Radar and MIT Lincoln Laboratory: A View from a Distance

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I spent five very important and formative years early in my career, in the late 1950s, at Lincoln Laboratory acquiring a thorough foundation in radar by being in the presence of the numerous radar pioneers who were there. It was at Lincoln Laboratory I discovered that the pursuit of new radar development could be a joy and an adventure, as well as provide the satisfaction of making a contribution to national defense. What I learned there about radar and the "sociology" of the radar development process has been of lasting value to me in my career.

In looking back from a distance of many years, I am truly impressed by the consistent innovations and important radar advances contributed by those at the Laboratory for almost fifty years. It started with the SAGE system, the first automatic radar command-and-control system for continental air defense. The SAGE system was a success but it indicated how poor our then-current air-surveillance radars were for continuous automatic tracking of aircraft. The Laboratory led the way in showing that "big is beautiful" when it comes to antenna size and transmitter average power, and that clutter echoes need not be allowed to mask the target echo. Radar in World War II did not employ the Doppler effect for the detection of moving aircraft in clutter, but Lincoln Laboratory addressed the problem, and now it is unthinkable to have a military or a civil air-surveillance radar that doesn't include Doppler processing.

The need in the 1950s to provide warning of air attack from across the northern borders of North America led to the Distant Early Warning (DEW) Line. The radars of the DEW Line were the first to employ automatic target detection, as was demonstrated by Lincoln Laboratory. The DEW Line also included the first U.S. operational bistatic radar system, which was originated by engineers at the Laboratory. To operate and survive in the harsh climate of the North, radar antennas had to be protected from the weather. This need gave rise to the successful development of the rigid geodesic radome that is still widely used as the first choice when an antenna has to be enclosed for environmental protection.

After World War II, military attack aircraft were built to fly at low altitude to evade radar detection. Low-altitude aircraft led in turn to the development of airborne air-surveillance radar that could detect low-flying aircraft well beyond the normal horizon of ground-based radar. Engineers at the Laboratory showed the benefits of the UHF frequency band for this purpose. One of the limitations of any AMTI (airborne moving-target indication) radar was that the clutter echo also had a Doppler frequency shift that changed as the radar antenna scanned in azimuth. The Laboratory developed a technique, called TACCAR (Time-Averaged Clutter-Coherent Airborne Radar), to automatically compensate for the Doppler shift of the clutter echo. The technique continues to be used in the U.S. Navy's Airborne Early Warning (AEW) radar system, an essential part of naval-aircraft carrier operations. Lincoln Laboratory's contribution to the success of AMTI radar was recognized when Melvin Labitt of the Laboratory shared the 1991 IEEE Aerospace and Electronic Systems Society Pioneer Award for "Contributions to Improved Airborne Moving Target Radar Systems."

When the threat of intercontinental ballistic missiles arose in the 1950s, Lincoln Laboratory was there to meet the challenge. The Laboratory formulated the concept for what became the Ballistic Missile Early Warning System (BMEWS) to provide warning of the approach of intercontinental ballistic missiles to the United States. Such radars were the first to radiate the high average power of one-half megawatt in each of their beams. The formulation of the BMEWS concept was one of the few instances (outside World War II) in which a research-and-development organization was tasked to configure a new type of radar system to deal with an entirely new threat. The "blueprint" for the BMEWS system devised by Lincoln Laboratory was the basis, with little significant change, for the warning system that was installed in Greenland, the United Kingdom, and Alaska by industry.

In the late 1950s the Laboratory also began to consider how best to use radar not only for ballistic missile warning but for satellite surveillance and ballistic missile defense. The 84-ft-diameter Millstone Hill radar, a very large radar for its time, was built to gain experience in the detection and tracking of missiles and satellites. This radar was followed later in the early 1960s by the even larger 120-ft-diameter Haystack Hill radar. Herbert G. Weiss of the Laboratory received the 2000 IEEE Aerospace and Electronic Systems Society Pioneer Award for "The Millstone and Haystack Radars," in recognition of his role in the development of these two radars.

Lincoln Laboratory also participated in the development of a unique long-range radar system that was installed overseas by the Air Force to view the first Soviet ballistic missiles as they were being tested. This radar needed long pulse durations to obtain large energy on the target, and it was the first operational radar to employ pulse compression (using a binary phase-coded waveform) to achieve the resolution of a short pulse with the energy of a long pulse. The pioneering pulse-compression work by the Laboratory under the leadership of William Siebert shared the 1988 IEEE Aerospace and Electronic Systems Society Pioneer Award for "Contributions to Pulse-Compression Techniques for Radar Systems."

In the early days of ballistic missile defense it was soon realized that the radar had to recognize the reentry vehicle (carrying the warhead) and reject the unwanted echoes from any accompanying missile debris or deliberate penetration aids. The Laboratory made a major contribution by establishing a long-term experimental site with highly capable instrumentation radars at Kwajalein, an atoll in the western Pacific Ocean, to explore the reentry physics of ballistic missiles and methods for discriminating the warhead from all the other objects that could confuse a defending radar system.

Lincoln Laboratory pioneered long-range, high-power wideband radar for missile defense discrimination and space-object identification with the development and deployment of the ALCOR radar at Kwajalein in the early 1970s.

The start of Lincoln Laboratory in the early 1950s was also the beginning of interest in electronically steered phased-array radars. It took over twenty years, however, before the serial production of phased arrays began to appear for military applications. During that gestation time, the Laboratory contributed significantly to the growth of phased-array radar techniques by conducting a fundamental engineering-research effort to advance knowledge in phased-array technology, especially phase shifters and mutual coupling.

To properly design radars to detect small moving targets in clutter, the radar engineer needs to know the characteristics of land-clutter echoes. Measurements made during World War II of typical land clutter remained for many years the major source of clutter information for radar design, but these measurements were inadequate when better radars were needed for such missions as cruise missile defense. However, this need to characterize clutter echoes was filled through a series of well-documented, multiple-frequency measurements made by the Laboratory over a large number of sites in North America. The results of this effort have now become the standard for radar clutter information at low grazing angles.

Although much of its efforts in radar have been for military purposes, the Laboratory has also made significant contributions to civil air-traffic-control radars. In the 1970s several innovative waveform and signal processing techniques were synergistically combined to significantly improve the detection of moving targets in the presence of large clutter echoes. MTI, or moving-target indication, radar was well known, but Lincoln Laboratory engineers went far beyond what was practiced at the time by taking advantage of the benefits offered by digital processing to configure a system superior to anything that preceded it. It was called moving-target detection, or MTD, to signify its advantages over conventional MTI. The MTD concept devised at the Laboratory is now used in all major airport-surveillance radars.

There have been many more highly significant radar developments made by the Laboratory over the years of its existence, many of which the reader will find described in this issue.

In looking back at the unique and plentiful accomplishments in radar at Lincoln Laboratory, one naturally might ask how did it happen? The Massachusetts Institute of Technology, of which Lincoln Laboratory is a part, has always had the goal of being the best in anything it attempts, but it took more than that. The Laboratory has always had enlightened, forward-thinking management that understood the needs of the military customer, that actively participated in military research-and-development affairs in Washington, that provided the means whereby talented engineers and scientists could be recruited, and that insured an environment in which they could work effectively. The radar engineers at the Laboratory also benefited from collaboration with colleagues in technical areas other than radar, including semiconductors, computers, propagation, antennas, communications, and mechanical engineering, as well as excellent shops and publications services. But perhaps most significant was Lincoln Laboratory's ability to consistently attract adequate funding resources to permit their engineers to work in an innovative manner with a major degree of technical independence, so that they might perform their tasks as they thought best, something probably unique in defense research and development.

As one who worked at Lincoln as a young radar engineer struggling in the trenches, later as a colleague in the pursuit of military radar research and development, and at times as a competitor, I can say that their accomplishments have been impressive. They have made many important contributions to the growth of radar and its application to national defense as well as the civil sector. The job of Lincoln Laboratory and the rest of us in military research and development is to insure that we can maintain and increase the effectiveness of radar in the future in spite of new challenges and threats. I have no doubt that Lincoln Laboratory will continue, as it has done so successfully in the past, to be a major leader in such endeavors.

MERRILL I. SKOLNIK *served as Superintendent of the Radar Division at the Naval Research Laboratory, a Senior Executive Service position, from 1965 to 1996. Before that he was with the Institute for Defense Analyses, Research Division of Electronic Communications, MIT Lincoln Laboratory, Sylvania Boston Engineering Laboratory, and the Johns Hopkins University Radiation Laboratory. He received B.E., M.S.E., and Dr. Eng. degrees in electrical engineering from the Johns Hopkins University, as well as the Distinguished Alumnus Award and election to the Johns Hopkins Society of Scholars. He is a Fellow of the IEEE, a member and former chairman of the IEEE Radar Systems Panel, and former editor of the* Proceedings of the IEEE. *He has received the IEEE Harry Diamond Award, the IEEE Centennial Medal, the Institute of Electronic and Radio Engineers (UK) Heinrich Hertz Premium, and the Navy Distinguished Civilian Service Award. He is the author of the seminal textbook* Introduction to Radar Systems, *as well as the author of the article on radar in the* Encyclopaedia Britannica. *In 1986 he was elected to the National Academy of Engineering.*