



INSPECTOR GENERAL
DEPARTMENT OF DEFENSE
400 ARMY NAVY DRIVE
ARLINGTON, VIRGINIA 22202

REPORT
NO. 92-019

December 12, 1991

MEMORANDUM FOR DIRECTOR, DEFENSE RESEARCH AND ENGINEERING
ASSISTANT SECRETARY OF THE AIR FORCE (FINANCIAL
MANAGEMENT AND COMPTROLLER)
DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS
AGENCY
DIRECTOR, DEFENSE INTELLIGENCE AGENCY
DIRECTOR, NATIONAL SECURITY AGENCY

SUBJECT: Final Report on the Assessment of Balanced Technology
Initiative for Ultra Wideband Technology
(Project No. 1PT-5005)

This report is provided for your information. We were requested by Senator Slade Gorton to assess allegations made by one of his constituents that a report generated by the Defense Advanced Research Projects Agency (DARPA) for the Balanced Technology Initiative (BTI) was flawed. The report addressed the potential military uses of Ultra Wideband technology for radar applications. The allegations presented to Senator Gorton concerned the credibility of the Ultra Wideband Radar Review Panel's assessment. It was alleged that many Panel members were biased against the use of Ultra Wideband technology. Our overall objective was to determine the validity of the allegations. We conducted our review by interviewing Panel members and individuals who made presentations to the Panel, and by reviewing applicable documentation.

Scope of Assessment

We conducted a comprehensive on-site review of selected contractors and Government laboratories involved in Ultra Wideband testing and technology development. The review was supported by documentation received from the Balanced Technology Initiative Office, DARPA Ultra Wideband Program Office, Battelle Tactical Technology Center, Columbus, Ohio, Panel members, and presenters. We conducted an extensive evaluation of Ultra Wideband technology, impulse radar, threat assessment related to stealth platforms, test results of Ultra Wideband systems and development of basic theories of operation of Ultra Wideband systems.

In addition, we obtained statements from DARPA, Office of the Secretary of Defense/Balanced Technology Initiative Office, Massachusetts Institute of Technology Lincoln Laboratory, and Battelle personnel. The review was made from December 1990 through May 1991. The activities visited were DARPA; Balanced Technology Initiative Office, Arlington, Virginia;

Battelle, Columbus, Ohio and Battelle, Richland, Washington; Lincoln Laboratories, Lexington, Massachusetts; MITRE Corporation, Bedford, Mass; Naval Research Laboratory, Washington D.C.; Harry Diamond Laboratory, Adelphi, Maryland; Science Applications International Corporation, Tucson, Arizona.

The assessment team consisted of members of our Technical Assessment Division of the Audit Planning and Technical Support Directorate, listed in Enclosure 3. The team members had expertise in such engineering specialties as communications, radar, electronic warfare, and radar countermeasures. They also had extensive experience in the areas of contracts and system engineering.

Background

Congressional interest in the potential use of Ultra Wideband technology resulted from a presentation made to Representative Norman Dicks in 1989. The presentation was given to secure Government funding to continue internal research and development work on light-activated high-power microwave switch technology, which had been ongoing for several years.

One of the primary uses of the switch technology is the generation of extremely narrow pulses of high energy content. The wide frequency bandwidth of a narrow pulse relates to high radar range resolution. Another characteristic of the narrow pulse is its low frequency content. It has been established that stealth technology is more susceptible to low frequency radars, so it appeared that this technology might be able to detect low cross-section stealth targets.

The presenter's proposal was to combine radar system engineering with Ultra Wideband technology to determine cost and performance benefits, perform experiments, collect and analyze data, and design studies to support system development, thereby establishing a niche for the light-activated switch.

The House Appropriations Committee, at the request of Representative Dicks, designated \$25 million of the BTI Fiscal Year 1990 Budget to be used for Ultra Wideband technology research. The congressional language specified that the funding be "available only for a new program in Ultra Wideband technology development and light-activated high-power microwave technologies."

The BTI Office directed DARPA to convene a Panel of experts to review Ultra Wideband technology and applications and to identify and prioritize Ultra Wideband research to be pursued. DARPA contracted with Battelle, Columbus Division to form the

Panel. The Panel was to examine the state of the art and the potential performance benefits and limitations of Ultra Wideband technology.

The Panel was commissioned to look only at radar related applications of the technology. The majority of Panel members were selected based on either their knowledge of Ultra Wideband technology or their recognized expertise in the radar field. Individuals who understood classified stealth and anti-stealth technology were included on the Panel to provide a perspective on the ability of Ultra Wideband technology to detect stealth targets. Individuals who were familiar with Ultra Wideband technology being pursued by foreign interests were also included.

A report prepared by MITRE Corporation for the Air Force was made available to the Panel. The report (Report M90-18, "Ultra Wideband Radar Applicability to Air Defense - Red Team Assessment," dated March 1990) addressed long-range airborne surveillance. The conclusions of the report, based on a strawman model for an Ultra Wideband Impulse Radar, follow.

(1) "The use of short pulses on the order of 1 nanosecond in duration is not feasible for long-range (approximately 200 nmi) surveillance, owing to the extremely high peak powers that are required by this approach."

(2) "Although the use of short pulses reduces the ground clutter level by several orders of magnitude over systems with megahertz bandwidths, an additional reduction of clutter by a factor of about 10,000 is required in order to detect cruise missile sized objects."

(3) "A pervasive problem for an Ultra Wideband broadcasting (transmitting) system is the fact that it shares the spectrum with a large number of critical military and civilian services (such as UHF, VHF, voice communications, cellular telephone, TV and FM broadcasting). It is susceptible to interference from these services and could potentially interfere with them. The problem has been managed in the laboratory for short-range radar and communication systems; however, a long-range wide area surveillance radar requiring perhaps 10,000,000 times as much effective radiated power makes the electromagnetic interference problem effectively insurmountable."

As a result of this analysis, it became necessary that a unique phenomenon associated with Ultra Wideband signals prove practical so that an Ultra Wideband radar system could be considered feasible for long-range surveillance. The presenters claimed that self-induced transparency, out-of-band effects, non-linear effects, and high electric field strength

effects would mitigate the obstacles to development of an Ultra Wideband Surveillance Radar. However, no claims of such phenomena, as related in the Ultra Wideband Technology Report, were demonstrated or validated, either theoretically or experimentally for microwave frequencies, to the satisfaction of the Panel.

The Panel recommended that the Department of Defense:

(1) Fund analyses of point designs using impulse and non-impulse approaches for four radar applications that appear to have important military uses:

(a) A short-range radar for detecting moving targets behind walls or foliage.

(b) A short-range airborne imaging radar for detecting military targets under canopy or in wooded terrain.

(c) 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.

(d) A medium-range (20 km) radar for detection of sea skimming missiles in fleet defense applications.

(2) Support the point design studies by funding review and analysis of clutter behavior for Ultra Wideband systems, and analysis that characterizes the range and angle pattern of Ultra Wideband linear and planar radar arrays.

(3) Review the status of Ultra Wideband source development to determine if additional research and development efforts were needed.

Discussion

The OSD/DARPA Ultra Wideband Radar Review Panel Report was released on July 13, 1990. Altogether, the full Panel convened nine times, sub-panels convened twice, and Panel representatives spent four days at the Los Alamos Ultra Wideband conference. Thirty three speakers addressed the Panel to provide the Panel with the most recent technical, tactical, and industrial information about Ultra Wideband technology.

As the Panel deliberations unfolded, technical issues began to emerge and the Panel determined it was necessary to separate the claims, theories, and measurements into engineering and scientific perspectives.

The author of the allegations was the chief proponent of claims that Impulse Radar had a low probability of intercept, that Impulse Radar could defeat radar absorbing materials, that Maxwell's equations did not apply to Impulse type waveforms without profound reformulation, and that Impulse Radar effects could not be understood using conventional spectral analysis techniques. He asserted that the Soviets recognized the special attributes of nonsinusoidal waves and had developed a significant technical program to exploit these properties. His position was supported by a few of the other presenters. The Ultra Wideband Panel Chairman assigned Panel members the task of examining the above issues for substance. They were asked to organize their conclusions and report to the full Panel. The Panel found no merit to these claims.

In addition to the positive recommendations mentioned previously, the Panel recommended against Department of Defense investments in Ultra Wideband Radar related efforts regarding:

(1) measurement programs of any kind on stealth materials or vehicles.

(2) funding of any system studies based on unsubstantiated materials phenomena.

(3) system development until results of the other recommendations are assessed and the military value of such systems is demonstrated.

The Panel recommended that the Department of Defense sponsor a modest effort to document the characteristics of self-induced transparency and any other non-linear effects relevant to possible contributions to military systems. Finally, the Panel stated that it had found interesting work under way and recommended additional efforts, but that it did not believe Impulse Radar offered a major new military capability nor did it present the threat of a serious technological surprise.

Conclusion

We found the DARPA's report on Ultra Wideband technology to be credible and the Panel balanced in terms of the technical biases of its members. The Panel identified potential benefits for simultaneous low frequency and imaging quality range resolution. Many issues that remain unanswered are being pursued in accordance with the Panel recommendations. These issues include signal processing techniques for Ultra Wideband systems, research for Ultra Wideband antennas and arrays, and clutter statistics of Ultra Wideband signals. The report made

recommendations to not pursue certain technology areas. The Panel believed those areas to be non-productive because claims by proponents of Impulse Radar, about detection of stealth targets, were not adequately supported from a theoretical or experimental basis. Some of the ideas presented to the Panel, such as energy transfer and propagation and transient versus steady state effects, were not recommended for further study. While we found these ideas interesting, we found no basis to challenge the recommendations of the Panel. We also found no evidence to corroborate the allegations. A summary and specific comments on each of the allegations are contained in Enclosure 1.

Please contact Mr. Jacob E. Rabatin on (703) 614-6300 or Mr. Kenneth H. Stavenjord on (703) 614-6297, if you have any questions concerning this report. No response is necessary. The distribution of this report is listed in Enclosure 3.



Robert J. Lieberman
Assistant Inspector General
for Auditing

Enclosures

ALLEGATIONS AND REVIEW COMMENTS

Our assessment concluded that there was no evidence to corroborate the allegations. The allegations considered were those contained in the letter to Senator Gorton and others disclosed in our subsequent interview with the complainant. The following summarizes the allegations and our evaluation of the allegations based on our review.

Allegation A: The Panel was biased. The Panel was deliberately composed of many individuals who were biased against the technology they were to assess. Ultra Wideband radar technology is potentially counter-stealth and two members of the Panel were either employed by, or affiliated, with the manufacturer of the stealth bomber.

Review Comments: The OSD/DARPA Ultra Wideband Radar Review Panel was convened to study the military applications of Ultra Wideband technology. Proponents of the technology claimed that it might be a viable means of countering and thereby negating stealth platforms in a manner not possible with conventional narrow-band radars. Many of the Panel's radar experts did not have a complete understanding of stealth technology, due to its highly classified nature. Therefore, to evaluate and assess this claim, the sponsors of the Panel decided to include members who had a working familiarity with stealth technology.

To balance the Panel, two Panel members represented the Joint Counter Low Observable Office (JCLLO). The primary function of the JCLLO is oversight of the development of highly classified techniques to counter modern stealth technology.

Even if the allegation of bias were valid regarding Panel members affiliated with the stealth community, their input was balanced by many Panel members who had no vested interest in suppressing the use of Ultra Wideband technology as it related to anti-stealth applications. The Panel was naturally skeptical against unverified claims of performance.

Allegation B: The assessment was incompetent. Appendix E, which addressed the phenomena of self-induced transparency and non-linear microwave materials effects, was considered, by the authors and discoverers of the phenomena, to be wrong and incompetent.

Review Comments: The allegation was based on interpretation of the work of Drs. E. L. Hahn and S. L. McCall, the principal investigators of the phenomena, and correspondence received from both individuals indicating that they thought Appendix E was wrong. Dr. McCall's memorandum stated "The Appendix E which you

supplied me does not reflect my views because most of it is wrong." Dr. Hahn's reply stated "Unfortunately it is riddled with errors, misconceptions, and dead wrong conclusions. The verbiage and syntax is permeated by poor logic."

The Ultra Wideband Technology Report consisted of two sections. The first was an assessment of the technology area. It included definitions, features, status of development, major issues, potential applications, conclusions, and recommendations relating to Ultra Wideband radar. The second was a number of appendixes included by Battelle, Columbus Division, to provide a tutorial for Panel members and readers not familiar with essential issues presented to the Panel by the Ultra Wideband technology proponents. The issues needing clarification were in the area of physics, since most of the Panel members were engineers from the radar community and not completely familiar with some of the concepts.

Battelle requested Drs. Hahn and McCall to review the report and to comment on the accuracy of Appendix E. Dr. Hahn replied to the Battelle request in a telephone conversation with Mr. Jim Corum, Program Manager at Battelle. During the conversation, Dr. Hahn stated "The core of what was said in Appendix E of the Ultra Wideband Final Report is certainly true. I'm not up on new technology, but to my knowledge SIT (self-induced transparency) is not a practical device for radar - no. . . . Our critical memo [referred to previously] was used for further purposes than I intended. I resent the fact that we were misrepresented by those to whom it had been sent." Further he expressed his conviction "that SIT is a beautiful physical phenomenon and that fundamental scientific investigation of it should be encouraged." Dr. Hahn stated "I am appalled that our remarks are being used to discredit the Panel's Report."

Allegation C: The Panel recommended that work on anti-stealth be limited, thereby undermining Ultra Wideband technology investigations.

Review Comments: The Panel did recommend limited work on stealth testing. The Air Force was already conducting detectability performance testing on stealth, and the Panel concluded that nothing would be gained from a duplicative effort.

The report stated that the recommendations to not pursue measurement programs on stealth materials, unsubstantiated materials phenomena, and system development were not meant to exclude the investigations in progress at several Government laboratories that are aimed at understanding the technology and implementation implications of Ultra Wideband Radar systems.

In order to not limit relevant work, the Panel recommended that "the Department of Defense 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." It was suggested that "this work could be accomplished as part of the JASONS' 1990 Summer Study, a National Science Foundation effort, or a funded University effort."

The claims advanced by the presenters were that Impulse Radar has a low probability of intercept, that they defeat radar absorbing materials, that they can thwart radiation seeking missiles, that they cannot be treated by conventional spectral analysis, that Maxwell's equations do not work for Impulse Radar without a profound reformulation, and that specially crafted Ultra Wideband pulses suffer far less attenuation than classical steady state wave propagation phenomena (i.e., self induced transparency). The Panel, in its deliberation, was not presented with any experimental evidence supporting the claimed uniqueness of Ultra Wideband signals.

None of the Ultra Wideband proponents presented an argument adequate to convince the Panel that a practical radar, capable of defeating a stealth platform, was feasible utilizing the technology.

Allegation D: The assessment contained written attacks against the author of these allegations.

Review Comments: The author's ideas were mentioned twice in the Ultra Wideband Report. The first assertion was that, for sufficiently short pulses, the response of a material is fundamentally different than the response to steady state signals. The assertion questioned the applicability of Fourier transform theory and linear system theory and whether or not swept frequency measurements can be used to duplicate the Fourier components of a short pulse in linear media. The Panel concluded that "this idea is counter to all conventional electromagnetic principles, and, after serious deliberation, the Panel recommended against any system studies based upon unsubstantiated materials phenomena."

The second assertion was that "a short 'Zero Area' pulse can somehow penetrate an absorbing medium without suffering the exponential attenuation usually associated with such media." This idea is attributed to Dr. M. D. Crisp, a physicist at Columbia University. Dr. Crisp published the results of his experiments in Physical Review-A, Vol. I., No. 6, June 1970, in an article entitled "Propagation of Small-Area Pulses of Coherent Light through a Resonant Medium." After review of the assertion

and Dr. Crisp's work, the Panel concluded "The bottom line is that all of Crisp's observed phenomena, the so-called 'Zero-Area Theorem', sub-exponential attenuation, etc., can be explained by conventional, classical, linear system theory. No pulse-unique phenomena are involved, no magic way of subverting the attenuation encountered in a lossy medium has been discovered, and it is evident that those persons promoting 'Zero-Area' pulses as a panacea for 'seeing through' lossy media do not understand Crisp's analysis."

The Panel, further responding to the contention that Fourier analysis was somehow not applicable to short pulse lengths, quoted from Dr. Crisp's article "In terms of this spectral argument, the anomalously low absorption can be simply understood as the result of small absorption of those Fourier components which are far off resonance." The Panel concluded that "all the phenomena Crisp describes are 'out-of-band' effects for which Fourier analysis is valid."

The contention that the Ultra Wideband Report was a personal attack on the writer is unsupported by the contents of the report. There was technical disagreement on the interpretation of two theoretical issues, but the report addressed both in a professional manner.

Allegation E: The appendices to the Ultra Wideband Report are technically incorrect. The bulk of correspondence generated by the author of the allegations criticized the technical merit of the appendixes, and centered on Appendix E.

Review Comments: Appendix E addresses self-induced transparency (SIT). After a dissertation on the effect, the report concludes "SIT phenomena have been observed at optical wavelengths in media which have been specially prepared to represent ideal two-level systems and requiring either liquid helium temperatures, 4.2 ° K, or essentially vacuum conditions. Such conditions clearly do not exist for normal microwave materials or at ambient atmospheric conditions. In addition, most microwave materials at ambient temperatures exhibit essentially a continuous absorption spectrum comprised of a number of independent, nearly homogeneous contributors. The oscillator lifetimes in these materials can range from subnanoseconds to tens of seconds. In general, one can not simply extrapolate short pulse effects observed in the optical region to the microwave region. It is considered very unlikely that radiated short pulse signals in the microwave/millimeter wave region could induce SIT effects in the ambient atmosphere at any power density levels below those resulting in atmosphere breakdown."

The appendixes were written to provide a tutorial for the Panel members, many of whom were not familiar with some of the concepts presented by the Ultra Wideband proponents. The appendixes, for the most part, do not support the contentions of the presenters.

Our review of the Panel report, along with interviews with Panel members, indicated that the complainant presented no evidence that the SIT effect is possible in normal materials. The fact that self-induced transparency has been observed only under stringent laboratory conditions is counter to the proposition that SIT would be useful in the implementation of an Ultra Wideband radar.

As in Allegation B, there was a technical disagreement between the complainant and the Panel members.

Allegation F: Panel members received the bulk of funding. "The Panel not only advised against investigating all long range Ultra Wideband technology and materials testing, . . . but achieved sequestering of funds to Panel members [Panel member's organizations], further containing development of this new technology."

Review Comments: The House Appropriations Committee designated \$25 million of the BTI 1990 Fiscal Year Budget to be used for Ultra Wideband technology research. Subsequent direction designated that \$8 million be used for other projects.

Of the \$17 million available, the following organizations, represented on the Panel, received funding totalling \$4.205 million:

Harry Diamond Laboratory	\$1.250M
Naval Research Laboratory	\$1.250M
Rome Air Development Center	\$0.475M
Naval Ocean Systems Center	\$0.250M
U. S. Army Missile Command	\$0.305M
Science Applications International Corp.	\$0.275M
Battelle, Columbus Division	\$0.400M

Non-panel organizations received \$11.0 million:

Phillips Laboratories received \$5.75M for Susceptibility/Sources Research

Battelle, Pacific Northwest Laboratories received \$5.25M for performance comparison of conventional radar (narrowband or synthesized wideband) versus Ultra Wideband Impulse Radar.

A total of \$1.795 million was held in reserve as follows:

BTI	\$0.950M
DARPA	\$0.845M

Not all funding was channeled through DARPA. BTI provided funding directly to Naval Research Laboratory, Harry Diamond Laboratory, MICOM, and Phillips Laboratory.

The allegation that Panel members' organizations received the bulk of BTI funding for Ultra Wideband research is not correct. Some of the funds were directed toward organizations represented on the Panel, since the Panel represented the range of expertise in the Ultra Wideband radar community. However, individual Panel members' organizations have not received the bulk of the funding. In addition, Battelle, Pacific Northwest Laboratories was tasked to pursue Ultra Wideband processing methods and to contract for additional Ultra Wideband research study efforts with industry.

Allegation G: The assessment represented in no way a unanimous opinion of the Department of Defense.

Review Comments: The Panel report was not intended as a Department of Defense-wide opinion. Its purpose was to provide recommendations of experts in the radar field to BTI for use in funding research efforts that would advance Ultra Wideband technology. The report represents the technical opinions of Panel members.

Prior to the publication of the Ultra Wideband Technology Report, the Panel was reconvened to resolve any differences the members had with the report. Each member and observer had the opportunity to voice his position with respect to each section of the report. As a result, the report represented a consensus of the Panel. The appendixes were prepared, as Panel assignments, by volunteers with appropriate technical expertise in each area. As such, they represent the professional opinions of the writers, but they too were subjected to full Panel review. Our interviews with Panel members, OSD/BTI, and DARPA did not provide support for the allegation.

Allegation H: Soviet literature on Ultra Wideband technology was not considered by the Panel.

Review Comments: While the content of available translated Soviet literature was not the subject of specific Panel discussions, we found that many of the Panel members had been provided with and were familiar with Soviet literature

dealing with Ultra Wideband technology. The Panel members stated that applications addressed in the literature dealt, in general, with measurement techniques utilizing Ultra Wideband pulses. They stated that the literature did not indicate that a practical long-range radar system had been constructed. There was general agreement, by interviewed Panel members, that Ultra Wideband technology would be a candidate for a sophisticated instrumentation and measurement system.

Our interviews with Panel members refute the allegation that the Soviet literature was not considered in providing recommendations in the Ultra Wideband Report.

FINAL REPORT DISTRIBUTION

Office of the Secretary of Defense

Assistant Secretary of Defense (Public Affairs)
Assistant Secretary of Defense (Legislative Affairs)
Assistant Secretary of the Air Force (Acquisition)

Other Defense Activities

Director, Defense Research and Engineering
Director, Defense Advanced Research Projects Agency
Director, Defense Intelligence Agency
Director, National Security Agency

Non-DoD Distribution

U. S. General Accounting Office, NSIAD Technical Information
Center
Representative Norman Dicks
Senator Slade Gorton

Congressional Committees:

Senate Subcommittee on Defense, Committee on Appropriations
Senate Committee on Armed Services
Senate Committee on Governmental Affairs
Senate Ranking Minority Member, Committee on Armed Services
House Committee on Appropriations
House Subcommittee on Defense, Committee on Appropriations
House Ranking Minority Member, Committee on Appropriations
House Committee on Armed Services
House Committee on Government Operations
House Subcommittee on Legislation and National Security,
Committee on Government Operations

REPORT TEAM MEMBERS

Kenneth H. Stavenjord, Technical Director
Technical Assessment Division

Jacob E. Rabatin, General Engineer
Technical Assessment Division

Jaime A. Bobbio, Electronics Engineer
Technical Assessment Division