Good morning ladies and gentlemen.

Today I want to talk to you about some of the exciting programs we are working on in photonics in the Microsystems Technology Office.

In many respects, photonics, which is the art and science of using light, is not new. More than 300 years ago, Isaac Newton was already working in the field. Everyday, we live our lives in a world that would be hard to imagine without light. We see because of light; the plants that sustain us draw energy from light.

When we talk about photonics as a technology, we are talking about our conscious and deliberate effort to harness the power of light to perform useful tasks for us.

More to the point, what we really want to do is focus our efforts into creating technologies for sensing, communications, and processing.

When we use photonics for sensing, it is because we realize we can extend our senses to see, smell, and hear. We can see clearer and further with light; we can improve our sense of smell by using photonics; and we can hear things that our natural ears cannot. In communications, we are using light in new ways to shuttle large volumes of information between distances as short as a few centimeters, and as large as across oceans.

Lastly, we are just beginning to harness the power of light for processing and analyzing information. This is an area that has largely remained outside of the capabilities of light because most of our needs in processing have been satisfactorily met by purely electronic systems. But that is beginning to change, and we are now slowly, but surely, incorporating photonics in information processing systems.

In a typical system that processes information, whether it is a military or civilian system, there are distinct functional blocks into which the system can be broken. Right at the front-end of the system is a sensor: this sensor gathers the raw information from the environment; the information is then passed on to the processor through a gateway.

The gateway controls the flow of information to the other parts of the system such as the storage unit, or the pre-processing subsystem, and then to the processor itself.

The gateway also channels the processed information to the display subsystem and to the human interface.

Photonics can significantly impact the overall operation of any information processing system. What I want to do later on, is show how several of our on-going efforts in photonics map onto the functional blocks of a typical information processing system; I will then highlight the difference the use of photonics makes. But before I do that, let me review where photonics has already made a major difference.

Today, transport of long-haul data and voice traffic is almost exclusively carried over fiber-optic communication networks.

DARPA was there at the beginning of the revolution in fiber-optic communication. It supported the development of the optoelectronic technologies necessary for the systems that are being deployed or have been deployed. One effort that was particularly influential in the development of some of the key technologies in communications, was the Broadband Information Technology (BIT) program. This program supported and guided the development of long wavelength lasers and detectors for transmission and reception of data at extremely high data rates --- in excess of 2-and-a-half billion bits per second per channel. Many of you have heard of Wavelength Division Multiplexing, also known by the acronym WDM. The components of this technology were developed under the Broadband Information Technology program*. [And today on Wall Street, stockbrokers think that the acronym WDM means Watching Dividends Multiply.] I also want to add that the Broadband Information Technology program was the forerunner of the Next Generation Internet program. After the long haul comes the short haul, that is distances in the range of 10's to 100's of meters. In this distance range, DARPA developed fiber-optic links based on vertical-cavity, surface-emitting laser arrays.

With linear laser arrays, parallel links useful for optical interconnections at this distance range begin to be cost-effective and competitive. To further realize the benefits of optics at even shorter distances, we are now developing the necessary technologies in a program called VLSI Photonics. The primary objective of this program is to link high- performance chips with optics. The VLSI Photonics program aims to merge the superior signal transport properties of optics with the proven advantages of processing information in the electrical domain: what we want to do is perform most of the computations in the electrical domain, but communicate the results of the computations to where they are needed by using photons. The motivation for using optics for interconnections is that the communication bandwidth is larger and information can be more cost-effectively transported this way than it can in the traditional electrical scheme of using wires.

Let me now tell you about our current programs in the areas where photonics is beginning to play a major role. In infrared sensing, we are developing uncooled sensors for imaging, night vision, target acquisition, and missile guidance.

These sensors are being developed in our Infrared Sensitive Materials program.

We have two other programs in sensing: these are the Solar-blind AlGaN Sensors program, and the Photonic Wavelength and Spatial Signal Processing program.

In communications, we have the Radio Frequency Lightwave Integrated Circuits program; there is also the Steered Agile Beams program.

Two programs fall under the rubric of processing --- and I use the word processing here very loosely.

The main programs in the processing area are: the VLSI Photonics program, and the Photonic Analog to Digital Converter program. VLSI Photonics is aimed at solving the chip-to-chip interconnect bottleneck. The Photonic Analog to Digital Converter program will develop technologies for achieving dramatic advances in the conversion of analog signals to the digital domain for further processing; we want to enhance the processing of raw radar signals. One of our goals is to achieve analog-to-digital conversion rates in the range of 100's of billions of samples/second.

The program managers in our Office who lead the photonics effort are Ray Balcerak, Edgar Martinez, David Honey, James Murphy, and myself. These gentlemen are all here today, and I hope you will get a chance to talk with them and learn more about our programs during the breaks or during the sidebar sessions.

Let me show again the typical architecture of an information processing system in its functional blocks. Lets now see how our programs map onto this architecture.

In the Photonic Analog to Digital Converter program, one desirable goal is to move the analog-to-digital conversion process as close as possible to the sensor head itself. The major advantage of doing this is simpler overall system architecture. This comes about from reduced component count for the radio frequency signal processing.

In the Photonic Analog to Digital Converter program, we will develop the optical versions of the key elements of an analog-to-digital converter: the first of these elements is a precise, high-speed clock which can generate pulses that are less than one trillionth of a second; the second element is a very broadband sampler; and the third is a fast, high-resolution sample quantizer. The photonic clocks we are working on are based on mode-locked semiconductor lasers and compact solid-state lasers which pump fiber-ring lasers; the samplers we are working on are variants of a Mach-Zender interferometer.

We are also looking into fast photodetectors for the front-end of the quantizer. These detectors must be linear, and should exhibit high dynamic range.

I want to talk briefly about our VLSI Photonics program --- this program straddles the areas of processing and communications. Here, we are interested in developing low power, oxide-confined vertical-cavity surface-emitting laser arrays for chip-to-chip, board-to-board, and back-plane optical interconnects.

We are also developing technologies for fast, parallel access for level two memory. The broad objective of this program is to provide high bandwidth optical connectivity for electronic systems in the distance range between 1 to 10 centimeters.

Lets see where the technologies developed in the VLSI Photonics program would be useful. Consider this image of some land area of interest.

Suppose that the total area is about 10,000 square miles. If you wanted to see objects in this picture and be able to estimate their size to an accuracy of a foot, you would need to generate about 3 trillion bits (Tbs) of information. And this is being conservative --- I have assumed that we digitize at 10 bits/pixel/color, and that the image is in black-and- white. If the picture were in color, it would generate even more bits.

Pictures like this can be acquired by an airborne synthetic aperture radar system.

To identify and classify the objects in the image, we would most likely use an array of processors working on different parts of the image in parallel. Since vast amounts of information must be passed back-and-forth between and among the processors, wire interconnects between the processors would not be the best way to do this because of their limited capacity and speed.

What we really want to use is large capacity optical interconnects; this would speed the process.

And as a side benefit we would consume less power; and if we really designed the system right, it would also be smaller and lighter.

Now we come to the Radio Frequency Lightwave Integrated Circuits program.

In this program we will develop a broad range of technologies that can be used to assist in the transport and processing of analog radio frequency signals.

The technologies developed under this program will benefit the management of signals from sensors (such as radio antennas) that are located near or remote from the processor itself.

To be specific, what we want to do in this program is to extend the techniques that are now used to transmit and process audio analog signals in the radio frequency range to the optical domain.

In this way, we will be able to transmit and process the entire radio frequency spectrum in the lightwave frequency domain.

The main reason for wanting to do this is to achieve very broadband radio frequency signal handling from a few million cycles per second (MHz) to over several hundred billion cycles per second (GHz). And, we want to do this in a single photonic signal-processing module. Working in the optical domain will allow us to take advantage of new photonics technologies that are very compact, consume very low power, and have the potential to allow the realization of complex signal processing applications.

This chart illustrates some of the goals of the Radio Frequency Lightwave Integrated Circuits program.

It highlights the advantages in link gain and noise figure that can be realized when we use photonics.

With the technologies developed in this program, we expect to be able to realize links with gains from about 0 to +20* dB. This will be a substantial improvement over what is possible with current technologies.

Some of the technologies we will develop include advanced light sources compatible with new generation, low loss fibers; we will also develop optical modulators that require extremely low voltages (less than 1 volt); and special photodetectors that can handle high optical powers.

And by the way, there are many applications that would be enabled with signal processing based on the technology of Radio Frequency Lightwave Integrated Circuits. Perhaps the most obvious and important commercial applications are the distribution and remoting of wireless antennas for cell phones, and the distribution of cable TV service to homes.

We have three programs that are specifically for developing new sensor technologies; these are the Photonic Wavelength and Spatial Signal Processing program, the Uncooled Infrared Imaging program, and the Steered Agile Beams program. In each of these programs, the sensor module and the pre-processing functionality are co-located within the sensor-head itself to give the sensor more capabilities.

In the Photonic Wavelength and Spatial Signal Processing program, we will develop technologies and new architectural concepts for advanced multi-spectral and hyper-spectral imaging.

The modules in this program will be tailored for multi-domain functionality. They will enable the design of systems that allow vision where it is otherwise not possible, and chemical species identification, where it is normally difficult. The paradigm shift in this program is that the new sensor systems will exhibit, simultaneously, high resolution in the spatial and spectral domains. These are extremely useful attributes for detection, classification, and identification.

In the Advanced Uncooled Infrared Sensor program, we are working on sensors that can operate without cryogenic cooling. There are some very goods reasons why one would want to use uncooled sensors; I will get to these shortly.

The uncooled sensors we are working on are based on micromachined bolometers. The performance of these sensors is not yet where we want it to be; but we are improving. Just a few months, we broke the 100 mK sensitivity barrier.

We continue to strive to understand the fundamental thermal noise limitations of these sensors; we are also improving the materials out of which the sensors are made. The bottom line is that we believe we can achieve performance as good as the cooled sensors.

Now I want to briefly mention some of the reasons why uncooled sensors are so desirable. First, as you can see from the image on the screen, there is a reduction in size of anywhere from about 10 to 100 times. Second, there is reduction in the power required to operate the sensors, and finally, there is an inherent cost reduction associated with the simplified packaging, and of course because of the elimination of cooling devices.

The last of our new programs in sensing and communications is the Steered Agile Beams program. This program will focus on developing technologies for beam steering for applications in infrared countermeasures. One of things we would like to do is to develop chip-scale technologies for target acquisition in ranges of up to 3 km; we are also working on transceivers for covert optical data communications in all-weather conditions. The emphasis on the program is to develop components that will enable the design of compact, low power systems.

Finally, I hope I have given you a sense of what we are doing in photonics in the areas of sensing, communications, and processing. It should now be obvious that photonics offers some unique performance advantages in information systems. These advantages would be missed if only purely electronic systems are deployed. Most of you already know that photonics has been playing an important role in storage and communications. You only have to think of your pc with its optical CD-ROM and of your long- distance phone system to realize this. I hope this presentation has expanded your view of what other things photonics can do. You can learn more about the details of our efforts in this exciting area from the other program managers who are there today. I look forward to interacting with some of you. Thank you very much for your attention, ladies and gentlemen.