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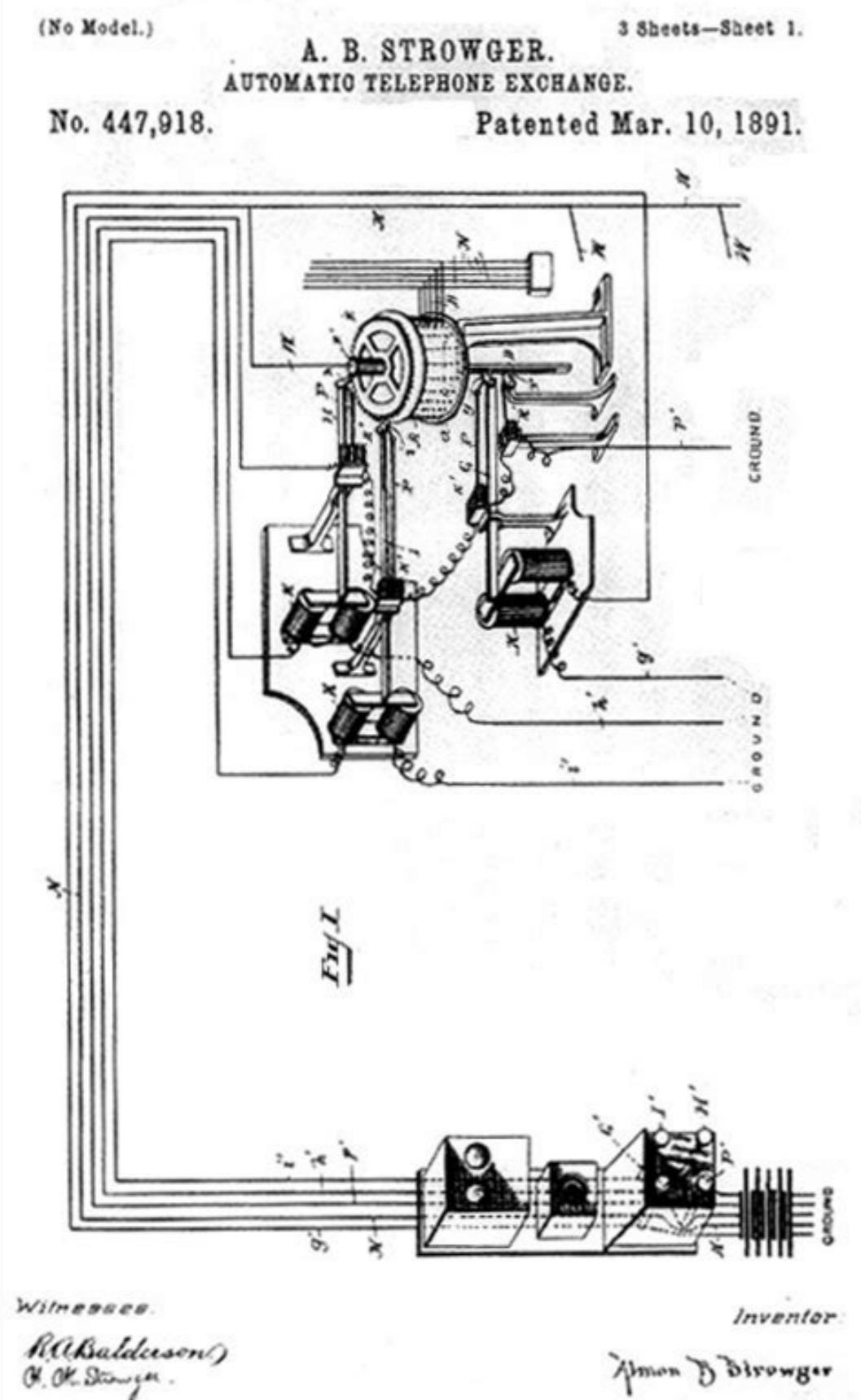
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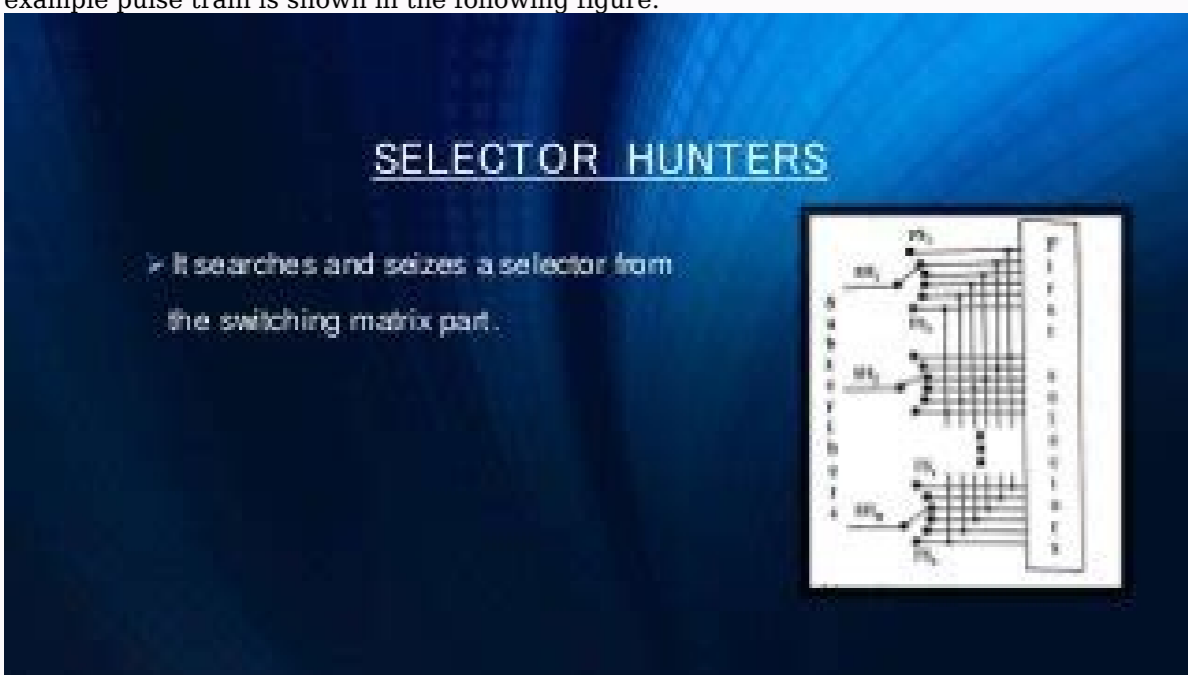
You're Reading a Free Preview Pages 62 to 67 are not shown in this preview. Academia.edu uses cookies to personalize content, tailor ads and improve the user experience. By using our site, you agree to our collection of information through the use of cookies. To learn more, view our Privacy Policy. In this chapter, we will discuss how the Strowger Switching system works. The first ever automatic telephone switching was developed by Almon B Strowger. As the operator at the Manual telephone exchange was the wife of his competitor and was diverting all the business, Strowger thought of developing a switching system, which does not require an operator. This led to the invention of the automatic switching system developed by Strowger.



The Strowger Switching system is also called the step-by-step switching system as the connections are established in a step-by-step manner. Automatic Switching System The Manual Switching system requires an operator who after receiving a request, places a call. Here, the operator is the sole in-charge for establishing or releasing the connections. The privacy of the calls and the details of the called and the calling subscribers are at stake. Overcoming the disadvantages of Manual Switching systems, the Automatic Switching systems come with the following advantages – Language barriers will not affect the request for connection. Higher degree of privacy is maintained. Faster establishment and release of calls is done. Number of calls made in a given period can be increased. Calls can be made irrespective of the load on the system or the time of the day. Let us now throw some light on how a call is made and how dialing is done without the help of an operator. Dialing Unlike in Manual Switching system, an automatic switching system requires a formal numbering plan or addressing scheme to identify the subscribers. Numbering plan is where a number identifies a subscriber, is more widely used than the addressing scheme in which a subscriber is identified by the alpha numerical strings. So, there needs to be a mechanism to transmit the identity of the called subscriber to the exchange. This mechanism should be present in the telephone set, in order to connect the call automatically to the required subscriber. The methods prevalent for this purpose are Pulse Dialing and Multi Frequency Dialing. Of them, the Pulse dialing is the most commonly used form of dialing till date.



Pulse Dialing As the name implies, the digits that are used to identify the subscribers are represented by a train of pulses. The number of pulses in a train is equal to the digit value it represents except in the case of zero, which is represented by 10 pulses. Successive digits in a number are represented by a series of pulse trains. These pulses have equal number of time intervals and the number of pulses produced will be according to the number dialed. Two successive trains are distinguished from one another by a pause in between them, known as the Inter-digit gap. The pulses are generated by alternately breaking and making the loop circuit between the subscriber and the exchange. An example pulse train is shown in the following figure.



The above figure shows the pulsating pattern. The pulse rate is usually 10 pulses per second with a 10 percent of tolerance. The gap between the digits, which is called the Inter-digit gap is at least 200ms. The pulse dialing pattern in recent times employs the duty ratio (ratio between the pulse width and the time period of the waveform) of the pulse as 33 percent nominally and there exists an upper limit for the inter-digit gap. Rotary Dial Telephone In this section, we will learn about what the Rotary Dial Telephone is and how it works. To start with, we will discuss the drawbacks that were prevalent before the invention of the Rotary Dial Telephone. The pulse dialing technique is where there is making and breaking of the subscriber loops. This might disturb and affect the performance of speaker, microphone and bell contained in the telephone. In addition, the dialing timings should not affect the timing of the pulse train as this will lead to the dialing of a wrong number. The Rotary Dial Telephone came into existence to solve the problems prevailing then. The microphone and the loudspeaker are combined and placed in the receiver set.

The design team had to handle a much bigger, heavier piece of equipment, but did not have to unwrap and rewrap dozens of wires. The two controllers in each Junctor Frame had no-test access to their Junctors via their P-switch, a ninth line in the Stage 1 switches which could be opened or closed independently of the crosspoints in the grid.

When setting up each call through the fabric, but before connecting the fabric to the line and/or trunk, the controller could connect a test scan point to the talk wires in order to detect potentials. Current flowing through the scan point would be reported to the maintenance software, resulting in a "False Cross and Ground" (FCG) teletypewriter message listing the path. Then the maintenance software would tell the call completion software to try again with a different junctor. With a clean FCG test, the call completion software told the "A" relay in the trunk circuit to operate, connecting its transmission and test hardware to the switching fabric and thus to the line. Then, for an outgoing call, the trunk's scan point would scan for the presence of an off hook line. If the short was not detected, the software would command the printing of a "Supervision Failure" (SUPP) and try again with a different junctor. A similar supervisory check was performed when an incoming call was answered. Any of these tests could alert for the presence of a bad crosspoint. Staff could study a mass of printouts to find which links and crosspoints (out of, in some offices, a million crosspoints) were causing calls to fail on first tries. In the late 1970s, teletypewriter channels were gathered together in Switching Control Centers (SCC), later Switching Control Center System, each serving a dozen or more IESS exchanges and using their own computers to analyze these and other kinds of failure reports. They generated a so-called histogram (actually a scatterplot) of parts of the fabric where failures were particularly numerous, usually pointing to a particular bad crosspoint, even if it failed sporadically rather than consistently. Local workers could then busy out the appropriate switch or grid and replace it. When a test access crosspoint itself was stuck closed, it would cause sporadic FCG failures all over both grids that were tested by that controller. Since the J links were externally connected, switchroom staff discovered that such failures could be found by making busy both grids, grounding the crosspoint test and then testing a 128 J links, 25 wires, in a ground plane, an unavoidable failure occurred. The detected, the system was designed to connect the test person rather than a computer, etc.[7] Scan and distribute the computer-generated input from the peripherals via magnetic scanners, composed of ferrods being analogous in principle to magnetic core memory, except that the output was controlled by control windings and analog to the windings of a relay. Specifically, the ferrrod was to be interrogated through holes in the center of a rod of ferrite. A pulse on the Interrogate winding was induced into the Readout winding, if the ferrite was not magnetically saturated. The larger control windings, if current was flowing through them, saturated the magnetic material, hence decoupling the Interrogate winding from the Readout winding which would return a Zero signal. The Interrogate windings of 16 ferrods of a row were wired in series to a driver, and the Readout windings of 64 ferrods of a column were wired to a sense amp. Check circuits ensured that an Interrogate current was indeed flowing. Scanners were Line Scanners (LSC), Universal Trunk Scanners (USC), Junctor Scanners (JSC) and Master Scanners (MS). The first three only scanned for supervision, while Master Scanners did all other scan jobs. For example, a DTMF Receiver, mounted in a Miscellaneous Trunk frame, had eight demand scan points, one for each frequency, and two supervisory scan points, one to signal the presence of a valid DTMF combination so the software knew when to look at the frequency scan points, and the other to supervise the loop.

The supervisory scan point also detected Dial Pulses, with software counting the pulses as they arrived. Each digit when it became valid was stored in a software hopper to be given to the Originating Register. Ferrods were mounted in pairs, usually with different control windings, so one could supervise a switchward side of a trunk and the other the distant office. Components inside the trunk pack, including those determining if performed reverse battery on an incoming trunk, or detected reverse battery from a distant trunk, i.e. was an outgoing trunk. Lins ferrods were also provided in pairs, of which the even numbered one had contacts brought out to the front of the package in lugs suitable for wire wrap so the windings could be strapped for loop start or ground start signaling. The original IESS packaging had all the ferrods of an LSF together, and separate from the line switches, while the later IAESS had each ferrrod at the front of a steel box containing its line switch. Odd numbered line equipment could not be made ground start, their ferrods being inaccessible. The computer controlled the magnetic latching relays by Signal Distributors (SD) packaged in the Universal Trunk frames, Junctor frames, or in Miscellaneous Trunk frames, according to which they were numbered as USD, JSD or MSD. SD were originally contact trees of 30-contact wire spring relays, each driven by a flipflop. Each magnetic latching relay had one transfer contact dedicated to sending a pulse back to the SD, on each operate and release. The pulser in the SD detected this pulse to determine that the action had occurred, or else alerted the maintenance software to print a FSCAN report.

In later IAESS versions SD were solid state with several SD points per circuit pack generally on the same shelf or adjacent shelf to the trunk pack. A few peripherals that needed quicker response time, such as Dial Pulse Transmitters, were controlled via Central Pulse Distributors, which otherwise were mainly used for enabling (alerting) a peripheral circuit controller to accept orders from the Peripheral Unit Address Bus. IESS computer The duplicate Harvard architecture central processor or CC (Central Control) for the IESS operated at approximately 200 kHz. It comprised five bays, each two meters high and totaling about four meters in length per CC. Packaging was in cards approximately 410 circuits (10x25 centimeters) with an edge connector in the back. Backplane wiring was cotton covered wire-wrap wires, not ribbons or other cables.

CPU logic was implemented using discrete diode transistor logic. One hard plastic card commonly held the components necessary to implement, for example, two gates or a flipflop. A great deal of logic was given over to diagnostic circuitry. CPU diagnostics could be run that would attempt to identify failing card(s). In single card failures, first attempt to repair success rates of 90% or better were common. Multiple card failures were not uncommon and the success rate for first time repair dropped rapidly. The CPU design was quite complex - using three way interleaving of instruction execution (later called instruction pipeline) to improve throughput. Each instruction would go through an indexing phase, an actual instruction execution phase and an output phase. While an instruction was going through the indexing phase, the previous instruction was in its execution phase and the instruction before it was in its output phase. In many instructions of the instruction set, data could be optionally masked and/or rotated. Single instructions existed for such esoteric functions as "find first set bit (the rightmost bit that is set) in a data word, optionally reset the bit and tell me the position of the bit". Having this function as an atomic instruction (rather than implementing as a subroutine) dramatically sped scanning for service requests or idle circuits. The central processor was implemented as a hierarchical state machine. Memory card for 64 words of 44 bits Memory had a 44-bit word length for program stores, of which six bits were for Hamming error correction and one was used for an additional parity check. This left 37 bits for the instruction, of which usually 22 bits were used for the address. This was an unusually wide instruction word for the time. Program stores also contained permanent data, and could not be written online. Instead, the aluminum memory cards, also called twistor planes,[5] had to be removed in groups of 128 so their permanent magnets could be written offline by a motorized writer, an improvement over the non motorized single card writer used in Project Nike. All memory frames, all buses, and all software and data were fully dual modular redundant.

The dual CCs operated in lockstep and the detection of a mismatch triggered an automatic sequencer to change the combination of CC, buses and memory modules until a configuration was reached that could pass a sanity check. Buses were twisted pairs, one pair for each address, data or control bit, connected at the CC and at each store frame by coupling transformers, and ending in terminating resistors at the last frame. Call Stores were the system's read/write memory, containing the data for calls in progress and other temporary data. They had a 24-bit word, of which one bit was for parity check. They operated similar to magnetic core memory, except that the ferrite was in sheets with a hole for each bit, and the coincident current address and readout wires passed through that hole. The first Call Stores held 8 kilowords, in a frame approximately a meter wide and two meters tall. The separate program memory and data memory were operated in antiphase, with the addressing phase of Program Store coinciding with the data fetch phase of Call Store and vice versa. This resulted in further overlapping, thus higher program execution speed than might be expected from the slow clock rate.

Programs were mostly written in machine code. Bugs that previously went unnoticed became prominent when IESS was brought to big cities with heavy telephone traffic, and delayed the full adoption of the system for a few years. Temporary fixes included the Service Link Network (SLN), which did approximately the job of the Incoming Register Link and Ringing Selection Switch of the 5XB switch, thus diminishing CPU load and decreasing response times for incoming calls, and a Signal Processor (SP) or peripheral computer of only one bay, to handle simple but time-consuming tasks such as the timing and counting of Dial Pulses. IAES eliminated the need for SLN and SP. The half inch tape drive was write only, being used only for Automatic Message Accounting. Program updates were executed by shipping a load of Program Store cards with the new code written on them. The Basic generic program included constant "audits" to correct errors in the call registers and other data. When a critical hardware failure in the processor or peripheral units occurred, such as both controllers of a line switch frame failing and unable to receive orders, the machine would stop connecting calls and go into a "phase of memory regeneration", "phase of reinitialization", or "Phase" for short. The Phases were known as Phase 1,2,4 or 5. Lesser phases only cleared the call registers of calls that were in an unstable state that is not yet connected, and took less time. During a Phase, the system, normally roaring with the sound of relays operating and releasing, would go quiet as no relays were getting orders. The Teletype Model 35 would ring its bell and print a series of P's while the phase lasted. For Central office staff this could be a scary time as seconds and then perhaps minutes passed while they knew subscribers who picked up their phones would get dead silence until the phase was over and the processor regained "sanity" and resumed connecting calls. Greater phases took longer, clearing all call registers, thus disconnecting all calls and treating any off-hook line as a request for dial tone.

If the automated phases failed to restore system sanity, there were manual procedures to identify and isolate bad hardware or buses.[8] IAESS Head of view IAESS Master Control Center Most of the thousands of IESS and IAESS offices in the USA were replaced in the 1990s by DMS-100, 5ESS Switch and other digital switches, and since 2010 also by packet switches. As of late 2014, just over 20 IAESS installations remained in the North American network, which were located mostly in AT&T's legacy BellSouth and AT&T's legacy Southwestern Bell states, especially in the Atlanta GA metro area, the Saint Louis MO metro area, and in the Dallas/Fort Worth TX metro area. In 2015, AT&T did not renew a support contract with Alcatel-Lucent (now Nokia) for the IAESS systems still in operation and noted Alcatel-Lucent of its intent to remove them all from service by 2017. As a result, Alcatel-Lucent dismantled the last IAESS lab at the Naperville Bell Labs location in 2015, and announced the discontinuation of support for the IAESS (9) [10] In 2017, AT&T completed the removal of remaining IAESS systems by moving customers to other newer technology switches, typically with Genband switches with TDM trunking only. The last known IAESS switch was in Odessa, TX (Odessa Lincoln Federal wirecenter ODSSTXL). It was disconnected from service around June 3, 2017 and cut over to a Genband G5/G6 packet switch. Other electronic switching systems The No. 1 Electronic Switching System Arranged with Data Features (No. 1 ESS ADF) was an adaptation of the Number One Electronic Switching System to create a store and forward message switching system. It used both single and multi-station lines for transmitting teletypewriter and data messages. It was created to respond to a growing need for rapid and economical delivery of data and printed copy.[11] Features The No. 1 ESS ADF had a large number of features, including:[12] Mnemonic addresses: Alphanumeric codes used to address stations Group code addresses: Mnemonic codes used to address a specific combination of stations Precedence: Message delivery according to four levels of precedence Date and time services: Optional date and time of message origination and delivery Multiline hunting groups: Distribution of messages to the next available station in a group Alternate delivery: Optional routing of all messages addressed to one station to another station See also Nonblocking minimum spanning switch SP1 switch TXE 4ESS switch 5ESS switch References ↑ Ketchledge, R.: "The No. 1 Electronic Switching System" IEEE Transactions on Communications, Volume 13, Issue 1, Mar 1965, pp 38–41 ↑ IA Processor, Bell System Technical Journal, 56(2), 119 (February 1977) ↑ "No. 1 Electronic Switching System"

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Michael J. McKinley (2017-04-05). "The Position Light Now Means: Compactly The Same (8% ESS Retirement)". "The Position Light. Retrieved 2021-11-24." No. 1 ESS ADF: System Organization and Objectives, Bell System Technical Journal, 49(10), 2733 (1970) ↑ No. 1 ESS ADF: System Organization and Objectives, Bell System Technical Journal, 49(10), 2733 (1970) ↑ No. 1 ESS ADF: System Organization and Objectives, Bell System Technical Journal, 49(10), 2747–2751 (1970) External links AT&T Bell Labs 1 ESS (Electronic Switching System) Manufacturing Processes (video). 1965. Retrieved from sThs article includes a list of references, related reading, or external links, but its sources remain unclear because it lacks inline citations. Please help to improve this article by introducing more precise citations. (June 2019) (Learn how and when to remove this template message) 5ESS used in a mobile telephone network The 5ESS Switching System is a Class 5 telephone electronic switching system developed by Western Electric for the American Telephone and Telegraph Company (AT&T) and the Bell System in the United States. It came into service in 1982 and the last unit was produced in 2003.[1] History The 5ESS came to market as the Western Electric No. 5 ESS. It commenced service in Seneca, Illinois on March 25, 1982, and was destined to replace the Number One Electronic Switching System (1ESS and IAESS) and other electromechanical systems in the 1980s and 1990s. The 5ESS was also used as a Class-4 telephone switch or as a hybrid Class 4/Class 5 switch in markets too small for the 4ESS. Approximately half of all US central offices are served by 5ESS switches. The 5ESS was also exported, and manufactured outside the US under license. [citation needed] The 5ESS-2000 version, introduced in the 1990s, increased the capacity of the switching module (SM), with more peripheral modules and more optical links per SM to the communications module (CM). A follow-on version, the 5ESS-R/E, was in development during the late 1990s but did not reach market. Another version was the 5E-XC.[citation needed] The 5ESS technology was transferred to the AT&T Network Systems division upon the 1984 breakup of the Bell System. The division was divested by AT&T in 1996 as Lucent Technologies.[2] and after becoming Alcatel-Lucent in 2006,[3] it was acquired by Nokia in 2016.[4] The 5ESS switch is still in widespread use in the public switched telephone network (PSTN) in the United States and elsewhere, but they are being replaced with more modern packet switching systems. 5ESS switches in service in 2021 also included several operated by the United States Navy.[5] Architecture The 5ESS switch has three main types of modules: the Administrative Module (AM), which contains the central computers; the Communications Module (CM) is the central time-divided switch of the system; and the Switching Module (SM) makes up the majority of the equipment in most exchanges. The SM performs multiplexing, analog and digital coding, and other work to interface with external equipment. Each has a controller, a small computer with duplicated CPUs and memories, like most common equipment of the exchange, for redundancy. Distributed systems lessen the load on the Central Administrative Module (AM) or main computer.[citation needed] Power for all circuitry is distributed as -48 VDC (nominal), and converted locally to logic levels or telephone signals.[citation needed] Switching Module Each Switching Module (SM) handles several hundred to a few thousand telephone lines or several hundred trunks or combination thereof. Each has its own processors, also called Module Controllers, which perform most call handling processes, using their own memory boards. Originally the peripheral processors were to be Intel 8086, but those proved inadequate and the system was introduced with Motorola 68000 series processors. The name of the cabinet that houses this equipment was changed at the same time from Interface Module to Switching Module.[citation needed] Peripheral units are on shelves in the SM.

In most exchanges the majority are Line Units (LU) and Digital Line Trunk Units (DLTU). Each SM has Local Digital Service Units (LDSU) to provide various services to lines and trunks in the SM, including tone generation and detection. Global Digital Service Units (GDSU) provide less-frequently used services to the entire exchange. The Time Slot Interchanger (TSI) in the SM uses random-access memory to delay each speech sample to fit into a time slot which will carry its call through the exchange to another or, in some cases, the same SM. T-carrier spans are terminated, originally one per card but in later models usually two, in Digital Line Trunk Units (DLTU) which concentrate their DS0 channels into the TSI. These may serve either interface trunks or, using Integrated Subscriber Loop Carrier, subscriber lines. Higher-capacity DS3 signals can also have their DS0 signals switched in Digital Network Unit SONET (DNUS) units, without demultiplexing them into DS1. Newer SM's have DNUS (DS3) and Optical OIU interfaces (OC12) with a large amount of capacity. SMs have Dual Line Interface (DLI) cards to connect them by multi-mode optical fibers to the Communications Modules for time-divided switching to other SMs. These links may be short, for example within the same building, or may connect to SMs in remote locations. Calls among the lines and trunks of a particular SM needn't go through CM, and an SM located remotely can act as distributed switching, administered from the central AM. Each SM has two Module Controller/Time Slot Interchange (MCTS) circuits for redundancy. In contrast to Nortel's DMS-100 which uses individual line cards with a codec, most lines are on two-stage analog space-division concentrators or Line Units, which connect as many as 512 lines, as needed, to the 8 Channel cards that each contain 8 codes, and to high-level service circuits for ringing and testing. Both stages of concentration are included on the same GDX (Gated Diode Access) board. Each GDX board serves 32 lines, 16 A links and 32 B links. Limited availability saves money with incompletely filled matrices. The Line Unit can have up to 16 GDX boards connecting to the channel boards by shared B links, but in offices with heavier traffic for lines a lesser number of GDX boards are equipped. ISDN lines are served by individual line cards in an ISLU (Integrated Services Line Unit), Administrative Module (AM) or Wired ORM's. The RSM is controlled by T1 lines connected to a DLTU unit. The first 2 T1's are the control of the RSM and are necessary for any Recent Changes to take place. RSM's can have up to 10 T1's. There can be multiple RSM's in an office. An ORM can be fed via direct fiber or via coax thus called Wired ORM's. An RSM has a limited distance and can serve parts of a larger metro area or rural offices. An ORM or wired ORM can be anywhere technically, and preferred over the RSM once the ORM became available. Both the RSM and ORM is often used as a Class-5 wire center for small to medium towns hosted from a 5ESS located in a larger city. The Wired ORM is connected via coax from a MUX unit and fed to a TRCU which converts the coax to connection to the DLI. There was also a two-mile ORM that was used when an office was broken out or took an area from another office. The distance on this was 2 miles from a host office and fed direct via fiber. As with any SM, the size is dictated by the number of time slots needed for each peripheral unit. ORM's are linked with DS3, RSM's are linked with T1 lines. The VCDX was also used as a large private branch exchange (PBX). Small communities of less than 400 lines or so were also provided with SLC-96 units or Anymedia units. The standalone VCDX has a single Switching Module, and no Communications Module. Its Sun Microsystems SPARC workstation runs the UNIX-based Solaris (operating system) that executes a 3B20/21D processor MERT OS emulation system, acting as the VCDX's Administrative Module. The VCDX uses the CO's normal telephone power sources (which are very large uninterruptible power supplies), and has connections to the CO Digital cross connect system for T1 access, etc. Signaling The 5ESS has two different signaling architectures: Common Network Interface (CNI) Ring and Packet Switching Unit (PSU)-based S57 Signaling. Software The development effort for 5ESS required five thousand employees, producing 100 million lines of system source code, mostly in the C language, with 100 million lines of header files and makefiles. Evolution of the system took place over 20 years, while three releases were often being developed simultaneously, each taking about three years to complete. The 5ESS was originally U.S.-only and the international sales resulted in a complete development system and team, in parallel to the U.S. version. The development systems were Unix-based mainframe systems. There were around 15 of these systems active at the peak. There were development machines, simulator machines, and build machines, etc. Developers' desktops were multi-window terminals (versions of the Blit developed by Bell Labs) until the mid 1990s, when Sun workstations were deployed. Developers continued to login into the servers for their work, using X11 on their workstations as a multi-window environment. Source code management was based on SCCS and utilized "#feature" lines to separate source code between releases, between features specific to US or Intl, and the like. Customisation around the vi and Emacs text editors allowed developers to work with the appropriate view of a file, hiding the parts that were not applicable to their current project. The change request system used the SCCS MR to create named change sets, tied into the IMR (initial modification request) system which had purely numeric identifiers. An MR name was created with subsystem prefix, IMR number, MR sequence characters, and a character for the release or "load". So, for the gr (generic retrofit) subsystem, the first MR created for the 2371242 IMR, destined for the 'F' load, would be gr2371242aF. The build system used a simple mechanism of build configuration that would cause makefile generation to occur.

The system always built everything, but used checksum results to decide if a file had actually changed, before updating the build output directory tree. This provided a huge reduction in build time when a core library or header was being edited. A developer could add values to an enum, but if that did not change the build output, then subsequent dependencies on that output would not have to be relinked or libraries built. OAMP Main article: Operations, Administration, Maintenance and Provisioning The system is administered through an assortment of teletypewriter "channels", also called the system console, such as the TEST channel and the Maintenance channel. Typically provisioning is done either through a command line interface (CLI) called RCV:APPTXT, or through the menu-driven RCV:MENU:APPRC program. RCV stands for Recent Change/Verification, and can be accessed through the Switching Control Center System. Most service orders, however, are administered through the Recent Change Memory Administration Center (RCMAC). In the international market, this terminal interface has localization to provide locale-specific language and command name variations on the screen and printer output. See also PRX (telemetry) – an earlier switch acquired by AT&T in Europe References ↑ "Western Electric/Lucent Modern Telephone Switching Systems". Telephone World. Retrieved January 27, 2022. ↑ "History of Lucent Technologies Inc". FundingUniverse. Retrieved January 27, 2022. ↑ "Alcatel and Lucent Technologies to Merge and Form World's Leading Communication Solutions Provider". Alcatel-Lucent.com. Archived from the original on December 25, 2008. ↑ Tomner, Andrew (January 6, 2016). "Nokia and Alcatel-Lucent Finally Seal the Deal". The Motley Fool. Retrieved January 27, 2022. ↑ "DEPT OF DEFENSE Issues Federal contract notice for " DG11 - REPAIR AND EXCHANGE SERVICE FOR LUCENT 5ESS "" US Official News. March 15, 2021. Retrieved January 27, 2022. ↑ via Gale OneFile. Martersteck, K. E.; Spencer, A. E. (1985). "The 5ESS wching System: Introduction". AT&T Technical Journal. 64 (6): 1305–1314. doi:10.1002/1538-7305.1985.tb00276.x.

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