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ET Docket No. 98-153, First Report and Order
Potential Interference to PCS from UWB Transmitters
Based on Analyses from Qualcomm Incorporated
February 14, 2002

On March 5, 2001, Qualcomm Incorporated ("Qualcomm") submitted a report addressing potential interference from UWB transmission systems to the Personal Communications Services (PCS) operating in accordance with Part 24 of our regulations.[1] Qualcomm presented this information in two formats. The first of these consisted of a mathematical analysis of interference potential. The second involved testing of a simulated PCS system with a simulated UWB emission.

Description of Study

Mathematical Analysis.

Qualcomm assumed several specifications for PCS receivers that it applied, as shown below, to calculate that UWB transmitters must be separated from PCS handheld units by at least 24 meters.[2]

Parameter	Value	Units	Equation
Frequency	1900	MHz	F
KT[3]	-174	dBm/Hz	KT
Victim bandwidth	1.25	MHz	B
Victim noise figure	8	dB	NF
Noise floor	-105	dBm	N = KT + 10 log B + NF
Allowed IX level	-111	dBm	IX = N - 6
UWB EIRP level/1.25 MHz	-40.22[4]	dBm	P = -41.22 + 10 log (1.25)[5]
UWB antenna gain	0	dBi	GT
Victim rcvr. antenna gain	-3	dBi	GR
Victim rcvr. line loss	2	dB	LR
Path loss required	64.78[6]	dB	L = P + GT + GR – LR - IX
Minimum separation	24	m	20 log (d) = L – 20 log (F) - 26.4[7]

1 *See* 47 C.F.R. Part 24

2 Qualcomm's original filing cited a separation distance of 35 meters due to the application of an incorrect formula. Qualcomm corrected this value in its comments of May 10, 2001, at pg. 18.

3 K is Boltzmann's constant of 1.38×10^{-23} W/Hz/°K, and T is the temperature in degrees Kelvin (°K). Using T 90°K, KT = 4.00×10^{-21} and 10 log KT = -204 dBW/Hz = -174 dBm/Hz.

4 The corrected signal level should be –41.25 + 10 log (1.25) = -40.28 dBm.

5 Qualcomm's calculations are based on the 1.25 MHz bandwidth employed with its CDMA signal. The emission limits proposed by the Commission in the *Notice* were based on a 1 MHz reference bandwidth. Changing values from a 1.25 MHz bandwidth to a 1 MHz bandwidth can be accomplished by subtracting 0.97 dB.

6 The corrected path loss requirement is 65.72 dB.

7 In its comments of May 10, 2001, Qualcomm applied a formula of L = 20 log (d) + 20 log (F) + 32.4, stating that this would result in a required separation distance of 24 meters. Solving for (d), this formula becomes 20 log (d) = L – 20 log (F) – 32.4. Applying this formula with L = 64.78 and F = 1900 would have resulted in a calculated separation distance of 0.0022 meters. The formula for calculating free space propagation loss is –10 log

Qualcomm expressd harmful interference to PCS as any level of emission that caused a 1 dB increase to the PCS receiver thermal noise floor. This is equivalent to an interference-to-noise ratio (I/N) of –5.87 dB which Qualcomm rounded off to –6 dB.[8] Thus, Qualcomm calculated that a signal level of –111 dBm constituted harmful interference. This is the "allowed IX level" in the previous table. The proposed UWB emission limit in the PCS band, 500 uV/m/MHz, was converted to an EIRP of –40.22 dBm/1.25 MHz. From this, it could be calculated that a path loss of 65.72 dB is required to reduce the UWB emission to a level of -111 dBm. Applying free space attenuation, a 65.72 dB path loss at 1900 MHz is achieved at 24.3 meters.

Qualcomm used this calculation to graphically display the minimum separation distances required between a UWB transmitter and a PCS receiver based on different receiver noise figures and different levels of increases to the noise floor. Finally, Qualcomm displayed a graph which it claimed indicated the percentage of increased number of base stations that would be required based on degradation to the receiver noise floor.

Laboratory Measurements. Qualcomm conducted a laboratory measurement that demonstrated that a signal-to-interference ratio (S/I) of about 6 dB is required to prevent interference from a UWB transmitter and a PCS receiver.

Qualcomm employed a base station emulator, a PCS handset and a pulse generator module to simulate interference from an UWB system to PCS operation. This interference took the form of an increase in the frame error rate (FER) of full rate frames sent by the emulator and reflected back to the emulator by the handset. The pulse generator was operated with a pulse rise time of 35 pS, a fall time of 50 pS and a duration of 70 pS with a pulse repetition frequency of 1 to 17.5 MHz. Only results at PRFs of 10, 15 and 17.5 MHz were displayed.

PCS systems are designed to work with an average FER of 2 percent.[9] Qualcomm's graph demonstrated that the FER was at 2 percent when the PCS received signal strength was –87 dBm and the UWB emission level was approximately –93 dBm; the PCS received signal strength was –92 dBm and the UWB emission level was approximately –98 dBm; and the PCS received signal strength was –97 dBm and the UWB emission level was approximately –105 to –103 dBm.

Qualcomm concluded by stating that the FCC must not proceed with its rule making proposal until sufficient testing and analysis conclusively prove there will be no interference to PCS phones. It added that the close proximity of UWB devices to wireless phones would degrade their equivalent noise figure

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$[(G_T G_R \lambda^2)/(4\pi d)^2]$ dB. Since the transmitter antenna gain, G_T, is already incorporated by employing the equivalent isotropically radiated power (EIRP) of the UWB transmitter, it may be assigned a value of 1 and subsequently deleted from the formula. Similarly, the antenna gain of the PCS receiver, G_R, was separately incorporated in the calculations in the table and may be deleted from this formula. The wavelength, λ, is equal to the speed of light, $c = 3 \times 10^8$ meters/second, divided by the frequency, $f = 1.9 \times 10^9$ Hz. The remaining symbol, d, is distance in meters. Thus, this formula also may be expressed as $L = 20 \log [(4\pi df)/c)$ dB or as $L = 20 \log (d) + 20 \log (f) - 147.56$ dB. Solving for d, $20 \log (d) = L - 20 \log (f) + 147.56$ dB. If (f) is expressed in MHz, the solution formula becomes 20 log (d in meters) = L – 20 log (F in MHz) + 27.56 dB. Substituting L = 65.72 and F = 1900, d = 24.3 meters.

8 The 1 dB increase to the receiver noise floor is represented by $10 \log [(I + N)/N] = 1$ dB. Thus, $[(I + N)/N] = 1.26$ and $I/N = 0.26$. $10 \log (I/N) = -5.87$ dB.

9 *See* Qualcomm comments of 5/10/01 at pg. 17.

to the extent of rendering their operation useless, especially in marginal coverage areas. Qualcomm also expressed concern about the reception of GPS signals for E911 location information. Potential interference to GPS reception is addressed in the Report and Order.

Public comments

Qualcomm indicated that one meter is a realistic separation distance between a PCS receiver and a UWB transmitter.[10] It added that at 3 meters separation the UWB signal is 17.3 dB above the noise floor of a CDMA handset receiver. According to Qualcomm, no current commercial receiver can withstand this level of degradation.[11]

TDC stated that Qualcomm used unrealistic signal levels, failing to note that a call can not be maintained at –105 dBm, probably even in an anechoic chamber.[12] Sprint stated that the link budget for PCS includes margins for fading, intra- and inter-cell interference, and a receive sensitivity of –105 dBm with the intent of having the handsets operate at this level of sensitivity. It added that Sprint PCS would incur enormous costs if it had to redesign its network to –95 dBm.[13] Sprint also stated that it and other PCS licensees have no obligation to modify their networks to accommodate UWB.[14]

TDC argues that a 1 dB increase in the receiver noise floor does not constitute harmful interference. It adds that this type of interference criteria recently was rejected by the Commission in its *Second Memorandum Opinion and Order* in WT Docket No. 99-168.[15] Qualcomm responded that it is theoretically impossible to negate the effect of a 2.66 dB or higher noise figure degradation. It added that the noise figure is set predominantly by the noise figure of the first low noise amplifier, the insertion loss of the duplexer which is dominated by size and comes from the current density in the cavity walls, and the insertion loss of the receive RF filter. Thus, Qualcomm believes that the Commission's rejection of a 1 dB noise figure degradation applies to base stations, not handsets, because there is no constraint on increasing the size of the base station equipment in order to improve the noise figure.[16]

According to XSI, Qualcomm's analysis makes 3 unrealistic assumptions: the use of free space propagation indoors; the use of emissions limits 12 dB above those proposed in the *Notice*; and the use of an unrealistic interference threshold. It adds that correcting just these assumptions reduces the predicted

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10 *See* Qualcomm comments of 5/10/01 at pg. 10.

11 *See* Qualcomm comments of 5/10/01 at pg. 12.

12 *See* TDC comments of 4/25/01 at pg. 84.

13 *See* Sprint comments of 4/25/01 at pg. 7.

14 *See* Sprint comments of 4/25/01 at pg. 4.

15 *See* TDC comments of 4/25/01 at pg. 80. *See*, also, *Second Memorandum Opinion and Order* in WT Docket No. 99-168, 16 FCC Rcd. 1239 (2001), at para. 6-8.

16 *See* Qualcomm comments of 5/10/01 at pg. 12-13.

IX range to less than 2 meters.[17] XSI adds that a better propagation model indoors shows a 12 dB loss, relative to free space, over a 10 meter range in a typical indoor environment.[18]

FCC Staff Analysis

Mathematical analysis. The staff's primary concern with Qualcomm's analysis, after correction of its calculation on propagation loss, is that Qualcomm based its definition of harmful interference on any emission greater than 6 dB below the thermal noise floor of a PCS receiver. While such an analysis can determine if a signal will increase the receiver noise floor in situations where no RF background noise exists, this is not indicative of harmful interference to a communications system. An interference analysis for a communications system needs to be based on a signal to noise ratio using the signal levels actually employed by that system. As defined in Section 2.1 of our rules, harmful interference is interference that endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radiocommunication service.[19]

As noted by TDC, in the *Second Memorandum Opinion and Order* in WT Docket No. 99-168[20] the Commission rejected the use of increases to the thermal noise floor for determining harmful interference to the 794-806 MHz public safety band. It stated that this type of analysis is unduly pessimistic and that systems are more likely to be designed so that an interfering signal greater than 10 dB above the noise floor would have to exist before disruption to communications would occur. The staff continues to concur with this earlier assessment.

For a radiocommunications service, such as PCS, harmful interference is defined as interference that seriously degrades, obstructs, or repeatedly interrupts.[21] Certainly, we can not see how PCS should be afforded greater interference protection than that provided to the public safety services employed under Part 90 of our rules. Accordingly, the staff sees no basis for protection of PCS receivers from a signal level that increases the thermal noise floor of the receiver by 1 dB, *i.e.*, from an emission that is 6 dB below the PCS receiver thermal noise floor. Further, the staff does not agree with Sprint that its PCS system is designed to work at a thermal noise level of –105 dBm. Such a level provides no margin for fading or from noise from other sources, *e.g.*, harmonic emissions from microwave stations and from television broadcast stations, multipath effects, and noise from other PCS stations.

The staff also disagrees with Qualcomm that the discussion in the above *Second Memorandum Opinion and Order* in WT Docket No. 99-168 is limited to base stations. Qualcomm appears to be under the

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17 *See* XSI comments of 4/25/01 at pg. 2.

18 XSI, in its comments of 4/25/01, at pg. 2-3, cites an IEEE paper containing a propagation model that has 12 dB of additional path loss, relative to free space, over a 10 meter range in a typical indoor environment. *See* Robert J. C. Bultitude, Samy Mahoud and William Sulivan, "A Comparison of Indoor Radio Propagation Characteristics at 910 MHz and 1.75 GHz," IEEE Journal on Selected Areas in Communications, Vol. 7, No. 1, January 1989.

19 *See* 47 C.F.R. § 2.1.

20 *Supra.*

21 *See* 47 C.F.R. § 2.1. The staff recognizes that PCS may at times function like a safety service, *e.g.*, consumer calls to 911. A safety service is defined as any radiocommunication service used permanently or temporarily for the safe-guarding of human life and property. However, PCS is primarily a radiocommunication service which is defined as a service involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes.

misunderstanding that it would have to lower the noise floor of its receivers whereas what was actually stated is that the system should be designed for the reception of a higher signal level from the transmitter in order to retain system reliability. A higher receiver noise figure simply means that the PCS mobile unit needs to be closer to the base station or that the base station needs to operate at a higher power than would be required if the mobile receiver had a lower noise figure. However, that still misses the point that the Commission attempted to make in WT Docket No. 99-168. Simply, it is not reasonable to design a communications system to operate at or near the thermal noise floor of the receiver. Noise from other radio frequency devices, including other PCS mobile and base stations, will prevent the system from functioning at this low of an emission level.

If Qualcomm's calculations are reexamined and based on the signals from the UWB transmitters not being permitted to exceed the thermal noise floor of the PCS receiver by greater than 10 dB, the minimum separation distance between the UWB transmitter and the PCS receiver becomes 3.2 meters. This table also adjusts the PCS receiver antenna gain to –4.6 dBi, as measured in the tests performed by Sprint PCS.

Parameter	Value	Units	Equation
Frequency	1900	MHz	F
Received signal level	-85	dBm	R
Allowed IX level	-95	dBm	IX
UWB EIRP level/1.25 MHz	-40.28	dBm	P = -41.25 + 10 log (1.25)
UWB antenna gain	0	dBi	GT
Victim rcvr. antenna gain	-4.6	dBi	GR
Victim rcvr. line loss	2	dB	LR
Path loss required	48.12	dB	L = P + GT + GR – LR - IX
Minimum separation	3.2	m	20 log (d) = L – 20 log (F) + 27.56

If the emission level of the UWB signal is reduced by 6 dB, the separation distance calculated in the above table decreases to 1.6 meters. If the emission level of the UWB signal is reduced by 12 dB, as proposed in the *Notice*, the separation distance calculated in the above table decreases to 0.8 meters.

If an additional protection margin is provided by requiring that the emission level from the UWB transmitter be reduced to the thermal noise floor of the PCS receiver, -105 dBm/1.25 MHz, the required separation distance becomes 10.1 meters with the UWB operating at the limit in 47 C.F.R. § 15.209, 5.1 meters if the emission level of the UWB signal is reduced by 6 dB, and 2.5 meters if the emission level of the UWB signal is reduced 12 dB below the Part 15 general limits, as proposed in the *Notice*.

It must be noted that the separation distances calculated above are based on absolute worse case conditions. The calculations assume that the UWB transmitter is pointed directly at the PCS receiver without additional losses due to mismatched antenna polarizations, head loss[22], or attenuation from intervening objects, as would typically occur at these short ranges with indoor operation,[23] and that free space attenuation applies to the propagation. It is highly likely that in a real world situation, as demonstrated in the Sprint PCS/TDC open field test data, a UWB transmitter and a PCS handset would need to be closer than shown by these calculations in order for harmful interference to occur.

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22 Head loss is signal blockage from the head and body of the person holding the PCS handset. As discovered in the joint Sprint PCS/TDC tests, head loss can range between 12 to 15 dB. Loss from antenna polarization can vary between 1.5 and 2.5 dB. *See* XSI comments of 5/10/01 at pg. 11.

23 Greater average separation distances would be expected with outdoor UWB operations.

Laboratory Measurements. Qualcomm demonstrated that the emissions from a UWB transmitter received by the PCS receiver must be approximately 6 dB lower than the PCS signal in order for the frame error rate (FER) not to exceed 2 percent.[24] While there is some confusion as to the measurement characteristics employed by Qualcomm, this 6 dB S/I could be employed to calculate the minimum separation distance between a UWB transmitter and a PCS receiver at various emission levels from the UWB transmitter. However, the minimum signal level that is expected to be received by a PCS handset is unknown.

The statement from Sprint PCS that PCS systems operate at the –105 dBm thermal noise floor is unreasonable, as discussed above. However, we do not have any data regarding the actual signal levels employed in PCS systems. 47 C.F.R. § 24.236 states that the median field strength at any location on the border of the PCS service area shall not exceed 47 dBuV/m. As this is the signal level established in the rules as what is necessary to prevent unintended operation in an adjacent site belonging to a different licensee, it appears reasonable that PCS systems are designed to operate at this signal level or higher. For a 50 ohm system, this emission level is equivalent to a received signal level of –96 dBm over the 1.25 MHz PCS bandwidth.[25] We note that this level is equivalent to the lowest emission level tested outside by Sprint PCS/TDC/Telcordia for which data was submitted and that this outdoor test was limited to a single test cell, avoiding outer-cell interference. Accordingly, this level appears to be acceptable as a minimum cellular signal level on which a decision regarding the impact of harmful interference can be based.

Based on the above minimum PCS signal level and the receiver parameters provided by Qualcomm, a minimum separation distance can be calculated as follows:

Parameter	Value	Units	Equation
Frequency	1900	MHz	F
Received signal level	-96	dBm	R
Allowed IX level	-102	dBm	IX = R - 6
UWB EIRP level/1.25 MHz	-40.28	dBm	P = -41.25 + 10 log (1.25)
UWB antenna gain	0	dBi	GT
Victim rcvr. antenna gain	-4.6	dBi	GR
Victim rcvr. line loss	2	dB	LR
Path loss required	55.12	dB	L = P + GT + GR – LR - IX
Minimum separation	7.2	m	20 log (d) = L – 20 log (F) + 27.56

If the emission level of the UWB signal falling within the PCS band is reduced by 6 dB, the minimum separation becomes 3.6 meters. If the emission level of the UWB signal falling within the PCS band is reduced by 12 dB as proposed in the *Notice*, the minimum separation becomes 1.8 meters. Again, free space propagation was employed and no additional losses are incorporated in these calculations due to mismatched antenna polarizations, head loss, or attenuation from intervening objects. It also appears that the signal level being protected would be an absolute minimum level received by the PCS handset. Consequently, we believe that PCS signals at this level might be unreliable due to fluctuations from fading and interference from other noise sources, such as emissions from other PCS base stations. Thus,

[24] The signal to noise ratio for a 2 percent FER, as measured by Sprint PCS and TDC, was 5 dB. *See* Sprint PCS comments of 9/12/2000 at Attachment 2, pg. 3.

[25] This is consistent with the statement from Qualcomm that PCS carriers use -100 dBm as a rule of thumb to define the edge of coverage in CDMA. *See* Qualcomm comments of 5/10/01 at pg. 18

we believe that the minimum separation distances will be less than the distances determined in this last set of calculations, comparable to those determined through the Sprint PCS/TDC/Telcordia outdoors tests.

Questions regarding the above analyses should be directed to John A. Reed, Senior Engineer, Technical Rules Branch, OET, (202) 418-2455, jreed@fcc.gov.