# First Newton Offers High-Integration Design

## Single ASIC Combines All Control Functions

by Michael Slater

Apple's MessagePad, the first Newton product, packs a lot of capability into a compact, lightweight package. Newton's hardware and software design required many difficult tradeoffs, weighing performance against cost, power consumption, and size. The end result is an impressively simple hardware design that integrates all the system control functions into a single ASIC. The high level of integration is essential to the MessagePad's ability to pack all its capabilities into a 0.75" thick, 7.25" × 4.5" package that weighs only 0.9 pounds.

The ASIC is the heart of the MessagePad design. The ARM610 processor itself does not integrate any system logic or I/O functions. The only off-the-shelf system-logic chips available for use with the ARM processor were designed for desktop systems and are not appropriate to a PDA application, so it is not possible to build an ARM-based PDA without developing an ASIC. The Newton System Services ASIC (nick-named Runt)—a 256-pin, 40K-gate, 1.0-micron device fabricated by LSI Logic—is being made available to Newton licensees (see sidebar "Newton Licensing Opens Up").

According to Michael Culbert, manager of Newton's hardware design, the ease of system implementation is a major reason why Apple abandoned its original Hobbit-based design and switched to ARM. The cost issue was not the processor itself, but the expensive four-phase clock Hobbit required and the high external bus performance needed to provide acceptable processor performance. While the peak performance of the ARM chip is lower than that of Hobbit, Culbert said that ARM's performance per unit of power is much higher.

### Highly Integrated Design

Figure 1 shows a block diagram of the MessagePad. The ASIC connects directly to the ARM610 processor, the SRAM and ROM memory, the PCMCIA interface, and the LCD display. It also provides interfaces to the dual-channel serial controller (SCC), multichannel A/D, and sound output.

Newton's built-in software is stored in 4 Mbytes (1M word) of mask-programmed ROM, implemented with two 150-ns, 1M × 16 chips. A total of 640K bytes of SRAM is used for system data memory, including buffers for handwriting traces pending recognition, and for user program and data memory. This memory is implemented with four 85-ns, 128K × 8 SRAMs, providing a 128K × 32 memory, and a fifth 128K × 8 SRAM that provides a byte-wide, 128K memory. The unusual configuration represents a

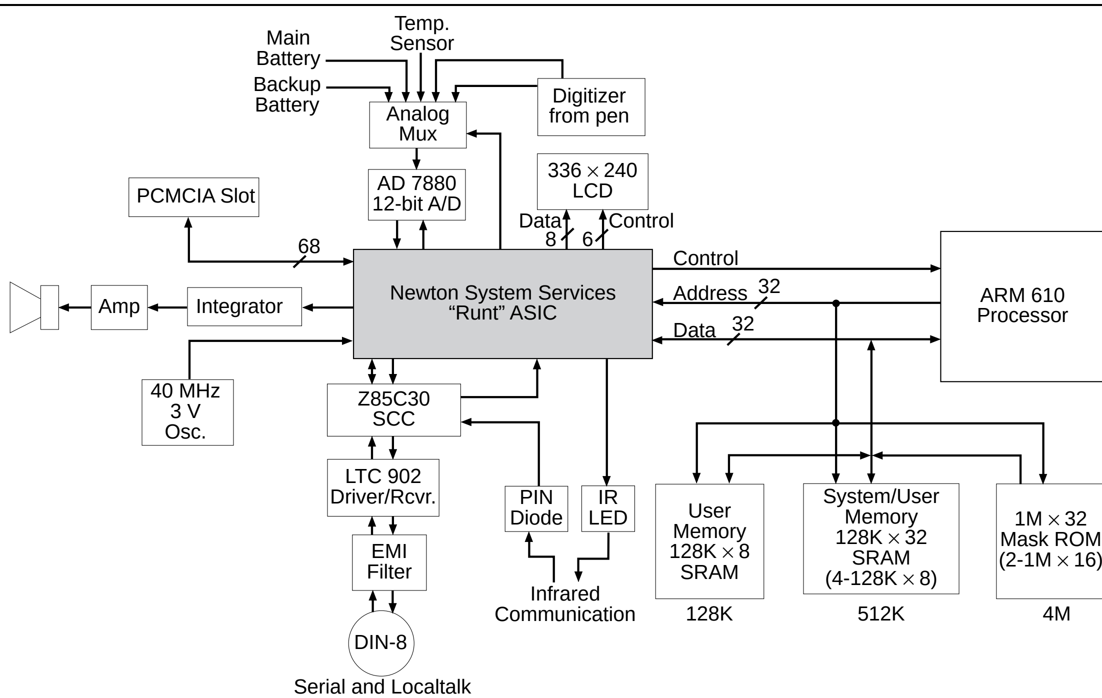


Figure 1. Block diagram of the Newton MessagePad shows all control functions implemented in a single ASIC.

 

compromise between the natural 512K and 1024K configurations. Of the 640K total, 192K is available for user programs and data. Of this 192K, 128K is in the byte-wide memory area; the rest is in the 32-bit-wide section. User programs are stored in an interpreted, byte-coded format, so fetch bandwidth is not a limiting resource and the byte-wide configuration is acceptable.

The MessagePad uses SRAM, instead of less costly DRAM, because this memory serves as the system's mass storage and must therefore subsist on battery power for long periods of time. Even low-power, self-refreshing DRAMs require much more power than SRAMs.

The ASIC is paced by a 40-MHz clock, from which the 20-MHz clock for the ARM610 is derived. This gives the bus-control state machines a resolution of 25 ns, while the CPU clock has a 50-ns cycle.

Each SRAM access requires two CPU cycles, or 100 ns, while ROM accesses require four cycles, or 200 ns. In addition, the first access in a series to either SRAM or ROM requires one additional cycle for address decoding and control delays. The ARM610 has an on-chip cache with a four-word line size, so instruction fetches typically occur in bursts of four accesses. The slow ROM represents another cost tradeoff; while the ARM610's 4K on-chip cache hides some of the memory access time, faster memory chips would improve the system's performance.

Programs and data can also be accessed directly from the PCMCIA slot, which is mapped into the ARM address space. PCMCIA accesses as fast as 100 ns are supported. Apple offers 1M and 2M flash memory cards for program and data storage; the MessagePad provides the 12-V supply needed to write to these cards.

PCMCIA hard disks cannot be used because of their power requirements. Also, Newton uses an object-oriented data base, not a traditional file system. This data structure is designed for semiconductor memory, not disk-based file systems.

Figure 2 shows a block diagram of the ASIC. In addition to interfaces for the processor, memory, and peripherals, it has a timer, a DMA controller, and a real-time clock.

The timer is a 32-bit, free-running counter that runs at 2 MHz (500-ns resolution). Four 32-bit comparators allow different intervals to be measured. The counter itself is never loaded; software simply reads the counter, adds the desired number of counts before an interrupt should be generated, and loads the sum into one of the comparators. This avoids the "lost time" problem that occurs when a timer, such as the common type used in PCs, must be reloaded after an interrupt; there is often no way to compensate for the latency between the interrupt and the reloading of the timer.

The DMA controller provides separate channels for each serial port and the sound port. The initial ASIC design provided DMA for the PCMCIA interface, but Newton software never used this feature and it has been deleted from the ASIC.

The real-time clock runs from its own 32-kHz crystal. In addition to keeping the time of day and generating wake-up alarms, this block of logic—which has the lowest power consumption because of its low clock rate—performs power sequencing and other power-management functions.

## Display and Digitizer

The MessagePad's primary user interface is via the 336 × 240 pixel LCD panel, which is covered with a transparent digitizer tablet. The LCD assembly, which is manufactured by Sharp, includes three row/column driver chips. Unlike traditional LCD panels, which require continuous refresh from an external LCD controller, this panel has a frame buffer integrated into the row/column drivers. This eliminates the need for any signaling to the LCD panel when the displayed information is not chang-

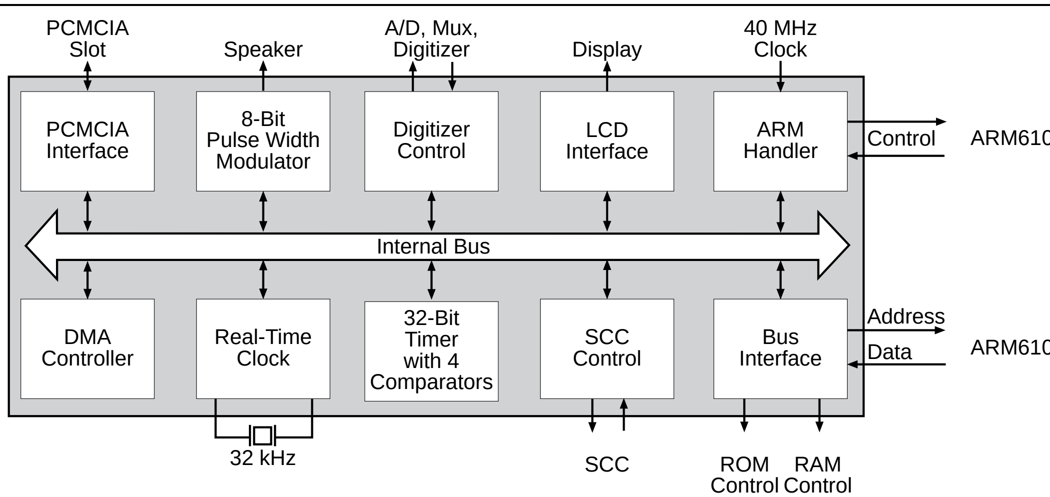


Figure 2. Block diagram of the Runt ASIC, which interfaces directly to the ARM610, RAM, ROM, PCMCIA, and peripherals.

 

## Newton Licensing Opens Up

When Apple first began talking about Newton, the stated licensing policy was one of picking a few selected partners. Apple's position was that the market would take time to grow, and that it was inappropriate to have a large number of licensees soon. While not as completely closed as Apple's Macintosh, this still left Newton somewhat short of fully open; for a company wishing to get into the PDA market that was not one of Apple's selected few, it meant that PenPoint was the only available option.

During the course of 1992, however, the situation both inside and outside of Apple changed. Other alternative operating systems emerged, including GeoWorks, which will soon be shipping in the Tandy/Casio Zoomer, and General Magic's Magic Cap, which has yet to be formally announced. Larry Tesler, who had led the Newton work at Apple, returned to Apple's Advanced Technology Group. Gaston Bastiaens, an executive from Philips, was brought in to run the Personal Interactive Electronics (PIE) division. Bastiaens' experience at Philips, where he was involved with the licensing of CD technology, instilled a bias toward fully open licensing. While it is not clear just when the official position changed, sometime in early '93 Apple dropped the selective aspect of Newton licensing.

So far, only four licensees have been announced: Sharp, Kyushu Matsushita Electric, Motorola, and Siemens/Rolm. Only Sharp has introduced a product, and it is very similar to Apple's MessagePad.

According to Subra Iyer, PIE's manager of licensing, Newton licenses are now limited to 10–15 companies because Apple has limited bandwidth to support them, but no companies have been turned away. Apple plans to provide technical support to all licensees and to ensure compatibility of all Newton products. Apple is also negotiating OEM arrangements in which the manufacturer (such as Sharp, which is making the MessagePad for Apple) sells the product to a third-party OEM, which puts its name on it. Apple then collects a royalty, just as it does from any Newton licensee.

At the heart of the Newton technology is the Newton operating environment, which consists of a multitasking operating system, forms engine, user interface, personal information management applications, and peripheral drivers. This software is licensed in object-code form only; Apple has no plans to license the source code, which is PIE's crown jewels.

Today, the Newton software is supported only on PIE's reference design, which is the MessagePad. Apple is now staffing up to support porting to other hardware designs, possibly including other processor architectures.

The core of the reference design is the Newton system services ASIC, which licensees can purchase from LSI Logic. For companies that wish to modify this design, Apple will license them the Verilog design files that define the ASIC.

Apple declined to discuss licensing fees, other than to say that there is an up-front, non-refundable fee, a per-unit royalty, and a required minimum number of units per year. This structure is presumably designed to make the cost-of-entry significant, so Apple can focus its support resources on those companies prepared to make a substantial investment. Apple said that there are no restrictions placed on the type of products licensees can produce, as long as they are compatible with Newton software; Apple is not trying to limit licensees to products that do not compete directly with Apple's.

ing, which is most of the time. In this quiescent state, the display consumes a maximum of 5 mW. There is no backlight, since this would dramatically decrease the battery life.

The display is a simple one-bit-per-pixel design, and unlike VLSI Technology's Polar chip set *(see **071302.PDF**)*, there is not a separate bit plane for "ink." The software does support various pixel depths, and PCMCIA display controllers for external monitors are expected to exploit this capability in the future.

Sharp has applied for several patents on the LCD design; it has not yet decided whether this display will be offered to other manufacturers. The LCD display is the single most expensive component in the system, representing more than 30% of the material cost.

Apple has designed another ASIC, nicknamed Squirt and not used in Apple's MessagePad, to interface the Runt ASIC to a standard LCD display. This allows larger LCDs or LCDs that do not have the proprietary internal frame buffer to be used.

The digitizer is a multilayer assembly, with indium-tin-oxide (ITO) coated Mylar on top, an insulating gel in the middle, and ITO-coated glass at the bottom. The pen is entirely passive; its only function is to apply pressure to the digitizer, so any object can be used as a pen. When pressure is applied to the surface, the gel is pushed aside and the ITO layers on the Mylar and the glass touch. The system alternately determines the horizontal and vertical positions of the contact by applying a voltage across the Mylar and measuring the voltage on the glass plate, or vice versa. Proprietary hardware and software, for which Apple has applied for patents, deal with multiple points of contact, which can occur if, for example, the user's palm presses on the surface at the same time as the pen.

The digitizer position is sensed by a 12-bit A/D converter, which gives a potential of 4096 points on each axis. The system resolves eight digitizer points for each displayed pixel, for an overall digitizer resolution of 2688 × 1920. This enhanced resolution provides the handwriting recognition algorithm with more detail than can be displayed. Traces are stored as compressed vectors, not as bit maps.

### Touch-Tone Dialing

The MessagePad's speaker is driven by an 8-bit pulse-width modulator, whose output is integrated and amplified. This very-low-cost sound system is adequate for simple sounds and low-quality music, and it can also generate the DTMF tones required for telephone dialing. The MessagePad can be used as an automatic dialer either by connecting it to the phone line via an external modem or by holding the speaker up to the telephone's microphone. The MessagePad has no sound input capability.

A serial communications controller (SCC) chip, identical to that used in Macintosh systems, provides two serial ports. One is used for the infrared link; the other provides an RS-422 or LocalTalk interface. The LTC902, a chip developed by Linear Technology for Macintosh PowerBook systems, provides all the line buffering required. The serial port can connect to an external modem, or to a host PC or Macintosh. It can connect to a LocalTalk network and access any LaserWriter printer on the network. With appropriate software on the Macintosh, it can also exchange data with any Macintosh on the network. The MessagePad will be able to exchange information with a range of Macintosh and Windows personal information manager programs via "Connection Kits."

The infrared (IR) interface uses one of the SCC channels to serialize and deserialize the bit stream. For the output channel, the serial data is passed through the ASIC, which modulates the 9600-bps data stream on a 500-kHz carrier. The half-duplex IR link uses a protocol derived from Sharp's Wizard, which enables it to communicate with that device. Newtons can also beam messages to each other—one can imagine bored attendees at a meeting pretending to take notes but actually beaming electronic gossip.

An IR interface for a Macintosh, a PC, or a LAN could allow Newtons to connect to desktop systems without wiring, but Apple has no announced plans for such products.

The IR output is capable of serving as a television remote control, given appropriate software (which is not part of the current MessagePad design). Because the IR input has a fixed, 500-kHz bandpass filter, however, it is not compatible with TV remote controls, so it cannot act as a "learning" remote; it would have to be programmed with the specific codes required for each brand of television and VCR. The IR port is unfortunately not compatible with that in HP's palmtops and calculators. This is a hardware limita-

## Newton's Portable Software

While the initial Newton products will all be ARM-based, the system has been designed to be as software-independent as possible. The Newton operating system is written almost entirely in C++, and the built-in applications are written in NewtonScript. According to Michael Tibbott, Newton's manager of software tools, only a half dozen files are written in assembly language. This will enable the Newton system to be ported to other processors with relative ease. Apple says that it will work with licensees to port the operating system when there is a compelling business reason to do so.

One likely port is to the PowerPC, which Motorola no doubt wants to use in its own Newton products. Motorola would surely like to convert Apple's Newton products over to PowerPC as well. This will require chips with dramatically lower power consumption than any PowerPC chips Motorola has yet described publicly. A low-power derivative of the forthcoming PowerPC 603 might meet this need.

One special feature of the ARM610 processor is the memory management unit (MMU), which was designed by Apple especially to support its object-oriented software environment. While it is in many ways similar to traditional MMUs, it has unusual support for object domains, which makes some aspects of the operating system (specifically garbage collection) more efficient. Porting to another architecture with a conventional MMU would therefore sacrifice some efficiency. Apple has the right to use the design of this MMU as it pleases, however, so it is possible that Apple will work with other processor suppliers to add it to their chips. Good candidates might be the NEC V800 family and the Hitachi SH7000 family, both of which are aimed at the PDA market but lack any MMU at all.

Newton applications—including those built-in to the Newton operating environment—are written in NewtonScript, an object-oriented, dynamic language. NewtonScript supports automatic memory management, incremental development, dynamic linking, self-identifying objects, and introspection. These features simplify the development process; Apple believes that developing Newton applications is significantly easier than developing Macintosh applications.

All third-party applications must be distributed in NewtonScript, which makes them processor-independent. A NewtonScript interpreter is part of the Newton operating environment. The NewtonScript development environment, which runs on a Macintosh, translates NewtonScript symbolic code into a byte-coded form interpreted by the Newton.

Interpreted software has a reputation for being slow. In Newton, however, most of the time-consuming functions are performed by the rich set of system services included in the Newton's ROM. A typical application will spend the majority of its CPU time executing routines from the ROM, not interpreting NewtonScript code. This also makes applications more compact.

Normal applications should never need to resort to assembly language. Some driver software for peripherals, however, must generally be written in assembly language to achieve acceptable performance. This makes hardware add-ons, such as the PCMCIA paging card, processor-specific. Apple has defined a mechanism for such devices to provide driver software for multiple architectures, allowing them to support various types of Newtons. They will require upgrading, however, when a new processor architecture is introduced; all of the initial Newton peripherals will support only the ARM processor.

 

tion, not just a software issue, so it will not be easy to change.

Apple sells the MessagePad bundled with an external fax modem and calls it the MessagePad Communications System. This modem can send faxes but cannot receive them, and when operating as a data modem, runs at only 2400 bps. The modem can be powered by two AA batteries or by the Newton AC power adapter.

Apple has announced a paging receiver for the MessagePad, developed by Motorola, that is implemented in a PCMCIA card with an external bulge. This card has an internal 68HC08 microcontroller that handles low-level paging functions, while software in the Newton handles higher-level message functions. The paging receiver and service are not yet available, but are promised for some time this fall.

While the omission of a built-in modem is one factor behind the MessagePad's small size and light weight, having to carry an external modem is inconvenient. Furthermore, the modem lacks 9600-bps data and fax-receive capabilities. A PCMCIA modem (from Megahertz Corp.) can also be used, which is more compact and provides higher data rates. It uses the internal Newton power supply, however, so battery life will be reduced.

Compared with Eo's Personal Communicator *(see **061509.PDF**)*, the MessagePad is very weak on its communications abilities. Some future Newton devices will presumably incorporate internal modems and possibly even wireless data or cellular telephone functions. Motorola, which is a Newton licensee and a major manufac-

## The Recognition Barrier

Much of the press criticism of Newton has focused on its poor handwriting (or printing) recognition. Handwriting recognition is the user's primary method for entering information into Newton or interacting with its programs; it forms an immediate barrier to using the machine. As a result, few reviewers have gotten as far as evaluating the quality of the built-in notebook, calendar, or address book applications in real-world situations. For a product of this physical size, keyboards are impractical, and the success of the PDA industry is dependent on good handwriting recognition. Since Newton doesn't even offer the option of a keyboard, handwriting recognition is doubly important.

Getting Newton's handwriting recognition to work acceptably is a two-way learning process: the Newton learns from the user's writing, and the user must learn to write in ways that are easier for Newton to recognize. Apple feels that users have been too impatient and haven't given Newton enough of a chance to get trained. But with recognition being critical to the device's usefulness, the number of prospective users may be significantly reduced if they have to endure an extensive training period. If Newton is going to replace paper pads for note taking, it must be nearly as transparent; users don't want their attention diverted to the mechanics of the process.

Newton uses more information in its recognition algorithm than appears on the display. The path of the pen is tracked with much higher resolution than is displayed, and timing information is also captured. As a result, it is not possible to defer the recognition; if information is stored as "ink," it cannot later be converted to text. This means that it's not possible to just scribble notes and worry about the translation later—recognition errors are constantly annoying. It's possible to let the translation occur without making corrections, and then clean it up later, but the translations are sometimes so bad that it is impossible to figure out what you have written.

Newton normally uses a dictionary, recognizing entire words instead of individual letters. This greatly enhances the recognition accuracy, but also exaggerates mistakes; Newton will sometimes choose a word that bears no apparent similarity to the intended word. It also means that Newton is guaranteed to select the wrong word if the intended word is not in its dictionary. Words can be added to the dictionary, but this is a tedious process. Word recognition can be turned off, but the overall accuracy of recognition then drops considerably. When names and addresses are entered, nearly every word is unlikely to be in the dictionary.

For Newton to be effective, users must be willing to put up with a long training period in which they adapt their handwriting, the system learns their handwriting, and perhaps most importantly, all the words they use often are added to the dictionary. Users must also remember to put the system in "guest" mode when someone else is using it, to prevent the system from adapting to other users and thereby reducing accuracy for the primary user. For some people, Newton seems unlikely ever to be good enough with the current software.

It is clear that Newton would be far more enthusiastically received by the public if handwriting recognition were much improved. Apple plans to open the recognition interface in the future, allowing licensees to differentiate their products through improved recognition engines or larger dictionaries, and possibly enabling third-party alternatives to appear. Apple surely is working furiously to improve its algorithms. Faster processors in future Newtons may also help improve recognition by allowing more complex algorithms to be implemented while maintaining an acceptable response time.

Apple made the task of providing good recognition especially difficult by deciding to support cursive, connected handwriting. Apple is considering adding separate algorithms for isolated, printed characters, for which recognition is considerably easier. This would be especially valuable when entering names and addresses.

This problem, we hope, will not be as elusive as high-quality, large-vocabulary speech recognition has been. Until it is solved, relatively few people will make it through this barrier to experiencing the value that Newton could provide to them.

 

turer of cellular telephones, would be a natural company to combine the two functions.

## A Pure 5-V Design

Newton draws its power from four AAA batteries. Either disposable Alkaline or rechargeable NiCd batteries can be used. A boost converter followed by a very-low-dropout linear regulator provides the system's 5-V supply. The internal charger provides trickle-charging from the external adapter, which provides approximately 7 V. An external fast-charger and a NiCd battery pack are available as options. Apple claims that with normal use, the rechargeable battery pack lasts about one week (4-16 hours of use), and disposable batteries last about two weeks (5-32 hours of use). Depending on their usage pattern, some users may find batteries last a day or less.

Because Newton is designed to hold critical user information in SRAM, continuous power is essential. A lithium battery supplements the main battery to provide power to the SRAMs and real-time clock while batteries are being changed. This battery will also keep the RAM alive for at least one year if the main battery dies.

Curiously, Newton is almost entirely a 5-V design, a decision that was driven by component availability. The ARM610, in particular, does not run at 3 V. (A revised ARM design that will run at 3 V, implemented in 0.8-micron instead of 1.0-micron technology, will soon be available.) Availability of memory and I/O chips, as well as PCMCIA cards, specified for 3-V operation is also problematic. A future transition to a 3-V system design will provide a relatively painless way to double battery life.

There is one 3-V component in the system: the 40-MHz oscillator. Unlike most devices, which typically consume about half as much power at 3 V as at 5 V, the oscillator uses only one-fourth the power of the 5-V version.

The Runt ASIC aggressively manages the system power, stopping the clock to the CPU when it is not needed and shutting down power to the peripheral chips when the system goes into idle mode. The system is entirely interrupt-driven. When the processor must take an action, an interrupt is generated and the CPU clock is enabled. When the action is complete, the CPU clock is stopped, cutting its power drain to under 10 µA.

## Cirrus to Develop New Chip Set

A second-generation pair of ASICs is under development at Cirrus Logic. This chip set is likely to be used in Apple's future Newton products, but unlike the LSI Logic ASIC, it is not being built specifically for Apple; Cirrus is developing it for all Newton licensees. Thus, it will probably be more flexible. The set is divided into an analog chip and a digital chip, enabling it to integrate all of the functions that require additional chips in the MessagePad design. The Cirrus chip set will reduce power consumption by running at 3 V and by operating entirely from the 32-kHz oscillator, with an on-chip phase-locked-loop creating the 20-MHz CPU clock from the slower-speed clock input.

Cirrus Logic is seeking an ARM license to enable it eventually to integrate the CPU core into a future chip set. This will take at least one more generation, however. Future implementations may divide into lower-performance designs that integrate the CPU core and the system logic, and higher-performance designs that keep the CPU separate to allow larger caches to be integrated on the processor chip. Because the off-chip memory is relatively slow, and object-oriented code tends to have poor locality of reference, larger caches on the CPU could significantly improve performance.

The MessagePad design illustrates the high degree of integration that can be achieved without adding application-specific functions to the processor itself. The single ASIC provides the vast majority of the support logic; unless all of these functions were integrated onto the processor, there would be little benefit in putting some of them on the processor and leaving some of them in a less-complex ASIC.

Newton will soon have at least four competitors: Eo's Hobbit-based PenPoint system, Tandy/Casio's Zoomer using an 8086-type core CPU and the GeoWorks operating system, 68349-based systems running General Magic's Magic Cap, and systems using chips with 386 cores running At Work, a derivative of Microsoft

## Newton Developer Resources

Prospective developers of Newton hardware should contact Mr. Subra Iyer, Manager, OEM and Licensing, Personal Interactive Electronics, Apple Computer, 5 Infinite Loop, MS 305-4Q, Cupertino, CA 95014; 408.974.7377, fax 408.974.6777, email iyer@applelink.apple.com.

For Newton application software developers, the Newton Toolkit is available from the Apple Programmers and Developers Association (APDA) for $695. The Toolkit includes a graphical development environment that runs on a Macintosh, and support software that runs on a Newton MessagePad. The Macintosh is connected to the Newton via each device's serial port. The developer can interactively lay out the user interface and manipulate objects to customize or extend their behavior. The application is then compiled into processor-independent byte-codes, placed in a package with other objects such as pictures and sounds, and downloaded into a MessagePad. The developer can monitor and interact with the application as it is executed by the interpreter in the Newton operating system.

NewtonScript documentation will eventually be made available as a separate publication, but now it is available only as part of the Toolkit. Order from APDA, at 1.800.282.2732.

 

Windows. Each platform will be distinguished in the eyes of users more by the software and the set of functions the system designer chooses to include than by the microprocessor architecture or chip-set design.

The effectiveness of the CPU and system-logic implementation, however, will be a major factor in the system's size, cost, speed, and battery life. The MessagePad design shows that the ARM processor, when supplemented by an appropriate ASIC, meets the needs of this application category very well. The forthcoming chip set from Cirrus Logic should go even further in reducing chip count while adding features, and the next-generation ARM7 CPU core will allow 3-V operation and improve performance. These designs will do nothing for ARM in non-Newton PDA applications, however, since only Newton licensees can purchase the ASICs.

The MessagePad design is much more highly integrated, though less flexible, than AT&T's Hobbit chip set. The forthcoming 386-based chip sets from AMD and VLSI Technology *(see* ***071302.PDF****)* come closer to the MessagePad's level of integration, as will AT&T's next-generation design. Motorola has developed a two-chip set for General Magic, using the 68349 CPU and a companion analog chip, that may provide the highest functional integration of all.

In comparing these implementations, however, it is important to keep in mind that this product category is still in its infancy, and the intense competition will ensure that PDA chip sets evolve rapidly in the coming years. Whether the market grows rapidly enough to justify all this development will depend on how quickly the software improves. ♦

 