

4)

R-type	LW	SW	beq
11	13	10	9
40%	30%	10%	20%

$$CPI = (0.4 \times 11) + (0.3 \times 13) + (0.1 \times 10) + (0.2 \times 9)$$

$$CPI = 11.1 \text{ cycles}$$

5) a) Iterations: 32

7ns/iteration

$$32 \times 7 = 224 \text{ ns}$$

b) Iterations: 16

7ns/iteration

$$16 \times 7 = 112 \text{ ns}$$

+ Adder delay

$$112 \text{ ns} + 7 \text{ ns} = 119 \text{ ns}$$

6) Delay =  $(k+7)T$

$$G_0 = a_0 b_0$$

$\hookrightarrow a_0, b_0$  avail. @  $T=0$

$$G_0 = (2+7)T = 9T$$

$$P_0 = a_0 \oplus b_0$$

$\hookrightarrow a_0, b_0$  avail. @  $T=0$

$$P_0 = (2+7)T = 9T$$

$$G_{25} = a_{25} b_{25}$$

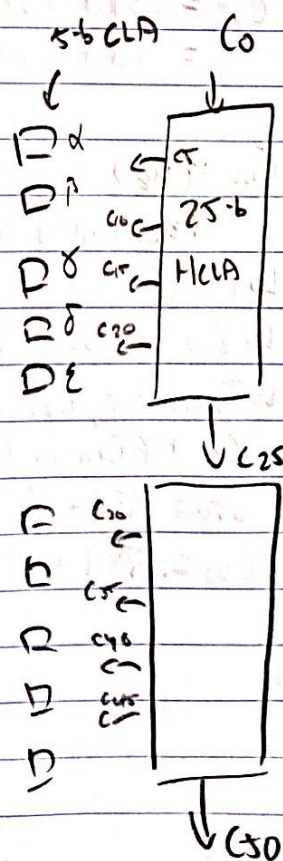
$\hookrightarrow a_{25}, b_{25}$  avail. @  $T=0$

$$G_{25} = (2+7)T = 9T$$

$$P_{25} = a_{25} \oplus b_{25}$$

$\hookrightarrow a_{25}, b_{25}$  avail. @  $T=0$

$$P_{25} = (2+7)T = 9T$$





$$6) C_d = (G_u) + (G_{15}P_4) + (G_{12}P_3P_4) + (G_{11}P_2P_3P_4) + (G_{10}P_1P_2P_3P_4)$$

↳ All  $G_i / P_i$  avail. @ 9T

↳ Therefore,  $G_{10}P_1P_2P_3P_4$  is critical path

$$↳ G_i + 5 \text{ Fan-In AND} + 5 \text{ Fan-In OR} = 9T + (5+7)T + (5+7)T = \boxed{33T}$$

$$P_\alpha = (P_4P_3P_2P_1P_0)$$

↳ All  $G_i / P_i$  avail. @ 9T

$$P_\alpha = (5+7)T + 9T = \boxed{21T}$$

$$C_{25} = (G_E) + (G_8P_E) + (G_{18}P_8P_E) + (G_{15}P_8P_8P_E) + (G_{11}P_8P_8P_8P_E) + (G_{10}P_\alpha P_8P_8P_E)$$

↳  $G_d$  is avail. at 33T

↳  $G$  is avail. @ 0T

↳ Therefore,  $G_dP_\alpha P_8P_8P_E$  is the critical path

$G_{11} + 5 \text{ Fan-In AND} + 6 \text{ Fan-In OR}$

$$C_{25} = 33T + (5+7)T + (6+7)T$$

$$= 33T + 12T + 13T = \boxed{58T}$$

$$C_{50} = (G_E) + (G_8P_E) + (G_{18}P_8P_E) + (G_{15}P_8P_8P_E) + (G_{10}P_\alpha P_8P_8P_E) + (G_{25}P_\alpha P_\alpha P_8P_8P_E)$$

↳  $G_d$  is avail. @ 33T

↳  $C_{25}$  is avail. @ 58T

↳ Therefore,  $G_{25}P_\alpha P_\alpha P_8P_8P_E$  is the critical path

$C_{25} + 6 \text{ Fan-In AND} + 6 \text{ Fan-In OR}$

$$C_{50} = 58T + (6+7)T + (6+7)T$$

$$C_{50} = 58T + 13T + 13T = \boxed{84T}$$



$$6) C_{45} = (G_8) + (G_8 P_8) + (G_8 P_8 P_8) + (G_8 P_8 P_8 P_8) + (G_8 P_8 P_8 P_8 P_8)$$

↳  $G_8$  is avail. @ 33T

↳  $G_{25}$  is avail. @ 58T

↳ Therefore  $G_{25} P_8 P_8 P_8$  is the critical path

$G_{25} + 5 \text{ Fan-in AND} + 5 \text{ Fan-in OR}$

$$C_{45} = 58T + (5+7)T + (5+7)T$$

$$C_{45} = 58T + 12T + 12T = \boxed{82T}$$

$$C_{49} = (G_3) + (G_3 P_3) + (G_3 P_3 P_3) + (G_3 P_3 P_3 P_3) + (G_3 P_3 P_3 P_3 P_3) +$$

↳  $G_{45} P_3 P_3 P_3$  is critical path

$G_{45} + 5 \text{ Fan-in AND} + 5 \text{ Fan-in OR}$

$$82T + (5+7)T + (5+7)T$$

$$C_{49} = 82T + 12T + 12T = \boxed{106T}$$

$$S_{49} = (a_{49} \oplus b_{49}) \oplus C_{49}$$

↳  $C_{49}$  is the critical path

$C_{49} + 2 \text{ Fan-in XOR}$

$$106T + (2+7)T =$$

$$S_{49} = 106T + 9T = \boxed{115T}$$

$$8) \text{ Single-cycle} \Rightarrow \boxed{CPI=1}$$

$$CT = \frac{1}{f} = \frac{1}{3.5 \times 10^9 \text{ Hz}} = \boxed{0.29 \times 10^{-9} \text{ s}}$$

$$IC = \boxed{3005.1}$$

$$ET = IC \times CPI \times CT$$

$$ET = 3 \times 10^3 \times 1 \times 0.29 \times 10^{-9} \text{ s}$$

$$ET = 0.87 \times 10^2 = \boxed{87 \text{ s}}$$



8)  $CPI = 1 \Rightarrow$  single-cycle

$$CT = 0.29 \times 10^{-9} s + 300 \times 10^{-12} s$$

$$CT = 0.29 \times 10^{-9} s + 0.3 \times 10^{-9} s$$

$$CT = 0.59 ns$$

$$0.4 \times 300,000,000,000$$

$$120,000,000,000 \text{ LUs} \times 257$$

$$1230,000,000,000 \text{ LUs}$$

$$30,000,000,000 \text{ Add}$$

$$\rightarrow 30,000,000,000 \text{ LUAs}$$

$$IC = 300 \times 10^9 - 30 \times 10^9 = 270 \times 10^9$$

$$ET = 270 \times 10^9 \times 0.59 \times 10^{-9} = 159.3 s$$

### Main Controller

Input or Output	Signal Name	R-format	lw	sw	Beq
Inputs	Op5	0	1	1	0
	Op4	0	0	0	0
	Op3	0	0	1	0
	Op2	0	0	0	1
	Op1	0	1	1	0
	Op0	0	1	1	0
Outputs	RegDst	1	0	X	X
	ALUSrc	0	1	1	0
	MemtoReg	0	1	X	X
	RegWrite	1	1	0	0
	MemRead	0	1	0	0
	MemWrite	0	0	1	0
	Branch	0	0	0	1
	ALUOp1	1	0	0	0
	ALUOp0	0	0	0	1

### ALU Controller

opcode	ALUOp	Operation	func	ALU function	ALU control	WTFc
lw	00	load word	XXXXXX	add	0010	0
sw	00	store word	XXXXXX	add	0010	0
beq	01	branch equal	XXXXXX	subtract	0110	0
R-type	10	add	100000	add	0010	0
		subtract	100010	subtract	0110	0
		AND	100100	AND	0000	0
		OR	100101	OR	0001	0
		set-on-less-than	101010	set-on-less-than	0111	0
R-type	10	LTF	111111	subtract	0110	1