Development of a Low-Cost, High-Performance, Multiuser Business Server System

Using leveraged technology, an aggressive system team, and clearly emphasized priorities, several versions of low-end multiuser systems were developed in record time while dramatically improving the product's availability to customers.

by Dennis A. Bowers, Gerard M. Enkerlin, and Karen L. Murillo

The HP 9000 Series 800 Models E25, E35, E45, and E55 (Ex5) and the HP 3000 Series 908, 918, 928, and 938 (9x8) business servers were developed as low-cost, performance-enhanced replacements for the HP 9000 F Series and low-end G Series and the HP 3000 Series 917, 927, 937, and 947. The development of the PA-RISC PA 7100LC processor chip and the LASI (LAN/SCSI) I/O interface and the evolution of DRAMs for main memory enabled the development of these low-end servers. The PA 7100LC and the LASI I/O interface are described in the articles on pages 12 and 36 respectively.

The priorities for the Models Ex5 and Series 9x8 server project were short time to market, low cost, and improved performance. The functionality and quality of the new servers were to be as good as the products they were replacing, if not better. The challenge was to get these new servers to market as soon as possible so that HP could continue to be competitive in the business server market and our customers could benefit from better performance at a lower price. We were able to get the first versions of these systems completed, released, and shipping on time with all new VLSI components.

Low-Cost, Higher-Performance Features

The principlal reason for achieving high integration and low cost for the Model Ex5 and Series 9x8 servers was the development of the PA 7100LC processor chip, which was being developed at the same time as our servers. Integrating the floating-point unit, the 1K bytes of internal instruction cache, the external cache interface, the TLB (translation lookaside buffer), the memory controller, and the general system connect (GSC) I/O interface inside the PA 7100LC processor chip allowed the Model Ex5 and Series 9x8 designers to condense the CPU and main memory onto the same board.

Also, at the same time as our new servers were being developed, DRAM densities doubled (in some cases quadrupled) to allow more memory to be put into a smaller space. The Model Ex5 and Series 9x8 servers use the same industry-standard ECC (error correction coded) SIMM modules used in the HP 9000 Model 712 and other HP workstations. The Model Ex5 and Series 9x8 servers use 16M- and 32M-byte SIMMS which must be inserted in pairs to provide 32M to 256M bytes of main memory. ECC memory was chosen because it carries two additional address lines making it possible to put four times the memory capacity on one SIMM while staying compatible with industry-standard modules. The 64M-byte SIMM was designed several months after first introduction of the new low-end servers to boost their maximum memory to 512M bytes. This larger SIMM is not available as an industry standard.

Four versions of the Model Ex5 and Series 9x8 processor have been developed, differentiated by clock speed, cache size, and cost. Each version is fully contained on the system board (which also contains cache, main memory, processor dependent hardware and firmware, and 802.3 LAN connect) and is easily installable and upgradable. Table I lists the technical specifications for the different Model Ex5 systems and summarizes the HP-UX* performance characterizations. The Series 9x8 MPE/iX systems have equivalent CPU hardware, and their specifications are close to those given in Table I.

Table I
Technical Specifications for HP 9000 Model Ex5 Systems Running the HP-UX Operating System

Processor Performance	Models			
	E25	E35	E45	E55
Clock (MHz)	48	64	80	96
SPECint92	44	65	80	104
SPECfp92	66	98	120	156
OLTP Transactions/s	80	125	155	180
Standard memory/cache (M bytes)	16	16	16	16
Maximum memory (M bytes)	512	512	512	512
Cache size (K bytes)	64	256	256	1000
Cache SRAM speed (ns)	15	12	10	7.5

Architecture

Fig. 1 shows a block diagram for the Model Ex5 and Series 9x8 servers.

The general system connect (GSC) bus was designed as a new, more powerful system bus for higher performance. The Model Ex5 and Series 9x8 servers only use the GSC bus for the processor, main memory, and 802.3 LAN through the LASI chip. The midrange and high-end server systems also support the GSC bus as their high-performance I/O bus. All PA-RISC systems support the HP-PB[1] (HP precision bus) as the common I/O bus because multiple functionality (hardware and drivers) currently exist for this bus. The interface from the GSC bus to the HP-PB is accomplished in a chip called the HP-PB bus converter.

The HP-PB bus converter chip is a performance-improved version of the bus converter that was used in the HP 9000 F and G Series and HP 3000 Series 9x7 machines. This chip allows the Model Ex5 and Series 9x8 servers to leverage HP-PB I/O functionality from the systems they are replacing.

The HP-PB bus converter implements transaction buffering† as an HP-PB slave, gaining performance improvements of 10% to 28% over its predecessor. The chip supports GSC to HP-PB clock ratios ranging from 3:1 to 5:1 in synchronous mode when the GSC bus is operating under 32 MHz. It switches to asynchronous mode when the GSC bus operates in the 32-to-40-MHz range. These ratios and the asynchronous feature of the HP-PB bus converter allow fair flexibility in CPU and GSC operating frequencies while maintaining a constant 8-MHz HP-PB frequency. The bus converter also provides an interface to the access port used for remote support, and the control signals used for the chassis display and status registers. The chip is designed for the HP CMOS26B process and comes packaged in a 208-pin MQFP (metal quad flat pack).

The other key VLSI chip used in the I/O structure for the Model Ex5 and Series 9x8 servers is the LASI chip. The LASI

† With transaction buffering, during reads from disk, data is buffered so that HP-PB transactions can continue at maximum pace.

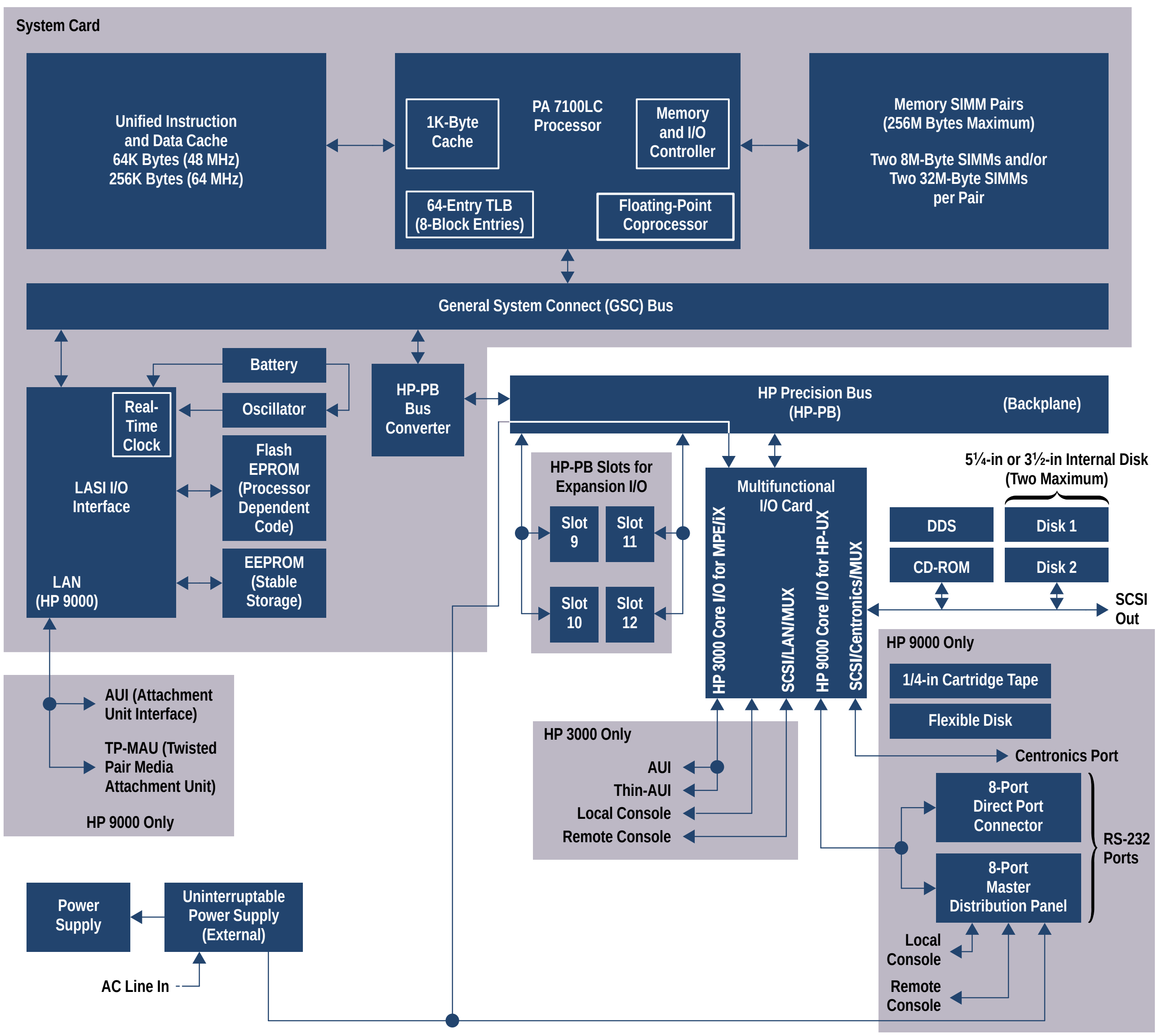

Fig. 1. Block diagram for the HP 9000 Series 800 Models Ex5 and the HP 3000 Series 9x8 business servers.

chip is designed to have the same integration impact on core I/O as the PA 7100LC had on the CPU and GSC bus interface. The workstation products are able to take advantage of this (see article on page 6), but the multiuser server systems were not able to take advantage of LASI functionality.

LASI functionality includes interfaces to IEEE 802.3 LAN, SCSI, processor dependent code, Centronics, RS-232, audio, keyboard, flexible disk, and GSC bus arbitration logic and the real-time clock. Because HP-UX and MPE/iX software drivers could not be made available in time for our release, only a small subset of LASI functionality could be used on the new servers. Thus, the decision was made to continue using the core I/O card from the previous versions of low-end servers because it provides all the functionality needed.

For the 96-MHz version of the Model Ex5 and Series 9x8 servers, a chip with a subset of the functionality of LASI was used. This was developed as a cost reduction for those applications that use only the LAN, GSC bus arbitration, and processor dependent code path. The 96-MHz version had to add a real-time clock on the system board to have equivalent functionality to what was needed from LASI.

In addition to the above VLSI chips and printed circuit boards, the Model Ex5 and Series 9x8 servers have the internal capacity for two disk drives (4G bytes), two removable media devices, and up to four I/O slots. The packaging and power supplies for the new servers are highly leveraged from the previous low-end server systems.

Meeting Fast Time-to-Market Goals

Meeting deadlines for any program is always a challenge. Too often it is believed that a few extra hours a week is all that is needed to keep the project on track. But many well-intentioned programs soon lose time with unexpected delays even when the project team is made up of industrious folks willing to do whatever it takes to stay on schedule.

At large corporations like HP, where releasing a product to market may span several divisions, the task is even more daunting. With our lab's mission of providing world-class low-end commercial business systems and servers, time to market is always expected to be a key objective. In the case of the Model Ex5 and Series 9x8 program, it was the primary objective. Additionally, we were challenged to keep cost projections in line with the set goals, and to meet or exceed the quality of the versions of the low-end servers that we were replacing. Quality is consistently a key objective on all HP products.

The main challenge for the Model Ex5 and Series 9x8 program was to achieve (on schedule) an order fulfillment cycle time† of 10 or fewer days for the entire product family. With the existing product family averaging order fulfillment cycle times four to five times larger than our 10 or fewer days goal, it was evident that for the new servers a well-orchestrated program that involved the entire system team was necessary to meet this challenge.

Fig. 2 shows a spider chart of the overall metrics for the Model Ex5 and Series 9x8 program. Note that the program achieved or exceeded all planned manufacturing release goals. Even the factory cost goal was exceeded, which was

† Order fulfillment cycle time is measured from when HP receives a customer's order to the time when the order is delivered at the customer's dock.

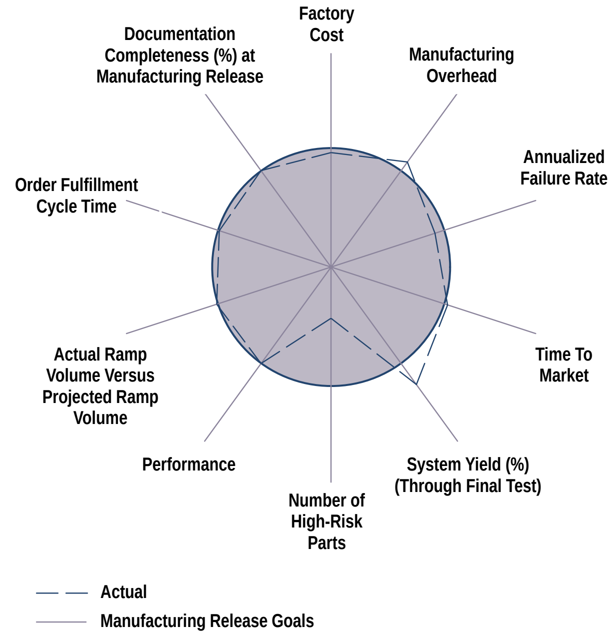

Fig. 2. Spider diagram showing how well the project team for the Models Ex5 and Series 9x8 servers met their project goals.

at risk when the hardware team added existing material into the design over less expensive functionality, reducing the software development schedule. The order fulfillment cycle time objective was not only achieved but exceeded! For the first three months of production, order fulfillment cycle time averaged under nine days.

The following sections summarize the reasons we met or exceeded our cost, quality, time-to-market, and manufacturing release goals.

Consolidation of Project Team. When the Model Ex5 and Series 9x8 program was in its early stages of design the development team was dispersed in two different geographic locations. The remote organization was eliminated and the project development and management were consolidated in one location under one manager. With this organization, technical decisions regarding system requirements could be made quickly and effectively.

Ownership of Issues. A system team composed of representatives from the different organizations involved in the development of the Models Ex5 and Series 9x8 servers was organized. Weekly one-hour meetings were held with the main focus on issues or concerns that impacted the project schedule. Communication was expected to be limited to discussions that affected everyone. Issues were captured and assigned an owner with a date assigned for resolution of the issue. Representatives at the meeting were expected to own the issues that were presented to their organization. No issue was closed until the team agreed upon it. This ensured that technical problems did not "bounce" around looking for an owner.

Interdivisional Communication. Effective interdivisional teams establish good working relationships to ensure timely response to actions and issues. An example was the decision to change the core I/O functionality. While the hardware team improved their factory cost by incorporating new, less costly hardware, the software team would have realized a longer schedule to provide new software features to support the new hardware. After reviewing the plans, the hardware team, aware of the critical time-to-market objective, recommended a return to the existing I/O feature implementation at an impact to factory cost for the sake of the software development team's ability to improve their schedule. The end result was that the hardware team still achieved their factory cost goals (by making adjustments elsewhere), and the software development team achieved their schedule goals.

Leverage Design Where Possible. When time to market was established as the key objective for the project, the development teams realized that leveraging from as many existing products as possible would greatly benefit achieving this goal. The following components were leveraged from new or existing products:

- Product package. Sheet metal was leveraged from the existing low-end business servers with minor changes to accommodate new peripherals and a different processor and main memory partitioning scheme. Plastic changes were kept to a minimum in an effort to use tools already established. (Only one new tool was required.)
- Base system configuration. The base system was established using the I/O printed circuit boards and several peripherals available on the existing low-end servers.
- Memory. The memory design was leveraged from the memory configuration used in the HP 9000 Model 712 workstation, which uses SIMM modules for the base memory system. Higher-density memory was designed specifically for the Model Ex5 and Series 9x8 servers after first release to increase their maximum memory capacity.
- Power supply. The power supply was leveraged from the existing servers.
- Printed circuit boards. The core I/O boards from the existing servers were used with only minor firmware changes to the HP-UX version. The processor board and backplane were new designs based on ideas shared with the Model 712 development team.
- VLSI. The PA 7100LC processor chip and the LASI core I/O chip were leveraged from the Model 712 workstation, which was being designed at the same time as our server systems.
- Firmware. Some of the firmware and I/O dependent code was codeveloped with the Model 712 development team.

Fast Time to Manufacturing Release. The use of concurrent engineering played a key role in reducing the back-end schedule. The back end of the schedule consists largely of manufacturing activities (including final test and qualification) aimed at achieving a release of the product for volume shipment. In the case of the Model Ex5 and Series 9x8 servers, with the individual boards being built in two geographically different manufacturing facilities, it was imperative that communication between these entities receive ample attention.

To facilitate this communication, a coordination team consisting of new product introduction engineers and new product buyers and logistics people were located in close proximity with the R&D development team. Everyone attended the system team meetings, which were led by the hardware lab, to ensure that the most current information was applied to the overall system schedule. In addition, production build meetings were held before, during, and after each prototype run to discuss build results. Ensuring that all manufacturing personnel realized that these systems were engineering prototypes, with a high potential for problems, was a difficult task. Most people were not used to seeing lab prototypes being built in a production process. Since the line was shared with currently shipping products, it was extremely important to ensure that building the prototypes did not impede shipping other products.

Prototype Management. Two operating system environments were required for the new servers, the HP-UX operating system release 9.04 and the MPE/iX operating system version 4.0. Since these environments were under development at the same time as our products, it was essential that hardware prototypes be delivered efficiently and be of sufficient quality to ensure expedient use by the software development groups. Thus, three key objectives were considered essential by the development groups. First, units had to be of the highest quality. Second, delivery of the units had to be on time. Finally, downtime because of hardware problems had to be minimized.

To accomplish the first goal, all prototypes were built using the entire production process. No prototypes were handcrafted in the lab. This ensured that units were built with the same quality standards as are applied to released systems. Additionally, each customer was assured of receiving the latest revision of materials released to production. Even new parts not covered under manufacturing release criteria were guaranteed to be of the same revision level. All revision levels were tracked on each unit for the life of the project.

For the second objective, a customer priority list was generated based on customer orders and needs. After the orders were submitted to the manufacturing systems, build priorities were set based on the critical needs being supplied first. From functional prototypes to production prototypes, upgrade kits were structured and made available. In cases where a new system was not required, customers had the option of moving immediately to an upgrade. Also, performance upgrades were designed to require a swap of the processor card only.

Tracking the revision level of all hardware was essential to achieving the third objective of minimizing downtime because of hardware. Another key point was being able to react to a customer's problem quickly. We used a prerelease support team at another HP division to ensure timely response. Spare material was purchased by the support team and defective parts were returned to the lab for analysis.

Using all these methods, we were able to achieve the goal of having all operational prototype units upgraded to manufacturing release equivalence before manufacturing release. This guaranteed test partners use of the machines for future development without the "not-quite-final-product" concerns.

We were not without our share of problems in terms of effectively managing the prototypes. For instance, several units were placed inside an environmental test chamber for weekend testing. During the early morning hours on a

Sunday, the temperature controller of the chamber went out of control, ramping the temperature to beyond 70 °C. The additional heat caused the fire sprinkler system in the chamber to turn on, flooding the chamber at a rate estimated at 10 gallons per minute. The units were standing in four feet of water, but with the disk drives external to the chamber, the test continued. When the chamber was finally shut down, the water mopped up, and the results checked, it was discovered that two of the seven units,which were on the top rack, out of the standing water, continued to operate without failure throughout the test. This test was affectionately named the "bathtub test."

Time-to-Market Focus. Establishing the time to market as the key objective for the program was not enough to ensure its success. The teams involved required constant reminders to stay focused on this objective and make trade-offs accordingly. Once the schedule was confirmed and accepted, it was important to acknowledge the progress. Any activities that appeared in danger of jeopardizing the schedule were reviewed and tackled accordingly.

However, the project team realized that in the past changes to system requirements had a big impact on meeting project schedules. Changes to system requirements to modify or include a feature that might improve sales or could be easily implemented at the cost of another metric might result in significant changes to the hardware or operating system design. In the case of the Model Ex5 and Series 9x8 servers, the system team implemented a process that was also used by the software development teams to control design changes. This process is called *change control,* which requires the change requester to provide a specific level of information to determine whether a particular change is viable. While this is not a new idea, the Model Ex5 and Series 9x8 development team elected to make one additional rule change. Each change request submitted would be briefly looked at to determine how the change would affect the base system. In other words, we wanted to ensure that a change was critical enough that it needed to be added to the products planned for the first release.

The hardware system team put on hold all change requests that were determined not to be required for the first release. To avoid causing lots of changes to the software after first release, some of the critical enhancements that were considered crucial to future sales were briefly reviewed and included in the initial software release. In some cases this meant no changes were required after the first software release. However, there were some instances of patches required for full functionality.

Customer Order Fulfillment Cycle Time

For the Model Ex5 and Series 9x8 servers to stay competitive, cost and performance were not the only items that played an important role. During 1993, it was clear that HP had an order fulfillment cycle time problem, which of course made our customers unhappy and affected our competitiveness. A task force was formed to address HP's order fulfillment cycle time problems. We found out that results from this task force would not arrive in time to help us with our new products. Thus, we formed a team seven months before introduction to ensure that the reduced order fulfillment cycle time process for the Model Ex5 and Series 9x8 servers was in place when the products were ready to be shipped to customers.

Our goal was to reduce the time between the receipt of a customer purchase order for a system and the time when the system is delivered to the customer site. We wanted to reduce this time by 75% of what it was for our existing servers. To accomplish this goal, the following changes were made before product introduction:

- The product structure was made much simpler and it includes fewer line items.
- Product offerings to distributors were unbundled.
- Product numbering for distributors' orders had a single SKU (stock keeping unit) for ease of ordering.
- The rules for our factory configuration system and field configuration system were mirrored.
- Early and proactive material stocking was performed before introduction to ensure that plenty of material was on hand to meet customer demand immediately.
- Factory acknowledgments were automated for clean orders.
- Intensive training was given to order processing personnel in the field and the factory about the Model Ex5 and Series 9x8 servers two months before introduction.
- Consignment, demonstration, and distributor units were stocked before introduction.
- More capacity was added to the factory, and assembly processes were streamlined.
- All new processes were tested intensively before introduction.

With these steps we were able to meet and exceed our order fulfillment goal.

Conclusion

The real success of the Model Ex5 and Series 9x8 server program was that the goals for fast time to market and reduced order fulfillment cycle time were achieved. These were major accomplishments considering the events that took place throughout the whole project including the development of a major VLSI component, consolidation of the design team from different divisions and locations, communication between different manufacturing entities, and a stream of last-minute catastrophes such as flooding prototypes in the environmental test ovens and several eleventh-hour VLSI bugs that had to be fixed.

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2. *Ibid*, p. 17.