NEW ERA IN AUTOMOTIVE ELECTRONICS, A CO-DEVELOPMENT BY GEORGIA TECH AND ITS AUTOMOTIVE PARTNERS

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ABSTRACT
The new trends in automotive electronics such as autonomous driving, in-car infotainment, and all-electric cars, require an entirely different electronic vision and technologies than are pursued today for automotive industry. Georgia Tech proposes system scaling as a new frontier to address the upcoming era of automotive challenges. It also proposes an innovative 3D system package architecture taking into account electrical, mechanical and thermal designs as well as new digital, RF, sensors, radar millimeter-wave and power technologies.It proposes highly innovative large panel-based, ultra-thin glass packaging with many innovations in electrical, thermal, mechanical designs, materials, processes, wiring lithography, fine-pitch and high-throughput assembly and highly-conductive through-Cu vias for signal, power and heat transfer. Such an approach is proposed to lead to highly-functional sub-systems for integration of disparate set of technologies at lowest cost, in smallest ultra-miniaturized size with shortest interconnections with lowest power consumption.

INTRODUCTION
Automotives are becoming "Ultimate Electronic Devices," unlike in the past, mainly, as mechanical devices only. Automotive electronics are expected to account for about a third of the total cost of the entire car, about $10,000 for each car. The total number of cars in 2025 is expected to be around 100M globally, a huge market. Georgia Tech sees unprecedented challenges in: 1) autonomous driving, 2) secure and high speed communications and infotainment, and 3) all-electric cars with very high power.

1.1 Autonomous Driving
The journey to autonomous driving has already started with the development of collision-avoidance sensors requiring further advances for a new era in connectivity to infrastructure, as shown in Figure 1.

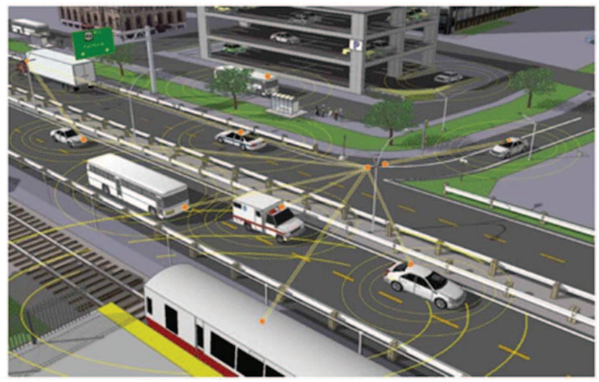

Figure 1: new era in automotive electronics – connectivity to infrastructure [1]

Google's self-driving cars are reported to be on the road in several states [2]; Tesla announced that its cars will be fully autonomous in three years [3]; and Uber has opened a test facility in Pittsburgh [4] to develop an autonomous taxi fleet. Toyota reported a self-driving highway car with 12 sensors for capturing data, which include: 1 camera module behind the front mirror, 5 radar devices that use radio waves to capture speed of other cars and 6 lasers that detect position of objects around the car. In addition, the regulatory framework for testing and operation of autonomous vehicles on public roads was already established in California.

European car makers predict that the implementation of highly-automated self-driving cars will start in 2020 [5]. Autonomous driving technologies have progressed rapidly in recent years due to the advancements in vehicle sensors and communication technologies. These advancements have led to better visibility and awareness – around the vehicle – and to features such as park assistance, adaptive cruise control, lane-keep assistance, traffic-sign recognition and pedestrian detection, as illustrated in Figure 2.

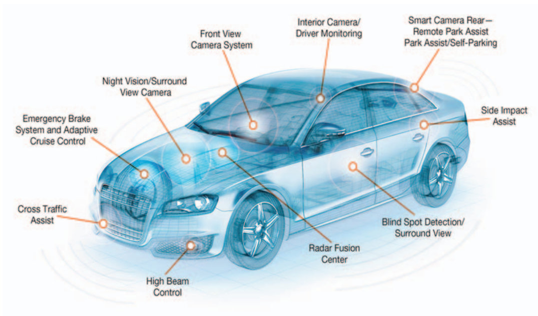

Figure 2: Advanced Driver Assistance Systems (ADAS) application example [6]

1.2 All-electric Cars

In addition to autonomous driving, advancements are also taking place in environmentally-friendly propulsion techniques, using all electric energy.

The powertrain electrification trend in all-electric and hybrid vehicles is picking up speed at every major automotive company and is expected to account for more than 10% of the market share in the next five years and growing faster in the next two decades.

Figure 3 illustrates the three critical component technologies in electric cars that include inverter, battery charger and battery itself to be designed and developed to serve this market.

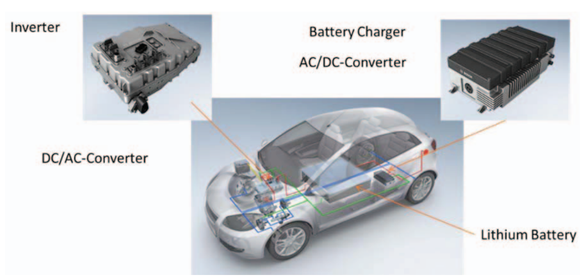

Figure 3: new era in automotive electronics – powertrain of electric vehicles

1.3 Secure, High-speed and Infotainment Electronics

All the electronic advances that are currently used in smartphones, are being enhanced and planned to be used in the car, particularly as self-driving cars become a reality within a decade. Apple is reported as focusing on CarPlay [7], its in-car infotainment system that integrates iPhone features, like messaging, music and maps into a vehicle's dashboard. It appears that every major auto brand is committing to use CarPlay.

2 Georgia Tech Vision for Automotive Electronics

Semiconductor, packaging and systems landscape are changing dramatically. These changes will have a great impact on emerging automotive electronics. For example, ICs, on one hand, for the most part, are becoming commodities, providing much lower profit margins than ever before. This leads to industry consolidation to less than five companies within the next decade, worldwide. In addition, the cost and complexity of transistor scaling is growing exponentially. There is no longer a cost reduction as the next node is introduced with higher transistor density. The driving engines for electronic systems, on the other hand, are also changing dramatically to smart, wearable, wireless sensors and networks and emerging self-driving, smart and all-electric cars, requiring an entirely different vision and strategy than transistor-scaling alone that has been practiced during the last 60 years. These systems must perform dozens of functions that include wireless communications; wireless sensing, stereo cameras, mm-wave electronics, high bandwidth electronics or Photonics for data processing with security for autonomous driving; and high-power and high-temperature electronics for all-electric cars.

Integration of all these into one or more packages is more than Moore's Law, with on-chip transistor integration and, lot more than Moore's Law (MTM) with stacked heterogeneous integration or SIP. It is System Moore's Law (SM) for complete system integration, leading to "A-SOP", (Automotive System-on-Package) with a market size as big as all the electronics to date.

Such a vision is shown in Figure 4, leading to the entire automotive electronic system-on-package (A-SOP) with all the functions necessary for the car. Georgia Tech proposes a modular and incremental approach to evolve to A-SOP over the next decade. It involves 11 basic or core technologies, as listed in the first column of Figure 4 to be explored and demonstrated. Those that are successfully demonstrated move on to form design and demonstration test vehicles, demonstrating functional modules. Some of these to date are digital modules, photonic modules, RF modules, and power modules. The new ones to be added include high-temperature, high-power, sensor arrays and radar modules.

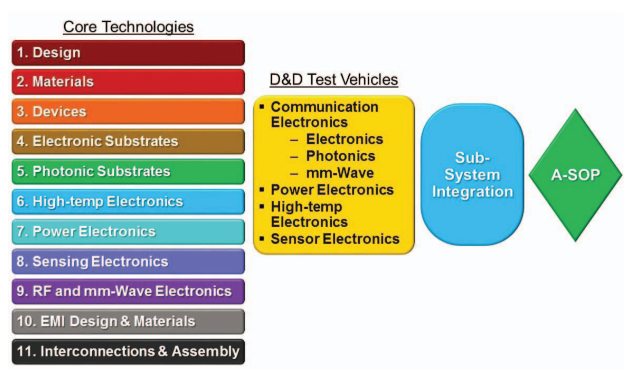

Figure 4: Georgia Tech Strategy with 11 core technologies to functional modules to system Integration to A-SOP.

3 Systems Scaling and Integration (SSI) Industry Consortium for Automotive Electronics

Georgia Tech proposes an industry consortium based on system scaling technologies in many research areas that include:

- Electrical design
- Mechanical design
- Thermal design
- High temperature materials and processes
- Devices
- Substrates
- Power, RF, mm-wave, radar components
- Interconnections and assembly

The purposed consortium is a co-development consortium with global industry, involving manufacturing supply-chain companies, semiconductor, package, assembly, automotive component and system companies.

The automotive electronics will be based on system scaling fundamentals that include:

- Short interconnect length for highest performance
- Ultra-low loss substrates and dielectrics for minimum power consumption in interconnections
- Ultra-low loss substrates and dielectrics for high frequency (mm-wave), and data-secure communications
- Low-dielectric constant dielectrics for high signal speed
- Through TSV-like vias at fine-pitch for double-side interconnections and assembly of actives and passives to form 3D Packages at same as TSV pitch for miniaturization and performance
- Thick Cu ground planes and large Cu through-vias or slugs for high-thermal dissipation
- Large panel (510mm) manufacturing for lower cost than 300 mm wafers
- High-performance capacitors and inductors for power
- High-temperature substrates, passives, and interconnections for high-reliability

Such a strategy over the next decade is expected to close the gap between transistor scaling and system scaling that exists today, as illustrated in Figure 5, resulting in System Moore as illustrated in Figure 6. The manufacturing foundry consistent with this vision must be large panel-based, to produce and assemble low-cost and ultra-small automotive modules, sub-systems and systems.

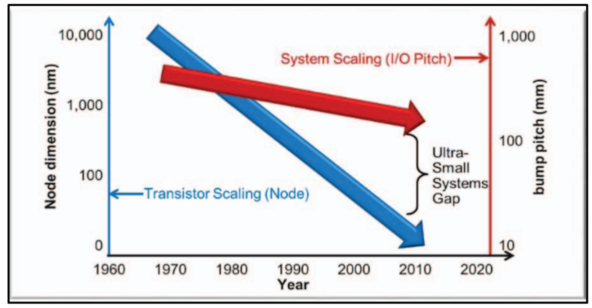

Figure 5: Gap between transistor and system scaling for electronics systems

Change in Fig 5 from Ultra-small systems gap to Heterogeneous Systems gap

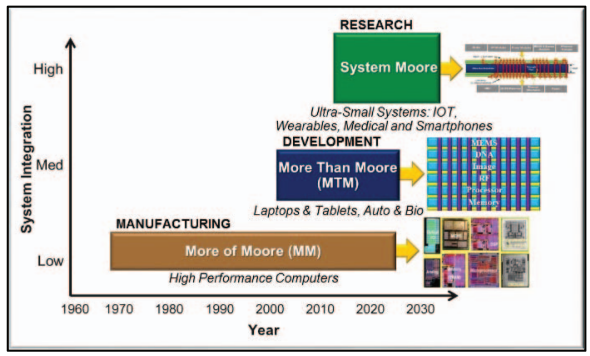

Figure 6: System Moore with the 3D System-on-Package for all systems functions in one package

Georgia Tech proposes to enhance its current Industry Consortium that is already a broadly-participated, pre-competitive, industry-led and industry-funded R&D consortium involving around 50 companies in materials, tools, substrates, and assembly as well as semiconductor and systems users.

4 Industry Consortium R&D Areas

The proposed SSI for automotive electronics is based on highly integrated, miniaturized, highly-reliable and low-cost modules, sub-systems and systems to perform four primary functions as shown in Figure 7, that include:

1. Communication Electronics
   a. Dedicated short-range communications (DRSC)
   b. Computing for fast and safe navigation
2. Sensing Electronics
   a. Smart internal-state sensing
   b. Environment and navigational sensing (lidar, radar, ultra-sonic, video camera, GPS)
3. High-power Electronics
   a. Energy efficient smart power modules
   b. Packaging for SiC and GaN power modules
4. High-temperature Electronics
   a. High-temperature driver modules
   b. High-temperature sensor and actuator electronics

The proposed research projects within each of these are:

- Communication Electronics
    - Digital, RF and mm-wave electronics
    - Mixed signal electrical design
    - mm-wave Glass module
    - 3D Package for high bandwidth
    - 3D Glass photonics
    - EMI shielding
- MEMS and Sensor Electronics
    - Miniaturized wireless 3D-Glass BGA sensor interface
    - Packaging platform for sensor arrays
    - Camera electronics
    - Packaging platform for sensor fusion
    - Sensor packages for high ambient temperatures
- High-power Electronics
    - Control and safety electronics
    - High-power modules
    - Thermal technologies
    - Power module reliability
- High-temperature Electronics
    - High-temperature glass substrates
    - High-temperature interconnects
    - High-temperature passives
    - High-temperature encapsulation

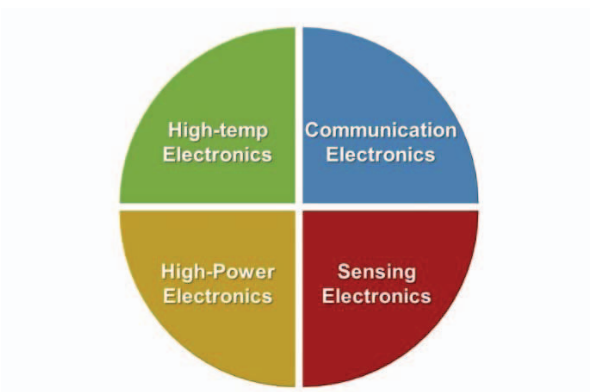

Figure 7: Georgia Tech's focus on four areas of automotive R&D

SUMMARY

The new era of automotive electronics requires new transformative fundamental and integration technologies. Georgia Tech sees unprecedented challenges and opportunities for system integration of many disparate technologies that hitherto fore thought to be impossible. It proposes system scaling, heterogeneous integration and innovative package architectures as the new frontiers with particular focus in electrical, mechanical and thermal designs; new, digital, RF, sensors, mm-wave and power technologies. The Georgia Tech team proposes a transformative and strategic approach to automotive electronics, called System Scaling, leading to entire automotive system on a 3D package. The approach will be modular and incremental over a decade of exploration and demonstration.

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