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Unit 10
Circuit Switches

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Overview - Circuit Switching

- Basics
- Space division switching
- Bus time division switching
- Memory time division switching
- Concentration-distribution-expansion
- Multiple stage space switches
- Blocking probabilities
- Multistage mixed switching
- Time-space-time switch
- Real world switch: Siemens EWSD

Literature

- Primary Literature:

  John Bellamy, “Digital Telephony”, Wiley&Sons, 2nd edition, 1991, Chapter 5: Digital Switches

  or

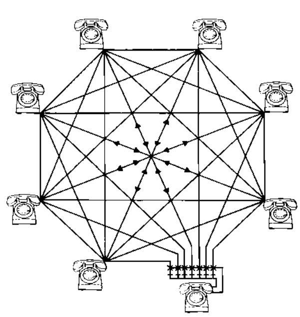
- Mischa Schwartz: “Telecommunication Networks -Protocols, Modeling and Analysis”, Addison Wesley 1987, Chapter 10

- Supplementary Reading

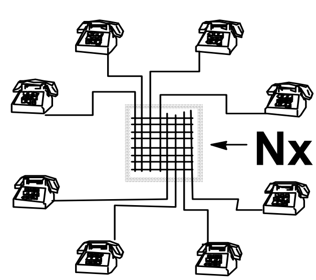
- A. Michael Noll: “Introduction to Telephones & Telephone Systems”, Artech House

Introduction (1)

- Definition
  - Circuit switching is defined as switching that provides for the establishment of dedicated paths for the passage of messages between two or more terminal.
- Evolution of Switching



Station Switching:
- N(N-1)/2 two way lines
- N local switches each with (N-1) crosspoints
- N(N-1) crosspoint



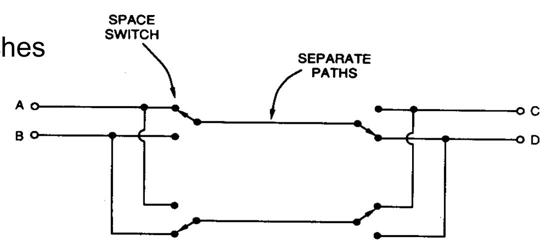
Central Switching:
- N two way lines
- NxN crosspoints

Introduction (2)

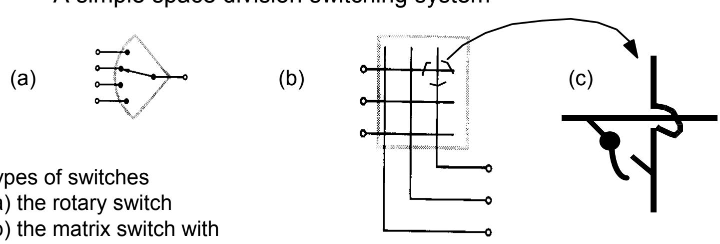
- Functional parts
- Switching network that connects input lines to output lines
- Control unit for instructing the switching network to make specific connections
- Approaches to Circuit Switching
  - Space Division Switching
  - Time Division Switching
    - Bus
    - Memory

Space Division Switching (1)

- A dedicated physical path through the switching network has to be established for each connection.
- Basic types of switches



A simple space division switching system



The basic types of switches
(a) the rotary switch
(b) the matrix switch with
(c) one crosspoint of the matrix switch.

Space Division Switching (2)

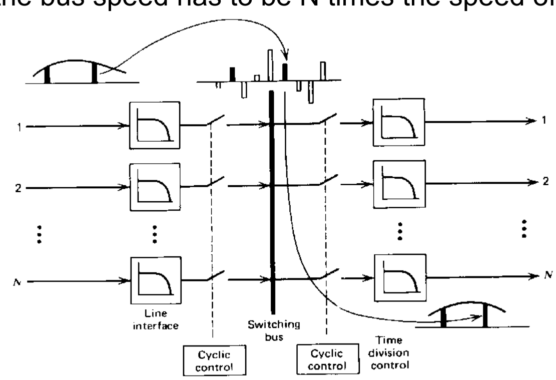
- Matrix switch (N x K)
  - Measure of complexity is the number of crosspoints needed
  - A switch is called non-blocking if a connection between a free input and any output is always possible (provided the output to which a connection is to be made is not already connected)

    Blocking means that a requested connection can not be switched although unused inlets (end-points) are available
  - In case of a non-blocking switch N x K crosspoints are needed
  - To reduce the number of crosspoints some probability of blocking is introduced
- Imagine 100.000 lines have to be interconnected. This requires 10^{10} crosspoints if blocking is unacceptable.

  How to reduce the number of crosspoints while retaining either non-blocking or a very small probability of blocking? We shall discuss...

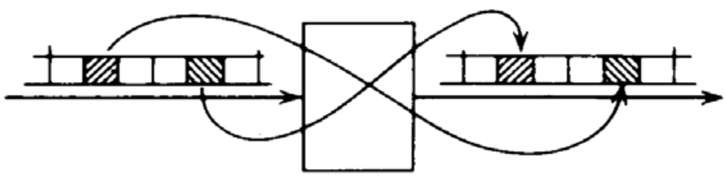
Bus Time Division Switching

- A single switching bus supports a multiple number of connections by interleaving samples from receive line interfaces to transmit line interfaces.
- A complete set of pulses, one from each active input line, is referred to as a frame.
- For N inputs and N outputs 2N gates are required
- For a non-blocking switch the bus speed has to be N times the speed of the input line
- Mainly for analog signals (see picture).

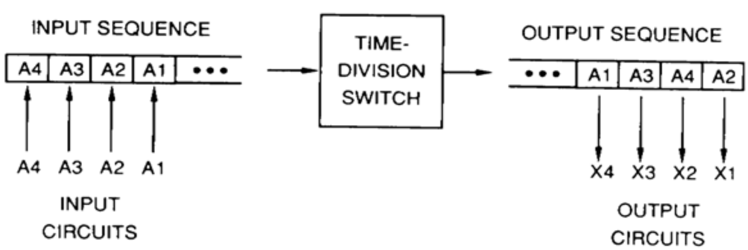


Memory Time Division Switching (1)

- A switch operates by writing data into and reading data out of a single memory
- The exchange of information between two different time slots is accomplished by a time slot interchange (TSI) circuit.
- The data store memory is accessed twice during each link time slot.
- The required memory operation speed t is: t = 1/(2*SlotRate).
  - Example: 24 sources, 64 kbit/s each (125 microsecond frame time), slot = 8 bit, SlotRate = 24 x 8kslot/s = 192.000 slots/s
    t = 1/2x192.000 = 2.6 µs = 2600 nanoseconds
- Memory requirement c =125 /(2t) times 8 bit words of data.

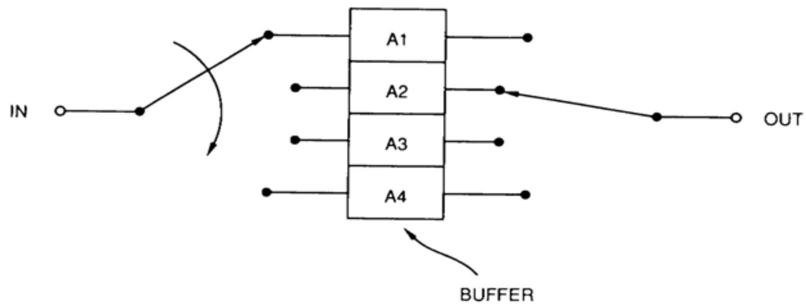


Time Division Switching (2)



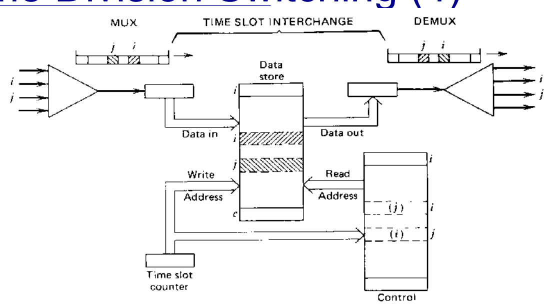
Time-division switching is a accomplished simply by reordering the sequence of information contained in the time slots in a digital transmission path. In this example, input circuit A1 is connected to output circuit X4, A2 to X1, A3 to X3, and A4 to X2.
This technique is called time-slot interchange.

Time Division Switching (3)

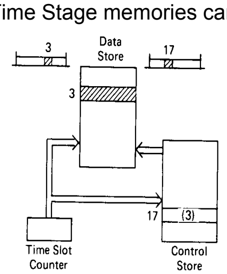


Time-slot interchange is performed through the use of a buffer memory into which the input samples are entered In the sequence received. The samples are then read from memory by a programmable switch. The order of the output switch in this example is 2-4-3-1, thereby reordering the output samples to correspond to the switching of the figure before.

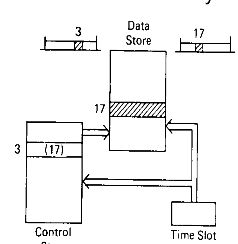
Memory Time Division Switching (4)



Time Stage memories can be controlled in two ways



Sequential write/targeted read



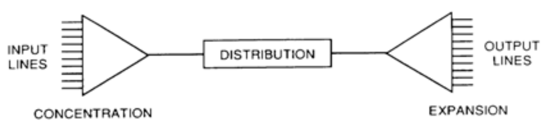
targeted write/ sequential read

Conclusion

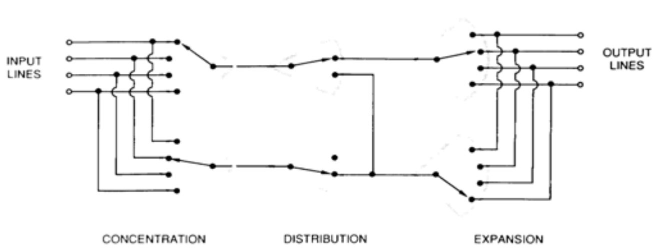
- Both Space Division Switching and Time Division Switching are not suitable for interconnecting a larger number of lines.
- Space Division Switching requires to many crosspoints
- Time Division Switching requires very high memory or bus speeds

➔ What we need are more complex combined structures

Not all Customers are Calling Simultaneously!

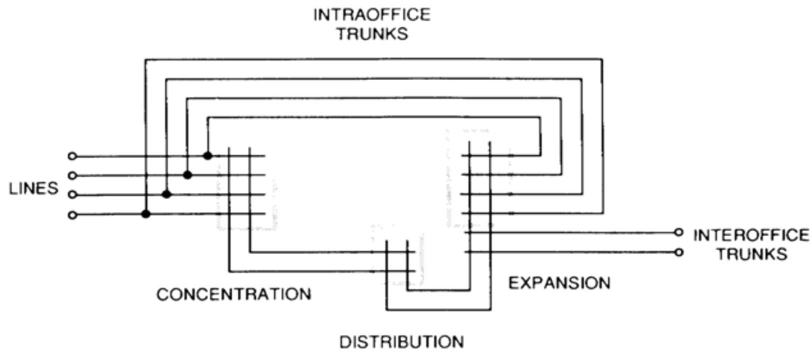


There are three stages of switching in a space-division switching network. Many input lines are concentrated together into a smaller number of serving lines. The ratio of the number of input lines to serving lines is greater than one. These serving lines are then distributed to output switches, which expand service to a large number of output lines. The ratio of the number of output lines to input serving lines is greater than one.



A three-parts rotary switching network. At most two customers served!

Three - Parts Configuration... Electronic...



A basic matrix, or coordinate, three-stage switching network. Calls within the office are made over interoffice trunks that connect the output from the switching network back to the input lines.

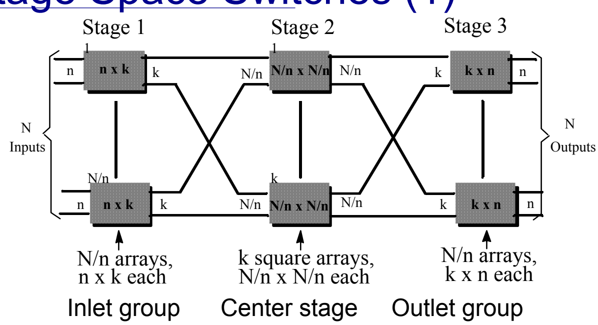
Traffic Characterization - Erlang

- Useful measure for traffic intensity is called erlang. Erlang is a unit which means the number of hundred (century) call seconds per hour (CCS).
    - 1 erlang = 36 CCS, since 1 hour has 3600 seconds
- The maximum capacity for one channel is 1 erlang, which is to say that the channel is all the time busy. The maximum capacity in erlangs is the number of channels.
- Usual Assumptions: Exponential Inter-Call distribution, Exponential call duration with mean 3 Minutes.
- Multiserver queuing system with Blocking or losses. Analytical formulae available...see additional reading....

Concentration

- The usual assumption used to be concentration ratio up to 10... Meaning that only 10% of customers can be served!
- The usual traffic assumptions do not hold if telephone network is abused for other goals - like internet access... Mean holding time - half an hour...
- Consider the distribution part **only**. There might still be a lot of lines to be served.
- Idea: would it be possible to reduce the number of crosspoints in a space switch by just introducing three stages instead of one? Without introducing any blocking? Yes !!

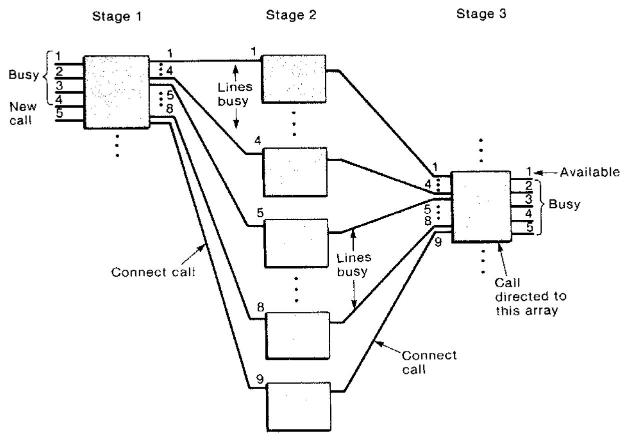
Multiple Stage Space Switches (1)



- Three-stage space switching matrix. Number of inputs N is given.
- The complexity depends of the parameters n and k. Goal: reduce it to a value less than N^2.
- A multiple stage switch may exhibit non-blocking or blocking behavior.
- Total number of crosspoints needed

$$C = 2\left(\frac{N}{n}\right)nk + k\left(\frac{N}{k}\right)^2 = 2Nk + k\left(\frac{N}{n}\right)^2$$

Multiple Stage Space Switches (2)



- Example of a non-blocking three stage switch (n=5, k=9)
- How to chose the parameters n and k in order to achieve: a/non-blocking and b/the minimal number of crosspoints?

Closs Formula for non-blocking case

- Requirements of a three stage non-blocking switch (C.Clos 1953)
  - Each individual array must be non-blocking
  - The number of center arrays k must be equal to 2n-1. Derivation follows!
  - A connection through the switch requires locating a center stage array with an idle link from the appropriate first stage and an idle link to the appropriate third stage.
  - Since each first stage array has n inlets, only n-1 of these can be busy when the inlet corresponding to the desired connection is idle.
  - If k > n-1 at most n-1 links to center stage arrays can be busy.
  - Similarly, at most n-1 links to the appropriate third-stage array can be busy if the outlet of the desired connection is idle.
  - The worst case situation for blocking occurs if all n-1 busy links from the first stage array lead to one set of center stage arrays and if all n-1 busy links to the desired third stage array come from a separate set of center stage arrays.
  - Thus, if one more center stage array exists, the appropriate input and output links must be idle so that this array can be used to set up the connection.
  - That means k = (n-1) + (n-1) + 1 = 2n-1 center stage arrays are necessary for a strictly non-blocking switch.

Optimal configuration for three stages

- How to find the optimal number of crosspoints
  - Substitute the value of k into the equation for the total number of crosspoints

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

  - The number of crosspoints in a non-blocking three stage switch depends on how the inlets and outlets are partitioned into subgroups of size ***n***.
  - Differentiating this equation with respect to ***n*** and setting the resulting expression equal to 0 results in the optimum value of $n = \sqrt{\frac{N}{2}}$
  - Substituting this value of n in our previous equation provides an expression for the minimum number of crosspoints of a nonblocking three-stage switch:

$$C(\min) = 4N(\sqrt{2n} - 1)$$

Does three stage structure pay?

- Comparison of crosspoint requirements of nonblocking switch Configurations

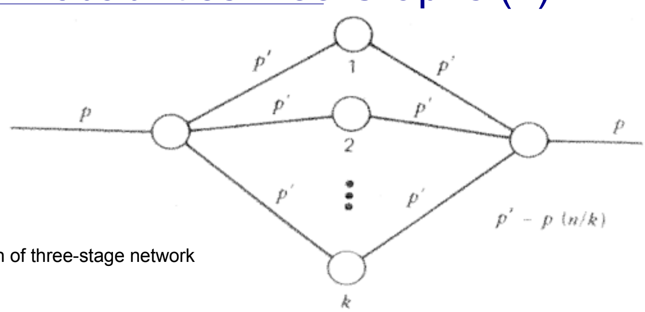
Number of Crosspoints in a Nonblocking Switch

Number of Lines	Number of Crosspoints for Three-Stage Switch	Number of Crosspoints for Single-Stage Switch
128	7,680	16,384
512	63,488	262,144
3,048	516,096	4.2×10^6
8,192	4.2×10^6	6.7×10^7
32,768	3.3×10^7	1×10^9
131,072	2.6×10^8	1.7×10^{10}

Blocking Probabilities

- A significant reduction in crosspoint numbers is achieved by allowing the switch to introduce a positive probability of blocking.
- The determination of blocking probability in a multistage switch is inherently complex!
- The problem is to calculate the probability of not finding a free path through the switch between a given input-output pair
- Approximations are commonly used for the calculations
- The simplest approximation (by C.Y. Lee) involves the use of probability graphs
  - Main assumption: Each link is busy or idle independently of other links

Blocking Probabilities: Lee Graphs (1)



Probability graph of three-stage network

- In the following analysis we determine the blocking probability using the utilization percentages of individual links
  - The letter p is used to represent the fraction of time that a particular link is in use.
  - The probability that a link is idle is denoted by q=1-p.
  - When any one of n parallel links can be used to complete a connection, the composite blocking probability B is the probability that all links are busy: $B = p^n$
  - When a series of n links are all needed to complete a connection, the blocking probability is: $B=1 - q^n$.

Blocking Probabilities: Lee Graphs

- The probability of blocking B for a three-stage network can be determined as
- B= probability that all paths are busy
  = (probability that an arbitrary path is busy)^k
  = (probability that at least one link in a path is busy)^k
  = $(1 - q'^2)^k$.
- Note: This approximation results in B>0 even for a non-blocking switch with k=2n-1! This is an approximation error.

Size N	n	k	Number of β	Number of Crosspoints Crosspoints	in Nonblocking Design	
128	8	5	0.625	2,560	7,680	(k = 15)
512	16	7	0.438	14,336	63,488	(k = 31)
2,048	32	10	0.313	81,920	516,096	(k = 63)
8,192	64	15	0.234	491,520	4.2 million	(k = 127)
32,768	128	24	0.188	3.1 million	33 million	(k = 255)
131,072	256	41	0.160	21.5 million	268 million	(k = 511)

Three-Stage Switch Design for Blocking Probabilities of 0.002 and inlet Utilizations of 0.1

Switch Size N	n	k	β	Number of Crosspoints	Number of Crosspoints in Nonblocking Design	
128	8	14	1.75	7,168	7,680	(k = 15)
512	16	22	1.38	45,056	63,488	(k = 31)
2,048	32	37	1.16	303,104	516,096	(k = 63)
8,192	64	64	1.0	2.1 million	4.2 million	(k = 127)
32,768	128	116	0.91	15.2 million	33 million	(k = 255)
131,072	256	215	0.84	113 million	268 million	(k = 511)

Three-Stage Switch Design for Blocking Probabilities of 0.002 and inlet Utilizations of 0.7

Joint Optimization

- User does NOT care where the blocking occurs... In the concentration, in the distribution... Acceptable joint blocking probability has to be assured.
- We have been talking about space switching lately. **New Idea**: Usage of Time Switching instead of space switching at some stages pays out.
- How to evaluate the design?

$$\text{Complexity} = N_x + N_b/a$$

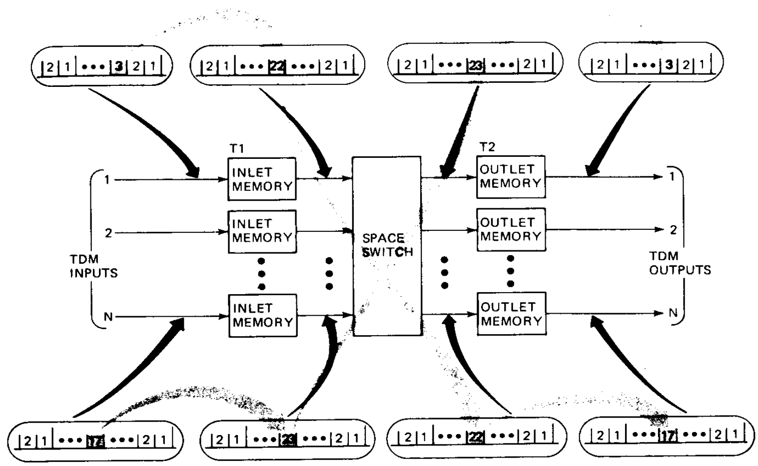
where N_x = Number of crosspoints

N_b = Number of addressable memory places

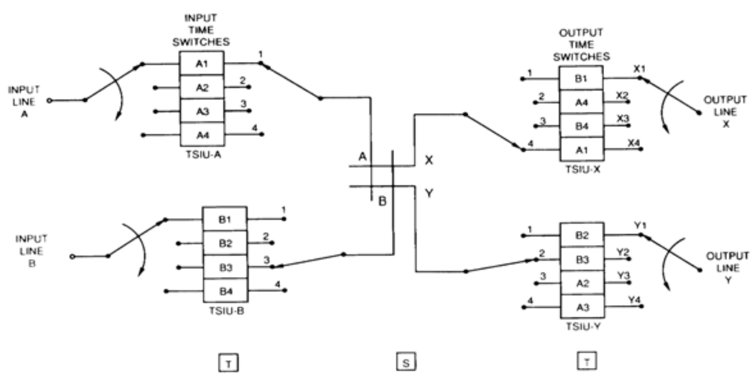
a = equivalency coefficient, used to be 100

Multistage Mixed Switching -TST

- One option for multistage switching Time-Space-Time Switch (TST)



TST: How does it Work?



Four circuits on each of the input lines. Required setting:
A1-X4, A2-Y3, A3-Y4, A4-X2
Switching accomplished in three stages: TST

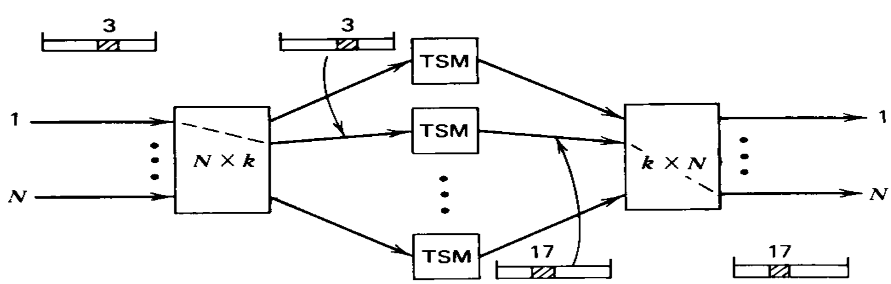
Switch time	Space switch		Time switch			
	A	B	A	B	X	Y
1	X	Y	1	3	4	2
2	X	Y	4	2	2	1
3	Y	X	3	4	3	4
4	Y	X	2	1	1	3

TST Features

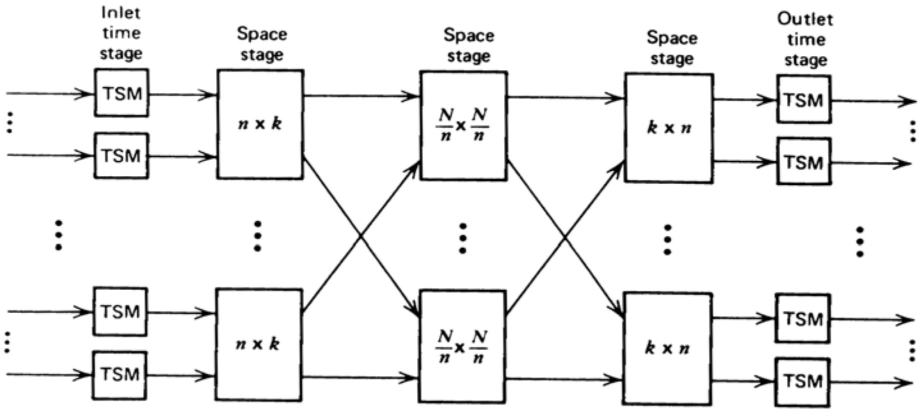
- Time-Space-Time Switch (TST)
  - Information arriving in a TDM channel of an incoming link is delayed in the inlet time stage until an appropriate path through the space stage is available.
  - At that time the information is transferred through the space stage to the appropriate outlet time stage where it is held until the desired outgoing time slot occurs
  - The operation of a TST switch is analogous to the three stage space switch.
    - Instead of switching N channels with a very fast TSI, group them into N/n TSIs
    - Let the number of output channels in a frame time be k>n.
    - Connect these N/n TSI to a single N/n x N/n space switch
    - The N/n outputs of the space switch are in turn each connected to a TSI in a third stage.
    - The crosspoint settings of the space switch are changed at each of the k time intervals corresponding to the k time slots

Space-Time-Switch (STS): an alternative

- Establishing a path through an STS switch requires finding a time switch array with an available write access during the incoming time slot and an available read access during the desired outgoing time slot.
- When each individual stage is non-blocking the operation is functionally equivalent to the operation of a three stage space switch

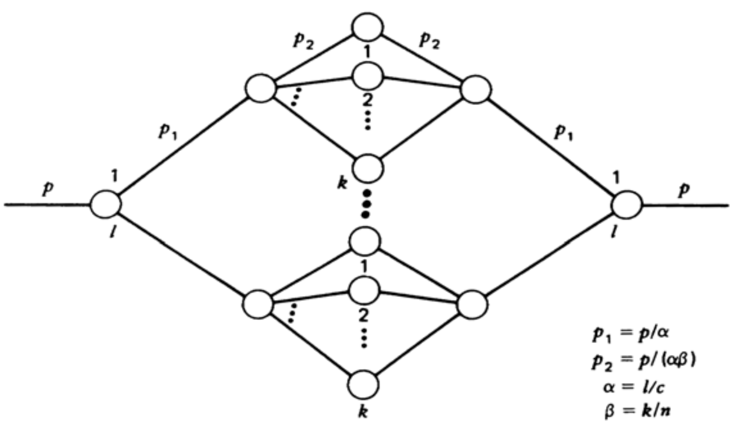


EWSD from Siemens...TSSST (1)



Time–space–space–space–time (TSSST) switching structure.

EWSD from Siemens...TSSST (2)



$p_1 = p/\alpha$
$p_2 = p/(\alpha\beta)$
$\alpha = l/c$
$\beta = k/n$

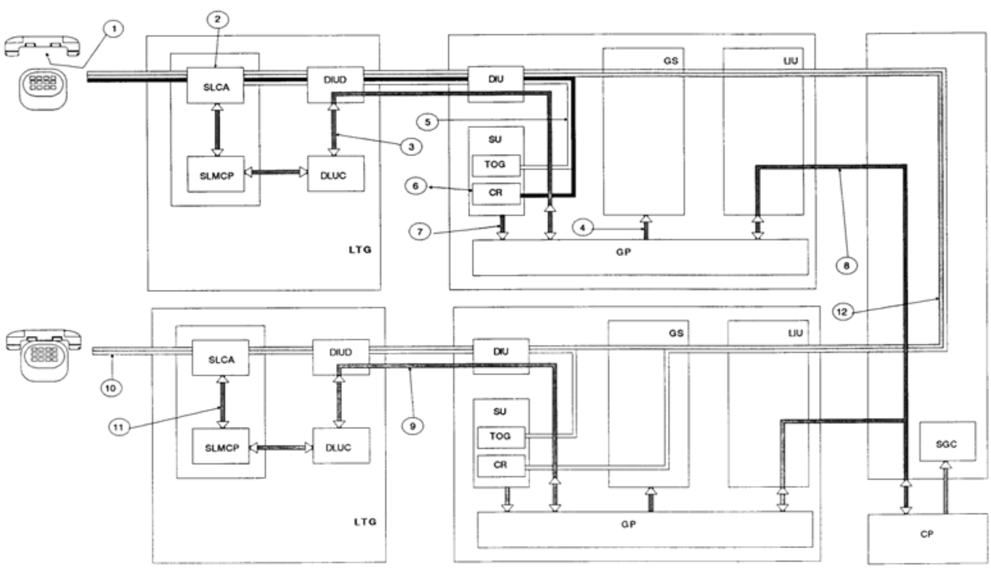
Probability graph of TSSST switch.

... = ...

Siemens EWSD (2)

Anzahl der Teilnehmerltg.	7500	30000	60000	125000	250000
Anzahl der Verbindungsltg.	1800	7500	15000	30000	60000
Verkehr in Erl	750	3150	6300	12600	25200
Anschließbare LTG	15	63	126	252	504
Struktur T = Zeitstufe S = Raumstufe	TST	TST	TSSST	TSSST	TSSST

Siemens EWSD (3)



Siemens EWSD (4)

- Some abbreviations:
- SLCA: Subscriber Line Circuit Analog
- SLMCP Subscriber Line Module Control Processor
- DLU Digital Line Unit
- DIUD Digital Interface Unit for DLU
- DLUC DLU Controller
- DIU Digital Interface Unit
- SU Signaling Unit
- TOG Tone Generator
- CR Code Receiver
- GS Group Switch
- LIU Link Interface Unit
- GP Group Processor
- SGC Switch Group Control
- CP Coordination Processor

Another Real World Switch No4. ESS