# Dual-element Diversity Antenna for Galileo/GPS Receivers

Masood Ur Rehman, Yue Gao, Xiaodong Chen and Clive Parini
*School of Electronic Engineering and Computer Science, Queen Mary University of London*

## BIOGRAPHY

Masood Ur Rehman received his B.Sc(Hons.) degree in Electronics and Communication Engineering from University of Engineering and Technology, Lahore, Pakistan in 2004 and completed his M.Sc in Wireless Networks at Queen Mary, University of London in 2006. He then joined the Department of Electronic Engineering at Queen Mary, University of London as a research student to pursue the degree of PhD. His main research interests include electromagnetic interaction of antennas and the human body, antennas for Galileo/GPS mobile terminals and environmental effects on the performance of these antennas.

## ABSTRACT

Theoretically the Galileo/GPS antennas should have good Right Hand Circular Polarisation (RHCP) in order to receive the incoming Galileo/GPS signal efficiently. However, this requirement is hard to fulfil nowadays due to the size and space limitations of handheld Galileo/GPS receivers. Preliminary studies carried out at Queen Mary, University of London show that a diversity antenna has a potential to overcome this problem for Galileo/GPS receiver (Gao et al., 2008). In this paper, a novel antenna for the Galileo/GPS receiver is proposed which can also operate at GSM bands. The performance enhancement of dual-element antenna in terms of Galileo/GPS signal reception and coverage is analysed to further establish the benefit of diversity antennas in modern day navigation devices.

## INTRODUCTION

The field of wireless communications has been revolutionised by the advent of satellite communication systems. Global Navigation Satellite System (GNSS) is an important part of this technology. The essential features of navigation, positioning, rescue and monitoring has given it a pivotal role in modern day communication devices. Global Positioning System (GPS) is the fully functional navigation system that provides the navigation and positioning services to millions of users worldwide. Galileo is also catching up fast to serve the navigation needs and provide a backup to the GPS. Introduction of handheld Galileo/GPS receivers has further added to its popularity and made it an essential part of most of the communication devices including mobile terminals.

Antenna is an important element of a Galileo/GPS receiver. Great care is needed to design the Galileo/GPS antenna that fulfils the required specifications. Theoretically, the Galileo/GPS antennas should have good Right Hand Circular Polarisation (RHCP) in order to receive the incoming Galileo/GPS signal efficiently (Boccia et al., 2003). However, this requirement is hard to fulfil nowadays due to the size and space limitations of handheld Galileo/GPS receivers. It has also been reported by some researchers that RHCP is not a strict requirement for the GPS antennas in a highly scattered working environment (Pathak et al., 2003). This paves the way to explore other options to enhance the antenna performance while maintaining relatively small size including dielectric loading, high value substrates, active circuits and diversity antennas. From these options, diversity is the one that also maintains the cost limitations.

A number of Galileo/GPS antenna solutions are reported in the literature taking into account the antenna diversity enhancements (Gao et al., 2008). However, this gap in the Galileo/GPS market still needs more ideas. This paper presents a novel antenna for the Galileo/GPS applications. The antenna is designed to operate in the L1 (1.57542GHz) frequency band using Computer Simulation Technology (CST) Microwave Studio® package based on Finite Integration Technique (FIT) for the numerical modelling (CST, 2009).

Vigorous design modifications are then considered to enhance the antenna performance while reducing the antenna size employing diversity. The performance of the antenna is evaluated using statistical model for the multipath GPS environment replicating actual working scenarios. The effectiveness of the diversity is analysed in terms of Mean Effective Gain and coverage efficiency of the antenna. The results indicate that the proposed antenna is a viable solution for the Galileo/GPS receivers.

## SINGLE-ELEMENT ANTENNA DESIGN

First, a single-element antenna is designed. Figure 1 shows the geometrical structure of the single-element antenna. The antenna is fed by a microstrip line with a substrate of 100×50mm and having dielectric permittivity of 3. The radiating element is a combination of monopole and loop structure. Ground plane size is only 18×80mm. The radiating element consists of 11 loops of 23.2×2mm. The antenna resonates at 1575.42MHz with an impedance bandwidth of 107MHz covering the frequencies from 1520.2MHz to 1627.5MHz for an $S_{11}$ level better than -10dB. The simulated gain of the antenna is found to be 2.31dBi and is linearly polarised.

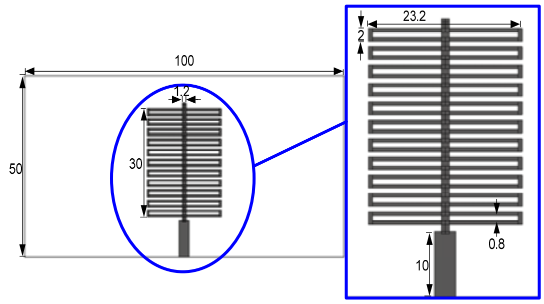


**Figure 1: Geometrical configuration of single-element mono-loop antenna (units are in mm)**

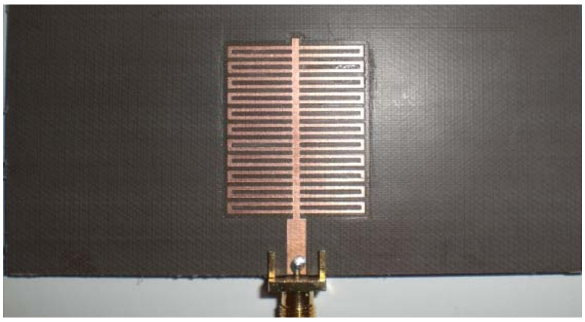

**Figure 2: Prototype of single-element mono-loop antenna**

The fabricated prototype of the designed structure is shown in Figure 2. The antenna is tested in the anechoic chamber in the Antennas Measurement lab at Queen Mary. The simulated results are compared with the measurements and an excellent agreement is found between the two $S_{11}$ curves as depicted in Figure 3.

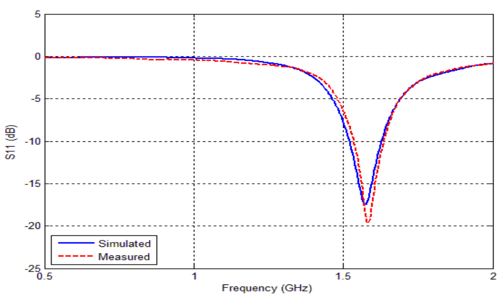


**Figure 3: Simulated and measured $S_{11}$ curves for single element mono-loop antenna**

The simulated and measured 2-D co-polar and cross-polar radiation patterns are shown in Figures 4, 5. A good agreement between the two results can be observed in both planes. However, some differences are present due to small fabrication errors and coupling of the SMA connector.

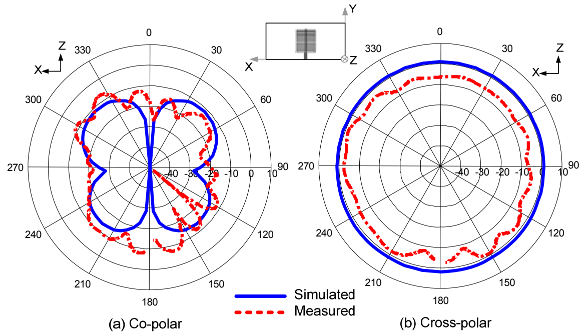


**Figure 4: 2-D simulated (blue) and measured (red) radiation patterns of single element mono-loop antenna in xz-plane at 1575.42MHz**

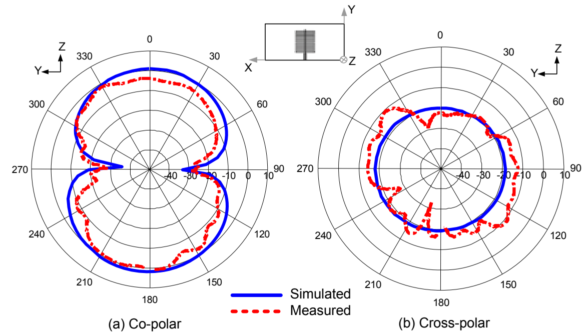


**Figure 5: 2-D simulated (blue) and measured (red) radiation patterns of single element mono-loop antenna in yz-plane at 1575.42MHz**

## DUAL-ELEMENT ANTENNA DESIGN

Vigorous design modifications are then considered to enhance the antenna performance employing antenna diversity. A dual-element mono-loop antenna is then designed with a distance of 41.8mm between the two elements. Figure 6 illustrates the geometrical structure while Figure 7 depicts the fabricated prototype of the designed antenna. The elemental dimensions are the same as illustrated in Figure 1. Measured and simulated return loss curves ($S_{11}$) are shown in Figure 8. The antenna achieves the -10dB impedance bandwidth of 250MHz covering all frequencies required by the Galileo/GPS system. Small differences between the measured and simulated results are observed due to imperfections in the fabrications of such small antennas.

Figures 8, 9 illustrate the simulated and measured co-polar and cross-polar 2-D radiation patterns for the left element while the right feed port is terminated with a 50Ω matched load. Again good agreement is found between the two results in both the xz-plane and yz-plane with minor differences due to imperfections in the fabrications of such small antennas.

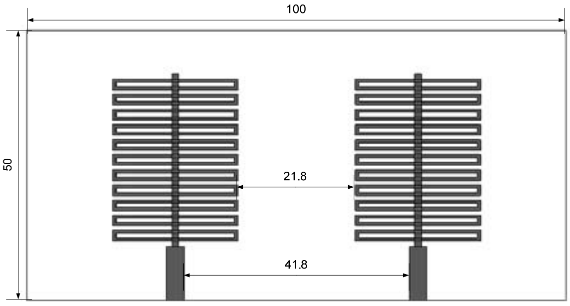


Figure 6: Geometrical configuration of dual-element mono-loop antenna (units are in mm)

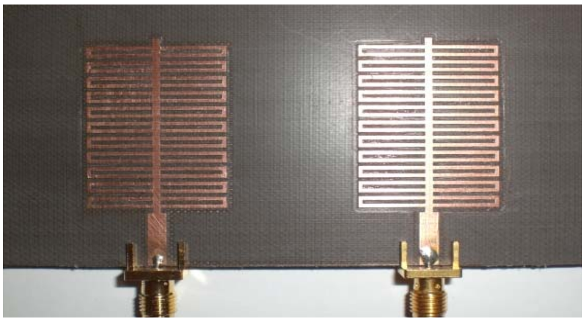

Figure 7: Prototype of dual-element mono-loop antenna

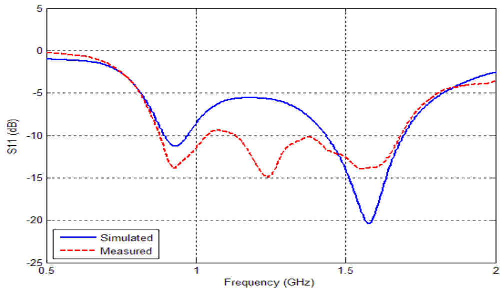


Figure 8: Simulated and measured return loss curves for the dual-element mono-loop antenna

Figure 11 presents a comparison of the simulated and measured transmission coefficient, $S_{21}$. Again the agreement between the two results is quite acceptable. At 1575.42MHz, the simulated value of the $S_{21}$ is -16.5dB while the measured value is -13.8dB that makes the coupling between the two elements acceptable. These differences can be avoided with more sophisticated fabrication process.

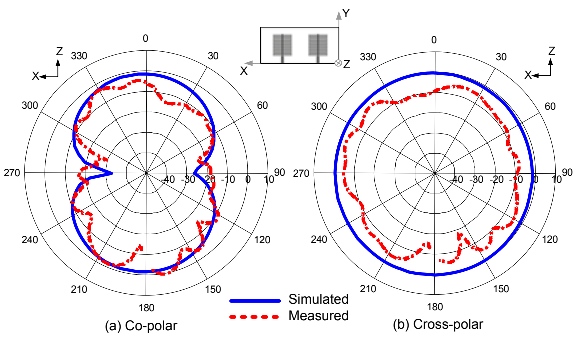


Figure 9: 2-D simulated (blue) and measured (red) radiation patterns of left element of dual-element mono-loop antenna in xz-plane at 1575.42MHz

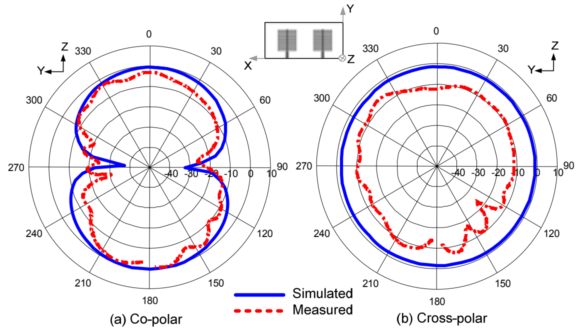


Figure 10: 2-D simulated (blue) and measured (red) radiation patterns of left element of dual-element mono-loop antenna in yz-plane at 1575.42MHz

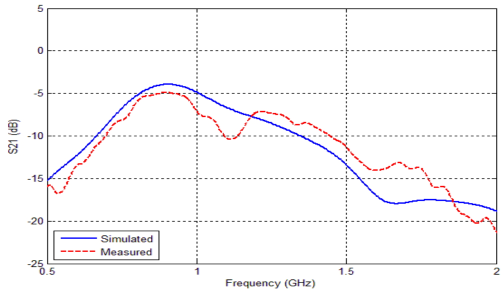


Figure 11: Simulated and measured $S_{21}$ curves for the dual-element mono-loop antenna

## STATISTICAL PROPAGATION MODEL FOR GALILEO/GPS

The environmental factors are usually defined by Mean Effective Gain and Angle of Arrival distribution of the incoming wave. The MEG is the average gain of the antenna performance in a multipath radio environment (Taga, 90). The MEG expression for the GPS antenna is formulated as (Ur Rehman et al., 2009):

$$\begin{aligned} MEG_{GPS} = \int_0^{2\pi}\int_0^{\pi} \Bigg[ & \frac{XPR}{1+XPR} G_{\perp}(\theta,\phi) P_{\perp}(\theta,\phi) \\ & + \frac{1}{1+XPR} G_{\parallel}(\theta,\phi) P_{\parallel}(\theta,\phi) \Bigg] \sin\theta d\theta d\phi \end{aligned} \quad (1)$$

where $G_{\perp}(\theta,\phi)$ and $G_{\parallel}(\theta,\phi)$ are the perpendicular and parallel components of the antenna power gain pattern respectively, $P_{\perp}(\theta,\phi)$ and $P_{\parallel}(\theta,\phi)$ indicate the angular density functions for the perpendicular and parallel components of the incoming wave respectively. The simultaneous transmission of two linearly polarised waves out of phase by $\pi$ / 2 (radian) results in the generation of a circularly polarised wave. Therefore, the circular polarisation of the incoming GPS signal is achieved by keeping the XPR=0dB.

The real working environment should be replicated in statistics to evaluate the antenna performance. The multipath radio environment has been studied for land mobile environments (Taga, 90) (Kalliola, 2002) but no study is reported for the GPS multipath environment. A novel statistical model for the GPS multipath environment was proposed and tested by Ur Rehman et al. This model considers the angular density function of incoming wave as uniform in azimuth due to multiple reflections, scattering and diffraction. Then the ground reflections are also accommodated in elevation dividing the angular density function in two parts namely incident and reflection regions. Therefore, angular density function for the incoming GPS waves is uniform in upper hemisphere while the ground reflections reduce it by a factor $A(\theta)$ in the lower hemisphere resulting in the following equations:

$$P_{\perp}(\theta,\phi) = P_{inc_{\perp}}(\theta,\phi) + P_{ref_{\perp}}(\theta,\phi) = \begin{cases} 1 & 0 \le \theta \le \pi/2 \\ A_{\perp}(\theta) & \pi/2 \le \theta \le \pi \end{cases} \quad (2)$$

$$P_{\parallel}(\theta,\phi) = P_{inc_{\parallel}}(\theta,\phi) + P_{ref_{\parallel}}(\theta,\phi) = \begin{cases} 1 & 0 \le \theta \le \pi/2 \\ A_{\parallel}(\theta) & \pi/2 \le \theta \le \pi \end{cases} \quad (3)$$

where $A(\theta)$ depends upon the reflection coefficients for the perpendicular and parallel components which are affected by incident angle $\theta$.

The coverage efficiency is another important parameter defined by Ur-Rehman et al (Ur Rehman et al., 2009). It is the capability of the GPS antenna to receive the incoming satellite signal. The signal received in certain angles is above the defined threshold and considered as useful. The signal below this threshold is too weak to play a role in GPS operation and hence these receiving angles are not useful. A threshold level of -6dB is selected for GPS operation based on link budget calculations for a received power level of -130dBm.

Coverage efficiency is calculated as a ratio of the antenna coverage area and the total area. The coverage area is defined by the solid angle subtended by the GPS antenna in useful angles in the incident region ($0 \le \theta \le \pi/2$). The total area is taken as the half hemispherical solid angle for an isotropic antenna (i.e $\pi$). Calculations are based on RHCP radiation pattern of the receiving antenna.

$$\eta_c = \frac{\text{Coverage Area}}{\text{Total Area}} \quad (4)$$

Overall performance of a mobile terminal GPS antenna in the multipath environment is defined in terms of $MEG_{GPS}$ and coverage efficiency.

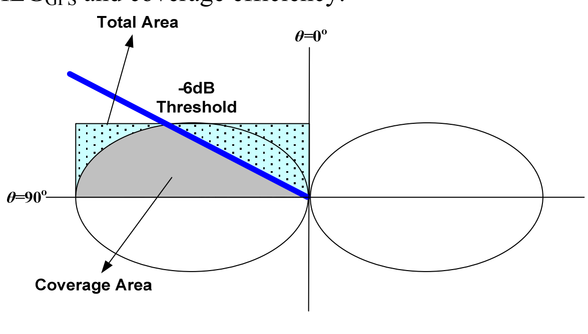


**Figure 12: Illustration of coverage efficiency calculations for a GPS antenna with an arbitrary donut shaped radiation pattern**

## ANTENNA PERFORMANCE IN MULTIPATH GALILEO/GPS ENVIRONMENT

The performance of the proposed antenna in the multipath GPS environment is evaluated using the described model. In the actual reflection environment, part of the incident wave is reflected back, depending upon the corresponding reflection coefficients. Both the vertical and horizontal orientations were taken into account. 3-D power radiation patterns of the simulated antenna configurations are input to the model. The ground reflections in actual environment are considered from a dry concrete ground plane with a relative permittivity of 4.5 (Jemai, 2005).

| Antenna | $\eta_c$ (%) | $MEG_{GPS}$ (dB) |
|---|---|---|
| Single element antenna (vertical) | 79 | -5.4 |
| Single element antenna (horizontal) | 75 | -5.5 |
| Dual element antenna (vertical) | 83 | -4.5 |
| Dual element antenna (horizontal) | 81 | -4.8 |

**Table I: Performance of proposed GPS antennas in the multipath environment considering both the vertical and horizontal orientations**

Table I summarises the $MEG_{GPS}$ and coverage efficiency results for different test set-ups. The results show that dual-element antenna offers an increased coverage of the incoming GPS signal as compared to the single-element antenna. This increased coverage efficiency results in increased $MEG_{GPS}$. However, this performance enhancement is not as good as expected as $MEG_{GPS}$ is increased upto 1dB only. This is due to the fact that dual-element antenna gain patterns are less directive in useful angles region. It is also evident from the results that antenna orientation has a key role in GPS signal reception. Although, vertical configurations has shown better performance as more signals can be received and less are the diffused components, it is hard to define a clear pattern.

Overall, the dual-element antenna has shown better performance in general and further modifications could make it a viable solution in terms of effective GPS reception.

## CONCLUSIONS

In this paper, the design of a single-element and dual-element mono-loop antenna for the GPS/Galileo operation is presented. The simulated designs are fabricated in the Antenna Measurement Lab at QMUL and tested in the anechoic chamber for the return loss and radiation pattern measurements. The simulated results are compared to the measurements and a good agreement is found between them except some small differences due to fabrication imperfections. The designed antennas have a gain of ~2.5dBi with a maximum size of 100×50mm of the PCB.

The presented results show that the two linear antennas have a strong potential to be used for the Galileo/GPS operation in real working environment. It is also evident that the diversity antennas are a viable solution for the Galileo/GPS receivers as the dual-element mono-loop linear antenna has depicted performance enhancement due to increased $MEG_{GPS}$ and coverage efficiency. Few modifications and removal of the fabrication imperfections can make this antenna to perform even better in the multipath environment.

## REFERENCES


Boccia, L.; Amendola, G.; and Di Massa, G.; (2003), "A Shorted Elliptical Patch Antenna for GPS Applications", *IEEE Antennas and Wireless Propagation Letters,* Vol. 2.

CST Microwave Studio® User Manual (2009).

Douglas, M.G.; Okoniewski, M. and Stuchly, M.A. (1998), "A Planar Diversity Antenna for Handheld PCS Devices", *IEEE Transactions on Vehicular Technology,* Vol. 47, No. 3.

Gao, Y.; Chen, X. and Parini, C.G. (2008), "Study of Diversity Antennas for Galileo/GPS Receivers", *Proceedings of the European Navigation Conference - Global Navigation Satellite Systems (ENC-GNSS 2008)*.

Jemai, J.; Kurner, T.; Varone, A.; and Wagen, J.F. (2005), "Determination of the Permittivity of Building Materials through WLAN Measurements at 2.4GHz", *Proceedings of the IEEE International Symposium on Personal, Indoor and Mobile Radio Communication.*

Kalliola, K.; Sulonen, K.; Laitinen, H.; Kivekas, O.; Krogerus, J.; and Vainikainen, P. (2002), "Angular Power Distribution and Mean Effective Gain of Mobile Antenna in Different Propagation Environments", *IEEE Transaction on Vehicular Technology*, Vol. 51, No. 5.

Pathak, V.; Thornwall, S.; Krier, M.; Rowson, S.; Poilasne, G.; and Desclos, L. (2003), "Mobile Handset System Performance Comparison of A Linearly Polarized GPS Internal Antenna with A Circularly Polarized Antenna", *IEEE Antennas and Propagation Society International Symposium*, Vol.3.

Taga, T. (1990), "Analysis for Mean Effective Gain of Mobile Antennas in Land Mobile Radio Environments", *Transactions on Vehicular Technology,* Vol. 39, No. 2.

Ur Rehman; M., Gao, Y.; Chen, X.; Parini, C.G. and Ying, Z. (2009), "Environmental Effects and System Performance Characterisation of GPS Antennas for Mobile Terminals", *IET Electronics Letters*, Vol. 45, No.5.