Before the
Federal Communications Commission
Washington, DC 20554

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's	)	
Rules Regarding Ultra-Wideband	)	Docket No. 98-153
Transmission Systems	)	

COMMENTS

OF

<u>INTERVAL RESEARCH CORPORATION</u>

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SUMMARY

Interval Research Corporation, a Silicon Valley research laboratory founded by Paul Allen and David Liddle, strongly supports the Commission's initiative to examine ultra-wideband technologies. Interval urges the Commission to proceed with the issuance of a Notice of Proposed Rulemaking to specify Part 15 rule modifications to allow and encourage operation of UWB radio systems.

Interval firmly believes that this leading-edge technology will breed a whole new generation of radio frequency devices that will serve the public interest without causing harmful interference to existing operations in any frequency band. UWB devices have many potential safety and consumer applications, advanced telecommunications capabilities, and scientific, environmental, medical, and educational uses.

Interval strongly recommends that the Commission refrain from specifying a frequency range for UWB radio systems due to the fact that advances in technology will no doubt lead to the utilization of more frequencies. The Commission should also refrain from using a pulse desensitization correction factor for measuring emissions from a UWB device. In addition, because the potential for interference from UWB devices would be no greater than the interference potential from Class A and Class B devices currently operating pursuant to Part 15, § 15.109 existing field strength limits are adequate to protect other users of the spectrum.

Interval further believes that UWB transmissions should be permitted in the TV broadcast and restricted bands because no harmful interference will result. UWB radio systems will appear to other spectrum users to be nothing more than unintentional radiators. Thus, UWB devices should be subject to the same conditions as other Part 15 devices.

The Commission should act without delay to adjust its rules under Part 15 to permit the experimentation, development and use of these UWB devices that can save lives, boost economic growth, and enrich our world.

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COMMENTS
OF
INTERVAL RESEARCH CORPORATION

Interval Research Corporation ("Interval"), by its attorneys, pursuant to Sections 1.415 and 1.430 of the Commission's rules, hereby submits these comments in response to the *Notice of Inquiry* issued in the above-captioned proceeding ("*Notice*" or "NOI").[1] The Commission is to be applauded for initiating this forward looking proceeding to examine new ultra-wideband ("UWB") technologies and develop a regulatory structure for UWB transmission systems. Interval strongly supports the Commission's initiatives in this area and, as discussed more fully below, firmly believes that this leading-edge technology will breed a whole new generation of radio frequency ("RF") devices that will serve the public interest without causing harmful interference to existing operations in any frequency band. Interval therefore urges the Commission to proceed with the issuance of a Notice of Proposed Rulemaking to specify Part 15 rule modifications to allow operation of UWB radio systems.

[1] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, FCC 98-208, Docket No. 98-153. 63 Fed. Reg. 50184 (Sept. 21, 1998). Interval is also a signatory to the comments submitted in this proceeding by the Ultra-Wideband Working Group.

As discussed more fully below, UWB spread spectrum technology is a new and promising wireless technology that can save lives, boost U.S. economic growth, and enrich our society. Because UWB systems can be small and inexpensive, they will be relatively easy to commercialize. UWB technology has tremendous potential to create an entirely new industry that will be the basis for significant economic growth in the U.S. Commission rules permitting these devices will foster development of this new industry, benefiting the economic future of the nation and establishing the United States as a leader in this field. Accordingly, the Commission should continue to encourage the development and implementation of UWB systems in accordance with the Congressional mandate at Section 7 of the Communications Act, wherein it is specified that "it shall be the policy of the United States to encourage the provision of new technologies and services to the public."[2]

I. STATEMENT OF INTEREST

1. Interval Research Corporation, located in Silicon Valley, is a research laboratory founded in 1992 by Paul Allen, a visionary entrepreneur in high technology,[3] and Dr. David E. Liddle, a computer industry veteran with deep roots in research. Its goals are to frame issues, map out concepts, and develop technologies that will be vital to our society in the future.[4] Interval is engaged in basic research and commercialization. Interval has identified UWB as an important new technology, and it is participating in this proceeding because it believes that there may be many commercial applications for UWB radio systems that will be quite beneficial to the

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[2] 47 U.S.C. § 157 (1998).

[3] For additional information concerning Mr. Allen, see www.paulallen.com.

[4] In addition to developing UWB technology, Interval researchers are pursuing innovations in a number of different fields such as Signal Computation, Tangible Interfaces, and Reconfigurable Computing. Interval also collaborates with other research groups and university laboratories, including the MIT Media Lab, the Santa Fe Institute, and Stanford University. *See* Exhibit 1, "Interval Research Corporation and its Spin-off Companies," attached hereto. Additional information regarding Interval may be obtained from its website at www.Interval.com.

public interest, but which will go unrealized if the Part 15 rules are not altered to permit UWB technology to develop.

2. To bring a fresh and real-world perspective to creating the future, Interval has assembled a broad range of individuals with advanced degrees for its research staff.[5] Interval has a great deal of experience with UWB, and has a 10-member UWB multidisciplinary research team to investigate this new technology.[6]

II. ULTRA-WIDEBAND TECHNOLOGY

A. Potential Applications

3. UWB technology will allow for the creation of a wide variety of inexpensive RF devices serving a multitude of purposes. Some examples of potential UWB operations are as follows:

(1) Safety Applications. UWB devices have many potential safety applications. As the Commission noted in the NOI, these devices can be used to detect people buried in debris resulting from earthquakes. They can also be used to locate children in peril through emergency broadcast devices worn as part of a ring or watch. Further, through linkage to the GPS satellite system, they can also be used to find people who are lost or in need of help, such as hikers caught in blizzards or accident victims, and give them directions to reach safety. Moreover, instruments using UWB technology can sense side auto collisions faster than current devices are able to react to front-end collisions, thereby offering a new measure of security to drivers and passengers.

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[5] *See* Exhibit 1.

[6] The research management team for this group includes Dr. G. Roberto Aiello, Dr. William Lynch, Dr. Jim Boyden Dr. David E. Liddle and Dr. Arati Prabhakar. See Exhibit 2 for biographical information.

In addition, enabling the development of UWB technology will allow U.S. companies to create life-saving devices that would be invaluable abroad. For example, UWB technology can be used to produce devices to detect and explode plastic or metal land mines.[7] These UWB devices could prevent countless injuries and deaths throughout the world.

(2) Scientific and Environmental Uses. Since their signals are able to pass through solid objects, UWB devices have the potential for numerous scientific and environmental uses. For example, they can aid in oil exploration, sense the depth of peat or of ice in permafrost and glaciers, locate aging pipes, check for flaws in highways or airport runways, detect hazardous voids beneath roads or in building materials for bridges and skyscrapers, help examine land for buried drums of waste or plastic pipelines, and find archeological treasures. In addition to these many potential applications, it is important to recognize that over the past 10 years UWB has been actively used around the world for various environmental purposes.

(3) Medical. UWB devices can help make advances in the medical field. They have the potential to check inner body functions, such as heartbeat and insulin level, through tiny machines. UWB devices might also be used as pressure sensors in breast implants, strain gauges on screws, stress and vibration sensors for shoulder and hip implants, and digital

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[7] *See, generally,* www.spie.org/web/abstracts/2400/2496.html. *See also,* SPIE Proceedings Vol. 2496, Detection Technologies for Mines and Minelike Targets, Editor(s): Abinash C. Dubey (Naval Surface Warfare Ctr., Panama City, FL, USA), Ivan Cindrich (Environmental Research Institute of Michigan, Valencia, CA, USA), James M. Ralston (Institute for Defense Analysis, Alexandria, VA, USA), Kelly A. Rigano (U.S Army Environmental Ctr., Aberdeen Proven Ground, MD, USA), ISBN: 0-8194-1852-8, 1048 pages, published 1995, Meeting Date: 04/17 - 04/21/95, Orlando, FL, USA; Army Research Laboratory ultrawide-band testbed radar and comparisons of target data with models (Paper #: 2496-06); SAR imaging of minelike targets over ultrawide bandwidths (Paper #: 2496-07); Co- and cross-polarizations for mine detection (Paper #: 2496-02), pp.7-13, Author(s): Roshni J. Mehta (U.S. Army Night Vision & Electronic Sensors Directorate, Fort Belvoir, VA, USA), Douglas P. Byrne (Kaman Sciences Corp., Colorado Springs, CO, USA).

hearing aids. Further, this technology could be utilized to monitor ongoing surgery, or even the status of fetuses, via tiny cameras in the body.

(4) Education. UWB technology has the potential to play a key role in our education system. Although universal schoolroom access to the Internet is one of our declared national goals, we are nowhere close to meeting this goal in part because most classrooms lack the wiring. In fact, most classrooms lack telephones or any device for communication among teachers, students and school administrators. Traditional solutions are proving too expensive. UWB technology can help to solve this problem with low-cost "virtual wiring," which would allow not just Internet access, but cordless phones throughout the school as well.

(5) Assistance to the Elderly. UWB technology can also give elderly and disabled people greater control over their environment. UWB would enable the development of remote-command devices that react to a voice, whistle or handclap. Such devices could let an elderly or disabled person lock or unlock doors, windows, and alarms from afar, as well as operate appliances, turn faucets on and off, open awkward cabinet doors, and see into other rooms. Although some existing devices may perform some of these tasks, they are costly, require installation, lack portability, and have complex interfaces. UWB devices are inexpensive, and can be designed to be ready-to-use, movable, and easy to understand.

(6) Other Consumer Applications. UWB technology will lead to a multitude of consumer devices such as wireless speakers and audio equipment, wireless home computer networks, home and automobile alarm systems, automated home and yard cleaning systems, and other labor-saving appliances. While some UWB devices for consumers will mimic the functions of current technology, they will operate more inexpensively and efficiently than today's devices.

(7) Advanced Telecommunication Capabilities. Because of the vast potential of UWB systems, they may be able to provide high-speed, switched, broadband telecommunications services. As such, in accordance with Section 706 of the Communications Act, 47 U.S.C. § 157 nt (1998), the Commission should encourage the deployment of this technology.

B. Technical Issues

4. UWB technology has many characteristics that provide unique advantages over currently existing conventional technologies for several classes of applications. For example, the propagation characteristics of the short pulses generated by using a very large bandwidth result in lower attenuation through foliage and dielectric materials, allowing better performance in harsh environments. The time diversity inherent in UWB systems results in robustness to multipath fading, a difficult problem for many existing systems to resolve in indoor environments, and the low level of power spectral density with UWB systems guarantees no harmful interference to existing services. Finally, the time structure of the short pulses allows the design of UWB receivers to be immune from narrowband interference.

5. UWB transmitters appear as a number of spectral lines at the pulse repetition frequency. These lines are blurred when modulation is employed, resulting in even lower power spectral density; accordingly, there is less likelihood of interference being caused by UWB transmissions. Typical UWB transmitters can generate pulses as short as a few hundreds of picoseconds, though some applications may require longer pulses. Interval believes that as this technology develops, even shorter pulses will result, extending the operational bandwidth to even higher operational bandwidths.

6. Because technology for RF transmissions is advancing at such a rapid pace, Interval strongly recommends that the Commission refrain from specifying a frequency range for UWB radio systems. While the highest frequency currently used for these devices is 5 GHz, advances in technology will no doubt lead to the utilization of higher frequencies. In order to be forward looking and not limit the potential for UWB transmissions, the Commission should not specify what may be unnecessary frequency limits for UWB operations.

7. Interval believes that transmitters, below the present Part 15 power spectral density limits are adequate to provide sufficient range for most commercially viable applications. Accordingly, Interval recommends that the Commission maintain these Part 15 specifications for UWB transmitters.

(1) Definition of UWB

8. In the *Notice*, the Commission requested guidance as to how to define UWB technology if provisions are made for this technology under Part 15.[8] Although there is no standard ultra-wideband definition, Interval recommends that the Commission adopt the definition of UWB as a signal whose relative bandwidth η is larger than 0.25[9], as expressed in:

$$\eta = 2(f_H - f_L)/(f_H + f_L)$$

where f_H and f_L are the highest and lowest frequencies of interest. For the purpose of measurements, f_H and f_L can be identified at the 20dB attenuation level with instruments currently available in FCC testing facilities. This definition fits better than the traditional definition for narrowband systems, $\Delta f/f_c$, where f_c is the center frequency and Δf the absolute bandwidth, because very often these UWB signals do not have any carrier frequency (and,

[8] *Notice* at ¶ 10.
[9] *Assessment of Ultra-Wideband (UWB) Technology*, OSD/DARPA, Ultra-Wideband Radar Review Panel, R-6280, Arlington, VA (1990). *See also*, *Introduction to Ultra-Wideband Radar Systems*, James Taylor, CRC Press (1995).

therefore, a center frequency) to which to refer. Conventional technology for radar and radio communication are based on the phenomenon of resonance and small relative bandwidth, while UWB systems operate in the range of $0.25<\eta<1$. This property results in a number of characteristics that provide some advantages with respect to conventional technology, such as robustness to multipath, robustness to interference, and low level of interference to other conventional systems.

(2) Emission Limits

9. The Commission is concerned about the potential for harmful interference due to the cumulative impact of emissions if there is a large proliferation of UWB devices, and requests information on the cumulative impact of UWB transmissions, and whether the cumulative affect could result in an unacceptably high increase in the background noise level.[10] The NOI notes that the current emissions limits were established based on the potential interference from a single Part 15 device, and do not take into account cumulative effects that could occur if there is a high level of equipment proliferation.[11] In addition, the Federal Aviation Administration is particularly concerned about aircraft safety due to substantial line-of-sight propagation through the air. Interval is, of course, concerned about aircraft safety. However, both the theoretical analysis and past experiences with actual, spatially reused, radio systems are related to the same theoretical model used for UWB systems and these analyses and experiences strongly indicate that substantial background noise build-up does not, and will not, occur as a result of the operation of a substantial number of UWB devices.

10. While an infinite number of UWB transmitters on the earth's surface will

[10] *Notice* at ¶ 12.
[11] *Id.*

eventually aggregate to a finite amount of power at some height, researchers at Interval have derived a theoretical model clearly demonstrating that possible interference problems cannot come from an aggregation of emitters within a 45-degree cone below an aircraft's victim receiver. *See* Exhibit 3 attached hereto, W.C. Lynch et. al., *An Analysis of Noise Aggregation from Multiple Distributed RF Emitters*, IRC #1998-069.[12] Rather, any possible interference problem must come from an aggregation of transmitters on the horizon. However, the smallest amount of attenuation eliminates any possibility of serious aggregation from such a source. The Interval model applies equally to all radio emitters, addressing spatial reuse of AM and FM radio, spread spectrum, and UWB sources alike. The density of the emitters is not an issue, only the spatial reuse is.

11. The long-standing observation of non-aggregation of noise of such emitters as AM and FM radio and cellular systems illustrates the effectiveness of damping on the possible horizontal aggregation. A receiver on the earth's surface, as opposed to in an aircraft, will have similar results, being subject to a finite degradation of the signal-to-noise ratio.[13] Victim wideband receivers are at no additional disadvantage when compared to narrowband receivers. In conventional CW, receivers capture additional signal and noise in a fixed proportion independent of receiver bandwidth. If each received subband has equal total interference, whether from a single or from several transmitters, the interference-to-noise ratio at the receiver is preserved. A wider bandwidth receiver will detect more energy from a UWB transmitter, but it will also detect more thermal noise in the same ratio, keeping the signal-to-noise ratio constant.

[12] *See* Exhibit 2 for biographical information on Dr. Lynch.

[13] T.J. Shepard, *Decentralized Channel Management in Scalable Multihop Spread-Spectrum Packet Radio Networks*, Ph.D. Thesis, July 1995, MIT/LCS/TR-670.

12. The foregoing considerations lead to the conclusion that the § 15.109 field strength limits will alleviate harmful interference from UWB operations and are, therefore, adequate to protect other users of the spectrum, even those in the restricted bands. Thus, the potential for interference from these devices would be no greater than the interference potential from Class A and Class B devices currently operating pursuant to Part 15 of the Commission's rules.

(3) Measurements

13. As noted in the NOI, the current procedures for measuring compliance with the technical requirements applicable to Part 15 intentional radiators use a pulse desensitization correction factor to measure the total peak power emitted by a device.[14] The Commission asks if a pulse desensitization correction factor is appropriate for measuring emissions from a UWB device.[15] Interval asserts that pulse desensitization is a significant obstacle to the realization of UWB radio systems. Pulse desensitization is enforced to protect receivers from an overload of power, which may cause saturation, in case of pulsed RF systems when transmitters are periodically turned on and off. Fixed frequency receivers, like spectrum analyzers, are less sensitive to a pulsed RF signal and the measured signal strength appears lower. UWB systems, however, use wide frequency range and very little spectral power density at each specific frequency. The spectrum produced by the short pulses has a very wide frequency content. This does not result in a high signal level at any specific frequency at any time, but only the combination of all frequencies can reconstruct the complete signal. Thus, the currently required pulse desensitization correction factor should ***not*** be used by the Commission to measure emissions from a UWB device.

[14] *Notice* at ¶ 13.

14. Existing test equipment in FCC test labs is adequate to measure UWB transmitters and emissions, provided that they are set up to measure the average energy, rather than the peak that is not indicative of the amount of interference given to other users of the spectrum. Interval's proposed procedure for operations above 960 MHz is as follows: the analyzer should be set up with a resolution bandwidth of 1 MHz and a video bandwidth of 1 MHz, and the sweep speed should be set to automatic. With the EUT continually transmitting, the center frequency and/or span are adjusted so that the highest emission component is near the center of the analyzer display screen. Readings obtained using this method are peak readings. This will show the peak level of interference. The video bandwidth should then be lowered to 10 Hz with the sweep set to automatic to measure the average power over the band.

(4) Other Matters

15. The *Notice* also asks whether the prohibition against Class B, damped wave emissions apply to UWB systems or if the prohibition is irrelevant, especially in light of the relatively low power levels employed by UWB devices.[16] Because of the difference in spectrum's usage between the two types of radiators, Interval agrees with the Commission's tentative decision not to apply the damped sine wave prohibition to UWB emission. UWB transmitters are designed not to interfere with other users and present a unique signal. Unlike spark gaps, UWB receivers use all the spectrum they see, in order to capture the whole transmitter's energy.

16. Interval urges the Commission to issue a Notice of Proposed Rulemaking so that a record can be developed on the technical and operational characteristics of UWB devices. Only

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[15] *Id.*

[16] *Notice* at ¶ 14.

then will the Commission be in a position to intelligently and realistically evaluate the technical and operational issues presented by UWB systems.

C. <u>TV Broadcast and Restricted Bands</u>

17. The Commission observes in the NOI that the wide bandwidth of UWB systems emissions may result in their fundamental emissions being transmitted into the TV broadcast and restricted frequency bands, which is currently prohibited under Part 15 of its rules.[17] Thus, it requests guidance as to whether to eliminate the requirement that only spurious emissions are permitted to fall within these bands.[18] Interval believes that UWB transmissions should be allowed in TV Broadcast and restricted bands because UWB transmissions will not cause harmful interference in these bands. UWB radio systems operate using a very large bandwidth with very low power spectral density. Therefore, UWB radio systems appear to other spectrum users to be nothing more than unintentional radiators, which currently emit RF energy into the restricted bands and the TV broadcast bands, and which must comply with the field strength limits set forth in § 15.109 of the Commission's rules. The large number of existing unintentional radiators that populate homes, cars, offices and any human environment, has demonstrated the minimal effect that such unintentional radiators have caused to existing services operating in the TV and restricted bands. In fact, laboratory measurements show a striking spectrum similarity between UWB transmitters and the emissions from computer boards.[19]

18. It is Interval's position that existing techniques for measuring emissions from

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[17] *Notice* at ¶ 5.
[18] *Notice* at ¶ 11.
[19] *See* Exhibit 4, attached hereto, showing a comparison of emissions measurements on a Pentium and a UWB transmitter.

unintentional radiators are appropriate for measuring emissions from UWB radio systems. As noted above, to a non-UWB device, a UWB signal looks like random noise. Therefore, it is reasonable to view a UWB device as if it was an unintentional radiator and the § 15.109 field strength limits for unintentional radiators should be applied to UWB devices. UWB radio systems should also be subject to the digital device emissions limits that currently apply to AC line conducted emissions. In addition, UWB devices should be subject to the same conditions as other Part 15 devices, including that they may not cause harmful interference and must accept harmful interference caused by existing services. Such regulations would promote the development of UWB consumer devices while protecting existing services and operations.

19. The *Notice* asks what the impact on the viability of UWB technology would be if the rules continue to prohibit operation of UWB systems within the restricted bands and the TV broadcast bands.[20] Interval submits that requirements to notch some frequencies would defeat the purpose of UWB systems, because one of the most attractive features of UWB technology is the simplicity of its receiver design. The unique characteristics of UWB technology are derived from the large bandwidth that creates impulses rather than sinewaves. Most of the advantages of UWB technologies would vanish if the rules required notching some frequencies, because it would force resonances that would make the system less effective for positioning and less robust to multipath fading. Such requirements would also create additional implementation costs that would make UWB systems less appealing for many consumer applications.

20. The Commission should issue a Notice of Proposed Rulemaking to develop a comprehensive record on the issues of the TV broadcast and restricted bands. The input of government agencies using the restricted bands as well as that of TV broadcasters will be

[20] *Notice* at ¶ 11.

invaluable in assisting the Commission to understand the impact of UWB operations in those bands.

III. CONCLUSION

21. Interval urges the Commission to act without delay to permit UWB field experimentation; this is the only way that the necessary knowledge regarding this exciting technology can be compiled. Some adjustment to the Part 15 rules is necessary, however, to permit such operation. Specifically, UWB transmission must be allowed in the TV Broadcast and restricted bands and current emission measurement procedures, especially as they relate to a pulse desensitization correction factor, must be modified to measure emissions from a UWB device. At the outset, it must be noted that unless the Commission is willing to make necessary modifications to the rules, UWB technology will be stifled, and this promising new technology will never reach fruition.

22. There are some basic principles the Commission should keep in mind in adopting rule modification for UWB transmission. First, the whole notion of spectrum utilization has changed and is changing because of new technologies. Years ago, there was ample frequency spectrum available so there was not a great need to be an efficient spectrum user, and particular uses could be granted exclusivity. With technological advances and significant public demand for new services, the frequency spectrum is becoming increasingly congested. Accordingly, there now exists a necessity to use the spectrum in a most efficient manner, and share the frequency spectrum with other uses. Technological advancements make more efficient, non-exclusive and shared operations possible. This is exactly the technology which UWB represents because it can share already used spectrum and not create any harmful interference to existing users.

23. Second, the Commission should avoid any temptation to set unnecessary limits on new technologies. Specifying unnecessary limitations will only hinder the development of UWB systems and prevent newer and better technology from being implemented. As the Commission noted in the NOI, new spread spectrum technology has been very successful and has provided many services in the public interest.[21] Interval submits that the main reason that spread spectrum systems have enjoyed enormous growth is because the Commission had the foresight to create very simple rules for operation – specifying only minimal standards to assure that: (1) no harmful interference is caused; and (2) providers of spread spectrum services can share the band. By specifying these simple rules, the Commission promotes and encourages technological developments, and it allows the best technologies to be successful in the marketplace. This same approach should be utilized for UWB transmissions.

24. The benefits of UWB technology are clear. Small, inexpensive UWB devices will make possible innovative, socially important applications that will serve the public in many ways, including safety, education, and health. This technology will breed a new generation of devices that will save lives, boost economic growth, and enrich our world. UWB technology will make many useful household, automobile, and other consumer devices more affordable. The FCC has a long history of adjusting its regulations to meet new technology when it promises major societal advances. Indeed, Section 7 of the Communications Act would appear to require the Commission to make such adjustments. This flexibility, which is vital to keeping our nation in the forefront of technology, is crucial to the continued development of UWB technology.

[21] *Notice* at ¶ 8.

Interval urges the Commission to issue a Notice of Proposed Rulemaking to amend Part 15 of its rules to permit the development and use of UWB.

Respectfully submitted,

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Dated: December 7, 1998

EXHIBIT 1

Interval Research Corporation
(and its Spinoff Companies)

Interval Research Corporation
(and its Spinoff Companies)

Interval Research Corporation ("Interval") is a high-technology research lab studying technologies that will be important to people in the future. Founded in 1992 by computer visionaries Paul Allen and Dr. David E. Liddle, Interval studies new market opportunities at the intersection of technology, consumers and popular culture. It is Interval's purpose to discover or invent technologies that individuals will use in their everyday lives. The work at Interval is long-term and multidisciplinary.

Of its 168 full time employees, more than half, or 102 are members of the research staff. Of the researchers, 44 have Ph.D. Degrees and 41 have other advanced degrees. Interval's engineers, computer scientists, and other researchers have broad technical expertise related to ultra wideband and communications technologies. Interval's interest in scientific papers and intellectual property is demonstrated by the fact that since its founding, Interval researchers have published nearly 200 articles in the professional literature and Interval has been issued 27 patents.

Interval is pursuing breakthroughs in a score of seedling technologies and is working to build industries around them, thereby creating opportunities for entrepreneurs. Interval has spun off four start-up companies that have gone on to pursue commercial endeavors: Purple Moon., Electric Planet Interactive, Mirvo Toys, and Avio Digital. These companies, which were launched with staff, intellectual property and initial funding provided by Interval, stem from several long-term, high technology research initiatives.

In November 1996, Purple Moon (www.purple-moon.com) spun out of Interval. Purple Moon was founded to meet the need for a new entertainment concept that is truly meaningful and relevant to girls' lives, identified after four years of intensive research. Based on these findings, Purple Moon developed the first entertainment experience - "friendship adventures for girls" - that got to the core of girls' interests. In September 1997, Purple Moon introduced its "friendship adventures". They were widely heralded as the first products to truly "get it right" for girls, and were immediately successful. Purple Moon was the top-performing new publisher during the 1997 holiday season. Purple Moon employs more than 50 people, including top entertainment software, technology and consumer products executives.

Electric Planet Interactive (www.e-planet.com) is engaged in the design and production of novel, technology-based entertainment that is targeted at children between the ages of 6-11. The technology enables kids to extend their own creativity and imagination, while playing in ways that are not traditionally associated with typical multimedia computer-based games or applications. The company's products are based on research conducted at Interval.

Mirvo Toys, Inc. (www.mirvo.com) is a new high-tech toy and entertainment company that spun-out of Interval Research in February 1998. Mirvo's mission is to create modern entertainment and learning experiences for kids and adults that leverage the processing power and interactivity of the PC. Initially, Mirvo is creating games for children under the age of 8. Among other things, the Mirvo technology brings toys to life with the sound and animation of

CD-ROM software. The Mirvo experience emphasizes hands-on active play, and it inspires imaginative role-play, creativity, and problem solving in children.

Avio Digital, Incorporated (www.aviodigital.com) was formed in July 1998 to pursue opportunities in the consumer electronics and home networking markets, after three years of extensive research and development at Interval. Avio Digital publicly introduced one of its core technologies, the MediaWire™ home network, in June 1998 at the Digital Living Room Conference sponsored by *Upside Magazine*. This technology allows existing home telephone wiring to carry digital information such as high-quality audio and video (including HDTV), computer data, home control data, and telephone calls at rates up to 88 million bits per second. This breakthrough technology will enable a new era of consumer electronics devices and services. The company is also developing a wide range of consumer electronics products for the growing home theater, home telephony, and personal computer markets.

EXHIBIT 2

Interval Research Corporation
(Communications and Radio Expertise and Management)

Interval Research Corporation
(Communications and Radio Expertise and Management)

The president, CEO, and co-founder of Interval Research Corporation is Dr. David E. Liddle. After his education (B.S., E.E., University of Michigan; Ph.D, Computer Science, University of Toledo, Ohio), Dr. Liddle spent ten years at the Xerox Palo Alto Research Center and the Xerox Information Products Group where he was responsible for the first commercial implementation of the Graphical User Interface and local area networking. He then founded Metaphor Computer Systems whose technology was adopted by IBM and the company ultimately acquired by IBM in 1991. In 1992, Dr. Liddle co-founded Interval Research with Paul Allen. Dr. Liddle is a consulting professor of Computer Science at Stanford University. He is chairman of the board of trustees of the Santa Fe Institute. He has served as a director at Sybase, Broderbund Software, Starwave and Ticketmaster. He currently serves as a director at Metricom, Inc. He was honored as a distinguished alumnus from the University of Michigan and is a member of the national Advisory committee at the College of Engineering from that University. He is also a member of the advisory committee of the school of Engineering at Stanford University. He has been elected a Senior Fellow of the Royal College of Art.

Arati Prabhakar is Vice President of Research at Interval Research Corporation. In this role, Dr. Prabhakar oversees the cultivation of the lab's research projects and directs Interval's research team members who are designing technologies intended for individuals' everyday use. Before joining Interval in October 1998, Prabhakar was senior vice president and chief technology officer at Raychem Corporation. Previously, she held a U.S. Senate-confirmed Presidential appointment as a director of the National Institute of Standards and Technology (NIST), which works with companies on broad-based technologies for U.S. economic growth. While at NIST, she was responsible for the Advanced Technology Program, the NIST Laboratories, the Manufacturing Extension Partnership, and the Malcolm Baldrige National Quality Award. Prior to NIST, she was an office director for the Defense Advanced Research Projects Agency where she set strategic directions for and managed investments in electronics R&D projects in over 300 companies, universities and labs. Dr. Prabhakar was also a Congressional Fellow, conducting a study on critical issues in microelectronics R&D for the House Science, Research and Technology Subcommittee. Dr. Prabhakar has a Ph.D. in Applied Physics, California Institute of Technology, 1984; an M.S. in Electrical Engineering, California Institute of Technology, 1980; and a B.S. in Electrical Engineering, Texas Tech University, 1979. She also holds a number of honors and professional memberships, including an honorary doctorate, Rensselaer Polytechnic Institute; Fellow, Institute of Electrical and Electronics Engineers; and Member, Stanford University School of Engineering Advisory Council.

Dr. Jim Boyden is in charge of the general program in which the ultra-wideband research falls. He has a Ph. D. in Physics (Thesis in high energy particle physics) from Caltech; a B.S. and M.S. in Physics from Carnegie-Mellon. At Interval since December '92, he has worked primarily in the area of wearable and portable technology and systems, emphasizing short-range wireless communications at frequencies from HF to 2 GHz. He was responsible for a Metricom/Interval wireless network due diligence and initial liaison. Prior to working at Interval, Dr. Boyden was at HP Laboratories for 17 years as a Lab Director. He proposed and managed the development of

HP's first laser printer. Prior to his work at HP, Dr. Boyden was Division Manager for a laser/electro-optical systems company. In this position, he developed actively mode-locked solid state lasers involving application of RF technology. He also developed atomic frequency standards for commercial and military applications, requiring application of microwave techniques up to 10 GHz. He designed and developed high-Q microwave cavities and mixing systems. He is also a Chief Engineer (licensed) of a commercial broadcast station (AM) and an amateur radio operator (W4PDK).

Another member of Interval's research management team, and also a member of the ultra wideband research group, is Dr. William Lynch. Dr. Lynch received his B.S. in Mathematics from Case Institute of Technology in 1959, and his M.S. (1960) and Ph.D. (1963) in Mathematics from the University of Wisconsin in Madison. From 1963-1976 he was Assistant, Associate, and Full Professor of Computer Engineering and Information Sciences in the Engineering School of Case Western Reserve University. During this period he published extensively on the topics of operating systems, communications, and performance analysis. He has also been on the faculty of or a Visiting Professor at the University of Wisconsin, The University of Newcastle-Upon-Tyne (England), The Federal University of Rio de Janeiro, The State University of Campinas (Brazil), and has taught post-graduate courses at Stanford University. From 1976 to 1993 Dr. Lynch was employed by the Xerox Corporation in Palo Alto, CA. He was responsible for the design and implementation of the Pilot operating system underlaying the Xerox Star, the first commercial GUI workstation. Later at Xerox he had responsibility for the creation of the specifications for the Ethernet and the adoption of those specifications by IEEE 802.3. After leaving Xerox PARC, Dr. Lynch joined Interval Research Corporation as a Member of the Research Staff. He has conducted research on video processing and on novel radios. Dr. Lynch is member of the American Mathematics Society, the Association for Computing Machinery, the Institute of Electrical and Electronic Engineers, the American Association of University Professors, and the American Association for the Advancement of Science.

Dr. G. Roberto Aiello, who leads Interval's UWB team, received his Laurea (Ph.D.) in physics from the University of Trieste, Italy. He worked from 1988 to 1996 in particle accelerators, where he significantly contributed to the advance of beam diagnostics in the particle accelerators' community. He has published extensively in scientific journals and particle accelerator conferences. From 1988 to 1990 he helped build Elettra, a third generation Synchrotron Radiation Source in Trieste, Italy, where he designed and built the optical diagnostics for the machine. He served as thesis advisor in the Physics and Engineering Departments at the University of Trieste, Italy. From 1991 to 1993 Dr. Aiello was a Group Leader at the Superconducting Super Collider Laboratory, Waxahachie, TX, operated by the Department of Energy. His group was responsible for the design and fabrication of the electronics for the instrumentation of the whole complex of five accelerators, including the fifty-four miles collider. He also technically contributed by specifying the diagnostics required for the Low Energy Booster that resulted in the publication of a book to which he contributed with a chapter. For that work, he received recognition as an "Outstanding Researcher" by the Department of Energy. In 1994, Dr. Aiello was Visiting Professor at the Arcetri Astrophysics Observatory, Arcetri, Italy, where he worked on the electronics' design for the adaptive optics of the Large Binocular Telescope under construction on Mt. Graham in Arizona. From 1995 to 1996 Dr. Aiello was a

Group Leader at the Stanford Linear Accelerator Center, Stanford, CA. His Group successfully designed, built and installed beam diagnostics that lead to performance's improvements in the Stanford Linear Collider and that contributed to the commissioning to the PEP-II B-Factory. Dr. Aiello joined Interval Research Corporation as a Member of the Research Staff in 1996, where he has conducted research on wireless architectures and Ultra Wideband technology. Dr. Aiello is member of the American Physical Society, the Institute of Electrical and Electronic Engineers and the American Association for the Advancement of Science.

The other members of the ultra wideband research team are a multidisciplinary group with expertise ranging from computer science and engineering to applications design to art and behavioral science. Many of the team hold advanced degrees and have extensive research experience.

EXHIBIT 3

An Analysis of Noise Aggregation from Multiple Distributed RF Emitters

An Analysis of Noise Aggregation from Multiple Distributed RF Emitters

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Interval Research Corporation
December 6, 1998

Abstract

The purpose of this technical note is to explore the aggregate noise generated by a large number of distributed radio emitters. There have been concerns that the widespread and ubiquitous use of ultra-wide-band (UWB) devices might increase the ambient noise levels beyond today's conditions. There are particular concerns regarding aircraft safety due to substantial line-of-sight propagation through the air.

Both the theoretical analysis [1] and past experiences with actual, spatially reused, radio systems are related to this theoretical model and *strongly indicate that substantial noise build-up does not and will not occur.*

From our derivations, it becomes clear that problems cannot come from an aggregation of emitters within a 45 degree cone below the victim receiver. On the other hand, the effects of an aggregation of emitters near the horizon are controlled by either of the curvature of the Earth or damping at ground level near the emitters.

The developed model applies equally to all radio emitters, addressing spatial reuse of AM and FM radio, spread spectrum, and UWB sources alike. The density of the emitters is not an issue, only the spatial reuse. The longstanding observation of non-aggregation of noise of such emitters as AM and FM radio and cellular systems speaks to the effectiveness of damping and the finite Earth in mitigating the effects of an aggregation of emitters on the horizon.

1. Aggregation Model

We consider the aggregate power at the apex of a solid cone resulting from the aggregate power emitted by the disk forming the base of the cone (Fig. 1). We will eventually apply this model with the base of the cone on the surface of the Earth and the apex at some height above the surface. We take the radius of the disk to be r and the height of the apex above the ground plane to be h. The areal power density in the base disk is P. Using the inverse square law we can integrate in cylindrical coordinates over the base disk and arrive at P_{apex}, the apex receiver power density per unit area of apex receiver antenna (x is the radius from the base of the cone):

$$P_{apex} = \int_0^x P \frac{2\pi x_*}{h^2 + x_*^2} dx_* = \pi P \int_0^x \frac{d\left(h^2 + x_*^2\right)}{h^2 + x_*^2} = \\ = \pi P \ln\left(h^2 + x_*^2\right)\Big|_{x_*=0}^{x_*=x} = \pi P \ln\left(\frac{h^2 + x^2}{h^2}\right) = \pi P \ln\left(\sin^{-2}(\theta)\right) \tag{1}$$

If $\theta = \pi/4$ then the power density at the apex is

$$P_{apex,\theta=\pi/4} = \pi P \ln\left(\sin^{-2}(\pi/4)\right) = \pi P \ln(2) = 2.178P \qquad (2)$$

This is not a very big increase.

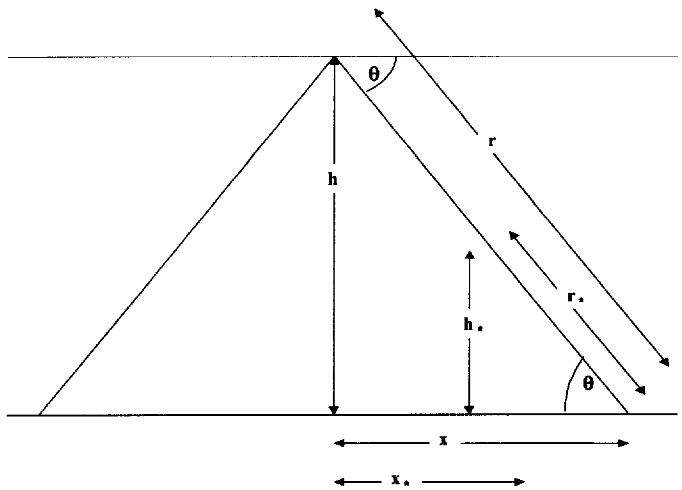


Fig 1 – Setup Geometry

Beyond $\theta = \pi/4$ we are ultimately limited by the radius of the Earth R_E =6,375,000 m, whose effect is not negligable. For $h << R_E$ (true for any altitude in the atmosphere) we have $hR_E = x_H^2$ where x_H is the distance from directly below the apex to the horizon.

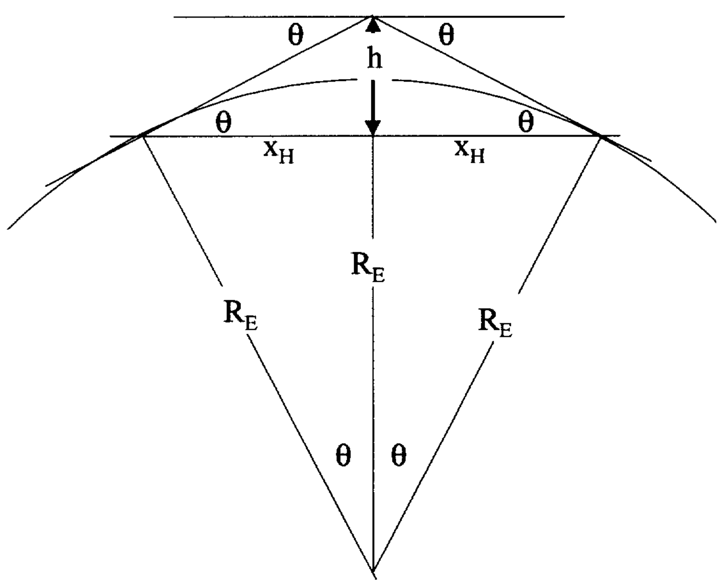


Fig 2 – Earth Curvature

Then we have

$$P_{apex\ to\ horizon} = \int_0^{\sqrt{hR_E}} P \frac{2\pi x_*}{h^2 + x_*^2} dx_* = \pi P \ln\left(1 + \frac{R_E}{h}\right)$$
$$= \pi P \ln\left(\sin^{-2}(\theta_H(h))\right) \approx 2\pi P \ln\left(1/\theta_H(h)\right) \tag{3}$$

As an example, if the apex height h is 100 m we will have

$$P_{apex,\ h=100m} = \pi P \ln\left(1 + \frac{6{,}375{,}000}{100}\right) = 34.75P \tag{4}$$

2. Electromagnetic Damping

There are only two possible dispositions for emitted photons. They may either be lost to space or they may be absorbed here on Earth. Such absorption in this context is referred to as *damping*. Interaction with matter which is neither perfectly conducting nor perfectly insulating (i.e., most materials) will result in a non-zero proportion of the photons being absorbed. Damp materials found close to the surface of the Earth are particularly effective in absorption. Moreover, the complex natural and man-made geometry near the surface of the Earth causes many reflections and other changes of course to the photons, resulting in increased interaction with absorbing materials.

We therefore need to modify the above derivation to take damping into account.

Damping is characterized by an absorption coefficient b_* which describes the proportion of photons absorbed in traversing a unit length of a given material. We will not assume that the absorption coefficient is a constant, but rather that it varies widely for different materials. In our context we will assume that it varies with the distance from the apex and with the height h_* above the surface of the Earth. (Do not confuse h_*, the height of a photon in propagation, with h, the height of the apex.) We expect the height to be the parameter causing the largest variations.

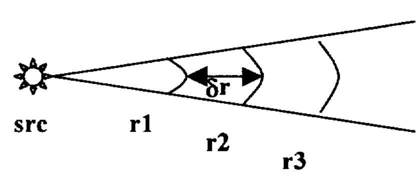


Fig 3 – Signal Propagation

The signal power degrades as it travels farther away from the source (Fig. 3). If the signal strength at the distance *r1* is *P(r1),* then, with the inverse quadratic law, the signal strength at the distance *r2* can be described by the following equation.

$$P(r_2) = \frac{r_1^2}{(r_1 + \delta r)^2}(1 - b_*(h_*(r_2), r_2)\delta r)P(r_1) \tag{5}$$

This process is repeated and thus at a distance of r_n, the signal strength is the following:

$$P(r_n) = \prod_{i=1}^{r_n/r_0} \frac{r_i^2}{(r_i + \delta r)^2}(1 - b_*(h_*(r_i), r_i)\delta r)P(r_1)$$

$$\ln(P(r_n)/P(r_0)) = \ln\left(\frac{r_0^2}{(R+\delta r)^2}\right) + \sum_{i=1}^{r_n/r_0} \ln(1 - b_*(h_*(r_i), r_i)\delta r) \tag{6}$$

$$\approx \ln\left(\frac{r_0^2}{r_n^2}\right) - \sum_{i=1}^{r_n/r_0} b_*(h_*(r_i), r_i)\delta r \approx \ln\left(\frac{r_0^2}{r_n^2}\right) - \int_{r_0}^{r_n} b_*(h_*(r_*), r_*)dr_*$$

In the limit as $\delta r \to 0$ we have

$$P(r_n)/P(r_0) = \frac{r_0^2}{r_n^2} e^{-\int_{r_0}^{r_n} b_*(h_*(r_*), r_*)dr_*} \tag{7}$$

Equation (1) is then generalized to

$$P_{apex} = \int_0^r P \frac{2\pi x e^{-\int_0^{\sqrt{h^2+x^2}} b_*(h_*(r_*), r_*)dr_*}}{h^2 + x^2} dx \tag{8}$$

In the case where b_* is a function of h_* alone the value of b_* will be noticeably greater than zero for small h_* (near the Earth's surface) and negligibly small for larger h_* where the propagation path is "line-of-sight" through the air. The integral of b_* along a ray is still definitely greater than zero. Notice that in the geometry of Fig. 1 that $h_* = \sin(\theta)r_*$

$$b_*(h_*(r_*), r_*) = b_*(h_*(r_*)) \Rightarrow$$

$$\int_{r_*=0}^{r_*=\sqrt{h^2+x^2}} b_*(h_*(r_*), r_*)dr_* = \csc(\theta)\int_{h_*=0}^{h_*=h} b_*(h_*)dh_* = r\frac{1}{h}\int_0^h b_*(h_*)dh_* = br \tag{9}$$

where we define

$$b = \frac{1}{h}\int_0^h b_*(h_*)dh_* \tag{10}$$

Therefore, in this case, the damping integral is still O(*r*). The aggregated signal power at the apex, considering damping, is

$$
\begin{aligned}
P_{apex,damped} &= \int_0^{\sqrt{hR_E}} P\frac{2\pi x_* e^{-br}}{h^2+x_*^2}dx_* = \int_0^{\sqrt{hR_E}} P\frac{2\pi x_* e^{-b\sqrt{h^2+x_*^2}}}{h^2+x_*^2}dx_* = \\
&= \int_0^{\sqrt{hR_E}} P\frac{\pi e^{-b\sqrt{h^2+x_*^2}}}{h^2+x_*^2}d\left(h^2+x_*^2\right) = \int_h^{h\sqrt{1+\frac{R_E}{h}}} P\frac{\pi e^{-bu}}{u^2}du^2 = \int_{bh}^{bh\sqrt{1+\frac{R_E}{h}}} P\frac{2\pi e^{-v}}{v}dv = \\
&= 2\pi\left(\exp\mathrm{int}(bh) - \exp\mathrm{int}\left(bh\sqrt{1+\frac{R_E}{h}}\right)\right)P
\end{aligned}
\tag{11}
$$

It's not so clear what happens when the damping coefficient b is very small. If $bh\sqrt{1+\frac{R_E}{h}} << 1$ we obtain

$$
\begin{aligned}
P_{apex,damped,b\ small} &= \int_{bh}^{bh\sqrt{1+\frac{R_E}{h}}} P\frac{2\pi e^{-v}}{v}dv \approx \int_{bh}^{bh\sqrt{1+\frac{R_E}{h}}} P\frac{2\pi}{v}dv = \\
&= 2\pi\left(\ln\left(bh\sqrt{1+\frac{R_E}{h}}\right) - \ln(bh)\right)P = 2\pi\ln\left(\sqrt{1+\frac{R_E}{h}}\right)P = \pi P\ln\left(1+\frac{R_E}{h}\right)
\end{aligned}
\tag{12}
$$

so that the aggregation is bounded even if b is zero (as in eq. 3) so long as h is not.

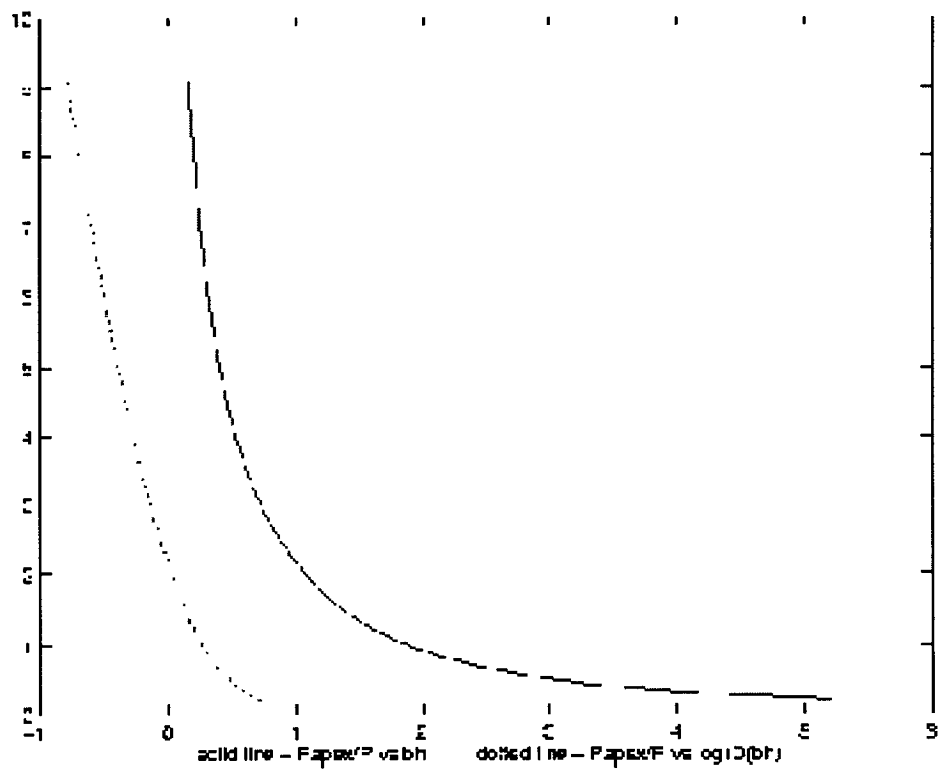


Figure 4 – Relative apex power vs. scale height

Thus this integral is finite for all positive values of h. Rather than speculate on the values of b, we'll shortly address the question qualitatively. A similar computation shows that the apex aggregate power is finite even if the damping integral increases as slowly as $O(\ln(r))$.

Thus it is clear that very small amounts of damping prevent the aggregate power from growing large.

Figure 4 graphs the aggregation factor as a function of the *scale height bh* and also of the $\log_{10}$ of the scale height.

3. Application to Spacially Reused Radio

An examination of the preceding arguments reveals that the model depends neither on the bandwidth nor on the modulation of the signal. The arguments depend only on the spatial reuse of the frequencies to the extent that a continuous emitting source plane is a good approximation. However, as any aggregate is linear in the power density, that aggregate will be finite if both the height and damping are positive (non-zero) and remains so as long as the power density has an upper bound (surely so if there are a finite number of transmitters).

Conversely, if the analysis given above is faulty we would conclude that we would observe unbounded aggregate power levels from the many contemporary RF sources that are spatially divided. Such sources include cellular phone systems, FM radios and even AM radio stations. *No such aggregation is observed.*

4. Conclusions

A theoretical analysis for the noise aggregation of spatially reused radio systems has been developed. Both this analysis and past experience with actual spatially reused radio systems related to this model *strongly indicate that substantial noise build-up does not and will not occur.*

From our analysis, it is clear that noise buildup from an aggregation of emitters within a 45 degree cone below an airborne victim receiver is very limited (approximately a factor of two).

Aggregation of noise from emitters near the horizon is controlled by either of the curvature of the Earth or damping at ground level near the emitters. . Such radiation departs its source essentially parallel to the plane (clearly not perpendicular to it). Damping of these plane parallel rays is significant as described in the next section.

The developed model applies equally to all radio emitters, addressing spatial reuse of AM and FM radio, spread spectrum, and UWB sources alike. The density of the emitters is not an issue, only the spatial reuse. The longstanding observation of non-aggregation of noise of such emitters as AM and FM radio and cellular systems speaks to the effectiveness of damping in controlling horizontal aggregation.

References

[1] T. Shepard, "*Decentralized Channel Management in Scalable Multihop Spread-Spectrum Packet Radio Networks*", Ph.D. Thesis, MIT/LCS/TR-670, July 1995.

[2] M. Rofheart, J. McCorkle, "*Short Analysis on the Effects of a Large Number of UWB Systems*", OC Technologies Inc. Technical Report, 1998.

Appendix A – Numerical Approximation and Simulation

Alternative to an analytic solution of the problem stated, one might be tempted to numerically approximate the problem. However, as we will show in the following, it is extremely difficult to numerically calculate large RF aggregations accurately without inadvertently introducing the equivalent of some damping. To illustrate this, consider the numerical summation of $\sum_{i=0}^{\infty} \frac{1}{i}$

The obvious way of calculating the (divergent) summation is to set a running sum to zero and then add terms in the order of indexing until convergence is obtained. Numerical convergence generally will be obtained and we can approximate the converged value. Suppose that the calculation is performed with single precision IEEE arithmetic, with 24 bits of mantissa. Eventually the running sum will become 2^24 times the running sum and further additions will not increase it.

Let this happen after N terms. Then the running sum will be about ln(N) so we need ln(N) ~ 2^24/N. Solving for N we obtain 1,198,700. So "convergence" is obtained after a million terms and the running sum is ln(N) = 14, approximately! In effect the terms that are 2^24 times smaller are "damped" to zero.

Such series are well known to be difficult to sum. Since the terms are positive, any convergence will be absolute so that the sum can be calculated in any order. If, say, 3.25x10^6 = 1.2*e terms are summed from smallest to largest the running sum will increase from 14 to 15 and we can get the sum to 16 by summing 1.2*e^2 terms. Double precision with 56 bits of precision will converge with 2*10^15 terms yielding a summation value of just 35.

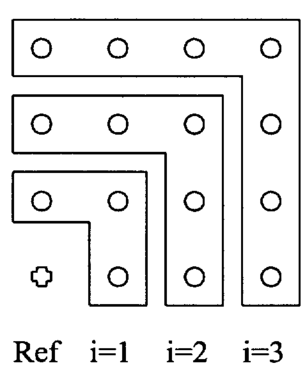


Fig 5 – Field of Emitters

Even worse, it is clear that any absolute or any relative convergence criteria will eventually be met, even with very high precision arithmetic. In essence, we must know that the series diverges in order to program the calculation correctly!

A double summation of the form $\sum_{j>0,k>0} \frac{1}{j^2+k^2}$, is closely related to the integral in section 1 and diverges in the same way. A divergent lower bound can also be calculated in layers as Fig. 5 illustrates.

$$\sum_{j>0,k>0} \frac{1}{j^2+k^2} > \frac{3}{1^2}+\frac{5}{2^2}+\frac{7}{3^2}+\bullet$$

yields the corresponding lower bound series.

$$\sum_{j>0,k>0} \frac{1}{j^2+k^2} > \sum_{i=1}^{\infty} \frac{2i+1}{i^2} > 2\sum_{i=1}^{\infty} \frac{1}{i} > 2\int_1^{\infty} \frac{dx}{x} = \ln(x)\Big|_1^{\infty} = \ln(\infty) \tag{14}$$

a slowly diverging one that goes to infinity.

Appendix B – Estimating the Damping

Empirical studies have often fit their data with a propagation law that is not inverse square ($\frac{1}{r^2}$), but rather a higher power ($\frac{1}{r^{2+\varepsilon}}$).Any positive, non-zero value of ε leads to finite aggregate power [1] for all values of bh, including zero. These studies [1] generally have found $2.4 \le 2+\varepsilon \le 4$.

There is a particular form for the damping $b(h(r),r)$ that reconciles this empirical form with the earlier analysis. From equation (8) we have

$$P_{apex} = \int_0^r P\frac{2\pi x e^{-\int_0^{h^2+x^2} b(h(r),r)dr}}{h^2+x^2}dx = \int_0^{\infty} P\frac{2\pi x}{\sqrt{h^2+x^2}^{\,2+\varepsilon}}dx \tag{15}$$

and this will be satisfied if

$$e^{-\int_0^{h^2+x^2} b(h(r),r)dr} = \sqrt{h^2+x^2}^{\,-\varepsilon} \tag{16}$$

Taking the log and the differentiating each side

$$-\int_0^{h^2+x^2} b(h(r),r)dr = \ln\left(\sqrt{h^2+x^2}^{\,-\varepsilon}\right) = -\frac{\varepsilon}{2}\ln(h^2+x^2)$$

$$\frac{d\left(\int_0^{h^2+x^2} b(h(r),r)dr\right)}{d(h^2+x^2)} = \frac{\varepsilon}{2}\frac{d\left(\ln(h^2+x^2)\right)}{d(h^2+x^2)} \tag{17}$$

we end up with

$$b(h(x),x) = \frac{\varepsilon/2}{h^2 + x^2} \tag{18}$$

This damping function decreases rapidly with distance but is still sufficient to limit aggregation. Physically, it is consistent with a "foamy" propagation medium where the matrix is lossy and where there is a suitable "long-tailed" distribution of void sizes. Such a propagation environment seems consistent with the interiors of buildings. It also seems consistent with the tangent plane out-of-doors where the role of the lossy matrix is played by vegetation and tree canopies, structures, and terrain relief.

Appendix C – Matlab Code for Figure 4

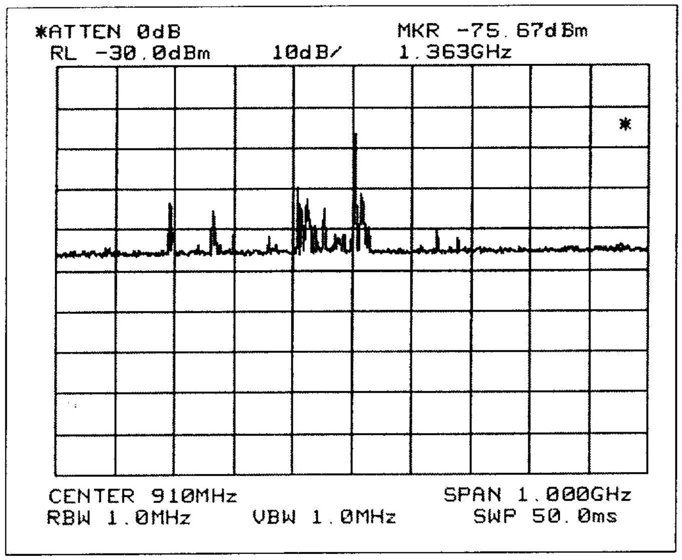
```
for i = 24:-1:1,
   x(i) = exp(0.15*(12-i));
   y(i) = WhiteSky(x(i));
end;
hold off;
plot(x, y, 'b');
hold on;
plot(log(x)/log(10), y, ':r');
xlabel('solid line - Papex/P vs bh        dotted line - Papex/P vs log10(bh)');
print -dbmp256 'C:\WINDOWS\Desktop\WhiteSky.bmp';

function v = WhiteSky(H);

global bh;
if  H > 1/10^8,
   bh=H;
   A=1;
   v = quad8('Integrand', A, 14); % the range of integration must be split
   while A > H/1000,              %   in order to avoid excessive recursion depth
      A=A/8;                      %   errors in quad8
      v = v+quad8('Integrand', A, 8*A);
   end;
   v = v+quad8('Integrand', 0, A);
   v = 2*pi*v;
   % disp(v);
else
   v = 2*pi*(log(1/H)+log(10^-4)+expint(10^-4));
   %    2*pi*(log(10^-4)+expint(10^-4))= -3.6269;
end

function u = Integrand(t)

global bh;
u = t.*exp(-t)./(bh*bh+t.*t);
```

EXHIBIT 4

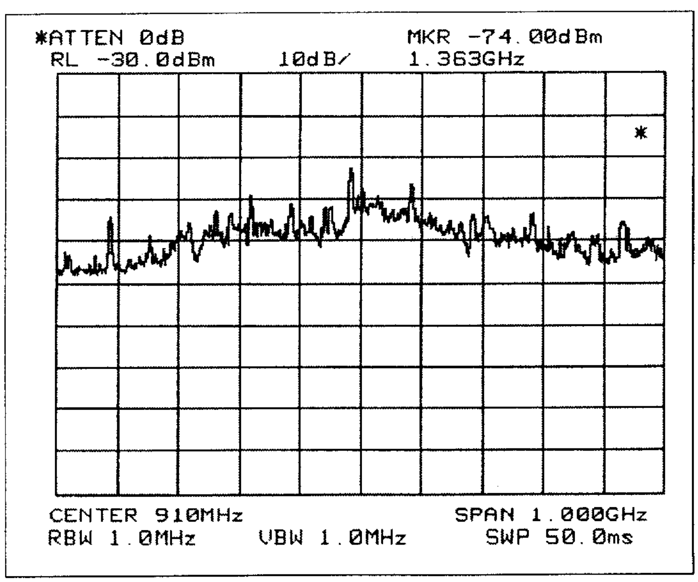
Comparison of Emissions Measurements
On a Pentium and UWB Transmitter

Comparison of Emissions Measurements
on a Pentium and UWB Transmitter

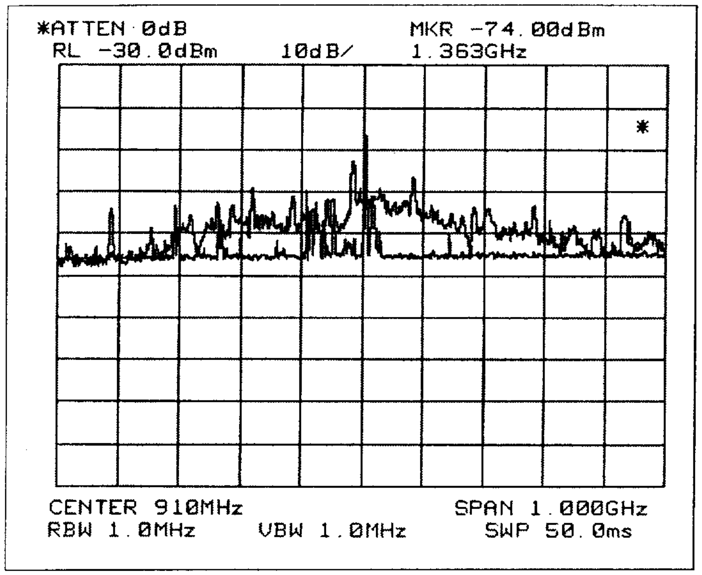
Background noise measured before measuring 450MHz Pentium



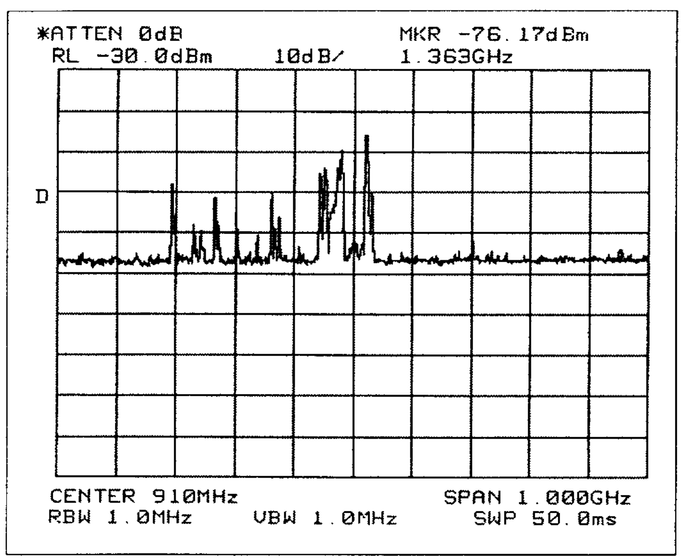
Emissions of 450MHz Pentium



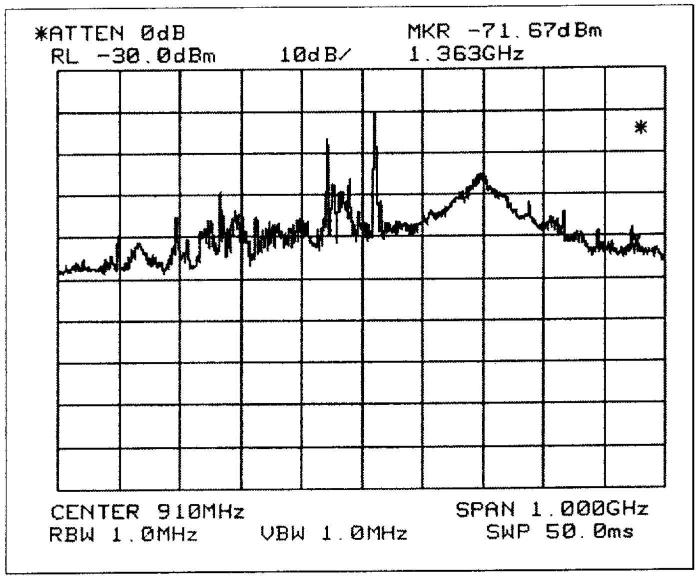
Background noise plus Pentium emissions on same plot.



Background noise measured before measuring UWB transmitter emissions (at different time and location)



Emissions of UWB Transmitter



Background noise plus UWB transmitter emissions on same plot