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Teleprompter Script for Dr. Amit Lal, Program Manager,
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Micro and Nano Electro-Mechanical Systems: Technology Engineering Metamorphosis

» AMIT LAL:
Imagine a mechanical computer that can operate at high temperatures eliminating the need for heat sinks, allowing us to push Moore's law in coming decades.

Imagine the power of precise time offered currently by shoe-box size atomic clocks in tiny sugar-cube size
chip-scale atomic clocks, which will enable us to revolutionize navigation and communications.

Imagine an intelligent micro air vehicle maneuvering around wires, birds, even bullets, without human controls, perhaps being piloted by a hybrid-insect cyborg.

We are approaching technology that supports these visions, and that technology lies within micro-electromechanical systems – MEMS.

In the next few minutes,
I will attempt to engage your imagination and your resources so we can transform these visions into reality.

The core of MEMS technology is the capability to form chip-integrated micro beams, cantilevers, and plates.

DARPA has mined MEMS technology since the early 1990s in an effort to provide increased performance and functionality with integrated circuits.

From the number of ongoing and past efforts, we are finding out that MEMS technology changes systems so rapidly that there is less of an evolution, and more of a metamorphosis;
gradual growth is replaced rapidly by complete transformation.

You and I can see the transformative power of MEMS in our everyday lives.

We see the metamorphosis in televisions with digital light processing technology and its reliable
million-mirror arrays, enabling television imaging to proliferate from walls to eye-glasses.

We hear it in our mobile phones as large quartz resonators for timing references are replaced by micromechnanical resonators, opening up space for more functions in our cell phones.

We enjoy it in our video game entertainment as hand-held controllers incorporate MEMS accelerometers creating highly realistic virtual environments.

But MEMS goes beyond fun and games, it has the potential to save lives!

For example,
MEMS enables high speed accelerometers that are fast enough to detect side-impact collisions in time to deploy side-airbags.

The faster speed capability saves over 1000 lives a year during potentially deadly side impacts, in addition to front impacts.

MEMS inertial measurement units,
or IMUs, are being used to improve the accuracy and reliability of precision weapons,
such as JDAMs,
reducing collateral damage and reducing the number of weapons.

In the future,
we foresee that MEMS accelerometers and gyros can be used for extremely sensitive robotic motion control, allowing doctors to save the lives of warfighters by performing remote robotic surgery.

Lets now look at a few other examples of MEMS fueled metamorphosis -- starting with MEMS
RF-switch based RADAR.

Traditional semiconductor switches used in
transmit-receive modules, better known as
T/R modules, have high insertion losses, generating heat,
requiring several fuel trucks and heavy heat removing equipment.

In contrast, in MEMS
RF-switches, the ultra low on-state insertion loss, and high off-state isolation of MEMS RF switches reduces power and weight by two order of magnitude.

Efforts are ongoing on using thousands of MEMS RF-switches to realize electronically scanned arrays for low cost and low weight RADARs.

While early DARPA work identified MEMS switch failure mechanisms, current DARPA programs are solving the problems.

MEMS switches require mechanical contact between two surfaces.

Surface stiction can occur in the event of charging or material transfer in the presence of contaminants, resulting in device failure.

DARPA has led the way by using micro and nano scale packaging to isolate switches from external environments.

These efforts have resulted in switches lasting nearly a trillion cycles.

The packaging has also been tested in high humidity environments equivalent to operation in tropical forest for sixty years.

MEMS switches have
high reliability, adequate enough that anyone can now purchase them from standard commercial electronic component distributors.

Indicative of successful industry adoption, the MEMS switch commercial market for test equipment is projected to be into the 100s of millions in the next five years.

Not resting on its laurels, DARPA is already exploring exciting metamorphosis,
that of micro RF switches to nano-switches.

If a MEMS RF-switch is comparable to the diameter of a human hair, then a nano-electromechanical switch is comparable to the diameter of a virus.

The speed of micro-scale MEMS switches is limited to a few microseconds, and switching voltages are 50 to 100 volts.

In contrast nansoscale switches, can operate at sub-nanosecond speed and only at 1 volt, factors of 1000 improvement in speed and power over the existing MEMS switches.

Nanoelectromechanical switches could even metamorphosize transistors!

For example, nanoelectromechanical switches will have zero leakage current in the
off-state.

By placing these switches in series with leaky deep-sub-micron transistors,
we can achieve high density digital circuits with zero idle power!

This enables batteries to last longer reducing the battery load of warfighters.

We also forsee a revolution enabled by nano electro mechanical switches in high temperature computing.

Before me, my colleague Michael Fritze spoke about how power consumption is a problem because it leads to temperatures too high for silicon devices to operate.

This is because,
the silicon transistor switches cannot operate beyond 110C, as the carrier concentration differences cannot be maintained at higher temperatures.

While Mike and others are tackling this problem by trying to reduce the power consumed to keep temperatures low, another approach we are taking is to see if we can have switches that can work at high temperatures!

For example,
the mechanical switches are only potentially limited by the metallurgical properties such as the melting point,
perhaps allowing switching even at 700C.

NEMS high temperature switches could revolutionize computing in three ways:

First, heat sinks,
which keep computer temperatures below 110 degrees Celsius,
would become obsolete.

Second, with heat no longer a limiting factor; computers could be placed on top of each other, increasing computing power to revolutionary levels.

These 3-D computers could even approach the processing power of the human brain.

Third, due to the high operating temperatures,
it becomes more efficient to convert the computing generated heat back into electricity which gives rise to computers that are truly Carnot efficient…
or which can be called GREEN COMPUTERS!

Now, let me move on to another MEMS component, namely microscale spring-mass based MEMS resonators.

Remarkably, MEMS resonators can be engineered such that even with increased frequency in the GHz range, their quality factor or the sharpness of their response does not dramatically drop…

an IMPOSSIBLE feat by macro standards.

These resonators are poised to revolutionize frequency synthesis and filtering as hundreds of highly selective resonators with high Q can be used to reduce power and area consumed today by transistor phase-locked loops and bulky discrete components.

This technology is poised to shrink communication receivers and place the power of ultra-secure communications found in large airplanes in the hands of the warfighter.

But you may ask how far can we shrink these resonators?

It turns out the smallest resonators are individual atoms themselves.

We are already using atom resonators in the highly successful
chip-scale atomic clock program.

In cesium and rubidium atoms, the magnetic force between the electron spin with the nuclear spin acts as a spring.

This force, combined with the mass of the nucleus and the electron,
results in a resonator with f*Q product of $>10^{15}$, almost three orders of magnitude higher than that of mechanical MEMS resonators.

Unfortunately, to create metal atomic vapor,
we must heat the metal to around 100C, which takes 3-5 Watts in shoe-box size atomic clocks.

MEMS overcomes this power problem,
by using long-thin tethers to thermally isolate the vapor cavity.

Now, only 5mW,

or 100 times times less, power is needed to create a vapor, delivering a 1cc chip-scale atomic clock with only a 30mW power budget.

Another name for
chip-scale atomic clock could be National Institute of Standards and Technology on chip or NIST-on-Chip providing time and distance standards from the optical wavelength and frequency locked to atomic resonances.

The chip-scale atomic clocks are literally placing the National-Institute of Standards and Technology in the hands of the warfighter,
for more jam-resistant GPS signal acquisition and enabling future
self-calibrated sensors.

Indicative of the high rate of success of this program, Chip-scale atomic clocks are already being sampled for
several applications,
and are on their way to be commercially available from several vendors.

Now that we have tamed atoms-on-chip at low power, we are surging ahead in an effort to mine other atomic physics effect on chip.

An example is achieving navigation grade atomic gyros by using the nuclear magnetic resonance precession of atoms as a signal of rotation.

Spins of the atoms in the vapor cells precess like spinning tops.

If the frame of reference rotates around the top,
the measured frequency of precession is shifted by the rotation rate.

This metamorphosis of large to tiny, navigation grade gyroscopes,
may allow even small insects to carry navigation grade gyros.

So far, I’ve described MEMS fueled metamorphoses that are mostly symbolic.

Now, allow me to describe the Hybrid-Insect MEMS program, which is using metamorphosis very literally, transforming insects into unmanned air-vehicles.

In the Hybrid-Insect-MEMS program,
we are using biological metamorphosis to tightly integrate microsystems with nature’s microsystems,
namely insects.

Early biological experiments showed that tissue can form around pupae-inserted objects with insects that can fly even after major modifications.

Using this gift of nature, the HI-MEMS program seeks to grow MEMS and electronics inside the insect pupae.

The new tissue forms around the insertions, making the bio-electronic interface long-lasting and reliable.

Using insect integrated electronics, we might be able to control insect flight!

Much in the way we have farmed horses and camels as beasts of burden, we might now consider farming insects for robotic missions.

This endeavor would lead to useful wartime applications.

As an example,
perhaps you can develop insect-MEMS sensors that can sense explosives and biological weapons in remote areas to keep our soldiers out of harms way.

I invite your ideas for other revolutionary applications.

In summary,
you might recall the robot R2D2 who assisted flight missions in Star Wars.

You might recall Gandalf the friendly wizard in the recent classic Lord of the Rings, used a moth to call in air-support.

This science fiction vision is within the realm of reality using MEMS.

MEMS technology can transform how our soldiers fight on the battlefield and improve their chances of coming home.

With future visions of UAVs, computation, navigation, and RADARs, I hope I have convinced you that in MEMS metamorphosis is the rule, not the exception.

With your resources and leadership I hope we can bring these visions into reality.

Thank you for your attention.

Now, I would now like to introduce my colleague, Dr. Dennis Healy,
who will tunnel his way onto the stage with quantum mechanical tools.