The American Society of Mechanical Engineers

ABACUS II
Serial No. 1
Integrated-Circuit
Wire Bonder

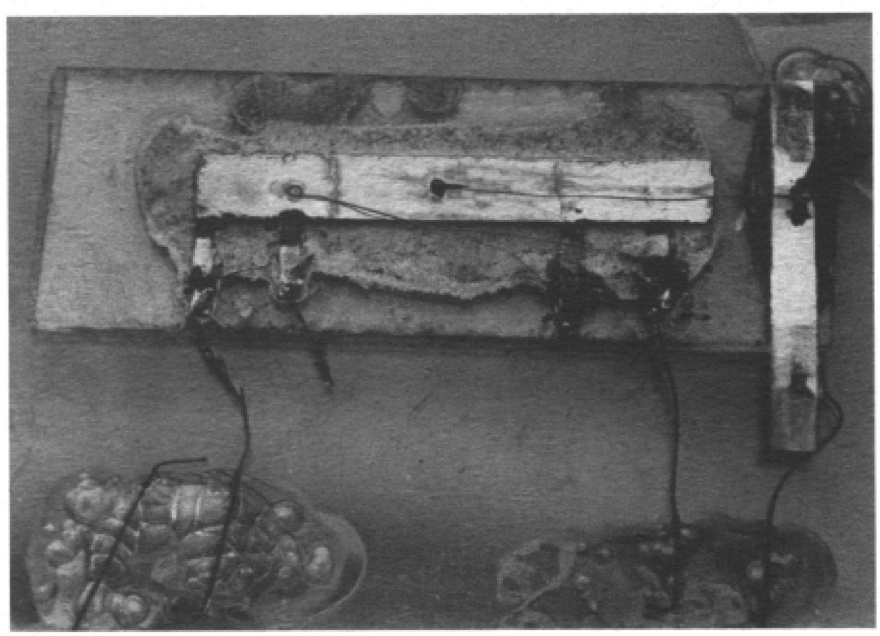
International Historic Mechanical Engineering Landmark
Designated March 31, 1992

Texas Instruments Incorporated

Many inventions, like the power loom and the steam engine, are labor-saving devices. They expand people's physical capabilities. Other inventions, like the telescope, improve people's ability to comprehend their universe. They extend the senses. All great inventions revolutionize society, either by drastically altering human lifestyles or by changing the way people perceive themselves and their world.

The integrated circuit constitutes an unprecedented revolution in today's society. For the first time, we are developing a technology that supports and directs all other technologies, expanding exponentially people's capabilities. The integrated circuit is at the heart of all electronic equipment today: navigational systems, computers, pocket calculators, industrial monitoring and control systems, digital watches, digital sound systems, word processors, communications networks, and innumerable others. Few of these devices would exist, or could work reliably, without the integrated circuit. In the future, the integrated circuit will enable us to develop powerful, versatile, reasoning devices to guide those technologies and our own lives more intelligently than ever before.

The ABACUS II played a major part in bringing the integrated circuit from an expensive electronic specialty to the ubiquitous microchip of today. The availability of the inexpensive, reliable, and broadly flexible ABACUS II spurred a revolution in assembly factories around the world.



The first working integrated circuit, invented by Jack St. Clair Kilby of Texas Instruments, was demonstrated on September 12, 1958.

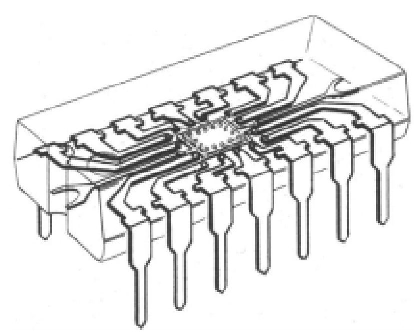
Background

Ten years after the invention of the transistor, another generation of electronics emerged with the demonstration of the first working integrated circuit by Jack St. Clair Kilby of Texas Instruments on September 12, 1958.

The integrated circuit, or IC, as it has come to be called, solved the problem of interconnecting discrete electrical components to form a single complex circuit, but manufacturing difficulties kept the price high and the quantities modest in the early years of production. The first commercially available circuit, the Texas Instruments (TI) Type 502 "Micro-electronic Binary Flip-flop," was introduced in 1960 and priced at $500 in sample quantities. In 1961, TI brought the 5l-Series "Solid Circuits," a basic line of digital circuit building blocks, to the market at an average unit price of $200. By the beginning of the 1970s, IC prices had dropped below $5, and sales were increasing rapidly as new applications were found.

Manufacturing techniques for integrated circuits in the wafer form were similar to, and extensions of, transistor technology. The assembly of the integrated circuits was also a modification of the mesa transistor packaging technology in that a chip (a small square of silicon) was bonded to a header (the package base), and the microscopic electrical contacts on the chip were connected to the appropriate package connections by thermal-compression bonding of fine gold wire.

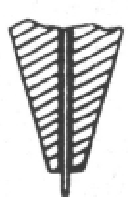
This tedious technique approached an art form with the manual bonding equipment of the day. Integrated circuits required eight to sixteen connections per chip, compared with only two connections, base and emitter, for a transistor. Making these connections became a major production bottleneck. A first-class operator could bond approximately 60 16-pin devices per hour. The quality of the units was highly dependent on the skill of the operator, which varied with fatigue and distractions. It became obvious that some method of automating this difficult process was required to reach satisfactory levels of production quality and cost. It was recognized that the future of TI's integrated-circuit program hinged on assembling the devices in a cost-effective manner.



A 14-pin DIP (dual in-line package) IC with molded plastic body showmg the internal construction and wire bonding.

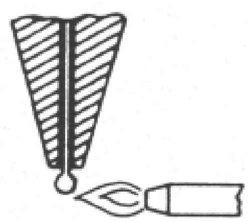
Automatic Wire Bonding Before the ABACUS II

The invention of the basic thermocompression wire bonding concept is covered in Patents 3,618,199 and 3,641,660, issued to TI in 1971 and 1972, respectively. The inventors, Lewis King, Gerald Yearsley, Anthony Adams, Marion Simmons, Eugene Altenburger, and Billy Yager, had developed a bonding concept that carried over directly from the wire bonding of transistors to the assembly of integrated circuits and is still in use, virtually unchanged, today. The adjoining diagrams illustrate thermo-compression ball-and-stitch wire bonding as it is used in the assembly of integrated circuits.



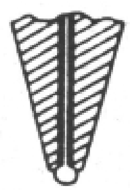
Tip of bondjng capillary with gold wire

TI mechanical and electrical engineers in the Semiconductor Mechanization Department designed several automated integrated-circuit wire bonders that preceded the ABACUS II. The first semiautomatic bonder, the ABACUS (Alloy, Bond, Assembly Concept, Universal System), was based on work done earlier in Dallas, Texas, and in the Texas Instruments Limited plant in Bedford, England, for semiautomatically bonding mesa transistors. The ABACUS was controlled by a "HAL-9" computer. Designed and built in-house, it was probably the first 16-bit computer designed especially for machine control. Thirteen ABACUS wire bonders were built and installed in Sherman, Texas, in 1970.



Ball formed on gold wire with torch

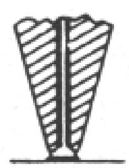
This first model was soon followed by the ABACUS A and ABACUS B. Although this first family of machines showed good improvements in quality and throughput, they were expensive to build ($65,000 each) and were not as reliable as anticipated. Fifty-eight machines of these three types were built and put into operation.



Ball pulled up to end of capillary

The ABACUS II Project

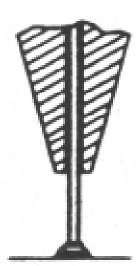
The ABACUS II project was begun in late 1971. This all-new automatic wire bonder was to be controlled by the recently announced TI960A computer, a powerful and inexpensive "bit-pusher" process-control computer. The project goals were to reduce the manufacturing cost of the bonder to $15,000, increase the throughput, improve the reliability substantially, and employ modular design to allow continual upgrading of the system for accomodation of new products and technical improvements.



Ball bond made to bonding pad on chip

The prototype ABACUS II bonder, the Serial Number 1 machine, was demonstrated to TI management in the fall of 1972.

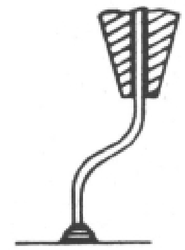
The cost of the ABACUS II bonder was $15,164 each for the first production run of 100 systems. Throughput was about 375 16-pin devices per hour, and the other goals of the design were met or exceeded. The success of the modular concept was borne out by the series of ABACUS IIA, IIB, and IIC machines that followed and by the use of these machines on more than 100 product types. A small quantity of these machines are still in service doing a special type of ultrasonic bonding. About 1,000 ABACUS II series wire bonders were built, with the later versions bonding more than 800 devices per hour.



Capillary retracts and feeds out wire

When the development of the ABACUS II wire bonder was near completion, a spin-off team designed the ABACUS II alloyer. This companion to the ABACUS II wire bonder attached the integrated circuit chip to the leadframe prior to wire bonding. Though somewhat less sophisticated, the alloyer was also designed for reliability and easy adaptation to new products.

Production of the ABACUS II series of wire bonders and alloyers ceased in 1982. The ABACUS III, released in 1983, was a major redesign, but it utilized nearly all of the original ABACUS II concepts of motion control and thermocompression bonding. The current ABACUS III-SR will bond about 2,000 devices per hour, using dual bond heads.

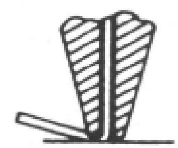


Capillary moves toward leadframe contact

Worldwide ABACUS II Fanout

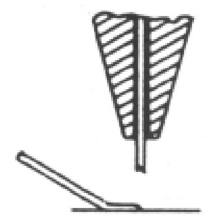
The ABACUS II integrated-circuit wire bonder gave TI the ability to build integrated circuits at high volume and low cost, accelerating the acceptance of integrated circuits into the marketplace. Recognizing the manufacturing advantage that the low-cost ABACUS II could give TI, company management directed that the machines be built in quantity and distributed to TI's assembly plants worldwide.

The first sites to receive the ABACUS II bonders and the matching ABACUS II alloyers were Japan and Taiwan in early 1973. Over time, TI's ABACUS II machines were installed at manufacturing facilities in Singapore, Malaysia, France, England, Portugal, Germany, Italy, the Philippines, Argentina, Mexico, El Salvador, and Brazil.



Stitch bond made on leadframe contact with edge of capillary

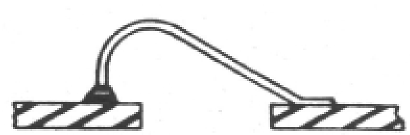
The ABACUS II: Systems and Functions



Capillary retracts as wire is clamped and broken

Operating the ABACUS II

Typically, magazines holding twenty 14 or 16-pin leadframe strips arrive at the ABACUS II bonder from the ABACUS II alloyer. The alloyer has positioned and alloyed, or epoxied, the silicon IC chip to the center of each leadframe. After wire bonding and transfer molding the plastic body, each of these leadframe strips will be cut and formed into ten complete integrated circuits.



Completed ball-and-stitch bond

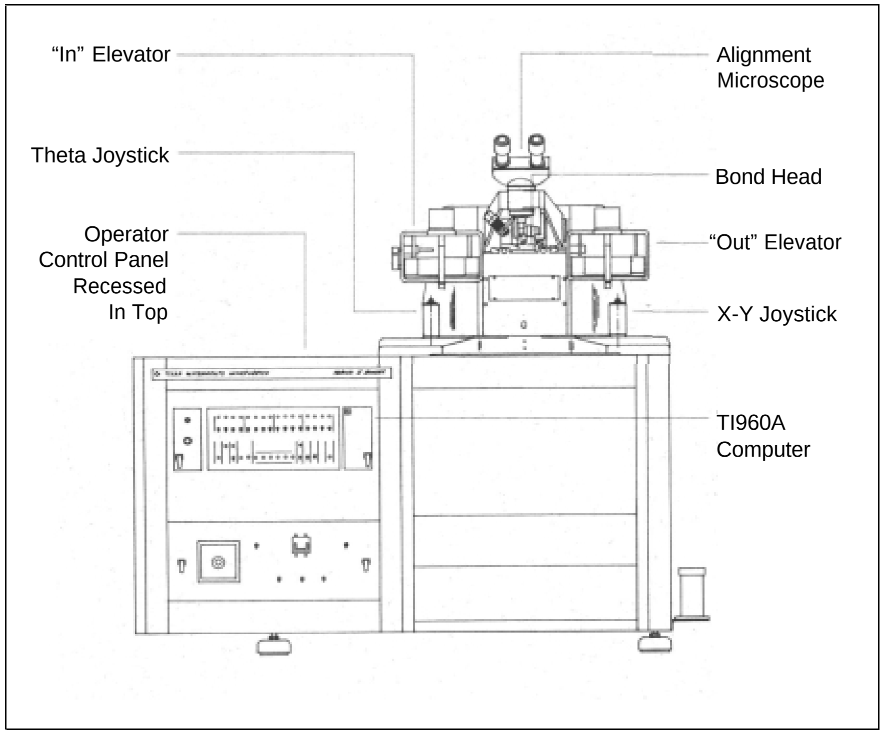
The ABACUS operator loads the leadframe magazine into the "N" elevator on the left side of the machine. An empty magazine is placed in the "OUT" elevator on the right.

At the command of the operator, a blade pushes the first leadframe strip out of the magazine into the work station. Photosensors detect the correct location of the leadframe and activate a clamp, securing the first chip in the wire-bonding position.

The leadframe is brought into the bonding station and mechanically located with sufficient accuracy for the bonding mechanism to dead-reckon to the proper wire-bonding locations on the tips of the frame connections. The IC chip, however, is not located accurately enough for the bonding mechanism to hit within the 0.005 inch bonding pad, so the operator is required to do the fine positioning.

Thermocompression bonding uses heat and pressure to form a metallurgical contact between the bonding wire and the chip or package connection. The wire is typically 0.001 inch diameter pure gold. The temperature of the contact surface is generally maintained at 325 degrees Celsius and the bonding pressure is applied for 25 to 100 milliseconds.

The ABACUS II



ABACUS II bonders in the Texas Instruments Sherman, Texas, plant. Machines have been equipped with automatic chip alignment systems and are running without operators.

The operator observes the precise position of the chip, with reference to a reticle in the microscope. Correction of the chip position in the X and Y directions is controlled by a joystick held in the operator's right hand. Simultaneously, the operator is correcting the rotational error with a second joystick in the left hand.

The operator completes the X-Y and rotational correction of the IC chip with respect to the microscope reticle, then presses the "START" button on the left joystick. The computer now has the information on the actual chip position and calculates the precise bonding pad locations.

The computer, with its corrected table of bond locations, drives the X-Y positioning mechanism to each point in turn, and then actuates the bonding mechanism.

First, a ball-bond is performed on the chip bonding pad with the ceramic bonding capillary. The gold wire is then strung out to form a stitch-bond on the appropriate lead tip. The wire is clamped in the feed mechanism after the stitch-bond, causing the wire to break off at the bond as the capillary is raised. As the capillary is moving away from the leadframe, a tiny oxy-hydrogen flame-off torch swings across and melts the free end of the gold wire to form a ball, about three times the diameter of the wire, for the next bond.

The gold wire is then retracted into the capillary until the ball is against the bonding tool, and the bond head is ready for the next cycle. The ABACUS II total cycle time for bonding one wire is about 550 milliseconds.

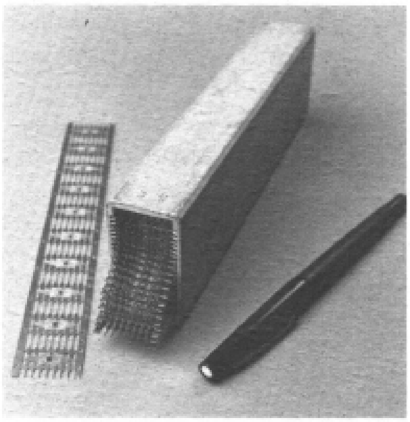
After the operator pushes the "START" button, the computer automatically bonds all 14, or 16, wires on the device, then unclamps the leadframe and advances it to the next IC chip. The operator again aligns the chip, and the cycle is repeated.

As the bonding tip descends to the chip on each ball-bond cycle, a sensor checks for the presence of the ball on the end of the gold wire. If the ball is not detected, the machine automatically goes into a repair cycle. The bond head is moved to the side, a new ball formed, and a practice ball-and-stitch-bond cycle performed.

The Material Feed Mechanisms

The magazine of devices to be bonded is loaded into the "IN" elevator on the left side of the bonder. At the push of the "LOAD" button, an air-cylinder-driven blade pushes the first leadframe out of the magazine into a set of drive rollers. These rollers are timing-belt driven from a stepping motor and have solenoid-controlled pinch rollers for positive engagement with the leadframe.

The correct stopping position of the leadframe is determined by two optical sensors. Indexing of the leadframe between devices is performed by the same drive and sensing mechanisms.



Integrated circuit leadframes with ABACUS II magazine

The central area of the platen, supporting the leadframe in the bonding position, has a cartridge heater that will heat the chip and leadframe to 300-325 degrees Celsius. This is a necessary condition for a thermocompression bond with gold wire.

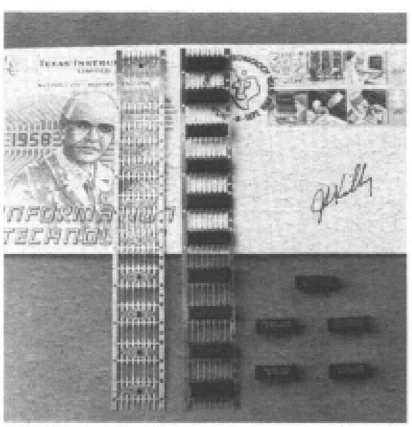
For unloading, the completed leadframe is driven as far to the right as possible by the drive rollers. From this position, another air-cylinder-driven blade completes the travel into the exit magazine.

Each magazine elevator is driven vertically from slot to slot with a leadscrew and stepping motor.

The Alignment Viewing System and Rotational Correction

The 30X binocular microscope used for observing and correcting the alignment of the integrated circuit chip on the leadframe has a crosshair reticle installed in the body. This reticle is rotated by worm gears and driven by a flexible shaft, which is directly connected to the operator's left joystick. The center of the crosshairs must be at the center of rotation of the reticle so that the X-Y position is not disturbed.

The rotating system is coupled to a digital shaft-angle encoder, which supplies the error input data to the computer. This encoder is a Gray-code type with a nine-bit output and a resolution of 512 positions per revolution.



Leadframes before and after plastic transfer molding and completed DIP integrated circuits

The X-Y Positioning System

The alignment microscope is mounted on the X-Y table, which also carries the wire-bonding mechanism, while the leadframe and chip are rigidly attached to the ABACUS II frame. When the operator-controlled right joystick is moved for an X-Y alignment correction, the two joystick shaft-angle encoders send the desired movement data through the computer to the X-Y table stepping motors. The table moves in response to the joystick motion, and the chip is moved in the field of the microscope and reticle. The encoders are of the same type as those used in the reticle-rotation system.

The leadscrews for the X-Y table have 20 threads per inch and adjustable backlash compensation. Each screw is driven by a stepping motor with 200 steps per revolution when driven in the half-step mode. This combination gives a smallest step of 0.00025 inch, with a maximum slewing speed of 0.45 inch per second at the highest stepping rate of 1,800 steps per second.

During the computer-controlled multiple bonding cycle, the actual X-Y position of the table at each bonding location, as indicated by the shaft-angle encoders, is compared to the desired location in the computer memory. A discrepancy usually indicates missed steps of the stepping motor, and an error signal is displayed to the operator. The travel of the X-Y table is 1.5 inch in both X and Y directions.

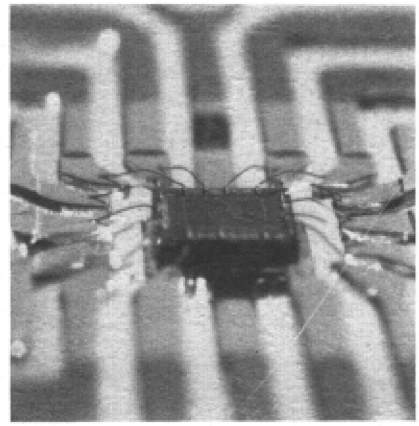
The Bond-Head Assembly

The bond-head assembly includes the bonding capillary, the wire-feed venturi, the wire-clamp mechanism, the ball detector, the flame-off torch, the wire-supply spool, and the Z-axis and torch-drive stepping motor.

The bonding capillary, generally made of ceramic or quartz, carries the bonding wire through its center and is the tool for forcing the gold ball against the chip bonding pad to perform the thermocompression bond.

The gold wire, usually 0.001-0.0015 inch diameter, is fed off a small spool, through a tensioner and solenoid-controlled clamping jaws, and down through the center of the bonding capillary. A nitrogen-powered venturi is used to suck the wire down through the top of the capillary and out the bottom when the system is threaded.

The missing-ball detector is also in the gold wire path. This device determines whether the ball is present on the end of the wire during each bond cycle. The detection of a ball is based on the stopping of the gold wire when the ball is retracted up against the end of the capillary.



Bonded integrated circuit

Auxiliary Equipment

The ABACUS II has a variety of peripheral systems. They include the oxygen- and hydrogen-flow control, isopropyl-alcohol bubbler (to make the flame visible) and electric igniter for the flame-off torch; the temperature-controller for the leadframe platen; the microscope light; the power supplies; and the operator controls and data-display panels.

The Control System

The TI960A computer was announced in November 1971. The selling price, with 4,096 16-bit words of MOS memory, was $2,850. This price reflected the major change from core memory to MOS integrated circuit memory. The earlier TI960 computer, with 4K of core memory, sold for more than $8,000 in 1970.

The TI960A in the ABACUS II wire bonder used the minimum memory of 4K 16-bit words, although the computer was capable of being fitted with 64K words. The system clock was 4 MHz with a typical instruction execution time of 3.6 microseconds. The instruction set had 78 instructions, each in a 32-bit format. Data was carried in 16-bit words. The system could operate in either a "Supervisor" or "Worker" mode for greater efficiency.

Connections to outside devices were through either the Communication Register Unit (CRU), with up to 4,096 input/outputs, or the Direct Memory Access Channel (DMAC), with up to eight 16-bit parallel ports.

The computer communication with the bonder hardware was primarily through special printed circuit boards in the CRU. The sensors and actuators were both single-bit devices, such as switches, lights, and solenoid valves, and multiple-bit, like the shaft encoders and paper-tape reader input. All were connected through 32-bit input and 32-bit output boards. The original ABACUS II used 108 input and 64 output bits.

The driver boards were more complex, as they were required to drive, at substantial levels, each of the 4 windings of the 3 stepping motors and several solenoids. The sequencing of the motor driving currents was done with the software so that each motor winding was essentially a single-bit output device.

A major software constraint was the cost of memory in the TI960A. A 24K-word add-on memory was $4,500, which more than doubled the price of the computer. The $15,000 cost goal of the ABACUS II dictated that the control software and device information fit into the 4K words of memory in the basic computer.

Since the only available operating system used about 7K words of memory, the ABACUS II software was written in assembly language and made to run stand-alone.

To load the computer memory the first time, or to reload it after maintenance, a few lines of machine-language code were loaded into memory with the front-panel bit-switches to “clear core.” Next, a primitive loader was keyed in with the bit-switches that could control the loading of data from a paper-tape reader. The paper-tape reader was then used to load a bootstrap program, followed by a second and third paper tape containing the ABACUS operating commands and the device-specific information for the bonder.

Readying the ABACUS II for bonding a new device required connecting the roving paper-tape reader system to the port on the operator control panel. The new device bonding data was then read into the TI960A memory.

The 4,096-word memory in the computer was sufficient to store the complete bonder-control program and three device-data files. The data files contained the information on pin spacing, chip configuration, and wiring. The operator could select any of the three device programs with a toggle switch on the control panel.

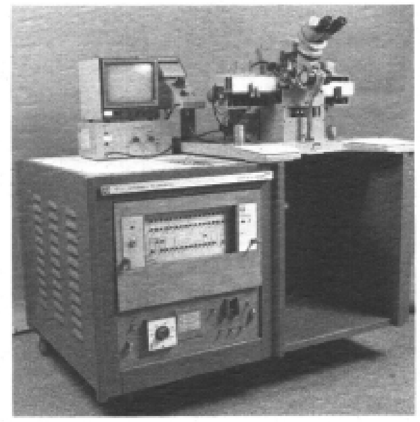
Bonder Capabilities

"X-Y" travel	1.5 inch square maximum
"Z" travel	0.187 inch, programmable
Bonding force	35 grams minimum
Positioning accuracy	±0.00025 inch
Incremental position selection	0.00025 inch
Bar size accommodation	Limited by X-Y travel
Ball-bond pad size limitation	0.003 inch square minimum
Bar location error compensation	Unlimited X-Y, ± 5 degrees
Continuous bonding rate	6,500 wires per hour
Number of bars on same substrate	15 maximum
Number of wires	255 maximum
Rebond feature	Standard
Optics	30X alignment scope, 20X and 40X observation scope
Control computer	TI Model 960A

Installation Requirements

Electrical	120/240 volts, 50/60 Hz, at 20 amperes	
Gases	Hydrogen	12 psi
	Oxygen	12 psi
	Nitrogen	25 psi
	Compressed air	30 psi
Machine dimensions	47" high x 48" wide x 32" deep	
Weight	Approximately 500 pounds	
Color	Tan, brown, ochre	

(Source for mechanical specifications: "Maintenance Manual ABACUS II Bonder," 8 May 1973.)



The ABACUS II, Serial No. 1, was first installed in TI's Sherman, Texas, production facility. It was later moved to Taiwan and then to Brazil, where it completed a 13-year production life in 1986. The machine has not been restored and reflects the typical condition of an old production bonder. Over the years, various parts and assemblies were changed from the original model to reflect technical improvements. For example, the bond head is the second version of the autoalign upgrade and was probably added in 1979. It is estimated that this machine bonded more than 50 million integrated circuits. Requests for additional information should be made to the TI Artifacts Program, MS-233, P.O. Box 655474, Dallas, Texas 75265.

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Commemorative Plaque

International Historic Mechanical Engineering Landmark
ABACUS II Integrated-Circuit Wire Bonder, 1972

The ABACUS II, designed and built by Texas Instruments, was the first practical, automated production machine for the assembly of integrated circuits. Using heat and pressure, it bonded fine gold wire to microscopic contacts on the silicon chip and pin connections on the package. The ABACUS II could maintain a positioning accuracy of ±0.00025 inch while bonding up to 375 devices per hour. Following the success of this prototype, almost 1,000 ABACUS II wire bonders were built, making the economical mass production of integrated circuits a reality.

The ASME History and Heritage Program

The ASME History and Heritage Recognition Program began in September 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee, initially composed of mechanical engineers, historians of technology, and (ex officio) the curator of mechanical engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording, and acknowledging mechanical achievements of particular importance.

The Texas Instruments ABACUS II is the 35th International Historic Mechanical Engineering Landmark to be designated. Since the ASME historic recognition programs began in 1971, 149 Historic Mechanical Landmarks, 6 Mechanical Engineering Heritage Sites, and 3 Mechanical Engineering Collections have been recognized. Each reflects its influence on society in its immediate locale, nationwide, or throughout the world.

An ASME landmark represents a progressive step in the evolution of mechanical engineering. Site designations note an event or development of clear historical importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The ASME historic mechanical engineering recognition program illuminates our technological heritage and serves to encourage the preservation of the physical remains of historically important works. It provides an annotated roster for engineering students, educators, historians, and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

The History and Heritage Committee is part of the ASME Council on Public Affairs and the Board on Public Information. For further information, please contact the Public Information Department, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, (212)705-7740.

Acknowledgments

The North Texas Section and the Electronic Packaging Division of the American Society of Mechanical Engineers gratefully acknowledge the efforts of all who contributed to the designation of the ABACUS II as an International Historic Mechanical Engineering Landmark. Particular thanks are extended to the staff of the Texas Instruments Archives who provided historical material and produced this brochure, to the members of the ASME Region X History and Heritage Committee for their advice and guidance, to the local Electronics Packaging Technical Chapter for organizing the ceremony, and to Texas Instruments employees, past and present, for their foresight in developing the ABACUS II and offering their encouragement, support, and participation in the designation ceremony.

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