Bridging the THz Gap
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Imagine you're on the scene as U.S. troops prepare to go into battle - let's say in a remote desert region.
The sun has been slipping below the horizon as the commander waits for the signal to attack.
Finally, the time is right - but now it's after dark.
What happens next?

We know the answer - thanks in large part to the groundbreaking research of DARPA.
The troops simply put on their night vision goggles and go on into battle.

Let's move to another scenario.
That same commander is leading U.S. soldiers into another battle.
Jeeps and humvees are rolling, single file, past dismounted warfighters packing sophisticated weapons.
The troops are briefed, the strategy is set, adrenaline is in the air.
Suddenly . . . a dust cloud comes whirling in over the desolate terrain.
In a minute the soldiers are engulfed with a blinding curtain of sand and dirt-it's impossible to see even a single vehicle length ahead.
Now what happens?

The answer to that question will take us into an unexpected new direction and will open up to us a huge, unseen world.
That's why I'm here today - to tell you about DARPA's Terahertz technology initiative, and how, as a result of it, the vast but unused THz spectral region will be filled by systems with capabilities beyond that of any current technology.
But first, let me mention that there are other scenarios we're working on, too.
Let me put THz imaging in the context of the many capabilities we're developing at MTO to help the U.S. military win wars and save lives.

Today's wars are waged not just with weapons.
We rely on sensors for battlefield vision - to allow us to see far beyond what our eyes alone can see.
We rely on secure, high-throughput battlefield communications - to enable the capture, processing and sharing of information.
So whether a conflict occurs on jungles or deserts, oceans or airspace, it would not be an exaggeration to say that the force that controls the electromagnetic spectrum controls the battlefront.
That's why one of MTO's primary responsibilities is to develop revolutionary component and sub-system technologies to maintain and expand US forces' dominance of the electromagnetic spectrum.

At the radio frequency end of the spectrum, MTO is working to provide better communications on-the-move.
In this portion of the spectrum, we have a long history of pursuing technologies to access increasingly higher frequencies.
Why? Because high-frequency electronics allows greater available bandwidth-enabling sensors and allowing them to communicate and process the vast amount of information required in today's tactical and strategic environments.
As Zach Lemnios described in his talk, previous DARPA programs led to the development of the monolithic microwave integrated circuit, which has become the fundamental building block for modern military RF systems, like these - and which enabled commercial applications like your cellular phone handset.
Today, MTO is leading research that will demonstrate high-performance RF and mixed signal "systems-on-a-chip" based on silicon technology with RF frequencies up to 100 GHz, levels that until recently would be considered impossible.
Need even more bandwidth?
We are also developing high-frequency digital synthesizer and related circuits at even higher frequencies, up to around 250 GHz, with high dynamic range, low phase noise, low DC power, and wide bandwidths.

And speaking of low DC power, we are also developing a new semiconductor technology which may reach operation frequencies of hundreds of GHz - but which consumes 10 times less power to operate than the best electronics technology now available.

Tomorrow's military communications and sensor systems will be based on these new RF technologies, which fill the need to collect, process, and communicate more information with less power consumption.

On the other side of the electromagnetic spectrum lies the world of photonics.

Let me tell you how MTO continues to expand dominance in this vital part of the spectrum.

Remember our soldiers, waiting to fight a battle at night?

The focal plane arrays that they will use and that DARPA helped develop are incredibly sensitive to infrared radiation.

They enable vision even in the darkest of conditions - such as on a moonless night, under cloud cover.

But they only function at a single color.

For better situational awareness, MTO is now developing high-performance focal plane arrays that are widely tunable across the near infrared to long wave infrared spectrum, thus enabling multispectral imaging on a chip.

But optics can provide more than a means of seeing.

MTO is developing small, lightweight visible and infrared laser beam scanning technologies to replace large, heavy gimbaled mirror systems to enable enhanced Tactical Laser Communications and infrared Countermeasure capabilities.

And MTO is exploiting one more thing that optics does well: its inherently parallel nature.

This will allow entirely new capabilities and architectures for tactical and strategic radio frequency systems by incorporating optical analog signal processing into the system's front ends

But what about that empty space between electronics and photonics?

This is the "THz Gap," as it's been often called: the region where wavelengths are from 100 microns to 1 mm, and frequencies are from 300 GHz to 3 THz.

In this region are enormous expanses of unused bandwidth - bandwidth that our adversaries lack the technology to make use of.

Many physical properties at THz frequencies are unique and are waiting to be exploited for practical advantage.

One such opportunity is the identification of chemical threats.

Low-pressure gases have astonishingly selective signatures in this region.

In MTO's recently completed Terahertz Technology for Sensing and Satellite Communications program, a relatively compact chemical sensor was developed and shown to have incredible absolute specificity even when dealing with very complicated mixtures.

Further advances could lead to very inexpensive and portable systems.

And what are the unique capabilities of THz imaging?

THz radiation can transmit through materials we normally think of as opaque: thick smoke, a cloud, fog, dust, or even the dry sand of a sandstorm.

While this neat trick can also be accomplished at some lower frequencies, by millimeter waves for instance, at THz frequencies there is a crucial advantage: As a consequence of optical diffraction, we can achieve higher resolution imagery in the THz with order-of-magnitude smaller imaging apertures - making THz imaging systems a practical option in the field of operations for many military platforms and missions.

THz offers other advantages.

Depth of field, which is the ability to resolve a target in the direction of propagation, is a stressing requirement for certain applications.

THz imaging can achieve ten times better depth of field as compared to passive millimeter waves.

And the extraction of phase information - imaging radar - can be realized at THz frequencies.

What are some application possibilities that will make use of this technology?

A THz imager could enable a tank traveling through dust and fog to see the vehicle ahead of it.
This technology could be provided for UAVs, helicopters, humvees-and it could be small enough to provide imaging for dismounted soldiers, some day, even for goggles.
THz imaging could be used at checkpoints-identifying threats at distances of perhaps 30 meters.
A THz beacon worn by a pilot could be detected if his plane is shot down, allowing a coordinated rescue as long as his general location is known.

Bridging the "THz Gap" will require revolutionary component and integration technologies.
MTO is focusing on four technical challenges:

* New sources of THz radiation, both to provide coherent illumination of the scene and for use as local oscillators.
In the THz regime, the best compact source technologies available currently produce only about 1 mW of average power - compared to the kilowatts or more commonly available at most other spectral frequencies.
The lack of high-power, highly efficient, and compact sources has been the greatest obstacle to exploiting THz.
Today's high speed transistor technology is not nearly fast enough, nor is today's vacuum tube technology nearly small enough, to do the job.
Are there radically different approaches to miniaturize the vacuum tubes and lasers that now require entire tabletops to allow them to fit onto a single semiconductor wafer?
Or are there are new ways to efficiently convert energy from frequencies where we can already make compact, high-power sources - that is, the RF electronics or the photonics regions we discussed before - to the THz domain?

* Sensitive THz receiver arrays.
Years of experience have taught us how to make extremely sensitive THz detectors, but to accomplish this performance requires cooling these detectors nearly to absolute zero.
How can we make detectors very sensitive and practical for defense applications?
And how can we combine single detectors into large arrays capable of capturing detailed images in real time?

* Low-loss THz interconnects.
In electronics, interconnect losses invariably increase with frequency.
That's bad news especially because, as we just saw, THz photons are so precious.
So THz imagers, consisting perhaps of thousands of elements, will demand radically different interconnect and integration strategies to insure efficient, low-loss distribution of local oscillator power and collection of THz signals.
How will this be achieved?
This is a huge problem that has never been faced before.

* Backend signal processing.
While much will be borrowed from infrared focal plane array technology, THz imaging presents unique technical challenges in data processing.
One of these is calibration and test in a spectral environment where water vapor variability often results in a rapidly changing background.
Another example is the collection of coherent signals across a very large array.

I've concentrated here on imaging with THz radiation.
But these technologies will certainly make possible many other kinds of THz sensor and communications systems, each with their own unique and important advantages.
What will these be?
At MTO, we envision. . .
* Chemical sensors capable of identifying and assessing threats remotely;

* Better means to see into materials to non-destructively evaluate their condition;

* Communication systems with enormous information bandwidths that can propagate

through a dark cloud; and

* Secure communications that cannot propagate to where an enemy might easily detect it.

All of these, and many more that perhaps you will imagine, will be enabled by the component and integration technologies we have begun building today, to bridge the "THz Gap."

The spectrum between millimeter waves and photonics is a world invisible to us today.
But with the technologies MTO is leading, we will have the ability to gaze into that world and see what our adversaries cannot-giving us the advantage in spectral dominance and on the battlefields of the future.