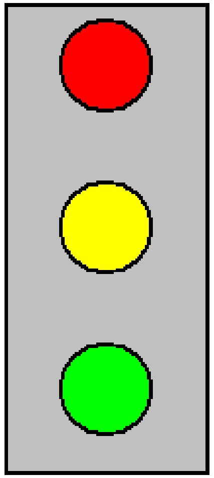
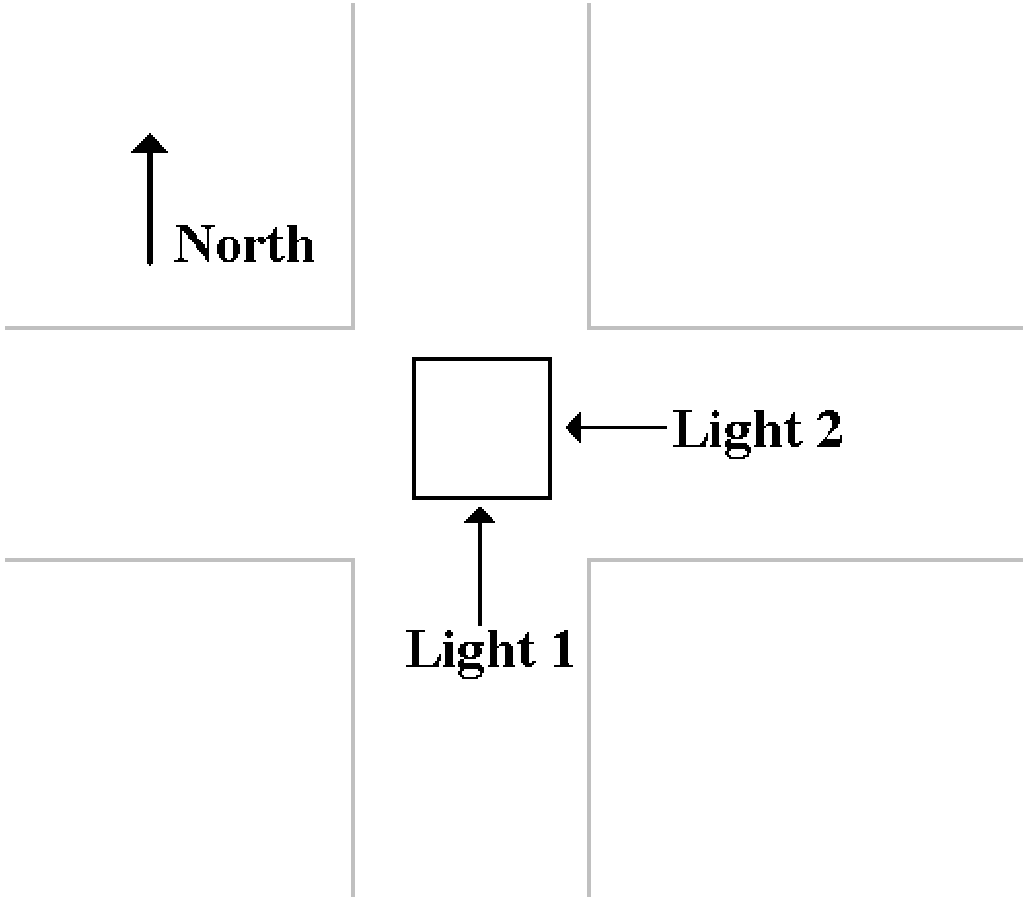
Sample Design:

A Controller for a Simple Traffic Light



Assumption: Two Linked Pairs of Traffic Lights



If one light is Green, the “cross light” must be Red.

Assumed Cycling Rules

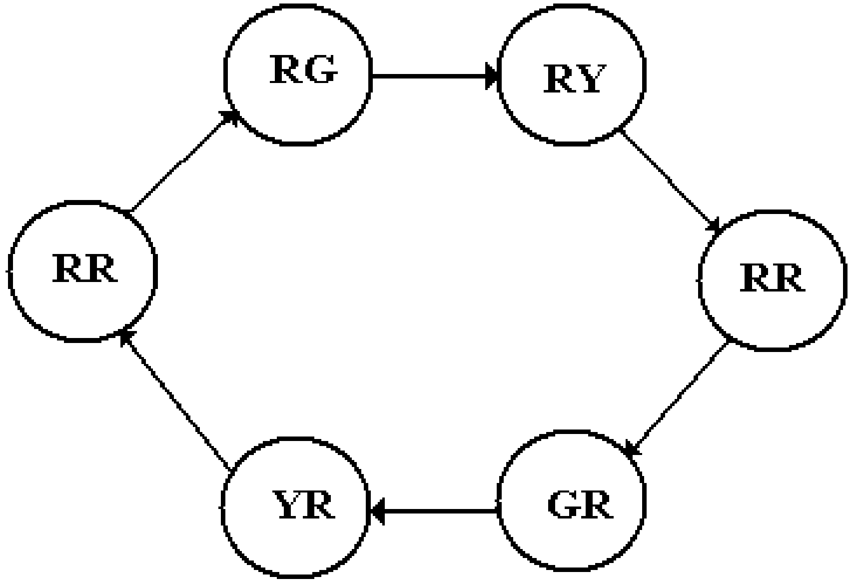
One Light	Cross Light	Comments
Green	Red	Traffic moving on one street
Yellow	Red	Traffic on cross street must wait for this light to turn red.
Red	Red	Both lights are red for about one second.
Red	Green	Cross traffic now moves.

This is the basic sequence for a traffic light without turn signals or features such as an “advanced green”, etc.

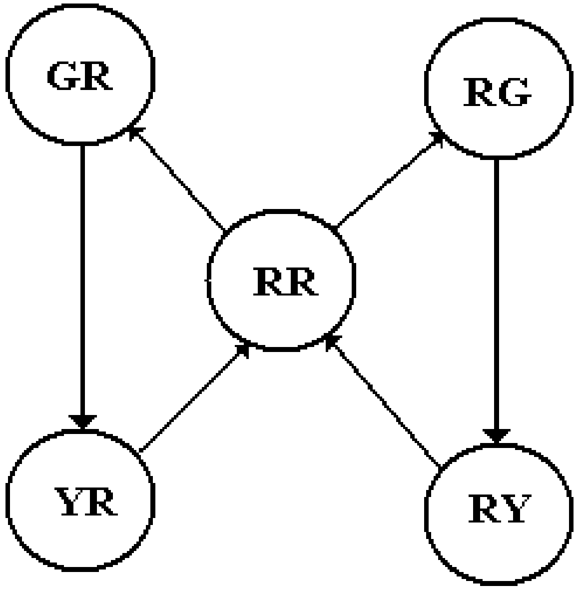
Name the States

State	Light 1	Light 2	Alias
0	Red	Red	RR
1	Red	Green	RG
2	Red	Yellow	RY
3	Red	Red	RR
4	Green	Red	GR
5	Yellow	Red	YR

Step 1a: State Diagram for the System



A Six-State Design



A Five-State Design

Notation: L_1L_2, so RG $\Rightarrow$ Light 1 is Red and Light 2 is Green

The six–state design is more easily implemented.

Step 1b: Define the State Table

Present State		Next State	
Number	Alias	Number	Alias
0	RR	1	RG
1	RG	2	RY
2	RY	3	RR
3	RR	4	GR
4	GR	5	YR
5	YR	0	RR

At the moment, this is just a modulo–6 counter with unusual output.

We shall add some additional circuitry to allow for safety constraints.

The choice of Red – Red as state 0 is arbitrary, but convenient.

Step 2: Count the States and Determine the Flip–Flop Count

There are six states, so we have N = 6.

Solve $2^{P-1} < N \leq 2^P$ for P, the number of flip–flops.

$2^{P-1} < 6 \leq 2^P$ gives P = 3, because $2^2 < 6 \leq 2^3$.

We denote the states by $Q_2Q_1Q_0$, because the symbol "Y" is taken to indicate the color Yellow.

Step 3: Assign a 3–bit Binary Number to Each State

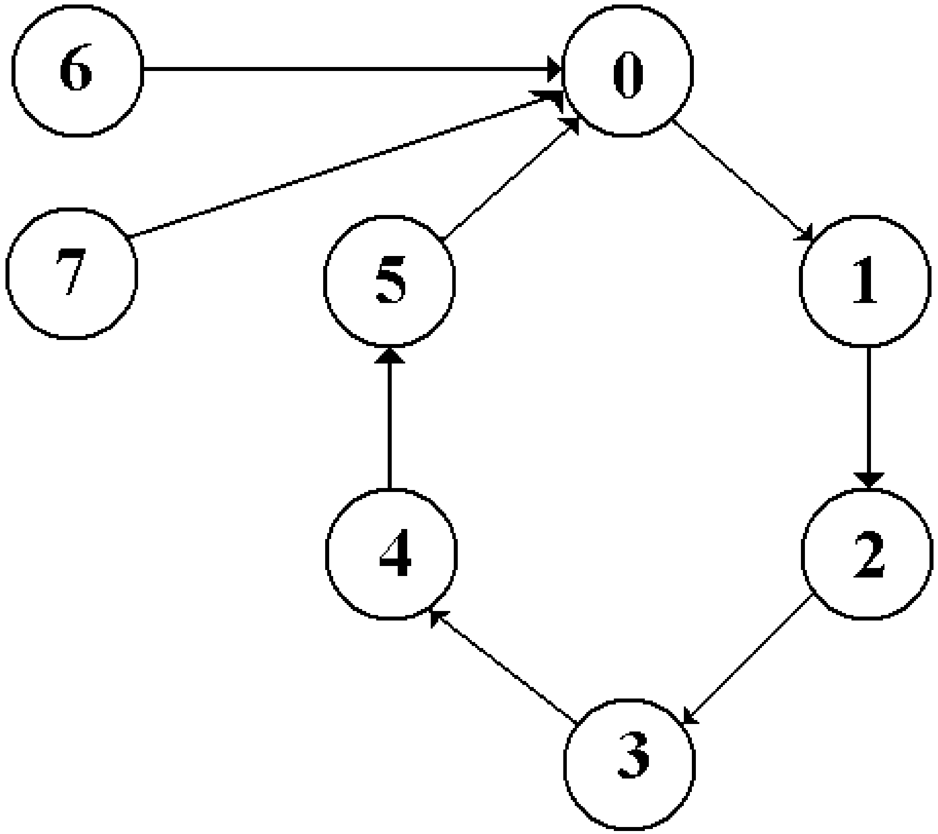
This is a modified counter, so the assignments are quite obvious.

State	**Q_2**	**Q_1**	**Q_0**
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1

We have two possible additional states: 6 and 7.

Normally, these are ignored, but we consider them due to safety constraints.

Redefine the State Diagram to Add Safety



States 6 and 7 should never be entered. Each is “RR” for safety.

Step 4a: Derive the Output Equations.

	Alias	$Q_2Q_1Q_0$	R1	G1	Y1	R2	G2	Y2
0	RR	0 0 0	1	0	0	1	0	0
1	RG	0 0 1	1	0	0	0	1	0
2	RY	0 1 0	1	0	0	0	0	1
3	RR	0 1 1	1	0	0	1	0	0
4	GR	1 0 0	0	1	0	1	0	0
5	YR	1 0 1	0	0	1	1	0	0
6	RR	1 1 0	1	0	0	1	0	0
7	RR	1 1 1	1	0	0	1	0	0

Here are the output equations

$G1 = Q_2 \bullet Q_1' \bullet Q_0'$ $G2 = Q_2' \bullet Q_1' \bullet Q_0$

$Y1 = Q_2 \bullet Q_1' \bullet Q_0$ $Y2 = Q_2' \bullet Q_1 \bullet Q_0'$

$R1 = (G1 + Y1)'$ $R2 = (G2 + Y2)'$

Step 4a: Derive the Output Equations. (page 2)

Here are the equations again.

$G1 = Q_2 \bullet Q_1' \bullet Q_0'$ $\quad$ $G2 = Q_2' \bullet Q_1' \bullet Q_0$

$Y1 = Q_2 \bullet Q_1' \bullet Q_0$ $\quad$ $Y2 = Q_2' \bullet Q_1 \bullet Q_0'$

$R1 = (G1 + Y1)'$ $\quad$ $R2 = (G2 + Y2)'$

We derive the Green and Yellow signals, which are easier.
We stipulate that if a light is not Green or Yellow, it must be Red.

Now add a safety constraint: If a light is Green or Yellow, the cross light must be Red.

$R1 = (G1 + Y1)' + G2 + Y2$, and
$R2 = (G2 + Y2)' + G1 + Y1$

These equations may lead to a light showing two colors.
This is obviously an error situation.

Step 4b: Derive the State Transition Table.

Present State		**Next State**
	$Q_2Q_1Q_0$	$Q_2Q_1Q_0$
0	0 0 0	0 0 1
1	0 0 1	0 1 0
2	0 1 0	0 1 1
3	0 1 1	1 0 0
4	1 0 0	1 0 1
5	1 0 1	0 0 0
6	1 1 0	0 0 0
7	1 1 1	0 0 0

Step 5: Separate the Table into Three Tables

Q_2			Q_1			Q_0	
PS	NS		PS	NS		PS	NS
$Q_2Q_1Q_0$	Q_2		$Q_2Q_1Q_0$	Q_1		$Q_2Q_1Q_0$	Q_0
0 0 0	0		0 **0** 0	0		0 0 **0**	1
0 0 1	0		0 **0** 1	1		0 0 **1**	0
0 1 0	0		0 **1** 0	1		0 1 **0**	1
0 1 1	1		0 **1** 1	0		0 1 **1**	0
1 0 0	1		1 **0** 0	0		1 0 **0**	1
1 0 1	0		1 **0** 1	0		1 0 **1**	0
1 1 0	0		1 **1** 0	0		1 1 **0**	0
1 1 1	0		1 **1** 1	0		1 1 **1**	0

Color added to emphasize the transitions of interest.

Step 6: Select the Flip–Flops to Use

Use JK flip–flops. What a surprise!

The excitation table for a JK flip-flop is given again.

Q(T)	Q(T + 1)		J	K
0	0		0	d
0	1		1	d
1	0		d	1
1	1		d	0

Step 7: Derive the Input Tables

Flip-Flop 2					Flip-Flop 1					Flip-Flop 0			
PS	NS	Input			PS	NS	Input			PS	NS	Input	
$Q_2Q_1Q_0$	Q_2	J_2	K_2		$Q_2Q_1Q_0$	Q_1	J_1	K_1		$Q_2Q_1Q_0$	Q_0	J_0	K_0
0 0 0	**0**	0	d		0 **0** 0	**0**	0	d		0 0 **0**	**1**	1	d
0 0 1	**0**	0	d		0 **0** 1	**1**	1	d		0 0 **1**	**0**	d	1
0 1 0	**0**	0	d		0 **1** 0	**1**	d	0		0 1 **0**	**1**	1	d
0 1 1	**1**	1	d		0 **1** 1	**0**	d	1		0 1 **1**	**0**	d	1
1 0 0	**1**	d	0		1 **0** 0	**0**	0	d		1 0 **0**	**1**	1	d
1 0 1	**0**	d	1		1 **0** 1	**0**	0	d		1 0 **1**	**0**	d	1
1 1 0	**0**	d	1		1 **1** 0	**0**	d	1		1 1 **0**	**0**	0	d
1 1 1	**0**	d	1		1 **1** 1	**0**	d	1		1 1 **1**	**0**	d	1

Step 8: Derive the Input Equations

Here they are

$J_2 = Q_1 \bullet Q_0$ $\quad J_1 = Q_2' \bullet Q_0$ $\quad J_0 = Q_2' + Q_1'$

$K_2 = Q_1 + Q_0$ $\quad K_1 = Q_2 + Q_0$ $\quad K_0 = 1$

There is no need to summarize the equations.

Step 10: Draw the Circuit