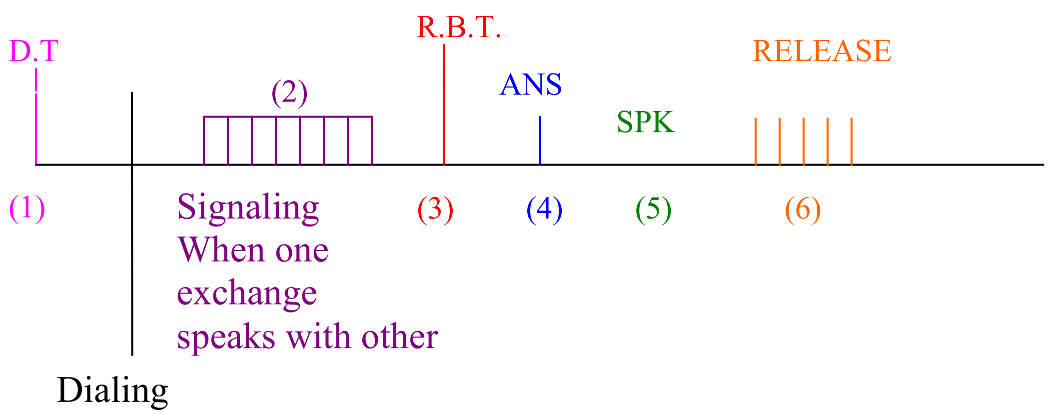
# Switching

## 1. General

Telephone is mainly used to have interactive communications between two people. In order to do this, subscriber has to lift the telephone and dial the required number. The communicating subscriber first listens to dial tone, then the progress tone, and finally the ring back tone. The followings diagram shows the main phases of a telephone call.




Among (1) to (6) except (5) is handled by the controlled unit.
(5) is handled by the switching unit.

## 2. Characteristics

(a) Control unit - It is the active element of an exchange. It is housed with programs. It gives instructions for feeding dial tone to the subscribers. Further monitors the dialing then analyses the dialed digits, activate the signaling with other exchanges etc.

(b) Switching unit –It is the passive element of an exchange. It Connects Inputs to an outputs according to the instruction given by the control unit.

## 3. Analogy

Telephone exchange is analogues to human body. The main organs of human body are as follows.

(i.) Heart - How much blood to be pumped to the body.

(ii.) Brain - Activates according to the instructions of the mind, and produce a results.

(iii.) Peripherals- Hands, nose, mouth ….etc. Brain will produce results with the use of peripherals.

Similarly - Heart is analogues to switching network.
Brain is analogues to controlled network.
Peripherals are analogues to interface units at the exchange.
Mind is analogues to the software developed in the exchange

## 4. Main Components

Hence there are 4 main components in a telephone exchange. They are as follows,

(i.) Switching Network
(ii.) Controlled Network
(iii.) Peripherals
(iv.) Software

## 5. Switching Network

The function of the switching network is to connect an I/P to the O/P. If all the voltages with respect to time generated in the telephone can be seen in the switching network, it is abbreviated as analog switch. In contrary in the switching network if you can see only the samples (or equivalent of samples like 8 bits in PCM) the network is said to be digital.

## 6. Main Factors

Important factors that is to be analyzed in the switching network is as follows.

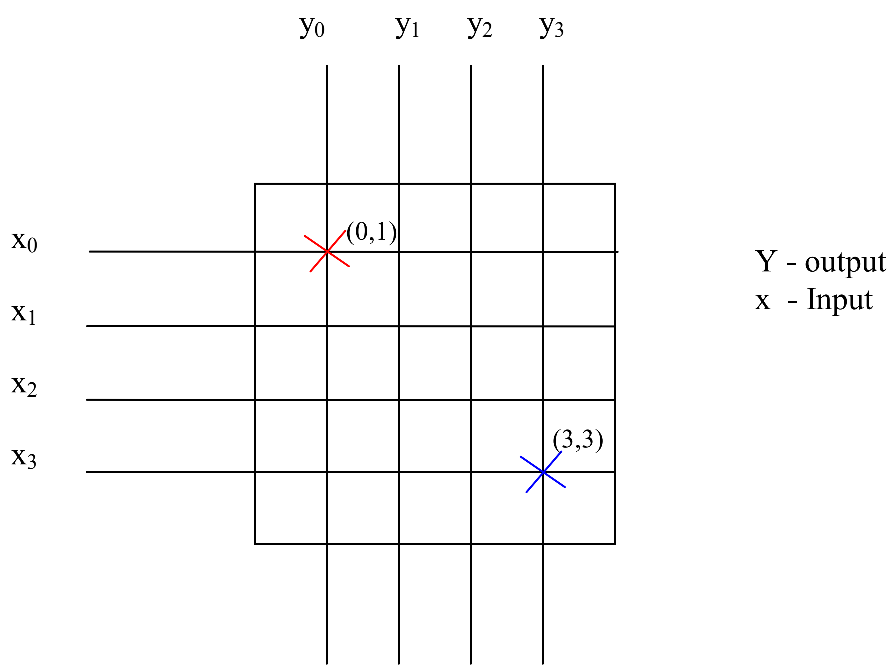
(i.) Availability
(ii.) Blocking
(iii.) No of cross points in the case of an analogue switch or
No of memories used and the cycle time of processor in the case of digital switch

## 6. a. Availability

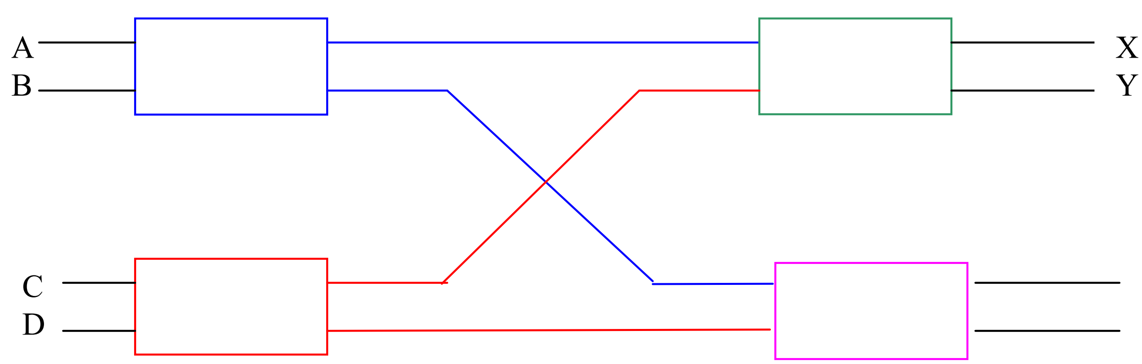
In a switching network if any input can have access (or path) to any out put, then the network is said to be full available system. Sometimes switching network can be of partial availability. In the limited available switching systems as the name implies that a limited number of inputs are having a path to a limited number of outputs.

**Example**

Full available switch




Partial available switch




**6. b. Blocking**

Given a switching network, when already an established connection exist, a further connection from a free input to a free output can be achieved, the network is said to be strict sense of non blocking.

For example if there is a 3 i/p, 3 o/p switch, If 2 i/p 2 o/p are already connected, and further the connection can be established from the 3rd free input to 3rd free output, the network is said to be non blocking.

## 6. c. Technology

Depending upon analog or Digital the technology aspect will differ.

Analog Switching Network

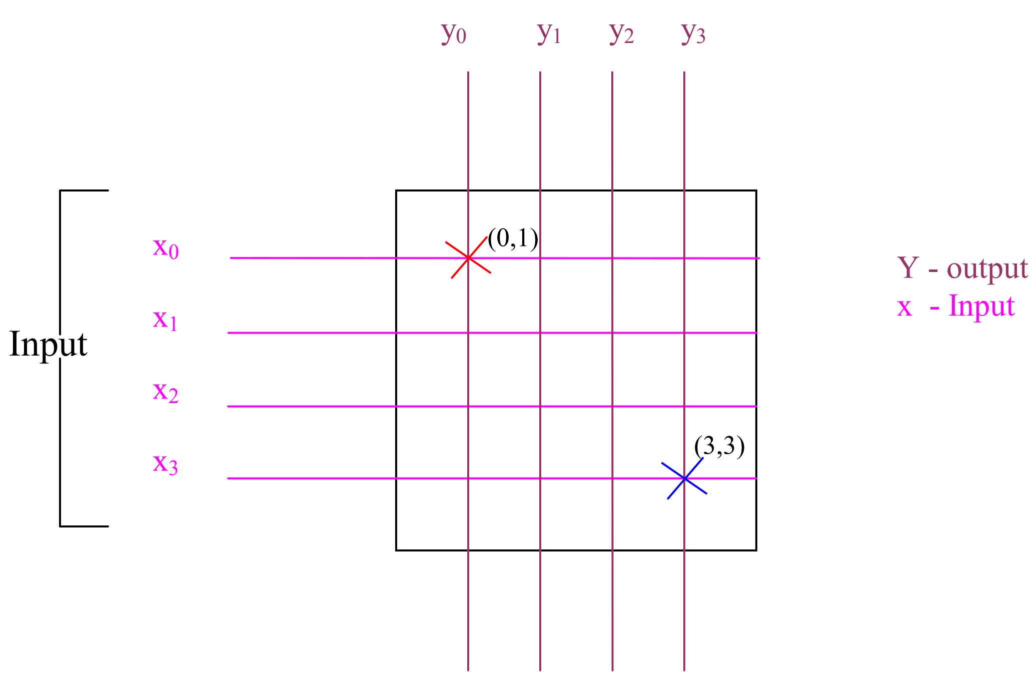
In analog switch, the number of cross points used to achieve a switching network will determine the cost.

## 7. Space or Analog Switching Network

Analog switching uses cross points. In connecting input to an out put with the cross point physical continuous path will be established from input to an output, one of the many devices, such as semi conductor cross points such as switching transistors etc. can be used as cross points. In other words cross point is a gating device. It is having two functionalities

(1.) Operate closing the gate
(2.) Release opening the gate.

We will now analyze a very simple cross point switch,

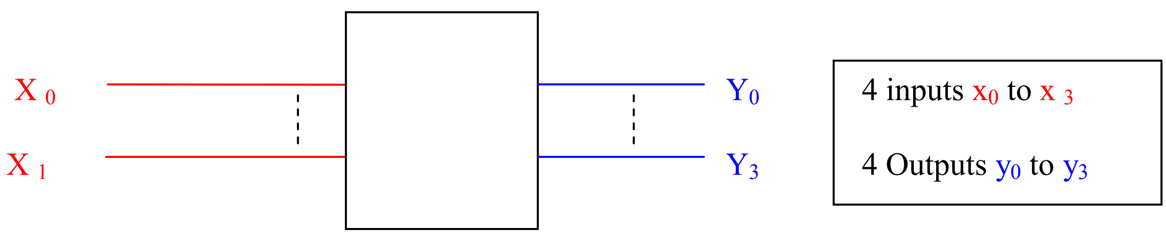


There are 4 input ports and 4 output ports connected through 4 x 4 cross point matrix. In connecting any input port to an output port the corresponding cross point will be operated. It can be observed that any input can be reached to any output through the operating of cross points. Hence it is a full available switching system.

Ex : $x_0$ to $y_1$ → (0,1)cross point will be energized (Marked in the figure)

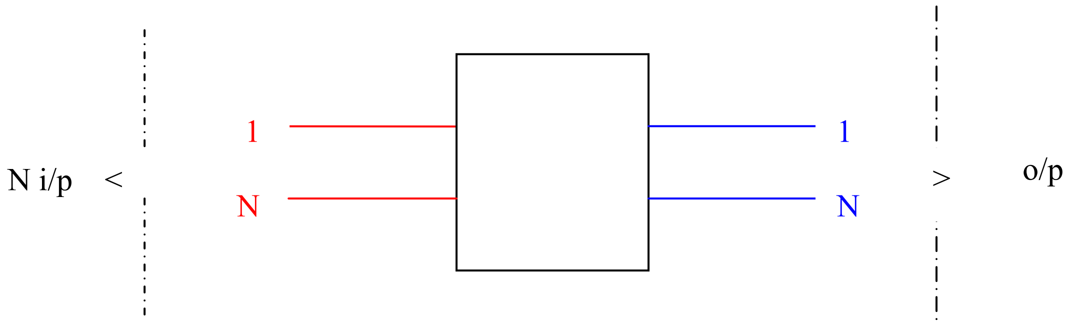
$x_3$ to $y_3$ → (3,3) cross point will be energized. (Marked in the figure)

In this switching matrix (4 x 4) 16 cross-points were used. The above cross-point matrix will be symbolically represented as follows. (in order to analyze the switching networks easily)




Cross-points are proportional to cost. More the cross points used in the switching network will give rise to more cost. How efficient is a switching network has to be analyzed. What is the function of a switching network? To connect any input to any output. But in some cases we will observe that an input is requesting a connection to the output, there is a free output but the switching network is such that it cannot be connected this input to the free output. This is called 'blocking'. Blocking of the switching network has to be clearly identified. Say in a free state if any input can find path to any output, this situation cannot be the non blocking state. Non blocking can be achieved when there are already established connections, one input can be connected to a free output. Blocking of a switching network is important to be analyzed. Take example in the above case, if $x_0$, $x_1$, $x_2$ are connected to $y_0$, $y_1$, $y_2$ respectively. At this moment the last free input $x_3$ can be connected to output $y_3$ by operating (3, 3) cross point. Hence this is a non blocking network.

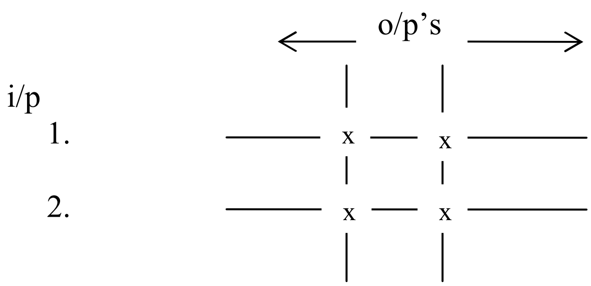
**(a.) Simple Case**




Any input can reach any output. There are $N^2$ cross points required. This network is non blocking, and is having full availability.

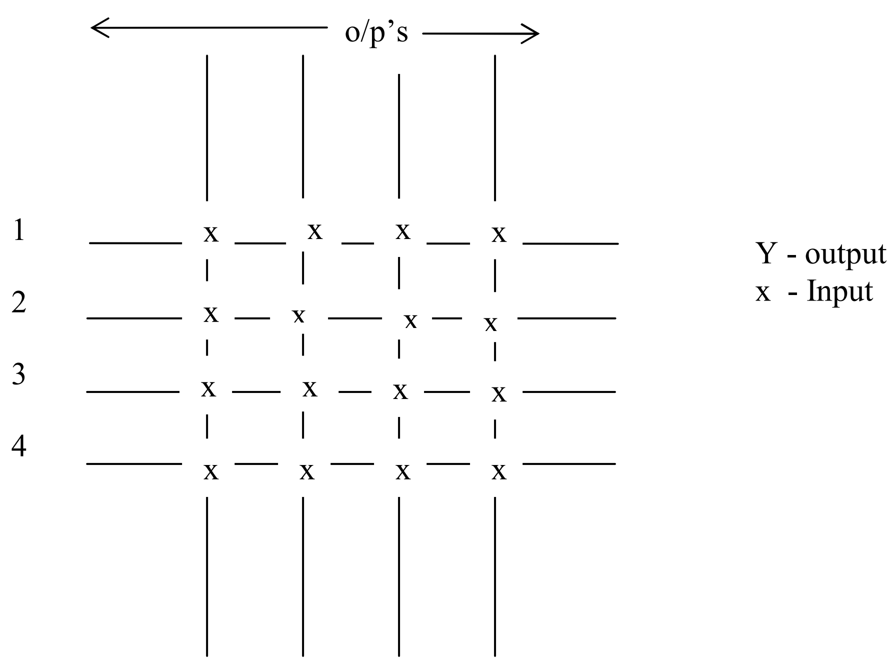
## 7.1 Analysis of a cross point switching network.

(a.)



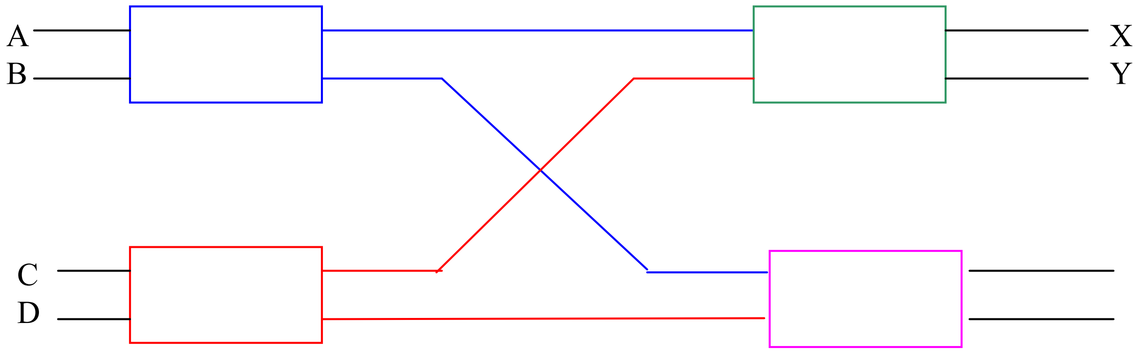

This is a non blocking full available network with 4 cross point.

(b.)

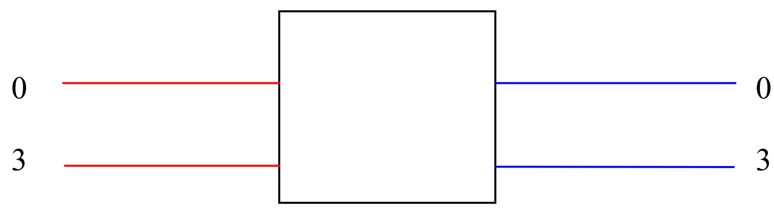


Non blocking full available network with 16 cross points.
Let us consider the link switching (two stage) network which can be achieved 4 input and 4 output.

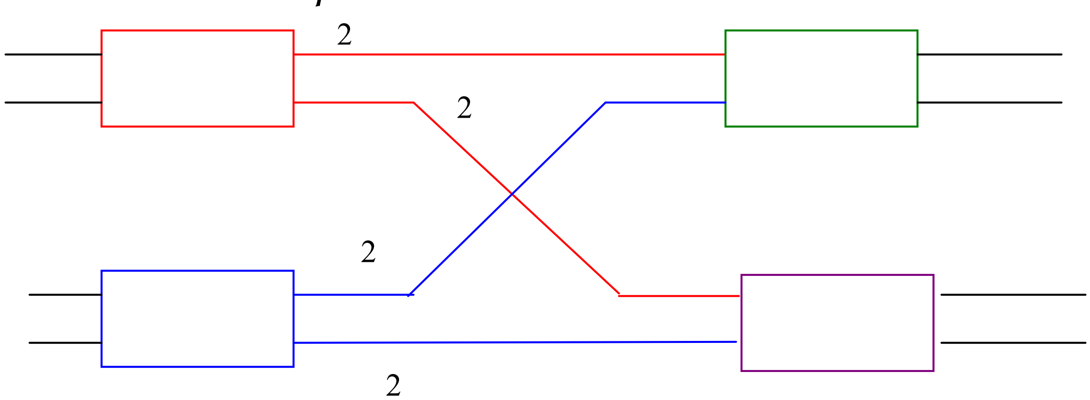
**7.2c.4 Input and 4 output switches.**




When we analyzed the above network, in Free State any input can be reach to any of the outputs. Hence it is a full available system. But is it possible that when A is connected to the x, B is connected to Y? No hence this is called a blocking network. There are 16 cross points. Hence with regard to cross points there is no change to the following network. However the following 4 i/p, 4 o/p single switch is non blocking where as the above 4 x 4, 2 stage link switching network is blocking




**7.2. d How to make this to (4 x 4) 2 stage link switch a non blocking Network?**
*Consider the links in question*

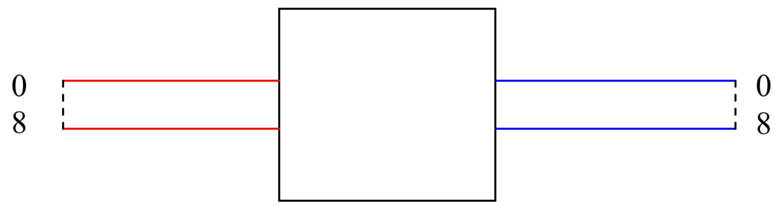



Each link in question instead of one link we should have two links.

We should have 2 x 4 Basic switches. The number of cross points will increase from 16 to 32 (double).

**7.3 Let's analyzed 9 x 9 cross point switch. A single switch will comprise as follows.**

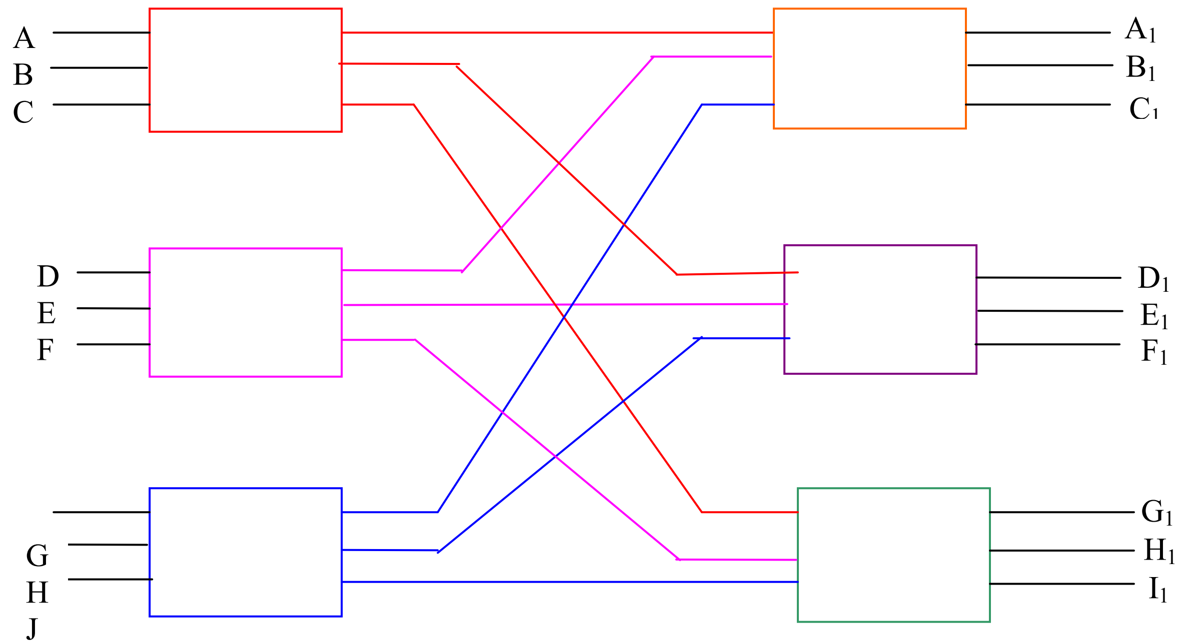
**7.3 (a.)**




The above is a full available – non blocking switch network, with total of 81 cross points.

**7.3 (b.) 9 x 9 Link (2 stage) switch with 3 i/p or o/p Basic Switches**

Now let us consider in achieving above the following line switching network (2 stage) which is build by 3 x 3 basic switches.



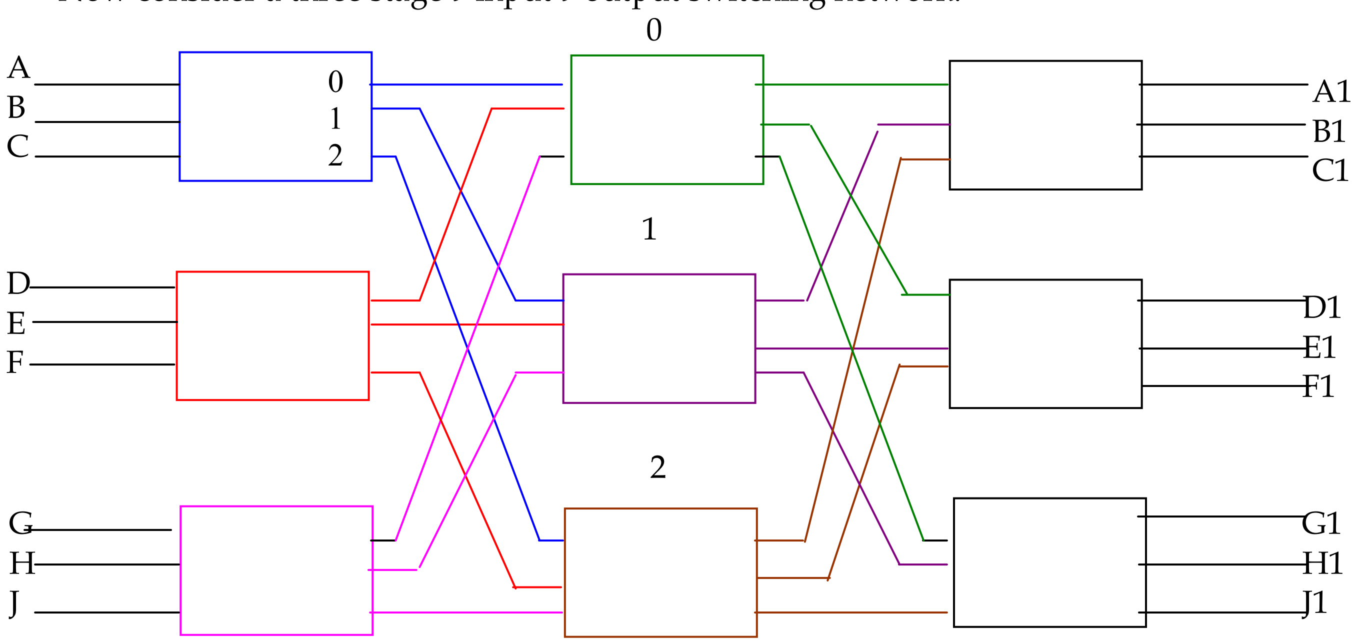

**Observations**

Full availability is achieved due to the fact any input can reach any output through the links provided between the primary basic switches to the secondary basic switches.

**Blocking**
It is not a non blocking switching network, due to the fact that if A is connected to $A_1$, B cannot be connected $B_1$.
**Network**
Comparing to the single switch 9 i/p/o/p switch, this two stage link switch also having the same number of inputs are same number of outputs. However the two switching networks are not same. One is non blocking and the two stage link switching network is blocking. Non blocking single switch was having 81crosspoints where as blocking link network was having 9 x 6 = 54 cross points.

**How to make the two stage link switch non blocking?**
Similar to the previous case a simple switch instead of having 3 x 3, should use 3 x 9 (From each i/p switch, 3 of outlets to each secondary switch has to be drawn. Hence the total number of cross points is going to be 27 x 6 = 162. 100% more cross points than single non blocking switch.

### 7.3 3 Stage Link Switch for 9 x9
Now consider a three stage 9 input 9 output switching network.




The above switching network is a full available system, since any input can reach any output, how to verify non blocking? Non blocking means if the switching network is loaded, a further input can be connected to a free o/p will be stated as non blocking. The above switching network is symmetrical and is having a basic (3 x3) switches at input stage and output stage. Hence in analyzing blocking one basic switch of input and one basic switch of output is considered.

**Input Switch**
Assume A, B are connected to A1, B1 via the middle switches 0 and 1 respectively.

**Output Switch**
Consider the output switch shown, if D, E is connected to D1, E1 through the 1, 2 middle switches respectively.

Now the question comes can we connected C to F shown in the Diagram? Not possible due to the following facts.

a. C to go out from its Basic switch. Only O/P No. 2 is available, and this output is connected to the middle switch 2.
b. There is no link or path from middle switch 2 to the output switch where the output $F_1$
c. is situated (Since for D – $D_1$connection this link is used).

Hence the 3 stage link network shown is a full available blocking network.

**7.3.d Wide sense of non blocking**
Wide sense of non blocking means achieving very close to non blocking by applying a switching rule. For example in the above case use the Ben's rule – "Don't" use a fresh middle switch unless it is really necessary.

Using this rule the above connection A, B to $A_1$, $B_1$ remains same. For D, E to $D_1$, $E_1$ use the 0, 1 (Same middle switches as for A, B according to the Ben's rule.) Now the question is can we connect F to C? Yes – Now there is a path or link from middle switch 2 to the output switch where F output stays.

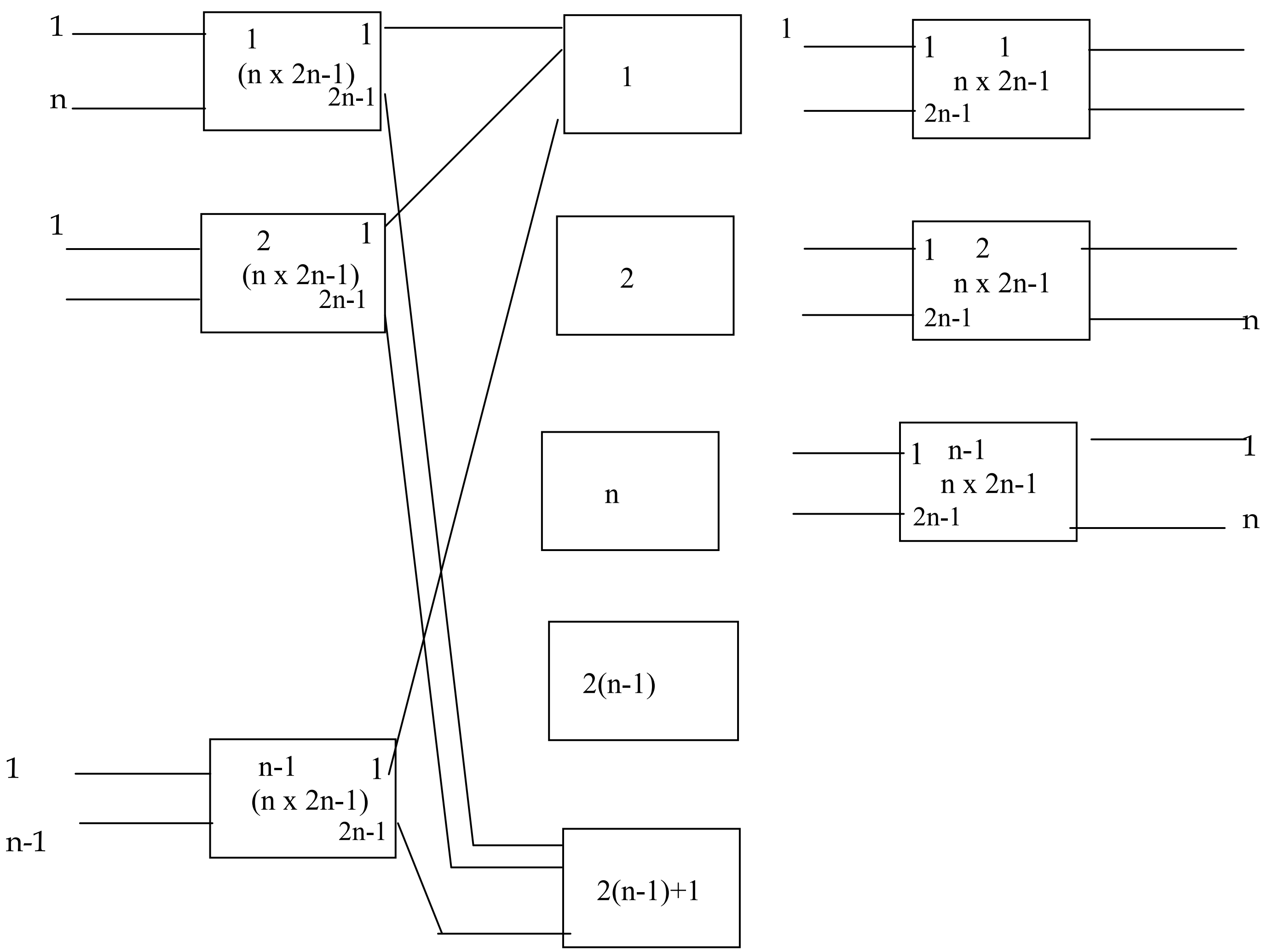
**7.4.d Strict sense of non blocking**
Strict sense of non blocking means achieving non blocking without applying any rules. This has been studied by charles clos (Bell System Technical Journal 1963) and is widely name as a clos switching network

We further study the example that was taken. What is the safety way to go from A, B to A1, B1 for this connection use two fresh middle switches. Also what is the safest way to go from D, E to D1, E1? Use two fresh middle switches. Then what is the safest way to go from F to C? Use another fresh middle switch.

Hence to achieve the above connections, how many middle switches we require? 5

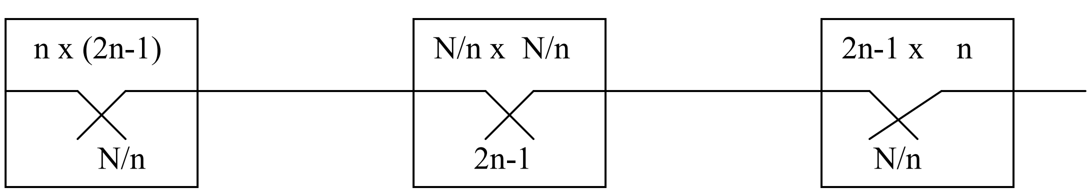
Instead 3 i/p basic switches, n i/p basic switch used with n basic switches as i/p stage and have the same number of o/p stage switches. To achieve strict sense of non blocking how many middle switches we require? 2n – 1.

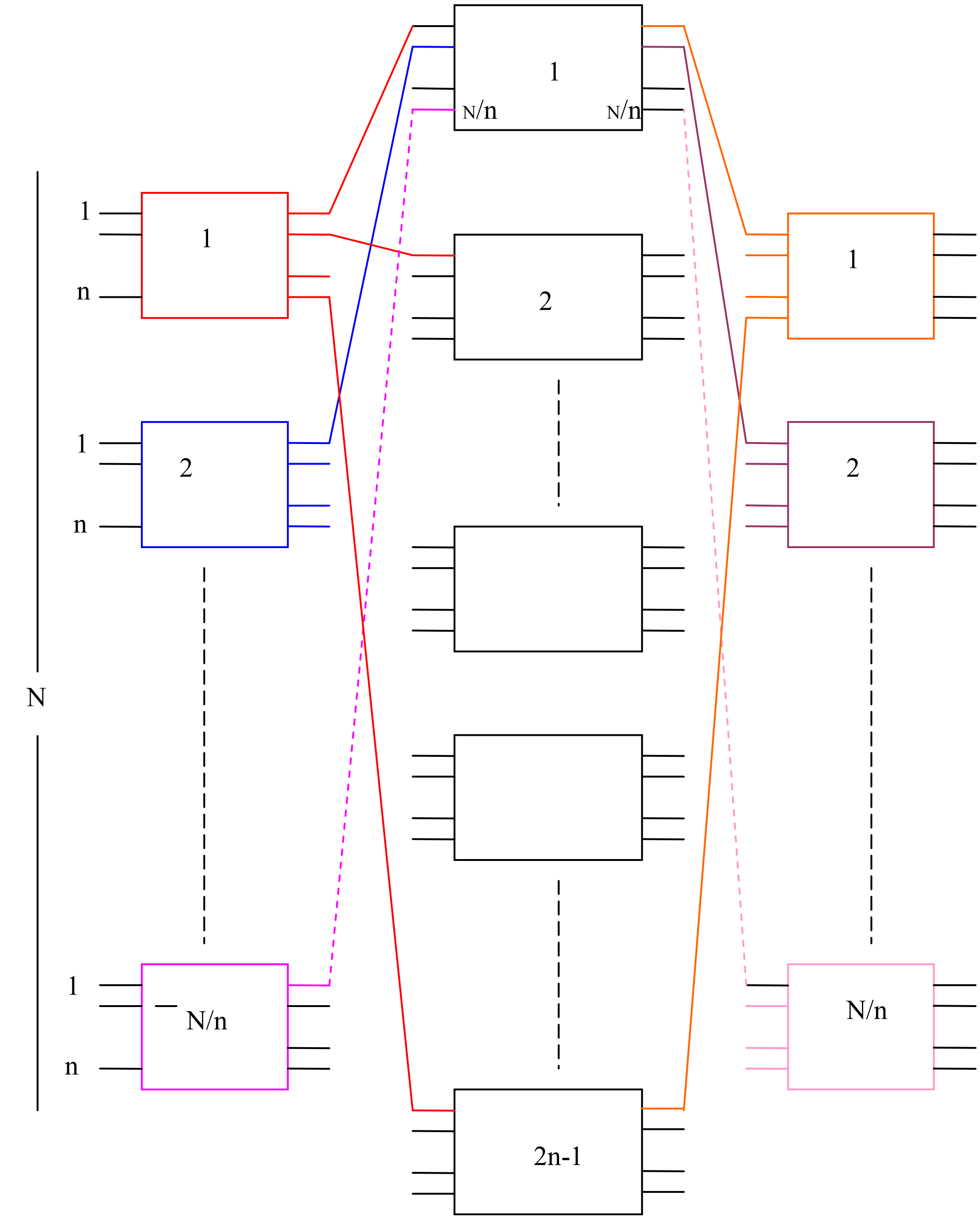
The Link diagram is shown as follows.




**8. Total number of cross points in a 3 stage non blocking network.**

Say N is the total number of inputs or total number of outputs and n be the i/p's or o/p's to basic (Small) switch.
Total number of cross points = Cross points in the input + Cross points in the middle stage + Cross points of the output stage.






Cross points at the input stage $= n\,(2n-1)\,\frac{N}{n}$

Cross points at the output stage $= n\,(2n-1)\,\frac{N}{n}$

N N

Cross points at the middle stage $= \frac{}{n} \cdot \frac{}{n} (2n-1)$

Total Number of cross points = C(3)

$$C(3) = 2n(2n-1) \frac{N}{n} + \frac{N}{n} \times \frac{N}{n} (2n-1)$$

$$= 2(2n-1)N + \frac{N^2}{n^2}(2n-1) = 4Nn - 2N + \frac{2N^2}{n} - \frac{N^2}{n^2}$$

$$= 2N(2n-1) + \frac{N^2}{n}\left(2 - \frac{1}{n}\right)$$

$$= 2N(2n-1) + \frac{N^2}{n^2}(2n-1)$$

$$= (2n-1)\left(2N + \frac{N^2}{n^2}\right)$$

$$C(3) = (2n-1)N\left(2 + \frac{N}{n^2}\right)$$

C(3) – Abbreviate for 3 stages total number of cross points

**Calculation of switch size in order to minimize cross points in 3 stage non blocking switching network**

In this equation N & n are variables

In order to arrive at the minimum value of C(3) with respect to n, and analyze the value of n in order to get the minimum number of cross points,

$$C(3) = (2n-1)N\left(2 + \frac{N}{n}\right) = 4Nn - 2N + \frac{2N^2}{n} - \frac{N^2}{n^2}$$

$$dc(3) = 4N - \frac{2N^2}{n^2} + \frac{2N^2}{n^3} = 0$$

$$4Nn^3 - 2nN^2 + 2N^2 = 0$$

$$4Nn^3 - 2N^2(n-1) = 0$$

If n is large n -1 can be approximated to n.

4Nn3 – 2N2n = 0

If $n \neq 0$ $4Nn^2 - 2N^2 = 0$

$$N = 2N^2$$

$$n = \underline{N}$$

2

When N is large N/2 = N

Hence to get the near minimum cross point for a 3 stage network $N = n^2$ has to be satisfied.

Substituting n = N1/2 to C(3)

$$C(3) = 4NN^{1/2} - 2N + \frac{2N^2}{N^{1/2}} - \frac{N^2}{N}$$

$$= 4N^{2/3} - 3N + 2N^{3/2}$$

$$= \underline{\underline{6N^{3/2} - 3N}}$$

Hence it will be interesting to note that up to n=30, there won't be any saving in cross point by 3 stage non blocking link network, as against single stage switch.

| **N** | **$N^2$** | **$3N(2N^{1/2} - 1)$** |
|---|---|---|
| 1 | 1 | 3 |
| 2 | 4 | 11 |
| 3 | 9 | 22 |
| 4 | 16 | 36 |
| 5 | 25 | 52 |
| 6 | 36 | 70 |
| 7 | 49 | 90 |
| 8 | 84 | 112 |
| 9 | 81 | 135 |
| 10 | 100 | 160 |
| 11 | 121 | 186 |
| 12 | 144 | 213 |
| 13 | 169 | 242 |
| 14 | 196 | 272 |
| 15 | 225 | 304 |
| 16 | 256 | 336 |
| 17 | 289 | 370 |

| **N** | **$N^2$** | **$3N(2N^{1/2} - 1)$** |
|---|---|---|
| 19 | 361 | 440 |
| 20 | 400 | 477 |
| 21 | 441 | 514 |
| 22 | 484 | 553 |
| 23 | 529 | 593 |
| 24 | 576 | 633 |
| 25 | 625 | 675 |
| 26 | 676 | 717 |
| 27 | 729 | 761 |
| 28 | 784 | 805 |
| 29 | 841 | 850 |
| 30 | 900 | 896 |
| 31 | 961 | 943 |
| 32 | 1024 | 990 |
| 33 | 1089 | 1038 |
| 34 | 1156 | 1088 |
| 35 | 1225 | 1137 |

| | | |
|---|---|---|
| 18 | 324 | 404 |

| | | |
|---|---|---|
| 36 | 1296 | 1188 |

So above 30 i/p switching networks, cross points saving can be achieved by having non blocking 3 stage link networks.

The following chart will show how much cross points are saved with 3 stage link switch over to a single stage.

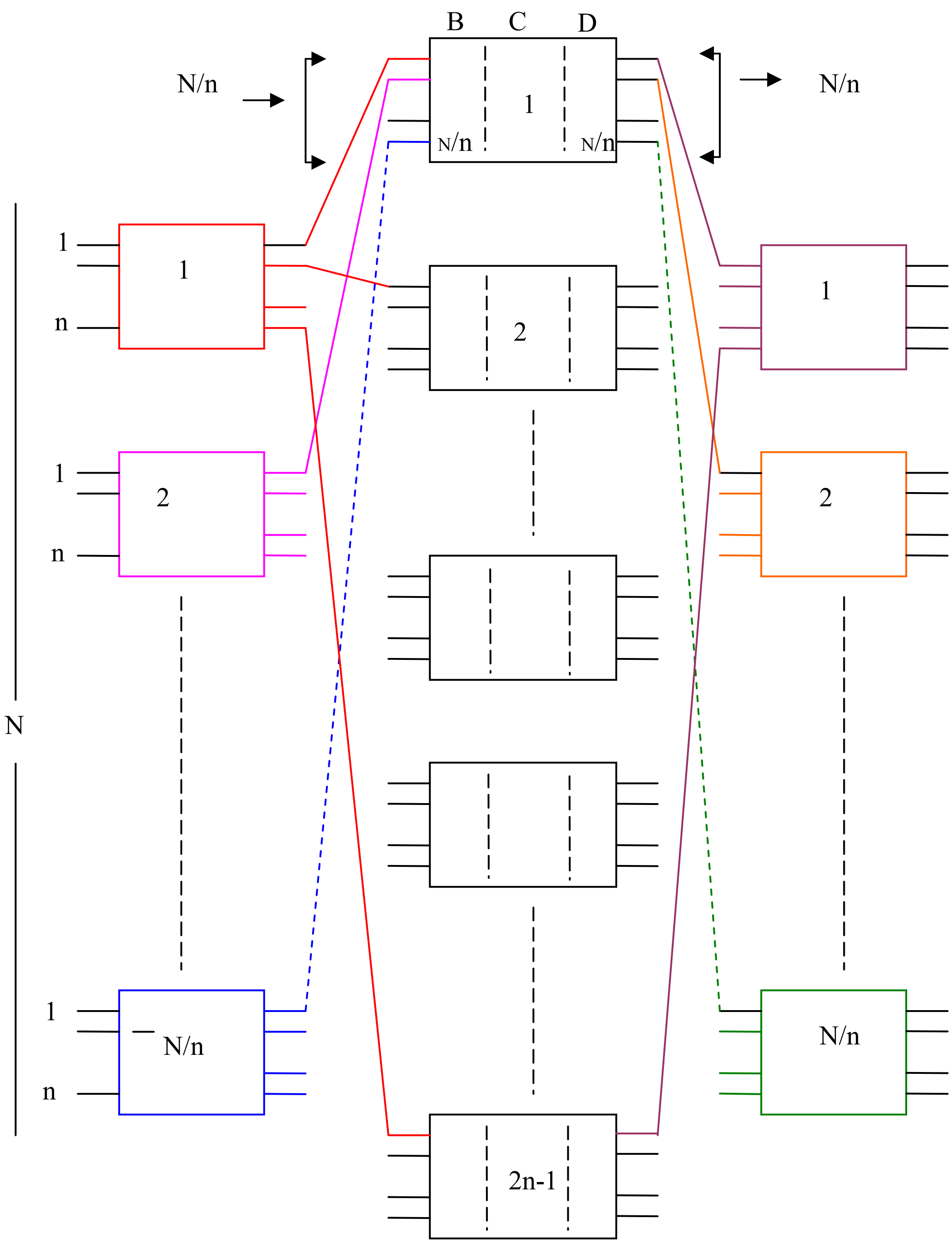
| N | Saving on cross points by having a 3 stage link Network. | Percentage on saving |
|---|---|---|
| 50 | 529 | 21% |
| 100 | 4300 | 43% |
| 200 | 23629 | 59% |
| 300 | 59723 | 66% |
| 400 | 113200 | 70% |
| 500 | 184418 | 74% |
| 700 | 380978 | 77% |
| 900 | 650700 | 80% |
| 1000 | 813264 | 81% |
| 5000 | 22893680 | 91% |
| 10000 | 94030000 | 94% |

You will observe upto $N = 30$, $N^2 < \{3N(2N^{1/2} - 1)\}$

Above $N = 30$, $N^2 > 3N(2N^{1/2} - 1) < N^2$

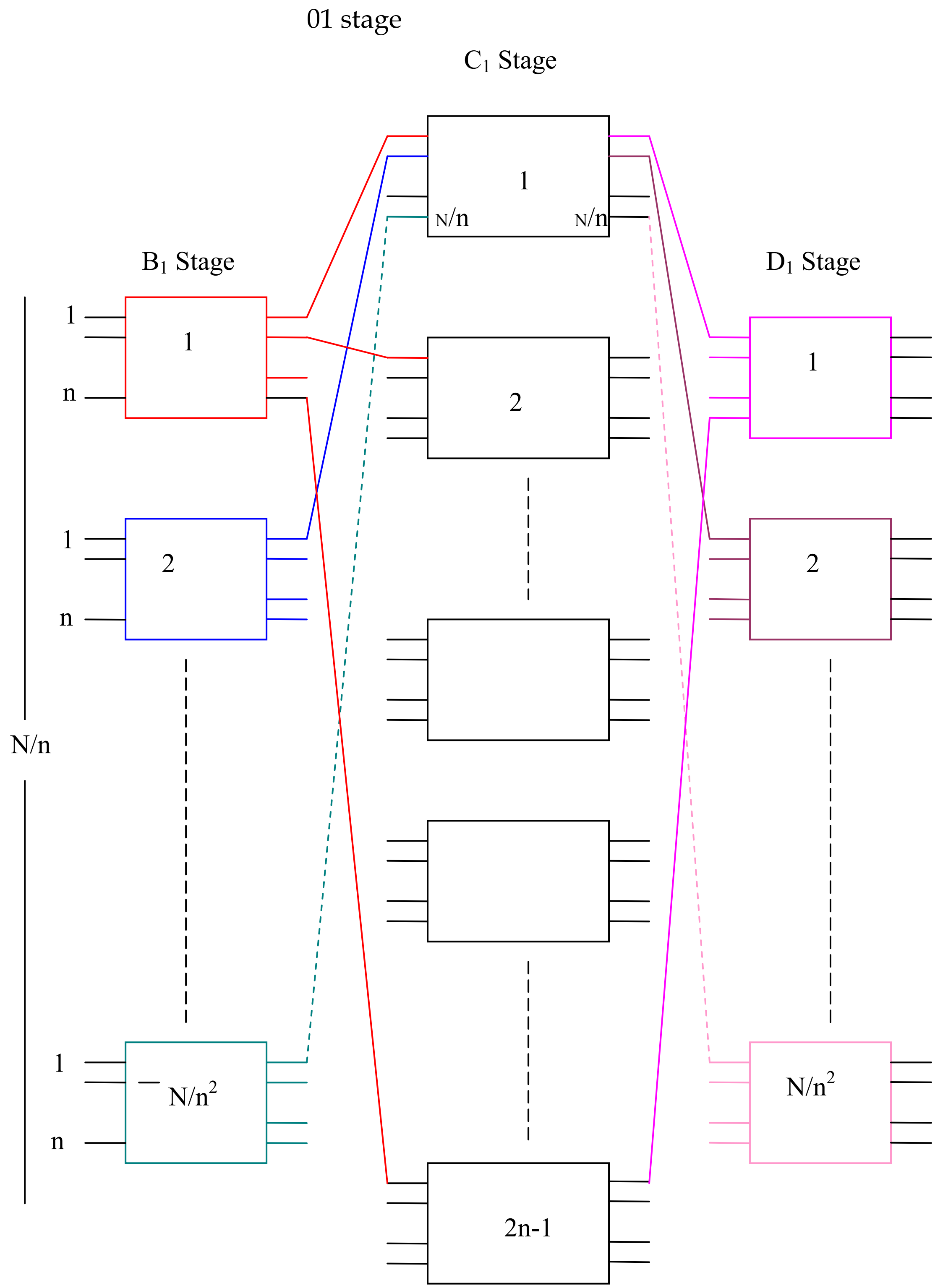
That is to say up to 30 inputs, one switch is advantageous than 30 input multistage link switch. Practical telephone exchanges cater for more than 36 inputs hence it will generally use multistage switching networks.
Now you will observe that the percentage saving of cross point increases drastically more than 50% when we increase the number of inputs more than 200. Here you will understand that when we increase the number of stages we will be able to reduce more cross points.

**10. Let us consider a three stage switching network**



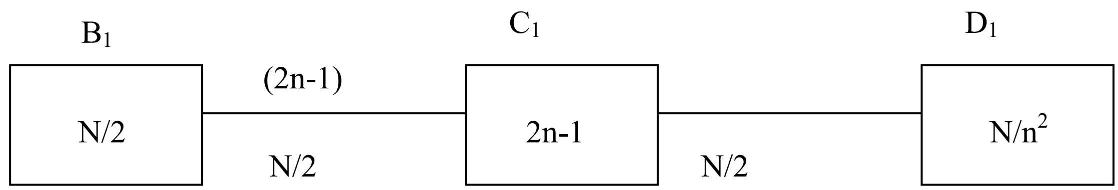

This 5 stage link switch comprises input switch (A) 3 middle switches (BCD) and output switch (E). The 3 middle switches are analogues to the 3 stage non blocking clos network studied in the previous section.

**10.a  Calculation or total number of  cross points 5 stage link switch**



Let's analyze one of the middle 3 switches BCD. (There are (2n-1) middle switches like this). Input to this switch is N/n and one basic switch of B1 stage. Can accommodate n lintels, then we should have $\frac{N}{n^2}$ basic i/p switches at B1.

Then C1, there should be (2n-1) basic switches, B1, C1, D1 switching diagram is as follows.




Total number of x points at $B_1$, $C_1$, and D1

$$\frac{2N}{n^2}(2n-1)n + \frac{N}{n^2}\frac{N}{n^2}(2n-1)$$

$$(2n-1)\left(\frac{2N}{n} + \frac{N^2}{n^4}\right)$$

Total number of cross points of BCD $\sum_{i=1}^{2n-1} B_iC_iD_i$

$$(2n-1)^2\left(\frac{2N}{n} + \frac{N^2}{n^4}\right)$$

Total number of cross points at A and E

$$2n(2n-1)\frac{N}{n}$$

$$\text{Hence } C(5) = (2n-1)\left[2N + (2n-1)\left(\frac{2N}{n} + \frac{N^2}{n^4}\right)\right]$$

$$= \left[2N + 4N + \frac{2N^2}{n^3} - \frac{2N}{n} - \frac{N^2}{n^4}\right]$$

$$C(5) = (2n-1)\left[6N - \frac{2N}{n} + \frac{N^2}{n^3} - \frac{N^2}{n^4}\right]$$

10b. Near minimum cross points for 5 stage non blocking switch from the previous section.

$C(5)$ = Total number of cross points

$$= (2n-1)\left[6N - \frac{2N}{n} - \frac{2N^2}{n^3} - \frac{N^2}{n^4}\right.$$

$$= (2n-1)\left[6N - \frac{2N}{n} - \frac{2N^2}{n^3} - \frac{N^2}{n^4}\right]$$

$$C(5) = 12Nn - 10N + \frac{4N^2}{n} + \frac{2N}{n^3} + \frac{N^2}{n^4} - \frac{4N^2}{n^3}$$

$$\frac{dc}{dn} = 12N - \frac{8N^2}{n^3} - \frac{2N}{n^2} - \frac{4N^2}{n^5} + \frac{12N^2}{n^4} = 0$$

Hence $12Nn^5 - 8N^2n^2 - 2Nn^3 - 4N^2 + 12N^2 = 0$

$$Nn^2\left\{ 12n^3 - 8n - 2n - \frac{4n}{n^2} + \frac{12n}{n} \right\} = 0$$

Near minimum cross points for a 5 stage non blocking switch.

We consider high value for N, n;

When you compare the other values $2n$, $\frac{4n}{n^2}$, $\frac{12N}{n}$ can be neglected.

Hence near minimum cross points are obtained if

$$12n^3 = 8N$$

$$3n^3 = 2N$$

$$n = \left(\frac{2N}{3}\right)^{1/3} = (N)^{1/3}$$