"Technology is no barrier; old thinking is."

William E. Kennard ~ February 2, 1999, in The Hill

I. Introduction – Evolution or Revolution

Spectrum managers are at a crossroads. They must find ways to quickly react to the evolution of RF technology and user demand or they must expect a revolution as demand and technological changes continue to overwhelm them. The United States must be the first to deploy new technologies; it cannot afford to be in second place; and access to spectrum is the gating factor for many new telecommunication technologies.

Today, the spectrum management process used to address change is to take spectrum allocations from one group and give them to another. The process is dependent upon legal and political power plays accompanied by expert divination of future demands for bandwidth; and it takes a long, long time. It took a decade to allocate spectrum for cellular communications, in part because experts grossly underestimated the demand for cellular communications services and in part because the various industries did not want to relinquish control over "their" spectrum. Had the United States reacted sooner to the cellular opportunity, it might have maintained leadership in the cellular marketplace. Now it is in second place.

The demand for spectrum is exploding, just as traffic has exploded on the Internet, and spectrum managers cannot keep up with the pace of technology. Some of the competing sources of demand include:

- The aviation industry. New systems for improving aviation safety through improved traffic management, advanced security systems, and communication services demand additional spectrum.
- The Department of Defense. The information warrior – the networked soldier – and networked weapons systems is really a "busy signal on the battlefield" as an Army general has stated. There are also needs for higher performance sensor and targeting systems. These concepts cannot be fully realized for the lack of spectrum.
- Public safety and law enforcement. Advanced sensor systems and mobile data communications are hampered by a lack of suitable spectrum.
- Consumers and industry. High-speed mobile cellular communications, wireless local area networking systems, cutting-edge internet appliance concepts, and new highly beneficial services are creating an unprecedented demand for additional spectrum.

At the same time, emerging technologies now allow for coexistence of users in ways never before possible. Ultra-wideband technologies (UWB) offer, in the words of the New York *Times,* "the potential to make vastly more efficient use of the increasingly precious radio spectrum." The timing is right for a controlled entry of UWB devices into our wireless fabric, particularly as the innovative and unarguable benefits that will result are not possible using traditional technology. This is an evolutionary approach that allows for the introduction of low power spectrum sharing devices. It is an evolutionary approach that allows for integration and evolution of legacy and emerging technologies while making few initial changes to existing FCC regulations. Moreover, it is an approach that can lead toward a dynamic, real-time spectrum management process.

The alternative is to lag further and further behind the demand and evolving technologies and to await a time when revolutionary changes must occur.

II. Myths

The foremost myth surrounding UWB is that there are very few UWB emitters in operation today. In fact there are billions. Some, like personal computers and other digital electronics, are regulated in the U.S. under the FCC's Part 15 rules; others, like electric razors and blenders, are not regulated at all. There are a few intentional UWB systems in operation. The GPR industry documented that some 2000 relatively high power GPR systems have been in use for decades, even at airports where they are used to inspect runways (concrete runways degrade first on the underside). Clearly, their experience strongly suggests these systems do not interfere with incumbent spectrum users, including safety of life aeronautical systems.

Another myth is that today's spectrum management rules keeps users neatly separated and thus secure from violation by unauthorized users. Clearly, these billions of UWB radiators emit RF energy across the bands, but so do licensed transmitters. Existing rules specify allowable spurious emission levels, i.e., emissions into other users' channels, and in many cases these limits are orders of magnitude larger than Part 15 limits.

Yet another myth is that today's rules ensure that safety of life systems are secure. The Federal Aviation Administration, in an attempt to argue against micro-powered UWB devices, submitted documentation to NTIA showing that a broken cash register could interfere with an aeronautical navigation system. The cash register located in a store on the glide path into Andrews Air Force Base started emitting a narrowband RF signal. If a single cash register can accidentally disrupt such a system, just what could someone do intentionally?

These myths obscure the greater issue of spectrum management, which is that old systems and concepts must evolve in the face of new technologies, user demand, and real world considerations.

III. Applications and Benefits of UWB

UWB radio technologies have solved critical problems as no other technology can. Much of the excitement over UWB came from users of UWB ground penetrating radars (GPR), which have been in use for over twenty years. "*No other non-destructive technique can provide such a rapid and accurate assessment of the conditions of concrete structures…*" [Geophysical Survey Systems, Inc.]; "*GPR has the highest resolution of any tool for noninvasive subsurface investigation. … The US Federal Government spends about $60,000,000/year on GPR radar applications or research…*" [G. R. Olhoeft, Professor of Geophysics, Colorado School of Mines]. One such Federally funded project is the Federal Highway Administration's award winning "High-speed Electromagnetic Roadway Mapping and Evaluation System" (HERMES). It is a large – 64 antennas – ground penetrating radar system for inspecting bridges and roadways. Regarding this project, Dr. Steven Chase of the Federal Highway Administration has stated: "If more reliable data was available, which resulted in even 10 percent savings, $100 million would be saved annually just on bridge deck repairs."

Another example of the value of ground penetrating radar was an article in the New York *Times* describing the use of a ground penetrating radar to find bodies in permafrost; bodies that might contain remnants of the deadly pandemic influenza virus of 1918.

UWB technologies have even more potential to create extraordinary benefits for the public and industry. Traditional wireless technologies are running into their physical limits. UWB technology avoids those limitations and is a leap forward in three areas.

(1) Radar. To achieve high resolution, radars must have high RF bandwidths. This requirement traditionally forces the use of millimeter wave frequencies. Yet, to

penetrate structures, radars must operate at lower frequencies. UWB radars are optimal for through-wall sensing. Additionally, UWB radars are more reliable than Doppler radars for many applications, for example security sensors.

(2) Geo-positioning. Physics also demands large bandwidths for precision ranging. UWB systems have large bandwidths at low frequencies allowing for relatively accurate position determination even within buildings where millimeter waves do not propagate effectively. Thus, UWB complements GPS in an arena where GPS cannot work.

(3) Wireless Communication. In the field of communications, the limit imposed by multipath prevents ultra-low emitted power communications from being reliable and also effectively prevents ultra-high speed wireless communications except over short, unobstructed paths. For traditional technologies, including spread spectrum technologies, Rayleigh fading demands the transmission of additional power to minimize the impacts of deep fades and the physical limitations of delay spread places an upper bound on data rates. By virtue of using an ultra-wide bandwidth signal, in high multipath environments, less power need be transmitted and higher data rates can be obtained. Given the public's on-going concerns about the biological impacts of electromagnetic radiation, such a reduction could have the additional benefit of reducing this concern.

TM-UWB technology has the capability to provide innovative and unprecedented solutions to critical problems in a number of sectors.

Aviation Sector

At nearly every airport today it is possible to walk from the general aviation area into the "controlled access" commercial aviation area without being questioned. According to personnel at the FAA Atlantic City Research Center this is one of aviation's greatest security holes. Fences would interfere with aircraft movement; guards are extremely expensive; and traditional radar sensors produce too many false alarms. UWB-based radar fences have been demonstrated that have the potential to fill this gap.

Airport security is not the only problem. As the traveling public is well aware, the volume of air traffic is causing problems with the air traffic management system. While some in the aviation industry hope that the GPS system can address this problem; others, including a past FAA administrator, are adamant that GPS is too fragile. Ultra-wideband, however, could complement a GPS-based solution with a highly robust terrestrial component. Time Domain is for example demonstrating a data communications link with integrated radio ranging that is accurate to better than 1 centimeter.

Other aviation applications for UWB technology include:

- Low cost collision avoidance radar.
- Low cost ground proximity warning.
- Obstacle Warning System for helicopters (to help helicopters avoid wires, a major cause of helicopter accidents).
- Ultra-high resolution (better than 3") airborne synthetic aperture radars for ground mapping.
- Integrated ground traffic control sensor and communications systems.
- Low Altitude Radar.

Defense Sector

As a deputy commander of the U.S. Army's Signal Corps has stated about UWB: "you appear to have an answer to our bandwidth and spectrum problems." They have insufficient spectrum to deliver bandwidth to the warfighter; they have busy signals on the battlefield; and they find they are dragging around too many cables in these days of maneuver warfare.

Military applications are as diverse as commercial, industrial and consumer applications. Time Domain was recently visited by a Program Director from the U.S. Department of Defense's Simulation, Training and Instrumentation Command. (STRICOM). STRICOM is charged with developing the war-gaming systems, including advanced "laser tag" systems. The program director noted that his "organization had scoured the world looking for a technology that would allow for precision in-building location and concluded that what they needed could not be found. Then, we found Time Domain's UWB technology." His objective is to develop an advanced urban combat training system, which is feasible only if the location of each individual soldier is known extremely accurately within and around buildings.

Such a system has wider applicability. As documented in the recent book, "Blackhawk Down: A Story of Modern War", U.S. soldiers died in Mogadishu, Somalia in 1993 because they lacked an understanding of their relative locations. Pinned inside of buildings in small units, they were unable to determine if they could consolidate forces for better self-protection. A UWB geo-location radio system could have helped them.

Other applications include: radar for detecting low flying cruise missiles, hard to detect communications systems and radars, landmine detection systems, and force protection radar systems.

Public Safety & Law Enforcement Sector

Public safety and law enforcement officials are already on record with the FCC in support of UWB technology. As a senior member of the Department of Justice's National Institute of Justice has written to the FCC that UWB is "a valuable technology alternative to address the secure communications and through-the-wall sensing needs of state and local law enforcement agencies."

Public safety and law enforcement lag far behind the military in the application of advanced sensors and command, control & communication systems. A short range public safety command and control network radio could provide geo-positioning information. For fire fighters, such a system would be invaluable as it would allow tracking and communications of fire fighters within buildings, where smoke and darkness obscure everything. Chief Francis W. Moriarty of the Chicago Fire Department has been working with NASA's Jet Propulsion Laboratory, engineers at the Redstone Arsenal, and others to develop just such a system and believes that every fire chief in the nation wants such a system.

Ground-penetrating radars are use to find buried evidence. Through-wall sensing radars could be of great potential benefit to both law enforcement and public safety organizations. Such systems can be used to look for people buried in rubble (e.g., the recent earthquake in Turkey) or trapped by an avalanche. They can also be used to sense the location of moving people within buildings.

Consumer Sector

There are many potential applications within this sector. Among them are:

Communications Applications

As nearly everyone who has attempted to install a wired computer network in an existing house has learned, there is a need for high performance wireless home networks. Existing technologies do not have the performance necessary to overcome the impact of multipath or the requisite number of channels. Especially, if as Scott McNealy's recent prediction that "it's not going to be people or [Internet] appliances, it's going to be sensors, microcontrollers. Trillions of these will be connected to the Internet." Such a system could be extended to deliver wider area network access.

Automotive Applications

There are two automotive sensor applications, both of which demand very high ranging precision (a few centimeters). One is an airbag deployment sensor to determine the location of passengers to allow safe triggering of airbags. The other is an automotive proximity radar ("pre-collision sensing") used to optimize the triggering of an airbag.

Such sensors could also play a part in the development of intelligent vehicles, with UWB systems operating as both radars and radios such sensors could create autonomous, self-organizing intelligent vehicle/highway systems.

Security Applications

UWB proximity sensors might dramatically reduce false alarms over existing sensors, since a tightly controlled range gated radar it is much harder to confuse than infrared and Doppler radar sensors. Moreover, such sensors can be installed within or behind walls. Today's Doppler security sensors detect motion without regard to target range. To minimize false alarms, the sensitivity is reduced. UWB radars, on the other hand, can be "range gated", i.e., hard limited to work out to a specific range. Such range gates can be a few inches wide.

Commercial and Industrial Sector

Again, there are numerous applications:

Industrial Wireless Local Area Network Applications

Industrial facilities are often filled with large electrical motors that product massive amounts of RF energy (unregulated by the FCC). The RF noise levels often preclude the use of wireless local area networks. However, UWB systems, by virtue of their robustness in the face of RF noise, can operate reliably.

Subsurface Inspection Radar Applications

Because of the low operating frequencies of UWB radars and their very high resolution, UWB radars can be used to look into walls, concrete structures, and soil to determine content and conditions. Thousands are already in use within the USA for:

- Roadway, runway & bridge inspecting ;
- Building construction compliance, surveying, and condition testing;
- Locating buried hazardous wastes and unexploded ordnance;
- Finding buried archaeological artifacts;
- Locating underground conduits and utilities; and
- Detecting sinkholes (sinkholes cause over $3 billion annually in property damage).

Miscellaneous Applications

- Highly reliable, low power biometric (including implanted sensors) telemetry systems.
- Navigation systems for those who are mobility impaired and robotics.
- RF Identification tagging & tracking.

Business and Electronic Commerce Applications

- UWB may enable the realization of exceptionally high performance, low cost wireless communication networks with exceptional capacity.

Security Sector

- Security fence and intruder tracking system for effective outdoor security sensors.

IV. UWB and TM-UWB

The value of UWB is that its RF bandwidth is significantly larger than the information bandwidth. The larger the ratio of the RF bandwidth to information bandwidth, the greater the signal's immunity to multipath fading, jamming from other signals (intentional and unintentional), and detection. UWB systems are in a sense a realization of the Claude Shannon's dictum on information theory, that is to maximize the carrying capacity of the spectrum, all signals should be made as noise like as possible relative to each other.

Typical UWB technologies include techniques involving very short pulses, extremely high chip rate direct sequence spread spectrum modulation, and fast slewing chirp or stepped frequency modulations. In considering ultra-wideband systems, it is customary to follow the lead of the Defense Advanced Research Projects Agency and to relate the bandwidth to the center frequency of the band. This is typically expressed as the "fractional bandwidth" which is defined as :

$$\text{Fractional Bandwidth} = \frac{2(f_H - f_L)}{(f_H + f_L)}$$

Time Domain and many others support the definition of UWB based solely on fractional bandwidth with the lower limit being 25%, however, some disagreement on this matter arises based on perspective. As XtemeSpectrum noted in their Reply Comments to the FCC UWB NOI: *"The motivation for preferring definitions based on bandwidth relative to center frequency follow from two primary desirable features. The first is immunity to scintillation and multipath. The only way to prevent scintillation (speckle or multipath fading...) is to have resolution that is approximately equal to the wavelength."*

Time Domain has developed a specific implementation of UWB, time modulated ultra-wideband. It is characterized by:

- Short Pulse waveform to produce the ultra-wide bandwidth signal;
- High pulse repetition rates so as to minimize time domain signal peaks;
- Random or pseudo-random time hopping that makes the signal noise-like in both time and frequency; and
- Fully coherent receiving techniques to maximize performance.

Time Domain has manufactured time modulated UWB radios for the military, research, and industry that transmit from bits per second to over five megabits per second. Time Domain has also built a through-wall sensing radar presently being tested by law enforcement personnel. Time Domain's newest systems incorporate integrated circuits fabricated by IBM using its most advanced silicon germanium process. One circuit divides time into 3 ps time steps. Radios built with these chips are able to measure range between radios to better than 5 millimeters.

V. Regulatory Proceedings on UWB

Until recently, UWB was an obscure technology. Nevertheless, the response to the FCC's *Notice of Inquiry on Ultra-Wideband* was larger than industry's participation in the spread spectrum proceeding over a decade ago and nearly all positive. The extreme interest in UWB is also reflected in a growing number of recent articles in the press. In fact USA Today stated that time modulated ultra-wideband "might be as important as the transistor….". Ultra-wideband is gaining recognition as a technology that can uniquely solve problems.

Nevertheless, during the recent FCC proceedings on UWB, when the UWB industry only asked for permission to radiate up to the same limits allowed of digital devices, spectrum incumbents expressed concerns.

A coordinated introduction and integration of UWB devices into the existing structure now is the best way to begin folding this state-of-the-art technology into the current technological framework. At present, emissions from billions of digital devices are allowed. These emissions create no harmful impact. Emissions from intentional UWB devices would be a method for effectively "refarming" the spectrum and improving the total capacity of spectrum that is already in heavy use. Furthermore, UWB techniques are often better matched to the propagation channel (especially indoors), allowing efficient communication at significantly lower emitted power levels, thereby reducing the overall RF noise floor.

The rules that currently prevent the lawful introduction of UWB devices were not conceived for the purpose of preventing the technology, but rather the technology was not anticipated at the time. Minor changes to the wording of existing regulations would not violate the spirit of existing regulations and would allow the introduction of many beneficial UWB products, including appropriate commercialization and application of technology which has been in use for decades by the federal government and the military.

Time Domain believes it is absolutely in the national economic and security interests for the United States to take a leadership position in UWB technology. We predict that whichever country allows deployment of this remarkable and potentially revolutionary technology the fastest will gain an important economic and social advantage.

VI. Limitations and Drawbacks to Imposing Restraints

Various operational restraints have been imposed or recommended to restrict the use of UWB. These restraints include “band notching” and geographical restrictions. An imposition of notch filters demonstrate a fundamental misunderstanding of the nature of UWB and geographical restrictions are often unworkable, especially for safety-of-life system such as through-wall sensing and public safety command and control systems.

A requirement to notch out restricted bands would be very disruptive to the UWB systems. Filtering out some of the energy is equivalent to spreading the energy in time. Notch filters decrease the signal available to the receiver, and so the signal to noise ratio. For communication systems, the decrease in bandwidth reduces processing gain resulting in reduced channel capacity and resistance to multipath. The extended pulse also adversely affects the ability of ranging devices to determine with precision the time of arrival of the first arriving signal associated with the direct path. All in all, notching drastically reduces or completely nullifies all of the factors, which make UWB technology a unique and superior solution.

The impact of notch filters on radar equipment is more severe than experienced in communication and geo-ranging systems. The distortion caused by notch filters effectively extends the duration of the pulse. This artifact degrades the range resolution prized by UWB systems. It also produces sidelobes in the radar's response, which will significantly degrade advanced processes such as imaging and object identification. Once again, the viability of UWB for radar applications would be greatly impaired by notch filters. (See Time Domain's NOI Comments for a detailed discussion on the impacts of notch filtering.)

Geographical limits are ridiculous and unwieldy. How is a police officer to determine if a UWB through-wall sensor is within a restricted area? How can firefighters wait for authorization to use a UWB sensor to search for inhabitants of a burning building? Yet some believe that such restrictions are necessary.

Computer, television, VCRs and other digital devices are ubiquitous, yet there are no complaints about compliant devices. UWB devices emitting the same signals at the same power levels are equivalent even if one group is labeled “unintentional” and the other “intentional”. Yet, there are minimal limits on their use.

VII. Conclusion

The comments from the UWB industry and users of UWB products document the unique value of UWB technology across a diverse universe of applications. There is the potential to create entirely new and beneficial services. The ground penetrating radar industry, with a history stretching back more than two decades, discussed the irreplaceable benefits of UWB. Current users of ground penetrating radar include law enforcement, utilities, geologists, transportation engineers and maintenance personnel, archeologists, and those concerned with locating land mines. There is no alternative to ground penetrating radar. Others see the potential to deliver through-wall sensing radars, high performance wireless networks, medical telemetry systems, ultra-high precision location and tracking systems, sensors to improve productivity and safety in the construction industry, and precision radar sensors.

Under the present regulatory structure, there is only one band below 10 GHz with a fractional bandwidth in excess of 25% (and it is only 28% around 6 GHz, which can be problematic for propagation), so there is little unrestricted spectrum into which UWB signals can be shoehorned. Ultra-wideband technology offers an opportunity to make additional use of the spectrum with a technology that in theory should be a more efficient approach to spectrum sharing. Moreover, UWB modulation techniques are often better matched to the propagation channel, allowing effective communication at significantly lower emitted power levels (100 times or more lower within buildings), thereby reducing the overall RF noise floor. The proposal by Time Domain, the Ultra-wideband Working Group and others represents a non-threatening approach to allowing the introduction of extremely low emitted power devices. It begins the evolution of spectrum sharing with the integration of a promising new technology in response to a revolutionary demand by consumers for advanced communication products and services.

With the more rational approach of regulating the impact of emissions and not the "intent", the FCC can allow the introduction of UWB technology while making very few changes to its existing regulations.

It is vital for the national economic and security interests for the United States to maintain its lead in the application of UWB and TM-UWB technology. Yet, with the existing regulatory uncertainty this technology cannot progress beyond prototypes for nonmilitary applications without a clear and rapid regulatory path forward. Deployment of this remarkable technology will foster a leading role and important economic and social advantage for the United States. Introduction of UWB into the current technological framework will ensure a moderated evolution, integrating the best of both technologies into a shared spectrum to provide all consumers and users with the next generation of technological benefits and applications.