227   6096738408 + 4960474159 = 11057212567
5350641731 + 4752740764 = 10103382495   5545828808 + 5935161763 = 11480990571
6339368421 + 6080424745 = 12419793166   6375512686 + 5902262331 = 12277775017
6240230742 + 4863341116 = 11103571858   5127674579 + 5603599112 = 10731273691
60 msd additions ,time elapsed is 119 us
average time per msd addition is  1.983333
```

数据对比见 MSD 数据对比.xlsx

附录

MSD 加法代码

```
#include "stdio.h"
#include "stdlib.h"
#include "string.h"
#include "xparameters.h"
#include "msd_33.h"
#include "xil_io.h"
#include "sleep.h"
#include "stdlib.h"
#include "stdint.h"
#include "math.h"
#include "xtime_l.h"
#define max(a, b) ((a) > (b) ? (a) : (b))
#define START_ADDRESS 0x43c00000
#define END_ADDRESS 0x43FB0000
#define STEP_SIZE 0x10000 // 假设步长为 0x10000
#define ROWS 60
#define COLS 3
#define ARRAY_SIZE 60

long long* generate_random_array(long long* array, int size, int
random_seed) {
    long long lower_bound = (1LL << 32) - 1;  // 2^32 - 1
    long long upper_bound = (1LL << 33) - 1;  // 2^33 - 1
    srand(random_seed);

    // 生成随机数并存储在数组中
    for (int i = 0; i < size; ++i) {
        array[i] = ((long long)rand() % (upper_bound - lower_bound + 1)) +
lower_bound;
    }

    return array;
}
void decToBin(long long dec, int bin[])
{
    if (dec < 0)
    {
        dec *= -1;
        bin[0] = 1; // 0代表正，1代表负
    }
    else
    {
        bin[0] = 0;
    }
    long long num = dec;

    int temp[99];
    int i;
    for (i = 0; num != 0; i++)
    {
        temp[i] = num % 2; // 使用 % 运算符计算余数
        num /= 2;
    }
    for (int j = 1, index = i - 1; j <= i; j++, index--)
    {
        bin[j] = temp[index];
    }
    bin[i + 1] = -2; // 结束标志
}

void binToMsd(int bin[], int msd[])
{
    int index_msd = 0;
    if (bin[0] == 1)
    {
        for (int index_bin = 1; bin[index_bin] != -2; index_bin++,
index_msd++)
        {
            msd[index_msd] = 0;
            if (bin[index_bin] == 1)
                msd[index_msd] = -1;
        }
        msd[index_msd] = -2; // 结束标志
    }
    else
    {
        for (int index_bin = 1; bin[index_bin] != -2; index_bin++,
index_msd++)
        {
            msd[index_msd] = bin[index_bin];
        }
        msd[index_msd] = -2; // 结束标志
    }
}

int bin_to_dec(char bin[], int len)
{
    int result = 0, base = 1;
    for (int i = len - 1; i >= 0; i--, base = base * 2)
        result = result + (bin[i] - '0') * base;
    return result;
}

long long msdToDec(int msd[])
{
    long long result = 0;
    int len = 0;
    for (; msd[len] != -2; len++)
        ;

    for (int i = 0, j = len - 1; i < len; i++, j--)
    {
        long long t = 1;
        for (int k = 0; k < j; k++)
        {
            t *= 2;
        }
        result += msd[i] * t;
    }
    return result;
}

void convertToBinaryString(int *msd, char *result)
{
    int i = 0;
    while (msd[i] != -2)
    {
        if (msd[i] == 0)
        {
            strcat(result, "00");
        }
        else if (msd[i] == 1)
        {
            strcat(result, "01");
        }
        else if (msd[i] == -1)
        {
            strcat(result, "10");
        }
        i++;
    }
}

void binaryStringToMSD(char *binaryString, int *intArray, int length)
{
    for (int i = 0; i < length; i++)
    {
        char tmp[3];
        strncpy(tmp, binaryString + i * 2, 2);
        tmp[2] = '\0';

        if (strcmp(tmp, "00") == 0)
        {
            intArray[i] = 0;
        }
        else if (strcmp(tmp, "01") == 0)
        {
            intArray[i] = 1;
        }
        else if (strcmp(tmp, "10") == 0)
        {
            intArray[i] = -1;
        }
        // Add more conditions as needed
    }
}

void cdecToBin(unsigned value, int bits, char *binaryArray)
{
    for (int i = bits - 1; i >= 0; i--)
    {
        binaryArray[bits - 1 - i] = ((value >> i) & 1) + '0';
    }
    binaryArray[bits] = '\0'; // 添加 null 终止符
}
```

```
void write_reg(unsigned int  array[][3], long long value,int row) {
    int bin[36];
    int msd[36];
    decToBin(value, bin);
    binToMsd(bin, msd);
    char z[67] = "";
    convertToBinaryString(msd, z);
    int len_z = strlen(z);
    if (len_z <= 32)
    {
        array[row][0] = bin_to_dec(z, len_z);
    }
    else if (len_z > 32 && len_z <= 64)
    {
        array[row][0] = bin_to_dec(z + len_z - 32, 32);
        array[row][1] = bin_to_dec(z, len_z - 32);
    }
    else if (len_z > 64 && len_z <= 96)
    {
        array[row][0] = bin_to_dec(z + len_z - 32, 32);
        array[row][1] = bin_to_dec(z + len_z - 64, 32);
        array[row][2] = bin_to_dec(z, len_z - 64);
    }
}
void printUnsignedArray(unsigned int array[][3], int rows, int cols) {
    for (int i = 0; i < rows; ++i) {
        for (int j = 0; j < cols; ++j) {
            printf("%u ", array[i][j]);
        }
        printf("\n");
    }
}

void regToDec(unsigned int decresult[][3],long long * ansDec,int index){
    char ans_c[70] = "";
    cdecToBin(decresult[index][2], 6, ans_c);
    cdecToBin(decresult[index][1], 32, ans_c + 6);
    cdecToBin(decresult[index][0], 32, ans_c + 38);
    int msd_c[40];

    int length = strlen(ans_c) / 2; // Assuming the length is even
    binaryStringToMSD(ans_c, msd_c, length);
    msd_c[length] = -2;
    ansDec[index] = msdToDec(msd_c);
}

void printLongLongArray(long long array[], int length) {
    for (int i = 0; i < length; ++i) {
        printf("%lld ", array[i]);
    }
    printf("\n");
}

int main() {
    long long array_a[ARRAY_SIZE];
    long long array_b[ARRAY_SIZE];
    int arrayLength = (END_ADDRESS - START_ADDRESS) / STEP_SIZE + 1;
    int deviceAddresses[arrayLength];
    int currentAddress = START_ADDRESS;
    for (int i = 0; i < arrayLength; ++i) {
        deviceAddresses[i] = currentAddress;
        currentAddress += STEP_SIZE;
    }
    XTime tEnd, tbegin;
    u32 tused;
    long long* data_a = generate_random_array(array_a, ARRAY_SIZE,123);
    long long* data_b = generate_random_array(array_b, ARRAY_SIZE,456);
    unsigned int reg_a[ROWS][COLS] = { {0} };
    unsigned int reg_b[ROWS][COLS] = { {0} };
    for(int i=0;i<ROWS;i++){
    write_reg(reg_a,data_a[i],i);
    write_reg(reg_b,data_b[i],i);
    }
    int k_reg[9]={0};
    unsigned int decresult[ROWS][COLS] = { {0} };

    for (int k = 0; k < 9; k++)
    {
        k_reg[k] = k * 4;
    }

    XTime_GetTime(&tbegin);
    for(int i=0;i<60;i++){
        MSD_33_mWriteReg(deviceAddresses[i], k_reg[0], reg_a[i][0]);
        MSD_33_mWriteReg(deviceAddresses[i], k_reg[1], reg_a[i][1]);
        MSD_33_mWriteReg(deviceAddresses[i], k_reg[2], reg_a[i][2]);
        MSD_33_mWriteReg(deviceAddresses[i], k_reg[3], reg_b[i][0]);
        MSD_33_mWriteReg(deviceAddresses[i], k_reg[4], reg_b[i][1]);
        MSD_33_mWriteReg(deviceAddresses[i], k_reg[5], reg_b[i][2]);
        decresult[i][0] = MSD_33_mReadReg(deviceAddresses[i], k_reg[6]);
        decresult[i][1] = MSD_33_mReadReg(deviceAddresses[i], k_reg[7]);
        decresult[i][2] = MSD_33_mReadReg(deviceAddresses[i], k_reg[8]);
    }
    XTime_GetTime(&tEnd);
    tused = ((tEnd-tbegin)*1000000)/(COUNTS_PER_SECOND);

    long long ansDec[ROWS] = {0};
    for(int i=0;i<ROWS;i++){
        regToDec(decresult,ansDec,i);
    }
    for(int i=0;i<60;i++){
        printf("%lld + %lld = %lld   ",data_a[i],data_b[i],ansDec[i]);
        if((i+1)%2==0){
            printf("\n");
        }
    }
    xil_printf("%d msd additions ,time elapsed is %d us\r\n",ROWS,tused);
    float tused_float = (float)tused / 60.0;
    printf("average time per msd addition is  %f\n", tused_float);
    return 0;
}
```

传统计算器加法

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <math.h>
#include "xtime_l.h"

#define NUM_BINARIES 60
#define MAX_BIT_LENGTH 34

// 十进制转二进制   数组低位存二进制低位
void decimal_to_binary(long long decimal_num, int
binary_num[][MAX_BIT_LENGTH], int index)
{
```

```c
    for (int i = 0; i < MAX_BIT_LENGTH; i++)
    {
        binary_num[index][i] = decimal_num % 2;
        decimal_num /= 2;
    }
}

void binary_to_decimal(int binary[][MAX_BIT_LENGTH], long long *result, int index)
{
    long long decimal = 0;
    for (int i = 0; i < MAX_BIT_LENGTH; ++i)
    {
        long long binary_bit = binary[index][i]; // 获取当前位的二进制值
        if (binary_bit)
        {
            decimal += (1LL << i); // 将当前位的二进制值乘以对应的 2 的次方，并累加到十进制数中
        }
    }
    result[index] = decimal;
}
void binary_add(int binary1[][MAX_BIT_LENGTH], int binary2[][MAX_BIT_LENGTH], int result_binary[][MAX_BIT_LENGTH], int index)
{
    int carry = 0;
    for (int i = 0; i < MAX_BIT_LENGTH; i++)
    {
        int sum = binary1[index][i] + binary2[index][i] + carry;
        result_binary[index][i] = sum % 2;
        carry = sum / 2;
    }
}

long long *generate_random_array(long long *array, int size, int random_seed)
{
    long long lower_bound = (1LL << 32) - 1; // 2^32 - 1
    long long upper_bound = (1LL << 33) - 1; // 2^33 - 1
    srand(random_seed);

    // 生成随机数并存储在数组中
    for (int i = 0; i < size; ++i)
    {
        array[i] = ((long long)rand() % (upper_bound - lower_bound + 1)) +
lower_bound;
    }

    return array;
}
void printArray(int array[][34], int rows, int cols)
{
    for (int i = 0; i < rows; ++i)
    {
        for (int j = 0; j < cols; ++j)
        {
            printf("%d", array[i][j]);
        }
        printf("\n");
    }
}

int main()
{
    long long array_a[NUM_BINARIES];
    long long array_b[NUM_BINARIES];
    int(*bin_nums_a)[MAX_BIT_LENGTH] = malloc(NUM_BINARIES *
sizeof(*bin_nums_a));
    int bin_nums_b[NUM_BINARIES][MAX_BIT_LENGTH]={{0}};
    int(*bin_result)[MAX_BIT_LENGTH] = malloc(NUM_BINARIES *
sizeof(*bin_result));
    XTime tEnd, tbegin;
    u32 tused;

    for (int i = 0; i < NUM_BINARIES; i++) {
        for (int j = 0; j < MAX_BIT_LENGTH; j++) {
            bin_nums_a[i][j] = 0;
            bin_nums_b[i][j] = 0;
            bin_result[i][j] = 0;
        }
    }

    long long dec_result[NUM_BINARIES]={0};
    // 生成60个随机的二进制数
    long long *data_a = generate_random_array(array_a, NUM_BINARIES, 123);
    long long *data_b = generate_random_array(array_b, NUM_BINARIES, 456);
    for (int i = 0; i < NUM_BINARIES; i++)
    {
        decimal_to_binary(data_a[i], bin_nums_a, i);
        decimal_to_binary(data_b[i], bin_nums_b, i);
    }


    XTime_GetTime(&tbegin);
    for (int i = 0; i < NUM_BINARIES; i++)
    {
        binary_add(bin_nums_a, bin_nums_b, bin_result, i);
    }
    XTime_GetTime(&tEnd);
    tused = ((tEnd-tbegin)*1000000)/(COUNTS_PER_SECOND);

    for (int i = 0; i < NUM_BINARIES; i++)
    {
        binary_to_decimal(bin_result, dec_result, i);
    }

    for (int i = 0; i < 60; i++)
    {
        printf("%lld + %lld = %lld   ", data_a[i], data_b[i],
dec_result[i]);
        if ((i + 1) % 2 == 0)
        {
            printf("\n");
        }
    }
    xil_printf("%d traditional additions ,time elapsed is %d
us\r\n",NUM_BINARIES,tused);
    float tused_float = (float)tused / 60.0;
    printf("average time per traditional addition is  %f\n", tused_float);
    free(bin_nums_a);
    free(bin_result);
    return 0;
}
```