Analysis of Immunity by RF Wireless Communication Signals

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Abstract— Despite of widespread use of new digital wireless communications, the radiated immunity test based on IEC 61000-4-3 only has been performed with using amplitude modulation (AM) signal. In this study, we have analyzed the radiated immunity test method that is going on recent standardization activity to investigate close proximity fields from radio frequency (RF) wireless communications and have investigated the impact of digitally modulated signals. The results show that the devices were influenced much more by digital modulation signal than by AM or pulse modulation (PM) signal. Also it shows that we need to investigate the depth research on radiated immunity testing for the environment of modern communication technology.

1. INTRODUCTION

Recently, portable wireless communication devices as wireless phone, smart phone and wireless local area network (WLAN) have come into widespread use and acceptance. Along with the increase of intentional radiated RF by those devices the everyday electromagnetic environment has greatly changed. New technology has continued to advance making mobile phones smaller and smaller. The newer and smaller mobile phones can be placed virtually anywhere in our living place and are often being placed in close proximity to electronic equipment, giving rise to potential interference and compatibility issues.

The achievement of adequate immunity of electrical or electronic equipment is a basic provision to ensure electromagnetic compatibility (EMC) in these circumstance. Such immunity has reflect the expected electromagnetic disturbance at the intended location of operation as well as the characteristics of the equipment. The corresponding immunity levels are determined taking into account for a probabilistic aspects of a disturbance and an economical aspects of immunity test. Such a process is currently being performed by a working group of IEC TC 77 [1].

Because the new technologies, such as long term evolution (LTE) and WLAN, use a very large range of the frequency spectrum it is necessary to use different test methods which consider the physical behavior of magnetic coupling in the lower frequency range and the more electrical based characteristic in the higher frequency range. Immunity testing according to existing standards, such as IEC 61000-4-3, may not be suitable to assess compatibility with the complex electric and magnetic fields generated by RF emitters located in close proximity. There are two kinds of new standardization work being performed in SC77B WG10. One is IEC 61000-4-31 to test broadband conducted disturbance immunity and the other is IEC 61000-4-39 to test radiated fields immunity in close proximity [2]. The revision of IEC 60601-1-2, immunity standard for medical equipment and systems, has also recently been done in IEC TC62/SC62A and has including immunity to proximity fields from RF wireless communication equipment [3].

Recent wireless communications use a digital modulation technology. In these standards, the AM signal is mainly used to reference source signal to test the radiated immunity. But, the wireless communication signal is being simulated simply into a PM signal. According to recent research results, it has known that an equipment were influenced by digital modulation signal more than by AM or PM signal [4].

In this study, we have investigated by reviewing an immunity standards in close proximity which is recently being standardized in IEC. We have then analyzed the characteristics of the reference source signal for a radiated immunity test in those standards and compared with those of mobile communication signal. We have verified the influence of digital modulation signal through the FTP throughput test has performed in Gigahertz Transverse Electromagnetic cell (GTEM). Finally, we have proposed that it should be consider to use a digital modulation signal during standardizing of new radiated immunity test.

2. STANDARDIZATION ACTIVITIES OF CLOSE PROXIMITY IMMUNITY

2.1. IEC 61000-4-39

The use of portable wireless devices has increased sharply due to the widespread diffusion of portable wireless communication services such as mobile communication and WLAN, which in turn increased the possibility of such devices affecting other devices due to the intentional electromagnetic interference of portable wireless devices.

To reflect those conditions, IEC TC77 decided to create a new standard for the close proximity immunity test, beyond the existing IEC 61000-4-3 radiated immunity standard. The standardization work is performed by SC77B/WG10, with the active participation of experts.

This standard defines immunity test procedures and specifications with regard to the reference source signal, test level, and test method for the close proximity immunity test. The following areas are currently standardized:

- Test levels related with the magnetic field immunity and radiated RF field immunity.
- Test equipment.
- Test setup including test facility and arrangement of equipment.
- Test conditions, detailed test procedure, and verification method.
- Evaluation of test results and test report.

The electromagnetic disturbances specified in this standard are limited to continuous narrowband signals (which may be pulse- or amplitude modulated by up to 1 kHz) but do not include disturbance signals that are basically transient or impulsive in nature. The frequencies or frequency bands to be selected for testing are limited to those where mobile radio telephones or other intentional RF emitting devices actually operate. Testing shall not be applied continuously over the entire frequency range covered by this standard.

Several test levels are defined for inhomogeneous fields in the frequency range of 9 kHz to 30 MHz and for RF fields in the frequency range of 400 MHz to 6 GHz. The test level applied during testing should be selected in accordance with the expected maximum output power of the portable transmitting device and the likely, or specified, separation distance between its transmitting antenna and the equipment subject to the disturbance created by the transmitting device.

For testing of equipment the carrier signal is modulated using pulse modulation. The pulse modulation shall adhere to the following parameters:

- Duty Cycle: 50%.
- Modulation frequency: 2 Hz, 217 Hz or 1 kHz.

2.2. IEC 60601-1-2

The medical equipment EMC standard, which has recently been revised, added the immunity test in the proximity field of wireless communications. The revised standard defined the immunity test specifications for the test frequency, modulation signal, and test level related with the latest representative wireless communication service.

Table 1 shows the test specifications for the proximity immunity of medical equipment, which specifies that the immunity test should be performed at the center frequency or three frequencies of the band, considering the bands of wireless communication services. The specification also defines that the additional test can be run at another frequency.

It is also defined that the test level should be determined after considering the minimum separation distance and maximum output of the wireless communication devices. Minimum separation distances for higher IMMUNITY TEST LEVELS shall be calculated using the following equation:

$$E = \frac{6}{d}\sqrt{P}$$

where P is the maximum power in W, d is the minimum separation distance in m, and E is the IMMUNITY TEST LEVEL in V/m.

Most of the standards define the reference immunity signal as a PM signal, in order to simulate the latest wireless communication signal.

This simplified modeling of the reference signal is based on an opinion that it is impossible to configure the cost-effective test conditions and set up all wireless communication services in the world using the real modulation signal, even though modulation makes a major contribution to causing electromagnetic interference in equipment.

Table 1: Test specifications for proximity immunity of medical equipment to RF wireless communications equipment.

Service	**Band (MHz)**	**Test frequency (MHz)**	**Modulation**	**Test level (V/m) at 0.3 m distance**
TETRA 400	380–390	385	PM 18 Hz	27
GMRS 460, FRS 460	430–470	450	FM ±5 kHz deviation 1 kHz sine	28
LTE Band 13, 17	704–787	710, 745, 780	PM 217 Hz	9
GSM 800/900, TETRA 800, iDEN 820, CDMA 850, LTE Band 5	800–960	810, 870, 930	PM 18 Hz	28
GSM 1800; CDMA 1900; GSM 1900; DECT; LTE Band 1, 3, 4, 25; UMTS	1700 –1990	1720, 1845, 1970	PM 217 Hz	28
Bluetooth, WLAN 802.11 b/g/n, RFID 2450, LTE Band 7	2400–2570	2450	PM 217 Hz	28
WLAN 802.11 a/n	5100–5800	5240, 5500, 5785	PM 217 Hz	9

3. ANALYSIS OF THE CHARACTERISTICS OF THE SIMULATED PULSE MODULATION SIGNAL

The radiated immunity standard uses the PM signal to simulate the latest mobile communication signal because it is cost effective and easy to implement.

The modulation frequency simulated in the standard refers to the frequency that is selected to simulate the frame transmission cycle of the time division multiple access (TDMA), which sends a signal to a particular time slot only, into the pulse signal. The entire TDMA frame rate can be mapped to the pulse signal frequency, and the time slot rate can be mapped to the duty cycle of the pulse signal. In the global system for mobile (GSM), a frame with time duration of 4.61 ms is divided into 8 slots of each 0.577 ms, which is the basic transmission unit. PM 217 Hz simulates GSM's transmission cycle, RF frame length, and 4.61 ms.

LTE, the latest mobile communication standard, uses orthogonal frequency division multiple access (OFDMA) as a modulation method. As OFDMA uses different time slots for the frequency and time domain, LTE can also simulate the multi-access time frame using pulse signals. The radio frame of LTE has time duration of 10 ms in the time domain. A frame is divided into 20 slots of each 0.5 ms. However, the simulated pulse frequency is slightly different from the LTE frame in the standard. Table 2 shows the characteristics of each communication signal and the frequency of

Table 2: Characteristics of each communication signals and simulated PM.

	GSM	LTE	WLAN
Frame rate	4.61 ms, 480 ms (at discontinuous transmission mode)	10 ms	1 ms
Time slot length (Duty cycle)	0.577 ms (1/8)	1 ms (1/10)	96 µs
Fundamental frequency of frame	217 Hz, 2.08 Hz	100 Hz	1 kHz
Simulated PM frequency on Std.	217 Hz, 2 Hz	217 Hz	217 Hz, 1 kHz

each simulated reference immunity signal.

The PM signal includes wide spurious due to the characteristics of the spectrum, which acts as an obstructive factor that causes interference to the audio system [5]. Figure 1 shows the PM frequency spectra defined by the new close proximity immunity standard IEC 61000-4-39. As the spectra exist within 2 kHz, which is the audible frequency band, it can cause a sound effect similar to 1 kHz AM (the standard analog immunity signal). Therefore, the PM simulation is valid as a reference signal to test the sound interference effect.

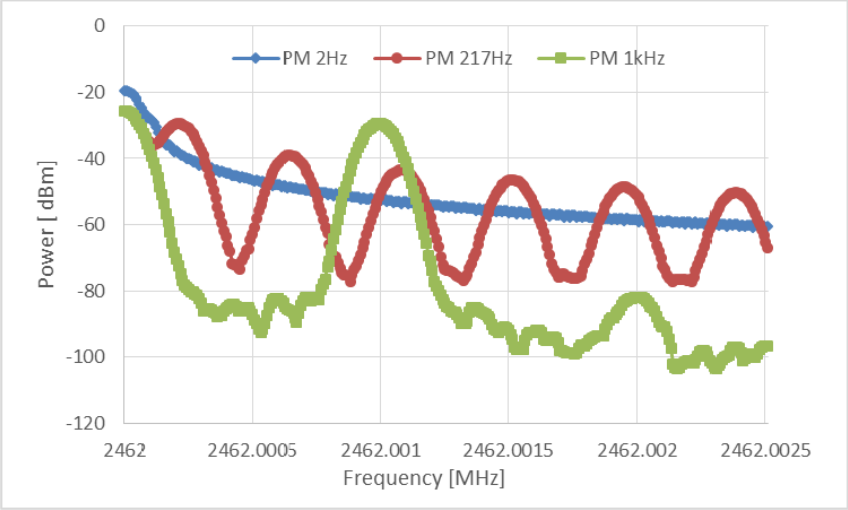

Figure 1: PM spectra simulated in IEC 61000-4-39.

4. CHARACTERISTICS ANALYSIS OF THE DIGITAL MODULATION SIGNAL

The latest mobile communication mainly uses the OFDM modulation method for high-speed transmission. Although the OFDM modulation increases spectral efficiency using the orthogonal frequencies, phase shift keying (PSK) modulation scheme is used as a basic data modulation method. The characteristics of the PSK modulation signal are fundamentally different from the PM signal that simulates mobile communication signal in the immunity standard.

The PM signal theoretically has a sector in which no signal exists in the time domain, and spectral discontinuity in the frequency domain depending on the duty cycle. On the other hand, the PSK signal has the modulation characteristic that the data and phase are mapped. Therefore, there is no sector in the PSK signal in which the signal is disconnected in the time domain, and

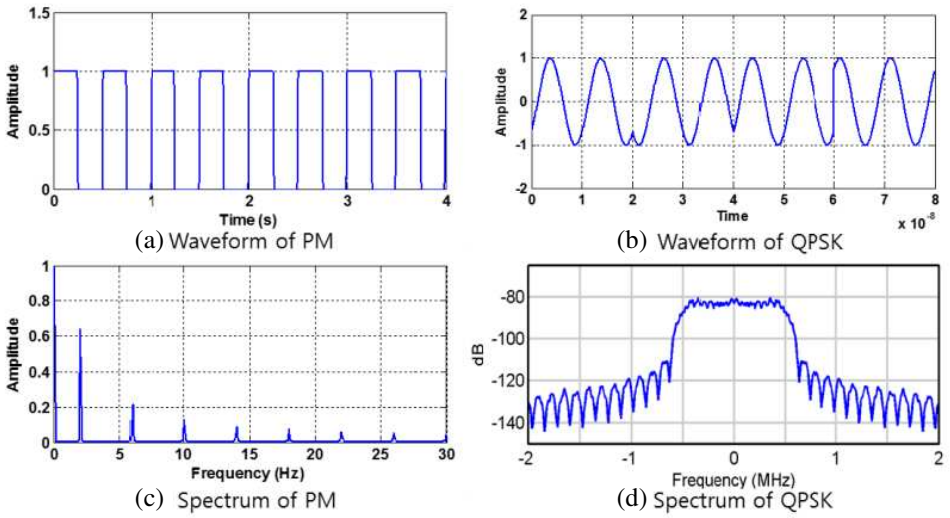

Figure 2: Comparison of the time domain signal and frequency domain spectrum for PM and PSK.

has the continuous spectrum in the frequency domain. Figure 2 shows the comparison of the time domain waveform and frequency domain spectrum.

Furthermore, the digital modulation signal used in the latest wireless communication has a broader bandwidth than the PM signal. The latest mobile communication or WLAN generally uses 10 MHz BW, and BW is expanding more and more for faster communication.

Due to this characteristic difference, the immunity test found that equipment was more influenced by digital modulation signal than by AM or PM signal.

We know the EMC's theoretical background is that the peak power of the reference test signal is the most dominant factor among the factors that affect the immunity test. In addition, based on this information, we can understand that the occupied bandwidth of the signal and the occupied energy on the time scale are also important factors.

We have tested the throughput difference by the reference signal of radiated immunity test in GTEM cell, to prove that the above hypothesis is valid in digital communication devices. For the test, a WLAN AP and a laptop were placed inside the GTEM, and a laptop connected to the WLAN AP was placed outside of the GTEM. The throughput was measured by sending files between two laptops using the FTP. The interference signal was provided through the GTEM, by adjusting the input signals in such a way that the signals have the same peak power according to the reference signal type. The WLAN communication was configured with the CH2 (2.417 GHz), 20 MHz bandwidth, and IEEE 802.11n mode. The interference signal was sent to 2.462 GHz so that it was not overlapped with the communication band. Table 3 shows the test result. It shows that the degradation of throughput by WCDMA is biggest than others. Through the simple WLAN test, the same trend of the interference effect as in the previous test result can be checked.

Table 3: Comparison of WLAN throughput according to reference signals used by radiated immunity test in GTEM Cell.

Status	Normal	Radiated immunity test				
Reference signal	None	AM 1 kHz	PM 2 Hz	PM 217 Hz	PM 1 kHz	WCDMA
WLAN throughput (kB/s)	6095.27	5752.58	5930.59	5806.19	6004.52	5593.35
Degradation of throughput (%)	0	5.6	2.7	4.7	1.5	8.2

5. CONCLUSION

As more and more portable mobile communication devices such as mobile communication and WLAN are used, international standards are being created to assess the impact of the intentional electromagnetic waves emitted by these portable wireless devices.

The close proximity immunity standard, which is standardized by the IEC, simulates the digital communication signal used by the latest wireless communication as a PM signal. The PM signal, as a reference signal of the radiated immunity test, can affect a wider frequency band than the AM signal, and has the strength of interfering in the audio system like AM. However, the latest digital modulation signals like LTE and WLAN have the broadband characteristics than PM in the frequency domain, and more occupied energy on the time scale. Due to these reasons, the digital modulation signal affects more than the PM signal, and this was verified by the WLAN throughput test. More studies are needed to take the effect of digital modulation signals into account during standardization activities in the future.

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