CASE STUDY

Differentiating Short-Range Radar with UWB Technology

A three-person design team advances software-defined single-chip radar through circuit-EM co-simulation

KEYSIGHT

UWB Saves Power, Penetrates Obstacles Better

Organization

- ARIA Sensing S.r.l.

Challenges

- Exploring, optimizing, and validating RF and ADC circuits within affordable computation resources and design time
- Aligning high-performance RF and high-speed digital subsystems in a single PDK for their foundry
- Full-up RF simulation including the chip in its QFN64 package

Solutions

- Performing selective EM extraction of 2 GSPS ADC features for accurate end-to-end signal chain analysis without extreme simulation times
- Creating a hybrid PDK using an ADS patch for modeling all devices and a stack-up for the back-end layout of the entire chip
- Modeling a QFN64 package with three types of bonding wires, ground, and terminations

Results

- PLL enhancements allowing longer, tighter coded pulse trains for increased resolution
- Beamforming capability improves 3D detection
- Lower-cost package with nominal insertion loss reached market faster

ARIA Sensing, headquartered in Rezzato, Italy, is changing how people think about short-range radar. Instead of Frequency-Modulated Continuous Wave (FMCW) technology operating in the 60 to 77 GHz mmWave range, ARIA is innovating with its emPulse Ultra-Wideband (UWB) technology at around 8 GHz to save power while improving obstacle penetration and Signal-to-Noise Ratio (SNR). Their Hydrogen System-on-Chip (SoC) offers scalable, high-resolution 1D, 2D, or 3D modes, applies advanced waveforms for challenging detection scenarios, and deploys in a worldwide spectrum.

ARIA's team of three design engineers uses Keysight Advanced Design System (ADS) with EMPro for RF circuit layout and Electromagnetic (EM) simulation as part of its Hydrogen SoC design workflow. Their observations indicate their design is much more effective at detecting targets in clutter, opening more potential applications that may have been unable to consider radar previously.

Challenge: Single-chip, monolithic die implementation

Short-range radars have one significant difference from their long-range counterparts: they operate at substantially lower transmit power. However, detection and discrimination challenges remain. For instance, in an in-cabin automotive application, counting vehicle occupants requires differentiating people from seats, which appear as clutter. Monitoring a driver's attentiveness to the road requires enough resolution to tell how a driver's head, arms, and torso are oriented and if their breathing and heart rate are normal just by observing minute body motions.

Similar conditions exist in applications set in homes or businesses (Figure 1). People counting must find and deconflict individuals of different sizes, whether seated far apart or close together. Fall detection involves spotting an individual lying on the floor, possibly amongst furniture and other objects. Gesture control requires more resolution to sense a person's arm and hand orientation and motion. Sleep monitoring again relies on checking vital signs through small movements while overall body positioning changes.

ENABLING FEATURE	Health & Safety	Smart Building	Smart Devices	Industry	In-Car	Retail
3D People Tracking	Elderly Care Fall Detection	Automation Anti-Intrusion Occupancy Space optim	Attendance Data Sound optim	Operator Safety	Passengers Counting	Rooms Occupancy Shelves Presence
Vital Signs	Patients Monitoring Vital Signs Sleep Monitor	Awake/Sleep activity monitor	Auto stand-by/play	Restart Prevention	Driver Monitoring System Baby-reminder	-
Gesture	-	Contact-less switches Light Dimming	Gesture Control	Cobots	-	Kiosk Automation

Figure 1. Short-range radar applications in people tracking, vital signs monitoring, and gesture detection

"If we want to pick out the breathing of an individual, perhaps wearing a thick jacket or layers of clothing or underneath layers of bedding while sleeping, we must have good obstacle penetration combined with improved signal quality for fine-grained motion detection," says Alessio Cacciatori, founder and CEO of ARIA Sensing. "Using UWB at a lower frequency and a shorter pulse duration versus FMCW reduces power at least an order of magnitude and improves link budget and resolution for better target detection." UWB also puts devices into an easier-to-field spectrum than FMCW, with an 8 GHz version of the Hydrogen SoC ready for Europe and the US.

Choosing UWB set off a series of challenges for ARIA Sensing in creating a single-chip, monolithic die implementation pairing an RF signal processing subsystem with a customized two-core RISC-V digital processing subsystem — and doing it with a three-person design team.

"The only IP block in Hydrogen we didn't design in-house was SRAM," says Cacciatori. "We knew our RF front end, including a Low-Noise Amplifier (LNA), a Power Amplifier (PA), and the Phase-Locked Loop (PLL), would be challenging. We didn't anticipate our 2 GSPS Analog-to-Digital Converter (ADC) would be so complex; our first naive EM extraction created a mesh that overwhelmed our computational capabilities."

Exploring, optimizing, and validating the entire RF signal chain, including the ADC, is only part of the design cycle for a single-chip solution. The second challenge was integration tasks nearer the finish line. The architecture also includes a dual-core RISC-V processor and memory subsystem, where ARIA uses a non-Keysight digital layout tool. Producing a final chip version for submission to a foundry required aligning the RF design in ADS with one Process Design Kit (PDK) suitable for the entire chip.

Recognizing that packaging structures could alter performance, the last challenge for ARIA was a full-up RF simulation of the chip with its package, including its ground cavity and bonding wires to the chip. "We originally envisioned going with a Chip-Scale Package (CSP) to minimize insertion loss, but again, with limited time and computational resources, we reverted to a simpler package that was much easier to model and simulate," says Cacciatori.

Solution: Careful EM extraction, iPDK, package models

The ARIA Sensing team was already familiar with ADS (chip layout in Figure 2) and EMPro for circuit-EM co-simulation. "Our choice made a while back, before the Hydrogen project started, came down to using SPICE for specific portions of RF circuits or using ADS with much more powerful modeling, co-simulation, and optimization capability for the entire signal chain and packaging structures," observes Cacciatori.

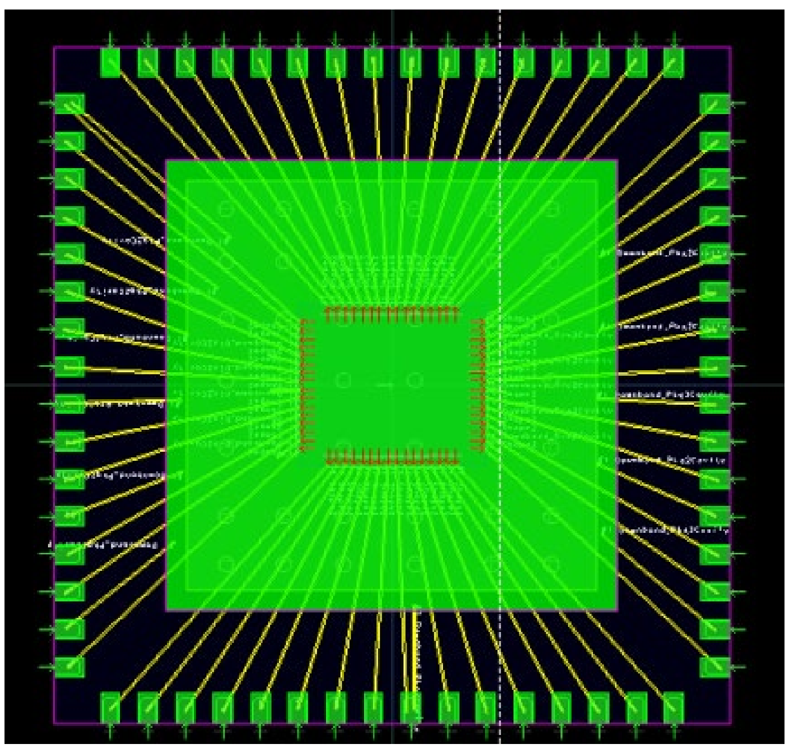

Figure 2. ADS parametric view of the Hydrogen chip layout

ARIA ran transient simulations to check impulse behavior with the short UWB pulses they use and to help with loop filter optimization for the PLL. They also used harmonic balance and envelope simulations to evaluate the performance of LNA and PA circuitry. When EM parameter extraction attempts ran head-on into their complex ADC, the solution became tuning the extraction process and reducing run times without sacrificing accuracy.

"We ended up using features in ADS to select and extract only the crucial parts of the ADC layout for simulation with enough detail to get a reliable estimate of the physical behavior of the entire chip," Cacciatori continues. Simulations helped optimize the comparator and buffer blocks in the ADC. The time savings in simulation allowed more analysis, including the ADC calibration phase, with the longest simulation runs taking four to five days on their in-house server.

Three variables drove ARIA's PDK choice: power consumption, RF performance, and cost per area. Co-simulation and EM extraction in ADS provided details on RF transistor fingers, vias, and metalization. However, getting to a single PDK file that models digital and RF devices, defines the back-end layout stack-up, and supports two different layout tools takes some engineering. A starting point for ARIA was the iPDK format, an open specification built on the OpenAccess database, fostering interoperability between EDA tools. "We try to avoid tweaking PDKs whenever possible," says Cacciatori. "The final integration tool works directly with iPDK, and with an ADS patch from Keysight and some code for adjustments in back-end layer connections, we got both layout tools automatically feeding one iPDK file for the chip."

Layout Versus Schematic (LVS) checks in ADS were what Cacciatori terms a "precious tool" in their workflow. Rather than waiting to do complete validation in their non-Keysight tool, ARIA ran LVS incrementally on the RF circuit layout in ADS, including verification of the non-schematic parasitic elements extracted from EM simulation for accurate line effects. "This workflow captured 99% of the layout errors that cropped up before we integrated the RF layout in the full-up chip, preventing back-and-forth layout passes and saving us a tremendous amount of time."

The final part of ARIA's solution was simulating the chip again as installed in its QFN64 package (Figure 3). "The QFN is also less expensive and simpler to mount to a board, so customers like it, and we hoped the impact on our performance would be acceptable," says Cacciatori. Accurately determining that insertion loss required deeper detail in their package model. "We decided to model the packaging cavity, the ground cavity, and a virtual ground plane for reference." The package schematic includes three distinct types of bonding wires with different properties: die-to-pad, die-to-cavity, and pad-to-cavity. "With the package model and terminations set up, we simulated the off-chip impulse transfer function for the QFP first, then imported that model to the on-chip impulse simulation."

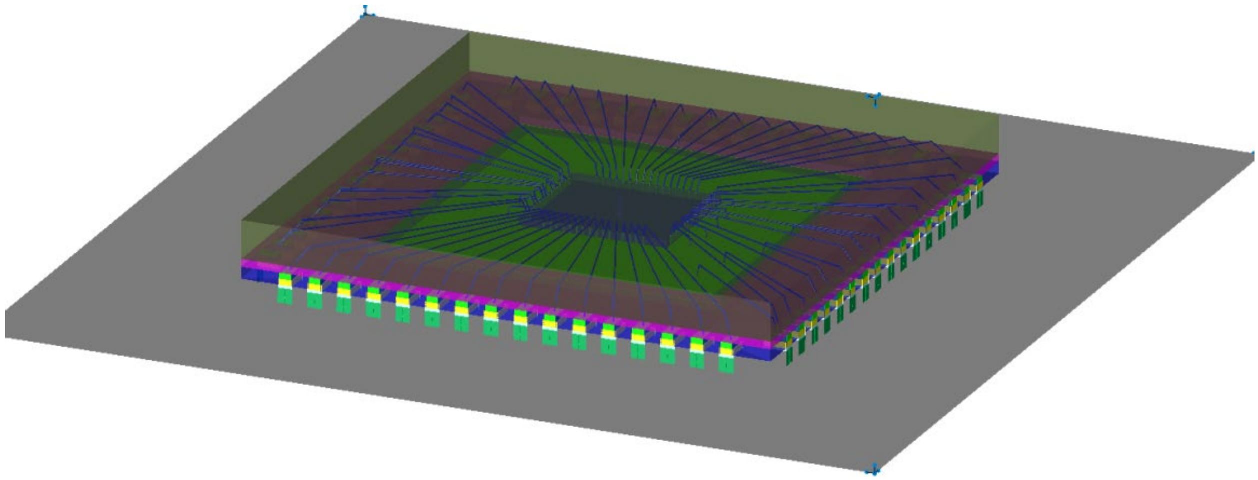

Figure 3. EMpro model of the hydrogen chip in its QFN64 package

Results: Coded pulse trains and beamforming

The decision to move to the QFN64 package resulted in only a 2 dB insertion loss at the center frequency, relieving the team's concerns and justifying the choice to get to market more quickly. The team also made phase coherence measurements on the PLL and noise figure measurements on the LNA in the physical chip, comparing well to the ADS-simulated results. More effort went into real-world scenarios.

Software-defined detection capabilities include using a single pulse or coded multiple pulses (Figure 4) and adjusting the pulse length and bandwidth. Users can start with a fast detection mode at increased SNR, then switch to a higher resolution mode, for instance, for vital sign monitoring. "PLL and transmitter refinements from EM simulations helped us pack more pulses closer together, giving us higher resolution and signal-to-noise ratio than any competing short-range radar solution we're aware of today," shares Cacciatori.

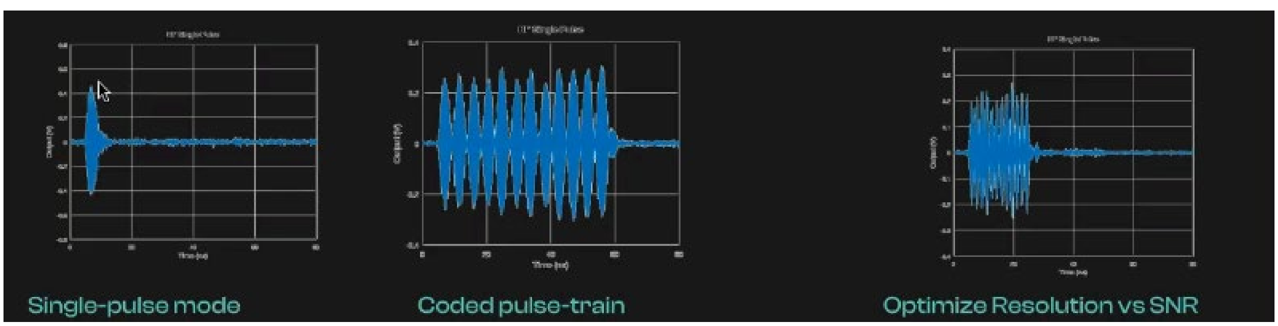

Figure 4. Comparing UWB waveforms for single-pulse mode and a coded pulse train

Hydrogen supports beamforming with antenna arrays, enhancing 2D and 3D performance. Figure 5 shows a detection demonstration using a 3 Tx, 3 Rx array configuration. Note the detail in the center of mass around the head and torso (yellow and green) and less dense arms and hands (blue), indicating how the person faces the radar.

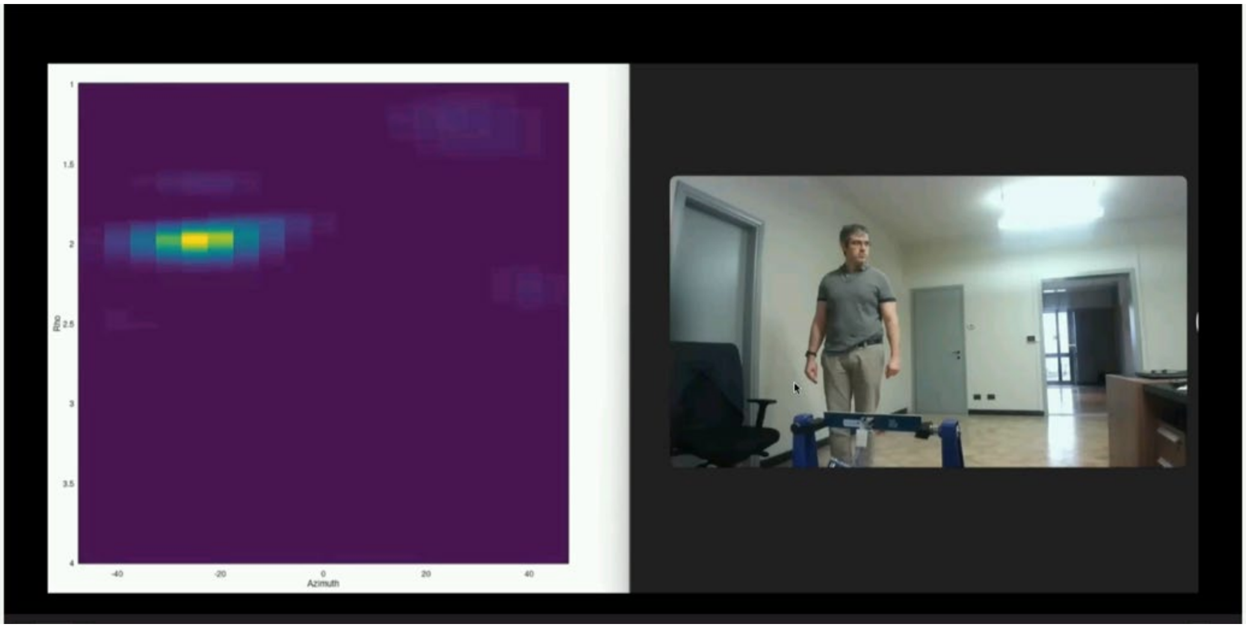

Figure 5. Detection of a person moving around a room in front of a Hydrogen with a 3 Tx, 3 Rx antenna array

> “**PLL and transmitter refinements from EM simulations helped us pack more pulses closer together, giving us higher resolution and signal-to-noise ratio than any competing short-range radar solution we're aware of today.**”
>
> **Alessio Cacciatori, Founder and CEO, ARIA Sensing**

Cacciatori sums up ARIA's achievements on the Hydrogen project with an interesting point: prospective customers can't believe a three-person team accomplished this. "Our experience with ADS and EMPro has taught us how to get the most out of the simulator, especially with non-linear circuits, and it's a very powerful tool that gives us an industry-leading RF front-end design."

Looking Ahead: Even better front-end, simpler workflow

ARIA is proceeding with its Hydrogen rollout, showcasing its production SoCs. Cacciatori says they might create a variant at a slightly higher frequency tuned for spectrum availability in Japan and South Korea.

Experiments are underway with a somewhat hidden feature in Hydrogen: a small Neural Processing Unit (NPU). Most of the advertised capability of the chip is running in conventional software on its RISC-V cores, but Cacciatori suggests they've just started looking at what the NPU might be able to do.

Extremely satisfied with their ADS-enabled workflow and the responsiveness of Keysight's support, ARIA is already working on next-generation short-range radar designs, concentrating on improving their RF front end further. For now, specifics of their foundry verification process will keep them with ADS and their other layout tool working together, but Cacciatori can see a future possibility of moving into an all-ADS layout environment with some verification enhancements.

Learn more about ARIA Sensing, its UWB technology, and its Hydrogen SoC here:

https://ARIAsensing.com/ARIA-products/ARIA-hydrogen-v1p1-chip/

For more information on Keysight EDA solutions for advanced RF design, please visit:

Keysight Advanced Design System (ADS)

Keysight EMPro

All figures courtesy of ARIA Sensing, S.r.l.