Project Description

1.0 Structural Blocks

--- "clk_wiz" - used for system clocking.

--- "idelay" - allows the measured signal from the "processing_system" to connect to the "ser_des".

--- "ser_des" - improves the accuracy of the measured signal using DDR mode.

--- "asyn_capture" - captures the first data edge.

--- "asyn_capture_negedge" - captures the last data edge.

--- "f_capture" - captures the data between the first and last edge.

--- "xlconcat" - used to combine data.

--- "processing_system" - controls the frequency of the measured signal sent to "ser_des" and is used for data collection and processing.

2.0 How It Works

The "processing_system" block sends a measured signal (with an adjustable frequency) to the "idelay" block using its FCLK_CLK0 output. The "idelay" block makes it possible to connect this signal to the "ser_des" block. The output from "ser_des" is then processed by "asyn_capture", "asyn_capture_negedge", and "f_capture" blocks, which handle different parts of the signal. The processed data is combined using the "xlconcat" block and sent back to the "processing_system". The final data processing is done using Python code.

2.1 The signal measurement accuracy

The working frequency of "ser_des" is 300 MHz, and with DDR mode, the effective frequency becomes 300 * 4 = 1200 MHz. At this frequency, we expect a measurement accuracy of 1/1200 = 0.8333 ns per edge. Since we are measuring the signal length, the expected accuracy will range from 0 to 1.6666 ns, or ± 0.8333 ns.

2.2 Python Code Description

As mentioned earlier, the "processing_system" sends a signal with variable frequency using the FCLK_CLK0 output. In the code, a test vector is created with the frequencies sent to "ser_des" -> listClock = [0.8, 1, 5, 10, 20, 25], and a vector with time values in ns that correspond to these frequencies -> gold_data = [625, 500, 100, 50.0, 25.0, 20].

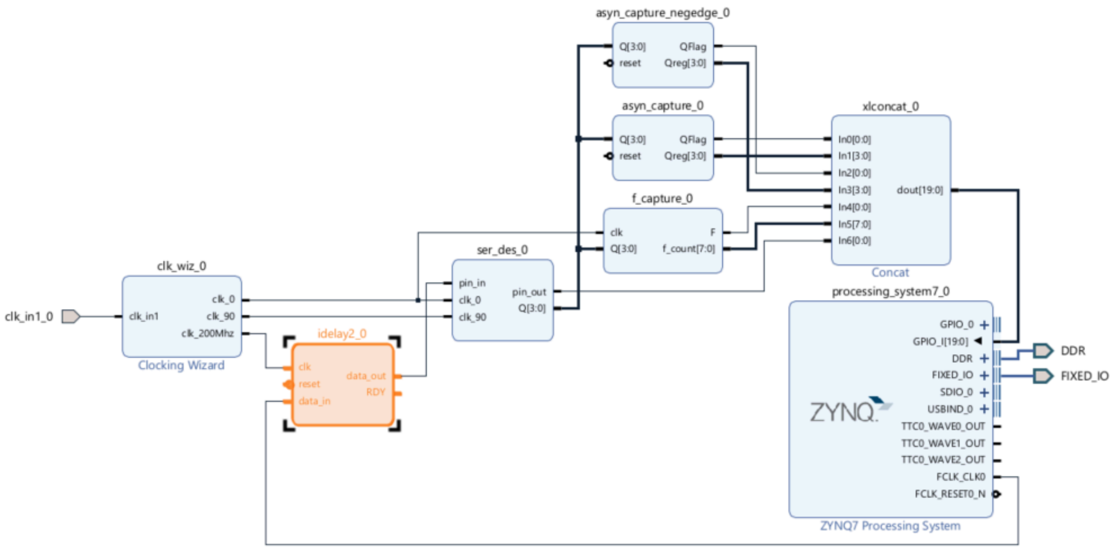
A loop iterates through the listClock vector, and the measured signal is stored in the result vector. Then, it's compared with gold_data, and the differences are saved in the diff vector.

To make tracking errors easier, the errors are displayed on a graph, with the error values in ns shown above the measured points.

3.0 Project scheme

In [4]:
```python
from IPython.display import Image
image_path = './sdup.png'
Image(filename=image_path)
```

Out[4]:



4.0 - Data processing code

In [13]:
```python
from pynq import Overlay

ol = Overlay("./design_300Mhz.bit")
```

In [14]:
```python
from pynq import GPIO

pin_0 = GPIO(GPIO.get_gpio_pin(0), 'in')   # QFlag_pos
pin_1 = GPIO(GPIO.get_gpio_pin(1), 'in')   # Asyn0
pin_2 = GPIO(GPIO.get_gpio_pin(2), 'in')   # Asyn1
pin_3 = GPIO(GPIO.get_gpio_pin(3), 'in')   # Asyn2
pin_4 = GPIO(GPIO.get_gpio_pin(4), 'in')   # Asyn3
pin_5 = GPIO(GPIO.get_gpio_pin(5), 'in')   # QFlag_neg
pin_6 = GPIO(GPIO.get_gpio_pin(6), 'in')   # Asyn_neg0
pin_7 = GPIO(GPIO.get_gpio_pin(7), 'in')   # Asyn_neg1
pin_8 = GPIO(GPIO.get_gpio_pin(8), 'in')   # Asyn_neg2
pin_9 = GPIO(GPIO.get_gpio_pin(9), 'in')   # Asyn_neg3
pin_10= GPIO(GPIO.get_gpio_pin(10), 'in')  # F_flag
pin_11= GPIO(GPIO.get_gpio_pin(11), 'in')  # Count0
pin_12= GPIO(GPIO.get_gpio_pin(12), 'in')  # Count1
pin_13= GPIO(GPIO.get_gpio_pin(13), 'in')  # Count2
pin_14= GPIO(GPIO.get_gpio_pin(14), 'in')  # Count3
pin_15= GPIO(GPIO.get_gpio_pin(15), 'in')  # Count4
pin_16= GPIO(GPIO.get_gpio_pin(16), 'in')  # Count5
pin_17 = GPIO(GPIO.get_gpio_pin(17), 'in') # Count6
pin_18 = GPIO(GPIO.get_gpio_pin(18), 'in') # Count7
pin_19 = GPIO(GPIO.get_gpio_pin(19), 'in') # Cer_des


capture_posedge     = [pin_4,pin_3,pin_2,pin_1]
```

```
capture_negadge      = [pin_9,pin_8,pin_7,pin_6]
capture_f            = [pin_18,pin_17,pin_16,pin_15,pin_14,pin_13,pin_12,pin_11]
```

In [15]:

```
import time
from pynq import Clocks

##############################################################################

listClock = [0.8,1,5,10,20,25]
gold_data = [625,500,100,50.0, 25.0, 20]

result = []
diff = []
##############################################################################

for enum in listClock:
    time.sleep(1)
    Clocks.fclk0_mhz = enum
    print(f'{Clocks.fclk0_mhz}')

    capture_posedge_list = []
    capture_negadge_list = []
    capture_f_list       = []

    int_capture_posedge = 0
    int_capture_negadge = 0
    int_capture_f_list  = 0

    ##############################################################################

    ##############################################################################
    print("posedge",end='       ')
    for list in capture_posedge:
        capture_posedge_list.append(list.read())
        print(list.read(),end=' ')

    print("")

    print("negedge",end='       ')
    for list in capture_negadge:
        capture_negadge_list.append(list.read())
        print(list.read(),end=' ')

    print("")

    print("capture_f",end='     ')
    for list in capture_f:
        capture_f_list.append(list.read())
        print(list.read(),end=' ')
    print("|",end=' ')
    binary_string = ''.join(map(str, capture_f_list))
    decimal_number = int(binary_string, 2)
    print(decimal_number)

    ##############################################################################

    ##############################################################################
    posedge_plus_negage_vector = capture_posedge_list + capture_negadge_list

    def count_ones(vector):
        count = 0
        for element in vector:
            if element == 1:
                count += 1
```

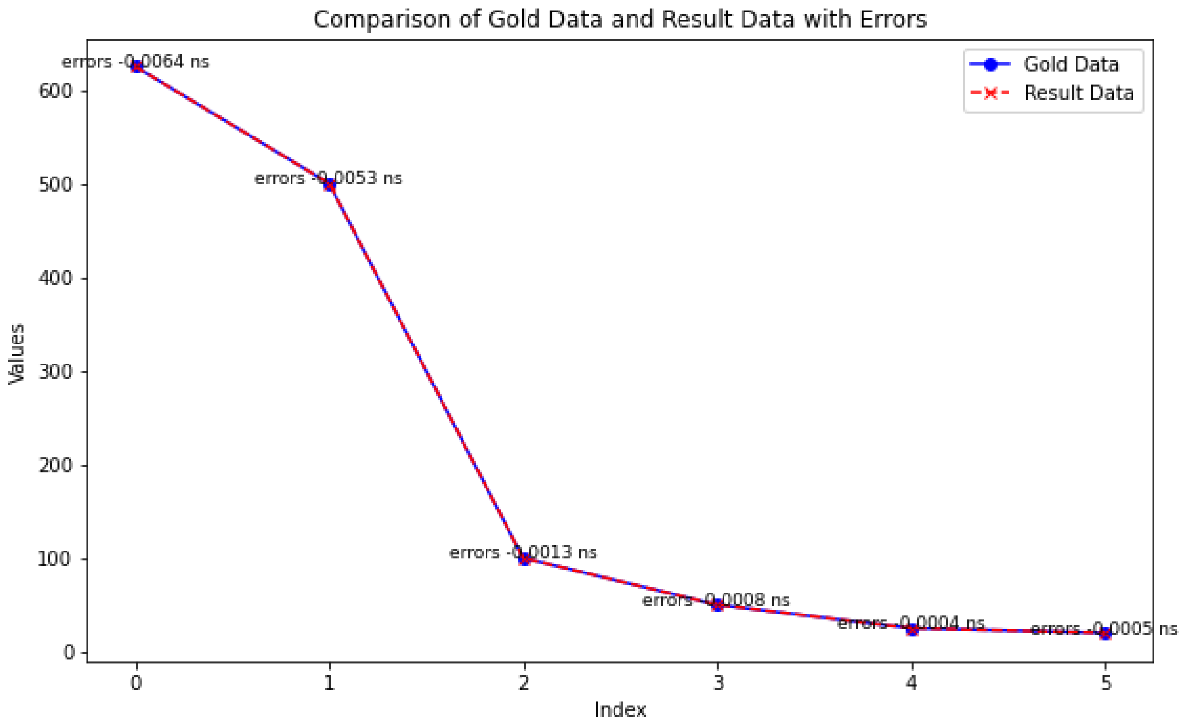
```
        return count
    print(count_ones(posedge_plus_negage_vector))

    ##############################################################################

    ##############################################################################
    tdc_resolution = 0.83325
    clock_resolution = 3.3333


    # The formula for calculating time
    min_time_impulse = (decimal_number * clock_resolution) + (tdc_resolution * cour
    print(min_time_impulse)
    #print(listClock.index(enum))
    result.append(min_time_impulse)
    print('________________________')

print(result)

for i in range(len(gold_data)):
    diff.append(gold_data[i] - result[i])

rounded_diff = [round(element, 4) for element in diff]
print(rounded_diff)
```

```
0.8
posedge      1 1 0 0
negedge      0 0 0 0
capture_f    1 0 1 1 1 0 1 1 | 187
2
624.9936
________________________
1.0
posedge      1 1 0 0
negedge      0 0 1 1
capture_f    1 0 0 1 0 1 0 1 | 149
4
499.9947
________________________
5.0
posedge      1 1 0 0
negedge      0 0 1 1
capture_f    0 0 0 1 1 1 0 1 | 29
4
99.9987
________________________
10.0
posedge      1 1 0 0
negedge      0 0 1 1
capture_f    0 0 0 0 1 1 1 0 | 14
4
49.999199999999995
________________________
20.0
posedge      1 1 0 0
negedge      0 0 0 0
capture_f    0 0 0 0 0 1 1 1 | 7
2
24.999599999999997
________________________
25.0
posedge      1 1 0 0
negedge      0 0 1 1
capture_f    0 0 0 0 0 1 0 1 | 5
4
19.999499999999998
________________________
[624.9936, 499.9947, 99.9987, 49.999199999999995, 24.999599999999997, 19.999499999
999998]
[0.0064, 0.0053, 0.0013, 0.0008, 0.0004, 0.0005]
```

In [17]:

```python
import numpy as np
import matplotlib.pyplot as plt



# Рассчитаем ошибки
errors = result - gold_data

# Построение графика сравнения
plt.figure(figsize=(10, 6))

# График значений gold_data и result
plt.plot(gold_data, label="Gold Data", marker='o', linestyle='-', color='b')
plt.plot(result, label="Result Data", marker='x', linestyle='--', color='r')

# Отображение ошибок над точками
for i in range(len(gold_data)):
    plt.text(i, result[i], f'errors {errors[i]:.4f} ns', fontsize=9, color='black',
```

```
# Оформление графика
plt.title("Comparison of Gold Data and Result Data with Errors")
plt.xlabel("Index")
plt.ylabel("Values")
plt.legend()

# Отображение графика
plt.show()
```



In [19]:
```
import numpy as np

# Data in the form of numpy arrays
gold_data = np.array(gold_data)
result = np.array(result)
rounded_diff = np.array(rounded_diff)

# Mean Absolute Error (MAE)
mae = np.mean(np.abs(result - gold_data))
print(f"Mean Absolute Error (MAE): {mae:.6f}")

# Root Mean Square Error (RMSE)
rmse = np.sqrt(np.mean((result - gold_data) ** 2))
print(f"Root Mean Square Error (RMSE): {rmse:.6f}")

# Mean Error
mean_diff = np.mean(result - gold_data)
print(f"Mean Error: {mean_diff:.6f}")

# Range of Errors
range_diff = np.max(result - gold_data) - np.min(result - gold_data)
print(f"Range of Errors: {range_diff:.6f}")

# Rounded Differences
print("Rounded Differences:")
print(rounded_diff)
```

```
Mean Absolute Error (MAE): 0.002450
Root Mean Square Error (RMSE): 0.003459
Mean Error: -0.002450
Range of Errors: 0.006000
Rounded Differences:
[0.0064 0.0053 0.0013 0.0008 0.0004 0.0005]
```

5.0 Measurement Results

From the provided data, it is clear that the measurement accuracy meets the designed expectations.

6.0 Vivado

To fully open the project in Vivado with the already assembled 'block_design', you can use the design_300Mhz.tcl file, which is also located in the repository.

In [ ]: