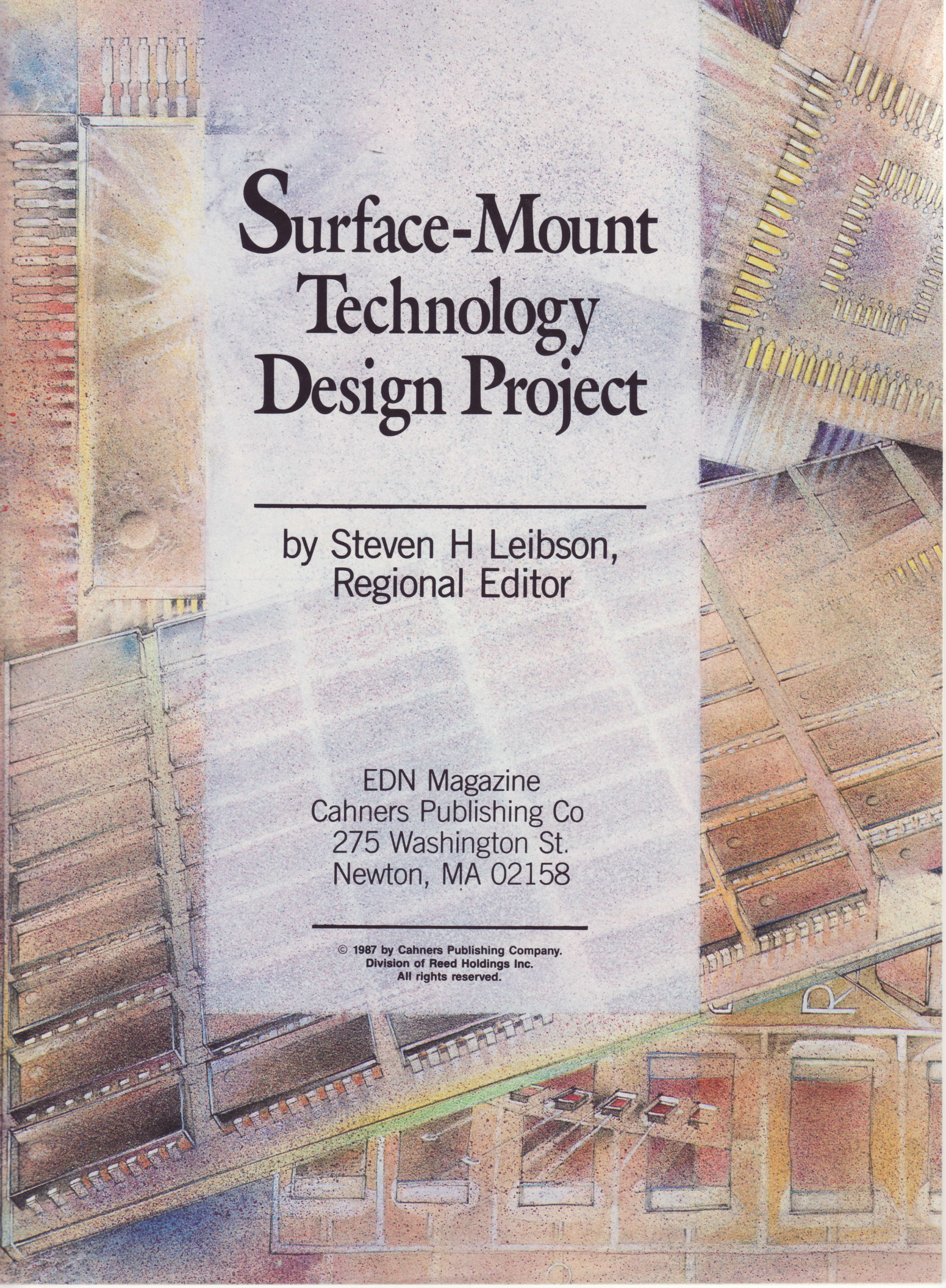

Surface-Mount Technology Design Project

by Steven H Leibson,
Regional Editor

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Newton, MA 02158

EDN's Hands-On
SMT Project—Part 1

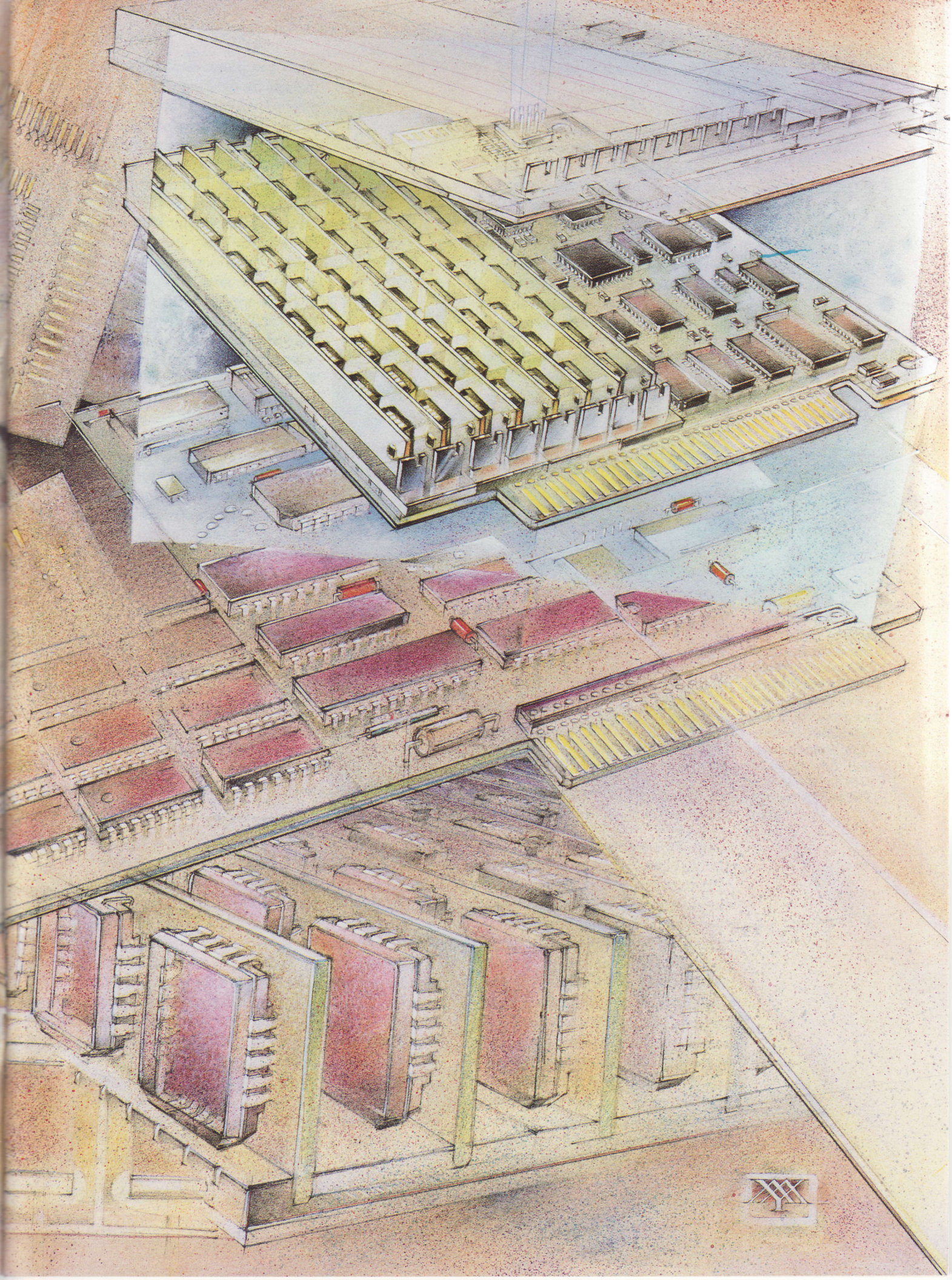
The promise of surface-mount technology

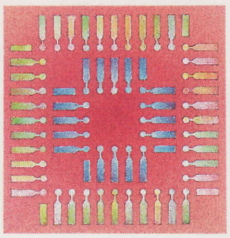
EDN set out to convert an existing through-hole pc board into a version populated by surface-mount devices. The challenges we faced while designing the SMT version and supervising its fabrication and test illustrate the problems you might encounter when pursuing SMT's benefits. This 5-part series, which will run in consecutive issues of EDN, chronicles this 18-month project. We begin at the beginning.

Surface-mount technology purports to compress your through-hole designs by more than half, make them easy to build, increase their reliability, and what's more, perform all of these feats while reducing manufacturing costs. We wondered whether SMT could meet the benefits attributed to it and, if it could, what difficulties might deter designers from enthusiastically embracing it. To investigate the promises of this technology and the difficulties involved in implementing it, we undertook to convert a full-length, through-hole IBM PC memory board into a

Steven H Leibson, *Regional Editor*

Illustration by Michael Young





half-length, surface-mount version.

Our project began with research for a report on information resources available to engineers contemplating SMT designs (**Ref 1**). Our preliminary research took us to Expo SMT (Los Gatos, CA, (408) 354-0700) in October 1985. At that show, we talked with vendors of SMT components and assembly tools and with several consultants. Although enthusiasm at the show ran quite high, experts estimated that only 5 or 10% of new electronic products designed in the US take advantage of SMT. This evidence of SMT's lack of popularity suggested the challenges that we might face in our hands-on project.

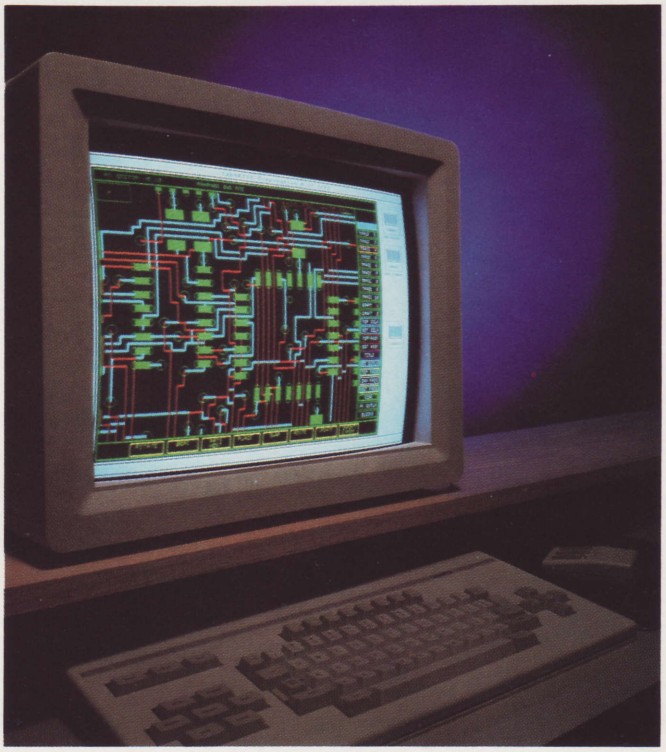


Photo by Bill Farrell, the Photo Works

Complex SMT designs demand the use of CAD systems for pc-board layout because of small trace and pad geometries. This CDX-50000 workstation from Cadnetix Corp became an essential tool for EDN's SMT project.

Convert an existing product

Although we could have chosen to create an original SMT design, we decided to convert a product based on through-hole technology to one based on SMT. This conversion approach would allow us to compare product size and manufacturing cost.

The same approach will serve you well in your first SMT endeavor. If you encounter delays, your company can continue to market its existing, through-hole product while you fix the bugs in your SMT design and in your SMT process. The pressure to get the new product to market will be substantially lessened if your company already offers a through-hole version that it can continue to sell.

The reasons for a cautious approach are simple. The newness of SMT creates the potential for several types of design errors that aren't so much of a problem when designing with through-hole components. For instance, you must be careful to specify SMDs that exist (as opposed to the devices that will appear in SMT packages "any day now"), to design to worst-case timing specs, and to pay careful attention to device power dissipation.

Availability problems

SMDs still suffer from spotty availability and long lead times. Moreover, because surface-mount devices are so small, vendors can pack a lot of product in one bulk package: For example, a 7-in. reel of SMD capacitors packaged on 8-mm embossed tape holds 2500 to 4000 parts. This bulk packaging provides a strong incentive for you to minimize the number of different devices your design em-

The SMT Association

Founded in January 1984, the SMT Association (SMTA) provides a forum for companies and individuals to exchange information about surface-mount technology. The national organization publishes a monthly newsletter, conducts technical seminars, and assists in the formation of local chapters. In addition, the SMTA sponsors several technical committees that are developing voluntary standards for components, computer-integrated manufacturing, pc-board design, workmanship, and testability. Dues range from $50 for individual memberships to $350 for international memberships; corporate memberships cost $295. For more information, contact the SMTA, Box 1811, Los Gatos, CA 95031; phone (408) 354-9275.

ploys, and it can create problems for you during the breadboard and prototype stages, when you need only a few parts.

Many designers discover heretofore unrealized timing problems when converting through-hole designs to SMT. The timing problems appear to be caused by two factors. First, ICs encased in SMT packages tend to run faster than the DIP versions, even though identical silicon die reside inside the packages. SMT ICs run faster because the lead frames are smaller and the leads are shorter. The smaller dimensions decrease propagation delays and lower capacitances. Many SMT experts say you can expect to see SMT components exhibit minimum, instead of typical, timing characteristics because of the smaller packaging. Second, an SMT board's traces are also shorter, further reducing signal-propagation delay and trace capacitance.

You can also encounter heat dissipation problems with SMT assemblies because of the incredible packing densities that can be achieved with the technology. If you take an existing design, shrink the assembly to 50% of its original size, and package the new design to reflect the compaction, you might find that your new, compact product is literally too hot to handle.

We wanted a product with a good mix of device types to find out if SMD availability would be a problem. Also, we wanted a product that would benefit from the reduced size of SMT components. AST Research's Rampage! EEMS memory board became our prime candidate. The board incorporates a few passive components, TTL logic, PLDs, PROMs, switches, connectors, and a large block of RAM. Most of these components were displayed at Expo SMT by several vendors. In addition, the board was receiving quite a bit of trade-press attention because AST's EEMS specification competes with the Lotus-Intel-Microsoft (LIM) spec (see **box,** "AST, Rampage!, and the EEMS").

An additional reason for choosing a product from AST Research related to our plans for CAD development of the SMT project board. We planned on using a Cadnetix pc-board design workstation, and AST uses them for its designs. We hoped to obtain the design data for the Rampage! on tape, eliminating the possibility of error from manual transcription of the product schematic. We chose Cadnetix because that company is located in the same city as the author, providing ready access to workstations and to technical assistance, and because the author, a former design engineer at Cadnetix, has more than a passing familiarity with Cadnetix systems.

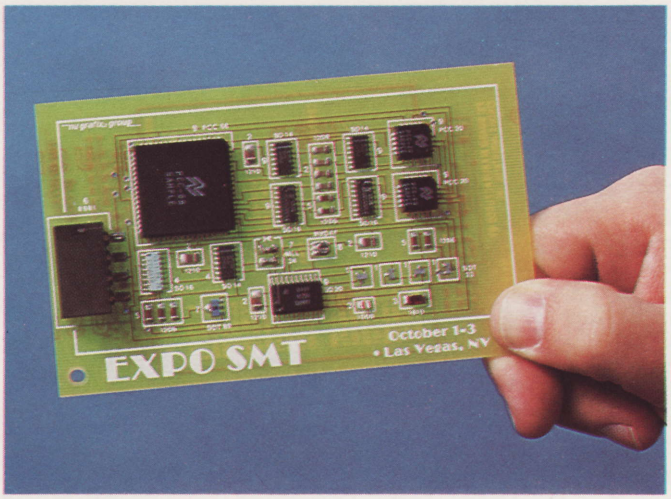


Photo by Bill Farrell, the Photo Works

This SMT demonstration board came off the surface-mount assembly line at the Expo SMT '85 show. Although the board showcases the use of SMDs like PLCCs, SOICs, connectors, and passive devices, it doesn't illustrate many of the problems you might encounter with a real design because it's too simple.

Initially, we planned to build a version of the Rampage! using SMT to achieve 8M bytes of storage on the same pc-board size as the original product. Although one through-hole Rampage! board can accommodate 2M bytes of memory, the EEMS allows you to put four Rampage! cards in a computer system to achieve 8M bytes of memory. We estimated that if all we needed to do was quadruple the size of the Rampage! memory array, an 8M-byte version could be achieved in the same form factor.

Before we could accomplish that conversion, however, we needed to meet with AST, con-

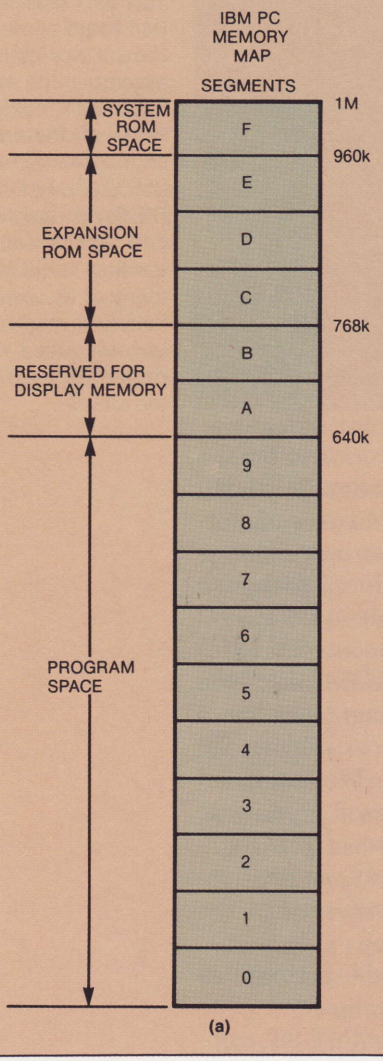
Breaking the IBM PC's 640k-byte memory barrier

The IBM PC's original design allocated only the lower 640k bytes of the 8088 μP's 1M-byte address space to applications programs (**Fig 1a**). Within two years of the PC's introduction, however, software vendors started to bump into the computer's 640k-byte memory limit. For example, many PC users found that their computers lacked sufficient memory to hold the enormous Lotus 1-2-3 spreadsheets that they needed to manipulate. Several vendors of IBM PC expansion products set out to remove this limitation.

Lotus Development teamed up with Intel and Microsoft to produce the LIM EMS (Lotus/Intel/Microsoft Expanded Memory Specification). The EMS specifies a block-switching scheme in which four contiguous, 16k-byte page frames are located somewhere in the memory space from address $C0000 to $EFFFF (**Fig 1b**). The 8088 accesses independent 16k-byte blocks of the expanded memory through this 64k-byte window by employing four address-translating page registers on the EMS board. Using this scheme, an application program can address 2M bytes of EMS RAM, but it can address only 64k bytes at a time. The LIM EMS specifies a software interface to an expanded-memory-management software routine that manages the EMS RAM and isolates the application program from the EMS hardware.

Because the EMS limits memory-block switching to segments C through E, above the operating system's program space, applications programs can only use EMS memory for data storage or for storing program overlays. MS-DOS can't accommodate noncontiguous program space above the 640k-byte threshold. Also, because only 64k bytes of the EMS memory are accessible at any time, the applications program must explicitly manage the memory-block switching for data-storage requirements exceeding 64k bytes.

AST Research's EEMS (Enhanced EMS), a superset of the LIM spec, offers two improvements to the LIM concept. The EEMS increases the number of page registers from four to 64, thus mapping EEMS RAM into any unused memory locations in the PC's 1M-byte address space (**Fig 1c**). Because its page registers can map EEMS memory below



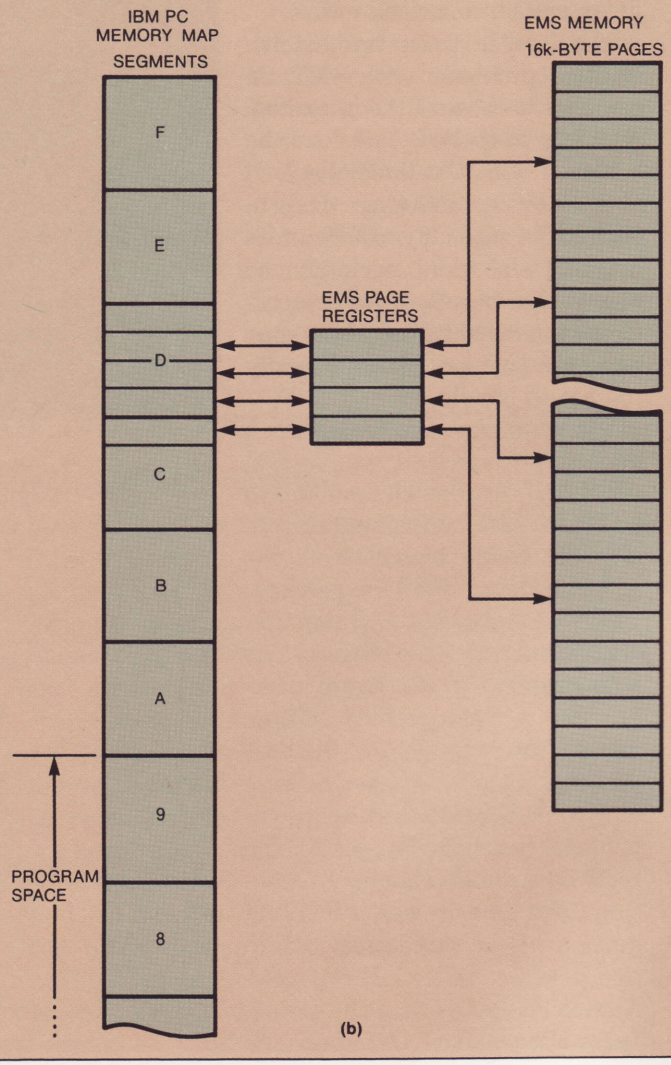
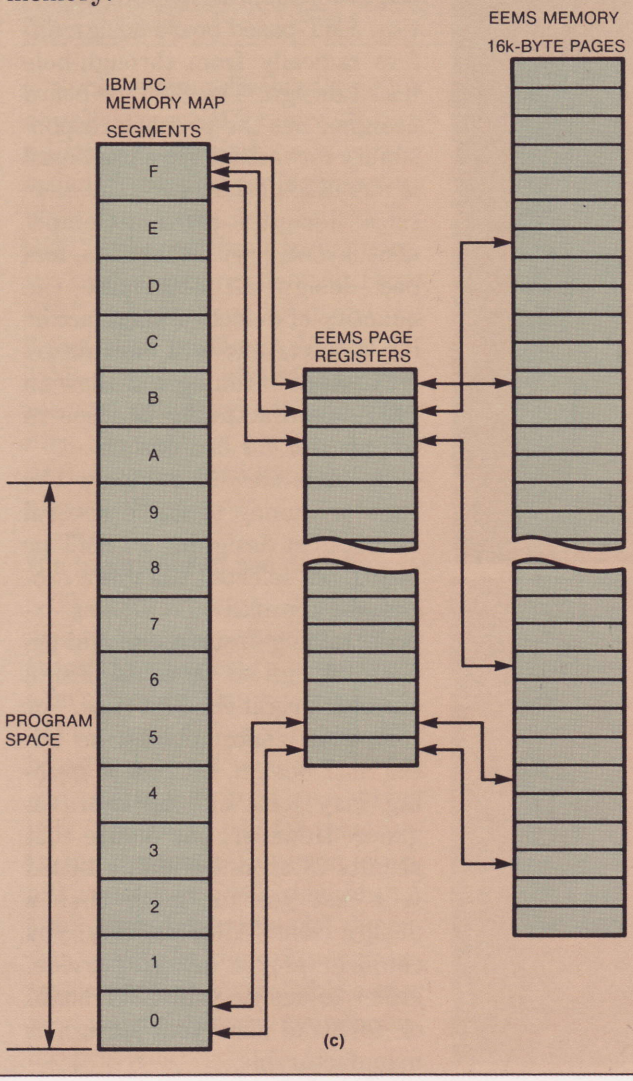


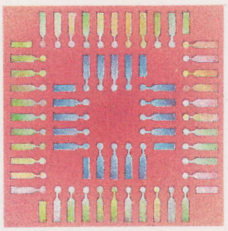
Fig 1—The memory map of the 8088-based IBM PC **(a)** limits you to 640k bytes of memory for applications software. A block switching scheme called EMS **(b)** uses a 64k-byte window in the PC's upper-memory space to access as many as 2M bytes of EMS RAM, but because this memory is not contiguous with the lower 640k-byte block, applications programs can only use this additional memory for data storage. The enhanced EMS (EEMS) scheme implemented by the Rampage! **(c)** can switch additional memory into any 16k-byte frame within the 8088's 1M-byte address range, thus supporting multiple resident programs and multitasking operations.

the 640k-address level, into the PC's program space, an EEMS board allows multitasking software to swap entire applications programs in and out of the memory space. AST maintained compatibility with the EMS through its memory-manager software interface so that applications programs written to use EMS memory managers also work with EEMS boards.

The first product from AST to implement the EEMS was the Rampage! memory card, which accepts 2M bytes of RAM. AST's memory-management software and utility programs allow the PC to use Rampage! memory as a RAM disk and as a print buffer. Desqview, an operating-system software shell for MS-DOS by Quarterdeck Office Systems (Santa Monica, CA, (213) 392-9701) and supplied by AST with the Rampage! hardware, provides a multitasking environment that can use all 2M bytes of memory on the Rampage! for applications-program storage. Desqview supports as many as four Rampage! cards, allowing you to assemble 8088-based PCs with 8M-bytes of memory.



vince the company that the Rampage! was a fine candidate for SMT conversion, and convince AST's management that it should hand over sufficient engineering documentation to allow us to reproduce the Rampage! using SMDs. That meeting occurred on December 18, 1985.

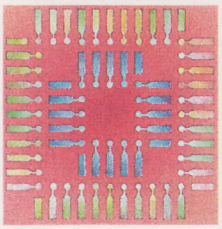


Adjusting our assumptions

At first, the representatives from AST wanted to understand why a technical publication like EDN wanted the complete plans for one of their latest and hottest products. They wanted to know if Cahners Publishing planned to enter the pc-board business. We assured them that was not the case and proceeded to explain the project and discuss the technical merits of our plans. We soon discovered that one of our fundamental assumptions was wrong. The Rampage! control circuits could drive only a 2M-byte RAM array. An 8M-byte memory requires almost four times the control circuitry used on the 2M-byte product.

We journeyed to Irvine-based AST Research to obtain the engineering documentation necessary for re-creating the Rampage! EEMS memory board using SMT.

Thus, an 8M-byte Rampage! on one card would not fly. Even using SMDs, 8M bytes of memory plus the enlarged control section simply would not fit within the existing board's form factor. The IBM PC constrains expansion-



board size, which prevented us from enlarging the pc board to accommodate the extra circuitry.

After a little more discussion, we settled on building a 2M-byte Rampage! using a "short-slot" form factor. From a technical viewpoint, this approach has much stronger appeal. The conversion would not change the board's fundamental design, so we could focus on the SMT aspects of the project.

From a marketing perspective, a short-card Rampage! would open new avenues of opportunity for the product. IBM PC/XTs and many similar computers incorporate one or more expansion slots that do not accommodate full-length boards like the Rampage!

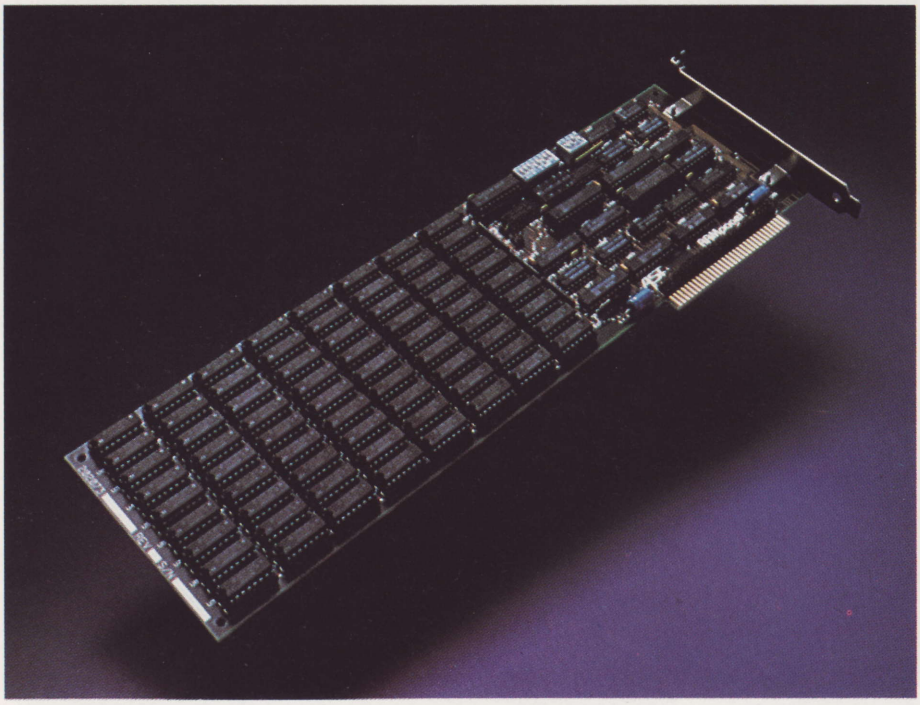


Photo by Bill Farrell, the Photo Works

Accommodating 2M bytes of RAM on one card, the AST Rampage! and its associated software greatly enhance the capabilities of 8088-based IBM PCs and compatible computers.

In addition, several hard-disk-on-a-card expansion boards occupy 1.5 expansion slots, transforming a full-length slot into a short berth. A short-card easily snuggles into these smaller slots. Thus, a short-card, SMT Rampage! would fit in many more available slots than the original product.

This example illustrates SMT's ability to let you choose between building more capability into an existing form factor or reducing the size of an existing product. Our original concept was to attempt the former approach, but we, along with AST, concluded that the latter solution stood a better chance of success.

Keeping people in the loop

AST provided us with the necessary documents and a sample Rampage! for comparison purposes. Unfortunately, the schematics had not been entered into a Cadnetix system at AST so we would have to make that conversion as part of the project. This was the first of many instances in this project where a human was responsible for transferring information to a computer-based tool. Although many vendors bill SMT as a highly automated technology, people aren't out of the loop yet by any stretch of the imagination.

As a next step, we needed to acquire some SMT design expertise. SMT-based board design differs radically from through-hole board design. The SMT pc-board designer has the primary responsibility for making sure the board is manufacturable, once the electrical design is proven. Component layout, part orientation, and pad design all determine the quantity of defects a manufacturing department will encounter. No amount of tuning will allow an SMT manufacturing process to compensate for bad design.

Because we did not have the time or money to make several attempts at designing an SMT pc board, we selected the more economical approach of obtaining expert training in surface-mount pc-board design so we could design our board right the first time. For companies contemplating an initial SMT design, the cost of training may look like an extravagance. However, one failure that results in an unbuildable board will cost you far more than a design class. Alternatively, you could employ a design service, either to design your SMT board or to make sure your design is manufacturable.

In training for SMT

SMT Plus offers a smorgasbord of services, including training, design, and consulting. The company still teaches the class we attended, "Designing for Manufacturability," but under a new new name: "SMT Fundamentals of Product Design." The 2-day, $950 class covers SMT packaging, component selection, substrates for SMT assembly, land-pattern design rules, design for testability, and considerations for using CAD systems to do SMT design. The company targets the class at pc-board designers with little or no SMT background.

Designers that have attended the fundamentals course or have designed at least one SMT board may be interested in a new class taught by the company called "Advanced Design Techniques." This class, which also costs $950 and lasts for two days, covers techniques for generating your own design rules and pad patterns, for managing thermal problems with SMT assemblies, and for selecting CAD systems with an eye toward features that aid SMT design.

Backing up these classes are the company's CAD-based design and prototyping services. SMT Plus designed 70 SMT boards on a contract basis for various customers in 1986, so its land patterns and design rules have been thoroughly tested. The company guarantees its designs to be manufacturable through the client's manufacturing process. If you prefer to do your own pc-board design, you can also arrange for SMT Plus to review your layout. In addition, the company can build SMT prototype assemblies in a shop maintained on the premises. Classes taught at the company's San Jose facility include a visit to the prototype shop.

Photo by Liane Enkelis

You can minimize false starts and costly errors when you begin to use SMT by attending a class in SMT-based design like "Designing for Manufacturability," taught by Jim Blankenhorn, president of SMT Plus.

Surface Mount Technology Plus supplied our SMT board-design education through a seminar called "Designing for Manufacturability" (see **box,** "In training for SMT"). We met Jim Blankenhorn, the company's president, at Expo SMT and arranged to attend the 2-day class on March 10 and 11, 1986. The class, attended by representatives of eight other companies, focused on surface-mount devices and on making the design manufacturable.

The importance of pad design

The course taught us that pad design is one area in which through-hole design experience won't benefit the conversion to SMT designs. For through-hole boards, a 35-mil hole in a 50-mil pad is about as good as a 40-mil hole in a 60-mil pad for manufacturing purposes. However, every mil counts in SMT designs. A 5-mil variation in one pad dimension can make the difference between a consistent, reliable solder joint and a persistent manufacturing problem.

The reason small changes in pad design have large effects on making a board manufacturable is rooted in the fundamentals of the SMT manufacturing process. For reflow-soldered boards, the volume of solder available to each joint during soldering is directly determined by the pad area multiplied by the thickness of the solder paste laid down during the solder-screen operation: Too little solder creates open joints; too much solder creates short circuits. You also need a reasonable

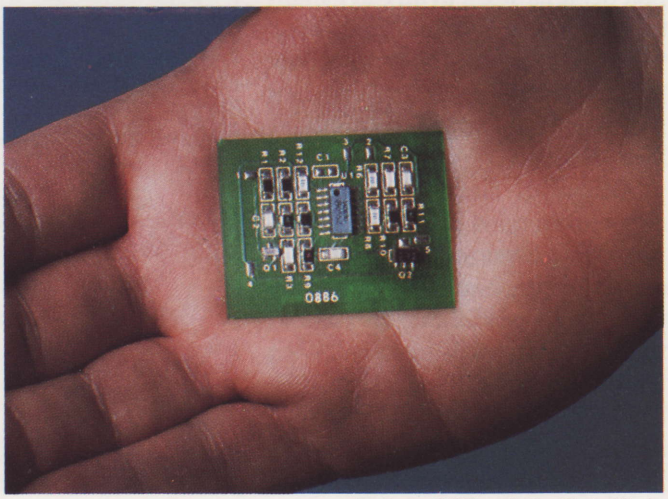
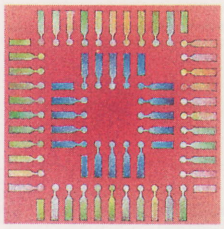


Photo by Bill Farrell, the Photo Works

As a final assignment in the "Designing for Manufacturability" class taught by SMT Plus, we designed a do-nothing pc-board. This board displays the instructor's solution to the problem. Although we gained experience with SMD layout through the assignment, the board's simplicity did not fully prepare us for the many problems we encountered when dealing with more complex circuits.



target zone for the SMD leads (realized by a pad of sufficient size) so that the "onsertion" equipment (the counterpart of through-hole technology's *insertion* equipment) is allowed a little placement tolerance.

Your boards can also exhibit short circuits if pads are too close to each other. Short circuits are especially likely for a board that has passive SMDs wave-soldered to its bottom. Components placed near or next to each other also complicate onsertion because of reduced clearances, increasing the probability of short circuits and device misalignment.

SMT assembly facilities require surprisingly little floor space, as illustrated by this assembly area at SMT Dynamics. One operator in the background tends three onserters. The other three people inspect and test the finished boards.

To design a manufacturable board, you need a set of pad designs that work well. The best way to obtain these pad designs is to acquire them from someone who has used the designs and found them to be effective. Not all pad designs work in all SMT manufacturing processes. Pads that work well for vapor-phase reflow processes may be unreliable when boards are soldered using IR-reflow systems.

SMT Plus claims its pad designs are a good compromise and work in all manufacturing processes. The company supplies pad-design guidelines as part of its design manual, included with the course. SMT Plus designed 70 SMT boards in 1986 and provides a guarantee on its designs: If the board proves not to be manufacturable, the company will redesign it for free. So far, a very few designs have required some minor fixes under this guarantee. These are strong arguments in favor of using the company's pad designs. They've been field proven.

Choosing IC packages

Component selection also influences how manufacturable a board will be. You will have to make many more component decisions for an SMT board design than for a conventional through-hole board. For example, some ICs might come in SOIC (small-outline IC) packages but not in PLCCs (plastic, leaded chip carriers), others might only come in PLCCs, and still others might come in both package styles.

Many semiconductor components, notably power devices and high-pin-count ICs, come only in through-hole versions. If you must use these ICs in your design, you will be forced to use a hybrid, through-hole/SMT manufacturing process.

As a finale to the SMT design course, we piled into cars for a field trip to SMT Dynamics Corp, a contract-assembly shop specializing in SMT manufacturing. There we saw a complete SMT manufacturing floor. The small size of the SMT assembly machinery and the trifling inventory space required to store SMT components make for a very compact

For more information . . .

For more information on the products discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or contact the following manufacturers directly.

AST Research Inc
2121 Alton Ave
Irvine, CA 92714
(714) 863-1333
Circle No 650

Cadnetix Corp
5757 Central Ave
Boulder, CO 80303
(303) 444-8075
Circle No 651

SMT Dynamics
10 Hughes St, Suite A107
Irvine, CA 92718
(714) 458-1035
Circle No 652

SMT Plus
2216 Lundy Ave
San Jose, CA 95134
(408) 943-0196
Circle No 653

facility. Gone are the long rows of board-stuffing push lines staffed by one or two dozen people. Instead, one or two operators can supervise a line of assembly machines and turn out large volumes of a high-quality product.

Breaking the bank

Companies like SMT Dynamics fill a need for other firms just starting out with SMT. Costs for SMT equipment are significant: A small prototype facility can cost you $100,000, and large production facilities can cost several millions of dollars. In fact, capital-equipment costs are one of the last major barriers to rapid acceptance of SMT. Many contract-assembly shops now offer you SMT-assembly facilities so you do not need to make that large capital investment. In the next few years, you can expect to see many more firms specializing in SMT assembly. Because these companies build products for many different clients, they can keep the SMT manufacturing machines busy and amortize capital equipment costs over many more boards than can small companies just starting with the technology.

At this point in the project, we had a product design ready for SMT conversion and the training necessary to perform that conversion. Now all we needed to do was select and obtain the components, design and fabricate the pc board, and build and test the assemblies. Piece of cake! **EDN**

Reference

1. Leibson, Steven, "Special Report: Surface-Mount Technology," *EDN*, October 2, 1986, pg 135.
