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DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
STANFORD UNIVERSITY, STANFORD, CALIFORNIA 94305-4035
http://aa.stanford.edu/

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WILLIAM F. DURAND BUILDING

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FCC MAIL ROOM

TELEPHONE (650) 723-3317

Phone: (650) 723 2853
Fax: (650) 725 5517
Email: per@relgyro.stanford.edu

September 2, 1999

Ms. Magalie R. Salas
Secretary
Federal Communications Commission
445 Twelfth Street, SW
Washington D.C. 20554

Re: Consolidated Reply to Oppositions to Petition for Reconsideration of Dockets DA 98-221, 222, and 924.

Dear Ms. Salas,

While we no longer choose to contest these limited waivers, we urge the Office of Engineering and Technology and the National Telecommunications and Information Administration to complete a comprehensive evaluation of interference from all sources to GPS before any increases in the number of UWB systems over those permitted by the subject waivers are even contemplated.

More specifically, our continuing concerns with respect to Part 15 and GPS are not based on the misconceptions listed in the responding letter from Mr. Ralph Petroff of Time Domain. Rather they are based on the Technical Analyses that Time Domain provided in their Reply Comments during the Notice of Inquiry process. As they stand, these analyses should not be used to evaluate the general interference potential of UWB technologies to GPS, and they should not form the basis for any more far-reaching policies concerning GPS. At present, they suffer from at least the following shortcomings:

1.) In their Reply to NOI comments, Time Domain describes field measurement of UWB interference to a single GPS receiver. They show that the receiver could only track two satellites when the transmitter was at a range of 4 to 6 feet depending on the polarization of the interfering wave. Two-satellite tracking is not a satisfactory criterion for interference to GPS. Most modern GPS applications track all satellites in view - typically 9 or 10 satellites - and performance may suffer with the loss of the first satellite. This is well illustrated by studies that have uncovered the sensitivity of GPS performance to elevation mask angle. The mask angle is the elevation angle above which satellites are deemed useable. As this angle increases from 5 to 10 degrees, many GPS applications suffer reduced availability. This indicates that the GPS solution is sensitive to the loss of low-lying satellites. These satellites have the weakest signal strength and are most vulnerable to UWB interference.

This sensitivity exists because the number of satellites in view is nothing more than a *necessary* condition for a position fix - it is not a *sufficient* condition. In fact, the number of satellites must be adequate *and* they must be well placed in the sky. In other words, the satellite geometry or placement relative to the user must also be good. Three satellites do not guarantee an accurate position fix in two dimensions nor do four satellites guarantee an accurate three dimensional position fix. Five to six satellites are generally required for accuracy, but even this number must be augmented for safety critical applications. For example, an aircraft approach operation cannot commence unless there is an additional satellite beyond what accuracy requires. This additional satellite guarantees that the approach may be completed even if the satellite hardware fails. In addition, many critical applications use extra satellites to autonomously cross-check the position solution. In general, one extra satellite is needed to detect a fault, and two extra satellites are required to detect and isolate the fault.

In summary, critical GPS applications generally make significant use of all satellites in view, and could suffer with the loss of the first satellite.

2.) In the same Reply to NOI comments, Time Domain, provides an approximate link analysis to corroborate their interference measurements described above. Several of the underlying assumptions are inappropriate. First, the gain of the GPS receive antenna is listed as 0 dBi. However, GPS antennas may only have a gain of –4.5 dBi at 5 degrees, because a gain taper with elevation angle is required to attenuate reflected signals. For the reasons described above, satellites at these low elevation angles are critical to many GPS applications. Second, the tracking C/N0 threshold is given as 26 dB Hz. Higher tracking thresholds must be used for demodulating the safety-critical data from the geostationary satellites used in the FAA's Wide Area Augmentation System (WAAS). Higher thresholds are also appropriate for the breadth of GPS operations that require highly reliable and continuous tracking of the GPS carrier without cycle slips. Third, the analysis does not include possible interference from a second UWB transmitter or the out-of-band-emission from a handset used with the Mobile Satellite Services.

3.) As described above, Time Domain has conducted interference measurements to a single GPS receiver, but they do not provide any information on the pre-correlator bandwidth of the GPS receiver under test. Moreover, they use a UWB device with a repetition rate of 5 MHz. If this repetition rate is large compared to the receiver bandwidth, the interference tests may measure nothing more than whether or not the UWB transmission lines fall inside the receiver pass band.

4.) The negative impact of notch filtering on UWB performance is not adequately understood. Time Domain has cited a 40% loss due to notching. This approximation is based on the fraction of their intended bandwidth that is currently restricted. However, the GPS band only occupies a very small portion of the currently restricted band, and so the impact of GPS notching may be much smaller. The true performance cost of notching on communication of ranging must be carefully investigated. In fact, performance loss due to notching is a function of the notch center frequency, the bandwidth of the notch and the depth of the notch.

5.) The equivalence of UWB interference and interference from a radiator such as a hair dryer or electric razor is not adequately understood. In a single uncontrolled trial, we found that a hair dryer could touch a GPS receiver without interfering with its operation. In contrast, prototype UWB devices operating at the proposed Part 15 levels in the GPS band interfere at tens of feet. The hair dryer may have a very different impact than an intentional UWB radiator, because it may consist of short pulses in the time domain or narrowband spikes in the frequency domain. GPS receivers are very robust to interference pulses provided the pulse rate is slower than 100 KHz and the duty cycle is less than 20 percent. Alternatively if the interference has a fixed power spectral density in a band that is narrow relative to the GPS band, then it will of course have less impact than raising the entire noise floor to that same power spectral density.

6.) Interference under faulted or anomalous conditions must be considered. The analyses of systems used for aircraft landing devote most of their attention to the detection, isolation and removal of system faults. They spend comparatively little time on nominal fault-free operation. GPS interference studies should also identify any faults or abnormal conditions that would cause greater than nominal interference. If these mechanisms are in fact threatening, then appropriate safeguards must be incorporated.

The following general concerns are noted regarding proliferation of many randomly located ultra wideband (UWB) sources of interference:
1.) While one, or even a small number of such UWB interference sources may cause only a small degradation in the noise level of wireless communications receivers, as well as GPS receivers as noted above, large numbers of such UWB interference sources distributed over an area can raise significantly the overall noise level of all receivers in the area. Such a noise level increase will significantly reduce the sensitivity of the receivers and with it wireless communications system range and GPS performance. We observe that such a rise in the overall noise level in the cordless telephone bands has already been reported for a highly populated area.
2.) An UWB interference source that causes a small increase in the noise level of a wireless communications or GPS receiver that is some distance from the source will cause more significant increase in the noise level of the receiver as the distance between source and receiver decreases. With proliferation of UWB sources throughout an area, the

likelihood of at least one UWB interference source being close enough to any particular wireless communications or GPS receiver to cause a significant increase in its noise level increases significantly.

A careful quantitative analysis of the interference effects described above is required to determine the magnitude of the significant effects, and such an effort must be completed before any increase in the number of UWB systems over those permitted by the initial waiver is even contemplated. These studies should be based on careful theory, controlled interference measurements and thoughtful consideration of likely operational scenarios. We invite Time Domain or any other UWB interest to contact Professor Enge directly, so that we can continue this critical technical discussion.

Per Enge is an Associate Professor of Aeronautics and Astronautics at Stanford University, and Co-Director of the GPS Research Program. Bradford Parkinson is the Edward C. Welles Professor of Aeronautics and Astronautics and also Co-Director of the GPS Research Program. He was the original Department of Defense Program Director for GPS. Donald C. Cox is the Harald Trap Friis Professor of Engineering at Stanford University where he conducts research for industry and government agencies on various wireless communications systems topics. He managed and conducted research on wireless systems at Bell Laboratories and at Bellcore before going to Stanford and has consulted for various wireless communications companies.

Sincerely,

Per Enge
Associate Professor

Bradford Parkinson
Professor

Donald Cox
Professor

## CERTIFICATE OF SERVICE

I, Per Enge, do hereby certify that copies of the foregoing "Consolidated Reply to Oppositions to Petition for Reconsideration" were delivered this 3rd day of September, 1999, to the following in the manner indicated:

**VIA FEDEX**

Chairman William E. Kennard
Federal Communications Commission
445 12th Street, S.W.
Room 8-B201
Washington, DC 20554

Commissioner Harold Furchtgott-Roth
Federal Communications Commission
445 12th Street, S.W.
Room 8-A302
Washington, DC 20554

Commissioner Susan Ness
Federal Communications Commission
445 12th Street, S.W.
Room 8-B115
Washington, DC 20554

Commissioner Gloria Tristani
Federal Communications Commission
445 12th Street, S.W.
Room 8-C302
Washington, DC 20554

Commissioner Michael Powell
Federal Communications Commission
445 12th Street, S.W.
Room 8-A204
Washington, DC 20554

Dale Hatfield
Chief, Office of Engineering and Technology
Federal Communications Commission
445 12th Street, S.W.
Room 7-C155
Washington, DC 20554

Don Abelson
International Bureau
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Tom Tycz
International Bureau
Federal Communications Commission
445 12th Street, S.W.
Room 6-A665
Washington, DC 20554

Ron Repasi
International Bureau
Federal Communications Commission
445 12th Street, S.W.
Room 6-A505
Washington, DC 20554

Alex Roytblat
International Bureau
Federal Communications Commission
445 12th Street, S.W.
Room 6-A623
Washington, DC 20554

**VIA FIRST-CLASS UNITED STATES MAIL, POSTAGE PREPAID**

Lawrence Irving
U.S. Department of Commerce
National Telecommunications and Information Administration
1401 Constitution Ave., N.W.
Room 4898
Washington, DC 20230

William Hatch
U.S. Department of Commerce
National Telecommunications and Information Administration
1401 Constitution Ave., N.W.
Room 4099
Washington, DC 20230

Jim Vorhies
U.S. Department of Commerce
National Telecommunications and Information Administration
1401 Constitution Ave., N.W.
Room 4076
Washington, DC 20230

David Anderson
U.S. Department of Commerce
National Telecommunications and Information Administration
1401 Constitution Ave., N.W.
Room 6725
Washington, DC 20230

David E. Hilliard, Esq.
Wiley, Rein & Fielding
1776 K Street, N.W.
Washington, DC 20006

Terry G. Mahn, Esq.
Fish & Richardson P.C.
601 13th Street, N.W.
Washington, DC 20005

Ronald C. LaBarca
President
U.S. Radar
P.O. Box 319
Matawan, N.J. 07747

Gerry Markey
Office of Spectrum Policy Management
Federal Aviation Administration
800 Independence Avenue, SW
#ASR1, Room 715
Washington, DC 20591

Sally Frodge
Office of Assistant Secretary for Transportation Policy
Department of Transportation
400 7th Avenue, SW
Room 10309
Washington, DC 20590-0003

Per Enge