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1. Counter에 대해서 조사하시오.

디지털 회로에서, counter는 특정 이벤트나 프로세스가 일어난 횟수를 보관하는 장치이다. 대부분 이 이벤트는 clock에 연관된 이벤트인 경우가 많다. 가장 흔한 방식의 counter는 하나의 input, clock과 여러 개의 출력 line을 가진 sequential 디지털 회로이다. 예를 들어, 다음과 같이 출력의 여러 line을 binary number 시스템으로 설정해 출력할 수 있다.

![텍스트이(가) 표시된 사진

자동 생성된 설명](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEASABIAAD/4REIRXhpZgAATU0AKgAAAAgABQEaAAUAAAABAAAASgEbAAUAAAABAAAAUgEoAAMAAAABAAIAAIdpAAQAAAABAAAIZuocAAcAAAgMAAAAWgAAAAAAAABIAAAAAQAAAEgAAAABHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAACJAAAAcAAAAEMDIxMJADAAIAAAAUAAAIzJAEAAIAAAAUAAAI4JKRAAIAAAADMjQAAJKSAAIAAAADMjQAAKAAAAcAAAAEMDEwMKABAAMAAAAB//8AAOocAAcAAAgMAAAI9AAAAAAyMDE5OjAxOjA2IDE2OjQzOjIzADIwMTk6MDE6MDYgMTY6NDM6MjMAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Counter는 대부분 여러 개의 flip-flop들이 cascade하게 연결된 구조로 구현된다. Counter는 디지털 회로에서 매우 널리 쓰이는 구조이며, 개별적인 IC 칩으로 제작되거나, 아니면 더 큰 IC칩의 일부분으로 포함된다.

Counter는 다음과 같은 분류로 나뉠 수 있다:

* Asynchronous ripple counter
* Synchronous counter
* Decade counter
* Up/down counter
* Ring counter
* Johnson counter
* Cascaded counter
* Modulus counter

각각의 종류는 각각 다른 사용처에 따라 사용된다. 일반적으로, counter 회로는 디지털 회로이기 때문에, 양의 binary 수로 카운팅을 한다. 그러나, 이따끔은 counting sequence를 사용하는 것이 natural binary 수열을 사용하는 것보다 유리할 때도 있는데, 그 예가 Gray-code를 사용한 gray-code counter가 있다.

Counter는 흔히 디지털 시계와 타이머 등에 쓰인다.

1. Decade Counter에 대해서 조사하시오.

Decade counter는 counter의 종류 중 하나이고, 10개의 state 단위로 카운팅을 하는 counter이다. 다시 말해, binary 값 대신, 10진수의 digit을 단위로 세는 counter이다. 따라서, decade counter는 일반적인 binary counter를 1010(10진수 10)개 까지만 셀 수 있게 구현하면 되므로, 일반적인 4-stage counter에 아래 다이어그램처럼 NAND gate를 추가함으로써 구현이 간단하게 가능하다. 아래 그림에서, NAND gate는 2 번째, 4 번째 Flip-Flop에서부터 input을 받아, output을 각 4개의 Flip-Flop의 CLR 입력으로 보내준다는 것을 확인할 수 있다.

텍스트, 지도이(가) 표시된 사진

자동 생성된 설명

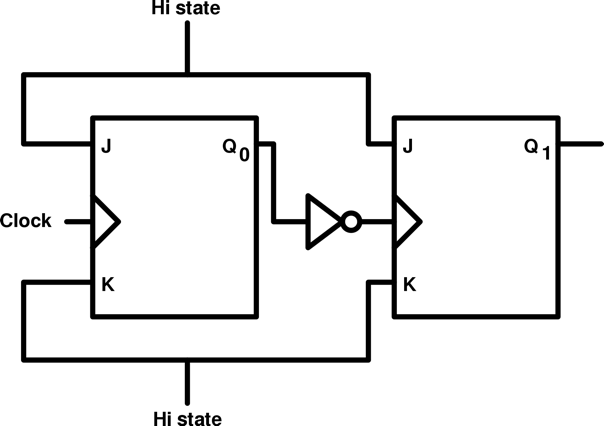
Decade counter는 0에서 9까지 센 뒤, 다시 0으로 리셋되는데, counter에 있는 reset line에 low 값을 주게 되면 출력 값을 다시 0으로 reset시킬 수 있다. 따라서, 1010 값이 될 때 리셋이 되어야 하므로(10 -> 0), NAND gate의 입력으로 해당 두 값을 연결해두면 이 경우에 NAND gate 출력이 high가 되어 값이 0으로 리셋된다.

1. 비동기식 Counter 및 동기식 Counter에 대해서 조사하시오.

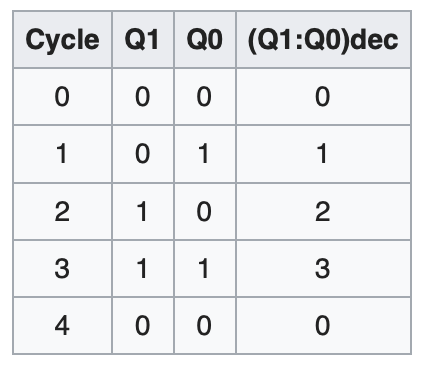
* 비동기식 counter

Asynchronous ripple counter는 하나의 D Flip-Flop과 같은 구조를 가지며, 데이터가 들어오는 J 입력이 자신의 반전된 출력과 연결되어있는 형태를 띈다. 이 회로는 1bit을 저장할 수 있기에, 0에서 1까지 카운팅이 가능하고 이후에는 overflow되어 0으로 돌아간다. 이 counter는 각 clock마다 1씩 증가하며, 2 clock cycle이 지나면 overflow가 일어난다. 따라서, 각 cycle마다 값이 0과 1 사이를 변화한다.

만약 이 counter의 출력이 다른 D Flip-Flop의 clock으로 쓰이면, 두 번째 D Flip-Flop의 clock은 첫 Flip-Flop의 clock보다 1/2의 주파수를 가지기 때문에, 두 Flip-Flop을 합쳐서 2-bit counter의 구현이 가능하다. 아래는 두 개의 JK Flip-Flop을 사용해 2bit를 저장하는 counter를 나타낸다.



해당 2bit counter의 진리표는 다음과 같이 나타낼 수 있다.



위와 같은 방식으로, 추가적인 Flip-Flop을 더 추가하고, 각각의 출력을 자신의 입력으로 연결시키며, 지난 Flip-Flop의 출력을 clock 신호로 사용하면 ripple counter를 구현할 수 있다.

n개의 Flip-Flop을 사용한 n-bit counter는 까지의 수를 카운팅 가능하다. Ripple counter는 overflow들이 각 Flip-Flop을 거치며 넘어간다는 점에서 불안정한 출력이 있을 수 있으나, clock signal을 나누기 위한 회로로서 자주 사용된다.

Flip-flop 출력을 clock으로 다시 사용한다는 부분이 각 bit 간의 timing 문제로 이어질 수 있기 때문에, 이 ripple 기술은 일반적인 동기식 회로 디자인 방식과 호환이 되지 않는다.

* 동기식 counter

Synchronous counter에서, 모든 Flip-Flop들의 입력은 서로 연결되어 input line으로부터 신호를 받는다. 따라서, 모든 Flip-Flop들은 병렬적으로, 동시에 각자의 상태가 변화하게 된다. 4-bit의 synchronous counter의 예는 다음 회로로 볼 수 있다.

개체, 시계이(가) 표시된 사진

자동 생성된 설명

위 다이어그램에서, 0번째 Flip-Flop의 J, K 입력은 high값에 연결되고, 그 이후의 Flip-Flop은 바로 전 Flip-Flop의 출력을 두 입력으로 받는데, 이는 T Flip-Flop을 입력으로 받은 것과 같으며, 결과적으로 bit 1은 bit 0이 high 상태일 때 토글되고, bit 2는 bit 1이 high일 때 토글되는 방식을 보이고 있다.

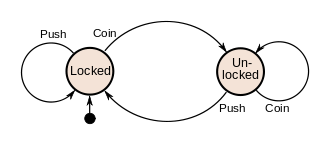
이러한 synchronous counter들은 하드웨어 유한 상태 기계로 구현이 가능하고, 이 때 구조는 더 복잡해지지만 안정적인 값의 변화를 얻어낼 수 있다.

1. FSM(Finite-State Machine)에 대해서 조사하시오.

Finite-state Machine, 유한 상태 기계는 간단히 state machine이라고도 불리며, 논리 회로를 설계할 때 사용되는 수학적 모델이다. 유한 상태 기계는 말 그대로 유한한 개수의 상태를 가질 수 있는 추상 기계(Automata)이다. 특정 시간에는 정확히 단 하나만의 상태(state)를 가질 수 있으며, 어떠한 외부의 입력 값이나 특정 조건이 만족되는 경우 하나의 상태에서 다른 상태로 바뀔 수 있는데, 이를 transition이라 부른다.

Finite-state machine은 세 요소로 정의되는데, state의 나열, 초기 state, 그리고 각 transition에 대응되는 조건이 그 세 요소이다. FSM은 두 가지 종류가 존재한다. 하나는 deterministic FSM(유한 오토마타)이고, 다른 하나는 non-deterministic FSM(비유한 오토마타)이다.

상태 기계의 프로세스는 현대 사회에서 현재 주어진 이벤트에 대해 미리 결정되어진 행동을 수행하는 수많은 기기로부터 확인할 수 있다. 예를 들면 자판기가 있는데, 자판기는 올바른 동전의 조합으로부터 특정 상품을 내놓는 작업을 한다. 또 다른 예시로는 지하철 출입 통제 장치 있는데, 이 장치를 directed 그래프로 나타낸 state diagram을 그리면 다음과 같이 나타낼 수 있다.



이 때, 이 통제 장치의 두 개의 state와 각 state에서의 condition들을 확인할 수 있다.

FSM은 튜링 머신과 같은 다른 컴퓨터 처리 모델들 보다는 더 적은 처리 능력을 가지고 있다. 다시 말해, FSM은 하지 못하지만 튜링 머신은 할 수 있는 계산이 있다는 것이다. 이는 FSM의 기억장치가 해당 FSM이 가지고 있는 state수에 제한되기 때문에 발생한다.

1. 기타 이론.

* Asynchronous ripple counter는 T Flip-Flop과 동일하게 각 clock cycle마다 1씩 증가하며, 2 clock cycle이 지나면 다시 overflow가 일어나 0으로 값이 돌아가기 때문에, 입력 받은 clock 주기의 2배가 되는 clock을 생성하는 데 사용이 가능하다.