1. Start with a Characteristic Table.
   Example: **SR Clocked Flip-Flop**

| | $CLK$ | $S$ | $R$ | $Q(t)$ | $Q(t+1)$ | |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | No Clock<br>SR Flip-Flop Retains State |
| 1 | 0 | 0 | 0 | 1 | 1 | |
| 2 | 0 | 0 | 1 | 0 | 0 | |
| 3 | 0 | 0 | 1 | 1 | 1 | |
| 4 | 0 | 1 | 0 | 0 | 0 | |
| 5 | 0 | 1 | 0 | 1 | 1 | |
| 6 | 0 | 1 | 1 | 0 | 0 | |
| 7 | 0 | 1 | 1 | 1 | 1 | |
| 8 | 1 | 0 | 0 | 0 | 0 | No Operation |
| 9 | 1 | 0 | 0 | 1 | 1 | |
| 10 | 1 | 0 | 1 | 0 | 0 | Reset |
| 11 | 1 | 0 | 1 | 1 | 0 | |
| 12 | 1 | 1 | 0 | 0 | 1 | Set |
| 13 | 1 | 1 | 0 | 1 | 1 | |
| 14 | 1 | 1 | 1 | 0 | x | Undefined |
| 15 | 1 | 1 | 1 | 1 | x | |

**SR Clocked Flip-Flop Characteristic Table**

2. Augment the Characteristic Table with the Binary Cell SET/RESET controls. Enter values in the Binary Cell control fields that implement the actions defined by the Characteristic Table.

| | $CLK$ | $S$ | $R$ | $Q(t)$ | $Q(t+1)$ | $SET$ | $RESET$ | |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | No Clock<br>SR Flip-Flop Retains State |
| 1 | 0 | 0 | 0 | 1 | 1 | x | 0 | |
| 2 | 0 | 0 | 1 | 0 | 0 | 0 | x | |
| 3 | 0 | 0 | 1 | 1 | 1 | x | 0 | |
| 4 | 0 | 1 | 0 | 0 | 0 | 0 | x | |
| 5 | 0 | 1 | 0 | 1 | 1 | x | 0 | |
| 6 | 0 | 1 | 1 | 0 | 0 | 0 | x | |
| 7 | 0 | 1 | 1 | 1 | 1 | x | 0 | |
| 8 | 1 | 0 | 0 | 0 | 0 | 0 | x | No Operation |
| 9 | 1 | 0 | 0 | 1 | 1 | x | 0 | |
| 10 | 1 | 0 | 1 | 0 | 0 | 0 | x | Reset |
| 11 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | |
| 12 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | Set |
| 13 | 1 | 1 | 0 | 1 | 1 | x | 0 | |
| 14 | 1 | 1 | 1 | 0 | x | x | x | Undefined |
| 15 | 1 | 1 | 1 | 1 | x | x | x | |

**Augmented SR Clocked Flip-Flop Characteristic Table**

| $Q(t)$ | $\rightarrow$ | $Q(t+1)$ | $SET(L)$ | $RESET(L)$ |
|---|---|---|---|---|
| 0 | | 0 | 0 | x |
| 0 | | 1 | 1 | 0 |
| 1 | | 0 | 0 | 1 |
| 1 | | 1 | x | 0 |

**SET-RESET Binary Cell Excitation Table**

3. Plot the SET/RESET control values so that equations for the Characteristic Table can be found.

SET(L)

| CLK S \ R Q(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 00 | 0 | x | x | 0 |
| 01 | 0 | x | x | 0 |
| 11 | 1 | x | x | x |
| 10 | 0 | x | 0 | 0 |

RESET(L)

| CLK S \ R Q(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 00 | x | 0 | 0 | x |
| 01 | x | 0 | 0 | x |
| 11 | 0 | 0 | x | x |
| 10 | x | 0 | 1 | x |

$$SET(L) = (CLK \cdot S)(L)$$

$$RESET(L) = (CLK \cdot R)(L)$$

4. Draw the Logic Diagram of the Flip-Flop.

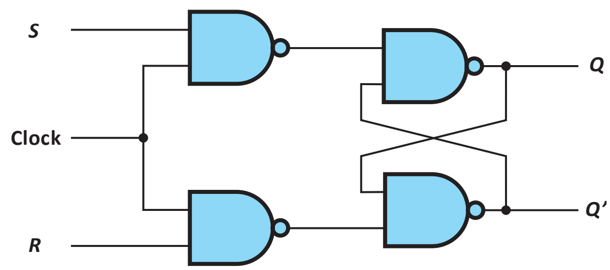



**FIGURE 3.31 (f) Clocked SR Flip-Flop implemented using cross coupled NAND gates**

1. Start with a Characteristic Table.
   Example: **D Clocked Flip-Flop**

| | $CLK$ | $D$ | $Q(t)$ | $Q(t+1)$ | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | No Clock<br>D Flip-Flop Retains State |
| 1 | 0 | 0 | 1 | 1 | |
| 2 | 0 | 1 | 0 | 0 | |
| 3 | 0 | 1 | 1 | 1 | |
| 4 | 1 | 0 | 0 | 0 | Reset |
| 5 | 1 | 0 | 1 | 0 | |
| 6 | 1 | 1 | 0 | 1 | Set |
| 7 | 1 | 1 | 1 | 1 | |

2. Augment the Characteristic Table with the Binary Cell SET/RESET controls. Enter values in the Binary Cell control fields that implement the actions defined by the Characteristic Table.

| | $CLK$ | $D$ | $Q(t)$ | $Q(t+1)$ | $SET$ | $RESET$ | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | x | No Clock<br>D Flip-Flop Retains State |
| 1 | 0 | 0 | 1 | 1 | x | 0 | |
| 2 | 0 | 1 | 0 | 0 | 0 | x | |
| 3 | 0 | 1 | 1 | 1 | x | 0 | |
| 4 | 1 | 0 | 0 | 0 | 0 | x | Reset |
| 5 | 1 | 0 | 1 | 0 | 0 | 1 | |
| 6 | 1 | 1 | 0 | 1 | 1 | 0 | Set |
| 7 | 1 | 1 | 1 | 1 | x | 0 | |

Augmented D Characteristic Table

| $Q(t)$ | $\rightarrow$ | $Q(t+1)$ | $SET(L)$ | $RESET(L)$ |
|---|---|---|---|---|
| 0 | | 0 | 0 | x |
| 0 | | 1 | 1 | 0 |
| 1 | | 0 | 0 | 1 |
| 1 | | 1 | x | 0 |

**SET-RESET Binary Cell Excitation Table**

3. Plot the SET/RESET control values so that equations for the Characteristic Table can be found.

***SET(L)***

| ***CLK*** \ ***D Q(t)*** | **00** | **01** | **11** | **10** |
|---|---|---|---|---|
| **0** | (0) **0** | (1) **x** | (3) **x** | (2) **0** |
| **1** | (4) **0** | (5) **0** | (7) **x** | (6) **1** |

$$SET(L) = (CLK \cdot D)$$

***RESET(L)***

| ***CLK*** \ ***D Q(t)*** | **00** | **01** | **11** | **10** |
|---|---|---|---|---|
| **0** | (0) **x** | (1) **0** | (3) **0** | (2) **x** |
| **1** | (4) **x** | (5) **1** | (7) **0** | (6) **0** |

$$RESET(L) = (CLK \cdot \overline{D})$$

4. Draw the Logic Diagram of the Flip-Flop.

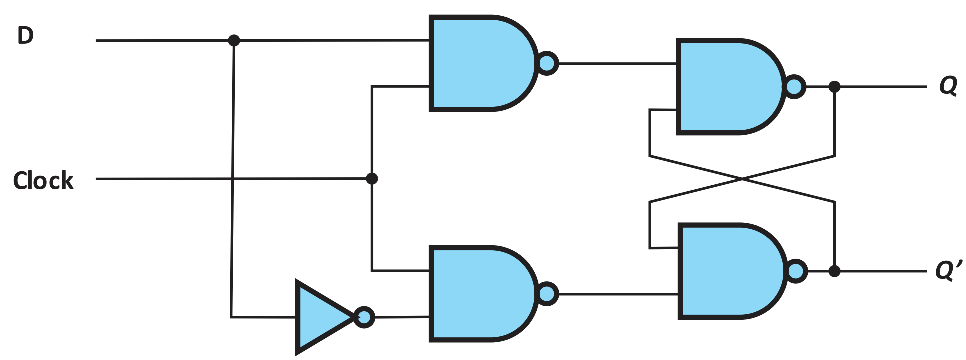



**FIGURE 3.32 Clocked D Flip-Flop implemented using cross coupled NAND gates**

1. Start with a Characteristic Table.
   Example: **D-LATCH Clocked Flip-Flop**

| | $CLK$ | $D$ | $Q(t)$ | $Q(t+1)$ | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | No Clock<br>D-LATCH Flip-Flop Retains State |
| 1 | 0 | 0 | 1 | 1 | |
| 2 | 0 | 1 | 0 | 0 | |
| 3 | 0 | 1 | 1 | 1 | |
| 4 | 1 | 0 | 0 | 0 | Reset |
| 5 | 1 | 0 | 1 | 0 | |
| 6 | 1 | 1 | 0 | 1 | Set |
| 7 | 1 | 1 | 1 | 1 | |

**D-LATCH Clocked Flip-Flop Characteristic Table**

2. Augment the Characteristic Table with the Binary Cell SET/RESET controls. Enter values in the Binary Cell control fields that implement the actions defined by the Characteristic Table.

| | $CLK$ | $D$ | $Q(t)$ | $Q(t+1)$ | $SET$ | $RESET$ | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | x | No Clock<br>D-LATCH Flip-Flop Retains State |
| 1 | 0 | 0 | 1 | 1 | x | 0 | |
| 2 | 0 | 1 | 0 | 0 | 0 | x | |
| 3 | 0 | 1 | 1 | 1 | x | 0 | |
| 4 | 1 | 0 | 0 | 0 | 0 | x | Reset |
| 5 | 1 | 0 | 1 | 0 | 0 | 1 | |
| 6 | 1 | 1 | 0 | 1 | 1 | 0 | Set |
| 7 | 1 | 1 | 1 | 1 | x | 0 | |

**Augmented D-LATCH Clocked Flip-Flop Characteristic Table**

| $Q(t)$ | $\rightarrow$ | $Q(t+1)$ | $SET(L)$ | $RESET(L)$ |
|---|---|---|---|---|
| 0 | | 0 | 0 | x |
| 0 | | 1 | 1 | 0 |
| 1 | | 0 | 0 | 1 |
| 1 | | 1 | x | 0 |

**SET-RESET Binary Cell Excitation Table**

3. Plot the SET/RESET control values so that equations for the Characteristic Table can be found.

SET(L)

| CLK \ DQ(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 0 | 0 | x | x | 0 |
| 1 | 0 | 0 | x | 1 |

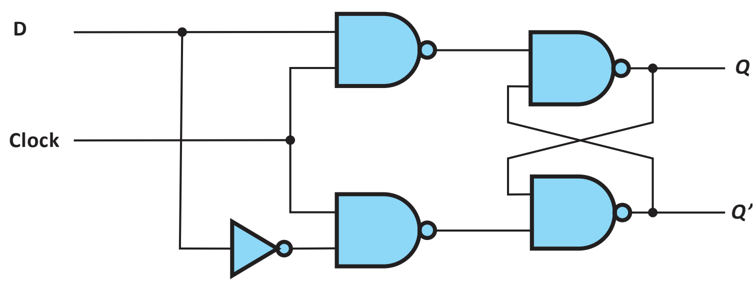
$$SET(L) = (CLK \cdot D)(L)$$

RESET(L)

| CLK \ DQ(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 0 | x | 0 | 0 | x |
| 1 | x | 1 | 0 | 0 |

$$RESET(L) = (CLK \cdot \overline{D})(L)$$

4. Draw the Logic Diagram of the Flip-Flop.




**Clocked D Flip-Flop Logic Diagram**

1. Start with a Characteristic Table.
   Example**: JK Clocked Flip-Flop**

| | $CLK$ | $J$ | $K$ | $Q(t)$ | $Q(t+1)$ | |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | No Clock<br>JK Flip-Flop Retains State |
| 1 | 0 | 0 | 0 | 1 | 1 | |
| 2 | 0 | 0 | 1 | 0 | 0 | |
| 3 | 0 | 0 | 1 | 1 | 1 | |
| 4 | 0 | 1 | 0 | 0 | 0 | |
| 5 | 0 | 1 | 0 | 1 | 1 | |
| 6 | 0 | 1 | 1 | 0 | 0 | |
| 7 | 0 | 1 | 1 | 1 | 1 | |
| 8 | 1 | 0 | 0 | 0 | 0 | No Operation |
| 9 | 1 | 0 | 0 | 1 | 1 | |
| 10 | 1 | 0 | 1 | 0 | 0 | Reset |
| 11 | 1 | 0 | 1 | 1 | 0 | |
| 12 | 1 | 1 | 0 | 0 | 1 | Set |
| 13 | 1 | 1 | 0 | 1 | 1 | |
| 14 | 1 | 1 | 1 | 0 | 1 | Toggle |
| 15 | 1 | 1 | 1 | 1 | 0 | |

**JK Clocked Flip-Flop Characteristic Table**

2. Augment the Characteristic Table with the Binary Cell SET/RESET controls. Enter values in the Binary Cell control fields that implement the actions defined by the Characteristic Table.

| | $CLK$ | $J$ | $K$ | $Q(t)$ | $Q(t+1)$ | $SET$ | $RESET$ | |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | No Clock<br>JK Flip-Flop Retains State |
| 1 | 0 | 0 | 0 | 1 | 1 | x | 0 | |
| 2 | 0 | 0 | 1 | 0 | 0 | 0 | x | |
| 3 | 0 | 0 | 1 | 1 | 1 | x | 0 | |
| 4 | 0 | 1 | 0 | 0 | 0 | 0 | x | |
| 5 | 0 | 1 | 0 | 1 | 1 | x | 0 | |
| 6 | 0 | 1 | 1 | 0 | 0 | 0 | x | |
| 7 | 0 | 1 | 1 | 1 | 1 | x | 0 | |
| 8 | 1 | 0 | 0 | 0 | 0 | 0 | x | No Operation |
| 9 | 1 | 0 | 0 | 1 | 1 | x | 0 | |
| 10 | 1 | 0 | 1 | 0 | 0 | 0 | x | Reset |
| 11 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | |
| 12 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | Set |
| 13 | 1 | 1 | 0 | 1 | 1 | x | 0 | |
| 14 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | Toggle |
| 15 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | |

**Augmented JK Clocked Flip-Flop Characteristic Table**

| $Q(t)$ | $\rightarrow$ | $Q(t+1)$ | $SET(L)$ | $RESET(L)$ |
|---|---|---|---|---|
| 0 | | 0 | 0 | x |
| 0 | | 1 | 1 | 0 |
| 1 | | 0 | 0 | 1 |
| 1 | | 1 | x | 0 |

**SET-RESET Binary Cell Excitation Table**

3. Plot the SET/RESET control values so that equations for the Characteristic Table can be found.

SET(L)

| CLK J \ K Q(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 00 | 0 (0) | x (1) | x (3) | 0 (2) |
| 01 | 0 (4) | x (5) | x (7) | 0 (6) |
| 11 | 1 (12) | x (13) | 0 (15) | 1 (14) |
| 10 | 0 (8) | x (9) | 0 (11) | 0 (10) |

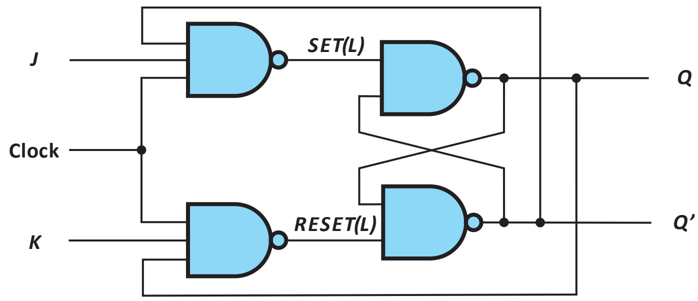
RESET(L)

| CLK J \ K Q(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 00 | x (0) | 0 (1) | 0 (3) | x (2) |
| 01 | x (4) | 0 (5) | 0 (7) | x (6) |
| 11 | 0 (12) | 0 (13) | 1 (15) | 0 (14) |
| 10 | x (8) | 0 (9) | 1 (11) | x (10) |

$$SET(L) = (CLK \cdot J \cdot \overline{Q})(L)$$

$$RESET(L) = (CLK \cdot K \cdot Q)(L)$$

4. Draw the Logic Diagram of the Flip-Flop.




**Clocked JK Flip-Flop Logic Diagram**

1. Start with a Characteristic Table.
   Example: **T Clocked Flip-Flop**

| | $CLK$ | $T$ | $Q(t)$ | $Q(t+1)$ | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | No Clock<br>T Flip-Flop Retains State |
| 1 | 0 | 0 | 1 | 1 | |
| 2 | 0 | 1 | 0 | 0 | |
| 3 | 0 | 1 | 1 | 1 | |
| 4 | 1 | 0 | 0 | 0 | Retain State |
| 5 | 1 | 0 | 1 | 1 | |
| 6 | 1 | 1 | 0 | 1 | Toggle-Set |
| 7 | 1 | 1 | 1 | 0 | Toggle-Reset |

**T Clocked Flip-Flop Characteristic Table**

2. Augment the Characteristic Table with the Binary Cell SET/RESET controls. Enter values in the Binary Cell control fields that implement the actions defined by the Characteristic Table.

| | $CLK$ | $T$ | $Q(t)$ | $Q(t+1)$ | $SET$ | $RESET$ | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | x | No Clock<br>T Flip-Flop Retains State |
| 1 | 0 | 0 | 1 | 1 | x | 0 | |
| 2 | 0 | 1 | 0 | 0 | 0 | x | |
| 3 | 0 | 1 | 1 | 1 | x | 0 | |
| 4 | 1 | 0 | 0 | 0 | 0 | x | Retain State |
| 5 | 1 | 0 | 1 | 1 | x | 0 | |
| 6 | 1 | 1 | 0 | 1 | 1 | 0 | Toggle-Set |
| 7 | 1 | 1 | 1 | 0 | 0 | 1 | Toggle-Reset |

**Augmented D-LATCH Clocked Flip-Flop Characteristic Table**

| $Q(t)$ | $\rightarrow$ | $Q(t+1)$ | $SET(L)$ | $RESET(L)$ |
|---|---|---|---|---|
| 0 | | 0 | 0 | x |
| 0 | | 1 | 1 | 0 |
| 1 | | 0 | 0 | 1 |
| 1 | | 1 | x | 0 |

**SET-RESET Binary Cell Excitation Table**

3. Plot the SET/RESET control values so that equations for the Characteristic Table can be found.

***SET(L)***

| CLK \ T Q(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 0 | 0 | x | x | 0 |
| 1 | 0 | x | 0 | 1 |

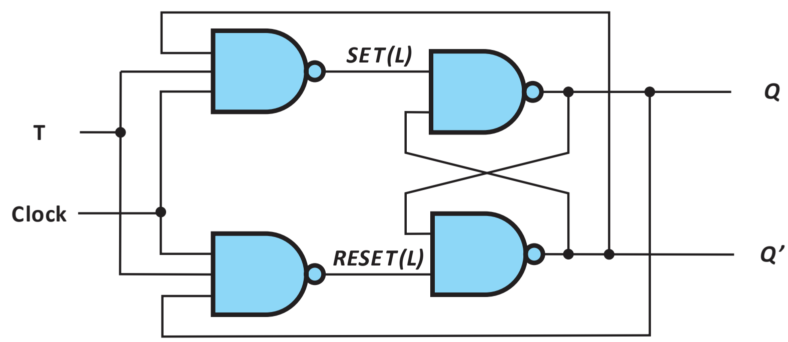
$$SET(L) = (CLK \cdot T \cdot \overline{Q})(L)$$

***RESET(L)***

| CLK \ T Q(t) | 00 | 01 | 11 | 10 |
|---|---|---|---|---|
| 0 | x | 0 | 0 | x |
| 1 | x | 0 | 1 | 0 |

$$RESET(L) = (CLK \cdot T \cdot Q)(L)$$

4. Draw the Logic Diagram of the Flip-Flop.




**Clocked T Flip-Flop Logic Diagram**