REPORT

Assessment of Ultra-Wideband (UWB) Technology

Charles Fowler, Panel Chairman
John Entzminger, Principal Government Advisor
and
James Corum, Battelle Corp. Study Manager

CHAIRMAN'S NOTE

The Appendix lists the Study Panel members and observers/advisors. This report is the result of their labors and I want to thank them for their dedication and hard work. It was a great personal privilege to work with such a distinguished group of nationally recognized, competent, fair-minded technical experts. In opening the first Panel meeting I couldn’t resist borrowing from President Kennedy to compliment the group and recognize the unusual brilliance of my first boss: “Never has so much radar talent been gathered in one room since Luie Alvarez dined alone.”

FOREWORD

The Defense Advanced Research Projects Agency (DARPA) and the Office of the Secretary of Defense (OSD) tasked Battelle to review ultra-wideband (UWB) technologies and applications. Battelle convened the Ultra-Wideband Radar Review Panel to examine the state-of-the-art and the potential performance benefits and limitations of UWB technology, with particular emphasis on radar applications. The Panel was tasked with identifying and prioritizing UWB research to be pursued and exploited. This summary report presents the Panel’s findings.

EXECUTIVE SUMMARY

Introduction

In view of the interest in ultra-wideband (UWB) technology, the Defense Advanced Research Projects Agency (DARPA)
and the Office of the Secretary of Defense (OSD) contracted with Battelle to assess UWB technology and its potential military applications. Battelle convened a panel of experts drawn from the various technical areas concerned with UWB technology in order to perform this assessment. The Panel's assignment was to review the status of the work in the field, to examine the validity of a number of claims made by proponents, to determine potential performance benefits and to recommend areas for Government R&D support. The Terms of Reference are given in the Appendix along with a list of Panel members, Government advisors and presenters, and the agendas of the Panel meetings.

The Panel reviewed available experimental data, analyses, literature and various studies. It examined past and proposed research at DoD and DoE laboratories, as well as by industry and academia. It invited the proponents of UWB technology to disclose and explain their approaches, methods and recommendations. It gave consideration to all views, and worked to identify and prioritize promising concepts for exploitation of UWB phenomena. This report presents the results of these efforts and recommends research which the Panel believes should be pursued and identifies areas which the Panel believes are not worthy of pursuit.

**Scope**

Interest in UWB technology has focused on three areas:

- **Radar**
- **Communications**
- **Electronic warfare (EW) and RF weaponization**

The Panel concentrated on radar but invited the presentation of ideas on communications. No ideas or proposals for UWB communications systems or techniques were presented, nor were any advantages for such systems apparent to the Panel. Examination of electronic warfare and RF weaponization applications was very limited. The restrictions imposed by the combination of security classification and the proprietary nature of many of the EW and weaponization concepts under development by the presenters made it difficult for the Panel to conduct an in-depth review of these areas. Further, the DoD has established a separate in-house committee to review a broader area that includes UWB applications to electronic warfare and weaponization. Thus, the Panel's efforts were almost entirely devoted to UWB radar issues.

**Features of UWB Radar**

UWB radars are characterized by very wide bandwidths and the commensurate fine range resolution. There are applications in which range resolutions on the order of one foot are desired, such as imaging typical tactical targets, and wideband techniques are routinely used for these. However, there are associated disadvantages as well, as evidenced by the preference to use the narrowest bandwidth consistent with need in order to minimize the processing burden. For example, a tenfold increase in bandwidth has significant impact on the cost of a system since, for a given surveillance volume, the number of resolution cells to be processed and the required processing for detection are both proportional to the bandwidth. In addition, the tenfold increase in number of cells, for all else constant, implies about a tenfold increase in the probability of false alarm or a small decrease in system sensitivity. For these reasons, wideband or ultra-wideband are used only when the increased percentage bandwidth presents a distinct advantage.

Essentially all of the interest in (and claims for) UWB radars have related to an impulse radar implementation which, in its simplest form, generates its radiated energy by applying a very short video pulse (hence "impulse") to an antenna. Other forms of UWB radars, "non-impulse" radars, are generally extrapolations and extensions of so-called conventional radars. Consequently, the Panel's efforts were concentrated on impulse radar technologies and capabilities.

**Discussion**

Impulse radars have been around for a long time and there are a number of fielded systems that have been successfully used for terrain profiling and ground penetration to find buried objects.

The recent general interest, however, has centered on claims involving counter-stealth capabilities, Low Probability of Intercept (LPI), and detection of relocatable targets (in camouflage and foliage). In the technical community, there has been controversy over assertions that the "standard" analytical tools were either inappropriate or inadequate to deal with impulse radar issues.

An impulse radar can have substantial low frequency content and typically has high peak power and short pulse length. These properties are the basis for claims of unusual capabilities. In examining the subject, the Panel found it useful to separate such claimed capabilities into two categories: 1) those involving phenomena which are unique to impulse radars and 2) those in which impulse radar may offer one or more advantages in implementation.

Most of the claims for unique performance capabilities were based upon non-linear effects due to high power and/or short pulses. The Panel found no theoretical or experimental evidence of such effects at frequencies and operating ranges of interest.

The use of self-induced transparency (a truly non-linear phenomenon) has been suggested as a possible method for reducing atmospheric attenuation of millimeter waves. The Panel was able to look into this only briefly. It concluded that the likelihood of achieving a useful military capability taking advantage of potentially reduced atmospheric attenuation was slight but that it would be useful to have someone (e.g., the JASONs, the National Science Foundation, or a university) review and document the whole area of non-linear effects and any possible military applications.

Other claims for unique capabilities were examined and found to be in error. Specifically, "precursors," which have figured prominently in some discussions, are linear transients in distributed media and not unique to impulse systems. Further, the Panel saw no practical radar application of this phenomenon.

There are a number of applications where the combination of high resolution and low frequency is desirable. The most demonstrated are terrain profiling and earth penetration, but others such as foliage penetration or the possibility of simultaneous low-frequency surveillance with high resolution target
identification have been suggested and should be considered. Either conventional wideband (non-impulse) or impulse radars could accomplish these functions, but impulse radars might have a substantive advantage in implementation as measured by cost, size, or weight and deserve detailed examination. Shorter-range applications are most likely to manifest this advantage.

There have been three proposed capabilities for impulse radar that have received wide attention:

A. Counter-Stealth. The Panel concluded that impulse radar is not “inherently anti-stealth.” The primary technique used for achieving low radar cross section is shaping. Low frequencies (HF and VHF) can exploit target resonance effects which are independent of shaping and only a function of size. This phenomenon, however, holds for any radar operating in those bands and impulse radars have no unique advantages against shaping.

There are no effects in radar absorbing material (RAM) that are unique to impulse radar. Field strengths in practical applications are too low to excite material non-linearities. All observed effects are due to “out-of-band” operation (with respect to the RAM) and predictions to the contrary are due to a misunderstanding of electromagnetics. Standard measurement and diagnostic techniques routinely used by the stealth community deal with these issues completely.

B. Detectability of the Radar (LPI). To make a radar’s signal more difficult to intercept, radar designers resort to the use of complex waveforms and large processing gains. Even so, it is difficult to make a radar hard to detect even in the side-lobe region. The Panel concluded that the impulse radar, which typically has less processing gain, has no special LPI characteristics and is readily detectable by an appropriately designed intercept receiver.

C. Detection of Relocateable Targets. A capability of interest to both strategic and tactical forces is the detection of military targets when shielded or obscured by trees. Consequently, there has been interest in developing a foliage-penetration imaging radar with sufficient resolution to detect targets of interest with an acceptable false alarm rate. A radar with a resolution on the order of a few feet and operating at frequencies low enough to have tolerable attenuation through foliage might provide a useful capability. The Panel suggests that an impulse radar with a center frequency of a few hundred Megahertz may well be the best way to implement such a system. These design efforts and, if appropriate, experiments are needed to establish the military utility of such a system.

The Panel reviewed and analyzed all the other areas and issues pertinent to impulse radar. The Panel was favorably impressed by the designs of the existing systems for terrain profiling, etc., by the possibilities of other short-range and possible medium range radar applications (See Recommendation A-1); and with the work on “sources” (i.e., generators of very high power pulses) and their possible application to conventional as well as impulse transmitters. Other than these issues, nothing startling or of unusual merit was found for impulse radar.

The Panel also reviewed the claim that conventional analysis techniques were not applicable to impulse radar, and found that this claim was due to inadequate understanding of the issues or erroneous application of electromagnetic theory and is incorrect.

**Principal Conclusions**

A. The Panel concluded that there is no credible evidence of unique phenomenological capabilities related to the claims made or proposals advocated to the Panel.

B. The Panel concluded that impulse radar is not “inherently anti-stealth.”

C. The Panel concluded that impulse radar has no special LPI characteristics and is readily detectable by an appropriately designed intercept receiver.

D. The Panel concluded that all applications presented could be implemented by alternative “non-impulse” techniques. For every application of impulse radar which was presented, a corresponding example using a non-impulse radar was found. The Panel saw no applications for which only an impulse radar could work.

E. The Panel found that impressive accomplishments have been achieved on impulse radars for terrain profiling, ground probing and diagnostics—all short-range applications. Terrain profiling can be done at higher frequencies, but terrain profiling through foliage requires low frequency and high resolution. The Panel suggests that impulse radar probably represents the most cost-effective solution for the terrain profiling and ground probing applications.

F. The Panel found that there may be other applications where impulse radars are preferable to non-impulse approaches due to potentially lower cost and lighter weight. Impulse radars might have specific advantages for certain applications with regard to size, cost, weight and ruggedness. Their applicability to other military requirements should be explored. (See Recommendation A-1)

G. The Panel concluded that the available analysis tools are completely adequate and appropriate for dealing rigorously with impulse radar performance. However, the Panel cautions that care must be given to ensure their correct application and notes that this has not always been the case. Excluding intensity-driven non-linearities and quantum phenomena, the Panel maintains that conventional classical, linear, time-invariant systems theory, statistical estimation and detection theory and Maxwell’s Equations fully describe all the phenomena presented that relate to impulse and non-sinusoidal radars.

H. The Panel concluded that advances in sources for generating very high power short pulses are impressive and may be promising for conventional short pulse radar as well as impulse transmitters. These advances do not enable any unique capabilities but may impact the choice among possible implementations to achieve cost or weight advantages.

**Key Recommendations**

A. The Panel makes three recommendations for DoD investments in UWB radar related studies and analyses:
1. In order to examine in detail the implementation trade-off advantages, the Panel recommends that the DoD fund analyses of point designs using impulse and non-impulse approaches for four radar applications which appear to have important military applications:
   • A short-range system for detecting moving targets behind walls or foliage
   • A short-range airborne imaging radar for detecting military targets under canopy or in wooded terrain
   • A medium-range (20 km) air defense radar for detection and non-cooperative identification of airborne targets, including but not limited to helicopters in the tree line
   • A medium-range (20 km) radar for detection of sea skimming missiles in fleet defense applications

Suggested performance parameters for each system are given in the text of this report. The suggested level of effort for each of the point designs is one to two person-years.

2. In order to support the point design studies in (A)(1) above, the Panel recommends that the DoD fund two other studies relevant to UWB (impulse or non-impulse) system designs:
   • A review and analysis (based upon existing theory and measurement data) of clutter behavior for UWB radar systems
   • An analysis that characterizes the range and angle pattern of UWB linear and planar antenna arrays.

The suggested level of effort of each study is one person-year.

3. The Panel recommends that the DoD review the status of UWB source development in order to determine if additional R&D efforts are needed. It is suggested that this review be an in house effort.

B. The Panel makes three recommendations against DoD investments in UWB radar related efforts:

1. The Panel recommends that no measurement programs of any kind on stealth materials or vehicles (e.g., to examine non-linear effects) be funded.

2. The Panel recommends against funding of any system studies based upon unsubstantiated materials phenomena.

3. The Panel recommends that no system development be undertaken until the results of recommendations (A)(1) and (A)(2) above are assessed and demonstrate the military value of such system(s).

This is not meant to exclude the investigations in progress at several Government laboratories which are aimed at understanding the technology and implementation implications of UWB radar systems.

C. Finally, the Panel recommends the DoD sponsor a modest effort to document the characteristics of self-induced transparency and any other non-linear effects relevant to their possible contributions to military systems. This work could be accomplished as part of the JASON’s 1990 Summer Study, a National Science Foundation effort, or a funded University effort.

Final Comment

Although, as noted herein, the Panel found interesting work under way and recommends additional efforts, it does not believe impulse radar offers a major new military capability nor correspondingly does it present the threat of a serious technological surprise.

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**APPENDIX**

**TERMS OF REFERENCE, PANEL MEMBERS, OBSERVERS, PRESENTERS AND MEETING AGENDAS**

**Ultra-Wideband Radar Review Panel**

**Terms of Reference**

1. Review what has been done in ultra-wideband radar development
   a. Available experimental data
   b. Literature, including Soviet unclassified, as available.

2. Review what is being done and what is proposed to be done
   a. Government laboratories, including DoE labs
   b. Industry and academe.

3. Determine potential performance benefits
   a. Radar technology for a variety of applications, including potential for low observable targets
   b. Countermeasures.

4. Identify technology issues and gaps in knowledge, and priority of importance.

5. Recommend research which should be pursued to resolve issues
   a. Areas for further investigation
   b. Experimental tools/hardware needed.

6. Determine possible applications.
Ultra-Wideband Review Panel
Panel Members

- Denotes Alternate

Eli Brookner, Raytheon
John Cashen, Northrop
George Cooper, Consultant/General Dynamics-Pomona
Jin Corum, Battelle
Curt Davis, Lincoln Labs
Bert Fowler, Consultant
Archie Gold, SAIC
Evan Iverson, LANL
Dave Kramer, MITRE
Ivan Lahauë*, ERIM
Jay Loomis, MICOM
Larry Lynn, Atlantic Aerospace Electronics Corp.
Roger Manasse, Consultant
Ed Miller, LANL
Dennis Murray, SAIC
Fred Nathanson, GTRI
Dave Nelson, Harvard/Jason
Richard Norton*, R.J. Norton Company
Alan Peterson, Stanford University
Lee Poirier*, RADC/E&G
Jim Ralston, IDA
Stan Robinson, ERIM
Jay Schindler, RADC/EE
Merrill Skolnik, Naval Research Laboratory
Nick Tomljanovich*, MITRE

Ultra-Wideband Review Panel
Observers

Gregory V. Cirincione, SAIC
Col. Barry Crane, ODDR/E (R&AT/E&T)
John David, Harry Diamond Laboratories
John N. Entzminger, DARPA/TTO
Dominick Giglio, DARPA/TTO
Brendon Godfrey
Pete Hoag, JCLO Office
Jim Hogarty, JCLO Office
Bert Hui, DARPA/DSO
John McCorkle, Harry Diamond Laboratories
Richard Muir, NAVSEA
Art Pavel, DARPA/AVSTO
Vincent Puglielli, Battelle

George T. Ruck, Battelle
Ray Stewart, ODDR/E (R&AT/E&T)
Philip L. Soucy, SAIC/AQ
Frank E. Weller, USAF/RADC
Mike Wicks, RADC/OCT
Robert Williams, DARPA/DIRO
Eli Zimet, Office of Naval Technology

Ultra-Wideband Review Panel
Presenters

M. Skolnik, NRL
M. Wicks, RADC
C. Davis, Lincoln Labs
D. Kramer, MITRE
E. Thompson, DIA
J. Coleman, DIA
B. Crane, U.S. Army
V. Pusatari, NOSC
L. Fullerton, Time Domain Systems
J. McCorkle, HDL
J. Corum, Battelle
H. Harmuth, CU
T. Johnson, Boeing
T. Barrett, Boeing
S. Davis, Power Spectra
W. Happer, JASON
C. Phillips, Thermo-Electron
D. Sullivan, MRC
L. Frazier, General Dynamics
R. Vickers, SRI
G. Ross, ANRO
F. Zucker, RADC
A. Schutz, GSSI
R. Morey, GSSI
J.P. Hansen, NRL
J. Young, Ohio State University
R. Hutchins, BDM
W. Pearson, McDonnell Douglas
G. Cooper, General Dynamics
S. Peng, Teledyne Ryan Electronics
D. Miller, University of Rochester
K. Ougston, University of Vermont
M. Friedman, Northeastern University
B. Williams, DARPA
M. Van Blaricum, TOYON
T. Sarkar, Syracuse University