Improving the Isolation of GPS Receivers for Integration with Wireless Communication Systems

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Abstract — **The impact of the inter-system and the intra-system isolations on the performance of GPS receivers is analyzed. The grounding, shielding and de-coupling structures were optimized to minimize the level of intra-system interference in the receiver. By reducing the intra-system interference, high sensitivity and high immunity to jamming signals were simultaneously achieved. The sensitivity value below the -141dBm and CW power level of -4dBm, 2dBm and 2dBm in the DCS1800, IS-95 and WCDMA frequency ranges respectively for 3dB degradation of the carrier to noise ratio were obtained.**

I. Introduction

The integration of GPS into portable mobile device provides wide coverage position estimation for enabling location based services. Alternatively, network based positioning technologies have been proposed and implemented recently. The accuracy of triangulation methods based on either angle of arrival (AOA), time-of-arrival (TOA), or time-difference-of-arrival (TDOA) depends among others on the number of base stations, on their geometric location related to the mobile user and on multi-path effect. By combining the positioning strengths of GPS and cellular communication systems, namely hybrid positioning, wide coverage positioning capability both in rural areas and in urban canyons, including indoor environments is possible.

An overview of the basic positioning technologies for mobile phones for the UTRAN and the GSM networks is presented in [1] and [2] respectively. Hybrid positioning methods and architectures are described in [3]. Refs [4,5] present RF related issues, requirements and specifications of GPS for operation in the presence of wireless communication systems.

The simultaneous operation of GPS and wireless communication systems (WCS) and the tight integration required in portable mobile devices impose severe constraints in the GPS receiver design. The performance of the GPS receiver should remain akin to its standalone performance regardless of the proximity of the wireless system. Highly linear low noise GPS receivers, operating at low power consumption levels are required.

Typical problems encountered with tight integration of GPS receivers into a hosting environment arise from the limited isolation between the distinct circuitry regions and between the antennas. These two isolation mechanisms are defined in this paper as intra-system or internal, and inter-system or external isolations respectively. The sources and the degradation mechanisms of the carrier to noise ratio in GPS receivers, caused by the limited inter-system and intra-system isolations, are outlined in Table I.

TABLE I

COUPLING PATH AND DEGRADATION MECHANISMS DUE TO LIMITED INTER-SYSTEM AND INTRA-SYSTEM ISOLATIONS

Isolation	Coupling path	C/No degradation
Inter-system	Air interface	Noise emission Spurious emission IMD Desensitization
Intra-system	Synthesizer VCC noise GND noise Radiation	LO leakage Spurious Noise coupling

Fig. 1 shows the partitioning diagram of a GPS receiver. The inter-system and intra-system isolations, i.e., the isolations 1 to 3 in Fig. 1, which represent the individual contributions to the intra-system isolation, are also indicated. The constraints in the receiver front-end design and partitioning imposed by the inter-system and the intra-system isolations are contradictory. The intra-system isolation specifications of the GPS receiver can be alleviated by placing an external high gain - low noise amplifier stage apart from the receiver as indicated in Fig. 1b. The specifications of the intra-system isolation, isolations 1, 2 and 3, can be relaxed. On the other hand, the limited inter-system isolation requires a low gain - low noise amplifier, usually below 15dB, in order to meet the jamming immunity requirements, providing that the sensitivity and the power consumption are not compromised. For mobile communication devices, the likely integration scenario is depicted in Fig. 1a. Since the tight system integration limits the isolation between

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antennas, high intra-system isolation is required, resulting in an increase of the size, the cost, and the design complexity of the shielding, grounding and de-coupling structures. Single chip or densely packed GPS solutions might suffer from the limited intra-system isolation.

A complete GPS receiver has been developed. The core functionalities are the low gain - low noise amplifier, the RF processor and the baseband processor. The design methodology for the chip-set integration, and the characterization of the sensitivity and jamming immunity of the GPS receiver are presented. The shielding and grounding structures were modeled and optimized with electromagnetic simulation tools. The reduction of the intra-system isolation and radiation energy originating from the digital regions of the circuitry, enabled the close integration of the GPS antenna and the GPS chip-set without compromising the jamming immunity and sensitivity characteristics of the receiver. The optimum operation point of the automatic gain control and the analog to digital converter, was set for 14dB gain at the low noise amplifier stage in Fig. 1a, eliminating the need for additional amplification.

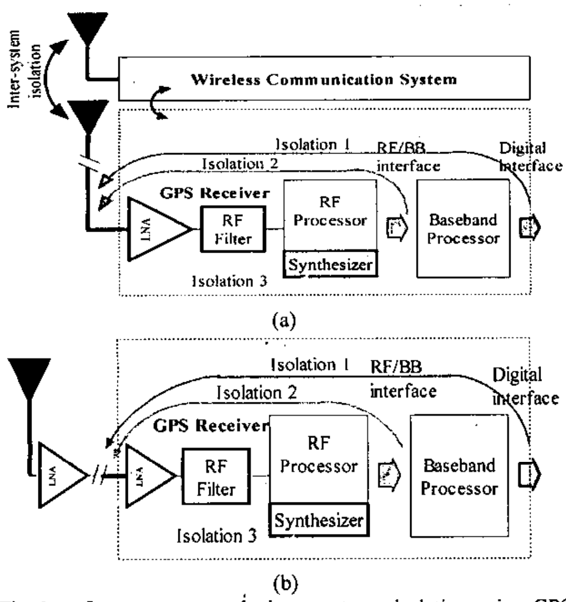


Fig. 1. Inter-system and intra-system isolations in GPS receivers operating in the proximity of wireless communication systems (1a). In (1b), the presence of an external low noise amplifier reduces the intra-system isolation requirements but also the jamming immunity of the GPS receiver.

An overall C/No degradation of 4.9dB of the complete receiver was obtained. CW jamming signal power levels above –4dBm, +2dBm and +2dBm in the frequency range occupied by the DCS1800, PCS and W-CDMA wireless transmitters respectively were needed to degrade by 3dB the carrier to noise ratio.

II. DESIGN METHODOLOGY

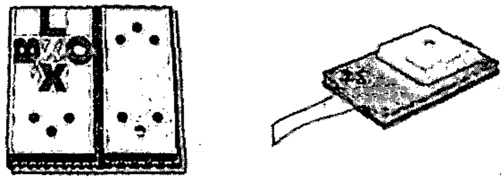
The integration of the GPS chip-set must guarantee low levels of intra-system interference within reduced dimensions. In order to minimize the occupied PCB area while meeting the intra-system isolation requirements defined according to the receiver thermal noise floor, the grounding, the shielding and the de-coupling structures must be carefully designed. The level of the intra-system interference should remain significantly below the thermal noise floor of the receiver.

The detailed description of the design methodology, in particular, the simulation and the optimization processes, is given in this section. The performance characterization of the GPS module is presented in section III.

The design methodology for the shielding and grounding structures of a GPS receiver consists of three major phases, i.e., the concept, the analysis, and the assembly and verification phases. The concept phase involves the initial layout visualization of the schematic drawing, the definition of the layer structure and the initial shielding and grounding connections concept. During the analysis phase, the radiation profile and the digital to analog electrical field in the structure are analyzed. The optimization of the ground via placement, of the shielding ground connections, and of the digital to analog ground connection are carried out. The reduction of the coupled and the radiated energy, originating from the digital region, into the GPS input port is verified. The final step consists of the production, assembly and characterization of the complete receiver.

The photograph of the GPS receiver module is shown in Fig. 2a. The module dimensions are 25.4mm x 25.4mm x 3mm. The presence of two distinct shielding structures was necessary to reduce the digital to analog noise coupling. Moreover, the antenna connection was placed in the opposite extreme of the analog to digital ground connection to improve the isolation. Fig. 2b shows the direct integration of the antenna and the GPS module. The realization of the direct integration in Fig. 2b was only possible through the careful design of the grounding and shielding structures as the antenna is attached directly at the back side of the GPS module, and the reduced size of the ground plane increases the back side radiation of the antenna.

The effectiveness of the grounding and shielding structures on the GPS module of Fig. 2a was analyzed using a 3D electromagnetic simulator. On the top layer of the printed circuit board, two resonant elements were designed. The printed resonant element in the digital of the circuitry represents the excitation source. In this configuration, the electric field originating from the digital circuitry is replaced by an equivalent excitation source. The confinement of the energy in the digital portion of the module demonstrates the effectiveness of the grounding structure.



(a) (b)

Fig. 2. Photograph of the GPS module (2a). Fig. 2b shows the photograph of the direct integration of a ceramic patch antenna and the GPS receiver.

To clarify the analysis of shielding and grounding structures, the distribution and intensity of the electric field on the surface layer of the GPS module are shown qualitatively in Fig. 3. The placement and the optimization of the ground vias around the analog and digital regions reduced the intensity of the electrical field around the antenna connection and the low noise amplifier, as defined by the "cold area" in Fig. 3. Due to assembly and size constraints on the placement of the ground via and the proximity of the regions, some energy leakage into the analog region is observed. The impact of this intra-system interference on the GPS performance was found, however, negligible.

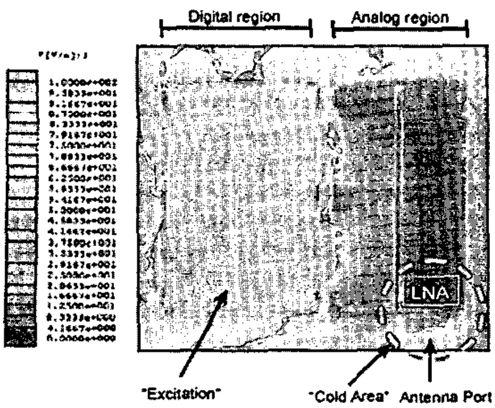


Fig. 3. Layout and electric field profile at the surface layer of the GPS module. The excitation in the digital region and the location of the LNA and the antenna port are indicated.

Fig. 4 shows the module cross-section and the radiation profile. The shielding structure confines almost all the energy in the digital region. Practically, no energy is coupled through radiation from the digital to the analog region, which indicates the importance of the shielding structure to the intra-system isolation.

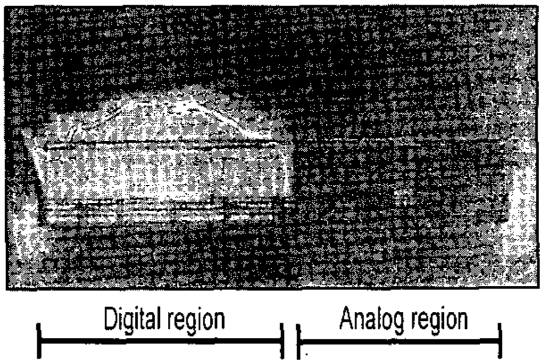


Fig. 4. Cross-section and radiation profile of the GPS module. The shielding structures over the analog and the digital regions are shown.

III. RESULTS

To quantify the performance of the GPS receiver and the effectiveness of the grounding, shielding and decoupling structures, sensitivity and jamming immunity measurements were performed. In standalone receivers, the sensitivity measurement, i.e., the measurement of the minimum GPS signal at the antenna terminal for maintaining the satellite tracking, reflects the overall degradation of the carrier to noise ratio originated in the receiver. The carrier to noise ratio, CNR, degradation is caused not only by the receiver noise figure, by the analog to digital converter and, by the losses in the correlation process, but also by the limited intra-system isolation. In the close proximity between GPS and wireless communication systems, the inter-system interference, in addition to the intra-system interference, contributes to a reduction of the CNR value. The respective sources of the CNR degradation are the noise and spurious emissions, the saturation of the GPS receiver by the transmitted wireless signal, and the intermodulation products in the GPS receiver generated by the transmitted wireless signal.

Fig. 5 shows the dependence of the carrier to noise ratio on the input signal power level applied to the u-blox GPS module of Fig. 2a. The minimum signal strength below the –140dBm in tracking operation mode was obtained with 5ms integration time. From the linear range, the overall C/No degradation of 4.9dB was determined. The characterization procedure of GPS receivers was presented in [5]. The influence of the intra-system interference on the system performance can be verified from the behavior of the automatic gain control unit. Equating the applied signal strength to the receiver noise floor, 3dB reduction of the gain of the variable gain amplification chain is observed. In Fig. 5, the receiver noise floor equals to −107dBm, point C. The agreement between the noise floor in the receiver bandwidth of 5.3MHz, and the value obtained in Fig. 5, confirms that the intra-system interference has been substantially attenuated to levels below the receiver thermal noise floor.

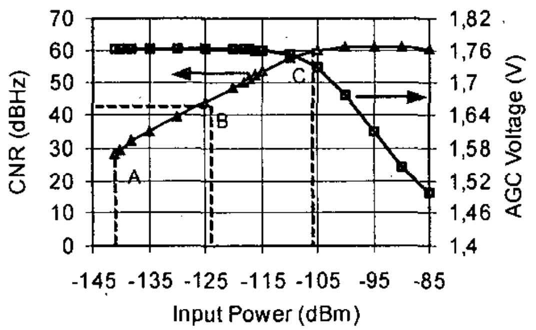


Fig. 5. Dependence of the carrier to noise and the automatic gain control voltage on the input signal level. The sensitivity, the overall CNR degradation, and the noise floor are determined at points A, B, and C respectively.

The reduction of the intra-system interference enables the design of the RF front-end with a low power gain GPS LNA stage, thus improving the linearity of the receiver. The CW jamming immunity performance of the GPS receiver, in the frequency occupied by the wireless communication transmit systems, is presented in Fig. 6. The results indicate that even with limited inter-system isolation between the GPS receiver and the wireless communication systems, due primarily to the proximity of the antenna structures, the degradation of the carrier to noise ratio remains acceptable. The 3dB degradation of the CNR occurs at power levels above +2dBm in the frequency ranges occupied by the PCS and the WCDMA communication systems.

The results obtained in Figs. 5 and 6 demonstrate that the realization of highly sensitive GPS receivers (5ms integration time) with strong immunity to jamming signals in the wireless frequency range are possible, providing that a high intra-system isolation is obtained. The requirements for the inter-system isolation can, consequently, be relaxed through the reduction of the gain and the increase of the out-of-band IIP3 [4] of the LNA stage.

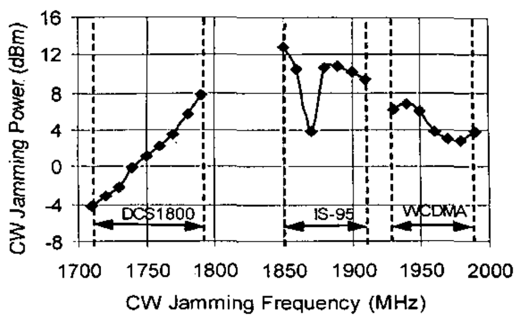


Fig. 6. Jamming immunity of the GPS receiver in presence of CW blocking signal. The plot indicates the CW power level for 3dB degradation of the C/No in the frequency ranges occupied by the wireless communication transmitters.

V. Conclusion

It has been demonstrated the importance of high intra-system isolation in GPS receivers to obtain, simultaneously, high sensitivity and high immunity to jamming signals. The increase of the intra-system isolation through a careful design of the shielding, grounding and de-coupling structures, resulted in lower inter-system isolation requirements between the GPS and the wireless communication systems, without compromising the overall GPS performance.

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