Title: The Next DARPA Revolution: Integrated Microsystems
Zachary Lemnios

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Zachary J. Lemnios, Director
Microsystems Technology Office
Defense Advanced Research Projects Agency

Do you remember the microelectronics revolution?

It changed the world forever... in ways that even the leading technologists of the day never could have imagined? Well, get ready.
Because DARPA is about to launch a whole new revolution, and this one could be even bigger than the last.
This will be the revolution of the integrated microSYSTEM, and I want you to join us as we lead the charge.

As Director of the Microsystems Technology Office, I'm looking forward to telling you how we plan to open this field of the Integrated MicroSYSTEM.
We think that in the next five to ten years we will have the elements to build a new class of components that sense and adapt to the environment across the full spectrum; that dynamically configure to the mission at hand; that influence and actuate elements of the environment with micro-scale precision; and that provide a communications channel that is nearly impossible to detect or jam, yet is perfect in its clarity.
Such capabilities will enable spectacular autonomous and interactive systems that can reason, sense, communicate, and actuate.
We'll interact with them in ways that will make "Matrix Reloaded" look like an old episode of "Lost in Space".
They'll change everything: from the way we buy groceries to the way we diagnose and treat diseases.
They'll be able to operate unattended for years at a time, and they'll give the DoD an overwhelming capability and advantage in response to surprise or emerging threats.
These integrated microSYSTEMs will enable small, and effective robotic systems that work autonomously in concert, to decisively engage and defeat a wide variety of enemies forces across the entire spectrum of conflict.

Think about it: within five to ten years conventional electronics will enable us to build systems containing perhaps a trillion transistors in roughly a liter of volume and dissipating less than 100 watts or so.
This is about the same complexity as the human brain, and the kind of complexity that integrated microSYSTEMs will exploit.
This us absolutely AMAZING!! And there is no way that we are about to just back and wait for nominal scaling trends to open this opportunity.
As Tony Tether would say, we're going to get out in front and we are going to bring these concepts from the far side, to the near side.
This will enable a new generation of systems that adapt and are highly effective against complex, dynamic signatures and a rapidly changing threat environment.

The integrated microSYSTEM exploits scaling in all physical domains, not only electronic but also photonic, mechanical, chemical, and perhaps even biological.
This multiple domain scaling and integration will greatly outperform today's single systems in some very interesting ways.
And we have some early examples.

Our Adaptive Focal Plane Array program is building a dense structure of addressable and programmable pixels resulting in a hyperspectral imager on a single chip.
In this case, we use MEMS to do the frequency domain filtering, electronics to do the high speed control and photonics as the principle transducer in the form of MCT

photodetectors.

Another example is flexible receivers that can tune themselves automatically and opportunistically capture signals.
As we develop systems like these - systems that interact with their environment in a truly intelligent way - we'll be able to reduce the burden of brute force computational processing we've been forced to rely on in the past.

Think about an RFID tag that could survey the environment, adaptively change it's coding to conserve power or communicate with a host of changing users and provide an infallible identification of friend or foe (IFF) capability.
And all made possible by microSYSTEM technology that combines scaled microelectronic, MEMS, and photonic technologies.

And were pushing novel integration concepts as well.
In a typical CCD sensor system, imaging pixels are connected laterally with A/D converters, digital signal processors, image processors, and output ICs by chip-to-chip interconnects.
This results in a large device with relatively small active area.
The sampling rate and resolution are largely limited by this interconnect approach.
Our Vertically-Integrated Sensor Arrays (VISA) program will change all of that.
Our VISA performers are creating a layered IC, in which each layer represents one of the subsystems in a traditional sensor device.
The layers are connected via strategically placed interlayer connections, effectively creating a three-dimensional chip.
This will result in devices that are much smaller, with more effective area and higher readout rates than are available today, and will move us from area integration to systems that are truly integrated by volume

Before I say much more about how MTO is literally inventing the future with integrated microSYSTEMs, let me take a moment to tell you about DARPA's track record in driving microelectronics innovation in the past.
William Shakespeare observed that "what is past is prologue."
And what a prologue it's been.

Shortly after the invention of the integrated circuit in 1958 by Jack Kilby and Bob Noyce, the Department of Defense grasped the military potential of this breakthrough research.
The DoD and ARPA investment in the emerging IC industry helped create the massive industry we know today.
By funding early research to improve the design, processing, and packaging of integrated electronics, the Defense Department helped establish the productivity engine that came to be known as "Moore's Law," a phenomenon that has made the integrated circuit one of the most important inventions of the 20th century.

DARPA programs in the 1970's and 80's produced important advances in design and processing leading to the scalable transistor concept.
This became the basis of modern design technology.
Accurate simulation and modeling tools like SPICE were developed and distributed.
MOSIS was created as a VLSI prototyping and low-volume production service.
Since 1981, it has fabricated more than 50,000 circuit designs for research and educational institutions, government agencies and commercial firms around the world.
The SEMATECH Program in the late 1980's and 1990's was critical in restoring US leadership in the semiconductor industry.

DoD's early success using IC technology in computers and communications inspired some visionary DoD researchers to consider applying IC integration techniques to RF components.

This led to the MIMIC program, and the results were spectacular.

This program delivered dramatic breakthroughs in high-yield fabrication techniques, advanced design tools and models, and the development of low-cost packaging and high-speed testing.
The MIMIC program launched a revolution in military capabilities and ultimately created a whole new industry.

Many wireless markets would not exist without the results of this program.
The RF components in cell phones, pagers, and even some of today's PCs rely on innovations that came out of the MIMIC program.

More recently, our office led the development of two emerging technologies that are again changing the integrated circuit industry.
We supported early work in silicon-on-insulator technology for low power and high radiation environments.
We also sponsored novel work in silicon-germanium for mixed signal systems built on a single chip.
These technologies have created new opportunities for reducing power consumption while boosting performance, and are key technical elements of the integrated microSYSTEM

But that is electronics.
In optical processing and data transfer, other MTO programs have enabled many of the component technologies used for the optical networks that carry the world's voice and data traffic.
Our photonics programs applied the IC design methodology to optical integrated circuits and new networking technologies.
During the 1990's, we helped develop a practical Vertical Cavity Surface Emitting Laser, or VCSEL.
This permitted tightly focused, robust coupling to optical fibers for signal transmission.
The ability to fabricate these VCSELs in arrays enabled highly parallel transmission.
This work was foundational to today's multibillion dollar optical networking industry.
These optical networking technologies continued DARPA's legacy of innovation in computer networking, which extends from the development of timesharing, packet switching, and the ARPANET, the predecessor of the Internet.

And then there is MEMS.

Our early involvement in the field of micro-electro-mechanical systems has led to miniature gyroscopes, miniature RF resonators and miniature sensors, to name just a few.
As Clark Nguyen will describe, MEMS components with enormous surface-to-volume ratio have resulted in huge improvements in speed, power consumption, and sensitivity.
You're going to hear how this technology will be used to create a chip scale atomic clock and extremely high performance resonators that will fundamentally change RF systems once again; another example of a couple of far side ideas brought to the near side.

But just like Moore's Law, the microSYSTEMs revolution doesn't quit.
It opens the future and delivers capabilities that we can barely imagine today.
The MTO program managers and I want to tell you about how we're going to lead this revolution, and we want you to join us.
As you can imagine, we face many challenges that must be addressed, But as you're about to hear, we're already driving breakthrough research in the science that will

enable this integrated microSYSTEM: things like the self assembly and integration of molecules and nano-particles, the conversion of chemical energy into electrical energy at the micro scale, and the development of incredible new materials with never-before-seen properties are just a few examples.
But where DARPA really excels is taking scientific breakthroughs from basic research and quickly moving them to the near side.
With that in mind, our office is pushing on three technical thrusts and new manufacturing concepts to enable the integrated microSYSTEM.

First, we are pushing the limits of scaling and integration.
In the past, DARPA-supported research has enabled the integrated circuit industry to make CMOS devices with line widths below 100 nm.
We are pushing the limits even further, developing device concepts that will have feature sizes well below 25 nm and will be fabricated with novel materials and entirely new integration techniques.
At this scale, we need to overcome a host of new physical effects.
We can then use these nano-scale devices for full spectrum applications in sensing, processing, and storage.
In the next talk, John Zolper will further discuss how we have launched efforts to push the limits of scaling and integration.

By full-spectrum, I mean the entire electromagnetic spectrum - truly DC to daylight... and beyond! In the RF arena, MTO has opened an entirely new capability of silicon-based RF systems.
Our new programs are optimizing the trade space of performance and integration, enabling a new class of ultra high-speed devices and highly integrated systems on a chip.

We're pushing the MEMS and optoelectronic scaling and integration limits as well.
To give you a glimpse of where we're headed, it looks like the emerging CMOS manufacturing processes have the extraordinary line smoothness to support wavelength-scale nanophotonic devices for the first time ever.
This will allow us to integrate electronics and photonics on the same substrate, and the vision for a new program MTO is about to launch called EPIC, short for Electronic and Photonic Integrated Circuits.
This is a concept that will reduce latency and increasing bandwidth while operating at very low power.
And it's one that looks like a key enabler for the integrated microSYSTEM,

With these new levels of scaling and integration, we plan to open vast unused regions of the spectrum and develop highly integrated microsensors.
Our programs here are pursuing work in areas like molecular devices, self-assembled integration and pushing quantum devices to their practical limits.
You will hear from John Carrano on how we have launched entirely new spectral imaging and sensor capabilities using ultraviolet light sources for biological agent detection, water purification, and non-line-of-sight covert communication.
You will also hear Mark Rosker's vision to open the THz regime of the electromagnetic spectrum to create new imaging capabilities.
While there are great hurdles to overcome, the pay-offs are enormous.

We are taking another run at electronically scanned arrays, this time with a new generation beam forming technology requiring minimal power while delivering ultra wideband performance.

We are also revisiting novel approaches for hyperspectral sensing, smart-pixel arrays, and compact, free space optical communications.
John Zolper will describe how we are pushing new wide bandgap materials and components.

We will open a new generation of high power microwave and millimeter wave devices for radars and for high voltage and high temperature power electronics.

Perhaps the greatest technical challenge for our office will be to use all of this integration, scaling and sensing capability in a way that allows us to intelligently interact with the environment.

Examples include flexible receivers and 3-D IC's.

But, as compelling as this vision might be, we really need a new way to build these microSYSTEMs in some affordable way and we really need your ideas.
The usual economies of scale for integrated circuits and devices are driven by high volume part count to reduce unit cost.
But it may be possible to develop new manufacturing methods or process flows that decouple product volume from cost.
In our advanced lithography program, we are exploring concepts in direct design, data-driven maskless technologies applied to the wafer scale.
Our objective is to eliminate the extremely costly phase shifting masks that make leading-edge integrated circuits so expensive when they are fabricated in low volumes.

We've also begun several efforts to extend automated design tools for mixed signal microSYSTEMs.
These will significantly reduce design cycle time and cost, perhaps by an order of magnitude, while advancing the design of very high-performance communication and sensing systems which are of vital military interest.
The challenge here is to develop new design, integration, and perhaps even fabrication tools that will lead to revolutionary changes in how DoD accesses microSYSTEM components.

The next revolution of the integrated microSYSTEM has begun and DARPA is out front once again.
We need your ideas and hope a few of you will step forward as Program Managers to help shape and drive this vision.

The commercial sector has brought us to a tipping point, and we are about to see CMOS technology driven into entirely new domains and enabling new types of functionality well beyond the notebook computer and cell phone.
At DARPA, we want to exploit commercial technology and drive it in new directions for the DoD by being the first to develop systems

* that can leverage performance at the limits of scaling and integration.

* that can exploit untapped regions of the spectrum, and

* that interact intelligently with their environment,

And we want to do all of this in a way that is affordable and available to the warfighter.

When you listen to the next several talks keep this in mind.

Let's turn this opportunity into a reality!
