**If we can make (W)rite operation when clock goes low-to-high and (R)ead operation when clock goes high-to-low;**

**a)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |  |
| **LD 0(R5), R1** | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  | **R1 <- M[R5]** |
| **LD 0(R6), R2** |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  | **R2 <- M[R6]** |
| **LD 0(R7), R3** |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  | **R3 <- M[R7]** |
| **NOP** |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |
| **ADD R3, R2, R3** |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  | **R3 <- R3 + R2** |
| **NOP** |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |
| **SUB R3, R1, R3** |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  | **R3 <- R3 - R1** |
| **BNZ EX** |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |
| **NOP** |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |
| **NEG R3** |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  | **NEGATE R3** |
| **NOP** |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |
| **ADD R3, R2, R2** |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  | **R2 <- R3 + R2** |

Total amount of penalty = 4

**b)** Since all opretions including branch operation are dependent with each other, it is not possible to change the order of most of the operations.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |  |
| **LD 0(R6), R2** | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  |  | **R2 <- M[R6]** |
| **LD 0(R7), R3** |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  | **R3 <- M[R7]** |
| **LD 0(R5), R1** |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  | **R1 <- M[R5]** |
| **ADD R3, R2, R3** |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  | **R3 <- R3 + R2** |
| **NOP** |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |
| **SUB R3, R1, R3** |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  | **R3 <- R3 - R1** |
| **BNZ EX** |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |
| **NOP** |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |
| **NEG R3** |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  | **NEGATE R3** |
| **NOP** |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |
| **ADD R3, R2, R2** |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  | **R2 <- R3 + R2** |

Total amount of penalty = 3

**Otherwise;**

**a)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |  |
| **LD 0(R5), R1** | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  |  |  | **R1 <- M[R5]** |
| **LD 0(R6), R2** |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  |  | **R2 <- M[R6]** |
| **LD 0(R7), R3** |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  | **R3 <- M[R7]** |
| **NOP** |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  |
| **NOP** |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |
| **ADD R3, R2, R3** |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  | **R3 <- R3 + R2** |
| **NOP** |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |
| **NOP** |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |
| **SUB R3, R1, R3** |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  | **R3 <- R3 - R1** |
| **BNZ EX** |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |
| **NOP** |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |
| **NEG R3** |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  | **NEGATE R3** |
| **NOP** |  |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |
| **NOP** |  |  |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |
| **ADD R3, R2, R2** |  |  |  |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW | **R2 <- R3 + R2** |

Total amount of penalty: 7

**b)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |  |
| **LD 0(R6), R2** | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  |  | **R2 <- M[R6]** |
| **LD 0(R7), R3** |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |  | **R3 <- M[R7]** |
| **LD 0(R5), R1** |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  | **R1 <- M[R5]** |
| **NOP** |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |  |  |
| **ADD R3, R2, R3** |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  | **R3 <- R3 + R2** |
| **NOP** |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |  |
| **NOP** |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |  |  |
| **SUB R3, R1, R3** |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  | **R3 <- R3 - R1** |
| **BNZ EX** |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |  |
| **NOP** |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |  |  |
| **NEG R3** |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  | **NEGATE R3** |
| **NOP** |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |  |
| **NOP** |  |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW |  |  |
| **ADD R3, R2, R2** |  |  |  |  |  |  |  |  |  |  |  |  |  | FR | EX | MW | **R2 <- R3 + R2** |

Total amount of penalty: 6