Response to FCC 00-163 Notice of Proposed Rule Making of Part 15 of the Commission's Rules regarding Ultra Wide Band Systems. ET Docket 98-153

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Summary
The proposed modified part 15 will enable the use of a number interesting devices but a number of details has to be investigated in order to avoid undesired influence on existing devices either they are licensed (mobile phones etc) or not (GPS etc.). Below are the answers from Saab Marine Electronics AB (SME) to the questions in FCC 00-163 and especially comments on frequency range, signal shape and proposed UWB definition. One comment (dated Dec 4 98) and one reply comment (dated Jan 6 99) has been earlier filed from SME as a response to FCC 98-153 and among other the conditions for microwave level gauging were treated there.

From the answers discussed in 00-163 it is recognized that UWB devices are likely to form a huge market with a wide-spread use (several per home plus mobile and industrial applications). The considerations for limits etc. should be accordingly and it seems likely that applications with special requirements on frequency and power (GPR and similar used in small numbers) may have to be regulated differently. A general note is that the limitations preferable should focus on the possible victims rather than the UWB devices aiming at general limits which will persist while new electronic units are developed. In order to minimize disturbances the typical property of a UWB unit can be said to be that its signals will appear like noise in the victim receiver. Low power levels will be one general trend with the thermal noise as the physical lower limit. Conclusions from good experience by present part 15 limits should be treated with a certain caution as the number of small electronic units, their clock frequencies etc. will increase strongly. Experiences from the past may thus have limited relevance. Interference is most likely caused by the closest UWB unit so widespread victim devices are most vulnerable (GPS, mobile phones/terminals, radio sets and TV sets) as small distances will be common. Looking in homes, cars etc. it seems like 3 m distance could be a compromise example for "most close" but even 1 m as "typical minimum distance" can be suggested. 10 m distance mentioned in 00-163 (point 32) may be too big in typical future environments. This distance limit applies especially to the rather high amplitudes typical for pulsed UWB units. Consequences of the un-linear behavior caused by high pulse amplitudes seems to have been underestimated by many earlier papers. Partly this seems to be related to the general narrowband approach in present part 15 rules which need to be modified for future equipment where victim receivers as well as the units under part 15 may use a wide band.

Below frequency range, pulse amplitude and UWB definition are discussed and in the last part the specific questions formulated in FCC 00-163 are answered.

Frequency range
Among possible victims for radiated emission the GPS close to 1.6 GHz has been identified as especially critical as a received noise-like signal even slightly above the thermal noise will decrease or inhibit GPS function. Present part 15 limits at 3 m distance are around 25 dB over the thermal noise for a 1 MHz wide signal at 1.6 GHz. Mobile phones and other mobile

terminals are other applications where the user may suffer from an increased background noise level in case of using the unit at places with poor coverage where signals having a spectral density comparable to thermal noise are received. This is especially true for the third generation units (W-CDMA, UMTS etc) using wider bandwidth at higher frequencies than the present PCS band. Existing plans cover frequencies up to 2.3 GHz, but for future use even frequencies in the range 2.5-3 GHz have been discussed. The lower limit 2 GHz discussed in 00-163 thus has to be looked on carefully. Consideration of all facts might lead to a higher value within the range 2.5-3 GHz rather than 2 GHz for this limit. This in turns should imply that some equipment limited by physical properties (like GPR where low frequencies but high powers must be used) have to be formulated separately. Many potential UWB applications are low cost devices used in large numbers (typically several per home) and without advanced filtering the typical pulse device will have a wide bandwidth with a slow roll-off. To avoid disturbance of the critical 1.6 GHz band the centre frequency of the UWB unit has to be considerable above 2 GHz or the used power has to be very low. Another consequence is that UWB signals emanating from a short “DC pulse” (i.e. including a low frequency spectrum) seems difficult to use in large scale without disturbing GPS or broadcasting services.

Pulse amplitudes etc

If a pulse is received there might occur a saturation in the victim receiver fairly independent of the intended frequency ranges of the transmitter and the victim. Some devices use input filtering to avoid this but many low cost devices save the filtering to a later stage in the signal processing. A typical amplifier using 50 ohm input will have a saturation level around 0.1 mW but for low power devices lower saturation levels can be noted. This may also be expressed as a few tenths of a volt over the semiconductors. An everyday example of this un-linear disturbance is a TDMA mobile phone making a humming sound in a radio set or even a pure audio set operating a frequency far away from the mobile phone. If the transmitter and the victim unit are sufficiently close disturbance will occur anyway. Thus a “typical minimum distance” should be assumed for such estimations and 3 m or 1 m can be suggested for wide spread devices.

For a wireless transmission between units using low gain antennas the transmission is given by $G_1G_2(\lambda/4\pi r)^2$ and at 2 GHz the transmission loss at 3 m and 1 m is around 45 and 35 dB respectively. This suggest a maximum wideband output power in the order of 0.1W regardless of the pulse length. Due to the un-linear nature of the interference the saturation may cause disturbance even by very short pulses not the least in new digital systems where a 1 ns pulse is rather long. The maximum pulse amplitude appears to be a more direct expression of possible disturbances than the peak to average quotient.

Definitions and levels

UWB is suggested to be defined as systems having a bandwidth of at least 25% or 1.5 GHz. The bandwidth is originally defined as –20 dB which for practical reasons is suggested to be changed to –10 dB. With regard to the slow roll-off of at least the low-cost type of UWB devices it can be considered to change the bandwidth (@-10 dB) to something like 17% (1/6) or 1 GHz to correspond to 25%/1.5 GHz (@-20 dB). This difference between –10 dB and –20 dB should correspond to a 3-4 resonator filter/antenna which is probably sharper than a really low-cost device would use. If the signal for comparison is thought to be generated by filtered white noise the quotient between –20 dB bandwidth and –10 dB bandwidth would be 3.3, 1.8, 1.5 and 1.34 for a maximum flat filter having 1, 2, 3 and 4 poles (resonant circuits) respectively. Typical for the part 15 use of a UWB is a low power level which simplified can be formulated as “low enough to avoid disturbances” even if intentional radiation occurs within frequency bands used by others. As seen from the potential victim receiver there are two power limitations:

> Average power over the bandwidth used by the potential victim acting an increased background noise level. This can be compared to the thermal noise and thermal noise can be used as a guideline for spectral power density. The average power is also the most typical measure to give the sensitivity performance both for radars and transmission equipment. The suggested increase from 1 MHz to 50 MHz is a good and practical idea for an adoption to modern wideband equipment. The present part 15 formulation is too much focused on narrow band receivers.
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> Peak power over the full spectrum is a measure of the possibility to generate disturbances through un-linear effects. It should be noted that even a fairly narrowband receiver may have a wide-band input amplifier making it more vulnerable for peak powers high enough to cause saturation is some stage. With regard to the function the peak power is generally more typical for possible problems than the quotient between peak and average power. A wide band peak power limit of 0.01-0.1 W is suggested. Peak power in terms of watt does not conflict with the rules expression in terms of peak-power as compared to average power depending on bandwidth with suitable numerical values. 0.5 mV/m at 3 m can be seen as 75 nW EIRP which is 60 dB below 0.075 W.

The concept UWB in the context of part 15 is by SME suggested to be formulated broadly to include various signal shapes appearing like noise in the victim receiver. It must be recalled that if various signal shapes having the same average power are compared a low peak to average power quotient will never be a disadvantage in terms of possible disturbances. On the contrary a low peak power will decrease the possibility to generate uncontrollable un-linear phenomena. A criteria based on the average measurements over 50 MHz (incl. lower bandwidths if appropriate) and peak measurements over the whole spectrum should be possible to formulate to give a safe power limitation regardless of the exact UWB waveform and the nature of the receiver. Many units will use ultra short pulses but as an example a pseudo-random white (or filtered below 2 GHz) noise would probably be the most safe signal shape in terms of potential generated disturbances as it would virtually disappear at such distances where it is below the surrounding thermal noise. In a non-exact way a “smearing out” of the signal in both time and frequency domain should be advantageous to avoid interference. In this context the counterpart to a jittering PRF is adding a FM noise to a fixed frequency. This is also discussed under the point 21 below.

One limitation in the formulation “x V/m at y m distance” is that it does not reflect the thermal noise conditions in a wide-band sense. The thermal radiation will according to Planck’s law be frequency dependent and thus the measure “V per meter” should be replaced by “volt per wavelength” (with suitable scaling!) which is the case in the limiting figures used in the US military standard MIL-STD-461C. One consequence of this is that the present limit can be seen as too high at low frequencies (where they allow severe disturbance of GPS systems) while it can be seen as unnecessary strict at high frequencies (where the present part 15 limits are below the thermal noise within for example the ISM-band around 24.5 GHz).

Questions related to FCC 00-163 where comments etc are asked for:

Point 7 on page 4: GPS and other sensitive and wide spread units would doubtless experience an increased noise level if strong UWB units got a widespread use. Several calculations in the earlier answers give good hints on how to set the limits to make the increase acceptable. It seems like the closest UWB unit would be the most critical so for calculation purposes a lower distance limit (3 m or 1 m?) can be used. Especially for GPS but also for mobile phones a lower frequency limit should be set under which more limitations apply. With a noise transmitter (1 MHz wide) giving the present part 15 limits (0.5 mV/m at 3 m) a GPS receiver 3 m from the transmitter would experience 25 dB increase in input noise (and stop working).

Point 19 on page 8: Small power level is a good combination with UWB for the adoption to part 15. Historical there has been a steady decrease of power levels in various electronic devices and that will continue with the thermal noise as the ultimate limit. UWB at low average power levels should be compared to thermal noise to fix limits which will persist. Those properties of a UWB signal deviating from thermal noise are necessary to limit so they will not cause practical problems for other users. Many proposed UWB units are low-cost devices where for instance advanced filtering is not feasible. A low power will then be the only way to limit spectral density far outside the main band.

Point 21 on page 9-10: Definitions for UWB. The general “at least 25%/1.5 GHz” is OK but the proposed change of limit from –20 dB to –10 dB implies two questions marks. First the consistency (between –10 and –20 dB) requires a certain decrease of the numerical bandwidth. If the signal for comparison is thought to be created by filtered white noise the quotient between –20 dB bandwidth and –10 dB bandwidth would be 3.3, 1.8, 1.5 and 1.34 for a maximum flat filter having 1, 2, 3 and 4 poles (resonant circuits). A reduction to 17%/1 GHz would be consistent with the three pole filter (incl. antenna) which probably is more complicated than most simple units would use. Second –10 dB is a fairly low figure in case of higher power devices in combination with a slow roll-off outside of –10 dB. Obviously it will be necessary to include the antenna when system parameters are measured as it is likely to be an important part of the band limitation.

Concerning the signal shape it should be stressed that the nice thing with UWB in connection with part 15 is that the signal under certain conditions appears like noise for a narrow band victim receiver. If the noise is weak enough it will be an acceptable decrease of the sensitivity and it is simple to decide when the influence can be neglected. For a wide band receiver it may be different as actual time dependence will be more important. For future electronics bandwidths and the spectrum congestion will increase. Signals appearing like noise will still be acceptable if sufficiently weak but it is the noise like appearance and not the pulse shape which does the trick. It is thus strongly urged that the definition should be based on bandwidth and measured important parameters (spectral density, peak power etc.) and not on construction details which may be easy to identify but which are without importance for the final result. Various kinds of noise-like modulations can be thought of but of course only those fulfilling the final formulation of test requirements can be used. Tests should be done with the unit in normal conditions (within all possible tolerances and settings). In the present rules there is for instance a point §15.31(c) (concerning frequency sweep) which seems to be adopted to old type of equipment both concerning the DUT (device under test) and test instrumentation. For modified rules test instruments capable of revealing possible undesired behavior without artificial modification of the DUT can be supposed to be used. Typical for the UWB can be said to be its appearance like noise in both wide and narrow band receivers. One obvious advantage with signals created by some kind of noise modulation rather than pulses is that the spectrum occupancy will be much more well defined even if sharp output filters should not be used. Especially for units operating at “low” frequencies (where 1.6 GHz is not to far away) a pulsed UWB signal will have big spill-over unless extra output filtering is used. Another advantage with a lower peak to average ratio is that the possibilities for un-linear disturbance in receivers with a wide band front end (without necessarily being a wide band system) will be less.

Point 25 at page 12: GPR units have to operate at low frequencies and at high powers where disturbance on broadcasting, GPS and mobile phone systems is likely if special protection is not applied. It seems like special rules should apply here due to the few numbers, special more or less professional use and the possibility to take some extra costs for protection means. It seems difficult to make GPRs and low-cost mass-produced units to fit into the same rules.

Point 27-28 on page 13: Among possible victims for radiated emission the GPS close to 1.6 GHz has been identified as especially critical as even a received noise-like signal slightly above the thermal noise will decrease or inhibit GPS function. Present part 15 limits at 3 m are around 25 dB over the thermal noise for 1.6 GHz for a 1 MHz wide signal. Mobile phones and other mobile terminals are other applications where the user may suffer from an increased background noise level in case of using the unit at places with poor coverage where signals comparable to thermal noise are received. This is especially true for the third generation units (W-CDMA, UMTS etc) using wider bandwidth at higher frequencies than the present PCS band. Existing plans cover frequencies up to 2.3 GHz, but for future use even frequencies in the range 2.5-3 GHz have been discussed. The lower limit 2 GHz discussed in 00-163 thus has to be looked on carefully. Consideration of all facts might lead to a higher value within the range 2.5-3 GHz rather than 2 GHz. This in turns should imply that some equipment limited by physical properties (like GPR) have to be formulated separately. Many potential UWB applications are low cost devices used in large numbers (typically several per home etc.) and without advanced filtering the typical pulse device will have a wide bandwidth with a slow roll-off. To avoid disturbance of the critical 1.6 GHz band the centre frequency has to be considerable above 2 GHz or the used power has to be very low. Another consequence is that UWB signals emanating from a short DC pulse seems very difficult to use without disturbing GPS or broadcasting services.

Point 29-30 on page 13-14. Due to future telephone system (W-CTDA, UMTS etc) the limit “2 GHz” will probably have to be a bit higher. With thermal noise as the guideline there may be some spillover below 2 GHz if the power in limited accordingly. Connected with the definition of UWB some kind of systems may be better than other to suppress out of band radiation. Examples are good output filters or a UWB signal generated by some kind of noisy modulation.

Point 33 on page 14-15: Comment on possible disturbances in victim receivers. High peak powers will be one source of disturbance and concentrated parts of the spectrum is another. Sufficient “smoothing out” both in time and frequency domain is probably the best case. For the function (communication etc) the average power generally is the most important parameter. There can be expected to be a general change towards more wide-band systems. Present experience using 1 MHz bandwidth may sometimes have underestimated the influence of very short pulses having high amplitude.

Point 36 on page 16: Comment on protecting GPS by UWBs working at low frequencies but using special modulation frequencies etc to keep the spectrum around 1.6 GHz clean. This is a bit complicated but feasible in case of a high-end equipment. However it will not help for the broadcasting and mobile phone systems occupying <2GHz. With the release of the restrictions for the GPS codes the lower GPS frequency (around 1250 MHz) may also be used in large scale.

Point 39 on page 18: The suggested –12 dB decrease of the general limits below 2 GHz are necessary to protect GPS and phones in the 1-2 GHz range. 12 dB may even be too little in the worst bands. With a suitable limitation it seems on the other hand not necessary to do anything special with the restricted bands as long as the connection to thermal noise is regarded.

Point 41-43 on page 19-20. The influence of peak levels is discussed above and seems to have been under-estimated in most comments. There should be a general peak power limitation regardless of pulse length. An everyday experience of peak power influence is the humming sound from TDMA mobile phones on radio or stereo sets.

Point 51-53 on page 23-24. Measuring methods using peak power in a wide bandwidth (50 MHz) and measuring absolute peak power should be adequate together with a measurement of average power.

Point 54 on page 25: Antennas for peak power with nice amplitude and phase performance are not easy to design. Log periodical and various flat or conical helix antennas are used but will probable distort the signal. One improvement may be to measure quite near (1 m?) to increase amplitude in order to allow for more losses to be acceptable to make it possible to widen the bandwidth by intentional losses. Special big horns bit resistive loading at the specially shaped edges have been used for UWB radar systems.

Point 55 on page 26: Frequency range may very well be over 10 times the PRF but this must be judged for each case. It will be more depending on what is named PRF than the UWB. Soft UWB pulses or modulation schemes may give bandwidths much less than 1:10. A modified formulating must be applied but anyway a bandwidth estimation for the UWB classification must be dome.

Point 58 on page 27: Frequency stability must ensure the upper and lower limit to be maintained with certain tolerances so again a modified definition should be used.