Declaration of

Dr. Charles L. Jackson

PCS Handset Vulnerability to H-Block Transmissions

Interpreting the Test Results

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This study was prepared for CTIA-The Wireless Association™

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1. Executive Summary

CTIA engaged two laboratories, Rutgers University's WINLAB and PCTEST. Each test laboratory measured the performance of several PCS handsets in the presence of a simulated H-block signal.

Both sets of tests showed that handset models, from several manufacturers representing current production equipment and state-of-the-art designs and representative of a substantial fraction of handsets currently in use, would be impaired by nearby operation of H-block mobile units transmitting in the top two-thirds of the H-block at the maximum power level proposed in the NPRM. Such impairments arose from two mechanisms—overload and intermodulation. *Overload* (sometimes also called desensitization) occurs when a strong unwanted signal impairs the ability of a receiver to pick up the desired signal. *Intermodulation* occurs when two or more signals combine to create a third signal that impairs reception. As far as I know, no empirical information on the intermodulation problem was provided earlier in this proceeding. The test design did not permit analysis of the possible harms from transmissions in the lower third of the H-block.

The tests indicate that the FCC should impose more stringent limits on the transmitted power of mobile H-block transceivers than proposed in the NPRM. The appropriate limit depends on the degree of harm that one is willing to impose on current and future PCS users. I describe four different grades of interference protection—Maximum, Medium (Intermodulation and Overload), Medium (Overload Only), and Minimal—and calculate separate H-block power limits under each grade of protection. The table below shows the limits associated with each grade of interference protection based upon the test data and taking into account only overload and intermodulation concerns. Because the tests showed that signals in the middle of the H-block created less interference that signals at the top of the H-block different limits are calculated for these two segments of the H-block.

Analysis of H-Block Power Limits

Power Limit	H-Block Power Limit (dBm)		Observations
	High Segment	Middle Segment	
Maximum	+1	+4	Would protect all tested handsets against both intermodulation and overload at one meter.
Medium (Intermodulation and Overload)	+5	+8	Would protect most tested handsets against both intermodulation and overload at one meter.
Medium (Overload Only)	+13	+16	Would protect most tested handsets against overload at one meter. Some tested handsets could be impaired by intermodulation interference at up to 4 meters.
Minimal (Protects a stronger receive signal level against overload only.)	+19	+22	Sacrifices the margin that is included in the higher level of protection. Equivalent to protecting a CDMA call in a fading environment with a mean signal level of about –95 dBm—a signal about 14 dB above the receiver sensitivity.

The protection levels in the table above were chosen assuming (1) that the H-block transmitter was located one meter from the PCS handset, and (2) that the loss in excess of free-space loss was 3 dB.

The maximum protection level is based on the level needed to protect all tested PCS handsets with a received signal level of –105 dBm and operating at +100 F from impairment by both intermodulation and overload caused by H-block signals.

The medium protection level (Intermodulation and Overload) is based on the level needed to protect the majority of tested PCS handsets with a received signal level of –105 dBm and operating at room temperature from impairment by both intermodulation and overload caused by H-block signals.

The medium protection level (Overload Only) is based on the level needed to protect the bulk of tested PCS handsets with a received signal level of –105 dBm and operating at room temperature from impairment by overload caused by H-block signals.

The minimal protection level (Overload) is based on the level needed to protect the bulk of tested PCS handsets operating at room temperature with a received signal level of –100 dBm from impairment by H-block overload.

Note, the power limits in the table above are shown in terms of dBm (dB relative to 1 milliwatt). The power limit proposed in the NPRM was200 mW, which is the same as +23 dBm.

The term *High Segment* and *Low Segment* refer to the top and middle thirds of the H-block.

The tests did not permit determining the appropriate limits on transmitted power in the bottom third of the H-block. On the basis of both the trend of the measurements and the structure of current PCS receivers, one would expect that the proper constraint in that subblock would be several dB higher than the constraint in the middle of the H-block.

The limits set forth above are appropriate for mobile and portable H-block devices. Fixed H-block units, such as a wireless local loop antenna mounted high on the side of a house, could operate at the power levels proposed in the NPRM with only negligible chances of creating interference to PCS handsets.

All radio transmitters generate some signals outside their desired band. Such signals are called *out-of-band emissions*, and sufficiently strong out-of-band emissions will interfere with nearby receivers. In the NPRM, the FCC proposed that out-of-band emissions into the nearby PCS handset receive band be limited to no more than –60 dBm (or in the alternative –66 dBm). The tests on the effects of inband white Gaussian noise show that the −66 dBm limit proposed in the NPRM would not provide sufficient protection against out-of-band emissions from an H-block unit 1 meter from a PCS handset. Rather, out-of-band emission limits consistent with those used in much of the PCS industry today (–76 dBm/MHz) are appropriate.

This report also demonstrates that any practical problem with overload of PCS handsets from base stations appears to be minimal and is irrelevant to understanding the harms of high-power H-block operations.

2. The Testing Process

This report describes the tests performed by WINLAB and PCTEST on PCS handsets, summarizes the results of those tests, and puts those test results into context—explaining the implications of those tests for the appropriate service rules for the AWS in the newly created H-block frequencies.

CTIA engaged two organizations, PCTEST and Rutgers University's WINLAB, to test representative models of PCS handsets in current use by carriers. PCTEST is a commercial test laboratory located in Columbia, Maryland. It is certified or accredited by several organizations, including ANSI, NMI (Netherlands), NIST, and CTIA.

PCTEST has tested more than a thousand different pieces of equipment for conformity with FCC performance and RF emission rules. PCTEST's clients include many major manufacturers. WINLAB is a research laboratory at Rutgers University in New Brunswick, New Jersey. It receives funding from the National Science Foundation, the Defense Advanced Research Projects Agency (DARPA), the New Jersey Commission on Science and Technology (NJCST), and several corporate donors. WINLAB researchers study a variety of topics in modern wireless technology.

CTIA chose to divide the test work between two laboratories for two reasons. First, given the short time frame available for the testing, the use of two laboratories provided CTIA with protection against unexpected delays in testing, such as might be caused by a fire or damage to test equipment. Second, the use of separate laboratories provided an opportunity to check the test measurements, to compare the results from the two laboratories, and to have increased confidence in the measurements because the test results were generally similar.

CTIA provided the laboratories with a test plan that specified the measurements that were to be taken in order to ascertain a handset's performance in the presence of (1) an H-block uplink signal, (2) an uplink signal in the top of the traditional PCS band, (3) cochannel interference such as would be caused by out-of-band emissions by an H-block mobile unit, and (4) intermodulation caused by H-block signals. CTIA member companies provided each laboratory with several handsets for testing, together with any cables and battery-charging equipment that were unique to those handsets and were needed for the testing. I understand that, for the most part, the handsets sent for testing were new-in-box handsets recently received from the manufacturer. All handsets tested were recent production units of models that one or more CTIA member companies are currently marketing to subscribers.

Each laboratory prepared a written report describing their testing and the results of that testing. The PCTEST and WINLAB reports are being filed by CTIA along with this report.

3. The Test Results

The tests showed that operation of a PCS handset—specifically, its ability to receive low-level signals—could be impaired by signals in the upper portion of the H-block at levels such as would be created by the operation of an H-block mobile unit near a subject handset. The tests showed that, in one particular configuration, a signal level slightly lower than −40 dBm at the antenna receiver port of the PCS handset from handset transmissions on frequencies near the top of the H-block would prevent a PCS handset from receiving a signal that it could otherwise receive.[1] At the other extreme, one handset tested was not impaired in any test configuration by H-block signals weaker than −15 dBm.[2] In contrast, signals on the top of the current PCS block were far less damaging—in the worst case, a signal level of −9 dBm impaired PCS reception.[3]

3.1. Overload by H-Block Signals

Handsets were tested for overload (desensitization) under a range of conditions, including different temperatures, different forms and carrier frequencies of the interfering signal, and different operating points of the subject receiver. Overload (sometimes also called desensitization) occurs when a strong unwanted signal impairs the ability of a receiver to pick up the desired signal.

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[1] WINLAB Results, CDMA DUT#2, test setup 1O.

[2] PCTEST Results, at 4.3.5.

[3] WINLAB Results, GSM DUT#2, test setup 2I.

Figure 1, taken from the WINLAB report, illustrates well the tests and the nature of the results. This figure displays the results of two tests of four PCS handsets—a total of eight tests in all.

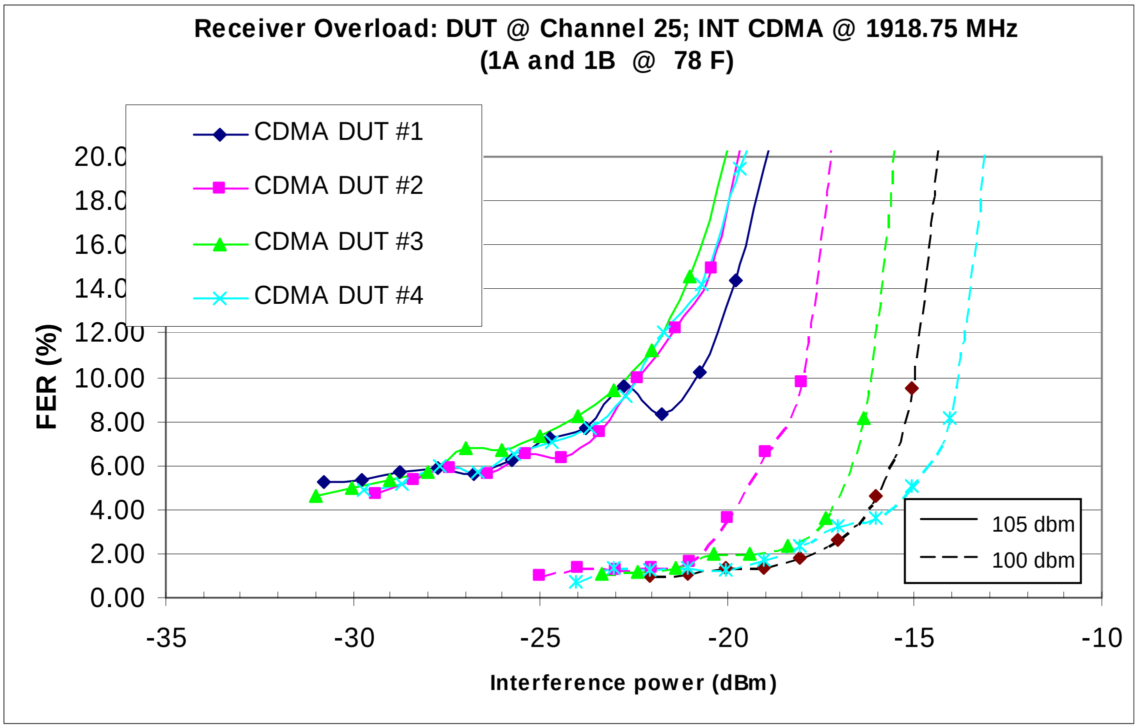

Figure 1. WINLAB Tests of CDMA Handsets (Configurations 1A and 1B at Room Temperature)

In the tests illustrated in Figure 1, the handsets were tested in two different operating configurations. In the first configuration, shown by the set of lines that are higher and to the left, the received signal level at the handset was adjusted to −105 dBm and noise added until the frame error rate was 5%. Then, an unwanted H-block signal (in this case, a CDMA signal at 1918.75 MHz) was added. The graphs tabulate the rise in the frame error rate as the power of the H-block signal was increased. In the second configuration, the received signal level at the handset was adjusted to −100 dBm and noise added until the frame error rate was 1%. Again, the graphs show the rise in frame error rate as the level of the interfering signal increases. The signal levels used in the tests (−105 dBm and −100 dBm) represent weak signal levels such as those that would be experienced at the limits of PCS coverage such as inside an office building. A CDMA system operating at the −105 dBm received signal level and at a 5% frame error rate is on the verge of losing the connection. In such a configuration, the system has no margin for further impairments. A CDMA system operating at the –100 dBm received signal level and at a 1% error rate has some margin to compensate for signal losses such as are caused by multipath fading and other changes in the radio propagation environment.

Figure 2 shows the signal levels that impaired each receiver.

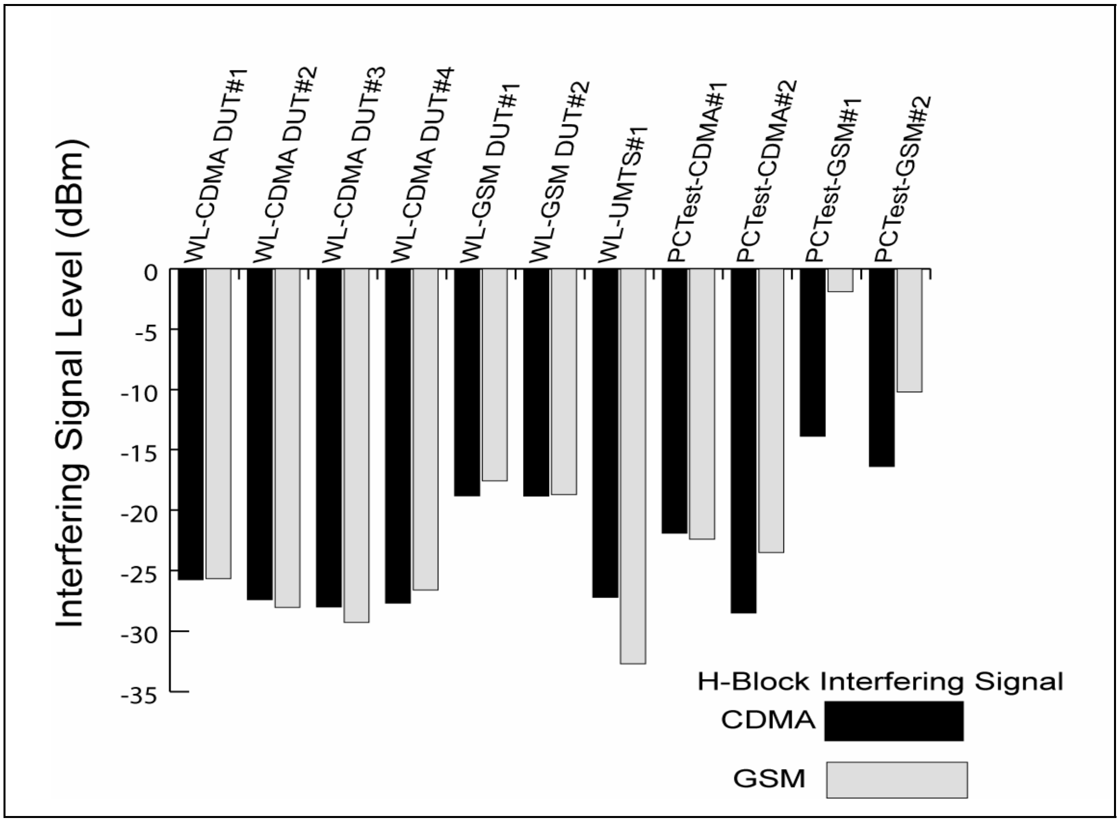

Figure 2. Harmful Levels of Signals at the Top of the H-Block

This figure is representative of the experimental data and does not summarize all the tests. Rather, it displays the effects of interfering H-block signals using both of the most widely used modern signal formats (CDMA and GSM). The H-block signal was at the highest frequency in the H-block that could be used for such a carrier. Figure 2 summarizes measurements that were taken at room temperature. Measurements taken at higher temperatures were similar but, in general, showed impairments at even lower H-block signals. The receivers under test were tuned to a channel near the bottom of the PCS A-block and were receiving a weak signal (–105 dBm for CDMA and UMTS, -102 dBm for GSM) just above the handset sensitivity. I defined a *harmful signal level* as one that appreciably increased the relevant error rate—specifically an increase of about 1%. Although 1% may seem like only a slight degradation, it indicates that the system has lost its entire margin against further impairments. These harmful levels were determined by inspecting the test results and choosing that interfering signal power associated with an increase in the relevant error rate of approximately 1%. The details of data extraction and references back to the test reports for each number so extracted for this figure and for Figures 3, 4, and 5 are contained in the Appendix.

The lowest third of the harmful signal levels shown in the above figure lie in the range from −27 to −32.7 dBm. If PCS handsets were protected so that they did not receive such overload signals at levels exceeding −28 dBm, the bulk of the handsets would be protected against overload.

The tests showed that the problems were not confined to PCS receivers operating on the bottom of the PCS receive band. Figure 3 shows the results of testing with a CDMA interfering signal but with the handset under test operating on both the low channel and a channel in the middle of the traditional PCS block.

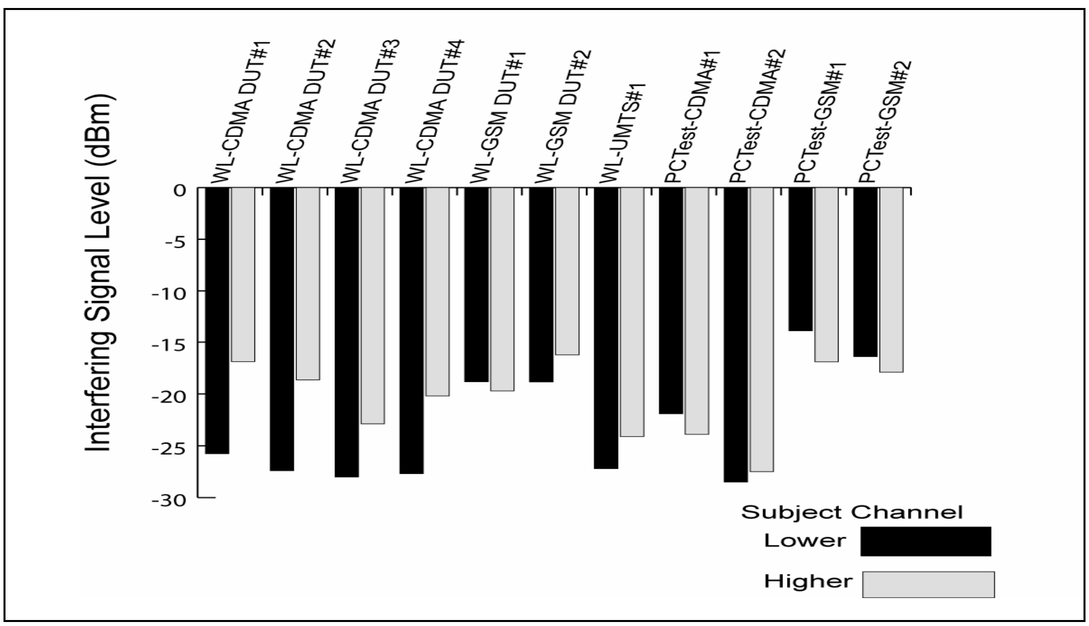

Figure 3. Variation of Harmful Signal Level with Changes in PCS Channel Impacted

The testing also showed that, as the frequency of the interfering signal dropped from the top of the H-block, higher power levels were required to create a given level of impairment. Tests were conducted with signals (1) at the top of the H-block, (2) in the middle of the H-block, and (3) at the top of the PCS band. Transmissions in the middle of the H-block were slightly less damaging than transmissions at the top of the H-block, and transmissions at the top of the current PCS block were far less damaging. Figure 4 summarizes the results of tests of interfering signals at different frequencies. In every case, a signal at top of the PCS band must be stronger than a comparable H-block signal to create interference—in most cases substantially stronger. These tests demonstrate that the problem of interference created by H-block transmissions has no counterpart created by transmissions in the current PCS bands.

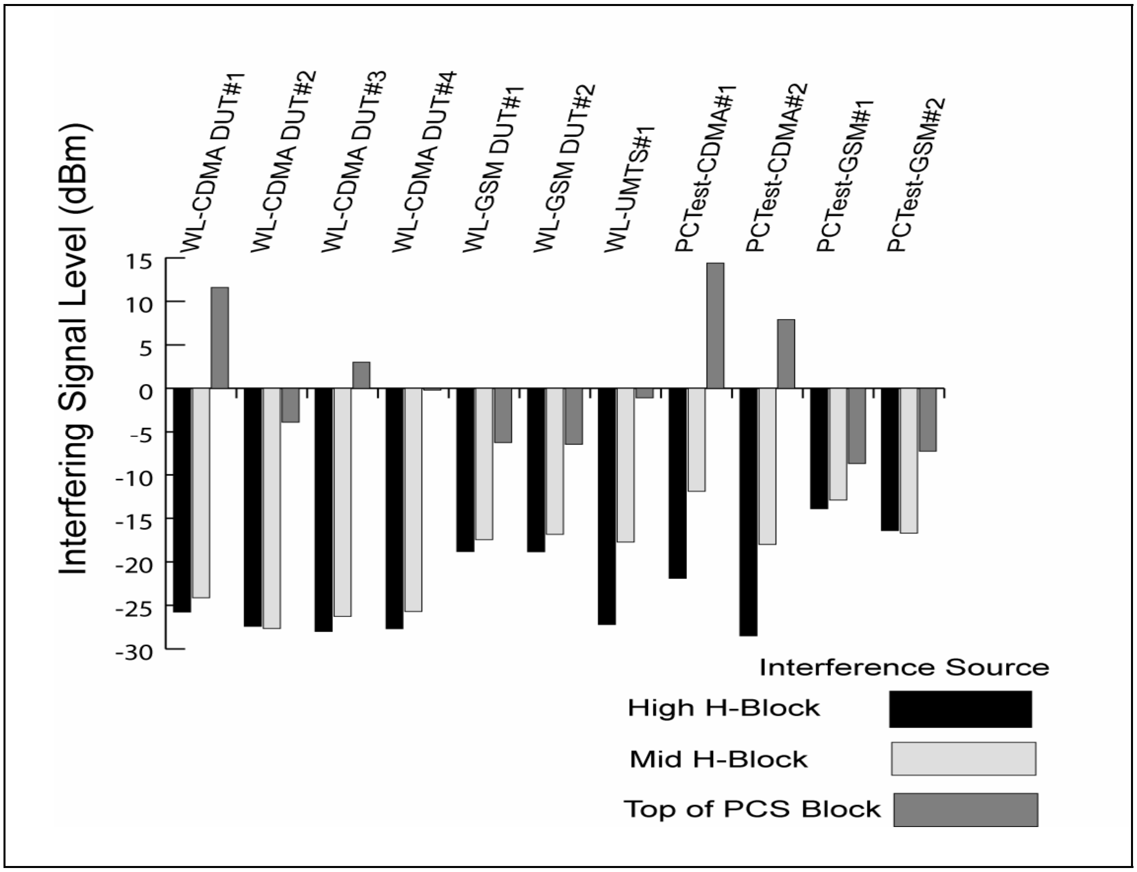

Figure 4. Variation of Harmful Signal Level with Frequency of Harmful Signal

Figure 5 presents the same data as does Figure 4, but the data are grouped by the frequency of the signal causing overload. Figure 5 shows more clearly that signals at the top of the existing PCS block are far less of an overload threat.

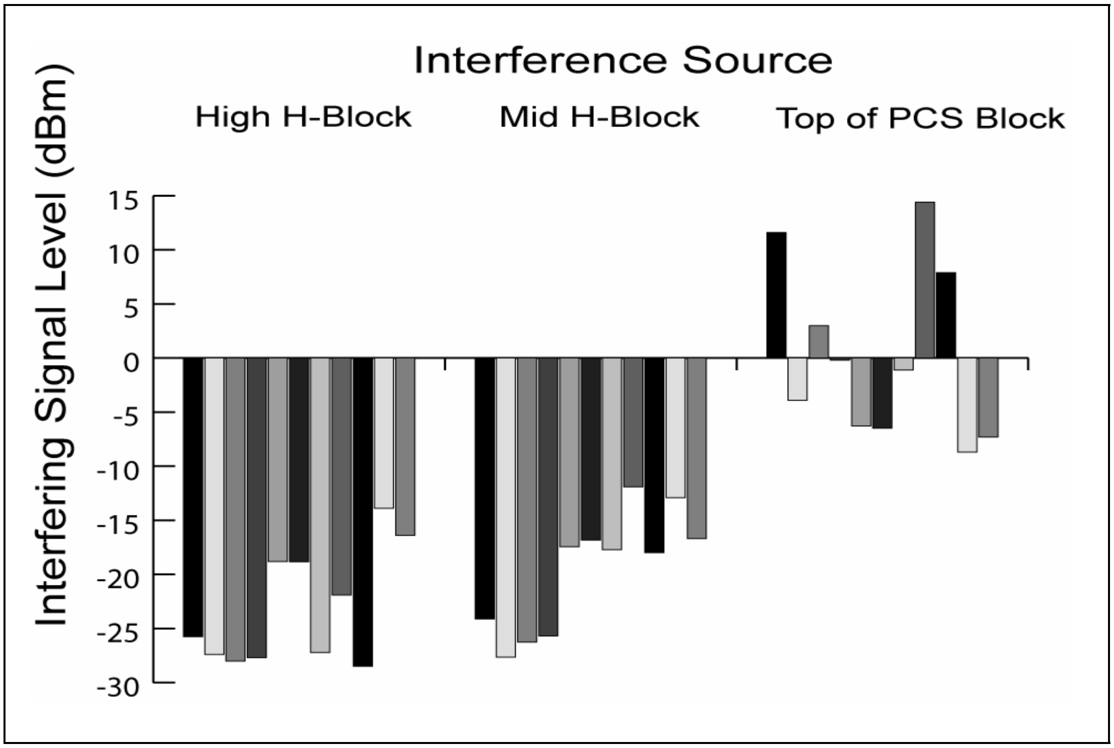

Figure 5. Variation of Harmful Signal Level with Frequency of Harmful Signal

3.2. Effect of Out-of-Band Emissions

The tests also considered the problem of out-of-band emissions. Three separate tests contribute to a better understanding the out-of-band issues. First, the sensitivity of the handsets was measured—that is, the handsets were tested to determine the lowest desired signal level at which they could reliably operate. Second, the negative effects of additive white Gaussian noise (AWGN) were measured on handsets operating at two different levels. Third, the PCS handsets were configured to transmit on the PCS uplink band, and the unwanted signals that these handsets generated into the nearby PCS downlink band were measured. These latter measurements are referred to as *out-of-band emissions*.

These tests can be summarized quickly. Handset sensitivity fell in the range of −106 to −110 dBm, with all but one of the handsets having sensitivity of −108 dBm or better.[4] Sensitivity did not vary appreciably with temperature. AWGN at −115 dBm impaired the operation of CDMA receivers with a receive signal level of −105 dBm, and AWGN at −110 dBm impaired the operation of CDMA receivers operating at a receive signal level of −100 dBm. These AWGN impairments are consistent with what one would expect from basic communications engineering theory. All handsets displayed relatively low levels of out-of-band emissions into the PCS handset receive band. Figure 6 summarizes the out-of-band emission tests performed by WINLAB. The out-of-band emissions (OOBEs) in the PCS receive band were measured for each PCS handset in six different configurations. Each handset was tested at both its maximum power and at one-tenth maximum power (10 dB below maximum) at each of three frequencies within the PCS band.

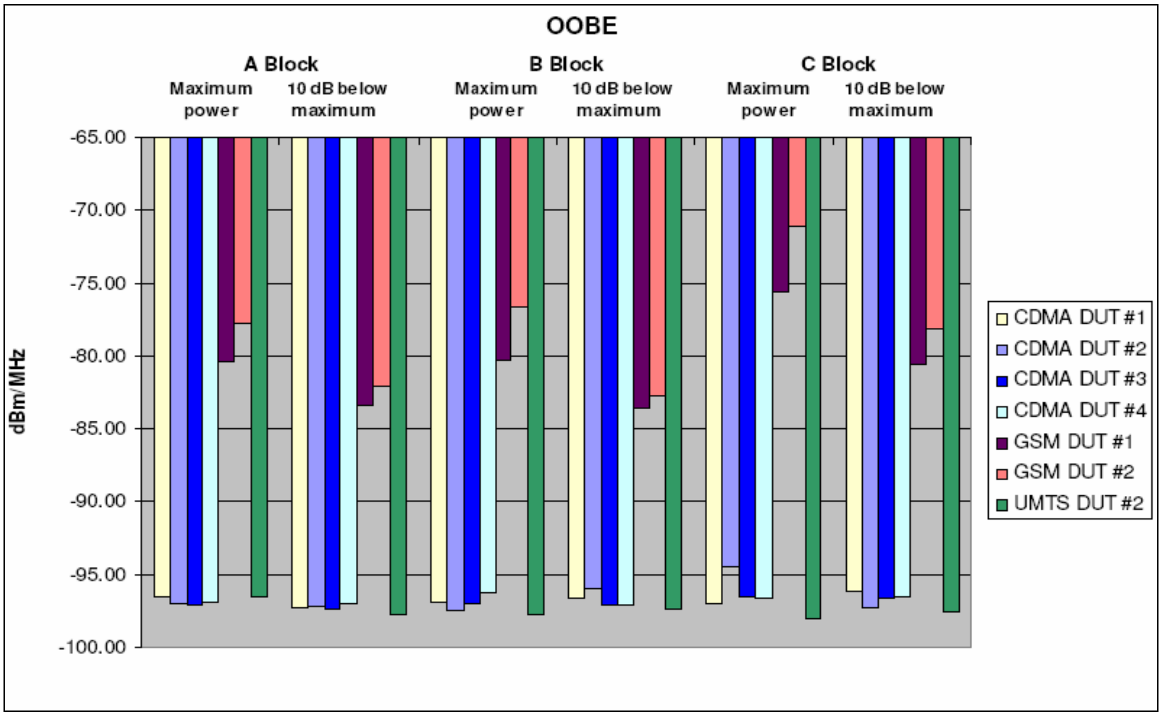

Figure 6. Out-of-Band Emissions Measured by WINLAB

[4] Sensitivity measurements were reported only by WINLAB.

Note that in every configuration but one, the out-of-band emissions are below −76 dBm/MHz and in a majority of cases the out-of-band emissions are below −90 dBm/MHz. In the one case that is not at or below −76 dBm/MHz, the out-of-band emissions are still at the low level of −71 dBm/MHz—5 dB below the −66 dBm proposed in the NPRM.

3.3. Intermodulation

Intermodulation occurs when signals at two frequencies combine to generate a new signal at a third frequency. Such intermodulation products can create unwanted interference. A CDMA or UMTS PCS handset operating in the B-block will be transmitting uplink while listening on the downlink. An H-block signal located exactly 40 MHz above the PCS uplink signal can combine with the uplink signal from the PCS handset to create an interfering signal on the downlink that can impair operation of the receiver in the handset. GSM handsets do not have a similar intermodulation problem because, unlike the case in CDMA and UMTS, GSM handsets do not transmit and receive at the same time.

The WINLAB tests of CDMA handsets (room temperature, −105 dBm received signal level) show that two handsets were impaired when H-block transmission at about −39 dBm were present. In the same test conditions, the two other CDMA handsets tested by WINLAB were impaired at about −31 dBm. PCTEST's measurements on CDMA receivers under the same conditions found impairments at −40 dBm and −24 dBm. WINLAB's tests on of a UMTS handset showed the handset impaired when the H-block signal was at −28 dBm.

The test results do not reveal the mechanism creating such impairments. However, I think it is likely that the duplexer filter in some handsets permits some of the relatively strong H-block signal to be transferred into the PCS handset low-noise amplifier (LNA) where it combines with some of the PCS handset's transmitted signal energy that has leaked into the LNA to create a sufficiently high intermodulation signal to impair the receive function.

4. Implications of the Test Results

Current PCS handsets—exemplified by the tested handsets that are instances of handset models that are good enough to be accepted under the carriers' demanding performance requirements—would be impaired by nearby H-block transmissions at the maximum power and out-of-band emission limits set forth in the NPRM.

The appropriate constraint on H-block power is a policy decision. Engineering analysis can only inform the policymaker regarding the relationship between H-block power levels and handset protection; it cannot determine the choice of the proper level. Below, I analyze several different scenarios ranging from maximum protection to weak protection and relate the protection level to the appropriate limit on H-block transmitted power.

4.1. Overload and Intermodulation

Overload by transmissions not in the range of frequencies that a receiver is designed to pick up arises from the fact that receivers are not ideal systems—receivers respond to radio signals outside the band or channel to which they are tuned. The nature of that response depends on the strength of the signals, the nature of those signals, and the frequency at which those signals appear. PCS receivers must be able to listen to transmissions from a base station while, at the same time, transmitting back to that base station on a nearby frequency. For example, a PCS portable operating in the PCS A-block would listen to transmissions in the range 1930-1945 MHz while, at the same time, transmitting in the range 1850-1865 MHz. The electronics in the PCS handset must protect the handset's receiver from the strong signal transmitted by the handset and from PCS signals, perhaps at 1910 MHz, transmitted by nearby PCS users.

The key building block in PCS handsets that provides this protection is the duplexer filter. Duplexer filters connect a handset's transmitter and receiver to the handset's antenna but isolate the transmitter from the receiver. Typically, a duplexer has a filter that passes the PCS base-to-mobile frequencies to the receiver but blocks PCS mobile-to-base signals from passing to the receiver.

The duplexers in existing PCS handsets were designed to prevent or block signals in the lower half of the PCS band from flowing to the receiver portion of a handset while permitting signals in the upper half of the PCS band to pass to the receiver. In the 20 MHz of separation between 1910 MHz (the highest transmit frequency for PCS handsets today) and 1930 MHz (the lowest frequency that PCS handsets must receiver), the duplexer's filters must change from blocking signals to passing signals without attenuation. Although 20 MHz may seem like significant frequency separation, one must recall that these filters operate at 1900 MHz, so 20 MHz is only 1% of the center frequency of the filter.

The lower half of the H-block is located in the middle of what today is the transition region for the duplexer filters. The filters in today's PCS receivers were designed to reject strong signals from nearby transmitters in the top of the C-block—just below 1910 MHz—and to accept signals at the bottom of the A-block at 1930 MHz; as the tests demonstrated, they were not designed to reject strong signals from nearby transmitters in the H-block.

Intermodulation impairment is somewhat similar in that the existing duplexers protect PCS handsets by attenuating by 40 dB any received uplink PCS signals that might be conducted into the PCS power amplifier. If the PCS duplexers do not sufficiently attenuate the H-block signal, then intermodulation impairments are possible.

Calculating the Protection Needed

Given that one knows the level of H-block power that will impair a handset, one can then use simple models to calculate the power level of an H-block transmission that will impair a PCS handset. The calculation is the same whether the impairment arises from either overload or intermodulation. The model simply requires calculating how much power would be deposited in a PCS receiver from a nearby H-block transmitter. Generally, three quantities are required to calculate such a power level—(1) the transmitted power from the H-block unit; (2) the free-space loss between the two units;

and (3) the effects of antenna gain, coupling losses, and path blockage that that must be considered in addition to free-space losses. I consider each of these in turn.

The transmitted power is easy—one should assume that the transmitted power is equal to the maximum EIRP permitted under the rules.

Similarly, the free-space loss is easy—the formula for free-space is agreed on by all. It yields an attenuation of 38 dB for the H-block signals with a separation of 1 meter.

The other effects are more complicated. Many PCS handset antennas are similar to dipole antennas—they display a few dB of gain above isotropic over a broad range of angles. On a moment's reflection, one can see that it would be natural for handset manufacturers to design handsets with slight gain toward the horizon and little gain straight up—such a design would slightly improve handset performance. Examination of handset test data by V-COMM indicates that such gain is common.[5] The typical handset examined by V-COMM showed slight gain between the output jack power and the maximum EIRP of the handset. If an H-block device and a PCS handset were being used near one another, one would expect that both units would be at about the same height and with each unit oriented so that maximum gain was pointed towards the horizon. In such a configuration, one would expect that the H-block device could transmit up to the maximum permitted EIRP and that the PCS handset would exhibit some slight antenna gain. These two effects would combine to reduce the free space loss by about 1 dB. However, the user's hand or body near the PCS handset can be expected to create an additional loss in excess of free-space loss. Depending on the service deployed in the H-block, the user's hand or body may be close enough to the H-block unit to create some excess loss. For the purpose of this analysis, I assume that such excess loss events total 4 dB. Combining this 4 dB loss with the 1 dB of antenna gain at the PCS handset leads to a total loss of 3 dB in excess of the free-space loss. So, the total loss at 1 meter would be 41 dB = (38 + 3).

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[5] Personal communication, Sean Haynberg of V-COMM.

Given this background, it is now easy to calculate the protection required. Assume that a PCS handset has to be protected against a signal level of 0 dBm generated by an H-block transmitter 1 meter away. The total attenuation is 41 dB so the H-block unit could transmit at up to 41 dBm without the received signal at the PCS handset exceeding the required protection.[6] Similarly, if the PCS handset required protection against a −41 dBm signal, then the H-block handset could transmit at no more than 0 dBm.

Below I employ this analysis in different scenarios based upon using different criteria to choose the required protection level. I consider several different criteria—each leading to a different limitation on allowable H-block handset power.

Maximum Protection

The intermodulation tests showed that one handset was impaired by a signal at slightly less than −40 dBm. If one wanted to set the protection sufficiently low that all tested handsets would be protected from all H-block devices at 1 meter, then 1 dBm would be the appropriate limit for H-block transmissions.[7] Such limits would probably not protect all handsets in use today given the natural variation of handset performance among production units, the many models that were untested, and the existence of older units in the field.

Medium Protection Based on Intermodulation

Alternatively, one might feel that a rule that protects against intermodulation impairments is appropriate but that the rule should protect the typical handset, not the worst-case handset in the tests. If so, examining the test results shows that a protection level of about −36 dBm would be appropriate—leading to a power limit of +5 dBm.

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[6] These numbers were chosen to make the example easy to follow. An H-Block transmitter at +41 dBm (12 watts) would likely exceed the permitted human RF exposure rules.

[7] This limit should only apply at the top of the H-Block. As I discuss elsewhere in this report, the tests indicated that a higher limit should apply at the middle of the H-Block and it appears reasonable that an even higher level should apply at the bottom of the H-Block.

Medium Protection Based Only on Overload

If one wished to be conservative but felt that only overload should be considered, then as discussed above a protection level of −28 dBm would protect the bulk of the tested handsets against overload—even when those handsets were receiving a signal only 3 dB above the handset's sensitivity. A protection level of −28 dBm leads to a power limit of +13 dBm. This protection level would mean that some handsets would suffer from intermodulation-based impairments at distances up to about 4 meters.

Minimal Protection

If one wished to be less conservative and choose to base the limit on overload of receivers with stronger signals (8 dB above the receiver sensitivity), then my examination of the test data indicates that a protection level of −22 dBm would be appropriate, leading to a power limit of +19 dBm. Essentially, this level of protection would sacrifice most of the fade margin for handsets receiving such weak signals. At this level of protection, intermodulation could be a problem at up to about 8 meters (25 feet).

Proper Limits for the Middle and Bottom Third of the H-Block

The above discussion of H-block power limits was based on tests using an interfering signal near the top of the H-block. Tests performed using an interfering signal in the middle of the H-block indicated, as one would expect, that PCS handsets could withstand such signals at levels up to about 3 dB higher than was the case at top of the H-block. As mentioned above, the tests do not permit one to calculate appropriate power limits for transmissions in the bottom third of the H-block; however, one can reasonably expect that such limits, based on the intermodulation and overload problems, would be at least a few dB higher than the appropriate limit for the middle of the H-block. Additional testing may be appropriate to determine reasonable power limits for the bottom third of the H-block.

Concluding Observations on Proper Power Limits

Engineering analysis alone cannot determine the proper limit on H-block power. Rather, engineering can illuminate the tradeoffs between alternative levels. The table below summarizes the tradeoffs in this case.

Analysis of H-Block Power Limits

Power Limit	H-Block Power Limit (dBm)		Observations
	High Segment	Middle Segment	
Maximum	+1	+4	Would protect all tested handsets against both intermodulation and overload at one meter.
Medium (Intermodulation and Overload)	+5	+8	Would protect most tested handsets against both intermodulation and overload at one meter.
Medium (Overload Only)	+13	+16	Would protect most tested handsets against overload at one meter. Some tested handsets could be impaired by intermodulation interference at up to 4 meters.
Minimal (Protects a stronger receive signal level against overload only.)	+19	+22	Sacrifices the margin that is included in the higher level of protection. Equivalent to protecting a CDMA call in a fading environment with a mean signal level of about -95 dBm—a signal about 14 dB above the receiver sensitivity.

The protection levels in the table above were chosen assuming (1) that the H-block transmitter was located one meter from the PCS handset, and (2) that the loss in excess of free-space loss was 3 dB.

The maximum protection level is based on the level needed to protect all tested PCS handsets with a received signal level of –105 dBm and operating at +100 F from impairment by both intermodulation and overload caused by H-block signals.

The medium protection level (Intermodulation and Overload) is based on the level needed to protect the majority of tested PCS handsets with a received signal level of –105 dBm and operating at room temperature from impairment by both intermodulation and overload caused by H-block signals.

The medium protection level (Overload Only) is based on the level needed to protect the bulk of tested PCS handsets with a received signal level of –105 dBm and operating at room temperature from impairment by overload caused by H-block signals.

The minimal protection level (Overload) is based on the level needed to protect the bulk of tested PCS handsets operating at room temperature with a received signal level of –100 dBm from impairment by H-block overload.

Note, the power limits in the table above are shown in terms of dBm (dB relative to 1 milliwatt). The power limit proposed in the NPRM was200 mW which is the same as +23 dBm.

The term *High Segment* and *Low Segment* refer to the top and middle thirds of the H-block.

4.2. Out-of-Band Emissions

As the FCC recognized in the Allocation Order and in this NPRM, the H-block service rules must impose a limit on H-block emissions in the PCS downlink band.[8] The FCC's analysis, presented at paragraph 23 of the Allocation Order and at paragraph 91 of the NPRM can be summarized as follows.

The FCC assumes (1) that out-of-band emissions equal to the desired signal level will create an undesirable impairment, (2) that the PCS handsets perform no better than the minimum performance required under industry standards, and (3) that the free-space attenuation is the appropriate measure of attenuation between the H-block unit and the PCS handset. Combining (1) and (2) leads to the conclusion that a signal of −104 dBm (CDMA) or −102 dBm (GSM) should be considered harmful. At a separation of 1 meter, the free space loss is 38 dBm, and at 2 meters, the free-space loss is 44 dB. So given a separation of 1 meter, an out-of-band signal of −66 dBm would be just at the acceptable limit for a CDMA receiver (−66 − 38 = −104), as would an out-of-band signal of −60 dBm at a separation of 2 meters.[9]

Two alternate ways to analyze this issue come to mind. First, one might change the signal level used in the calculation as the level at which an inband emission impairs a handset. The sensitivity and AWGN impairment tests indicate that current real-world handsets perform better that indicated by the standards and better than the sensitivity used by the FCC in its analysis of out-of-band limits. Typical receiver sensitivity was about –108 dBm. On the basis of the test results, it is reasonable to conclude that an out-of-band signal level in the range −115 to −110 dBm would impair PCS handset operation. If

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[8] *See* Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, including Third Generation Wireless Systems, ET Docket No. 00-258, *Sixth Report and Order*, FCC 04-219, (rel. Sept. 22, 2004) ("*Allocation Order*").

[9] I note that the FCC assumes no excess loss over free space in its analysis in paragraphs 23-26 of the *Allocation Order*. In contrast, in paragraph 27 of that order, the FCC assumes an excess loss of 6 dB over free space in exactly the same physical configuration. In my corresponding analysis, I use 3 dB both times for the reasons that I explain above.

one combines the lower level of −115 dBm with the free-space attenuation of 38 dB at 1 meter, the acceptable out-of-band signal level falls to −77 dBm.

Second, one might use a different link budget than did the FCC in its calculation. Recall that, in analyzing overload I assumed that there was a 3 dB propagation loss in excess of the free space loss at 1 meter. If such an additional 3 dB loss is taken into consideration along with the -115 dBm harmful level, then the acceptable out-of-band signal level would be −74 dBm. The table below shows the FCC calculation and my alternative calculations in three successive columns. In each of the two rightmost columns, I have italicized the entry that is changed from the column to the left.

Three Calculations of Permissible OOB Emission Levels

	FCC	Alternative 1	Alternative 2
Harmful Signal Level	−104 dBm	*−115 dBm*	−115 dBm
Free-Space Loss at 1 meter	38 dB	38 dB	38 dB
Excess Loss	0 dB	0 dB	*3 dB*
Maximum Allowed Out-of-band Power	−66 dBm	−77 dBm	−74 dBm

I believe that of the three alternative approaches to calculating the permissible out-of-band emissions, the last one (the one yielding −74 dBm as a limit) best represents the likely real world situation.

Given (1) the above analysis, (2) the fact that the current industry standard for CDMA is −76 dBm/MHz, (3) the fact that all but one of the tested handsets generated out-of-band emissions less than −76 dBm/MHz in every configuration, and (4) the fact that five of the seven handsets tested by WINLAB have emissions in the PCS band lower than −94 dBm/MHz, one sees that a limit of −76 dBm is both reasonable from the point of view of the protection needed and from a market viability standpoint (given the current availability of handsets that meet this limit). The disparity between the test results on the

GSM and CDMA handsets indicates that the Commission may wish to carefully examine the impact of a proposed out-of-band limit on GSM handsets.

5. A Related Topic: Overload from Nearby Base Stations

In thinking about the effects of H-block signals, it is natural for one to consider the effects of adjacent channel PCS downlink transmissions on the existing stock of PCS receivers. Such PCS base station transmissions provide a possible analogy to H-block transmissions. Because the duplexer in the typical PCS handset provides no attenuation of these signals, one might reason that, if a typical PCS handset can withstand adjacent channel PCS signals at about the same strength as the signal from a nearby H-block mobile unit, then one would be less concerned about any possible deleterious effects of such H-block signals.

However, three facts challenge this line of reasoning. First, the industry specifications for adjacent channel rejection do not require that a handset receiving a weak signal be able to withstand an adjacent channel signal anywhere nearly as strong as the signal that a handset would receive from a nearby H-block mobile unit. Second, one would be unlikely to find an adjacent channel signal as strong as the signal received from a nearby H-block mobile unit. Third, in those few locations where such a strong adjacent channel signal is found, it is likely that the desired signal would have roughly the same strength as the adjacent channel signal.

An earlier edition of the CDMA2000 mobile unit performance specification requires that a mobile unit be able to withstand a pure tone (continuous wave or CW in industry jargon) signal at −30 dBm in the base-to-mobile band. The latest version of that standard has a different test—replacing the requirement to withstand a −30 dBm tone with a requirement to withstand (1) a −54 dBm CW signal at +/- 5 MHz from the desired carrier and (2) a −44 dBm tone at +/- 7.5 MHz from the desired carrier.[10] The latest version of

[10] TIA/EIA-98-E, Table 3.5.5.2-1 at p. 3-114.

the standard also includes a specific adjacent channel test—requiring that a handset receiving a low-power signal be able to withstand a nearby carrier at −37 dBm.[11]

The WCDMA standard requires a receiver to withstand an adjacent channel signal that is 33 dB stronger than a weak desired signal. The test specified in the standard requires that a handset (denominated UE in the standard) that is receiving a signal of −101 dBm (desired carrier power of −90.7 dBm) withstand an adjacent carrier at −52 dBm.[12] [13] The WCDMA standard also only requires that a mobile handset be able to withstand an inband CW tone at −44 dBm.[14]

To recapitulate, the CDMA2000 and WCDMA standards do not require handsets that are receiving a weak desired signal to withstand inband signals stronger than about −40 dBm.

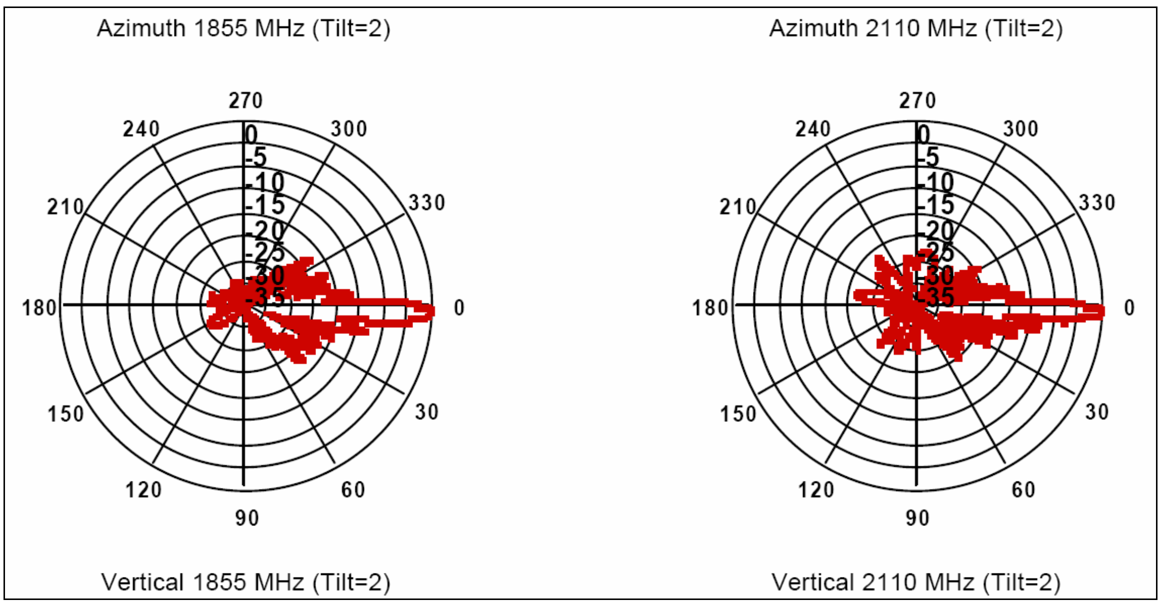

Figure 6. Azimuth Pattern for Andrew UMWD-03319-2D PCS Antenna

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11 TIA/EIA-98-E, Table 3.5.4.2 at p. 3-112.

12 See 3GPP TS 25.101 V6.4.0 (2004-03), March, 2003 at section 7.5.

13 This is a slightly simplified exposition which assumes that the <REFSENS> of the mobile handset is exactly the maximum permitted by the standard.

14 See 3GPP TS 25.101 V6.4.0 (2004-03), March, 2003 at at 7.6.

Figure 6 shows the azimuth pattern for a relatively high-gain (20 dBi) PCS antenna such as might be used in a large, high-power cell.[15] Note, however, that the gain toward the ground near the antenna is substantially reduced from the gain in the main lobe. Looking at the left portion of the figure, one can see that there is a side lobe at about 45 degrees below the horizontal. That side lobe has relative attenuation of about −22 dB.[16]

Consider a PCS system with 20 watts power using such an antenna mounted 30 meters above ground (about 100 feet). On level ground, that 45-degree side lobe would be pointing at a spot on the ground about 42 meters from the antenna. The free space loss over 42 meters at 1930 MHz is 71 dB. Given all this, we can easily calculate the received power as Transmit Power + Transmit Antenna Gain + Free Space Loss + Receive Antenna Gain. The transmit power is 20 watts, or +43 dBm. The antenna gain is −2 dB (22 dB down from the main lobe). For a case such as this, we can assume that the receive antenna gain is unity (0 dB). Combining these factors we have:

Transmit Power	+43 dBm
Transmit Antenna Gain	−2 dB
Space Loss	−71 dB
Receive Antenna Gain	0 dB
Total	−30 dBm

In this example, even in the hot spot near the tower created by the strongest side lobe, the received power only rises to −30 dBm.[17] Moving away from that hot spot would cause

[15] The datasheet for this antenna is available at http://www.decibelproducts.com/productnotebookantenna2.asp?Param=ModelNumber&Model=UMWD-03319-2D&freq=on

[16] That relative attenuation is for the frequency 1850 MHz. Comparing the two parts of the figure, it appears that the attenuation would be greater in the range 1930-1990 MHz, so the calculations here are somewhat conservative.

[17] This analysis has ignored some fine points such as transmission line loss and connector losses at the transmitter and the fact that a handheld mobile would be about 1.5 meters off the ground. Including these factors would complicate the story without making a material difference in the punch line.

the signal level to drop. For example, I calculated that the received signal would drop to −40 dBm at the base of the antenna.

In thinking about the possibility of interference from such strong signals, one must also take into account fact that it is reasonably likely that the desired signal is also quite strong near the tower. PCS antennas are often located together on the same tower. Other times, there are natural locations for towers, such as near a highway intersection, and the carriers build multiple towers in relative close proximity. The technical challenge of building a handset that can receive a −40 or −50 dBm desired signal in the presence of a −30-dBm undesired adjacent-channel signal is far less than the technical challenge of building a handset that can receive a −100 dBm signal in the presence of a −15 dBm undesired adjacent-channel signal.

6. Summary and Conclusion

Tests conducted by WINLAB and PCTEST show that current production PCS handsets would be impaired by H-block transmissions at the levels proposed in the NPRM. Such impairments can be avoided by setting appropriate H-block power limits. The choice of the proper limits depends on the degree of protection desired—with lower limits creating more protection. The table below shows the tradeoff between protection and power limits.

Analysis of H-Block Power Limits

Power Limit	H-Block Power Limit (dBm)	
	High Segment	Middle Segment
Maximum	+1	+4
Medium (Intermodulation and Overload)	+5	+8
Medium (Overload Only)	+13	+16
Minimal (Protects a stronger receive signal level against	+19	+22

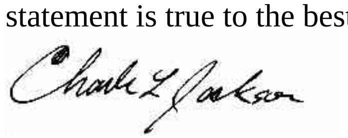
overload only.)

The tests indicated that a higher power limit was appropriate in the middle of the H-block than at the top of the H-block. The tests did not permit determining the appropriate limit for the bottom of the H-block, but that limit can be expected to be higher than the limit in the middle of the H-block. These limits are appropriate for mobile and portable H-block devices. Fixed H-block units, such as a wireless local loop antenna mounted high on the side of a house, could operate at the power levels proposed in the NPRM with only negligible chances of creating interference to PCS handsets.

7. About the Author

Chuck Jackson is an electrical engineer who has worked extensively in telecommunications regulation. He served on the staff of the FCC and of the Commerce Committee of the U.S. House of Representatives. He works as a consultant and is also an adjunct professor of electrical and computer engineering at George Washington University, where he has taught graduate courses about mobile communications, wireless networks, and the Internet. He is a member of the FCC's Technological Advisory Council. Dr. Jackson received his PhD from MIT. A more complete biography is available at www.jacksons.net.

I, Charles L. Jackson, declare under penalty of perjury that the above statement is true to the best of my knowledge and belief.



December 8, 2004

Appendix Data Sources for Figures 2-4

The three tables below contain the data values that were used to construct Figures 2 through 4.

In each case, the harmful level was determined by inspecting the test results and choosing that interfering signal power associated with an increase in the relevant error rate of approximately 1%. The power level that created the increase closest to 1% was chosen. Thus, if I had considered the two (power level, error rate increase) pairs (–28 dBm, 0.8%) and (–27 dBm, 1.3%), I would have put −28 dBm in the table. If the pairs had been (–28 dBm, 0.7%) and (–27 dBm, 1.2%), I would have put −27 dBm in the table. This method of defining the point of impairment facilitates checking the development of this table. The alternative of using interpolation to find the signal level at which the 1% rise occurs would be far harder for a reviewer to check. One should understand that numbers to the right of the decimal point are irrelevant to the analysis presented here.

The *Notes* column in Table 1 indicates the source of the data and the base error rate existing before the interfering signal was added. For example, *WLT10,4.5%* refers to the WINLAB report, Table 10, and a base error report of 4.5%. Similarly, *PCAB4.1.2*, *5%* refers to the PCTEST report, Appendix B, Table 4.1.2, and a base error rate of 5%.

WINLAB provided me with the base error rates for their tests. I used the nominal error rates when analyzing the PCTEST results.

Table 1. Harmful Levels of Signals at the Top of the H-Block

Unit	Interfering Signal Power (dBm)		
	CDMA (1918.75 MHz)	GSM (1919.8 MHz)	Notes
WL-CDMA DUT#1	−25.76	−25.66	WLT10, 4.5%; WLT11, 4.5%
WL-CDMA DUT#2	−27.4	−28.04	WLT20,4.98%; WLT21,4.94%
WL-CDMA DUT#3	−28.01	−29.28	WLT31, 4.68 %; WLT32, 4.68%
WL-CDMA DUT#4	−27.69	−26.6	WLT41, 4.66%; WLT42, 4.66%
WL-GSM DUT#1	−18.82	−17.59	WLT51, 2.09%; WLT52, 2.09%
WL-GSM DUT#2	−18.84	−18.71	WLT59, 1.97%; WLT60, 1.97%
WL-UMTS#1	−27.21	−32.7	WLT68, 4.6%; WLT69, 4.6%
PCTest-CDMA#1	−21.9	-22.4	PCAB4.1.2, 5%; PCAB4.1.4, 5%
PCTest-CDMA#2	−28.5	−23.5	PCAB4.1.2, 5% PCAB4.1.4, 5%
PCTest-GSM#1	−13.9	−1.9	PCAB4.3.1, 2% PCAB4.3.3, 2%
PCTest-GSM#2	−16.4	−10.2	PCAB4.3.1, 2% PCAB4.3.3, 2%

In Table 2, the entries in the right most column include a specification of the source data in the same format as is used in Table 1.

Table 2. Variation of Harmful Signal Level with Changes in PCS Channel

Unit	Channel in Use by Subject PCS receiver	
	Channel 25 CDMA 515 GSM	Channel 450 CDMA 615 GSM
WL-CDMA DUT#1	−25.76	−16.88 WLT13,5%
WL-CDMA DUT#2	−27.4	−18.64 WLT23,4.94%
WL-CDMA DUT#3	−28.01	−22.88 WLT34, 4.68%
WL-CDMA DUT#4	−27.69	−20.19 WLT44, 4.66%
WL-GSM DUT#1	−18.82	−19.71 WLT54, 1.27%
WL-GSM DUT#2	−18.84	−16.22 WLT62, 2.1%
WL-UMTS#1	−27.21	−24.11 WLT71, 4.68%
PCTest-CDMA#1	−21.9	−23.9 PCAB4.1.8, 5%
PCTest-CDMA#2	−28.5	−27.5 PCAB4.1.8, 5%
PCTest-GSM#1	−13.9	−16.9 PCAB4.3.7, 2%
PCTest-GSM#2	−16.4	−17.9 PCAB4.3.7, 2%

In Table 3, the entries in the right most column include a specification of the source data in the same format as is used in Table 1.

Table 3. Variation of Harmful Signal Level with Frequency of Harmful Signal

Unit	Interfering Signal Power (dBm)		
	Top of H-Block 1918.75 MHz	Middle of H-Block 1917.5 MHz	Top of PCS Band 1908.75 MHz
WL-CDMA DUT#1	−25.76	−24.13 WLT12, 4.5%	+11.6 WLT14,5%
WL-CDMA DUT#2	−27.4	−27.65 WLT22, 4.76%	-3.9 WLT24,5%
WL-CDMA DUT#3	−28.01	−26.26 WLT33, 4.98%	3.0 WLT35,5%
WL-CDMA DUT#4	−27.69	−25.7 WLT43, 4.66%	-0.2 WLT45,5%
WL-GSM DUT#1	−18.82	−17.45 WLT53, 2.09%	−6.28 WLT55,2%
WL-GSM DUT#2	−18.84	−16.84 WLT61, 1.97%	−6.48 WLT63,2%
WL-UMTS#1	−27.21	-17.72 WLT70, 4.6%	-1.1 WLT72,2% (may be higher)
PCTest-CDMA#1	−21.9	−11.9 PCAB4.1.6, 5%	+14.4 PCAB4.1.10, 5%
PCTest-CDMA#2	−28.5	−18 PCAB4.1.6, 5% (interpolated)	+7.9 PCAB4.1.10, 5%
PCTest-GSM#1	−13.9	−12.9 PCAB4.3.4, 2%	−8.7 PCAB4.3.9, 2%
PCTest-GSM#2	−16.4	−16.7 PCAB4.3.4, 2%	−7.3 PCAB4.3.9, 2%