Appendix

A No-Holds-Barred Seafood Gumbo

Well, my little avocado pears, festooned with slivers of spring onions and deluged with lashings of spicy Italian dressing . . . Having absorbed the myriad juicy snippets of information that are strewn so lavishly throughout *Bebop to the Boolean Boogie*, you are now uniquely qualified to regale an assembled throng with a discourse on almost any subject under the sun. So, this would be the perfect time to rest our weary brains and turn our attention to other facets of life's rich tapestry. For example, as soon as I've finished penning these last few words, I must return to practicing my down-hill mud-wrestling skills as, I have no doubt, so do you.

But first we need to recline, relax, lay back, unwind, and take the time to recharge our batteries—and what could be more appropriate than a steaming bowl of no-holds-barred seafood gumbo? So, here's the recipe for a fulsomely-flavored Epicurean taste-fest sensation sufficient to cause the most sophisticated of gastronomes to start salivating surreptitiously and to make a grown man break down and cry. This pert little beauty will pulsate promiscuously across your pallet and pummel it with a passion, titillate your taste buds and have them tap-dancing the tango on your tongue, reverberate and resonate resoundingly throughout your nervous system, and warm the cockles of your heart. In short, this frisky little number will grab you by the short-and-curlies, swing you sybaritically around the room in a syncopated symphony of delight, and leave you groveling on your knees, gnashing your teeth, and gasping for more.

Beware! If you are under 21, male, or a politician, don't attempt to do anything on the culinary front without your mother's permission and supervision, because kitchens contain sharp things, hot things, and a wide variety of other potentially dangerous things.

The following ingredients are for the main body of the gumbo—you'll have to sort out any rice, bread, and side dishes for yourself:

2 cups of diced onions
1½ cups of diced green bell peppers
1 cup of diced celery
2 cups of halved button mushrooms
3 large cloves of finely diced garlic
1 finely diced scotch bonnet or habañero pepper
10 thick-cut slices of bacon
1 pound of Cajun-style sausage
1 pound of peeled, medium-sized shrimp
½ pound of scallops
¾ pound white fish cut into slices
1 small tin of anchovies
2 bay leaves
½ teaspoon dried thyme leaves
¼ teaspoon dried oregano
½ teaspoons of salt
1½ teaspoons of white pepper
½ teaspoon of black pepper
½ teaspoon of cayenne pepper
2 teaspoons of Gumbo Filé
5½ cups of chicken stock
Lots of butter (more below)
¾ cup flour

If you can't get Cajun-style sausage, then Polish sausage will do nicely. Note that the teaspoon quantities in the list of ingredients do not refer to level measures, nor should you to attempt to set a new world record for the amount you can balance on one spoon—just try to aim for roughly the same sensuously rounded profile you get when you're casually spooning sugar into a cup of coffee. So, without further ado, let's gird up our loins and proceed to the fray:

1. First of all there's an art to cooking, and it starts by doing the washing up you've been putting off all day and putting all of the pots away.

3. Grill (broil) the bacon until it's crispy and crunchy; then put it on a plate to cool and set it to one side.

4. Prepare all of the vegetables, mushrooms, garlic, and scotch bonnet or habañero pepper (be careful with the latter—it's best to wear gloves here—

because these are ferociously hot and if you get the juice on your finger and then touch anywhere near your eyes you're going to be a very unhappy camper). Put them all in separate bowls, except for the scotch bonnet and garlic, which can go together.

5. Chop the Cajun-style sausage into ¼-inch pieces (cut at about a 45 degree angle because this looks nicer); put them in a bowl and set it to one side.

6. Mix the salt, thyme, oregano, Gumbo Filé, and the white, black, and cayenne peppers together in a cup and set it to one side (you'll need your hands free later).

7. Wash up all the knives, chopping boards, and everything else you've used and put them all away, and then wipe down all of your working surfaces. Trust me—you'll feel better when everything is clean and tidy (have I ever lied to you before?). Take a five-minute break and quaff[1] a glass of wine—after all, who deserves it more than you?

8. Put the chicken stock into a large chili pan and bring it to the boil. Then reduce the heat to a low, slow simmer and leave it on the back burner.

9. Using a medium to medium-high heat, melt ¾ of a cup of butter in a large, heavy skillet until it starts to bubble. Gradually add the flour using a whisk and stir constantly until the resulting roux is a dark-ish, red-ish brown (the darker the better—try to be brave here and leave it longer than you expect). Remove the skillet from the heat, but keep on stirring until it's cooled down enough so that the mixture won't stick to it and burn.

10. Maintain the stock at a low simmer and add the mixture that you've just made, stirring it in one spoonful at a time, and waiting for each spoonful to dissolve before adding the next.

11. Clean the skillet, put it on a medium-high to high heat, and melt a chunk of butter. Stirring all the time, sauté the celery for one minute, add the bell peppers and sauté for 1½ minutes, add the onions and sauté for 1½ minutes, then add the scotch bonnets and garlic along with the mixture of herbs, salt, and pepper and sauté for one more minute. Finally, chuck the whole lot into the chili pan with the stock.

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[1] Quaffing is like drinking, except that you tend to spill more down your chest.

12. Break the bacon into ½-inch pieces and toss them into the stock. Flake the anchovies with a fork and cast them into the stock. Hurl in the Cajun-style sausage and the bay leaves. Also, if you happen to have any lying around, add a couple of teaspoons of English Worcestershire sauce. Cover the chili pan and leave on a low simmer.

13. Return the skillet to a medium-high to high heat and melt another chunk of butter. Sauté the mushrooms until they're golden brown and squealing for more, then use them to swell the contents of the chili pan.

14. Simmer the whole mixture (stirring often) for at least one hour, which, by some strange quirk of fate, will give you all the time you need to wash the skillet and the dishes you used and put them away again. If you're ravenous you can proceed immediately to the next step. However, if you're wise, you'll remove the heat and leave your cunningly captivating creation to stand overnight (chilies, stews, curries, and gumbos always taste better if the ingredients have the time to formally introduce themselves). When you're ready to chow down, heat it back up again and proceed to the next step.

15. Add the shrimp, scallops, and fish. Bring to the boil then return to a simmer. Maintain the simmer until the seafood is cooked (I personally opt for around 15 minutes just to make sure) and you're ready to rock and roll.

This little beauty will put hairs on your chest, make them curl, and then take them off again. Seriously, this gumbo really is seductively, scintillatingly, scorchingly tasty—your friends will be singing your praises and dancing in the streets.

You can serve your gorgeous gourmet gumbo over steamed or boiled rice, with crusty French bread, or with whatever else your heart desires. The quantities given above will serve eight to ten manly-man sized portions with a little something left over for the following day. Of course, no meal would be complete without some wine—and the perfect complement to your scrumptious repast is . . . to be found in a very large bottle. Enjoy!

Abbreviations and Acronyms

Electronic engineers and computer buffs simply love abbreviations and acronyms. They are really happy if they can use one abbreviation to represent multiple things or different abbreviations to represent the same things, and they become close to ecstatic if they can generate a plethora of abbreviations from permutations of the same three or four letters. The situation is further confused, because the meanings behind abbreviations and acronyms may evolve over time. The list below contains the abbreviations and acronyms used in this book. For further reading, one could do a lot worse than *The Computer Glossary* by Alan Freedman.

2-D or 2D	Two Dimensional
3-D or 3D	Three Dimensional
A/D	Analog-to-Digital
ASIC	Application-Specific Integrated Circuit
ASSP	Application-Specific Standard Part
BDD	Binary Decision Diagram
BEDO	Burst EDO
BGA	Ball Grid Array
BiCMOS	Bipolar-CMOS
BiNMOS	Bipolar-NMOS
BIST	Built-In Self-Test
BJT	Bipolar Junction Transistor
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CGA	Column Grid Array
CGH	Computer-Generated Hologram
CMOS	Complementary Metal-Oxide Semiconductor
CMP	Chemical Mechanical Polishing
CNFET	Carbon Nanotube FET
COB	Chip-On-Board
COC	Chip-On-Chip
COF	Chip-On-Flex
COT	Customer-Owned Tooling
CPLD	Complex PLD
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSIC	Customer-Specific Integrated Circuit
CSP	Chip Scale Package
CVD	Chemical Vapor Deposition
CVI	Chemical Vapor Infiltration
D/A	Digital-to-Analog
DDR	Double Data Rate
DFT	Design-for-Test
DIL	Dual-In-Line
DRAM	Dynamic RAM
DSM	Deep-Submicron
DSP	Digital Signal Processor
DTL	Diode-Transistor Logic
DIMM	Dual In-line Memory Module
DWB	Discrete Wired Board

E²PROM	Electrically-Erasable Programmable Read-Only Memory
EBE	Electron Beam Epitaxy
ECC	Error-Correcting Code
ECL	Emitter-Coupled Logic
EDA	Electronic Design Automation
EDIF	Electronic Design Interchange Format
EDO	Extended Data Out
EDSAC	Electronic Delay Storage Automatic Calculator
EDVAC	Electronic Discrete Variable Automatic Computer
EEPROM	Electrically-Erasable Programmable Read-Only Memory
ENIAC	Electronic Numerical Integrator and Calculator
EPROM	Erasable Programmable Read-Only Memory
ESD	Electrostatic Discharge
EUV	Extreme Ultraviolet
EUVL	Extreme Ultraviolet Lithography
FET	Field-Effect Transistor
FIFO	First-In First-Out
FPC	Flexible Printed Circuit
FPD	Field-Programmable Device
FPGA	Field-Programmable Gate Array
FPIC	Field-Programmable Interconnect Chip[1]
FPID	Field-Programmable Interconnect Device
FPM	Fast Page Mode
FSM	Finite State Machine
GAL	Generic Array Logic[2]
GIGO	Garbage-In Garbage-Out
HDL	Hardware Description Language
HTCC	High-Temperature Cofired Ceramic
IC	Integrated Circuit
ICR	In-Circuit Reconfigurable
IDM	Integrated Device Manufacturer
I/O	Input/Output
IP	Intellectual Property
IR	Infrared
ISP	In-System Programmable
JEDEC	Joint Electronic Device Engineering Council
LED	Light-Emitting Diode
LFSR	Linear Feedback Shift Register
LIFO	Last-In-First-Out
LSB	Least Significant Bit
LSB	Least Significant Byte
LSI	Large-Scale Integration
LTCC	Low-Temperature Cofired Ceramic
LTH	Lead Through-Hole
MBE	Molecular Beam Epitaxy
MCM	Multichip Module
MCM-C	Multichip Module – Ceramic substrate
MCM-D	Multichip Module – Dielectric-covered substrate
MCM-L	Multichip Module – Laminate substrate
MCM-S	Multichip Module – Semiconductor substrate

[1] FPIC is a trademark of Aptix Corporation.

[2] GAL is a registered trademark of Lattice Semiconductor Corporation.

MEMS	MicroElectroMechanical Systems
MOS	Metal-Oxide Semiconductor
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
MRAM	Magnetic Random Access Memory
MSB	Most Significant Bit
MSB	Most Significant Byte
MSI	Medium-Scale Integration
MTJ	Magnetic Tunnel Junction
NMOS	N-channel MOS
NPN	N-type – P-type – N-type
NRE	Non-Recurring Engineering
nvRAM	Non-Volatile RAM
OMEMS	Optical MEMS
OTP	One Time Programmable
PAL	Programmable Array Logic[3]
PCB	Printed Circuit Board
PGA	Pad Grid Array
PGA	Pin Grid Array
PHB	Photochemical Hole Burning
PISO	Parallel-In Serial-Out
PLA	Programmable Logic Array
PLD	Programmable Logic Device
PMOS	P-channel MOS
PNP	P-type – N-type – P-type
PROM	Programmable Read-Only Memory
PTH	Plated Through-Hole
PWB	Printed Wire Board
QDR	Quad Data Rate
QFP	Quad Flat Pack
RAM	Random Access Memory
RDRAM	Rambus DRAM
RIMM	*See the Glossary for more details*
ROM	Read-Only Memory
RTL	Register Transfer Level
RTL	Resistor-Transistor Logic
RWM	Read-Write Memory
SDRAM	Synchronous DRAM
SIMM	Single In-line Memory Module
SIPO	Serial-In Parallel-Out
SISO	Serial-In Serial-Out
SMD	Surface Mount Device
SMOBC	Solder Mask Over Bare Copper
SMT	Surface Mount Technology
SoC	System-on-Chip
SOP	Small Outline Package
SPLD	Simple PLD
SRAM	Static RAM
SSI	Small-Scale Integration
TAB	Tape Automated Bonding
TTL	Transistor-Transistor Logic
μC	Microcontroller
UDSM	Ultra-Deep-Submicron
ULA	Uncommitted Logic Array
ULSI	Ultra-Large-Scale Integration
UNIVAC	Universal Automatic Computer
μP	Microprocessor
UV	Ultraviolet
VHDL	VHSIC HDL
VHSIC	Very High Speed Integrated Circuit
VLSI	Very-Large-Scale Integration

[3] PAL is a registered trademark of Monolithic Memories Inc.

Glossary

Absolute Scale of Temperature – A scale of temperature that was invented by the British mathematician and physicist William Thomas, first Baron of Kelvin. Under the *absolute*, or *Kelvin*, scale of temperature, 0K (corresponding to –273°C) is the coldest possible temperature and is known as *absolute zero*.

Absolute Zero – *see Absolute Scale of Temperature.*

Active-High – Once again, beware, here be dragons. In this book an *active-high* signal is defined as a signal whose active state is considered to be a logic 1. This definition, which is used by the engineers in the trenches, allows all forms of logic, including *assertion-level* logic, to be represented without any confusion, regardless of whether *positive-* or *negative-logic* implementations are employed.

Unfortunately, some academics (and even textbooks) define an active-high signal as being one whose asserted (TRUE or logic 1) state is at a higher voltage level than its unasserted (FALSE or logic 0) state. However, this definition serves only to cause confusion when combined with negative-logic implementations. Thus, when using the term active-high in discussions with other people, you are strongly advised to make sure that you're all talking about the same thing before you start.

Active-Low – Beware, here be dragons. In this book an *active-low* signal is defined as a signal whose active state is considered to be a logic 0. This definition, which is used by the engineers in the trenches, allows all forms of logic, including *assertion-level* logic, to be represented without any confusion, regardless of whether *positive-* or *negative-logic* implementations are employed.

Unfortunately, some academics (and even textbooks) define an active-low signal as being one whose asserted (TRUE or logic 1) state is at a lower voltage level than its unasserted (FALSE or logic 0) state. However, this definition serves only to cause confusion when combined with negative-logic implementations. Thus, when using the term active-low in discussions with other people, you are strongly advised to make sure that you're all talking about the same thing before you start.

Active Substrate – A hybrid or multichip module substrate formed from a semiconductor. Termed *active* because components such as transistors can be fabricated directly into the substrate.

Active Trimming – The process of trimming components such as resistors while the circuit is under power. Such components are fabricated directly onto the substrate of a hybrid or multichip module, and the trimming is usually performed using a laser beam.

Actuator – A transducer that converts an electronic signal into a physical equivalent. For example, a loudspeaker is an actuator that converts electronic signals into corresponding sounds.

Adaptive Hardware – Refers to devices that allow new design variations to be "compiled" in real-time, which may be thought of as dynamically creating subroutines in hardware *See also Virtual Hardware and Cache Logic*.

Additive Process – A process in which conducting material is added to specific areas of a substrate. Groups of tracks, individual tracks, or portions of tracks can be built up to precise thicknesses by iterating the process multiple times with selective masking.

Address Bus – A unidirectional set of signals used by a computer to point to memory locations in which it is interested.

A/D (Analog-to-Digital) – The process of converting an analog value into its digital equivalent.

Analog – A continuous value that most closely resembles the real world and can be as precise as the measuring technique allows.

Analog Circuit – A collection of components used to process or generate analog signals.

Analog-to-Digital – *see A/D.*

Analogue – The way they spell "analog" in England.

Anisotropic Adhesives – Special adhesives that contain minute particles of conductive material. These adhesives find particular application with the flipped-chip techniques used to mount bare die on the substrates of hybrids, multichip modules, or circuit boards. The conducting particles are only brought in contact with each other at the sites where the raised pads on the die are pressed down over their corresponding pads on the substrate, thereby forming good electrical connections between the pads.

Anti-Fuse Technology – A programmable logic device technology in which conducting paths (*anti-fuses*) are "grown" by applying signals of relatively high voltage and current to the device's inputs.

Anti-Pad – The area of copper etched away around a via or a plated through-hole on a power or ground plane, thereby preventing an electrical connection being made to that plane.

Application-Specific Integrated Circuit – *see ASIC.*

Application-Specific Standard Part – *see ASSP.*

ASIC (Application-Specific Integrated Circuit) – A device whose function is determined by a designer for a particular application or group of applications.

ASIC Cell – A logic function in the cell library defined by the manufacturer of an application-specific integrated circuit.

Assertion-Level Logic – A technique used to more precisely represent the function of logic gates with active-low inputs.

Associative Rules – Algebraic rules that state that the order in which pairs of variables are associated together will not affect the result of an operation: for example,[1] $(a \,\&\, b) \,\&\, c \equiv a \,\&\, (b \,\&\, c)$.

ASSP (Application-Specific Standard Part) – Refers to complex integrated circuits created by a device manufacturer using ASIC technologies, where these components are to be sold as standard parts to anybody who wants to buy them.

Asynchronous – A signal whose data is acknowledged or acted upon immediately, regardless of any clock signal.

Atto – Unit qualifier (symbol = a) representing one millionth of one millionth of one millionth, or 10^{-18}. For example, 3 as stands for 3×10^{-18} seconds.

Backplane – The medium used to interconnect a number of circuit boards. Typically refers to a special, heavy-duty printed or discrete wired circuit board.

Ball Grid Array – *see BGA.*

Bare Die – An unpackaged integrated circuit.

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[1] Note that the symbol ≡ indicates "is equivalent to" or "is the same as."

Barrier Layer – *see Overglassing.*

Base – Refers to the number of digits in a numbering system. For example, the decimal numbering system is said to be base-10. (May also be referred to as the "radix.")

Basic Cell – A predefined group of unconnected components that is replicated across the surface of a gate array.

BDD (Binary Decision Diagram) – A method of representing Boolean equations as decision trees.

Bebop – A form of music characterized by fast tempos and agitated rhythms that became highly popular in the decade following World War II.

BEDO (Burst EDO) – An asynchronous form of DRAM-based computer memory that was popular for a while in the latter half of the 1990s. Along with other asynchronous memory techniques, BEDO was eventually superceded by SDRAM technologies *See also FPM, EDO, and SDRAM.*

BGA (Ball Grid Array) – A packaging technology similar to a *pad grid array (PGA)*, in which a device's external connections are arranged as an array of conducting pads on the base of the package. However, in the case of a ball grid array, small balls of solder are attached to the conducting pads.

BiCMOS (Bipolar-CMOS) – A technology in which the function of each logic gate is implemented using low-power CMOS, while the output stage is implemented using high-drive bipolar transistors.

Binary – Base-2 numbering system (the type of numbers that computers use internally).

Binary Decision Diagram – *see BDD.*

Binary Digit – A numeral in the binary scale of notation. A binary digit (typically abbreviated to "bit") can adopt one of two values: 0 or 1.

Binary Encoding – A form of state assignment for state machines that requires the minimum number of state variables.

Binary Logic – Digital logic gates based on two distinct voltage levels. The two voltages are used to represent the binary values 0 and 1, and their logical equivalents FALSE and TRUE.

BiNMOS (Bipolar-NMOS) – A relatively new low-voltage integrated circuit technology in which complex combinations of bipolar and NMOS transistors are used for sophisticated output stages providing both high speed and low static power dissipation.

Bipolar Junction Transistor – *see BJT.*

Bi-quinary – A system that utilizes two bases, base-2 and base-5, to represent decimal numbers. Each decimal digit is represented by the sum of two parts, one of which has the value of decimal zero or five, and the other the values of zero through four. The abacus is one practical example of the use of a bi-quinary system.

BIST (Built-in Self-test) – A test strategy in which additional logic is built into a component, thereby allowing it to test itself.

Bit – Abbreviation *of binary digit.* A binary digit can adopt one of two values: 0 or 1.

BJTs (Bipolar Junction Transistors) – A family of transistors.

Blind Via – A via that is only visible from one side of the substrate.

Bobble – A small circle used on the inputs to a logic gate symbol to indicate an active low input or control, or on the outputs to indicate a negation (inversion) or complementary signal. Some engineers prefer to use the term "bubble."

Boolean Algebra – A mathematical way of representing logical expressions.

Bootstrapping – A sequence of initialization operations performed by a computer when it is first powered up.

Bounce Pad – A special pattern etched onto the power or ground plane of a microwire circuit board. The bounce pad is used in conjunction with a laser beam to create blind vias. The laser beam evaporates the epoxy forming the outer layers of the board and continues down to the bounce pad which reflects, or bounces, it back up, thereby terminating the via.

Braze – To unite or fuse two pieces of metal by heating them in conjunction with a hard solder with a high melting point.

Buckyballs – Prior to the mid-1980s, the only major forms of pure carbon known to us were graphite and diamond. In 1985, however, a third form consisting of spheres formed from 60 carbon atoms (C_{60}) was discovered. Officially known as Buckministerfullerine[2]—named after the American architect R. Buckminister Fuller who designed geodesic domes with the same fundamental symmetry—these spheres are more commonly known as "buckyballs." In 2000, scientists with the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and the University of California at Berkeley reported that they had managed to fashion a transistor from a single buckyball.

Built-In Self-Test – *see BIST*.

Bulk Storage – Refers to some form of media, typically magnetic, such as tape or a disk drive, which can be used to store large quantities of information relatively inexpensively.

Buried Via – A via used to link conducting layers internal to a substrate. Such a via is not visible from either side of the substrate.

Burst EDO – *see BEDO*.

Bus – A set of signals performing a common function and carrying similar data. Typically represented using vector notation: for example, *data*[7:0].

Bundle – A set of signals related in some way that makes it appropriate to group them together for ease of representation or manipulation. May contain both scalar and vector elements: for example, {*a*,*b*,*c*,*d*[5:0]}.

Byte – A group of eight binary digits, or bits.

Cache Logic[3] – A proprietary name intended to reflect designs realized in virtual hardware. Derived from its similarity to the concept of *Cache Memory*.

Cache Memory – A small, high-speed, memory (usually SRAM) used to buffer the central processing unit from any slower, lower cost memory devices such as DRAM. The high-speed cache memory is used to store active instructions and data,[4] while the bulk of the instructions and data reside in the slower memory.

Canonical Form – In a mathematical context this term is taken to mean a generic or basic representation. Canonical forms provide the means to compare two expressions without falling into the trap of trying to compare "apples" with "oranges."

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[2] Science magazine voted Buckministerfullerine the "Molecule of the Year" in 1991.

[3] Cache Logic is a trademark of Atmel Corporation.

[4] In this context, "active" refers to data or instructions that a program is currently using, or which the operating system believes that the program will want to use in the immediate future.

Capacitance – A measure of the ability of two adjacent conductors separated by an insulator to hold a charge when a voltage differential is applied between them. Capacitance is measured in units of Farads.

Carbon Nanotube FET – *see CNFET.*

Catalyst – A substance that initiates a chemical reaction under different conditions (such as lower temperatures) than would otherwise be possible. The catalyst itself remains unchanged at the end of the reaction.

Cell – *see ASIC Cell, Basic Cell, Cell Library, and Memory Cell.*

Cell Library – The collective name for the set of logic functions defined by the manufacturer of an application-specific integrated circuit. The designer decides which types of cells should be realized and connected together to make the device perform its desired function.

Central Processing Unit – *see CPU.*

Ceramic – An inorganic, nonmetallic material, such as alumina, beryllia, steatite, or forsterite, which is fired at a high temperature and is often used in electronics as a substrate or to create component packages.

CGA (Column Grid Array) – A packaging technology similar to a *pad grid array (PGA)*, in which a device's external connections are arranged as an array of conducting pads on the base of the package. However, in the case of a column grid array, small columns of solder are attached to the conducting pads.

CGH (Computer-Generated Hologram) – In the context of this book, this refers to a slice of quartz or similar material into which three-dimensional patterns are cut using a laser. The angles of the patterns cut into the quartz are precisely calculated for use in the optical communication strategy known as holographic interconnect. All of these calculations are performed by a computer, and the laser used to cut the three-dimensional patterns into the quartz is also controlled by a computer. Thus, the slice of quartz is referred to as a *computer-generated hologram.*

Channel – **(1)** The area between two arrays of basic cells in a channeled gate array. **(2)** The gap between the source and drain regions in a MOS transistor.

Channeled Gate Array – An *application-specific integrated circuit (ASIC)* organized as arrays of basic cells. The areas between the arrays are known as channels.

Channel-Less Gate Array – *An application-specific integrated circuit (ASIC)* organized as a single large array of basic cells. May also be referred to as a "sea of cells" or a "sea of gates" device.

Checksum – The final cyclic-redundancy check value stored in a linear feedback shift register (or software equivalent). Also known as a "signature" in the guided-probe variant of a functional test.

Chemically-Amplified Resist – In the case of a chemically-amplified resist, the application of a relatively small quantity of ultraviolet light stimulates the formation of chemicals in the resist, where these chemicals accelerate the degrading process. This reduces the amount of ultraviolet light required to degrade the resist and allows the creation of finer features with improved accuracy.

Chemical Mechanical Polishing – *see CMP.*

Chemical Vapor Deposition – *see CVD.*

Chemical Vapor Infiltration – *see CVI.*

Chip – Popular name for an integrated circuit.

Chip-on-Board – *see* COB.

Chip-on-Chip – *see* COC.

Chip-on-Flex – *see* COF.

Chip Scale Package – *see* CSP.

Circuit Board – The generic name for a wide variety of interconnection techniques, which include rigid, flexible, and rigid-flex boards in single-sided, double-sided, multilayer, and discrete wired configurations.

CMOS (Complementary Metal Oxide Semiconductor) – Logic gates constructed using both NMOS and PMOS transistors connected in a complementary manner.

CMP (Chemical Mechanical Polishing) – A process used to re-planarize a wafer—smoothing the surface by polishing out the "bumps" caused by adding a metalization (tracking) layer.

CNFET (Carbon Nanotube FET) – A new type of transistor announced by IBM in the summer of 2002. This device is based on a field-effect transistor featuring a carbon nanotube measuring 1.4 nanometers in diameter as the channel (the rest of the transistor is formed using conventional silicon and metal processing technologies). It will be a number of years before these devices become commercially available, but they are anticipated to significantly outperform their silicon-only counterparts.

Coaxial Cable – A conductor in the form of a central wire surrounded first by a dielectric (insulating) layer, and then by a conducting tube which serves to shield the central wire from external interference.

COB (Chip-on-Board) – A process in which unpackaged integrated circuits are physically and electrically attached to a circuit board, and are then encapsulated with a "glob" of protective material such as epoxy.

COC (Chip-on-Chip) – A process in which unpackaged integrated circuits are mounted on top of each other. Each die is very thin and it is possible to have over a hundred die forming a 3D cube.

Coefficient of Thermal Expansion – Defines the amount that a material expands and contracts due to changes in temperature. If materials with different coefficients of thermal expansion are bonded together, changes in temperature will cause shear forces at the interface between them.

COF (Chip-on-Flex) – Similar to *chip-on-board*, except that the unpackaged integrated circuits are attached to a flexible printed circuit.

Cofired Ceramic – A substrate formed from multiple layers of "green" ceramic that are bonded together and fired at the same time.

Column Grid Array – *see* CGA.

Combinatorial – *see Combinational*.

Combinational – A digital function whose output value is directly related to the current combination of values on its inputs.

Commutative Rules – Algebraic rules that state that the order in which variables are specified will not affect the result of an operation: for example,[5] $a \,\&\, b \equiv b \,\&\, a$.

[5] Note that the symbol ≡ indicates "is equivalent to" or "is the same as."

Comparator (digital) – A logic function that compares two binary values and outputs the results in terms of binary signals representing *less-than* and/or *equal-to* and/or *greater than*.

Compiled Cell Technology – A technique used to create portions of a standard cell *application-specific integrated circuit (ASIC)*. The masks used to create components and interconnections are directly generated from Boolean representations using a program called a *silicon compiler*. May also be used to create data-path and memory functions.

Complementary Output – Refers to a function with two outputs carrying complementary logical values. One output is referred to as the *true output* and the other as the *complementary output*.

Complementary Rules – Rules in Boolean Algebra derived from the combination of a single variable with the inverse of itself.

Complex Programmable Logic Device – *see CPLD*.

Computer-Generated Hologram – *see CGH*.

Computer Virus – There are many different types of computer viruses but, for the purposes of this book, a computer virus may be defined as a self-replicating program released into a computer system for a number of purposes. These purposes range from the simply mischievous, such as displaying humorous or annoying messages, to the downright nefarious, such as corrupting data or destroying (or subverting) the operating system.

Conditioning – *see Signal Conditioning*.

Conductive Ink Technology – A technique in which tracks are screen-printed directly onto the surface of a circuit board using conductive ink.

Conjunction – Propositions combined with an AND operator: for example, "*You have a parrot on your head AND you have a fish in your ear*." The result of a conjunction is true if all the propositions comprising that conjunction are true.

Configurable Hardware – A product whose function may be customized once or a very few times. *See also Adaptive Computing, Reconfigurable Hardware, Remotely Reconfigurable Hardware, Dynamically Reconfigurable Hardware, and Virtual Hardware*.

CPLD (Complex PLD) – A device that contains a number of PLA or PAL functions sharing a common programmable interconnection matrix.

CPU (Central Processing Unit) – The "brain" of a computer where all of the decision-making and number crunching is performed.

CRC (Cyclic Redundancy Check) – A calculation used to detect errors in data communications, typically performed using a linear feedback shift register. Similar calculations may be used for a variety of other purposes such as data compression.

Crossover – Used in discrete wire technology to designate the intersection of two or more insulated wires.

CSIC (Customer-Specific Integrated Circuit) – An alternative and possibly more accurate name for an ASIC, but this term is rarely used in the industry and shows little indication of finding favor with the masses.

CSP (Chip Scale Package) – An integrated circuit packaging technique in which the package is only fractionally larger than the silicon die.

Cure – To harden a material using heat, ultraviolet light, or some other process.

Cured – Refers to a material that has been hardened using heat, ultraviolet light or some other process.

Customer-Specific Integrated Circuit – *see* CSIC.

CVD (Chemical Vapor Deposition) – A process for growing thin films on a substrate, in which a gas containing the required molecules is converted into *plasma* by heating it to extremely high temperatures using microwaves. The plasma carries atoms to the surface of the substrate where they are attracted to the crystalline structure of the substrate. This underlying structure acts as a template. The new atoms continue to develop the structure to build up a layer on the substrate's surface.

CVI (Chemical Vapor Infiltration) – A process similar to *chemical vapor deposition (CVD)* but, in this case, the process commences by placing a crystalline powder of the required substance in a mold. Additionally, thin posts, or columns, can be preformed in the mold, and the powder can be deposited around them. When exposed to the same plasma as used in the CVD technique, the powder coalesces into a polycrystalline mass. After the CVI process has been performed, the posts can be dissolved, leaving holes through the crystal for use in creating vias. CVI processes can produce layers twice the thickness of those obtained using CVD techniques at a fraction of the cost.

Cyclic Redundancy Check – *see* CRC.

D/A (Digital-to-Analog) – The process of converting a digital value into its analog equivalent.

Data Bus – A bi-directional set of signals used by a computer to convey information from a memory location to the central processing unit and vice versa. More generally, a set of signals used to convey data between digital functions.

Data-Path Function – A well-defined function such as an adder, counter, or multiplier used to process digital data.

Daughter Board – If a backplane contains active components such as integrated circuits, then it is usually referred to as a motherboard. In this case, the boards plugged into it are referred to as daughter boards.

DDR (Double Data Rate) – A modern form of SDRAM-based memory. The original SDRAM specification was based on using one of the clock edges only (say the rising edge) to read/write data out-of/into the memory. DDR refers to memory designed in such a way that data can be read/written on both edges of the clock. This effectively doubles the amount of data that can be pushed through the system without increasing the clock frequency (like many things this sounds simple if you say it fast, but making this work is trickier than it may at first appear). *See also QDR and SDRAM.*

Decimal – Base-10 numbering system.

Decoder (digital) – A logic function that uses a binary value, or address, to select between a number of outputs and to assert the selected output by placing it in its active state.

Deep Sub-Micron – *see DSM.*

Delamination – Occurs when a composite material formed from a number of layers is stressed, thermally or otherwise, such that the layers begin to separate.

DeMorgan Transformation – The transformation of a Boolean expression into an alternate, and often more convenient, form.

Die – **(1)** An unpackaged integrated circuit. In this case, the plural of die is also die (in much the same way that "a shoal of herring" is the plural of "herring"). **(2)** A piece of metal with a design engraved or embossed on it for stamping onto another material, upon which the design appears in relief.

Dielectric Layer – **(1)** An insulating layer used to separate two signal layers. **(2)** An insulating layer used to modify the electrical characteristics of an MCM-D substrate.

Die Separation – The process of separating individual die from the wafer by marking the wafer with a diamond scribe and fracturing it along the scribed lines.

Die Stacking – A technique used in specialist applications in which several bare die are stacked on top of each other to form a sandwich. The die are connected together and then packaged as a single entity.

Diffusion Layer – The surface layer of a piece of semiconductor into which impurities are diffused to form P-type and N-type material. In addition to forming components, the diffusion layer may also be used to create embedded traces.

Digital – A value represented as being in one of a finite number of discrete states called *quanta*. The accuracy of a digital value is dependent on the number of quanta used to represent it.

Digital Circuit – A collection of logic gates used to process or generate digital signals.

Digital Signal Processor – *see DSP*.

Digital-to-Analog – *see D/A*.

DIMM (Dual In-line Memory Module) – A single memory integrated circuit can only contain a limited amount of data, so a number are gathered together onto a small circuit board called a *memory module*. Each memory module has a line of gold-plated pads on both sides of one edge of the board. These pads plug into a corresponding connector on the main computer board. In the case of a *dual in-line memory module (DIMM)*, the pads on opposite sides of the board are electrically isolated from each other and form two separate contacts. *See also SIMM and RIMM*.

Diode – A two-terminal device that conducts electricity in only one direction; in the other direction it behaves like an open switch. These days the term diode is almost invariably taken to refer to a semiconductor device, although alternative implementations such as vacuum tubes are available.

Diode-Transistor Logic – *see DTL*.

Discrete Device – Typically taken to refer to an electronic component such as a resistor, capacitor, diode, or transistor that is presented in an individual package. More rarely, the term may be used in connection with a simple integrated circuit containing a small number of primitive gates.

Discrete Wire Board – *see DWB*.

Discrete Wire Technology – The technology used to fabricate discrete wire boards.

Disjunction – Propositions combined with an OR operator; for example, *"You have a parrot on your head OR you have a fish in your ear."* The result of a disjunction is true if at least one of the propositions comprising that disjunction is true.

Distributive Rules – Two very important rules in Boolean Algebra. The first states that the AND operator distributes over the OR operator: for example,[6] $a \,\&\, (b \mid c) \equiv (a \,\&\, b) \mid (a \,\&\, c)$. The second states that the OR operator distributes over the AND operator: for example, $a \mid (b \,\&\, c) \equiv (a \mid b) \,\&\, (a \mid c)$.

Doping – The process of inserting selected impurities into a semiconductor to create P-type or N-type material.

Double Data Rate – *see DDR*.

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[6] Note that the symbol ≡ indicates "is equivalent to" or "is the same as."

Double-Sided – A printed circuit board with tracks on both sides.

DRAM (Dynamic RAM) – A memory device in which each cell is formed from a transistor-capacitor pair. Called *dynamic* because the capacitor loses its charge over time, and each cell must be periodically recharged if it is to retain its data.

DSM (Deep Submicron) – Typically taken to refer to integrated circuits containing structures that are smaller than 0.5 microns (one half of one millionth of a meter).

DSP (Digital Signal Processor) – A special form of microprocessor that has been designed to perform a specific processing task on a specific type of digital data much faster and more efficiently than can be achieved using a general-purpose microprocessor.

DTL (Diode-Transistor Logic) – Logic gates implemented using particular configurations of diodes and bipolar junction transistors. For the majority of today's designers, diode-transistor logic is of historical interest only.

Dual In-line Memory Module – *see DIMM*.

Duo-decimal – Base-12 numbering system.

DWB (Discrete Wire Board) – A form of circuit board in which a special computer-controlled wiring machine ultrasonically bonds extremely fine insulated wires into the surface layer of the board. This discipline has enjoyed only limited recognition, but some believe that it is poised to emerge as the technology-of-choice for high-speed designers.

Dynamic Flex – A type of *flexible printed circuit* which is used in applications that are required to undergo constant flexing such as ribbon cables in printers.

Dynamically Reconfigurable Hardware – A product whose function may be customized on-the-fly while remaining resident in the system. *See also Configurable Hardware, Reconfigurable Hardware, Remotely Reconfigurable Hardware, and Virtual Hardware*.

Dynamic RAM – *see DRAM*.

EBE (Electron Beam Epitaxy) – A technique for creating thin films on substrates in precise patterns. The substrate is first coated with a layer of dopant material before being placed in a high vacuum. A guided beam of electrons is fired at the substrate, causing the dopant to be driven into it, effectively allowing molecular-thin layers to be "painted" onto the substrate where required.

ECC (Error-Correcting Code) – Computer systems are very complicated and there's always the chance that an error will occur when reading or writing to the memory (a stray pulse of "noise" may flip a logic 0 to a logic 1 while your back is turned). Thus, serious computers use ECC memory, which includes extra bits and special circuitry that tests the accuracy of data as it passes in and out of memory and corrects any (simple) errors.

ECL (Emitter-Coupled Logic) – Logic gates implemented using particular configurations of bipolar junction transistors.

Edge-Sensitive – An input that only affects a function when it transitions from one logic value to another.

EDO (Extended Data Out) – An asynchronous form of DRAM-based computer memory that was popular for a while in the latter half of the 1990s. Along with other asynchronous memory techniques, EDO was eventually superceded by SDRAM technologies. *See also FPM, BEDO, and SDRAM*.

EEPROM or E²PROM (Electrically-Erasable Programmable Read-Only Memory) – A memory device whose contents can be electrically programmed by the designer. Additionally, the contents can be electrically erased, allowing the device to be reprogrammed.

Electrically-Erasable Programmable Read-Only Memory – *see EEPROM.*

Electromigration – **(1)** A process in which structures on an integrated circuit's substrate (particularly structures in deep sub-micron technologies) are eroded by the flow of electrons in much the same way as a river erodes land. **(2)** The process of forming transistor-like regions in a semiconductor using an intense magnetic field.

Electron Beam Epitaxy – *see EBE.*

Electron Beam Lithography – An integrated circuit fabrication process in which fine beams of electrons are used to draw extremely high-resolution patterns directly into the resist without the use of a mask.

Electrostatic Discharge – *see ESD.*

Emitter-Coupled Logic – *see ECL.*

Enzyme – One of numerous complex proteins that are produced by living cells and catalyze biochemical reactions at body temperatures.

EPROM (Erasable Programmable Read-Only Memory) – A memory device whose contents can be electrically programmed by the designer. Additionally, the contents can be erased by exposing the die to ultraviolet light through a quartz window mounted in the top of the component's package.

Equivalent Gate – A concept in which each type of logic function is assigned an equivalent gate value for the purposes of comparing functions and devices. However, the definition of an equivalent gate varies depending on whom you're talking to.

Equivalent Integrated Circuit – A concept used to compare the component density supported by diverse interconnection technologies such as circuit boards, hybrids, and multichip modules.

Erasable Programmable Read-Only Memory – *see EPROM.*

Error-Correcting Code – *see ECC.*

ESD (Electro-Static Discharge) – This refers to a charged person, or object, discharging static electricity, which can be generated in the process of moving around. Although the current associated with such a static charge is extremely low, the electric potential can be in the millions of volts and can severely damage electronic components. CMOS devices are particularly prone to damage from static electricity.

Etching – The process of selectively removing any material not protected by a resist using an appropriate solvent or acid. In some cases the unwanted material is removed using an electrolytic process.

Eutectic Bond – A bond formed when two pieces of metal, or metal-coated materials, are pressed together and vibrated at ultrasonic frequencies.

Extended Data Out – *see EDO.*

Face-Surface Mirror – A mirror in which the reflective coating is located on the face of the mirror, and not behind it as would be the case in the mirror you look into when you shave or apply your makeup (or both depending on how liberated you are).

Falling-Edge – *see Negative-Edge.*

Fan-In Via – *see Fan-Out Via.*

Fan-Out Via – In the case of surface mount devices, each component pad is usually connected by a short length of track to a via which forms a link to other conducting layers, and this via is known as a fan-out via. Some engineers attempt to differentiate vias that fall inside the device's footprint (under the body of the device) from vias that fall outside the device's footprint by referring to the former as *fan-in vias*, but this is not a widely used term.

Fast Page Mode – *see FPM.*

Femto – Unit qualifier (symbol = f) representing one thousandth of one millionth of one millionth, or 10^{-15}. For example, 3 fs stands for 3×10^{-15} seconds.

FET – A transistor whose control, or gate, signal creates an electro-magnetic field, which turns the transistor ON or OFF.

Field-Effect Transistor – *see FET.*

Field-Programmable Device – *see FPD.*

Field-Programmable Gate Array – *see FPGA.*

Field-Programmable Interconnect Chip – *see FPIC*[7].

Field-Programmable Interconnect Device – *see FPID.*

FIFO (First-In First-Out) – A memory device in which data is read out in the same order that it was written in.

Finite State Machine – *see FSM.*

Firmware – Refers to programs, or sequences of instructions, that are hard-coded into non-volatile memory devices.

First-In First Out – *see FIFO.*

Flash – *see Gold Flash.*

FLASH Memory – An evolutionary technology that combines the best features of the EPROM and E^2PROM technologies. The name FLASH is derived from the technology's fast reprogramming time compared to EPROM.

Flex – *see FPC.*

Flexible Printed Circuit – *see FPC.*

Flipped-Chip – A generic name for processes in which unpackaged integrated circuits are "flipped over" and mounted directly onto a substrate with their component sides facing the substrate.

Flipped-TAB – A combination of *flipped-chip* and *tape-automated bonding (TAB).*

Footprint – The area occupied by a device mounted on a substrate.

FPC (Flexible Printed Circuit) – A specialist circuit board technology, often abbreviated to "flex," in which tracks are printed onto flexible materials. There are a number of flavors of flex, including *static flex*, *dynamic flex*, and *rigid flex.*

FPD (Field Programmable Device) – A generic name that encompasses SPLDs, CPLDs, and FPGAs.

FPGA (Field-Programmable Gate Array) – A programmable logic device which is more versatile than traditional programmable devices such as PALs and PLAs, but less versatile than an *application-specific integrated circuit (ASIC).* Some field-programmable gate arrays use antifuses such as those found in programmable logic devices, while others are based on SRAM equivalents.

FPIC (Field-Programmable Interconnect Chip)[8] – An alternate, proprietary name for a *field-programmable interconnect device (FPID).*

FPID (Field-Programmable Interconnect Device) – A device used to connect logic devices together, and which can be dynamically reconfigured in the same way as standard SRAM-based FPGAs. Because each FPID may have around 1,000 pins, only a few such devices are typically required on a circuit board.

FPM (Fast Page Mode) – An asynchronous form of DRAM-based computer memory, which was popular for a while in the latter half of the 1990s. Along with other asynchronous memory techniques, FPM was eventually superceded by SDRAM technologies. *See also EDO, BEDO, and SDRAM.*

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[7] FPIC is a trademark of Aptix Corporation.

[8] FPIC is a trademark of Aptix Corporation.

FR4 – The most commonly used insulating base material for circuit boards. FR4 is made from woven glass fibers that are bonded together with an epoxy. The board is cured using a combination of temperature and pressure, which causes the glass fibers to melt and bond together, thereby giving the board strength and rigidity. The first two characters stand for "Flame Retardant" and you can count the number of people who know what the "4" stands for on the fingers of one hand. FR4 is technically a form of fiberglass, and some people do refer to these composites as *fiberglass boards* or *fiberglass substrates*, but not often.

Free-Space Optical Interconnect – A form of optical interconnect in which laser diode transmitters communicate directly with phototransistor receivers without employing optical fibers or optical waveguides.

FSM (Finite State Machine) – The actual implementation (in hardware or software) of a function that can be considered to consist of a finite set of states through which it sequences.

Full Custom – An application-specific integrated circuit in which the design engineers have complete control over every mask layer used to fabricate the device. The ASIC vendor does not provide a cell library or prefabricate any components on the substrate.

Functional Latency – Refers to the fact that, at any given time, only a portion of the logic functions in a device or system are typically active (doing anything useful).

Functional Test – A test strategy in which signals are applied to a circuit's inputs, and the resulting signals—which are observed on the circuit's outputs—are compared to known good values.

Fuse – *see Fusible-Link Technology*.

Fusible Link Technology – A programmable logic device technology that employs links called *fuses*. Individual fuses can be removed by applying pulses of relatively high voltage and current to the device's inputs.

Fuzz-Button – A small ball of fibrous gold used in one technique for attaching components such as multichip modules to circuit boards. Fuzz-buttons are inserted between the pads on the base of the package and their corresponding pads on the board. When the package is forced against the board, the fuzz-buttons compress to form good electrical connections. One of the main advantages of the fuzz-button approach is that it allows broken devices to be quickly removed and replaced. Even though fuzz-button technology would appear to be inherently unreliable, it is used in such devices as missiles, so one can only assume that it is fairly robust.

GaAs (Gallium Arsenide) – A 3:5 valence high-speed semiconductor formed from a mixture of gallium and arsenic. GaAs transistors can switch approximately eight times faster than their silicon equivalents. However, GaAs is hard to work with, which results in GaAs transistors being more expensive than their silicon cousins.

GAL (Generic Array Logic) – A variation on a PAL device from a company called Lattice Semiconductor Corporation.[9]

Gallium Arsenide – *see GaAs*.

Garbage-In Garbage-Out – *see GIGO*.

Gate Array – An application-specific integrated circuit in which the manufacturer prefabricates devices containing arrays of unconnected components

[9] GAL is a registered trademark of Lattice Semiconductor Corporation.

(transistors and resistors) organized in groups called *basic cells*. The designer specifies the function of the device in terms of cells from the cell library and the connections between them, and the manufacturer then generates the masks used to create the metalization layers.

Generic array logic – *see GAL*.

Geometry – Refers to the size of structures created on an integrated circuit. The structures typically referenced are the width of the tracks and the length of the transistor's channels; the dimensions of other features are derived as ratios of these structures.

Giga – Unit qualifier (symbol = G) representing one thousand million, or 10^9. For example, 3 GHz stands for 3×10^9 hertz.

GIGO (Garbage-In Garbage-Out) – An electronic engineer's joke, also familiar to the writers of computer programs.

Glue Logic – Simple logic gates used to interface more complex functions.

Gold Flash – An extremely thin layer of gold with a thickness measured on the molecular level, which is either electroplated or chemically plated[10] onto a surface.

Gray Code – A sequence of binary values in which each pair of adjacent values differs by only a single bit: for example, *00*, *01*, *11*, *10*.

Green Ceramic – Unfired, malleable ceramic.

Ground Plane – A conducting layer in, or on, a substrate providing a grounding, or reference, point for components. There may be several ground planes separated by insulating layers.

Guard Condition – A Boolean expression associated with a state transition in a state diagram or state table. The expression must be satisfied for that state transition to be executed.

Guided Probe – A form of functional test in which the operator is guided in the probing of a circuit to isolate a faulty component or track.

Guided Wave – A form of optical interconnect, in which optical waveguides are fabricated directly on the substrate of a multichip module. These waveguides can be created using variations on standard opto-lithographic thin-film processes.

Hard Macro (Macro Cell) – A logic function defined by the manufacturer of an *application-specific integrated circuit (ASIC)*. The function is described in terms of the simple functions provided in the cell library and the connections between them. The manufacturer also defines how the cells forming the macro will be assigned to basic cells and the routing of tracks between the basic cells.

Hardware – Generally understood to refer to any of the physical portions constituting an electronic system, including components, circuit boards, power supplies, cabinets, and monitors.

Hardware Description Language – *see HDL*.

HDL (Hardware Description Language) – Today's digital integrated circuits can end up containing millions of logic gates, and it simply isn't possible to capture and manage designs of this complexity at the schematic (circuit diagram) level. Thus, as opposed to using schematics, the functionality of a high-end integrated circuit is now captured in textual form using a *(HDL)*. The two most popular HDLs are Verilog and VHDL.

Hertz – *see Hz*.

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10 That is, using an electroless plating process.

Heterojunction – The interface between two regions of dissimilar semiconductor materials. The interface of a heterojunction has naturally occurring electric fields that can be used to accelerate electrons, and transistors created using heterojunctions can switch much faster than their homojunction counterparts of the same size.

Hexadecimal – Base-16 numbering system. Each hexadecimal digit can be directly mapped onto four binary digits, or bits.

High Impedance State – The state of a signal that is not currently being driven by anything. A high-impedance state is indicated by the 'Z' character.

Hologram – A three-dimensional image (from the Greek *holos*, meaning "whole" and *gram*, meaning "message").

Holographic Interconnect – A form of optical interconnect based on a thin slice of quartz, into which three-dimensional images are cut using a laser beam. Thus, the quartz is referred to as a *computer-generated hologram*, and this interconnection strategy is referred to as holographic.

Holography – The art of creating three-dimensional images known as holograms.

Homojunction – An interface between two regions of semiconductor having the same basic composition but opposing types of doping. Homojunctions dominate current processes because they are easier to fabricate than their *heterojunction* cousins.

Hybrid – An electronic sub-system in which a number of integrated circuits (packaged and/or unpackaged) and discrete components are attached directly to a common substrate. Connections between the components are formed on the surface of the substrate, and some components such as resistors and inductors may also be fabricated directly onto the substrate.

Hydrogen Bond – The electrons in a water molecule are not distributed equally, because the oxygen atom is a bigger, more robust fellow which grabs more than its fair share. The end result is that the oxygen atom has an overall negative charge, while the two hydrogen atoms are left feeling somewhat on the positive side. This unequal distribution of charge means that the hydrogen atoms are attracted to anything with a negative bias: for example, the oxygen atom of another water molecule. The resulting bond is known as a hydrogen bond.

Hz (hertz) – Unit of frequency. One hertz equals one cycle—or one oscillation—per second.

IC (Integrated Circuit) – A device in which components such as resistors, diodes, and transistors are formed on the surface of a single piece of semiconductor.

ICR (In-Circuit Reconfigurable)- An SRAM-based or similar component that can be dynamically reprogrammed on-the-fly while remaining resident in the system.

Idempotent Rules – Rules derived from the combination of a single Boolean variable with itself.

IDM (Integrated Device Manufacturer) – A company that focuses on designing and manufacturing integrated circuits as opposed to complete electronic systems.

Impedance – The resistance to the flow of current caused by resistive, capacitive, or inductive devices (or undesired parasitic elements) in a circuit.

In-Circuit Reconfigurable – *see ICR.*

Inclusion – A defect in a crystalline structure.

Inductance – A property of a conductor that allows it to store energy in a magnetic field which is induced by a current flowing through it. The base unit of inductance is the *Henry*.

Inert Gas – *see Noble Gas*.

In-System Programmable – *see ISP*.

Integrated Circuit – *see IC*.

Integrated Device Manufacturer – *see IDM*.

Intellectual Property – *see IP*.

Invar – An alloy similar to bronze.

Involution Rule – A rule that states that an even number of Boolean inversions cancel each other out.

Ion – A particle formed when an electron is added to, or subtracted from, a neutral atom or group of atoms.

Ion Implantation – A process in which beams of ions are directed at a semiconductor to alter its type and conductivity in certain regions.

IP (Intellectual Property) – When a team of electronics engineers is tasked with designing a complex integrated circuit, rather than "reinvent the wheel," they may decide to purchase the plans for one or more functional blocks that have already been created by someone else. The plans for these functional blocks are known as *intellectual property (IP)*. IP blocks can range all the way up to sophisticated communications functions and microprocessors. The more complex functions—like microprocessors—may be referred to as "cores."

ISP (In-System Programmable) – An E^2-based, FLASH-based, or similar component that can be reprogrammed while remaining resident on the circuit board.

JEDEC (Joint Electronic Device Engineering Council) – A council that creates, approves, arbitrates, and oversees industry standards for electronic devices. In programmable logic, the term JEDEC refers to a textual file containing information used to program a device. The file format is a JEDEC-approved standard and is commonly referred to as a *JEDEC file*.

Jelly Bean Device – An integrated circuit containing a small number of simple logic functions.

Joint Electronic Device Engineering Council – *see JEDEC*.

Jumper – A small piece of wire used to link two tracks on a circuit board.

Karnaugh Map – A graphical technique for representing a logical function. Karnaugh maps are often useful for the purposes of minimization.

Kelvin Scale of Temperature – A scale of temperature that was invented by the British mathematician and physicist William Thomas, first Baron of Kelvin. Under the *Kelvin*, or *absolute*, scale of temperature, 0K (corresponding to –273°C) is the coldest possible temperature and is known as *absolute zero*.

Kilo – Unit qualifier (symbol = K) representing one thousand, or 10^3. For example, 3 KHz stands for 3×10^3 hertz.

Kipper – A fish cured by smoking and salting.[11]

Latch-Up Condition – A condition in which a circuit draws uncontrolled amounts of current, and certain voltages are forced, or "latched-up," to some level. Particularly relevant in the case of CMOS devices, which can latch-up if their operating conditions are violated.

Laminate – A material constructed from thin layers or sheets. Often used in the context of circuit boards.

Large-Scale Integration – *see LSI*.

[11] Particularly tasty as a breakfast dish.

Laser Diode – A special semiconductor diode that emits a beam of coherent light.

Last-In First-Out – *see LIFO.*

Lateral Thermal Conductivity – Good lateral thermal conductivity means that the heat generated by components mounted on a substrate can be conducted horizontally across the substrate and out through its leads.

Lead – (1) A metallic element (chemical symbol Pb). **(2)** A metal conductor used to provide a connection from the inside of a device package to the outside world for soldering or other mounting techniques. Leads are also commonly called *pins*.

Lead Frame – A metallic frame containing leads (pins) and a base to which an unpackaged integrated circuit is attached. Following encapsulation, the outer part of the frame is cut away and the leads are bent into the required shapes.

Lead Through-Hole – *see LTH.*

Least-Significant Bit – *see LSB.*

Least-Significant Byte – *see LSB.*

LED (Light-Emitting Diode) – A semiconductor diode that behaves in a similar manner to a normal diode except that, when turned on, it emits light in the visible or infrared (IR) regions of the electromagnetic spectrum.

Level-Sensitive – An input whose effect on a function depends only on its current logic value or level, and is not directly related to it transitioning from one logic value to another.

LFSR (Linear Feedback Shift Register) – A shift register whose data input is generated as an XOR or XNOR of two or more elements in the register chain

LIFO (Last-in First-Out) – A memory device in which data is read out in the reverse order to which it was written in.

Light-Emitting Diode – *see LED.*

Line – Used to refer to the width of a track: for example, *"This circuit board track has a line-width of 5 mils (five thousandths of an inch)."*

Linear Feedback Shift Register – *see LFSR.*

Literal – A variable (either true or inverted) in a Boolean equation.

Low-Fired Cofired – Similar in principle to standard cofired ceramic substrate techniques. However, low-fired cofired uses modern ceramic materials with compositions that allow them to be fired at temperatures as low as 850°C. Firing at these temperatures in an inert atmosphere such as nitrogen allows non-refractory metals such as copper to be used to create tracks.

Logic Function – A mathematical function that performs a digital operation on digital data and returns a digital value.

Logic Gate – The physical implementation of a logic function.

Logic Synthesis – A process in which a program is used to automatically convert a high-level textual representation of a design (specified using a *hardware description language (HDL)* at the *register transfer level (RTL)* of abstraction) into equivalent Boolean Equations (like the ones introduced in Chapter 9). The synthesis tool automatically performs simplifications and minimizations, and eventually outputs a gate-level netlist.

LSB – (1) (Least Significant Bit) The binary digit, or bit, in a binary number that represents the least significant value (typically the right-hand bit). **(2) (Least Significant Byte)** – The byte in a multi-byte word that represents the least significant values (typically the right-hand byte).

LSI (Large Scale Integration) – Refers to the number of logic gates in a device. By one convention, large-scale integration represents a device containing 100 to 999 gates.

LTH (Lead Through-Hole) – A technique for populating circuit boards in which component leads are inserted into plated through-holes. Often abbreviated to "through-hole" or "thru-hole." When all of the components have been inserted, they are soldered to the board, usually using a wave soldering technique.

Macro Cell – *see Hard Macro.*

Macro Function – *see Soft Macro.*

Magnetic Random Access Memory – *see MRAM.*

Magnetic Tunnel Junction – *see MTJ.*

Mask – *see Optical Mask.*

Mask Programmable – A device such as a read-only memory, which is programmed during its construction using a unique set of masks.

Maximal Displacement – A linear feedback shift register whose taps are selected such that changing a single bit in the input data stream will cause the maximum possible disruption to the register's contents.

Maximal Length – A linear feedback shift register that sequences through $(2^n - 1)$ states before returning to its original value.

Max's Algorithm – A never-before-seen-in-public, soon-to-be-famous, mind bogglingly convoluted algorithm for automatically extracting Reed-Müller expressions.

Maxterm – The logical OR of the inverted variables associated with an input combination to a logical function.

MBE (Molecular Beam Epitaxy) – A technique for creating thin films on substrates in precise patterns, in which the substrate is placed in a high vacuum, and a guided beam of ionized molecules is fired at it, effectively allowing molecular-thin layers to be "painted" onto the substrate where required.

MCM (Multichip Module) – A generic name for a group of advanced interconnection and packaging technologies featuring unpackaged integrated circuits mounted directly onto a common substrate.

Medium-Scale Integration – *see MSI.*

Mega – Unit qualifier (symbol = M) representing one million, or 10^6. For example, 3 MHz stands for 3×10^6 hertz.

Memory Cell – A unit of memory used to store a single binary digit, or bit, of data.

Memory Word – A number of memory cells logically and physically grouped together. All the cells in a word are typically written to, or read from, at the same time.

Metalization Layer – A layer of conducting material on an integrated circuit that is selectively deposited or etched to form connections between logic gates. There may be several metalization layers separated by dielectric (insulating) layers.

Metal-Oxide Semiconductor – *see MOS.*

Meta-Stable – A condition where the outputs of a logic function are oscillating uncontrollably between undefined values.

Micro – Unit qualifier (symbol =μ) representing one millionth, or 10^{-6}. For example, 3 μS stands for 3×10^{-6} seconds.

Microcontroller (μC) – A microprocessor augmented with special-purpose inputs, outputs, and control logic like counter-timers.

Microprocessor (μP) – A general-purpose computer implemented on a single

integrated circuit (or sometimes on a group of related chips called a *chipset*).

Microwire[12] – A trade name for one incarnation of *discrete wire technology*. Microwire augments the main attributes of multiwire with laser-drilled blind vias, allowing these boards to support the maximum number of tracks and components.

Milli – Unit qualifier (symbol = m) representing one thousandth, or 10^{-3}. For example, 3 ms stands for 3×10^{-3} seconds.

Minimization – The process of reducing the complexity of a Boolean expression.

Minterm – The logical AND of the variables associated with an input combination to a logical function.

Mixed-signal – Typically refers to an integrated circuit that contains both analog and digital elements.

Mod – *see Modulus*.

Modulus – Refers to the number of states that a function such as a counter will pass through before returning to its original value. For example, a function that counts from 0000_2 to 1111_2 (0 to 15 in decimal) has a modulus of 16 and would be called a modulo-16 or mod-16 counter.

Modulo – *see Modulus*.

Molecular Beam Epitaxy – *see MBE*.

Moore's Law – In 1965, Gordon Moore (who was to co-found Intel Corporation in 1968) noted that new generations of memory devices were released approximately every 18 months, and that each new generation of devices contained roughly twice the capacity of its predecessor. This observation subsequently became known as *Moore's Law*, and it has been applied to a wide variety of electronics trends.

MOS (Metal-Oxide Semiconductor) – A family of transistors.

Most-Significant Bit – *see MSB*.

Most-Significant Byte – *see MSB*.

Motherboard – A backplane containing active components such as integrated circuits.

MRAM (Magnetic RAM) – A form of memory expected to come online circa 2003 to 2004 that has the potential to combine the high speed of SRAM, the storage capacity of DRAM, and the non-volatility of FLASH, while consuming very little power.

MSB – (1) (Most Significant Bit) The binary digit, or bit, in a binary number that represents the most significant value (typically the left-hand bit). **(2) (Most Significant Byte)** The byte in a multi-byte word that represents the most significant values (typically the left-hand byte).

MSI Medium Scale Integration) – Refers to the number of logic gates in a device. By one convention, medium-scale integration represents a device containing 13 to 99 gates.

MTJ (Magnetic Tunnel Junction) – A sandwich of two ferromagnetic layers separated by a thin insulating layer. An MRAM memory cell is created by the intersection of two wires (say a "row" line and a "column" line) with an MJT sandwiched between them.

Multichip Module – *see MCM*.

Multilayer – A printed circuit board constructed from a number of very thin single-sided and/or double-sided boards,

[12] Microwave is a registered trademark of Advanced Interconnection Technology (AIT), Islip, New York, USA.

which are bonded together using a combination of temperature and pressure.

Multiplexer (digital) – A logic function that uses a binary value, or address, to select between a number of inputs and conveys the data from the selected input to the output.

Multiwire[13] – A trade name for the primary incarnation of discrete wire technology.

Nano – Unit qualifier (symbol = n) representing one thousandth of one millionth, or 10^{-9}. For example, 3 ns stands for 3×10^{-9} seconds.

Nanobot – A molecular-sized robot. *See also Nanotechnology*.

Nanophase Materials – A form of matter that was only (relatively) recently discovered, in which small clusters of atoms form the building blocks of a larger structure. These structures differ from those of naturally occurring crystals, in which individual atoms arrange themselves into a lattice.

Nanotechnology – This is an elusive term that is used by different research-and-development teams to refer to whatever it is that they're working on at the time. However, regardless of their area of interest, nanotechnology always refers to something extremely small. Perhaps the "purest" form of nanotechnology is that of molecular-sized units that assemble themselves into larger products.

Nanotubes – A structure that may be visualized as taking a thin sheet of carbon and rolling it into a tube. Nanotubes can be formed with walls that are only one atom thick. The resulting tube has a diameter of 1 nano (one thousandth of one millionth of a meter). Nanotubes are an almost ideal material: they are stronger than steel, have excellent thermal stability, and they are also tremendous conductors of heat and electricity. In addition to acting as wires, nanotubes can be persuaded to act as transistors—this means that we now have the potential to replace silicon transistors with molecular-sized equivalents at a level where standard semiconductors cease to function.

Negative-Edge – Beware, here be dragons! In this book a *negative-edge* is defined as a transition from a logic 1 to a logic 0. This definition is therefore consistent with the other definitions used throughout the book, namely those for *active-high*, *active-low*, *assertion-level logic*, *positive-logic*, and *negative-logic*. It should be noted, however, that some would define a negative-edge as *"a transition from a higher to a lower voltage level, passing through a threshold voltage level."* However, this definition serves only to cause confusion when combined with negative-logic implementations.

Negative Ion – An atom or group of atoms with an extra electron.

Negative Logic – A convention dictating the relationship between logical values and the physical voltages used to represent them. Under this convention, the more negative potential is considered to represent TRUE and the more positive potential is considered to represent FALSE.

Negative Resist – A process in which ultraviolet radiation passing through the transparent areas of a mask causes the resist to be cured. The uncured areas are then removed using an appropriate solvent.

Negative-True – *see Negative Logic*.

Nibble – *see Nybble*.

[13] Multiwire is a registered trademark of Advanced Interconnection Technology (AIT), Islip, New York, USA

NMOS (N-channel MOS) – Refers to the order in which the semiconductor is doped in a MOS device. That is, which structures are constructed as N-type versus P-type material.

Noble Gas – Gases whose outermost electron shells are completely filled with electrons. Such gases are extremely stable and it is difficult to coerce them to form compounds with other elements. There are six noble gasses: helium,[14] neon, argon, krypton, xenon, and radon. This group of elements was originally known as the *inert gasses*, but in the early 1960s it was found to be possible to combine krypton, xenon, and radon with fluorine to create compounds. Although helium, neon, and argon continue to resist, there is an increasing trend to refer to this group of gasses as *noble* rather than *inert*.

Noble Metal – Metals such as gold, silver, and platinum that are extremely inactive and are unaffected by air,[15] heat, moisture, and most solvents.

Noise – The miscellaneous rubbish that gets added to a signal on its journey through a circuit. Noise can be caused by capacitive or inductive coupling, or from externally generated electromagnetic interference.

Non-recurring Engineering – *see NRE.*

Non-Volatile – A memory device that does not lose its data when power is removed from the system.

Non-Volatile RAM – A device which is generally formed from an SRAM die mounted in a package with a very small battery, or as a mixture of SRAM and E^2PROM cells fabricated on the same die.

NPN (N-type – P-type – N-type) – Refers to the order in which the semiconductor is doped in a bipolar junction transistor.

NRE (Non-Recurring Engineering) – This typically refers to the costs associated with developing an ASIC or ASSP. The NRE depends on a number of factors, including the complexity of the design, the style of packaging, and who does what in the design flow (that is, how the various tasks are divided between the system design house and the ASIC vendor).

N-type – A piece of semiconductor doped with impurities that make it amenable to donating electrons.

Nybble – A group of four binary digits, or bits.

Octal – Base-8 numbering system. Each octal digit can be directly mapped onto three binary digits, or bits.

Ohm – Unit of resistance. The Greek letter omega, Ω, is often used to represent ohms; for example, 1 MΩ indicates one million ohms.

One-Hot Encoding – A form of state assignment for state machines in which each state is represented by an individual state variable.

One-Time Programmable – A device such as a PAL, PLA, or PROM that can be programmed a single time and whose contents cannot be subsequently erased.

Operating System – The collective name for the set of master programs that control the core operation and the base-level user-interface of a computer.

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14 The second most common element in the universe (after hydrogen).

15 Before you start penning letters of protest, silver can be attacked by sulfur and sulfides, which occur naturally in the atmosphere. Thus, the tarnishing seen on your mother's silver candlesticks is actually silver sulfide and not silver oxide.

Optical Interconnect – The generic name for interconnection strategies based on opto-electronic systems, including *fiber-optics*, *free-space*, *guided-wave*, and *holographic* techniques.

Optical Lithography – A process in which radiation at optical wavelengths (usually in the *ultraviolet (UV)* and *extreme ultraviolet (EUV)* ranges) is passed through a mask, and the resulting patterns are projected onto a layer of resist coating the substrate material.

Optical Mask – A sheet of material carrying patterns that are either transparent or opaque to the wavelengths used in an optical-lithographic process. Such a mask can carry millions of fine lines and geometric shapes.

Opto-Electronic – Refers to a system which combines optical and electronic components.

Organic Resist – A material that is used to coat a substrate and is then selectively cured to form an impervious layer. These materials are called *organic* because they are based on carbon compounds as are living creatures.

Organic Solvent – A solvent for organic materials such as those used to form organic resists.

Organic Substrate – Substrate materials such as FR4, in which woven glass fibers are bonded together with an epoxy. These materials are called *organic* because epoxies are based on carbon compounds as are living creatures.

Overglassing – One of the final stages in the integrated circuit fabrication process in which the entire surface of the wafer is coated with a layer of silicon dioxide or silicon nitride. This layer may also be referred to as the *barrier layer* or the *passivation layer*. An additional lithographic step is required to pattern holes in this layer to allow connections to be made to the pads.

Padcap – A special flavor of circuit board used for high-reliability military applications, also known as *pads-only-outer-layers*. Distinguished by the fact that the outer surfaces of the board have pads but no tracks. Signal layers are only created on the inner planes, and tracks are connected to the surface pads by vias.

Pad – An area of metalization on a substrate used for probing or to connect to a via, plated through-hole, or an external interconnect.

Pad Grid Array – *see PGA.*

Pad Stack – Refers to any *pads*, *anti-pads*, and *thermal relief pads* associated with a via or a plated through-hole as it passes through the layers forming the substrate.

PAL (Programmable Array Logic)[16] – A programmable logic device in which the AND array is programmable but the OR array is predefined. *See also PLA, PLD, and PROM.*

Parallel-In Serial-Out – *see PISO.*

Parasitic Effects – The effects caused by undesired resistive, capacitive, or inductive elements inherent in the material or topology of a track or component.

Passivation Layer – *see Overglassing.*

Passive Trimming – A process in which a laser beam is used to trim components such as thick-film and thin-film resistors on an otherwise unpopulated and unpowered hybrid or multichip module substrate. Probes are placed at each end of a component to monitor its value while the laser cuts away (evaporates) some of the material forming the component.

16 PAL is a registered trademark of Monolithic Memories, Inc.

Pass-Transistor Logic – A technique for connecting MOS transistors such that data signals pass between their source and drain terminals. Pass-transistor logic minimizes the number of transistors required to implement a function, and is typically employed by designers of cell libraries or full-custom integrated circuits.

PC100 – A popular form of SDRAM-based computer memory that runs at 100 MHz (the data bus is 64-bits wide, although 128-bit wide versions (using dual 64-bit cards in parallel) have been used in high-end machines).

PC133 – A popular form of SDRAM-based computer memory that runs at 133 MHz (the data bus is 64-bits wide, although 128-bit wide versions (using dual 64-bit cards in parallel) have been used in high-end machines).

PCB (Printed Circuit Board) – A type of circuit board that has conducting tracks superimposed, or "printed," on one or both sides, and may also contain internal signal layers and power and ground planes. An alternative name, *printed wire board (PWB)*, is commonly used in America.

Peta – Unit qualifier (symbol = P) representing one thousand million million, or 10^{15}. For example, 3 PHz stands for 3×10^{15} hertz.

PGA (1) (Pad Grid Array) – A packaging technology in which a device's external connections are arranged as an array of conducting pads on the base of the package. **(2) (Pin Grid Array)** – A packaging technology in which a device's external connections are arranged as an array of conducting leads, or pins, on the base of the package.

PHB (Photochemical Hole Burning) – An optical memory technique, in which a laser in the visible waveband is directed at a microscopic point on the surface of a slice of glass that has been doped with organic dyes or rare-earth elements. The laser excites electrons in the glass such that they change the absorption characteristics of that area of the glass and leave a *band*, or *hole*, in the absorption spectrum.

Photochemical Hole Burning – *see PHB.*

Phototransistor – A special transistor that converts an optical input in the form of light into an equivalent electronic signal in the form of a voltage or current.

Pico – Unit qualifier (symbol = p) representing one millionth of one millionth, or 10^{-12}. For example, 3 ps stands for 3×10^{-12} seconds.

Pin – *see Lead.*

Pin Grid Array – *see PGA.*

PISO (Parallel-In Serial Out) – Refers to a shift register in which the data is loaded in parallel and read out serially.

PLA (Programmable Logic Array) – The most user-configurable of the traditional programmable logic devices, because both the AND and OR arrays are programmable. *See also PAL, PLD, and PROM.*

Place Value – Refers to a numbering system in which the value of a particular digit depends both on the digit itself and its position in the number.

Plasma – A gaseous state in which the atoms or molecules are dissociated to form ions.

Plated Through-Hole – *see PTH.*

PLD (Programmable Logic Device) – The generic name for a device constructed in such a way that the designer can configure, or "program" it to perform a specific function. *See also PAL, PLA, and PROM.*

PMOS (P-channel MOS) – Refers to the order in which the semiconductor is

doped in a MOS device. That is, which structures are constructed as P-type versus N-type material.

PNP (P-type – N-type – P-type) – Refers to the order in which the semiconductor is doped in a bipolar junction transistor.

Polysilicon Layer – An internal layer in an integrated circuit used to create the gate electrodes of MOS transistors. In addition to forming gate electrodes, the polysilicon layer can also be used to interconnect components. There may be several polysilicon layers separated by dielectric (insulating) layers.

Populating – The act of attaching components to a substrate.

Positive-Edge – Beware, here be dragons! In this book a *positive-edge* is defined as a transition from a logic 0 to a logic 1. This definition is therefore consistent with the other definitions used throughout the book, namely those for *active-high*, *active-low*, *assertion-level logic*, *positive-logic*, and *negative-logic*. It should be noted, however, that some would define a positive-edge as *"a transition from a lower to a higher voltage level, passing through a threshold voltage level."* However, this definition serves only to cause confusion when combined with negative-logic implementations.

Positive Ion – An atom or group of atoms lacking an electron.

Positive Logic – A convention that dictates the relationship between logical values and the physical voltages used to represent them. Under this convention, the more positive potential is considered to represent TRUE and the more negative potential is considered to represent FALSE.

Positive Resist – A process in which radiation passing through the transparent areas of a mask causes previously cured resist to be degraded. The degraded areas are then removed using an appropriate solvent.

Positive-True – *see Positive Logic.*

Power Plane – A conducting layer in or on the substrate providing power to the components. There may be several power planes separated by insulating layers.

Precedence of Operators – Determines the order in which operations are performed. For example, in standard arithmetic the multiplication operator has a higher precedence than the addition operator. Thus, in the equation $6 + 2 \times 3$, the multiplication is performed before the addition and the result is 12. Similarly, in Boolean Algebra, the AND operator has a higher precedence than the OR operator.

Prepreg – Non-conducting semi-cured layers of FR4 used to separate conducting layers in a multilayer circuit board.

Primitives – Simple logic functions such as BUF, NOT, AND, NAND, OR, NOR, XOR, and XNOR. These may also be referred to as *primitive logic gates*.

Printed Circuit Board – *see PCB.*

Printed Wire Board – *see PWB.*

Product-of-Sums – A Boolean equation in which all of the *maxterms* corresponding to the lines in the truth table for which the output is a logic 0 are combined using AND operators.

Product Term – A set of literals linked by an AND operator.

Programmable Array Logic – *see PAL.*

Programmable Logic Array – *see PLA.*

Programmable Logic Device – *see PLD.*

Programmable Read-Only Memory – *see PROM.*

PROM (Programmable Read-Only Memory) – A programmable logic device in which the OR array is programmable but the AND array is predefined. Usually considered to be a memory device whose contents can be electrically programmed (once) by the designer. *See also PAL, PLA, and PLD.*

Proposition – A statement that is either true or false with no ambiguity. For example, the proposition *"I just tipped a bucket of burning oil into your lap"* is either true or false, but there's no ambiguity about it.

Protein – A complex organic molecule formed from chains of amino acids, which are themselves formed from combinations of certain atoms, namely: carbon, hydrogen, nitrogen, oxygen, usually sulfur, and occasionally phosphorous or iron. Additionally, the chain of amino acids *"folds in on itself,"* thereby forming an extremely complex three-dimensional shape. Organic molecules have a number of useful properties, not the least of which is that their structures are intrinsically *"self healing"* and reject contamination. Also, in addition to being extremely small, many organic molecules have excellent electronic properties. Unlike metallic conductors, they transfer energy by moving electron excitations from place to place rather than relocating entire electrons. This can result in switching speeds that are orders of magnitude faster than their semiconductor equivalents.

Protein Memory – A form of memory based on organic proteins. *See also Protein.*

Protein Switch – A form of switch based on organic proteins. *See also Protein.*

Pseudo-Random – An artificial sequence of values that give the appearance of being random, but which are also repeatable.

PTH (Plated Through-Hole) – (1) A hole in a double-sided or multilayer board that is used to accommodate a through-hole component lead and is plated with copper. **(2)** An alternative name for the *lead through-hole (LTH)* technique for populating circuit boards in which component leads are inserted into plated through-holes.

P-type – A piece of semiconductor doped with impurities that make it amenable to accepting electrons.

PWB (Printed Wire Board) – A type of circuit board that has conducting tracks superimposed, or "printed," on one or both sides, and may also contain internal signal layers and power and ground planes. An alternative name, *printed circuit board (PCB)*, is predominantly used in Europe and Asia.

QDR (Quad Data Rate) – A modern form of SDRAM-based memory. The original SDRAM specification was based on using one of the clock edges only (say the rising edge) to read/write data out-of/into the memory. QDR refers to memory that has separate data in and data out busses both designed in such a way that data can be read/written on both edges of the clock. This effectively quadruples the amount of data that can be pushed through the system without increasing the clock frequency (like many things this sounds simple if you say it fast, but making this work is trickier than it may at first appear). *See also DDR and SDRAM.*

QFP (Quad Flat Pack) – The most commonly used package in surface mount technology to achieve a high lead count in a small area. Leads are presented on all four sides of a thin square package.

Quad Date Rate – *see QDR.*

Quad Flat Pack – *see QFP.*

Quantization – Part of the process by which an analog signal is converted into a series of digital values. First of all the analog signal is sampled at specific times.

For each sample, the complete range of values that the analog signal can assume is divided into a set of discrete bands or quanta. Quantization refers to the process of determining which band the current sample falls into. *See also Sampling.*

Quinary – Base-5 numbering system.

Radix – Refers to the number of digits in a numbering system. For example, the decimal numbering system is said to be radix-10. May also be referred to as the "base."

RAM (Random Access Memory) – A data-storage device from which data can be read out and new data can be written in. Unless otherwise indicated, the term RAM is typically taken to refer to a semiconductor device in the form of an integrated circuit.

Rambus[17] – An alternative computer memory concept that began to gain attention toward the end of the 1990s (this is based on core DRAM concepts presented in a cunning manner). By around 2000, personal computers equipped with memory modules formed from Rambus DRAM (RDRAM) devices were available. These memory modules were 16-bits (2-bytes) wide, and were accessed on both edges of a 400 MHz clock, thereby providing a peak data throughput of $2 \times 2 \times 400 = 1{,}600$ megabytes per second (these are officially quoted as 800 MHz devices, but that's just marketing spin trying to make clocking on both edges of a 400 MHz clock sound more impressive).

In the summer of 2002, a new flavor of Rambus was announced with a 32-bit wide bus using both edges of a 533 MHz clock (the official announcements quote "*1,066 MHz Rambus DRAM*," but this is the same marketing spin as noted above). Whatever, this will provide a peak bandwidth of 4,200 megabytes per second.

Random-Access Memory – *see RAM.*

RDRAM (Rambus DRAM) – A form of DRAM computer memory based on Rambus technology. *See also Rambus.*

Read-Only Memory – *see ROM.*

Read-Write Memory – *see RWM.*

Real Estate – Refers to the amount of area available on a substrate.

Reconfigurable Hardware – A product whose function may be customized many times. *See also Configurable Hardware, Remotely Reconfigurable Hardware, Dynamically Reconfigurable Hardware, and Virtual Hardware.*

Reed-Müller Logic – Logic functions implemented using only XOR and XNOR gates.

Reflow Oven – An oven employing infrared (IR) radiation or hot air.

Reflow Soldering – A *surface mount technology* process in which the substrate and attached components are passed through a reflow oven to melt the solder paste.

Refractory Metal – Metals such as *tungsten*, *titanium*, and *molybdenum* (try saying this last one quickly), which are capable of withstanding extremely high, or refractory, temperatures.

Register Transfer Level – *see RTL.*

Remotely Reconfigurable Hardware – A product whose function may be customized remotely, by telephone or radio, while remaining resident in the system. *See also Configurable Hardware, Reconfigurable Hardware, Dynamically Reconfigurable Hardware, and Virtual Hardware.*

[17] Rambus is a trademark of Rambus Inc.

Resist – A material that is used to coat a substrate and is then selectively cured to form an impervious layer.

Resistor-Transistor Logic – *see RTL.*

Rigid Flex – Hybrid constructions which combine standard rigid circuit boards with flexible printed circuits (flex), thereby reducing the component count, weight, and susceptibility to vibration of the circuit, and greatly increasing its reliability.

RIMM – This really doesn't stand for anything per se, but it is the trademarked name for a *Rambus* memory module. RIMMs are similar in concept to DIMMs, but have a different pin count and configuration. *See also DIMM and SIMM.*

Rising-Edge – *see Positive-Edge.*

ROM (Read-Only Memory) – A data storage device from which data can be read out, but new data cannot be written in. Unless otherwise indicated, the term ROM is typically taken to refer to a semiconductor device in the form of an integrated circuit.

RTL – (1) (Register Transfer Level) – A relatively high level of abstraction at which design engineers capture the functionality of digital integrated circuit designs described using a *hardware description language (HDL).* **(2) (Resistor-Transistor Logic)** – Logic gates implemented using particular configurations of resistors and bipolar junction transistors. For the majority of today's designers, resistor-transistor logic is of historical interest only.

RWM (Read-Write Memory) – Alternative (and possibly more appropriate) name for a *random access memory (RAM).*

Sampling – Part of the process by which an analog signal is converted into a series of digital values. Sampling refers to observing the value of the analog signal at specific times. *See also Quantization.*

Scalar Notation – A notation in which each signal is assigned a unique name; for example, *a3*, *a2*, *a1*, and *a0*. *See also Vector Notation.*

Scaling – A technique for making transistors switch faster by reducing their size. This strategy is known as *scaling*, because all of the transistor's features are typically reduced by the same proportion.

Schematic – Common name for a circuit diagram.

Scrubbing – The process of vibrating two pieces of metal (or metal-coated materials) at ultrasonic frequencies to create a friction weld.

SDRAM (Synchronous DRAM) – Until the latter half of the 1990s, DRAM-based computer memories were asynchronous, which means they weren't synchronized to the system clock. Over time, the industry migrated to *synchronous DRAM (SDRAM)*, which is synchronized to the system clock and makes everyone's lives much easier. Note that SDRAM is based on core DRAM concepts – it's all in the way you tweak the chips and connect them together.

Sea-of-Cells – Popular name for a channelless gate array.

Sea-of-Gates – Popular name for a channelless gate array.

Seed Value – An initial value loaded into a linear feedback shift register or random number generator.

Semiconductor – A special class of material that can exhibit both conducting and insulating properties.

Sensor – A transducer that detects a physical quantity and converts it into a form suitable for processing. For example, a microphone is a sensor that detects sound and converts it into a corresponding voltage or current.

Sequential – A function whose output value depends not only on its current input values, but also on previous input values. That is, the output value depends on a sequence of input values.

Serial-In Parallel-Out – *see SIPO.*

Serial-In Serial-Out – *see SISO.*

Sexagesimal – Base-60 numbering system.

Side-Emitting Laser Diode – A laser diode constricted at the edge of an integrated circuit's substrate such that, when power is applied, the resulting laser beam is emitted horizontally: that is, parallel to the surface of the substrate.

Signal Conditioning – Amplifying, filtering, or otherwise processing a (typically analog) signal.

Signal Layer – A layer carrying tracks in a circuit board, hybrid, or multichip module. *See also Wiring Layer.*

Signature – Refers to the *checksum* value from a *cyclic-redundancy-check (CRC)* when used in the guided-probe form of functional test.

Signature Analysis – A guided-probe functional-test technique based on *signatures.*

Sign Bit – The most significant binary digit, or bit, of a signed binary number (if set to a logic 1, this bit represents a negative quantity).

Signed Binary Number – A binary number in which the most-significant bit is used to represent a negative quantity. Thus, a signed binary number can be used to represent both positive and negative values.

Sign-Magnitude – Negative numbers in standard arithmetic are typically represented in sign-magnitude form by prefixing the value with a minus sign: for example, –27. For reasons of efficiency, computers rarely employ the sign-magnitude form. Instead, they use *signed binary numbers* to represent negative values.

Silicon Bumping – The process of depositing additional metalization on a die's pads to raise them fractionally above the level of the *barrier layer.*

Silicon Chip – Although a variety of semiconductor materials are available, the most commonly used is silicon, and integrated circuits are popularly known as *silicon chips*, or simply *chips.*

Silicon Compiler – The program used in compiled cell technology to generate the masks used to create components and interconnections. May also be used to create datapath functions and memory functions.

SIMM (Single In-line Memory Module) – A single memory integrated circuit can only contain a limited amount of data, so a number are gathered together onto a small circuit board called a *memory module.* Each memory module has a line of gold-plated pads on both sides of one edge of the board. These pads plug into a corresponding connector on the main computer board. A *single in-line memory module (SIMM)* has the same electrical signal on corresponding pads on the front and back of the board (that is, the pads on opposite sides of the board are "tied together"). *See also DIMM and RIMM.*

Simple PLD – *see SPLD.*

Single In-line Memory Module – *see SIMM.*

Single-Sided – A printed circuit board with tracks on one side only.

Sintering – A process in which ultra-fine metal powders weld together at temperatures much lower than those required for larger pieces of the same materials.

SIPO (Serial-In Parallel-Out) – Refers to a shift register in which the data is loaded in serially and read out in parallel.

SISO (Serial-In Serial-Out) – Refers to a shift register in which the data is both loaded in and read out serially.

Skin Effect – In the case of high frequency signals, electrons are only conducted on the outer surface, or skin, of a conductor. This phenomenon is known as the *skin effect*.

Small-Scale Integration – *see SSI*.

SMD (Surface Mount Device) – A component whose packaging is designed for use with *surface mount technology*.

SMT (Surface Mount Technology) – A technique for populating hybrids, multi-chip modules, and circuit boards, in which packaged components are mounted directly onto the surface of the substrate. A layer of solder paste is screen-printed onto the pads, and the components are attached by pushing their leads into the paste. When all of the components have been attached, the solder paste is melted using either *reflow soldering* or *vapor-phase soldering*.

SMOBC (Solder Mask Over Bare Copper) – A technique in which the *solder mask* is applied in advance of the *tin-lead plating*. This prevents solder from leaking under the mask when the tin-lead alloy melts during the process of attaching components to the board.

SoC (System-on-Chip) – In the past, an electronic system was typically composed of a number of integrated circuits, each with its own particular function (say a microprocessor, a communications function, some memory devices, etc.). For many of today's high-end applications, however, electronics engineers are combining all of these functions on a single device, which may be referred to as a *system-on-chip (SoC)*.

Soft Macro (Macro Function) – A logic function defined by the manufacturer of an *application-specific integrated circuit (ASIC)* or by a third-party IP provider. The function is described in terms of the simple functions provided in the cell library and connections between them. The assignment of cells to basic cells and the routing of the tracks is determined at the same time, and using the same tools, as for the other cells specified by the designer.

Software – Refers to intangible programs, or sequences of instructions, that are executed by *hardware*.

Solder – An alloy of tin and lead with a comparatively low melting point used to join less fusible metals. Typical solder contains 60% tin and 40% lead; increasing the proportion of lead results in a softer solder with a lower melting point, while decreasing the proportion of lead results in a harder solder with a higher melting point. Note that the solder used in a brazing process is of a different type, being a hard solder with a comparatively high melting point composed of an alloy of copper and zinc (brass).

Solder Bump Bonding – A flip-chip technique (also known as *Solder Bumping*) for attaching a die to a package substrate. A minute ball of solder is attached to each pad on the die, and the die is flipped over and attached to the package substrate. Each pad on the die has a corresponding pad on the package substrate, and the package-die combo is heated so as to melt the solder balls and form good electrical connections between the die and the substrate. *See also Solder Bumping*.

Solder Bumping – A flipped chip technique (also known as *Solder Bump Bonding*) in which spheres of solder are formed on the die's pads. The die is flipped and the solder bumps are brought into contact with corresponding pads on the substrate. When all the chips have

been mounted on the substrate, the solder bumps are melted using reflow soldering or vapor-phase soldering. *See also Solder Bump Bonding.*

Solder Mask – A layer applied to the surface of a printed circuit board that prevents solder from sticking to any metalization except where holes are patterned into the mask.

Solder Mask Over Bare Copper – *see SMOBC.*

Space – Used to refer to the width of the gap between adjacent tracks.

SPLD (Simple PLD) – Originally all PLDs contained a modest number of equivalent logic gates and were fairly simple. As more *complex PLDs (CPLDs)* arrived on the scene, however, it became common to refer to their simpler cousins as *simple PLDs (SPLDs).*

SRAM (Static RAM) – A memory device in which each cell is formed from four or six transistors configured as a latch or a flip-flop. The term *static* is used because, once a value has been loaded into an SRAM cell, it will remain unchanged until it is explicitly altered or until power is removed from the device.

SSI (Small Scale Integration) – Refers to the number of logic gates in a device. By one convention, small-scale integration represents a device containing 1 to 12 gates.

Standard Cell – A form of *application-specific integrated circuit (ASIC)*, which, unlike a gate array, does not use the concept of a *basic cell* and does not have any prefabricated components. The ASIC vendor creates custom masks for every stage of the device's fabrication, allowing each logic function to be created using the minimum number of transistors.

State Assignment – The process by which the states in a state machine are assigned to the binary patterns that are to be stored in the state variables.

State Diagram – A graphical representation of the operation of a state machine.

State Machine – *see FSM.*

Statement – A sentence that asserts or denies an attribute about an object or group of objects. For example, "*Your face resembles a cabbage.*"

State Table – A tabular representation of the operation of a state machine. Similar to a truth table, but also includes the *current state* as an input and the *next state* as an output.

State Transition – An arc connecting two states in a state diagram.

State Variable – One of a set of registers whose values represent the current state occupied by a state machine.

Static Flex – A type of *flexible printed circuit* that can be manipulated into permanent three-dimensional shapes for applications such as calculators and high-tech cameras, which require efficient use of volume and not just area.

Static RAM – *see SRAM.*

Steady State – A condition in which nothing is changing or happening.

Subatomic Erosion – *see Electromigration.*

Substrate – Generic name for the base layer of an integrated circuit, hybrid, multichip module, or circuit board. Substrates may be formed from a wide variety of materials, including semiconductors, ceramics, FR4 (fiberglass), glass, sapphire, or diamond depending on the application. Note that the term "substrate" has traditionally not been widely used in the circuit board world, at

least not by the people who manufacture the boards. However, there is an increasing tendency to refer to a circuit board as a substrate by the people who populate the boards. The main reason for this is that circuit boards are often used as substrates in hybrids and multichip modules, and there is a trend towards a standard terminology across all forms of interconnection technology.

Subtractive Process – A process in which a substrate is first covered with conducting material, and then any unwanted material is subsequently removed, or subtracted.

Sum-of-Products – A Boolean equation in which all of the *minterms* corresponding to the lines in the truth table for which the output is a logic 1 are combined using OR operators.

Superconductor – A material with zero resistance to the flow of electric current.

Surface-Emitting Laser Diode – A laser diode constricted on an integrated circuit's substrate such that, when power is applied, the resulting laser beam is emitted directly away from the surface of the substrate.

Surface Mount Device – *see SMD*.

Surface Mount Technology – *see SMT*.

Symbolic Logic – A mathematical form in which propositions and their relationships may be represented symbolically using Boolean equations, truth tables, Karnaugh Maps, or similar techniques.

Synchronous – (1) A signal whose data is not acknowledged or acted upon until the next active edge of a clock signal. **(2)** A system whose operation is synchronized by a clock signal.

Synchronous DRAM – *see SDRAM*.

System-on-Chip – *see SoC*.

TAB (Tape-Automated Bonding) – A process in which transparent flexible tape has tracks created on its surface. The pads on unpackaged integrated circuits are attached to corresponding pads on the tape, which is then stored in a reel. Silver-loaded epoxy is screen printed on the substrate at the site where the device is to be located and onto the pads to which the device's leads are to be connected. The reel of TAB tape is fed through an automatic machine, which pushes the device and the TAB leads into the epoxy. When the silver-loaded epoxy is cured using *reflow soldering* or *vapor-phase soldering*, it forms electrical connections between the TAB leads and the pads on the substrate.

Tap – A register output which is used to generate the next data input to a linear feedback shift register.

Tape Automated Bonding – *see TAB*.

Tera – Unit qualifier (symbol = T) representing one million million, or 10^{12}. For example, 3 THz stands for 3×10^{12} hertz.

Tertiary – Base-3 numbering system.

Tertiary Digit – A numeral in the tertiary scale of notation. A tertiary digit can adopt one of three states: 0, 1, or 2. Often abbreviated to "trit."

Tertiary Logic – An experimental technology in which logic gates are based on three distinct voltage levels. The three voltages are used to represent the tertiary digits 0, 1, and 2, and their logical equivalents FALSE, TRUE, and MAYBE.

Thermal Relief Pad – A special pattern etched around a via or a plated through-hole to connect it into a power or ground plane. A thermal relief pad is necessary to prevent too much heat being absorbed into the power or ground plane when the board is being soldered.

Thermal Tracking – Typically used to refer to the problems associated with optical interconnection systems whose alignment may be disturbed by changes in temperature.

Thick-Film Process – A process used in the manufacture of hybrids and multichip modules in which signal and dielectric (insulating) layers are screen-printed onto the substrate.

Thin-Film Process – A process used in the manufacture of hybrids and multichip modules in which signal layers and dielectric (insulating) layers are created using opto-lithographic techniques.

Through-Hole – *see Lead Through-Hole, Plated Through-Hole, and Through-Hole Via.*

Through-Hole Via – A via that passes all the way through the substrate.

Thru-Hole – A commonly used abbreviation of "through-hole."

Time-of-Flight – The time taken for a signal to propagate from one logic gate, integrated circuit output, or opto-electronic component to another.

Tin-Lead Plating – An electroless plating process in which exposed areas of copper on a circuit board are coated with a layer of tin-lead alloy. The alloy is used to prevent the copper from oxidizing and provides protection against contamination.

Tinning – *see Tin-Lead Plating.*

Toggle – Refers to the contents or outputs of a logic function switching to the inverse of their previous logic values.

Trace – *see Track.*

Track – A conducting connection between electronic components. May also be called a *trace* or a *signal*. In the case of integrated circuits, such interconnections are often referred to collectively as *metalization*.

Transducer – A device that converts input energy of one form into output energy of another.

Transistor – A three-terminal semiconductor device that, in the digital world, can be considered to operate like a switch.

Tri-State Function – A function whose output can adopt three states: 0, 1, and Z (high-impedance). The function does not drive any value in the Z state and, in many respects, may be considered to be disconnected from the rest of the circuit.

Trit – Abbreviation of *tertiary digit*. A tertiary digit can adopt one of three values: 0, 1, or 2.

Truth Table – A convenient way to represent the operation of a digital circuit as columns of input values and their corresponding output responses.

TTL (Transistor-Transistor Logic) – Logic gates implemented using particular configurations of bipolar junction transistors.

Transistor-Transistor Logic – *see TTL.*

µC – *see Microcontroller.*

µP – *see Microprocessor.*

ULA (Uncommitted Logic Array) – One of the original names used to refer to gate array devices. This term has largely fallen into disuse.

Ultra-Large-Scale Integration – *see ULSI.*

ULSI (Ultra-Large-Scale Integration) – Refers to the number of logic gates in a device. By one convention, ultra-large-scale integration represents a device containing a million or more gates.

Uncommitted Logic Array – *see ULA.*

Unsigned Binary Number – A binary number in which all the bits are used to represent positive quantities. Thus, an unsigned binary number can only be used to represent positive values.

Vapor-Phase Soldering – A surface mount process in which a substrate carrying components attached by solder paste is lowered into the vapor-cloud of a tank containing boiling hydrocarbons. This melts the solder paste thereby forming good electrical connections. However, vapor-phase soldering is becoming increasingly less popular due to environmental concerns.

Vaporware – Refers to either hardware or software that exists only in the minds of the people who are trying to sell it to you.

Vector Notation – A notation in which a single name is used to reference a group of signals, and individual signals within the group are referenced by means of an index: for example, *a*[3], *a*[2], *a*[1], and *a*[0]. This concept of a vector is commonly used in the context of electronics tools such as schematic capture packages, logic simulators, and graphical waveform displays.

Some people prefer to use the phrase *binary group notation*, but the *phrase vector notation* is commonly used by practicing electronic engineers. (Note that this type of vector notation is in no way related to the algebraic concept of vector notation for Cartesian 2-space or 3-space.)

Very-Large-Scale Integration – *see VLSI*.

VHDL – A *hardware description language (HDL)*, which came out of the American Department of Defense (DoD), and which has evolved into an open standard. VHDL is an acronym for *VHSIC HDL* (where VHSIC is itself an acronym for *very high speed integrated circuit*).

Via – A hole filled or lined with a conducting material, which is used to link two or more conducting layers in a substrate.

Virtual Hardware – An extension of dynamically configurable hardware based on a new generation of FPGAs that were introduced around the beginning of 1994. In addition to supporting the dynamic reconfiguration of selected portions of the internal logic, these devices also feature the following: no disruption to the device's inputs and outputs; no disruption to the system-level clocking; the continued operation of any portions of the device that are not undergoing reconfiguration; and no disruption to the contents of internal registers during reconfiguration, even in the area being reconfigured. *See also Configurable Hardware, Reconfigurable Hardware, Remotely Reconfigurable Hardware, and Dynamically Reconfigurable Hardware.*

Virtual Memory – A trick used by a computer's operating system to pretend that it has access to more memory than is actually available. For example, a program running on the computer may require 500 megabytes to store its data, but the computer may have only 128 megabytes of memory available. To get around this problem, whenever the program attempts to access a memory location that does not physically exist, the operating system performs a slight-of-hand and exchanges some of the contents in the memory with data on the hard disk.

Virus – *see Computer Virus*.

VLSI (Very Large Scale Integration) – Refers to the number of logic gates in a device. By one convention, very-large-scale integration represents a device containing 1,000 to 999,999 gates.

Volatile – Refers to a memory device that loses any data it contains when power is removed from the system: for example, random-access memory in the form of SRAM or DRAM.

Wafer – A paper-thin slice cut from a cylindrical crystal of pure semiconductor.

Wafer Probing – The process of testing individual integrated circuits while they still form part of a wafer. An automated tester places probes on the device's pads, applies power to the power pads, injects a series of signals into the input pads, and monitors the corresponding signals returned from the output pads.

Waveguide – A transparent path bounded by non-transparent, reflective areas, which is fabricated directly onto the surface of a substrate. Used in the optical interconnection strategy known as *guided-wave*.

Wave Soldering – A process used to solder circuit boards populated with through-hole components. A machine creates a wave[18] of hot, liquid solder which travels across the surface of the tank. The populated circuit boards are passed over the wave-soldering machine on a conveyer belt. The velocity of the conveyer belt is carefully controlled and synchronized such that the solder wave brushes across the bottom of the board only once.

Wire Bonding – The process of connecting the pads on an unpackaged integrated circuit to corresponding pads on a substrate using wires that are finer than a human hair. Wire bonding may also be used to connect the pads on an unpackaged integrated circuit, hybrid, or multichip module to the leads of the component package.

Wiring Layer – A layer carrying wires in a discrete wired board. *See also Signal Layer*.

Word – A group of signals or logic functions performing a common task and carrying or storing similar data: for example, a value on a computer's *data* bus could be referred to as a "data word" or " a word of data."

X Architecture – An initiative proposed by a group of companies in 2001 to use diagonal tracks to connect functions on silicon chips (as opposed to traditional North-South and East-West tracking layers). Initial evaluations apparently show that this diagonal interconnect strategy can increase chip performance by 10% and reduce power consumption by 20%. However, it may take some time for design tools and processes (and popular acceptance) to catch up and start using this technique.

X-Ray Lithography – Similar in principle to optical lithography, but capable of constructing much finer features due to the shorter wavelengths involved. However, X-ray lithography requires an intense source of X-rays, is more difficult to use, and is considerably more expensive than optical lithography.

Yield – The number of devices that work as planned, specified as a percentage of the total number actually fabricated.

[18] A large ripple, actually.

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f = footnote, s = sidebar, p = pronunciation, CD = CD-ROM

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