> Question from Bob Lucky
Responses from Bob Scholtz
Appendices contain comments from others, as indicated.

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>1. Does it work? Let me rephrase the question. What would stop it from working?
> For example, some people have said multipath.

Of course it works! There are early prototypes and UWB systems at several companies including Time Domain, Aether Wire and Location, Multispectral Solutions, etc. WWW links to these companies can be found on my lab's web page http://ultra.usc.edu/ulab/.

Multipath is not an issue with UWB radios in most situations, but on occasion it is. (See comments from Bob Fontana below). Time resolution is inversely proportional to bandwidth. One GHz of bandwidth gives rough a nanosecond of resolution, and that corresponds to the ability to resolve multipaths with roughly a foot of differential path length. In a dense indoor multipath environment, you can observe a hundred or more distinct paths and listen to them separately, then time-diversity combine some number of them in a Rake receiver.

>2. Does it scale? OK, so a few users aren't noticed, but what happens when millions
>want to do this?

There are some analyses that address this problem. I believe that Roberto Aiello at Interval Research Corporation mentioned an analysis that they performed which indicated that when propagation effects, attenuation, etc., are considered, it is generally the few UWB radiators closest to the victim receiver that provide the lion's share of the interference. The fact that there are thousands of other UWB radiators "out there" makes little difference. (See the comments of Paul Withington attached later in this response for more on this.)

The UWB overlay of a broad portion of the frequency spectrum must deal with a geometry that is variable (i.e., a complicated near-far problem), and with a large variety of systems sharing the spectrum. Can a UWB transmitter operating in a band from 1 to 3 GHz interfere with a GPS receiver? No one can say for sure without specifying a distance (allowable interference level in the victim receiver). This is a power game. The UWB system has to be designed to have its PSD as flat as possible using spread-spectrum techniques. The antenna has to be well designed (the antenna is one of the primary spectral- and pulse-shaping entities of a UWB system). With this then, the question becomes one of intrusion. How close to a GPS receiver (at what incident power density level on the victim receiver’s antenna) will the FCC permit a UWB device to operate? With this information and with good design, it is then possible to estimate a bound on the radiated power density of a compliant UWB radio.

Another possible approach is to say that the UWB transmitter cannot raise the equivalent noise level in the victim receiver by more than a fraction of a dB; but this is probably the wrong way to approach a specification because as receivers improve their thermal noise properties, a UWB transmitter that was compliant, may become non-compliant. Perhaps a viable approach is to allow UWB radiation at or below allowed spurious interference levels, i.e., make no distinction between spurious and intentional forms of radiation.

>3. Is it feasible to chop out forbidden bands? So the FAA doesn't want this stuff in
>their band, does it matter if we chop out this band, then another, etc.

I doubt that this is a viable approach because there are a lot of these forbidden bands, and they are not adjacent to each other. I suspect that costs would be prohibitive. If we are talking about reasonably large markets that would support the development of this technology, then we are probably talking about relatively low-cost transceivers. Building high-Q filters to do this chopping on chip is very difficult technically. (There are more comments from others below)

>4. If you were the FCC, how would you allow this to go forward, while protecting the
> interests of legacy spectrum holders?

I believe that the technology merits further exploration. I would pick one of the most sensitive bands, e.g., the GPS L1 and L2 carrier bands, and do an experiment to determine at what power spectral levels and distances the UWB radio begins to significantly affect the GPS performance. I think that it is reasonable to allow UWB trials at some reasonable fraction of this power density level. I don't know how to compensate the licensees of these bands for incidental use by the UWB radios.

It is worth noting that the UWB radios that I am familiar feed their transmit antennas with a power density that is on the order of a few microwatts of average power per megahertz of bandwidth. I believe that these levels of power density can be used in a variety of situations and environments without causing significant interference to others. (More comments in attachments)

>5. In your opinion, what is really good about ultra-wideband? (For example, to me the
>most important feature is that it uses the under-utilized portions of the spectrum.)

I view UWB radio as a potential solution to a variety of short-range (low power density) problems. Are there killer applications that only this radio can solve? Possibly:

Ranging down to a few inches or less (that reciprocal bandwidth relation again) possibly through walls, foliage, etc., should be routinely possible. There are some interesting propagation and ranging algorithm questions here.

Imaging through materials. Usually propagation through materials requires low frequencies, and imaging quality is proportional to bandwidth. You can only get both of these qualities optimally if the bandwidth to center frequency ratio is high. One accepted definition of UWB is that this ratio is at least 0.25.

Resolution of indoor multipath to mitigate fading and reduce fading margins in link budgets. This is a performance quality payoff.

>6. Any other opinions or advice would be appreciated.

There are a variety of possible applications that people are concentrating on.

Ground penetrating radar for land mine detection, etc. I believe that these are below 100 MHz. Don't know the details of their bandwidth, but would expect that their power levels a high, but aimed into the ground.

Position location within buildings. Aether Wire and Location is working in the range of roughly 100MHz to 1 GHz, with low power.

Communication, intrusion detection, etc.. Time Domain is working in the range of 1-3 GHz right now.

Communication systems (government only) by Multi Spectral Solutions. See comments by Bob Fontana below.

Stud (the kind in walls) finding is being explored by Zircon. Chuck Heger from Zircon has added some comments below.

As these systems go up in frequency, they lose their material penetrating capabilities, and possibly some of the rationale for their existence.

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Further comments from Paul Withington (paul.withington@tdsi.com) of Time Domain Corporation:

With regard to scalability and the fact that the few UWB radiators closest to the victim receiver that provide the lion's share of the interference:

Simulations and analyses of the cumulative impacts were also condu
Little, Time Domain, and XtremeSpectrum. All came to the same conclusion.

Moreover:

- UWB emissions resemble the emissions from digital devices, e.g., televisions, and answering machines. Two of the current requests approvals of UWB devices are at the same power levels allowed fr devices.
- Currently, spurious emissions from narrowband emitters are allow significant power well outside of their assigned operating bands
- Emissions from things like RF light bulbs, electric shavers, ele other devices with brush motors, can have significant emissions

With regard to eliminating transmissions in restricted bands:

The impact on UWB system performance would be highly undesirable as it would destroy the critical properties of a UWB signal. Filtering would effectively reduce signal bandwidth, thereby reducing processing gain. This in turn reduces multipath robustness and complicates the acquisition and synchronization process. A concomitant impact would then be that the radio ranging performance of UWB systems would then be sacrificed (some existing UWB system demonstrate sub-centimeter range measurements, this would be impossible if the waveform were distorted by filtering). Similarly, filtering a UWB radar signal would also decrease radar resolution.

If you were the FCC, how would you allow this to go forward, while protecting the interests of legacy spectrum holders?

Any test of UWB emission should be compared with common devices al use, e.g., workstations, personal computers, cell phones, Iridium phones, brush motor devices, etc. These devices are already emitting into the op legacy systems and, of course, some legacy systems put significant operating bands of other systems.

In your opinion, what is really good about ultra-wideband? (For example, to me the most important feature is that it uses the under-utilized portions of the spectrum.)

The Integrated Media Systems Center here at USC is working on appl would greatly benefit from a communications system that allowed fo performance in-building communications and precision location. The appear to be any alternative technical approach to delivering this than UWB.

Any other opinions or advice would be appreciated.

It would be advisable to go and visit some of the UWB companies to hardware, review UWB technology, and understand the issues from th perspective.

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Further comments from Bob Fontana (rfontana@multispectral.com) of Multispectral Solutions:

Multispectral Solutions, Inc. (MSSI) has been actively involved with UWB technology development since its inception in 1989; and I have personally been involved with UWB systems since 1984 when I first met Dr. Gerry Ross, one of the early pioneers in this field. (Gerry got his Ph.D. in 1962 from A. Papoulis in the field of time domain electromagnetics and was actively involved with UWB development while at Sperry Research in the early 1970's.) Gerry and I put together one of the first UWB communications systems for the U.S. Government back in 1986. Since 1986, all of our UWB systems have been designed either for the U.S. military or for non-DoD Government agencies.

I'd like to answer the four questions that you raised to Dr. Scholtz:

1. *Does it work? Let me rephrase the question. What would stop it from working? For example, some people have said multipath.*

   The fact that UWB can be made to work is backed by solid evidence. For example, MSSI has received approximately 27 contracts over the last 10 years to design, construct and field UWB systems for such diverse applications as LPI/D communications, precision altimetry, precision geolocation, collision and obstacle avoidance, RF tagging, radar fuzing, intrusion sensing and others. (Please see our Web site at http://www.multispectral.com for some additional details.)

   What can stop it from working is more subtle and, of course, strongly depends upon how the system is implemented. For example, some vendors have proposed "coherent" addition of hundreds to thousands of pulses to derive a single bit of information. These systems have been plagued by poor performance with relative platform motion. The same vendors have implemented pulse position modulation schemes with very small differential time offsets. These PPM systems have failed with both platform motion and multipath. In the latter case, we are aware of one system which could not communicate from a helicopter because of reflections off of the helicopter blades. In our systems, we utilize single pulse detection utilizing the integrating properties of a tunnel diode, obviating some of these problems.

   Dr. Scholtz suggested that "multipath is not an issue with UWB radios." It is our experience that this is not always the case. For example, in communications between two platforms whose antennas are close to the ground (e.g., handheld radios, boat-to-boat communications, etc.), the differential path time difference between the direct and reflected waves can be extremely small. A one kilometer path between two antennas which are each 2 meters off the ground has a time differential of only 27 picoseconds between the direct and single-bounce returns. This is typically much smaller than the pulsewidth of most practically implemented UWB systems. Such scenarios result in the all too familiar R^4 propagation loss model. We have developed UWB systems at lower operational frequencies (below 100 MHz) to take advantage of surface or ground wave propagation for extended range.

   Also, in-building propagation is plagued by numerous reflections from walls, equipment, file cabinets, etc. These "reverberations" often last hundreds of nanoseconds beyond the original pulse. This limits the maximum achievable data rate for such systems. Data rates of up to about 10 Mb/s have been achieved by MSSI in this severe multipath environment. Note, however, that this is significantly better than that achieved with competing (i.e., existing) spread spectrum technologies.

Another problem which can plague an improperly designed UWB system is signal deterioration due to in-band interferers. Thus, while the low energy densities of most UWB radios makes them difficult to intercept, and thus difficult to cause interference; the wide receiver bandwidths result in increased susceptibility to noise and interference from other services. We have addressed these problems with noise and interference tracking receivers which enable reception even in the presence of a large number of in-band signals.

2. *Does it scale? OK, so a few users aren't noticed, but what happens when millions want to do this?*

   Again, this is a function of the UWB system design. For those systems which need to transmit multiple symbols per bit, interference to other services can be a serious issue. It is often claimed that, because of the short pulse duration, one can design "time-orthogonal" codes which would permit thousands of simultaneous users. Unfortunately, while theoretically interesting, in realistic environments the platforms may be moving, there may be significant reverberation effects from multipath, etc., all of which can negate these orthogonality arguments. While we are obviously proponents of UWB systems, we would approach this issue cautiously when it comes to unlicensed operation. While a single UWB pulse may not be much of a concern, the manner in which these pulses are used to communicate information differs dramatically and can often lead to systems which can indeed interfere with existing services.

3. *Is it feasible to chop out forbidden bands? So the FAA doesn't want this stuff in their band, does it matter if we chop out this band, then another, etc.*

   The earliest UWB systems (1960's and 1970's) utilized fast risetime, high voltage waveforms (e.g., Marx generators) to directly excite a microwave diode located within a cavity or connected across the terminals of a wideband antenna. Such systems, while inexpensive, were extremely difficult to spectrally control. Unfortunately, many current system implementations have not progressed much further than these earlier system designs, still utilizing direct impulse excitation of an antenna. Ironically, many of these systems provide filtering on *receive* to eliminate potential in-band emitters.

   For the last 5 years or so, all MSSI UWB systems have utilized spectrally filtered pulse waveforms. Systems have included 30-50 MHz radios for ground and surface wave propagation (50% fractional bandwidth), 500 MHz bandwidth L-band systems for LPI/D radios (33% fractional bandwidth) and 500 MHz bandwidth C-band radars for collision and obstacle avoidance (10% fractional bandwidth), to name just a few. Note that many have been hung up on the 1990 DARPA definition of UWB as having 25% or larger fractional bandwidth.[1] We prefer the definition of UWB (at least for communications) as any waveform which has a large excess bandwidth over that required by Shannon theory. That is, UWB is essentially a modulation in which the instantaneous bandwidth is many times greater than the information bandwidth. Thus, a 500 MHz waveform at a center frequency of 1000 MHz, has similar (time-domain) properties to a 500 MHz bandwidth waveform centered at 10 GHz, even though the fractional bandwidth of the latter falls far short of the DARPA minimum.

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[1] Assessment of Ultra-Wideband (UWB) Technology, Report R-6280, prepared by OSD/DARPA UWB Radar Review Panel, July 13, 1990.

4. *If you were the FCC, how would you allow this to go forward, while protecting the interests of legacy spectrum holders?*
   Our recommendations were summarized in our recent response to the FCC's Notice of Inquiry ET 98-153, which we have extracted below:

   MSSI also wishes to suggest the following rule change for UWB emissions within the U-NII bands. Currently, the U-NII allocation is divided into three 100 MHz regions, only two of which are continuous (5.150 to 5.250 GHz and 5.250 to 5.350 GHz).

   We recommend that the 200 MHz (contiguous) span from 5.150 to 5.350 GHz be allowed for filtered UWB emissions, i.e., Bandlimited Short Pulse emissions, with out of band constraints below 5.150 GHz and above 5.350 GHz as currently specified. We also recommend that a peak power output of 1W be allocated for UWB emissions in this 200 MHz segment, with directional antenna gains of up to +6 dBi. As in the current allocation, peak output power will be reduced on a dB for dB basis for any antenna gain exceeding +6 dBi. In addition, we recommend that any decrease in instantaneous bandwidth below 200 MHz result in a dB for dB reduction in peak output power. (Thus, for example, a 100 MHz UWB emission would only be permitted a peak power output of 0.5 W, etc.)

   We feel that the U-NII band is currently an ideal location for UWB experimentation since its creation was designed specifically to encourage emerging technologies for high-speed wireless access. This would represent a first step in assessing the viability of UWB systems for unlicensed commercial utilization.

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Further comments from Chuck Heger (chuck@zircon.com) at Zircon:

To further clarify Zircon's UWB efforts, we are attempting to develop a 3-D imaging system capable of 'looking' into walls, floors, cement slabs and the like to map out the interior structural and embedded elements such as studs, wires, pipe (including plastic), rebar, etc. This will be mainly for the building and remodeling trades. I'm shooting for a resolution of 1/4". Results so far are very encouraging.

My pulse width is about 100pS with a peak power to the antenna of around 250mW. This is spread over about 2GHz for a PSD of 125 picowatts per megahertz.
I am purposely pseudo random spreading the 5MHz PRF with a 9 bit maximal length sequence so as to reduce the PRF 'bright lines'. This works very well and is completely repeatable.

Our current concerns are with the definition, measurement and specs of the radiated emissions. As you probably know, the NTIA has finally published their letter to the FCC with 'recommendations' as to permitted power and test procedures with regard to the waiver applicants.

I believe the testing procedures to be faulty and incomplete and have been struggling to both understand and develop meaningful methods. I have been to EMI test ranges three times recently. A large problem is simply the lexicon. The type of spectral emissions of UWB are just so different than more 'conventional' systems that trying to talk to EMI engineers just results in frustration on both sides.

As an example of a typical 'rat hole' we have gone down, consider why the signal level or background level on an analyzer changes when the video (not IF) bandwidth is changed from 1MHz to 10kHz. (The IF bandwidth was held constant at 1MHz.) The change is about 10dB. If the input were Gaussian noise there should be no change as the video filter is post-detection and the detector has 'integrated' the power from the IF. However, it does change. We think that this is due to the 1/f noise of the front end of the measurement system. As the video filter is reduced, less high frequency energy is passed. Since the typical 1/f curve has a continuously changing slope, the amount of detected spectral baseband energy passed changes non-linearly.

The reason for this concern is that the FCC tested several of our transmitters using a 1MHz resolution (IF) bandwidth and a 10 kHz video (avg) bandwidth. The NTIA only stated that the 'average' was to be measured in '1MHz'. The results are quite different depending upon the procedure and the NTIA has set a 'spec' that is right at the level measured by the FCC with no margin. I thought I was an engineer, not a politician!