Subsystem Embedded Microstrip Antennas and its Performance Evaluation

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1. Introduction

The increasing applications of the satellite communication have driven the need to design small-sized antennas. Microstrip antenna structures [1], which embed RF subsystems inside the structure[2], are thus proposed to retain small in size and thickness, where the overall subsystem size can actually be the antenna size itself.

This paper demonstrates the concepts and studies the impacts on the antenna and subsystem's performance. In particular, the antenna design applications for the signal receptions of satellite radio[3] and global positioning system (GPS) are considered to evaluate the characteristics. These types of antenna applications in the signal receptions have characteristics of low RF strengths on the antenna bodies, and thus are very suitable for the development of subsystem embedded antenna systems. Experimental results validate the concepts in the following sections.

2. The proposed antenna structure

The size reduction of the overall antenna system relies on two folds: the antenna size should be reduced, and the space for the RF circuit components should be minimized at an optimized performance. Even though the antenna size can be reduced by employing dielectric materials with higher permittivity, it may still occupy a large portion of the entire subsystem and does not indicate a smallest size of the overall subsystem. Also over size reduction may significantly impact the antenna and system performance, and is not very desirable. The proposed structure, as exampled in Figure 1, intends to integrate the RF circuit components into the antenna structure so that the overall size can be minimized at an optimized system performance. As indicated in Figure 1, a cavity within antenna substrate is created to accommodate the RF subsystems. This cavity can be further shielded if the EMI is found severe to impact the RF subsystem. However, in terms of the reception of satellite signals, the EM strengths on the antenna bodies are relative weak and will not impact the RF subsystem's performance as to be shown later. The advantages of this concept are that with the increasing maturity of the LTTC technologies, the antenna as well as the RF subsystem may be manufactured simultaneously[4]. Not only the subsystems can be highly integrated, but also the overall cost can be minimized.

3. Examples and Performance Evaluation

A. Satellite Radio Applications

The parameters are indicated in Figure 1 to produce a LCP operation. It is printed on a RO-4003 substrate of thickness 1.524mm that has a dielectric constant $\varepsilon_r = 3.38$. In order to avoid the EMI problems, the space to accommodate RF components (which is a low noise amplifier (LNA) in this case) is created by a metal circular cavity with a radius of 10mm inside the substrate of the antenna. The feed is coaxial cable with its center pin connected to the ground and its ground connected to patch, where the location of the feed, as well as cutting two squares of $4.64 \times 4.64 mm^2$ on the patch, is offset from the patch's center by 16.33mm to create LCP radiation. The coaxial cable is connected to the RF component through a small hole located at the center of the patch. Since only the antenna performance is examined, the coaxial cable will not be connected with the RF component in this case. Figure 2 shows the return loss, where a -10dB bandwidth of 2.28625~2.36625 GHz is shown and is sufficient to fulfill the need of satellite radio reception. The co-polarized radiation patterns are shown in Figure 3 at $\phi = 0$ and 90 degrees, respectively. A maximum gain of 5dBi is obtained. Within the observation range of interest gain larger than 2.6 dBi is achieved. Also a cross-polarization level below -15dB is achieved. The performance of axial ratio is shown in Figure 4 where at most frequencies the axial ratio of the co-polarized components is less than 2dB as required in the satellite radio applications. Finally the radiation efficiency is more than 57% of efficiency.

B. GPS Applications

The antenna, shown in Figure 1, is a square patch with two corners truncated to provide RCP reception. The patch is fed near the center via a microstrip transmission line. The patch has an initial size of 43.4 by 43.4 mm^2 with a ground plane of 60 by 60 mm^2. The substrate used is FR4 of $\varepsilon_r = 4.6$ and the substrate thickness is 2.4 mm. The length of the truncated sides is 3.95 mm and the feed point is offset by 8.9 mm. This design yields a resonant frequency in the vicinity of 1.575 GHz with a maximum gain of 2.5 dBi. The pattern exhibits a backlobe of -4 dBi because of the finite ground plane. A cavity is formed to accommodate the LNA within the substrate. As indicated in Figure 1, the substrate is divided into three layers. The cavity is placed in the middle layer with a 12 by 16 mm^2 footprint and a 1 mm thickness. An LNA chip is placed on top of the microstrip trace, and the rest of the cavity is left empty. Due to the existences of the cavity and LNA module, the resonant frequency of the antennas drifts and is corrected by rescaling the dimensions of the antenna structure. At normal GPS signal level, the received power strength at the antenna is between -60 and -130 dBm. In order to examine the influence from various received power level to LNA operation, the LNA is not connected to the receiving antenna. Instead the receiving antenna is connected to a power meter and the LNA is connected to a network analyzer in order to measure its S parameters. The input power feeding to the LNA is adjusted to be the same as the received power strength measured by the power meter to provide the same power condition for the LNA. The gain and noise figure are measured from the LNA module and are shown in Figures 6 and 7, respectively. In this case, the cavity is not shielded with any conducting material. As shown in Figure 6, the gain of the LNA remains almost constant in different received power levels. In Figure 7, the noise figure level remains unchanged when the received power strength is smaller than -85 dBm. It increases dramatically as the received power level exceeds -85dBm. These two observations show that the proposed antenna can be used in practical GPS reception applications since the actual GPS signal strength is far less than -85dBm. Furthermore, the EM fields in the antenna substrate impose no performance degradation to the LNA.

4. Conclusions

This paper presents an effort to reduce the overall antenna subsystem size by embedding the RF components inside the antenna structure. Studies exhibit that significant antenna performance has been achieved even with the embedded components. The resulted antenna subsystem is very thin, and can be easily integrated with many devices in many attractive applications.

References

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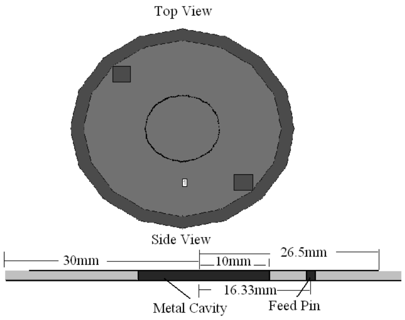


Figure 1: The proposed antenna structure for embedding RF components.

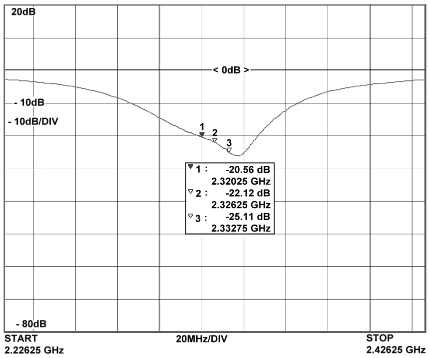
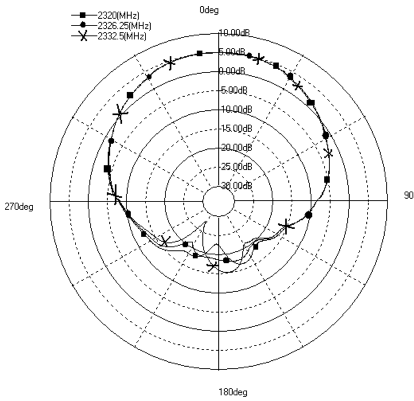
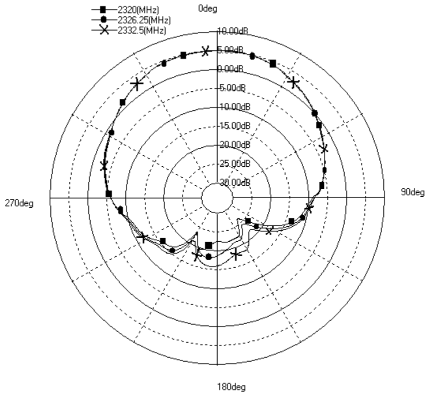


Figure 2: The return loss S_{11}obtained by an experimental measurement from the protyped antenna.

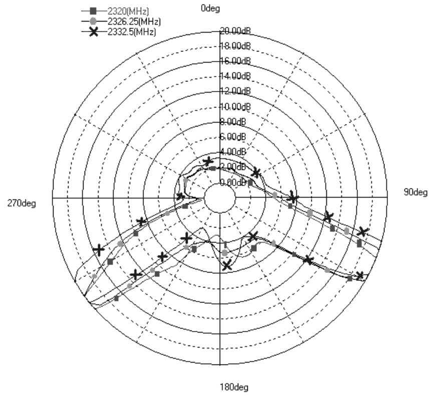


(a) $\phi = 0$ degree plane

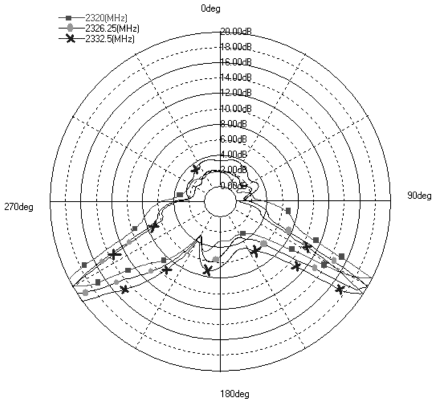


(b) $\phi = 90$ degrees plane

Figure 3: The measured radiation pattern of the protyped antenna.



(a) $\phi = 0$ degree plane



(b) $\phi = 90$ degrees plane

Figure 4: The measured axial ratio of the co-polarization component

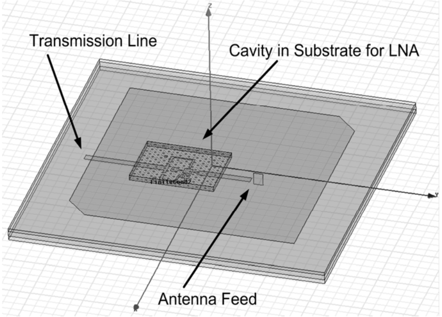


Figure 5: Circuit layout of the patch antenna and transmission line with a cavity in the substrate for embedding LNA.

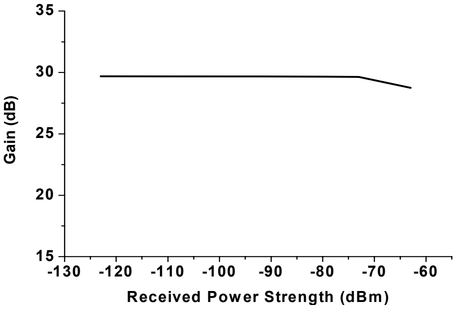


Figure 6: LNA gain with respect to the received power strength of the GPS antenna.

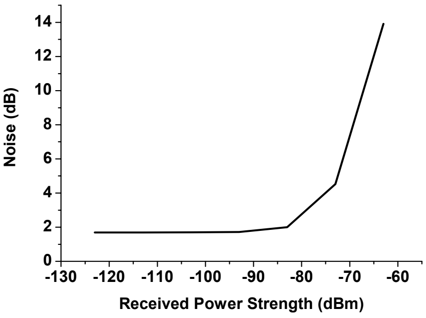


Figure 7: LNA's noise figure with respect to received power strength.