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A Conversation with Strategy Analytics’ Ian Riches

As vice president of Strategy Analytics’ Global Automotive Practice, Ian Riches is one of the automotive electronics industry’s most qualified experts to deliver a well-informed analysis of where we are today and what to expect in the future. We recently had the opportunity to speak in depth with Mr. Riches on topics that are reshaping automotive electronics.

Will most carmakers gravitate toward domain architectures first, and then toward centralized, multi-domain-computing architectures?

“Broadly, yes, led by the premium manufacturers,” Mr. Riches said. While the migration won’t happen for all domains simultaneously, the sheer complexity and number of functions, as well as the number of modules in today’s vehicles, mean that centralization makes a huge amount of sense. “We are seeing ADAS domain controllers beginning to come to the market, Audi’s zFAS, for example. We are starting to see cockpit domain controllers coming from a number of OEMs, and we are hearing more talk about powertrain domain controllers and central gateways being employed.”

For many OEMs, he noted, the transition to domain controllers might proceed on a use case by use case basis. The next step after domain-based control is likely to be geographic-based control, where different functional controls could be integrated depending on where they are geographically located in the vehicle. Such a cross-domain approach would simplify the wiring harness design, but presents its own organizational challenges. Some of the biggest obstacles for OEMs to move away from distributed architectures are their legacy products and practices and the way their operations are organized, in addition to the formidable software challenges.

“Some of the most innovative, boundary-pushing architectures tend to be proposed by new entrants to automotive, Tesla for example, and the startups,” said Mr. Riches. “When I talk to suppliers I ask who their most challenging customers are, and it is often the case where it is these startups, because they have no legacy, no platforms to carry over. They are starting from a blank sheet of paper, which in some sense is a huge advantage. Tesla is certainly going down the ADAS domain controller route.”

With premium carmakers just getting started with centralized architectures, Mr. Riches thinks we are unlikely to see mass market changes until sometime after 2025. Higher levels of ADAS and automated driving functions—Level 3 and beyond—will be the primary drivers. “Doing Level 3 and beyond on distributed
systems just doesn’t make sense.” Strategy Analytics does not see a mass market developing for Level 4 functionality until after 2030.

Do you want to give a brief prognosis for each of the vehicle networks used by carmakers today? What other networks are coming in the future?

“LIN and CAN are highly cost effective, and with a lot of automotive stuff today being low bandwidth, they aren’t going to disappear any time soon,” he observed. “Automotive solutions generally hang around for a long, long time, but MOST is slowly on its way out, and we are starting to see a little Ethernet and also HDBaseT. The new Mercedes S-Class will use HDBaseT for its infotainment system.”

Valens Automotive, which will supply the HDBaseT chipset for Mercedes, claims that its newest chipset enables 2.5 Gb Ethernet over a single unshielded twisted pair (UTP) with near-zero latency. In contrast, the MOST 150 network only supports 150-megabit Ethernet. Valens’ technology was recently selected by the MIPI Alliance as the basis for its new Automotive physical layer (A-PHY) to provide high speed links for cameras, displays and sensors. MIPI’s final specification is expected to be released by the end of this year.

According to Mr. Riches, “Ethernet still has a rosy future, for use cases such as the main vehicle backbone, as higher speeds become standardized. And we still see a lot of interest in point to point links—SerDes solutions for connecting sensors into control units or connecting displays, where you need multi-gig capability.”

He does not expect to see many new high-volume FlexRay implementations. “FD CAN is starting to get there in terms of offering similar bandwidth as FlexRay, and for those who want some of the deterministic nature of FlexRay, there are Ethernet protocol time-sensitive networks they can move on to.”

Mr. Riches noted that PCI Express (PCIe), a long-distance (up to 15 meters) in-vehicle connectivity solution, is quickly gaining traction in the automotive industry. “It is linked with automated driving applications, domain control, and the need to link redundant ECUs or connect with a central storage unit. The option to use an automotive-grade multimeter-class link, rather than the centimeter-class solutions that are used today, is gaining a lot of interest.” He expects some low-volume robotaxi implementations of PCIe in the near future but nothing in high volumes until after 2030.
Will Level 3 highway driving come to market any time soon?
“All of Strategy Analytics’ user experience experts, and all the research out there says that to drop someone back into the driving loop at 80 mph on a highway after they’ve been reading a book or watching a film is a recipe for disaster, even if you do give them 10 seconds warning.” L3 will come to market in Europe and the U.S., but only in low speed applications such as automated parking or traffic jam assist.

Mr. Riches believes China, however, could be the outlier when it comes to L3. “There doesn’t seem to be as much concern over the handover issue there, but more importantly, China at the moment appears to have both the capability and the political will to invest more in an infrastructure that can support broader L3 solutions,” he said. That infrastructure would include V2X communications that provide additional information on traffic conditions ahead, accidents, severe weather conditions and road anomalies such as flooding or washed-out pavement. “Increasing that handover time could be key in getting a viable L3 solution.”

Can we live without lidar?
“Good question and the answer is nobody knows. I think the answer is both yes and no.” The lack of affordable, high-resolution lidar means scaling back the use cases that were first proposed for L2 driver assist systems, for example in terms of operating speeds or weather conditions.

“We are seeing a lot more interest in technology such as night vision or stereo vision, sometimes in combination, as well as new, high-end radars, such as imaging or cognitive radar, as well as thermal technologies.”

Strategy Analytics’ forecast for electric vehicle sales?
“We expect electrified vehicles to be about one-third of light vehicle production in 2026. The conventional full hybrid is pretty much stalling in the market—still around but effectively flat in terms of market penetration. We see development going either toward 48-volt mild hybrids or toward plug-in or battery vehicles.”

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<th>2022</th>
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<tr>
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<td>6.0%</td>
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The Hansen Report on Automotive Electronics, September 2019
www.hansenreport.com
German Carmakers Call for Global AV Safety Standards

Most of the leaders of Germany’s automotive E/E ecosystem showed up at TTTech Auto’s The Autonomous event earlier this month. They gathered in Vienna to lend their enthusiastic support to the industry’s drive for a common platform for autonomous vehicle safety. “Safety is so important, if we screw this up in the beginning [by causing a lot of accidents] it is going to delay everything,” asserted Michael Hafner, head of automated driving and safety at Daimler AG.

Conference chair Ricky Hudi pointed out in his opening remarks that mass adoption of electronic stability control systems and airbag systems was preceded by the creation of global safety references. He urged the industry to follow those examples by “taking a holistic, comprehensive and global approach to developing safety standards for automated driving systems.” Mr. Hudi, who was Audi’s executive vice president for E/E development from 2009 to 2016, is a co-founder of TTTech Auto.

The Regulation Challenge

AV developers are facing enormous challenges, one of the biggest of which is how autonomous vehicles and their use will be regulated. It is not at all clear what regulations will eventually be put in place. Regulators around the world have barely begun their work and are not at all in sync. A consolidated global effort to educate state and national regulators to commonize regulation is recommended. According to Benedict Wolfers, who led the safety and regulation workshop at the conference, “This is about managing expectations of the regulators, some of whom believe that automated driving will eliminate crashes.”

His workshop participants agreed that between the regulators and engineers working on autonomous vehicle safety, it’s the engineers who should lead the way in standards-making. The regulators writing the general requirements will defer to the tech standards. Mr. Wolfers is the founding partner of Posser Spieth Wolfers & Partners, a law firm specializing in regulatory issues.

Regulation is especially problematic to AV developers operating in Europe. Jan Luehmann, regulatory affairs specialist on automated driving for Audi, noted: “It is difficult because as you develop the technology you need to bring it on the road to test it. But you are not allowed to bring it on the road without standards and regulations in place.”
Another issue that is particularly confounding to developers of L3 automation in Europe is that the requirements today vary from country to country. Mr. Wolfers observed, “The rules for cars have always been regulated by the UNECE [United Nations Economic Commission for Europe]. The good news there is the UNECE is international. The bad news is it is extremely slow.” The rules for drivers, however, are national laws so, for example, “If you drive from Germany into Switzerland you will not be able to take your hands off the steering wheel,” Mr. Wolfers said. “The bad thing with that is you’ve got 28 member states.”

Some argue that it is way too soon to be thinking about standards for autonomous driving, that the technology must first mature; otherwise innovation will be stymied. Robert Siegel, partner in XSeed Capital, lecturer at Stanford Graduate School of Business, and a Wall Street Journal Startup Guru, moderated The Autonomous event. Mr. Siegel takes the opposite view. “It is time to start standardization,” he asserts. “There are processes and parts of the technology stack that should not be reinvented multiple times. To the extent that those can be standardized, companies will have the ability to focus on the parts that will be differentiating. … You won’t have, ‘here is the end point and we are done, it is frozen.’ But if you can get the baseline nailed down and standardized, then you can continue to work on improving things over time.” Mr. Siegel also serves on the advisory board for TTTech Auto.

**The Development Cost Challenge**

The other main challenge to AV development is its cost. According to Thomas Müller, vice president of development, chassis, ADAS and autonomous driving at Audi, who spoke at the conference, the financial effort required to fund development of advanced driver assistance systems and automated driving is exploding. For example, the cost to develop Audi’s second generation system was 170% greater than the first. Gen 3 is 350% greater than Gen 2. “It is very important that we are talking about advancing standardization,” he told attendees. “Why? Because it [AV development] is risky, it costs a lot of money, and it is very difficult to manage. We have already had a number of discussions in many circles, with all of you, on this topic, trying to align on the same language, on methods, especially on HMI and defining what is the threshold of testing for the safe release of these functions.”
Safety White Paper
Alejandro Vukotich, senior vice president for fully automated driving and
driver assistance at BMW, spoke at the conference about the Safety First for
Automated Driving (SaFAD) white paper that BMW along with Aptiv,
Audi, Baidu, Continental, FCA, HERE, Infineon, Volkswagen and Daimler
goal is to use this as a platform for communicating with authorities, the
industry, and with customers in different parts of the world,” said Mr.
Vukotich. He asked everyone to support this initiative. The paper lays out
12 guiding principles for safe L3/4 automated driving. These principles
form the basis from which safety-by-design methods and verification and
validation strategies are derived. Seen as a living document, SaFAD will
next be updated in 2020.

China
China is aggressively developing autonomous vehicle technology and will
likely put pressure on U.S. and European developers. Zu Sijie, vice
president and CTO of SAIC Motor, surprised a lot of people during his talk
when he said that soon China will have a total of 20 autonomous vehicle
demonstration zones. Nine have been set up so far. SAIC is the world’s
seventh-largest carmaker by revenue. In April, SAIC introduced the world’s
first mass-produced vehicle to feature a final-mile autonomous parking
function.

Reaching Out beyond Germany
As a first step, The Autonomous event was a huge success. It attracted 408
attendees, many of whom are key executives. The planners initially
expected 350 people to attend. All five German carmakers as well as the
Chinese carmaker SAIC, the major tier ones, semiconductor suppliers and
many startups were represented. The big U.S. and Japanese OEMs,
including GM, Ford and Toyota, were among the missing. Noticeably
absent too were AV developers Waymo, Cruise Automation, Zoox and
others who were invited but chose not to participate. A second Autonomous
event is planned for September 2020. By then, more developers may realize
the benefits of choosing not to compete on safety. “People are fighting over
profit pools so there is uncertainty. Some people are playing close to the
vest,” Mr. Siegel observed. “But this is still so nascent. Eventually people
will realize they need to work with others.”◆
Advanced Safety Systems Becoming Affordable for Mass Market Vehicles

As the automotive industry deals with declining sales and shrinking margins due to the slowdown in global demand, global economic uncertainties, and increasing investments required for electric and autonomous vehicle development, which won’t yield returns for several years, there is a bright spot. While the promise of fully autonomous mobility is still years away from realization, the advanced electronics and software already developed for AVs is being widely deployed in advanced driver assistance systems. Tesla, Nvidia and many consumer media outlets use the term autopilot for some of this, but as yet there is no feature on the market that will safely function without human intervention in all conditions.

Motor vehicle deaths in the U.S. were down 3% during the first half of 2019, after climbing for four consecutive years. But the annual rate of fatalities per miles driven has remained stable, according to the National Safety Council.

Safety Democratized
Forward collision warning (FCW) with automatic emergency braking (AEB) was shown to reduce front-to-rear crashes by 50% compared with cars without the feature, according to the Insurance Institute for Highway Safety (IIHS). Forward collision warning alone can reduce crashes by 27%. In the U.S., the number of models in which FCW with AEB is a standard feature has been increasing modestly over the last three years, reaching 28.1% penetration in model year 2019.

**Percentage of U.S. vehicle models with forward collision warning with automatic emergency braking, 2017 – 2019 model years**

- **2017:**
  - 14.9%
  - 38.8%
  - 46.3%
- **2018:**
  - 24.3%
  - 37.3%
  - 38.4%
- **2019:**
  - 28.1%
  - 35.7%
  - 36.2%

Data: IIHS

The Hansen Report on Automotive Electronics, September 2019

www.hansenreport.com
Automatic emergency braking is required in Europe for a car to earn the top five-star Euro NCAP rating for safety. In the United States, NHTSA reached an agreement with 20 carmakers who voluntarily committed to equipping all their new vehicles with AEB as a standard feature by September 2022. According to NHTSA’s last report in March 2019, Tesla and Volvo lead the pack, both with 100% of 2019 models AEB-equipped. Toyota, among the world’s largest mass market manufacturers, and number two in unit sales in the U.S., has 90% of its new vehicles in compliance already. Lagging the field are General Motors and Fiat Chrysler with no standard AEB in any models. Ford reported 36% of models with standard AEB.

The major Japanese carmakers are including advanced safety systems in more entry level cars. Honda recently announced that its 2020 Civic Si, with an MSRP starting at $25,000, will come with the full Honda Sensing suite of safety and ADAS features as standard equipment. It plans to expand Honda Sensing throughout its line up by 2022. Nissan’s Safety Shield 360 is available on most models, including the high volume Altima, for example. Toyota’s Safety Sense, first introduced in 2015 and now in its second generation, has been standard on most Toyota models since 2018.

The IIHS rates the performance of vehicles whose forward front crash prevention systems detect and brake for pedestrians. The top performing vehicles for 2019 were the Honda CR-V, Subaru Forester, Toyota RAV4 and Volvo XC40.

Despite data showing that blind spot detection systems can reduce some types of lane change crashes by up to 23%, the feature is standard in only 15% of new vehicles. It is available in higher trim models or option packages in 85% of models, according to Consumer Reports magazine. In a survey of consumers on their experience with blind spot warning, 66% of respondents said the feature helped them avoid a crash. When assigning overall scores in its vehicle ratings, the influential magazine gives extra points to vehicles with blind spot warning as standard equipment, a decision it hopes will stimulate faster market penetration of the feature.

**Rear Occupant Detection**

Sadly, vehicle crashes are not the only danger vehicle makers need to address. So far this year 39 children have lost their lives to heatstroke after being left behind in hot cars. Carmakers serving the U.S. market have agreed to voluntarily equip all their passenger vehicles with rear-seat occupant reminders to prevent such tragic losses starting in model year 2025.
Hyundai’s basic ultrasonic rear occupant detection system senses if a rear door was opened or closed before the car was started and reminds the driver with a message on the cluster to check the back seat. The latest version of the Hyundai feature adds an ultrasonic sensor to detect movement of a child or pet after the driver leaves the vehicle and locks the doors. It sounds the horn and sends an alert to the driver’s phone via Hyundai Blue Link system. The feature is available as an option in the Santa Fe and Palisade SUVs and by 2022 will be standard on all models. Kia, Nissan, GM and Subaru also offer rear occupant detection on some models.

**Driver Monitors**

In the U.S., distracted driving kills nine people and injures 1,000 every day, according to the Centers for Disease Control and Prevention. Smartphones are a major contributor of course, but the proliferation of L2 driver assistance systems that ease the demands of driving will likely add to the problem of keeping the driver’s attention focused on the road. Regulatory bodies in the U.S., Japan and Europe are considering driver monitors as part of the solution. Camera systems to monitor driver drowsiness, largely by tracking head position, have been used for more than a decade in a handful of models, but more sophisticated algorithms available today are being used to improve the precision of monitoring systems. The market for driver monitors is expected to increase by 11% annually from 2019 to 2023 according to a recent report by Technavio.

Cadillac includes a driver monitor in its Super Cruise highway pilot feature to ensure that the driver stays focused while the system is engaged. Camera-based systems can precisely track eye movements and gaze patterns and determine the driver’s state of attention as well as fatigue. They can also include facial recognition.

Subaru introduced DriverFocus on the 2019 Forester standard on the Touring trim level, and is expected to expand the offering in the next few years. The system uses infrared sensors and facial recognition to determine if the driver is fatigued or looking away from the road for more than three seconds. If the driver fails to respond to warnings, the vehicle slows to a stop. DriverFocus can recognize up to five individuals and keep track of their pre-set preferences for seat position, music and climate settings.◆
Highlights from McKinsey Report, 
*Automotive Software and Electronics 2030*

In July, the elite consulting company McKinsey & Company published a report on the future of automotive software and electronics that is well worth the time spent studying it. Over the years I have read many reports like this one from major consulting companies and automotive equities analysts, but often the authors’ understanding of our technology and business seems newly acquired or tangential. However, this report stands out. It is comprehensive. Its predictions are bold, specific and well founded. Most importantly, it rings true.

◆ **Growth will be driven by ACES**

“Autonomous driving (AD), connected vehicles, electrification of the powertrain, and shared mobility (ACES) are mutually reinforcing developments in the automotive industry. Combined they are not only disrupting the automotive value chain and impacting all stakeholders involved but are also a significant driver of the expected 7 percent compound annual growth rate in the automotive software (SW) and electrical components (E/E) market, i.e. from USD 238 billion to USD 469 billion, between 2020 and 2030. At this rate, the SW and E/E market is expected to vastly outpace growth in the overall automotive market, which is estimated to grow at 3 percent CAGR in the same time span.”

◆ **Growth within the software and E/E components market will be uneven.**

“Significant variation is expected across the market’s various segments. Power electronics is expected to occupy the high end of the market’s growth at 15 percent CAGR. Growth in the SW and sensors segments, expected to be at 9 and 8 percent, respectively, will be fueled by AD. The ECU/DCU (domain control unit) segment will continue to hold the largest share of the market, but growth here is likely to be relatively low, at 5 percent. … Electric vehicle (EV) platforms will be a new market for high-voltage harnesses, while the demand for low-voltage harnesses is expected to shrink, resulting in the harness segment growing at the slowest rate.”

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The 2030 Automotive Electronics and Software Market by Geography:

2030 Market Total: $469 billion

- EU, 23.9%
- China, 34.3%
- U.S., Canada, Mexico, 14.5%
- Korea, Japan, 10.7%
- RoW, 16.6%

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The Hansen Report on Automotive Electronics, September 2019
www.hansenreport.com
◆ **Automotive SW and E/E Content per Car**

Content in traditional SAE AV Level 1 volume cars [with ICE powertrain] in the B segment will change only marginally. While more functions will expand into the mass market, commoditization of electronics and software functions due to standardization of the architecture and scale effects will lead to decreasing prices, keeping content per vehicle stable, rising only slightly from USD 2,023 per car in 2025 to USD 2,210 by 2030.

“Electronic and SW costs for [purpose built BEV] robotaxis will be significantly higher [than for L1 vehicles] in 2025, driven primarily by high costs for sensors as well as a low vehicle [volume] base, across which significant SW costs for SAE AV Levels 4 and 5 can be distributed. With increasing numbers of robotaxis and commoditization of sensor technology (especially lidar), robotaxis will see a significant drop in SW and electronics costs by 2030, improving the business case for them.” Per vehicle content in robotaxis will drop from USD 38,297 in 2025 to USD 19,453 in 2030, according to the report.

SW and E/E components in premium SAE Level 3 vehicles with PHEV powertrains will slightly devalue, from $15,361 in 2025 to USD 12,987 in 2030, due to scale effects. “The largest drop in individual contribution to cost will happen in SW as standardization and application of SW on a larger vehicle base, at nearly zero marginal cost, allows for better distribution of initial development costs,” the report states. The cost of software will decline from USD 2,888 per car in 2025 to USD 1,732 per car in 2030.

The 44-page McKinsey & Company report is available to download [here](#). ◆
The Company Profile: Analog Devices Inc.

**Thumbnail Sketch**

*Analog Devices’ fiscal year 2018 ended November 3, 2018.*

**Headquarters:** Norwood, Mass., USA; [www.analog.com](http://www.analog.com)

**FY 2018 Revenue:** $6,200.9 million

**R&D:** 18.8% of revenue

**Capital Spending:** 4.1% of revenue

**Interest Expense:** 4.1%

**Operating Margin:** 30.3%

**Net Margin:** 24.1%

**Net Cash Provided by Operating Activities:** $2,442 million

**Working Capital:** $532.4 million*

**Long-Term Debt:** $5,279 million*

**Shareholders’ Equity:** $11,790 million*

**Market Capitalization:** $40,823 million as of August 21, 2019

**Employees:** 15,800 as of fiscal year end 2018

**Revenue per Employee:** $392,462

**Key Products:** Data converters, amplifiers, power, RF and microwave, MEMS, DSPs

**FY 2018 Automotive Revenue:** $989 million

**Key Products:** Signal-chain, sensor and power management ICs

*As of August 3, 2019

**Background**

Electronics pioneers and MIT graduates Ray Stata and Matthew Lorber launched Analog Devices in 1965, in Cambridge, Massachusetts. Their focus was on manufacturing high-performance operational amplifiers for a developing test and measurement market. According to ADI, the company made money from the get-go: sales reached $5.7 million within three years and Analog Devices went public soon thereafter, in 1969. Much of the

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*The acquisition of Linear Technology Corporation on March 10, 2017, added revenue to these years.*

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**Analog Devices Revenue and Net Margin by Fiscal Year**

*2014 to 2018 CAGR: 21.3%*

<table>
<thead>
<tr>
<th>Year</th>
<th>Revenue</th>
<th>Net Margin</th>
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<tr>
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<td>2018*</td>
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**Net Margin by Fiscal Year**

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**Analog Devices Revenue by End Market**

*2018 Total: $6,200.9 million*

- **Industrial, 50%**
- **Communications, 20%**
- **Consumer, 14%**
- **Automotive, 16%**

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*The Hansen Report on Automotive Electronics, September 2019*

[www.hansenreport.com](http://www.hansenreport.com)
company’s business was with military and industrial customers and involved custom designs for specific applications. In 1977 the company opened up its first semiconductor manufacturing plant outside the U.S., in Ireland.

Analog Devices organized its MEMS (micro electro-mechanical systems) division in 1992 and launched its first MEMS-based product, an airbag sensor, in 1993 as carmakers were ramping up airbag installations and regulators were considering making them mandatory.

The company reports sales in four end-market segments: Industrial, the largest segment, Communications, Consumer and Automotive. The Automotive business remains a relatively small part of Analog Devices, accounting for just 16% of sales in the last fiscal year.

Why do automotive customers choose to work with Analog Devices? “We hang our hats on performance,” said Chris Jacobs, vice president of autonomous transport and automotive safety. “Whether it’s our IMUs [inertial measurement units], our signal-chain components, our radar transceivers or our power management, the first thing we want to differentiate on is performance. We also emphasize our system-level understanding. Before going in to a customer, we do a lot of homework so we can talk holistically about the system they are trying to develop. We like to work together with our customers, see how we can supplement their engineers.”

The Hansen Report on Automotive Electronics, September 2019
www.hansenreport.com
ADI is proud of its culture of innovation. It invests a high percentage of revenue—more than 18% in each of the past five years—on R&D, while maintaining strong profit margins. Net margins exceeded 20% in four of the past five years.

**Linear Technology Acquisition**

On March 10, 2017, ADI acquired Linear Technology Corporation (LTC) in a cash plus stock deal valued at $15.8 billion. LTC’s two biggest products at the time were power management solutions and amplifiers. Automotive accounted for 20% of LTC’s revenues. In fiscal 2018, LTC added $339.9 million to ADI’s automotive revenue. According to the company, the combination with LTC established ADI as the global high-performance analog industry leader in data converters, power management, amplifiers, interface, and RF and microwave products.

The power management capability that came with the Linear Technology acquisition now accounts for roughly one-third of ADI’s automotive business. A key component of that legacy is the coulomb counter IC, a mixed-signal device that accurately measures battery capacity.

**Automotive Business Today**

Analog Devices shipped $989 million worth of high-performance analog products to automotive customers in 2018. Three key products underpin that automotive business: MEMS safety sensors (crash and stability control), a DSP platform for high-end audio, and power management solutions.
MEMS Safety Sensors
Analog Devices has been shipping monolithic MEMS airbag crash sensors for more than 20 years. The integrated solution combines the sensor elements with data conversion circuitry and output via a PSI 5 interface. ADI also has a suite of gyroscopes and combination products for stability control applications. While these types of sensors have by now become commodities, Analog Devices continues to develop the technology that underpins these sensors, accelerometers and gyroscopes.

Audio Processors and Connectivity
◆ SHARC Audio Processor
Nearly 20 years ago ADI optimized DSP technology for use in premium audio systems and branded the outcome of that effort as the SHARC processor. The processor comes with software and a suite of development tools.

◆ A2B Automotive Audio Bus
Developed by ADI, A2B connects the audio head unit with multiple speakers via twisted pair cabling. A2B carries the audio signal and power and features ultra-low latency. “Low latency is needed because your ear is great at picking up slight differences in time delay,” noted Patrick Morgan, vice president of electrification and infotainment for ADI.

ADI booked a lot of design wins for A2B products in 2014-2015, business that is ramping up now. The total number of A2B nodes shipped will exceed 10 million this year. That number will grow by 10 times over the next five years. There is one node for each group of speakers, plus the head unit.

![ADI Diluted Earnings per Share by Fiscal Year](chart)

From August 2004 to August 3, 2019, Analog Devices repurchased 152.9 million shares of its common stock for approximately $5.9 billion.

![Distinctions Claimed by ADI](distinctions)

◆ The premier analog technology company with the industry’s most comprehensive suite of high-performance analog offerings
◆ Provider of the highest performance battery management system for EVs and HEVs
◆ First to offer a monolithic airbag sensor based on MEMS technology, in 1995
◆ First to market with CMOS digital-to-analog and analog-to-digital converters

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The SHARC audio processor and the A2B bus underpin the new high-performance audio systems supplied by Harman under the Revel brand for new Lincoln models. The system supports up to 28 speakers.

**Power Management**

- **12-Volt Stop-Start Battery Management System (BMS)**

On its website, ADI claims that it has “set the industry standard for 12V stop-start BMS by integrating the complete systems into one market-dominating system in package (SiP).” The system includes dual precision A-to-D converters, ARM processors, flash memory and transceiver.

**Automotive Business Looking Ahead**

With several new applications in development, including power management technology that came from Linear Technology, ADI’s automotive served market will accelerate from $250 per vehicle in 2017 to $800 per vehicle by 2025.

- **77/79 GHz Radar MIMICs (millimeter wave monolithic integrated circuits)**

The market for automotive radar is transitioning from 24 GHz to 77 or 79 GHz sensors. They are smaller and promise significantly better resolution. The market for 24 GHz radar is expected to peak in 2022 and not survive much past 2024. ADI provides signal-chain chips—for signal conditioning, data conversion and power management—to most of the tier-one suppliers of 24 GHz radar sensors. The sensors are used widely for blind-spot detection, an application that has matured.

ADAS and autonomous vehicle developers now want much better resolution from radar to fully complement camera and lidar sensors. According to McKinsey & Company, the ADAS and AV market for radar will accelerate from $4 billion in 2020 to $14 billion by 2030, a 13% annual growth rate. “We are focusing on 77 GHz radar solutions because, one, that is where the growth is, and two, getting good 77 GHz performance on CMOS is very difficult. We believe we can differentiate on performance,” asserted Mr. Jacobs. “Our integrated 28nm CMOS solution has leapfrogged the competition. It has very good power consumption and very low phase noise. The chip is software configurable to support both the 77 GHz and 79 GHz frequency bands.” ADI is presently sending final samples to prospects, targeting model year 2021 and beyond.

ADI is taking a two-track approach to winning radar engagements. In track one, the company is focused on the autonomous vehicle developers on the West Coast of the U.S., the so-called disrupters, who are developing robotaxis. “We want to capture the performance high ground with a solution that gives you the raw data output needed for sensor fusion,” said Mr. Jacobs. Robotaxi developers are working on high-end radar solutions that are able to provide camera-like images. To achieve that they are cascading multiple transmit and receive chips and

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feeding the raw data to powerful processors that fuse the radar output with camera and lidar outputs. Some front-facing applications are calling for as many as four chips, each with three transmit and four receive channels.

In track two, ADI is focusing on the tier-one radar developers (including Aptiv, Bosch, Continental, Denso and others) who are developing premium ADAS systems for the broader personal-ownership car market. In contrast with the disruptors, the tier ones want robotaxi performance but are far more demanding in their cost, size, weight, and power and thermal management requirements.

To answer the cost demands, ADI is offering cooperative radar software, which it packages with the silicon hardware. Today, each corner radar operates independently. Cooperative radar is different in that the transmissions from one corner radar can be captured by a second. They have overlapping fields of view, providing double the number of reflections from the target, which yields a clearer image. That translates into increased angular resolution by a factor of two without doubling the hardware. ADI is targeting model year 2024 for this product.

ADI is aiming its radar wherewithal at high-speed autopilot applications capable of unambiguous detection of an oncoming vehicle traveling at 160 km/h, while traveling at 160 km/h. No radar can do that today. A second key application is valet parking that allows the driver to exit the car and let the vehicle park itself in a mapped parking garage.

◆ Lidar
At $1,000 per unit, lidar is not at all ready for the high-volume automotive market. According to McKinsey, that market won’t significantly kick in until after 2020, climbing quickly to $12 billion by 2030. ADI is already exploring ways its high-performance semiconductors can contribute to making lidar less costly, smaller, lighter and less power hungry.

“We have to get the heat out of the system,” suggested Mr. Jacobs. “We want to improve the electrical signal chain, which accounts for half of the sensor’s cost. Our power management solutions can help. We also have very high performance A-to-D converters as well as low-noise transimpedance amplifiers.”

Transimpedance amplifiers (TIAs) are key for lidar systems to reach the level of performance required. When coupled with a high-performance photodetector, a low-noise system can be achieved by minimizing the impact of capacitance and dark current. ADI has a partnership with First Sensor to pair its automotive qualified TIA with First Sensor’s photodetector to achieve low noise performance. They are working with a European tier one who is developing the lidar sensor.
“Forty companies are investing in lidar sensor development. Some use a FMCW [frequency modulated continuous wave] approach. Others use a direct detect approach, which is pulse radar. Some are based on 900nm wavelengths. Others are on 1,500nm wavelengths. We have adopted a strategy to serve all these approaches,” said Mr. Jacobs.

◆ **IMUs**
Analog Devices has been delivering inertial measurement units to its aerospace and defense customers for 20 years. Its IMU sensors are based on multi-axis combinations of precision gyroscopes, accelerometers, magnetometers and pressure sensors. They have been typically applied in systems such as airline autopilots or missile-guidance systems to enable dead reckoning and minimize drift. ADI has used lower performance versions of the technology in passive safety systems including crash sensors and stability control. It is now working on bringing high performance military/aero grade IMU technology to automotive applications.

According to Mr. Jacobs, ADI’s most advanced AV development customers, the West Coast disrupters who have already gone through all the different esoteric use cases for Level 4 applications, are the customers that very quickly got to the conclusion that for some corner cases, you really need an IMU. “When the GPS is spotty, in urban canyons or in tunnels, you need to have that IMU to complement your radar, camera and lidar systems,” he said.

ADI is in the process of automotive qualifying its IMU and brought down its cost to the “two-digit dollar range.” To help support that price, the IMU will also take over gyroscope duties for the electronic stability control system. Most OEMs aren’t yet ready to consider IMUs, with the exception of some of the Chinese manufacturers developing L3 applications. IMUs could find their way into Chinese vehicles in 2021 or 2022. In North America and Europe, that’s not likely until 2023 or 2024.

◆ **Battery Management Systems**
Taking off from its 12V start-stop battery management chip solutions, ADI has high expectations for its high-voltage battery management solutions. The number of high-voltage xEVs produced each year will grow, and the battery voltages for those vehicles will get much higher as we transition from hybrids to battery electric vehicles. Higher voltages mean more battery cells to manage.

ADI’s chips precisely monitor cell voltage and current to balance the charging and discharging of those cells. Precise battery management leads to greater range that the xEV can drive between charges. “The system has to be rock-solid robust,
always making measurements down to the one millivolt level but also has to be able to handle a range of three to five volts across it,” noted Mr. Morgan. “Some of our competitors say they can provide 8 millivolts of accuracy over product lifetime. We give you a factor of three better than everyone else and guarantee that accuracy over all conditions for the lifetime of the product. We have unique IP in this area and we can back that up with data.”

ADI believes the best accuracy translates into the longest vehicle range, which is a critically important factor to enable mass market electric vehicles. But while accuracy is essential, it is not sufficient—the system must also be fully comprehensive in terms of diagnostics and safety. Battery management should be provided as part of a full system approach, enabling customers to achieve the best performance at a competitive total value.

“The electronics are less than 5% of the cost of a typical EV battery, yet they provide a tremendous amount of value to the end customer in terms of range, safety, fast charging and system value,” Mr. Morgan noted.

ADI’s battery management technology originated with Linear Technology, which began shipping its battery management solutions in volume ten years ago.◆
PEGASUS Develops Method to Assess Highly Automated Driving Functions

The PEGASUS project, which completed its 42-month term in June 2019, can be credited with coming up with a widely accepted overall model for assessing and proving how safe an automated vehicle will be on public roads. We first reported on the goals and progress of the project in the *February 2017 Hansen Report*.

According to PEGASUS organizers, while the project did not solve every challenge within the model, it was probably the first effort to successfully define the whole picture. At the risk of gross oversimplification, the comprehensive plan describes how to define AV test scenarios and reduce the number of them down to a manageable amount. It further defines which tests can be done in simulation, which can be done on proving grounds, and which must be performed on real roads. PEGASUS decided to use the OpenSCENARIO and OpenDRIVE standards for simulation and parts of the proving ground tests.

The figure below outlines each of the steps that will lead to that concrete conclusion. Click on the picture to view a larger image.
The PEGASUS model is built around a “highway chauffer” driving use case and excludes consideration of construction sites. In 2019 a second project started in Germany and will develop a validation and verification model to address L4-5 driving in urban environments.

The inspiration for PEGASUS came in mid-2014 as the German Federal Ministry for Economic Affairs and Energy was evaluating a plan to build a proving ground for automated driving that would be open to companies, universities and NGOs. After consulting with VDA members it was decided to first look a little deeper into what kind of test methods were needed that would guide the validation and verification process for automated driving functions before spending millions of euros to construct the proving ground. PEGASUS’ work began in 2016. To encourage international support and get feedback on its progress, the project held periodic symposiums in the U.S., EU and Japan.

The PEGASUS project was tasked with answering two questions: How safe is safe enough? And, What tools and processes are needed to prove the level of safety you require? The latter question was largely answered by the assessment method described by PEGASUS in the graphic on page 21.

But the project couldn’t answer the how safe is safe enough question with a concrete number. The current rate of traffic fatalities in Germany with humans at the wheel is approximately 3,200 per year. Merely matching that number with an automated vehicle would be unacceptable. Zero accidents is not achievable—just as it isn’t achievable in nuclear power plants, or air travel, or space exploration. So the acceptable number for Germany has to be somewhere between zero and 3,200 fatalities per year. Using the PEGASUS method for a specific automated driving function allows for a rough assessment.

Finding what level of safety society will accept will be left to automated vehicle developers before the systems come to market, and regulators will have to decide what level of safety will be politically acceptable before allowing AVs to operate on public roads. The real social acceptance—which is one of the critical success factors for automated driving—can only be provided with the real introduction of automated driving and when the technology becomes visible in large quantities.

An overview of the method and a description of the 20 steps involved are available at the project website. The project was coordinated by Prof. Karsten Lemmer from DLR (the German Aerospace Center) and Professor Thomas Form of Volkswagen. ♦