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CONTENTS

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Wolfson Chips In

By David J. Weinberg, Associate Editor

While the IC manufacturing arena is dominated by several large companies, certain smaller companies hold a strong position in more limited parts of the overall market. One of those, Wolfson Microelectronics, successfully competes in their portion of the IC marketplace with Texas Instruments, ST Microelectronics, National Semiconductor, and ADI, thus deserving the recognition it has received.

Wolfson Microelectronics plc (a public limited company based in Edinburgh, UK; *www.WolfsonMicro.com; +44(0) 131.272.7000; USA: 858.676.5090*) is a respected manufacturer of mixed signal ICs that recently was named New Company of the Year—the latest in a string of awards over the past several years—and has moved into new headquarters.

The company is currently fighting a lawsuit filed by Cirrus Logic just days prior to Wolfson's October 2003 IPO. The complaint alleges infringement on two Cirrus Logic patents. Wolfson informed prospective investors immediately, and claims to have suffered no substantive loss of investment capital. Wolfson maintains, and has presented evidence to the effect, that prior art and other factors render the referenced patents invalid. The case is pending with the US International Trade Commission and in the US District Court for the Southern District of California.

Dr. David Milne (CEO and Managing Director) co-founded the company with Jim Reid in 1984 as a design house (no manufacturing). Milne had served the previous 12 years as director of the University of Edinburgh's Wolfson Microelectronics Institute, which pioneered engineering CAD software and integrated circuit design techniques. He was awarded the Order of the British Empire for his efforts. Milne is a Fellow of the Royal Academy of Engineering and of the Royal Society of Edinburgh, a member of the Court of the University of Edinburgh, plus an Honorary Professor [no teaching responsibilities] in the School of Engi-

Wolfson's WM8780 is a stereo audio ADC designed for high performance recordable media applications.

neering. Milne serves as non executive director [a member of the board, but not involved in daily management] of Edinburgh Research & Innovation and the Edinburgh Technology Fund.

James R. C. Reid (Chief Technical Officer and Technical Director) held design engineering positions at RACAL-MESL and the Wolfson Institute. He maintains his ties to academia as Visiting Professor of Engineering Design at the University of Glasgow.

Julian Hayes is Wolfson's vice president of marketing. In 1998 he brought to Wolfson his honors degree in Physics from Southampton University, plus over ten years in sales and marketing at Analog Devices.

Responses to my queries were provided by Hayes as I sought to learn more about how Wolfson continues to efficaciously serve corporate goals and their customers.

. . .

In their first 10 years of operation, Wolfson designed more than 100 ICs for chip manufacturers. At that point they "made the strategic business decision to become a supplier of our own proprietary products, based on our accumulated design experience," working with contract fabs for manufacturing and packaging. "Since then we have grown to employ almost 200 people in eight locations internationally, and in 2003 shipped over 86 million products worldwide, for total sales of about $76 million. Wolfson has sales offices in the USA, Japan, Taiwan, and China, with Korea coming soon.

"Among our staff are about 10 system level algorithm designers (signal flow and processing, such as the sigma-delta converter algorithms), 26 IC designers (who design the functionality of the IC), 12 IC layout experts (who undertake the detailed implementation of the functionality on silicon), 12 test bench chip evaluation engineers, 12 production test developers, and six back-end engineers (who turn the IC design into a product). There are other engineers involved in process, packaging, reliability, quality, etc. About 60% of Wolfson's employees have an engineering background. Everyone in the

Julian Hayes is vice-president of marketing at Wolfson Microelectronics.

marketing group has an engineering degree. Customers are buying into Wolfson's engineering and expertise."

WOLFSON'S STRATEGY

"Wolfson doesn't design chips specifically for the industrial market, which some of the other large chip manufacturers include in their product lines. We concentrate on the development and sale of high performance, mixed signal ICs aimed at high growth, high volume, broad-based markets worldwide, rather than at narrowly focused opportunities. Our overall strategy—our focus—is to address the wide spectrum of digital consumer applications. Our ambition is to supply mixed signal chips in every box that delivers audio/video capabilities, from high-end professional and audiophile devices down through low-end portable and mass-produced consumer products, because we see the best return-on-investment in this area.

"With each product, we generally have a lead application in mind, but try to be clever enough to make the chip sufficiently flexible to support multiple functions. For example, in one product—an ADC/DAC in one chip—adding two pins facilitated a DVD recorder application by enabling separate clocks to drive the ADC and the DAC. Naturally, additional capability adds cost, and with the competitiveness of the marketplace, we have to be judicious in adding such flexibility so we don't lose competitive pricing.

"Size of the die, size of the package, plus test complexity and duration are the main factors that affect our product prices. We sometimes put the same silicon in different packages that highlight different functionality, enabling the single design and silicon to best serve multiple markets. Different packages can result in significantly different test costs due to dissimilar package handling and test jig complexity.

"In the consumer electronics field, we have to be quite nimble to keep up with the dynamic market—upgrades in chip foundry processes and product capabilities have to be quite quick, with short lead times in development, design and manufacture."

WOLFSON'S PRODUCT LINES

"Our analog-intensive products provide an essential user interface to digital information, by converting between real world analog signals and digital formats. We sell more than 50 products to over 150 customers worldwide," strategically targeting markets such as audio and home theater equipment, DTVs, STBs, scanners, digital cameras, PDAs, and MP3 players. Their product lines feature digital audio (including ADCs and DACs—codecs in their terminology—plus Class D amplifiers), digital video ADCs, digital imaging CCD/CIS interfaces, communications ADCs, instrumentation (ADCs, DACs), and touchscreen controller ADCs.

They introduced their first audio product in 1998, and shipped their 40 millionth product three years later. In 2002 their catalog expanded to 50 models and Wolfson reregistered from a privately-held to a public limited company (WLF.L) that has been publicly quoted on the London stock exchange since last year, when they opened offices in China and expanded their lines further by introducing their first integrated audio and touchscreen codec for PDAs. Two recently released audio products [from their website] are:

1. A high-voltage high-performance, low cost stereo ADC designed for recordable media applications including DVD recorders, PVRs, STBs, and studio audio processing equipment.

2. A 2.1-channel Class D amplifier designed for applications including boom-

boxes, domestic stereo systems, active speakers and in-car audio. It offers 100dB SNR and 0.1% THD @ 30W per channel.

"While we have a few pipeline and successive approximation converters, almost all our audio devices use sigma-delta converters (five-bit for low performance applications; 6-bit for high end products). The reason for more bits is our use of a second order sigma-delta modulator to shape the noise. This low order modulator results in a lot lower amplitude of the ultrasonic noise, although it means more noise in the audio passband. In order to reduce that, we therefore need more bits. In addition, multi-bit converters are less sensitive to clock jitter than true single-bit systems.

"Certainly we work with key customers, like Dell and Compaq, in defining new products. Much thought and effort is put into how our products will be used by our customers, and how they will perform in customers' applications, plus the design and foundry processes.

"We also use our own analysis of trends in our existing markets, and are always looking at new markets that exhibit the high growth, high volume characteristics we prefer."

IC DESIGN

"Typically it takes 9-12 months from device inception to delivery. Market life tends to be 3-5 years.

"All of Wolfson's product development is done in-house, using design tools we developed. Most of our designs start with a manual chip layout of the key digital and analog blocks. Semi-automated synthesis tools (auto-routers) are used for the detailed digital layout; we use Verilog synthesis and auto-routing for standard digital blocks, and for our own custom blocks. We use H-SPICE (http://www.seas.upenn.edu/~ee562/hspice.html) and P-SPICE simulation tools to model our analog performance."

In the October 2003 *European Semiconductor* was Hayes's paper "The Challenges of 0.18 micron Mixed Signal Design" (also titled "Analogue and Mixed Signal Models for Deep Sub-Micron Processes"), in which he outlines the reasons Wolfson produces their own simulation models:

• As process geometries get smaller, "analogue and mixed signal designers (as the paper explains) require more detailed and accurate models, which take expertise, time, and effort for the foundries [fabs] to develop. Mixed signal design kits for the latest process geometries, where provided by the foundry, tend to emerge one or two years after the first digital components to benefit from the shrink. At the same time, EDA [Electronic Design Automation] tools that claim to solve the challenges to analogue and mixed signal design at the finest geometries make many assumptions that are difficult for designers to identify or verify . . .

Transistor-level models are usually adequate to allow a designer to make assumptions that will, in the vast majority of cases, lead to a workable solution. But as far as other parameters are concerned, for example 1/f noise, models either do not exist because digital foundries simply do not measure this, or the models are outdated."

• Graphics included with the paper display the higher errors of typical fab models when compared with newer models and measured performance. In the competitive world of chip manufacturers, greater accuracy in the models enables better performance prediction and better, lower-cost designs for a given set of objectives. The foundries' lag in characterizing their analog processes with the latest models makes the use of those older models unacceptable to Wolfson for mixed signal design.

Still from the paper: "While it might be feasible to obtain test structures from the new foundry first, from which to take empirical 1/f measurements, it is often more pragmatic to wait and solve all the issues that emerge with the new silicon when the first prototypes arrive . . . Analogue designers must also deal with the probability that neither models nor data exist for some of the parameters they must consider in high-performance design . . . Substrate modeling tools exist, and produce very attractive, coloured plots. But analogue designers trust CAD results in inverse proportion to the prettiness of the results obtained: the assumptions made by such tools about parameters such as package electrical parasitics, for example, are too deeply embedded within the tool for analogue designers to take on trust."

• As the paper goes on to explain, Wolfson has found that even modeling of packaging effects "can often be deficient," as well as those for the "interactions between digital and analogue domains . . . Slide-rule-wielding analogue designers still rely on traditional rules of thumb, gut feelings, and scar tissue from previous experience to try and achieve their design objectives. Simulation is an aid, but cannot replace true understanding of the physical phenomena involved. Any data or models provided by foundries are treated as suspect until checked and proven otherwise. Any new CAD tool is treated with even greater suspicion.

"To err is human, to be downright wrong is often the result of working through EDA tools at a high level of abstraction, which forces the designer to accept the assumptions made by tool developers. How much longer this attitude can prevail as mixed-signal design progresses into the era of million-dollar mask sets and ever decreasing timescales is a matter of conjecture. But obvious designer oversights remain the top items on the Pareto of design disasters, rather than the last dB or so of

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simulation accuracy. There is still no substitute for the pattern-recognition faculties of an experienced designer in reviewing the designs of others, to catch the mistakes he himself made several years earlier."

"Future Design Challenges for Audio Converter Products" by Wolfson's Hayes, Pennock, and Magrath (March 2004 *AES Journal*) discusses some of the computer models and silicon structures developed in-house, and how their staff works with their customers to help codify and prevent conditions external to the chip from affecting performance in the field:

• "We have more than a decade's experience designing products to work in consumer electronics applications, building up expertise in insulating the product design from the varied external environments provided by our customers. We aim to achieve datasheet performance right out of the box, in the customer's design. Specific actions include:

1. "We take a number of preventive measures at the design level to try to ensure that our design performs as closely as possible to spec, even in non-ideal 'real world' situations, which might include a large, noisy digital chip located close to our part; poor board layout; poor power supply conditions; and high levels of EMI (especially in mobile phones).

2. "Before we complete our datasheet, we build a customer application board (reference design), and take a hard look at the performance the chip delivers on that board in characterizing the datasheet."

Wolfson's engineers specialize in either analog or digital chip design, and work in concert on the mixed-signal chips.

"Our analog designers need to fully understand IC-device physics, as well as the manufacturing process. Although there is no formal program, our designers work very closely with the fabs to learn the idiosyncrasies of their processes and to help them optimize their operation for our designs—to refine and characterize their processes to make them more suitable for our mixed signal devices, and to add specialized process extensions to give us a competitive advantage.

"We try to support multiple routings [a single part manufactured by multiple fabs] for our key high volume products, in order to build robustness into the supply chain. We also take steps in the design to make transfer among fabs relatively easy, should this become necessary.

"All of our products are designed to minimize the performance variability that will occur when they are produced in multiple fabs. There is pressure from many of our customers to produce a chip on one machine in one fab, even requiring re-qualification of the process if a change is made. The auto industry is one of the strictest in that regard, but they are not alone. Our ability to produce consistent performance from a product made in multiple fabs tempers our customers' insistence on single machine production.

"The fabs give us a characterized process [a set of rules that attempts to fully define the chip design parameters for that foundry process]. However, we use our own design cell libraries, combined with simulation and evaluation of the results to help the fab improve its own characterization. Wolfson's ownership of the cell libraries and the characterizations enables us to send our chip design to multiple fabs, which verify that it doesn't violate any of their rules.

"Our designs require fab processes of 0.35 to 0.18 microns, with the sweet spot currently at the high end of that range. Cost is partially dictated by the feature set, die cost, and testing. Our mixed signal chips typically consist of 30% pads, 30% digital, and 30% analog. To use a smaller chip size that would result from a smaller geometry, the digital portion of the layout would have to shrink significantly, since pad size is relatively fixed, and analog performance is degraded substantially with reduction in wafer area.

"Only once, when designing a product for automotive use, did we design for a more aggressive [smaller geometry] fab process than then existed. We were successful, and the product is now going into production. However, in the foreseeable future we will be more circumspect about designing aggressively, because the fabs are now concentrating their investments on the 0.35 micron processes, and not on smaller element sizes. There are much more complex physics issues, economic considerations, risk concerns, etc., for the smaller process geometries.

"More than half our chips run on 5V because of the analog circuitry. We use 3.3V for almost all our other products, some of which also operate at 1.8V to give the customer the option depending on the application. We obviously pay more attention to power drain and heat dissipation in the lower voltage chips that are intended for portable device applications.

"Wolfson was one of the first to use the special low voltage processes developed by the fabs, and as a result went through 'teething' problems with those fabs to debug them."

SELECTING FOUNDRIES

"Wolfson's customer base is 'tier one,' thus we need reliable, high quality, volume manufacturing. This dictates the procedure we use to contract with a select few world-class fabs. Unfortunately, I cannot be specific about how that process is conducted. We do not issue a test contract to evaluate a fab's capability. Historically, we choose fabs based on:

• "How responsive the fab is—how open they are with their data, capabilities and problems; how well they work engineer-to-engineer with our people.

• "Although we use CMOS, and double poly-silicon, we need stable high quality linear capacitors in our mixed-signal chip analog circuitry (particularly in the low-voltage chips). There are only about half a dozen fabs with reputations for good mixed signal processes that meet our needs.

• "We need fabs that can produce the high quantity we sell.

• "We also require fabs with good customer service, good technology, and high quality—the fabs must have intrinsically high and consistent wafer quality, since we do no wafer testing, only testing the chip after packaging. Thus the silicon failure rate must be low.

"Part of our evaluation of a fab comes through our characterization of their processes. Last year we entertained a design with a new fab, and were able to determine that the fab was not going to be able to perform up to our standards for that product. As a result, we contracted with a different foundry. In other cases, we have been able to adjust the fab's process and our design to satisfy our requirements."

PACKAGING AND TESTING

"The fabs don't have test facilities—we use dedicated assembly [packaging] and test sites.

"All our products are surface mount packaged. We often put a single wafer design in different packages to take into account different OEM circuit board assembly capabilities.

"We normally use packaging houses not associated with a fab, and as much as possible maintain more than one source for each package type to ensure a reliable supply chain. We try to balance our manufacturing and assembly volume among fabs and packaging houses to maximize cost-effectiveness while retaining supply integrity.

"Wolfson staff develop and write all of their own test programs, prior to high volume manufacturing release. We use Image, a language specific to Teradyne testers, and we use Teradyne's own simulation software to check program syntax. Our selection process for test houses ensures that the facilities we have here at Wolfson are replicated exactly by our partners. We expect our test houses to achieve test results that are identical to ours; any variance is identified and addressed immediately.

"We use both bench testing and statistical analysis of prototype production runs to reach a final specification. We expect that when customers test any of our chips using one of our reference evaluation boards (which we make available), it will perform up to the published specification.

"We have test runs made prior to authorizing production, and tested both here at Wolfson and at our test houses to ensure agreement of results. All tests (first run and production) are performed after packaging.

"We include hooks for our own investigation (not accessible by the customer) to ensure acceptable quality in the designed and delivered products. These are used during both developmental testing and production checks. They are designed to not only find problems, but to identify where in the design and manufacture the problem occurred.

"There are two types of production testing:

- "A performance (or functional) test, which checks the integrity of all the signal paths, but only tests a subset of the performance of those paths.
- "For characterization purposes we run initial lot testing, and get skew lots on which full testing is performed. Most of the problems we find are in design, not from process characterization errors—the fab process causes few problems. Therefore the characterization process is to primarily find sensitivities and failures of design.

"Test patterns are written for every chip design that Wolfson produces. We aim for digital test coverage of greater than 95%. Our typical chip has 30-60,000 gates, so we don't test all combinations of all the gates, but we do test each block and gate. We also perform 100% functional and performance tests on the analog parts of each device.

"During production, the wafer batch is broken down into sublots, some of which are selected via sampling, and within which additional sampling is used to select individual chips for testing, to ensure consistency and performance.

"Mechanical evaluation is performed on a quality test lot before release for production—against moisture ingress (THB—Temperature, Humidity, Bias [powered analog circuit bias current]), soilability, HTOL, plus package- and process-related mechanical integrity tests—bond shear, solderability, etc.

"Our test sequence, based on our experience and probability-of-failure prediction expertise, is specifically designed to run first the tests that are most likely to find a problem. This reduces overall test time."

CUSTOMER SUPPORT AND PRODUCT DOCUMENTATION

Another part of Wolfson's success comes from the support they deliver to their prospective and contracted clients: in addition to personal expertise, Wolfson provides online access to extensive product data, FAQs, tech support, application notes, white papers, software drivers, plus quality and packaging information.

"We have a dedicated team committed to supporting our customers with detailed documentation for each device, plus additional hands-on assistance, as needed.

"Our product specifications are based on our experience with the reference design board. However, parametric specifications on the data sheets are only a guide—a précis of the performance. We find that because of our design philosophy, using multiple fabs for a single product causes less than 5% widening of the performance specs, versus using a single machine in a single fab.

"A product's document package runs 20–80 pages long (most often 40–50 pages), with typically less than five pages devoted to specifications. The remainder of the package is function-related, addressing applications and how to get the most from the product. If a customer asks for specific performance data, we will measure it. We don't normally do so because chip test time is a key constituent in product cost.

"All our audio products have digital filter specifications provided, including filter delay. Most don't include impulse response on the data sheet, because our customers seem uninterested; they haven't been concerned with pre-ringing from our mostly FIR filters, a parameter I feel is not adequately considered in use. We are researching this factor, and expect to announce products that improve this parameter later this year.

"We characterize each product over the temperature range of -55 to +100 degrees C. Our production testing is at 25 degrees C. If a customer asks, we will test a product over their requested temperature range.

"The customers usually do their own evaluation to more tightly characterize the performance of our chips in their application circuitry. At their request, we assist them with a free application circuit optimization service." Wolfson has added software driver development capability to its staff, an expertise that is marketed "only to support the easier evaluation of our devices (demonstration software)."

"One can never account for all the ways customers will use a product. What separates one company from another is how the issue is handled. We are always polite with our customers. It can often be quite difficult to replicate a problem in order to try to solve it and resolve the customer's issue. We add the data from each situation to our database, enhancing our simulation matrix, to prevent the problem's recurrence."

EPILOGUE

"We believe that part of our success in the hi-fi domain is the architecture of our chips, which might not show up readily on the spec sheet, but results in superior real world performance. As one example, our chips exhibit quite flat noise modulation versus frequency, while other chips might have peaks dependent on the input frequency. As another, "Design and Evaluation of an Audio DAC with Non-Uniformly Weighted Dynamic Element Matching" (by Wolfson's Hossack, Frith, Hayes, and Jackson; April 2001 *AES Journal*) presents a DC offset sweep test that describes performance not contained on the data sheet but shines a light on differences between two DACs that nominally have the same 117dB SNR performance. The SNR is determined by reading the THD+N with no offset.

"We offer chips for portable device use that have lower power consumption with higher performance than many of our competitors' devices.

"Our expertise and customer service has proven an important factor in our chips being selected for use in consumer electronics products worldwide. Microsoft didn't buy our audio chips for the Xbox program because they were the cheapest, but because Wolfson could provide them an understanding of the application they didn't have but needed—for example, with respect to the Dolby performance specifications: what qualitative and quantitative trade-offs would be optimal. This expertise has earned us some accounts and enables us to keep them.

"Wolfson's experts seem to have an ability to find out from the customer what they really want, through interpretation of what they say regarding their needs. This shows up in the very high success of our products; very few models are slow sellers. Our products are typically among the top three considered by equipment manufacturers needing mixed signal ICs." **MM**