Heterogeneous Integration Roadmap (HIR)  
7th Annual Conference February 21 - 23, 2024

Three days Conference Program – February 23 Day 3

HIR Team 4 Friday:  
(13:15 am – 16:00 pm, Pacific)

14:40 + 10 min    Medical, Health & Wearables: Mark Poliks, Jan Vardaman

14:50 + 10 min    IoT: Robert Lo (ITRI Taiwan) Rockwell Hsu (Cisco)

15:00 + 10 min    Mobile: Benson Chan, William Chen

15:10 + 10 min    Reliability Abhijit Dasgupta, Richard Rao & Shubha Sahasrabudhe

15:20 + 10 min    Emerging Research Devices: Meyya Meyyapan

IoT: Robert Lo (ITRI), Rockwell Hsu(Cisco), Bill Chen (ASE)
Internet of Things (IoT) Chapter

Presenter: Wei-Chung(Robert) Lo, TWG Chair
Deputy General Director of Electronic and Optoelectronic System Research Laboratories (EOSL) of ITRI

Dr. Lo received his Ph.D. from National Taiwan University and joined Industrial Technology Research Institute (ITRI) to work in advanced electronic packaging and System scaling, such as WLP, 3D IC/ 3D stacking/ Monolithic 3D, wafer-level fan-out, Silicon-Photonics, Integrated smart system and Heterogeneous Integration technology for more than 20 years, 85 papers and 27 patent granted.
Dr. Rockwell Hsu is a Technical Lead at Cisco Systems, Inc. Most recently, he is with data center server group working on new UCS-X servers for AI workloads. He led an initiative on advanced semiconductor packaging development for 112Gbps per lane signaling for network equipment and SI/PI development for network line cards and fabric cards used in switches and routers. Prior to Cisco, he led RF and server CPU packaging development at Intel. Dr. Hsu holds one US patent.

Industry advisor for NSF’s Convergence Accelerator – 2022 Cohort, Track I.

Active Thrust 4 member in Southeastern Consortium for Assured and Leading-Edge Semiconductors (SCALES)

Dr. Hsu was the chair of the High-Speed, Wireless & Components Committee for the IEEE Electronic Component Technology Conference (ECTC) and has been a member of the ECTC since 2006.

Dr. Hsu was the chair of Santa Clara Valley Chapter of the IEEE Antennas and Propagation Society (APS).
The Vision for NAPMP

Need to have “Smart Factory” to reduce the domestic packaging cost → IIoT → Digital Twin → Wireless Sensors → Connectivity → real-time Data → ML → AI Inference → Actions
Batteries Undermine Adoption of IIoT

• Cisco 2017: 500B smart devices by 2030

500B IoT Devices
With 3 years Battery lifetime

457M batteries per day
for three years
Battery lifetime Requirement

• 10 years
  • Harsh environment (temperature variation and humidity) can degrade the battery lifetime
  • Avoid logistical nightmare (maintenance free) and environmental hazards
• <100uW is required for wireless sensors for AA battery to achieve 10 years lifetime
Landscape of Ultra-Low Power Radios

Survey of 214 radios, 2005 ~ 2023

Ultra-Low Power, <100uW
Long Range > 15km

Challenges and Dilemma in Battery Usage

• For long range applications > 15km
  • receiver sensitive < -120dBm → Need power > 100uW → shorten the batter lifetime < 10years

• For short/mid range applications <1km with <10uW radio
  • energy harvesters can replace battery
    → batteryless monitoring system (self-powered IoT sensors)

• The Choice for Wireless Sensors:
  • “battery + energy harvester”
  • “supercap + energy harvester” (batteryless system)
Four Sources of Energy Harvesting (EH)

- Ambient Light
- Vibration/Motion
- Thermal Energy
- Electromagnetic and Radio Frequency

→ MEMS-based EH is very suitable for IIoT due to available sources of vibration and motion in factory environment.
Challenges in MEMS-Based Energy Harvesting

• MEMS-based EH produce >100uW for broad range of environment with cost less than battery

• Resilience to harsh environment for MEMS packaging
  • Mechanical shock
  • Extended temperature and humidity range
INTEGRATED SENSING AND COMMUNICATION (ISAC) SIGNALS TOWARD 5G-A and 6G

- Application scenarios of ISAC systems: **UAV swarm, intelligent transportation, smart factory, smart home, etc.**
- **Efficient spectrum utilization and low hardware cost** for 5G-A/6G mobile communication systems
- Both communication and high-accurate sensing capabilities
- **Key index-I:** ISAC signal design, signal processing, and signal optimization, radar signal processing methods
- **Key index-II:** Peak-to-average power ratio optimization, interference management, and adaptive signal optimization for flexible and reconfigurable ISAC signals

Source: WEI et al.: IEEE INTERNET OF THINGS JOURNAL, VOL. 10, NO. 13, 1 JULY 2023
Examples of Heterogeneous Integration Solutions for IoT

[Can refer to other TWG chapter for 2D/3D, SiP, WLP, 5G, etc for good examples of the HI solutions for IoT.]

A. Connectivity;
B. Autonomous IoT system
C. Edge AI device
D. IoT for Wearables
E. Integrated sensor packaging
F. Heterogeneous Integration of IoT Basic Elements
G. Thin-Film battery for IoT microsystems
H. Sensor platform for IoT medical applications
I. Double Side SiP for IoT and 5G Application
J. Wafer-level Packaged Gauge for Industrial IoT (IIoT) Application
K. A novel FOWLP method to integrate delicate MEMS components for IoT Application
L. Module, antenna, and package design considerations for mm-scale IoT devices
K. A novel FOWLP method to integrate delicate MEMS components for IoT Application

• Packaging for MEMS pressure sensor + ASIC
• 3D stacking by TPVs, vertical interconnect elements (VIE) by Fan-Out Tech a Mold-first and RDL-first c
• Patterned thin film adhesive serves as a (first) dielectric layer which minimizes costs
• Process development: laser de-bonding from glass carriers and RDL processing for MEMS

Source: Markus Woehrmann et. al, 2023 ECTC
L. Module, antenna, and package design considerations for mm-scale IoT devices

• A supply chain application: small objects protected from counterfeit using a mm-scale IoT device
• Several mm-scale antennas and packages for battery-free wireless backscatter-based IoT
• Antennas: from 900 MHz to 28 GHz. 28 GHz mm-wave 2.1×2.1 mm$^2$ and 5.8 GHz 6×5 mm$^2$
• Both silicon interposer and organic substrates performed well in simulations across frequencies

Source: Arun Paidimarri et. al, 2023 ECTC
• AloT platform I: for smart home, smart city and smart factory
• AloT platform II: IoT based Smart Healthcare Monitoring Systems (overview)
• AloT platform III: Private 5G/Local 5G to meet IIoT applications (updated-Real Manuf. Site)

• AloT platform IV: Robust RF-System (planning)
AIoT platform III:
Private 5G/Local 5G to meet IIoT applications

- Programmable Analog Switch Array IC monitors up to 50 motors
- AIoT edge computing: data no longer transmitted to the cloud for processing and analysis.
- Key innovative designs include a Zero NG deep neural network and a non-intrusive pre-diagnosis module.
- Less energy offering alert to motor failures with 24/7 condition monitoring & fault pre-diagnosis
AloT platform III: Private 5G/Local 5G to meet IIoT applications

<table>
<thead>
<tr>
<th>CPU</th>
<th>MEDITAEK i500(MT8385) 0.75TOPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cortex73 x4@2GHz</td>
</tr>
<tr>
<td></td>
<td>+ Cortex A53 <a href="mailto:x4@2.0GHz">x4@2.0GHz</a> SoC</td>
</tr>
<tr>
<td>IO</td>
<td>I2C, I2S, SPI, UART, USB2.0, MIPI DSI</td>
</tr>
<tr>
<td>Wireless</td>
<td>Wi-Fi 802.11 a/b/g/n/ac MIMO</td>
</tr>
<tr>
<td></td>
<td>BT5.0</td>
</tr>
<tr>
<td>Camera</td>
<td>Integrated ISP support camera up to 24MP</td>
</tr>
<tr>
<td>OS</td>
<td>Android/Linux OS support</td>
</tr>
</tbody>
</table>
2024 IoT Chapter (possible) plans:

• **Specified application requirements input and HI technology solutions**
  - **MORE** “Sensing Specification” IIoT systems sensing specification in 2030
  - **MORE** “Heterogeneous Integration” technology spec requirements for IIoT/IoMT
  - **MORE** robust “IoT RF-System” prospective for reliability accessment of IoT

• **More discussing with other chapters(cross-TWG)**
Internet of Things Technical Working Group Membership

The TWG would like to thank the cooperation and supports in all the contributors as below, especially greatly appreciate for Dr. Shih-Chieh Chang, General Director of Electronic and Optoelectronic Systems Research Laboratories (EOSL)/ITRI.

Key Contributors:
- Wei-Chung (Robert) Lo, ITRI, Chair
- Bill Chen, ASE
- Rockwell Hsu, Cisco
- Sebastian Liau, TUSA/ITRI
- ...New members
- Chih-I Wu, EOSL/ITRI
- Shih-Chieh Chang, EOSL/ITRI
- Harrison Chang, ASE
- CK Chung, SPIL
- Gamal Refai-Ahmed, Xilinx
- Robert Kao, NTU
- Koji Yasui/Mitsubishi Electric
- Chi-Hsin Yang, ISTI/ITRI
- Che-Hao Fan, ISTI/ITRI
- Bor-Feng Jiang, ISTI/ITRI
- ...
Thank you for your attention

Internet of Things (IoT) Technical Working Group will need YOUR PARTICPATION!

William.chen@aseus.com
Rohsu@cisco.com
Lo@itri.org.tw