Evaluating Cell Phone and Personal Communications Equipment and their EMC Effects on Automotive Audio and In-Cabin Modules

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I. Introduction

Today, the use of cell phones and other personal communications devices has expanded to every corner of the world: in households, on street corners, in restaurants, in elevators, in libraries, and in hospitals. However, in terms of the cell phone usage explosion, no other location compares to the automobile.

Along with the increase in cell phone use in automobiles, technology has continued to advance making cell phones smaller and smaller. The newer and smaller cell phones can be placed virtually anywhere within the cabin of the vehicle. As a result, cell phones are now being placed in unforeseen locations and often in close proximity to in-cabin electronic modules, giving rise to potential interference and compatibility issues. Many interference issues occur during an incoming call where the cellular service provider site and the cell phone are interacting with each other to initiate the call. In some instances, the result is an annoying interference heard through the vehicle sound system.

The purpose of this R&D project was to identify the threats posed to vehicle in-cabin electronic modules by cellular phones and personal communications devices. The goal was to determine which types of radiated immunity tests, test levels, and carrier signal modulations, will effectively identify potential compatibility issues at the module test level before it reaches the vehicle.

Present and future personal communications technologies, in the 800 MHZ to 2.5 GHz frequency range, were evaluated as part of this study. From the evaluation, a summary of the frequency spectrums, modulations and output power levels used by these personal communications technologies was generated.

In-cabin vehicle modules were selected as a control group for comparison testing. The samples selected had known compatibility issues with cell phones when installed in the vehicle.

Various types of radiated immunity tests were performed on the selected modules. Test parameters were based upon the information gathered during the personal communications technologies evaluation. The testing was performed to determine if the effects experienced at the vehicle level could be replicated at the module test level in a laboratory environment.

Finally, suggested test levels and carrier modulations were established for each type of module radiated immunity test that was effective in finding compatibility issues similar to those experienced in the vehicle. These tests could be used during module level evaluation in order to identify potential compatibility issues before they reach the vehicle.

II. Applicable Standards

Several Automotive and Commercial specifications were referenced during this project. The standards that will be referenced and/or discussed in this paper include the following:

- ISO-11452-1 [1]
- ISO 11452-2 [2]
- SAE J1113-21 [3]
- ISO/DIS 11451-3 [4]
- ISO/CD 11452-9 [5]

III. Evaluation of Present and Future Personal Communications Used by Consumers

Present and future personal communications technologies, in the 800 MHZ to 2.5 GHz frequency range, were evaluated during this study. This investigation utilized experts in the field of FCC certification, in conjunction with EMC experts. The experts in FCC certification provided frequency ranges, modulation characteristics and output power levels currently utilized by personal communications devices. These experts also provided additional information in regards to future services currently under development. The EMC experts reviewed published and draft SAE and ISO standards for test methods that are already used in the automotive industry. The EMC experts referenced ISO/DIS 11451-3 during this portion of the project. The summary of the technology review is shown in Table 2.

IV. Modules Selected For Testing

Electronic modules with known cell phone compatibility issues in the vehicle were selected as a control group for testing. Since these items had known in-vehicle issues, they made good subjects for the investigational testing at the module level in a laboratory environment. Using test methods of ISO 11452-2, SAE J1113-21 and ISO/CD 11452-9, the samples were subjected to the interfering frequencies, modulations and power levels established during the technology review, as summarized in Table 2.

The test samples selected are described below:

Radios: Two AM/FM/CD automobile entertainment radios were provided for testing purposes. A radio designated as "Original Radio", was the initial design that demonstrated cell phone compatibility issues at the vehicle level. When a vehicle user placed a cell phone in the small dashboard storage compartment, located under the radio, the radio experienced a reset condition when the cell phone rang. Another radio designated as "Improved Radio", was an improved design of the Original Radio that corrected the vehicle compatibility issue. The radios were only monitored for a reset condition during the testing. No monitoring of the audio output was utilized during testing of the radios.

Amplified Speaker: An amplified speaker, used in vehicle applications for many years, was also provided for testing purposes. Audio interference can be heard from the amplified speaker during cell phone operation within the vehicle. The speaker was monitored for audible interference during the testing.

Electronic Control Module: An electronic control module, used in vehicle applications, was also evaluated during this project. This module is an electronic device used by the driver to select vehicle functions. Pursuant to the OEM requirements, this module was subjected to ISO 11452-2 radiated immunity testing during production validation. A 150 V/m, pulse modulated, radiated immunity test in the frequency range of 1000 MHz to 3000 MHz was performed in addition to a test with AM modulation. The module showed no signs of susceptibility during the radiated immunity tests required by the OEM. A compatibility issue was detected at the vehicle level when a call was made to a cell phone placed in a location very close to the device. During this project, the module was subjected to additional pulse modulated ISO 11452-2 radiated immunity testing in the frequency range of 800 MHz to 3000 MHz.

V. Testing Performed

ISO/CD 11452-9 Type Test With ¼ Wavelength Sleeve Antennas: The Original Radio, Improved Radio, and Amplified Speaker were subjected to complex GSM850, GSM1900, iDEN, D-AMPS, and CDMA modulated interfering signals using an HP signal generator (Model E4432B w/ options UN3, UN5, and UND), in conjunction with an RF amplifier and a ¼ wavelength sleeve antenna. The samples were also tested, utilizing the same power levels and antennas, while using the pulse modulations discussed in ISO/DIS 11451-3. The ¼ wavelength sleeve antenna is a custom built monopole antenna that is typically used for "simulated handheld transceiver" radiated immunity testing on automotive modules. Table 1 shows the list of frequencies used during the tests. Table 2 shows the modulations and power levels used during the tests. The test item and harness were elevated 5cm above a reference ground plane for this test series. Tests were performed with the transmitting antenna located 2 cm, 5 cm, and 10 cm from the bottom surface of the radio or top surface of the amplified speaker. Tests with the antenna located 5 cm and 10 cm away from the DUT (Device Under Test) were performed only when effects were observed at the 2 cm test distance.

The Original Radio design showed signs of susceptibility when exposed to interfering signals with complex and ISO pulse GSM850, iDEN, D-AMPS, and CDMA (800-1000MHz) modulations. The effects occurred at the 2 cm, 5 cm and 10 cm test distances. All effects noted were self-recoverable (Status II Response).

The Improved Radio design provided much better results than the Original Radio design. The Improved Radio design showed signs of susceptibility when exposed to interfering signals with complex and ISO pulse GSM850, D-AMPS, and CDMA (800-1000MHz) modulations. The effects occurred only at the 2 cm test distance. No effects were noted at the 5 cm and 10 cm test distances. All effects noted were self-recoverable (Status II Response).

The Amplified Speaker showed signs of susceptibility when exposed to interfering signals with complex and ISO pulse GSM850, iDEN, D-AMPS and CDMA (800-1000MHz) and Bluetooth modulations. The effects occurred at the 2 cm, 5 cm and 10 cm test distances. All effects noted were self-recoverable (Status II Response).

The test results revealed that this "simulated handheld transceiver" test of ISO/CD 11452-9 could be effectively used during module testing to find potential RF compatibility issues before they reach the vehicle. In addition, the pulse modulations suggested in the ISO/DIS 11451-3 and ISO/CD 11452-9 standards, which simulate complex modulations, proved adequate for laboratory testing purposes. This eliminates the need for a costly RF signal generator capable of generating complex personal communications modulations. A common RF generator with pulse RF modulation capabilities would be sufficient for laboratory test purposes. In addition, the extremely low power of the Bluetooth and Zigbee technologies were not an issue with devices that were extremely sensitive to the higher power simulated cell phone tests. Theses low power technologies represent a low threat and most likely do not need evaluation during module testing.

ISO/CD 11452-9 Type Test With Commercially Available Cell Phone Antennas: The ¼ wavelength sleeve antennas used during the previous tests are custom built devices. Commercially available magnetic mount cell phone antennas were utilized during these tests to evaluate their effectiveness. The commercial antennas had an advertised

VSWR of better that 2:1, a gain of approximately 6 dBi and were capable of handling 50 watts. Possible ground plane and antenna positioning issues, which could have effected the ¼ wavelength sleeve antenna test results, were addressed during this test series. For this testing, the ground plane was removed and the test item was set up per SAE J1113-21 Para 8.1 (ALSE without a ground plane).

The Original Radio was tested to all Table 2 conditions previously evaluated. The Improved Radio was only tested at the frequency/modulation combinations where effects were noted during the ¼ wavelength sleeve antenna testing. After comparing the ¼ wavelength sleeve antenna and commercially available antenna test results on the radios, the experts decided not to test the Amplified Speaker. The radio test result differences were not significant enough to warrant testing on the amplified speaker.

The pulse modulations proposed in Annex A of the ISO/DIS 11451-3 adequately simulated the actual complex modulations during the ¼ wavelength sleeve antenna tests. Therefore, only the ISO pulse modulations were used during these tests. The complex modulations capable with the HP E4432B generator were not used during this test. Table 1 was again referenced to determine the test frequencies. Table 2 was referenced to determine the modulations and power levels used for this abbreviated test.

During this test, each of the six sides of the DUT and the cable harness was tested. The DUT was rotated so that the side being tested was facing up. Each DUT side was swept at a 2 cm test distance. The commercially available cell phone antenna was oriented in two directions and parallel with the side being tested. Tests with the antenna located 5 cm and 10 cm away from the DUT were performed only when effects were observed at the 2 cm test distance.

The Original Radio design showed signs of susceptibility when exposed to interfering signals with ISO pulse GSM850 and D-AMPS modulations. The effects occurred at the 2 cm, 5 cm and 10 cm test distances on the bottom side of the radio. The extreme sensitivity with the antenna located at the bottom of the radio correlated well with the issue seen in the vehicle. All effects noted were self-recoverable (Status II Response).

The Improved Radio design provided much better results than the Original Radio design. The Improved radio showed signs of susceptibility when exposed to interfering signals with ISO pulse GSM850 and D-AMPS modulations. The effects occurred only at the 2 cm test distance on the bottom side of the radio. No effects were noted at the 5 cm and 10 cm test distances. All effects noted were self-recoverable (Status II Response).

The test results revealed that this "simulated handheld transceiver" test of ISO/CD 11452-9, using commercially available magnetic mount antennas, could be effectively used during module testing to find potential RF compatibility issues before they reach the vehicle. The use of commercially available antennas eliminates the need to custom build ¼ wavelength sleeve antennas. Depending upon the criticality of the module function, Status I (no effect) or Status II (self recoverable) response performance criteria would be required at the 2 cm test distance. If the cell phone can be located within 2 cm of the vehicle mounted module, a Status I response performance criteria is suggested at the 2 cm test distance. If the cell phone can be located within 5 cm of the vehicle mounted module, a Status I response performance criteria is suggested at the 5 cm test distance and a Status II response is suggested at 2 cm.

<u>Field Strength Measurements from Commercial Antennas and SAR Evaluations of Cell Phones:</u> The electric field strengths produced by the commercially available antennas were measured to determine the field intensities that were being applied to the modules during the "simulated handheld transceiver" tests. Field strength measurements were obtained from the commercial antennas at the frequencies and power levels used during the tests. The field strength was measured with an isotropic electric field probe located at distances of 2 cm, 5 cm, and 10 cm away from the antenna. Table 2 identified the power to be applied to the antenna, and the RF signal was CW (continuous wave). The results of these measurements are shown in Table 1. The field strength measurement data will be used to determine suggested test field intensities for pulse modulated ISO 11452-2 or SAE J1113-21 radiated immunity testing above 800 MHz.

Cell phone SAR measurement data, from submittals for FCC certification, were also evaluated to compare actual cell phone data to the field intensities produced by the commercial antennas. The SAR measurement shows the Specific Absorption Rate of body tissue located in close proximity to the cell phone and is used to determine FCC acceptance of the product. SAR evaluations are typically done at a test distance of 0.5 cm (5 mm). During SAR measurements, most systems show the SAR amplitude in w/kg and the resultant field intensity in V/m. In general, review of SAR measurements made on several cellular phones showed field intensities of approximately 100 V/m at a test distance of 0.5 cm and with an output power of approximately 2 watts (both 800-1000 MHz and 1800-2000 MHz frequency ranges). These numbers provided additional information for determining suggested ISO 11452-2 or SAE J1113-21 radiated immunity test levels.

Based upon the field strengths measured from the commercial antennas and the cell phone SAR data, if Status I response performance is desired for a cell phone to vehicle mounted module separation distance of approximately 5 cm, then in-cabin vehicle modules should be subjected to pulse modulated radiated immunity test levels of 70 V/m. If the cell phone can be located within 2 cm of the vehicle mounted module, a Status I response field intensity of at least 100V/m would be suggested. This is applicable to both the 800-1000 MHz and 1800-2000 MHz frequency ranges.

ISO 11452-2 or SAE J1113-21 Type Test: This test was performed to compare the results of ¼ wavelength sleeve and commercially available antenna tests to the ALSE w/o Ground Plane radiated immunity test in Section 8 of SAE J1113-21. These tests were performed with the interfering signal CW and with the Pulse Modulation (217 Hz period with a 12% duty cycle) discussed in the ISO/DIS 11451-3 and ISO 11452-1 standards. The test item was set up per Figure 4 of SAE J1113-21. The transmitting antenna was oriented in the vertical polarization for these tests. Typically, this direct illumination test is performed in three DUT orientations (three axis test). Due to chamber availability constraints, this experimentation was conducted in one DUT orientation. The radios were tested with the main circuit board parallel to the chamber floor, in the vehicle mounted position, and rotated so that the wiring harness connector faced the antenna. The amplified speaker was oriented with the main circuit board perpendicular to the chamber floor and broadside to the antenna.

Initial tests were conducted on the radios and amplified speaker in the 200 MHz to 1000 MHz frequency range. A test field intensity level of 70 V/m was selected to evaluate their performance. This test level selection was based on the fields measured from the commercially available antennas and the cell phone SAR data review. The tests were performed from 200 MHz to 1000 MHz with a CW interfering signal. The radios and the amplified speaker were tested individually. The Original Radio, which was extremely sensitive during ISO/CD 11452-9 "simulated handheld transceiver" tests, showed signs of susceptibility to the interfering signal in the 945 MHZ to 970 MHz frequency range. All effects noted were self-recoverable (Status II Response). The Improved Radio and Amplified Speaker showed no signs of susceptibility when they were subjected to the CW interfering signals at 70V/m.

Additional radiated immunity tests were performed on the radios and the amplified speaker in the 200 MHz to 2000 MHz frequency range. The interfering RF signal was pulse modulated (217 Hz period with a 12% duty cycle) during these tests. This pulse modulation is referenced in ISO/DIS 11451-3 and ISO 11452-1 and simulates the complex modulations of cell phones. The radios and the amplified speaker were tested individually.

The Original Radio design showed signs of susceptibility during the pulse modulated tests. Due to the numerous response frequencies, effects were recorded but thresholds were not taken. It appeared that the effects occurred at levels less than 35 V/m (½ the 70 V/m test level) since the unit was still responding during the changing and leveling of each frequency. This was evident since the test software dropped the power by 6 dB before stepping to the next frequency. This shows that the Original Radio design would have had compatibility issues at levels less than 35 V/m. All effects noted were self-recoverable (Status II Response).

No effects were seen from the Improved Radio design during the pulse modulated tests. The Improved Radio was only monitored for the reset condition response that was experienced at the vehicle level. If the audio output had been monitored, then the audio interference could have been present during the pulsed modulated tests.

The Amplified Speaker showed signs of susceptibility during the pulse modulated tests. Audio interference was present throughout the entire test frequency range during the pulse modulation tests. Due to the numerous response frequencies, effects were recorded but thresholds were not taken. It appeared that the effects occurred at levels less than 35 V/m (½ the 70 V/m test level) since the unit was still responding during the changing and leveling of each frequency. This was evident since the test software dropped the power by 6 dB before stepping to the next frequency. This shows that the Amplified Speaker would have had compatibility issues at levels less than 35 V/m. All effects noted were self-recoverable (Status II Response).

The Electronic Control Module was also evaluated during a series of ISO 11452-2 (with Ground Plane) type tests. Per OEM requirements, this electronic control module was subjected to ISO 11452-2, 150 V/m, pulse modulated, radiated immunity tests in the frequency range of 1000 MHz to 3000 MHz during the production validation tests. The unit showed no signs of susceptibility during the OEM required module radiated immunity test.

A retest of the Electronic Control Module was performed in the frequency range of 800 MHz to 3000 MHz. After two modifications were made to the original test, the DUT showed signs of susceptibility consistent with the vehicle response in the frequency range of 812 MHz to 900 MHz. To recreate the vehicle effect, repositioning of the transmitting antenna for direct illumination of the DUT and three axis testing of the DUT was necessary. The lowest threshold level measured in the frequency range of response was 68 V/m. This test showed that pulse modulated radiated immunity testing, with the transmitting antenna positioned for direct illumination of the DUT, and with the DUT tested in three axis, should be considered at frequencies above 800 MHz.

The test results show that ISO 11452-2 or SAE J1113-21 radiated immunity tests, using pulse modulated signals above 800 MHz, could be effectively used during module testing to find potential RF compatibility issues before they reach the vehicle. A Status I response test level required for these pulse modulated tests should be at least 70 V/m, based upon minimum cell phone to module separation of 5 cm. Testing at 100 V/m is suggested if separation can be 2cm.

VI. Summary Of Project Findings

The results of the various tests performed show the importance of subjecting audio and in-cabin modules to pulse modulated radiated immunity tests. The testing performed on the modules described in this study exposed potential cell phone EMC issues. Pulse modulated radiated immunity testing at the module level, in the 800-1000 MHz and 1800-2000 MHz frequency ranges, is necessary to find potential RF compatibility issues before they reach the vehicle.

Module testing showed that personal communications technologies, with power levels of 0.7 watts and greater, created compatibility and interference issues consistent with issues seen in the vehicle. Personal communications technologies with power levels of 0.1 watts and less represent a low risk threat and may not need evaluation during module radiated immunity testing.

Comparison testing, using complex modulations produced by specialized RF signal generators and the pulse modulations suggested in the ISO/DIS 11451-3 standard, showed that a 217 Hz period with a 12% duty cycle pulse modulation is effective for laboratory testing purposes. This eliminates the need for a costly RF signal generator capable of generating complex personal communications modulations.

The ISO/CD 11452-9 "simulated handheld transceiver" tests proved effective in finding potential RF compatibility issues at the module test level. Depending upon the criticality of the module function, Status I (no effect) or Status II (self recoverable) response performance criteria would be required at the 2 cm test distance. If the cell phone can be located within 2 cm of the vehicle mounted module, a Status I response performance criteria is suggested at the 2 cm test distance. If the cell phone can be located within 5 cm of the vehicle mounted module, a Status I response performance criteria is suggested at the 5 cm test distance and a Status II response is suggested at 2 cm.

The ISO 11452-2/SAE J1113-21 tests also proved effective in finding potential RF compatibility issues at the module test level. Three axis testing of the DUT, with the transmitting antenna positioned for direct illumination, should be considered for these tests above 800 MHz. Status I response performance requirements should be a minimum of 70 V/m for the pulse modulated tests (based upon a 5 cm separation distance of the cellular phone and the module). If Status I operation is desired with the cell phone located within 2 cm of a module, then a Status I field intensity requirement of at least 100 V/m would be suggested.

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References

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Frequency (MHz)	Type of Modulation	Net Power (Watts)	2 cm Field Intensity (V/m)	5 cm Field Intensity (V/m)	10 cm Field Intensity (V/m)
824.0	GSM 850	7	94.0	67.0	47.2
836.5	GSM 850	7	95.2	69.6	51.4
849.0	GSM 850	7	92.2	70.6	52.2
869.0	GSM 850	7	85.4	67.8	54.6
881.5	GSM 850	7	87.2	70.4	58.6
894.0	GSM 850	7	82.8	67.8	59.4
1850.0	GSM 1900	2	42.0	39.8	34.2
1880.0	GSM 1900	2	42.4	42.2	36.8
1910.0	GSM 1900	2	40.4	39.0	37.8
1930.0	GSM 1900	2	41.6	40.2	37.2
1960.0	GSM 1900	2	43.8	40.2	34.4
1990.0	GSM 1900	2	49.6	44.6	35.4
806.0	iDEN	0.7	32.3	22.9	15.7
815.5	iDEN	0.7	32.4	23.0	15.6
825.0	iDEN	0.7	32.6	23.4	16.2
896.0	iDEN	0.7	26.8	22.4	18.8
898.5	iDEN	0.7	27.2	22.2	19.0
901.0	iDEN	0.7	27.6	22.2	18.8
824.0	D-AMPS	7	97.8	71.2	50.0
836.5	D-AMPS	7	96.2	74.0	54.6
849.0	D-AMPS	7	93.6	70.4	53.0
869.0	D-AMPS	7	85.2	67.0	55.2
881.5	D-AMPS	7	86.0	69.4	58.2
894.0	D-AMPS	7	82.8	68.2	59.6
868.3	Bluetooth	0.1	10.2	8.2	6.6
902.0	Bluetooth	0.1	10.5	8.5	7.0
915.0	Bluetooth	0.1	11.2	8.6	7.1
928.0	Bluetooth	0.1	10.9	8.7	6.8
2402.0	Bluetooth	0.1	11.6	10.9	9.1
2442.0	Bluetooth	0.1	10.4	10.3	9.6
2483.5	Bluetooth	0.1	8.9	9.0	8.9
902.0	Zigbee	0.01	3.4	2.7	2.4
915.0	Zigbee	0.01	3.6	2.9	2.3
928.0	Zigbee	0.01	3.6	2.9	2.2
2402.0	Zigbee	0.01	3.8	3.6	3.0
2442.8	Zigbee	0.01	3.5	3.5	3.1
2483.5	Zigbee	0.01	2.9	3.1	2.9
2402.0	WiFi	1	36.6	34.4	29.4
2442.8	WiFi	1	32.8	33.2	29.2
2483.5	WiFi	1	26.0	28.2	27.4

Table 1 – Frequencies of Test and Fields Generated by Commercial Magnetic Mount Antennas

Type of Modulation	Group	Frequency Range (MHz)	Modulation Characteristics	ISO11451-3 Test Modulation	Typical Output Power (Watts)	Bandwidth
GSM 850(US/CAN) 900(Worldwide)	Cellular Telephone Technology	824-849, 869-894, 890-915,935-960	GMSK	PM 217Hz, 50% duty cycle or PM 217Hz, Ton = 577µs, t=4600µs	7	300kHz
GSM 1900(US/CAN) 1800(Worldwide)	Cellular Telephone Technology	1850-1910, 1930-1990, 1710-1785,1805-1880	GMSK	PM 217Hz, 50% duty cycle or PM 217Hz, Ton = 577µs, t=4600µs	2	300kHz
iDEN	Cellular Telephone Technology	806-825, 896-901	TDMA	PM 50 Hz, 50% duty cycle	0.7	25kHz
NADC (D-AMPS)	Cellular Telephone Technology	824-849, 869-894	TDMA	PM 50 Hz, 50% duty cycle	7	30kHz
CDMA	Cellular Telephone Technology	824-849, 869-894	CDMA (White Gaussian Noise)	CDMA/OFDM	7	1.25MHz
CDMA	Cellular Telephone Technology	1850-1910, 1930-1990	CDMA (White Gaussian Noise)	CDMA/OFDM	2	1.25MHz
CDMA2000	Cellular Telephone Technology	824-849, 869-894	CDMA (White Gaussian Noise)	CDMA2000/OFDM	7	1.25MHz
CDMA2000	Cellular Telephone Technology	1850-1910, 1930-1990	CDMA (White Gaussian Noise)	CDMA2000/OFDM	2	1.25MHz
EDGE	Cellular Telephone Technology	824-849, 869-894	GMSK	PM 217Hz, 50% duty cycle or PM 217Hz, Ton = 577µs, t=4600µs	7	300kHz
EDGE	Cellular Telephone Technology	1850-1910, 1930-1990	GMSK	PM 217Hz, 50% duty cycle or PM 217Hz, Ton = 577µs, t=4600µs	2	300kHz
W-CDMA	Cellular Telephone Technology	824-849, 869-894	CDMA (White Gaussian Noise)	W-CDMA/OFDM	7	5MHz
W-CDMA	Cellular Telephone Technology	1850-1910, 1930-1990	CDMA (White Gaussian Noise)	W-CDMA/OFDM	2	5MHz
UMTS	Cellular Telephone Technology	824-849, 869-894	CDMA (White Gaussian Noise)	UMTS/OFDM	7	4.9MHz
UMTS	Cellular Telephone Technology	1850-1910, 1930-1990	CDMA (White Gaussian Noise)	UMTS/OFDM	2	4.9MHz
Bluetooth	Personal Area Networks	868.3, 902-928, 2402-2483.4	QPSK	PM 1,600 Hz, 50 % duty cycle	0.1	1MHz
Zigbee	Personal Area Networks	902-928, 2402-2483.5	QPSK	PM 1,600 Hz, 50 % duty cycle	0.01	3MHz
WiFi	Local Area Networks	902-928, 2402-2483.5, 5150-5350, 5725-5850	QPSK	PM 1,600 Hz, 50 % duty cycle	1	200kHz-2MHz
WiMax	Wide Area Networks	2000-11000, 10000-66000	OFDM	In Development	In Development	In Development
UWB	Wide Area Networks	3100-10000	OFDM	In Development	-41dBm/MHz	500MHz

Table 2 - Personal Communications Technology Summary