# VLSI 2

## 32-point FFT (The Cooley-Tukey algorithm)


Submitted by :

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# Design:

The main operation of the FFT is

$$\text{Out1} = \text{I0} + \text{constant} * \text{I1}$$
$$\text{Out2} = \text{I0} - \text{constant} * \text{I1}$$

Expanding the Equations:

$$\text{Out1\_REAL} = ((\text{I0\_real} + \text{constant\_real} * \text{I2\_REAL})\text{FirstClk} - \text{CONSTANT\_IMAG} * \text{I2\_IMAG})\text{SecondClk}$$
$$\text{Out2\_REAL} = ((\text{I0\_real} - \text{constant\_real} * \text{I2\_REAL})\text{FirstClk} + \text{CONSTANT\_IMAG} * \text{I2\_IMAG})\text{SecondClk}$$
$$\text{Out1\_IMAG} = ((\text{I0\_imag} + \text{constant\_imag} * \text{I2\_REAL})\text{ThirdClk} + \text{CONSTANT\_Real} * \text{I2\_IMAG})\text{FourthClk}$$
$$\text{Out2\_IMAG} = ((\text{I0\_imag} - \text{constant\_imag} * \text{I2\_REAL})\text{ThirdClk} - \text{CONSTANT\_Real} * \text{I2\_IMAG})\text{FourthClk}$$

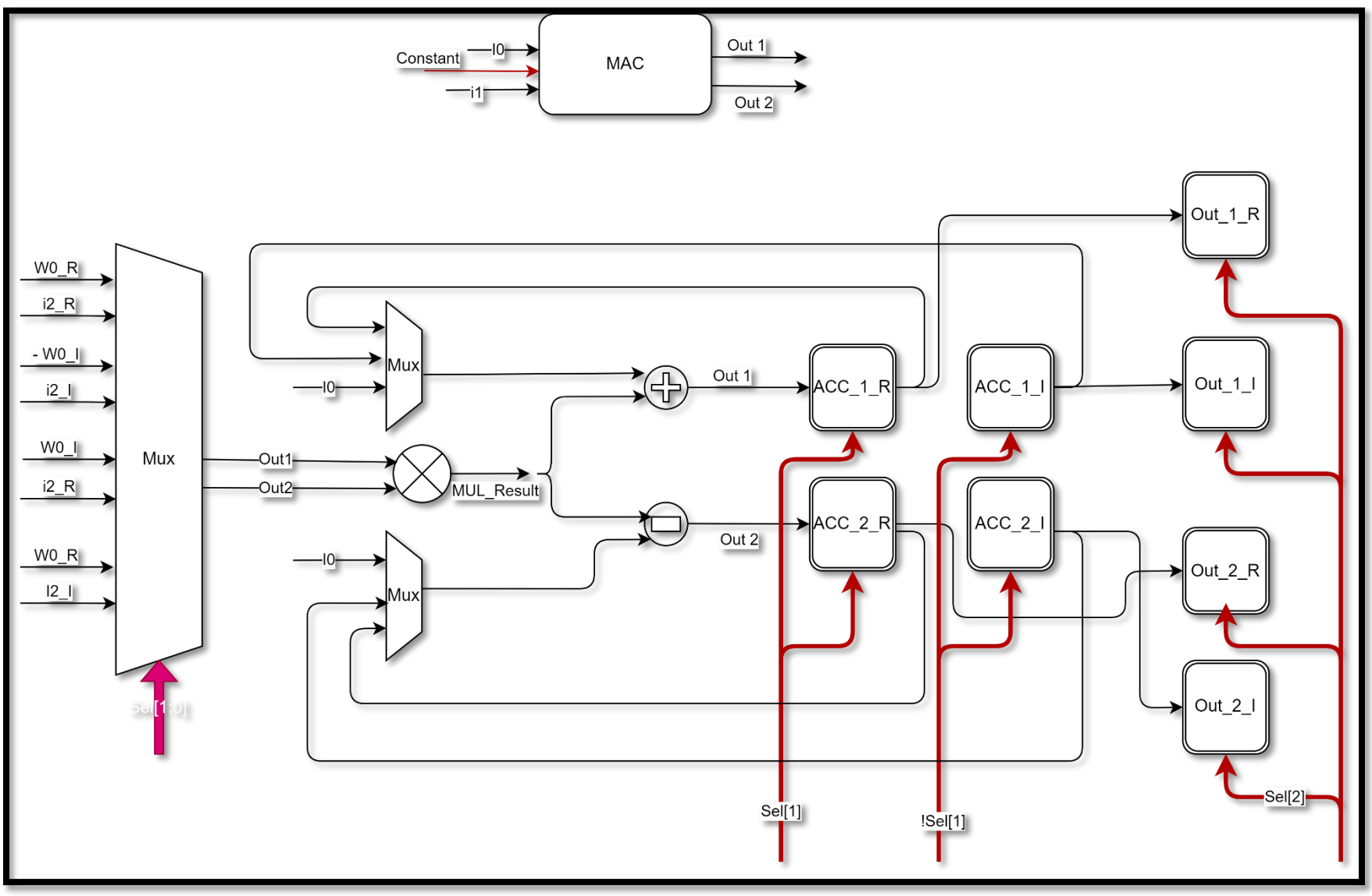
As shown, there is common operands between Out1Real & Out2Real same for Imaginary Part so in first 2 clks Real part is calculated (in first Clk the first part is calculated then in second clk the second part is accumulated on the Previous Result). Using Sel signals to select which inputs and which registers to write.

Same Idea applies for the Imaginary Part

In the 5th clk we store the 4 Results of the output and become the input of the second Stage

Here is the design showing all control signals (Red Lines) and the data path

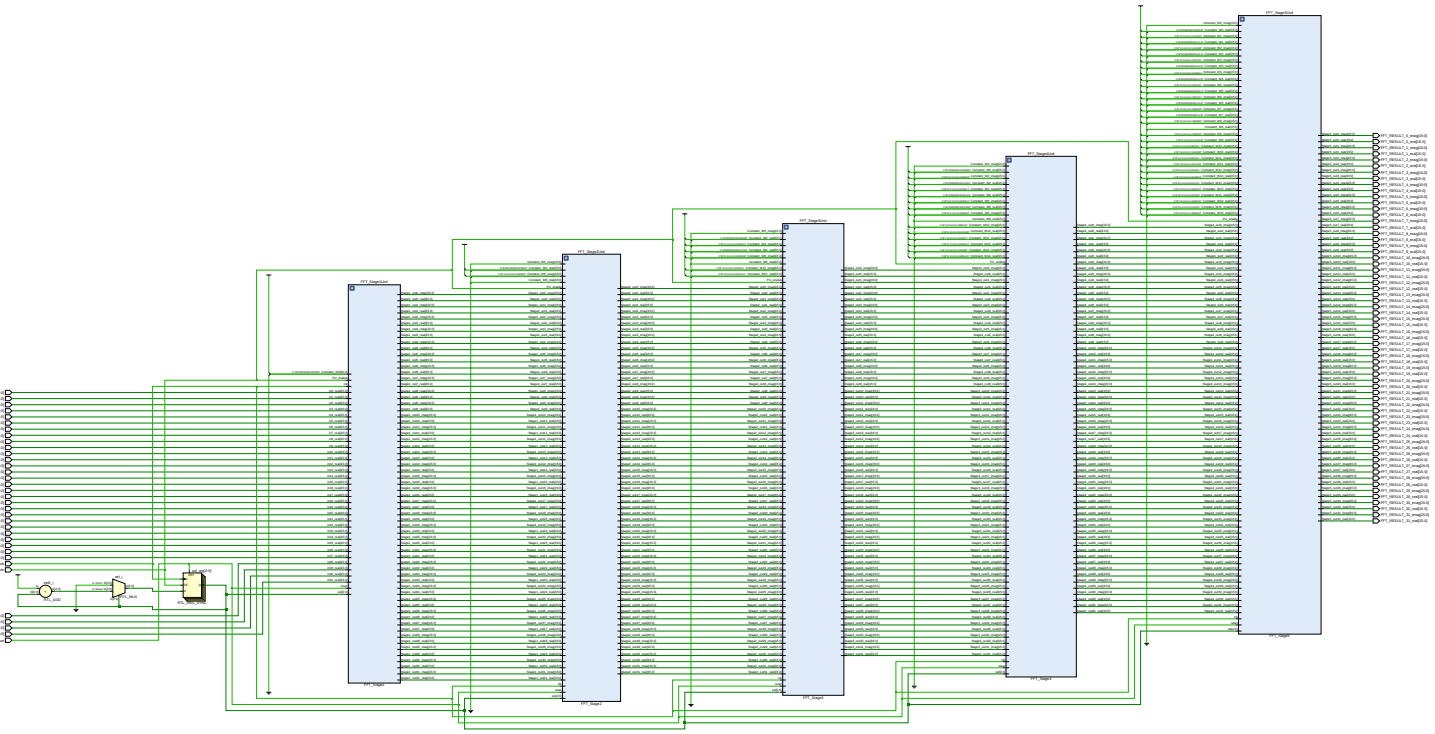
## Mac:



# Equations of stages:

| Index | inputs | Stage1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 (Result) |
|---|---|---|---|---|---|---|
| 0 | I0 | S01= I0 + W0 * I16 | S02= S01 + W0 * S21 | S03=S02 + W0*S42 | S04=S03+W0*S83 | S05=S04+W0*S164 |
| 1 | I16 | S11= I0 - W0 * I16 | S12= S11 + W8 * S31 | S13=S12 + W4*S52 | S14=S13+W2*S93 | S15=S14+W1*S174 |
| 2 | I8 | S21= I8 + W0 * I24 | S22= S01 - W0 * S21 | S23=S22 + W8*S62 | S24=S23+W4*S103 | S25=S24+W2*S184 |
| 3 | I24 | S31= I8 - W0 * I24 | S32= S11 - W8 * S31 | S33=S32 + W12*S72 | S34=S33+W6*S113 | S35=S34+W3*S194 |
| 4 | I4 | S41= I4 + W0 * I20 | S42= S41 + W0 * S61 | S43=S02 - W0*S42 | S44=S43+W8*S123 | S45=S44+W4*S204 |
| 5 | I20 | S51= I4 - W0 * I20 | S52= S51 + W8 * S71 | S53=S12 - W4*S52 | S54=S53+W10*S133 | S55=S54+W5*S214 |
| 6 | I12 | S61= I12 + W0 * I28 | S62= S41 - W0 * S61 | S63=S22 - W8*S62 | S64=S63+W12*S143 | S65=S64+W6*S224 |
| 7 | I28 | S71= I12 - W0 * I28 | S72= S51 - W8 * S71 | S73=S32 - W12*S72 | S74=S73+W14*S153 | S75=S74+W7*S234 |
| 8 | I2 | S81= I2 + W0 * I18 | S82= S81 + W0 * S101 | S83=S82+W0*S122 | S84=S03-W0*S83 | S85=S84+W8*S244 |
| 9 | I18 | S91= I2 – W0 * I18 | S92= S91 + W8 * S111 | S93=S92+W4*S132 | S94=S13 - W2*S93 | S95=S94+W9*S254 |
| 10 | I10 | S101= I10 + W0 * I26 | S102= S81 – W0 * S101 | S103=S102+W8*S142 | S104=S23 -W4*S103 | S105=S104+W10*S264 |
| 11 | I26 | S111= I10 - W0 * I26 | S112= S91 – W8 * S111 | S113=S112+W12*S152 | S114=S33 - W6*S113 | S115=S114+W11*S274 |
| 12 | I6 | S121= I6 + W0 * I22 | S122= S121 +W0*S141 | S123= S82- W0*S122 | S124=S43 - W8*S123 | S125=S124+W12*S284 |
| 13 | I22 | S131= I6 - W0 * I22 | S132=S131 + W8*S151 | S133= S92- W4*S132 | S134=S53 - W10*S133 | S135=S134+W13*S294 |
| 14 | I14 | S141= I14 + W0 * I30 | S142= S121 -W0*S141 | S143= S102- W8*S142 | S144=S63 - W12*S143 | S145=S144+W14*S304 |
| 15 | I30 | S151= I14 - W0 * I30 | S152=S131 - W8*S151 | S153= S112- W12*S152 | S154=S73 - W14*S153 | S155=S154+W15*S314 |
| 16 | I1 | S161= I1 + W0 * I17 | S162=S161 + W0*S181 | S163 = S162 + W0* S202 | S164=S163 +W0*S243 | S165=S04 - W0*S164 |
| 17 | I17 | S171= I1 - W0 * I17 | S172=S171 + W8*S191 | S173 = S172+ W4*S212 | S174=S173+W2*S253 | S175=S14 - W1*S174 |
| 18 | I9 | S181= I9 + W0 * I25 | S182=S161 - W0*S181 | S183= S182+ W8*S222 | S184=S183+W4*S263 | S185=S24 - W2*S184 |
| 19 | I25 | S191= I9 - W0 * I25 | S192=S171 - W8*S191 | S193= S192+ W12*S232 | S194=S193+W6*S273 | S195=S34 - W3*S194 |
| 20 | I5 | S201= I5 + W0 * I21 | S202=S201 + W0*S221 | S203 = S162 - W0* S202 | S204=S203+W8*S283 | S205=S44 - W4*S204 |
| 21 | I21 | S211= I5 - W0 * I21 | S212=S211 + W8*S231 | S213 = S172 - W4*S212 | S214=S213+W10*S293 | S215=S54 - W5*S214 |
| 22 | I13 | S221= I13 + W0 * I29 | S222=S201 - W0*S221 | S223= S182 - W8*S222 | S224=S223+W12*S303 | S225=S64 - W6*S224 |
| 23 | I29 | S231= I13 - W0 * I29 | S232=S211 - W8*S231 | S233= S192 - W12*S232 | S234=S233+W14*S313 | S235=S74 - W7*S234 |
| 24 | I3 | S241= I3 + W0 * I19 | S242=S241 + W0*S261 | S243=S242 + W0*S282 | S244=S163 -W0*S243 | S245=S84 - W8*S244 |
| 25 | I19 | S251= I3 - W0 * I19 | S252=S251 + W8*S271 | S253=S252 + W4*S292 | S254=S173-W2*S253 | S255=S94 - W9*S254 |
| 26 | I11 | S261= I11 + W0 * I27 | S262=S241 - W0*S261 | S263=S262 + W8*S302 | S264=S183-W4*S263 | S265=S104 - W10*S264 |
| 27 | I27 | S271= I11 - W0 * I27 | S272=S251 - W8*S271 | S273=S272 + W12*S312 | S274=S193-W6*S273 | S275=S114 - W11*S274 |
| 28 | I7 | S281= I7 + W0 * I23 | S282=S281 + W0 *S301 | S283=S242 - W0*S282 | S284=S203-W8*S283 | S285=S124 - W12*S284 |
| 29 | I23 | S291= I7 - W0 * I23 | S292= S291+W8*S311 | S293=S252 - W4*S292 | S294=S213-W10*S293 | S295=S134 - W13*S294 |
| 30 | I15 | S301= I15 + W0 * I31 | S302=S281 - W0 *S301 | S303=S262 - W8*S302 | S304=S223-W12*S303 | S305=S144 - W14*S304 |
| 31 | I31 | S311= I15 - W0 * I31 | S312= S291-W8*S311 | S313=S272 - W12*S312 | S314=S233-W14*S313 | S315=S154 - W15*S314 |

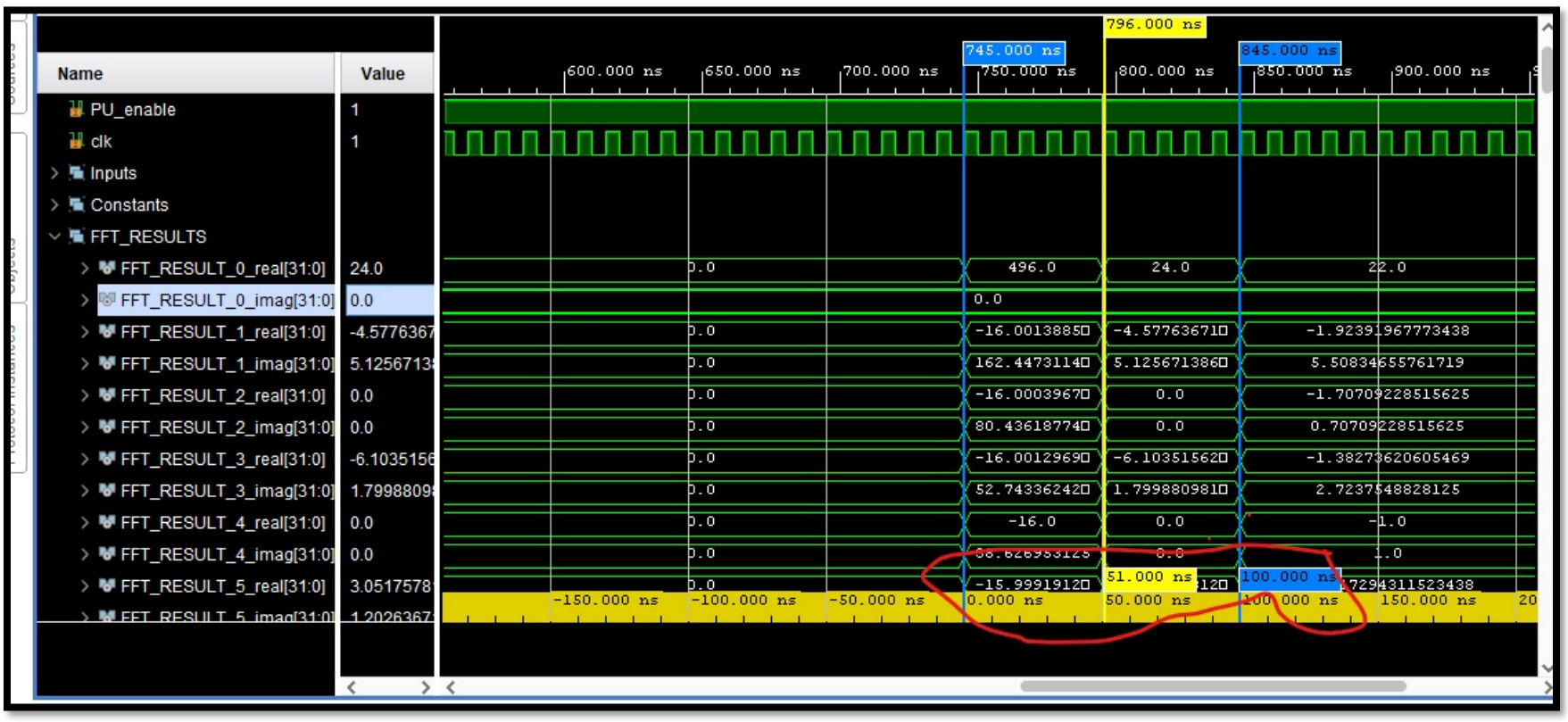
# Schematic



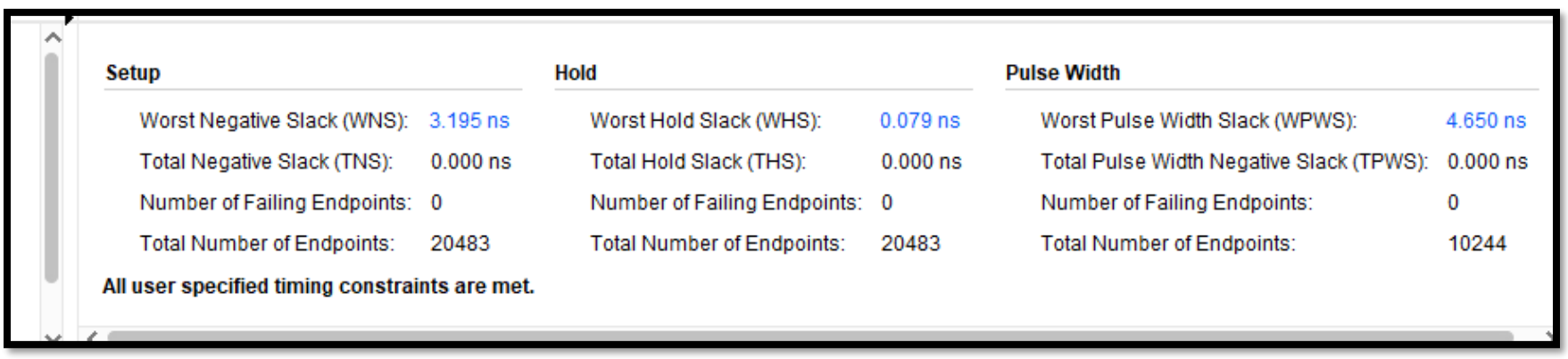
# Results

## Pipeline Result:

FFT block Output is with 20 MHz we inserted 3 different input with 20 MHZ and here is the output showing the time between each output is 50 ns

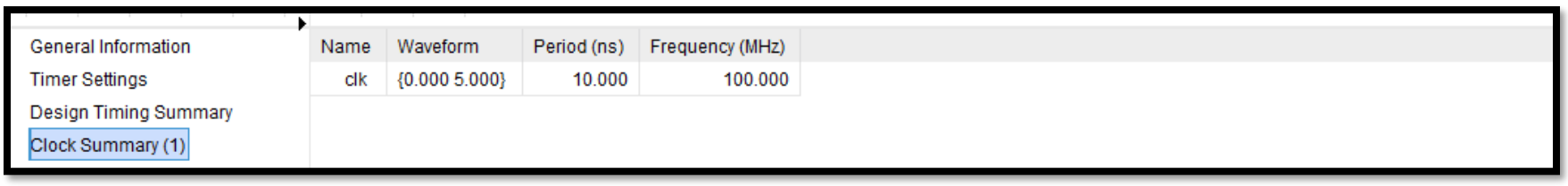



## Timing Results:



| Setup | | Hold | | Pulse Width | |
|---|---|---|---|---|---|
| Worst Negative Slack (WNS): | 3.195 ns | Worst Hold Slack (WHS): | 0.079 ns | Worst Pulse Width Slack (WPWS): | 4.650 ns |
| Total Negative Slack (TNS): | 0.000 ns | Total Hold Slack (THS): | 0.000 ns | Total Pulse Width Negative Slack (TPWS): | 0.000 ns |
| Number of Failing Endpoints: | 0 | Number of Failing Endpoints: | 0 | Number of Failing Endpoints: | 0 |
| Total Number of Endpoints: | 20483 | Total Number of Endpoints: | 20483 | Total Number of Endpoints: | 10244 |

**All user specified timing constraints are met.**



General Information
Timer Settings
Design Timing Summary
Clock Summary (1)

| Name | Waveform | Period (ns) | Frequency (MHz) |
|---|---|---|---|
| clk | {0.000 5.000} | 10.000 | 100.000 |

## MATLAB Check:

Equation.m | fd.m

```
1 -    x=[0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31];
2 -    y=fft(x);
3 -    z=transpose(y);
4
```

| Result | FFT |
|---|---|
| 0 | 496.000000000000 + 0.00000000000000i |
| 1 | -16.0000000000000 + 162.450726201742i |
| 2 | -16.0000000000000 + 80.4374318740136i |
| 3 | -16.0000000000000 + 52.7449313430131i |
| 4 | -16.0000000000000 + 38.6274169979695i |
| 5 | -16.0000000000000 + 29.9338945886302i |
| 6 | -16.0000000000000 + 23.9456922026478i |
| 7 | -16.0000000000000 + 19.4960564094076i |
| 8 | -16.0000000000000 + 16.0000000000000i |
| 9 | -16.0000000000000 + 13.1308606532586i |
| 10 | -16.0000000000000 + 10.6908582067088i |
| 11 | -16.0000000000000 + 8.55217817521267i |
| 12 | -16.0000000000000 + 6.62741699796952i |
| 13 | -16.0000000000000 + 4.85354693771748i |
| 14 | -16.0000000000000 + 3.18259787807452i |
| 15 | -16.0000000000000 + 1.57586245371462i |
| 16 | -16.0000000000000 + 0.00000000000000i |
| 17 | -16.0000000000000 - 1.57586245371462i |
| 18 | -16.0000000000000 - 3.18259787807452i |
| 19 | -16.0000000000000 - 4.85354693771748i |
| 20 | -16.0000000000000 - 6.62741699796952i |
| 21 | -16.0000000000000 - 8.55217817521267i |
| 22 | -16.0000000000000 - 10.6908582067088i |
| 23 | -16.0000000000000 - 13.1308606532586i |
| 24 | -16.0000000000000 - 16.0000000000000i |
| 25 | -16.0000000000000 - 19.4960564094076i |
| 26 | -16.0000000000000 - 23.9456922026478i |
| 27 | -16.0000000000000 - 29.9338945886302i |
| 28 | -16.0000000000000 - 38.6274169979695i |
| 29 | -16.0000000000000 - 52.7449313430131i |
| 30 | -16.0000000000000 - 80.4374318740136i |
| 31 | -16.0000000000000 - 162.450726201742i |

**Note: We got the same results approximately due to fixed point usage (quantization error)**