The Analysis of EMI Noise Coupling Mechanism for GPS Reception Performance Degradation from SSD/USB Module

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***Abstract*—Due to increasingly wide spreading applications of location-based services (LBS), a variety of portable devices are equipped with GPS module for navigation. If a notebook or ultrabook computer is embedded with a built-in GPS antenna and module, the EMI noise generated from SSD (Solid State Drive)/USB 3.0 module of the PC will radiate to affect the receiving performance of GPS antenna[1]. We have found that even if the SSD module locates far away (about 60 cm) from the GPS antenna, the positioning accuracy and performance is still affected. Not to mention that ever shrinking space for components placement will bring GPS antenna and noisy digital devices much closer, and thus further degrades the position and navigation performance. Since the receiving sensitivity of GPS system is the critical parameter for successful LBS applications, this study investigates the technique to evaluate the level of EMI noise from nearby SSD/USB 3.0 and provides the adequate analysis for application and integration of SSD/USB 3.0 with GPS for ultrabook or traditional notebook PC. To analyze the EMI effect on GPS performance, we have categorized the coupling mechanism between SSD/USB 3.0 and GPS RF modules into antenna coupling and circuitry coupling. With the utilization of platform noise scanner[2] on closely located GPS and noisy digital modules in this study, we can analyze and identify the root cause for receiving sensitivity degradation with compact form design limitation. We will also evaluate the noise limit for platform noise of GPS applications, and hope to further apply IEC 61967 IC-EMI measurement techniques on the component level to solve the problem of system integration and improve the performance in the future study.**

Keywords*—Solid State Drive (SSD); USB 3.0; LBS (Location Based Service); GPS antenna; EMI; receiving sensitivity; platform noise scanner; antenna coupling; circuitry coupling; IC-EMI

I. Introduction

Owing to its high memory/dimension ratio with fast processing speed, the Solid State Drive (SSD) is nowadays commonly installed in the portable devices. However, such high speed digital module has deteriorated RF performance of wireless communications with its unintended EMI emission. For the generalized point of view on noise coupling effect for this study, we did analyze the coupling coefficient (S21) by partitioning the general platform (e.g. Notebook/Ultrabook PC, Panel PC, etc.) into numbers of areas for possible locations of high-speed digital modules and sensitive RF modules respectively. Utilizing the coupling coefficient between various parts of the platform with receiving sensitivity requirement of wireless communications, we can then identify the root cause of the GPS performance degradation and further suggest the IC EMI noise budget for designer. For instance, the SSD usually radiates RF noise power which affects the receiving performance of the embedded GPS system with in-band noise. Even when external GPS device or SSD is used with WiFi tethering for LBS via mobile phone and WWAN, the SSD would also radiate the RFI noise to degrade the reception of GPS and navigation service. Moreover, when mobile phone is put beside the SSD for WWAN connection as shown in Fig 1, the transmitted signal of mobile phone might also deteriorate the GPS performance due to RF coexistent problem.

If an ultrabook or notebook computer is equipped with fast USB 3.0 interface with built-in GPS antenna, the RFI noise generated from SSD module will usually affect the receiving performance of GPS applications. From the measured result, we found that even when the SSD module is located far away from the GPS antenna, the EMI noise falling on 1.57 GHz band is excessively high for GPS applications as shown in figure 2.

Fig. 1. Scenario of GPS and WWAN coexistence

II. SSD EMI Noise Coupling Analysis

The result shown above in figure 2 clearly illustrates that even when the USB 3.0 module (or SSD) is very far away

(60cm) from the GPS antenna, the RFI noise power from high speed digital device or interface (USB 3.0 or SSD) still couple and affect the receiving performance of GPS application. Such RFI coupling phenomenon is called "Antenna Coupling", and it indicates when the portable device is integrated USB 3.0 or SSD module usually increases the potential risk for performance failure of GPS and LBS applications.

We here also illustrate the possible noise coupling configurations in figure 3 and it explains the reason why the GPS performance might degrade. We can thus figure out the dominant coupling path between SSD noise power and GPS antenna reception. In addition, it can also reveal the dependence of RFI noise level on relative position of GPS antennas with possible cable routing from de-sensing measurement.

From the measurement results, the analysis indicates that the main reason for degradation of GPS receiving sensitivity is circuitry coupling. The circuitry coupling here means that the SSD noise couples to GPS antenna and module via mini-coaxial cable. If the GPS antenna is further moved down to base due to compact form design limitation, then the digital EMI noise would even directly couple to the GPS antenna through antenna coupling.

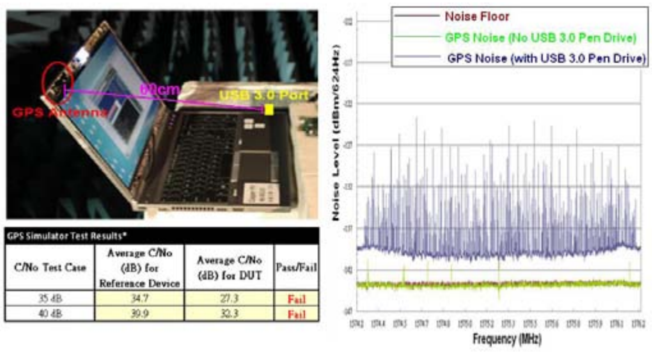

Fig. 2. GPS performance degrades by excessive RFI noise from SSD

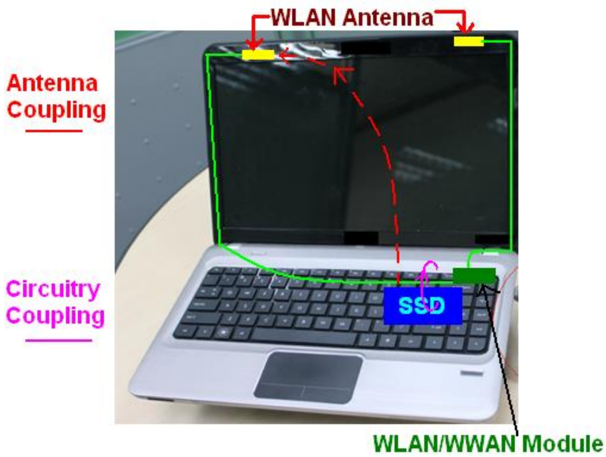

Fig. 3. GPS antennas and cabling configuration with SSD module

III. Measurement Setup and Procedures

To identify the root cause and dominant noise coupling mechanism of SSD or high speed digital component EMI problems on GPS receiving performance, we provide the EMI diagnosis steps for possible RF integration design.

1) Measure the SSD noise power received by the embedded GPS antennas. When SSD is located near the antenna, it should not couple excessive RFI noise power to antenna by the limited distance away for antenna coupling analysis.

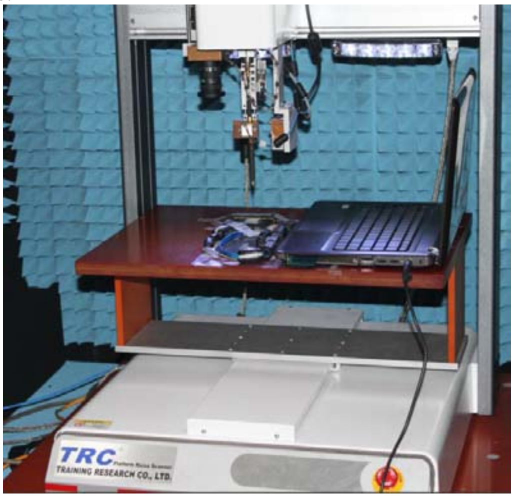

Fig. 4. Noise coupling analysis with surface scan measurement

2) When GPS module is placed nearby SSD module, the operation of SSD should not couple excessive EMI noise to the RF front-end circuit (magnetic field invading the shielded metallic can), antenna connector (Male and Female Connector), or mini-coaxial cable for circuitry coupling analysis.

3) The RFI noise falling in GPS band generated from SSD operation should not couple to GPS antenna located far away from SSD module to avoid antenna coupling.

For the critical GPS band interfered by SSD found in step1, we can utilize the PNS (Platform Noise Scanner) for near field noise scanning to locate the EMI noise distribution generated from SSD for coupling analysis as shown in figure 4.

IV. Investigation on SSD Noise Current Distribution in GPS Band

In general, it's very difficult to measure the SSD noise distribution in GPS band. From the characteristics of GPS band (Center Frequency = 1575.42 MHz, Span = 2 MHz), the thermal noise of the system is -174 dBm/Hz + 10*log(2000000) = -111 dBm/2 MHz. However, since the GPS signal level is -130 dBm, and then the total GPS signal level will become -125 dBm if another 5 dB noise power is generated from SSD operation onto GPS band. It is impossible to measure such low level signal by the traditional near field probe with PNS system which is shown in figure 4 because the -111 dBm/2 MHz of thermal noise level already submerges over the -125 dBm/2 MHz GPS signal level.

Therefore, we work with TRC to propose the GPS noise measurement technique based on the degradation level of GPS C/N (Carrier to Noise Ratio) value. The diagram of proposed GPS noise measurement technique is shown below in figure 5.

Based on the measurement diagram shown above, the PNS shown in figure 4 can be modified to become a GPS noise measurement system. That is, the traditional near field probe and spectrum analyzer can be replaced with dedicated GPS probe and GPS receiver module respectively.

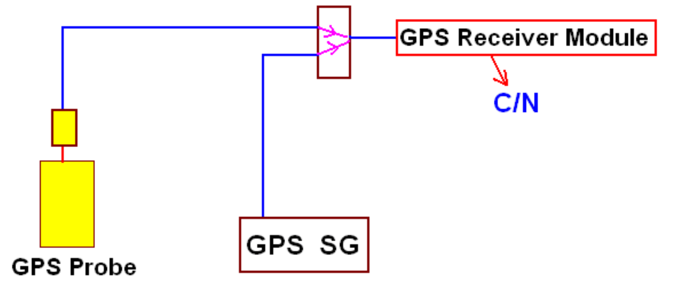

Fig. 5. Diagram of proposed GPS noise measurement setup

Fig. 6. GPS noise measurement illustration and result

The figure shown below in figure 6 is the modified PNS system for the GPS noise measurement, which is based on the degradation level evaluation of GPS C/N value. It also shows the measurement result for the GPS noise. Since the complete measurement spent less than 10 minutes, it reveals that the degradation level of GPS C/N value measurement technique is not time-consuming.

V. Estimation of Noise Limits and Corresponding Frequency Ranges for Wireless Communications

From the measurement and test plan mentioned for RFI noise evaluation in the previous section, we here suggest that the noise limit N_{Limit} of high speed digital component can be determined for a variety wireless communications systems with the following formula.

$$N_{Limit}\,(dBm) = S_M\,(dBm) + G_A\,(dBi) - SNR\,(dB) \qquad (1)$$

Where,

N_{Limit}: Noise Limit of Wireless Communications

S_M: Mobile Reference receiving Sensitivity (Industry Specified Standard: 3GPP, CTIA)

G_A: Antenna Gain

SNR: Depending on the demodulation scheme for each communication band, as shown below in Table I

For example, if a GSM device requires -105 dBm receiving sensitivity with -3 dBi antenna gain, then the noise limit could be determined as following.

$$N_{Limit} = -105\,(dBm) + -3\,(dBi) - 7\,(dB) = -115\,(dBm) \qquad (2)$$

TABLE I. Parameters for Noise Limit calculation

RAT/Band		Coding for OTA	SNR Required (dB)
GPRS	850	CS1	1.63
	900	CS1	1.63
	1800	CS1	1.63
	1900	CS1	1.63
EGPRS	850	MCS5	11.53
	900	MCS5	11.53
	1800	MCS5	11.53
	1900	MCS5	11.53
WCDMA/ HSDPA	Band I	12.2kbps	-9.38
	Band II	12.2kbps	-9.38
	Band III	12.2kbps	-9.38
	Band IV	12.2kbps	-9.38
	Band V	12.2kbps	-9.38
	Band VIII	12.2kbps	-9.38

Since the coupling coefficient is a transfer function of distance, the separation between digital module and WWAN, WLAN, and GPS antennas should also be taken into consideration when enacting the RF noise limit for each communication band. Once the SSD RFI noise limit is determined for wireless communications manufacturers, they can control the noise budget for SSD together with the corresponding test fixture shown previously to improve RF receiving performance. With the designated noise limit, the SSD noise level in each band should be further suppressed and validated by IEC 61967 IC-EMI measurement series. From the step 2 test item shown in previous section, the SSD noise level in hot spot image of surface scan is better not exceed -60 dBm/30 kHz in each communication band. Otherwise, the potential risk for RF de-sensitivity will increase if the antenna cable is routed across the SSD module.

VI. Conclusion

The EMI noise measurement from SSD and USB 3.0 interface is conducted to evaluate the noise level and measuring sensitivity needed for SSD integrated with GPS module. For the portable navigation device manufacturers, they can benefit the SSD noise impact on GPS system and further utilize the mitigation techniques to suppress the noise coupling with strict in-band noise limitation from this study. As to the high speed digital module manufacturers, they can also benefit from understanding the EMI noise distribution to improve their digital design to meet the system manufacturers' requirement for platform noise consideration.

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