UNIVERSITI PUTRA MALAYSIA

ACTIVE MICROSTRIP ANTENNA DESIGN FOR GLOBAL POSITIONING SYSTEM APPLICATION

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A circularly polarized microstrip antenna (MSA) was investigated for a commercial land-based Global Positioning System (GPS) application. Critical GPS antenna requirements are its gain, polarization and radiation characteristics. Advancements in electronic miniaturization techniques have made GPS receivers smaller and less bulky, paving the way for smaller antenna structures to improve aesthetic appearance. The crossed-drooping dipole, conventional and printed quadrifilar helix (QHA), archimedean spiral, conical spiral, printed cylindrical slot and the microstrip antenna were investigated for their circular polarization potential and broad beamwidth. Performance comparison analysis indicated the microstrip antenna as a suitable choice mainly for its simple design structure and attractive physical properties.

Two patch geometry, the circular and square patch antennas were fabricated and analyzed to investigate the MSA's design and fabrication sensitivity to geometry. Performance degradation due to fabrication tolerances is an important issue in

manufacturing. Experimental results showed good impedance matching and similar patch performance for both patches. The effect of patch size was also investigated using two different substrates. The only limitation of the MSA for GPS application was its low gain characteristic. However this was easily overcome by integrating an active circuit with the patch. A 16dB increase in gain was obtained without affecting its other performance parameters or low profile structure. GPS satellite acquisition measurements showed that the proposed active antenna could track satellites even at low elevation angles.

To further improve the axial ratio performance of the patch antenna, the effects of limited groundplane at GPS frequency L1 were investigated. Best axial ratio was obtained when groundplane surrounding radiating patch was kept as small as possible. Radiation pattern became omnidirectional but with lower gain characteristics. Attaching parasitic to patch periphery improved axial ratio but reduced gain further. The proposed omnidirectional antenna could find good use for GPS marine applications.

In conclusion the proposed active MSA is seen as a good candidate for commercial GPS applications. Its simple patch design is easy to fabricate and duplicate for mass production.

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ANTENA AKTIF MIKROJALUR UNTUK APLIKASI SISTEM KEDUDUKAN GLOBAL

Oleh

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Penggunaan antena mikrojalur yang mempunyai medan pengutuban membulat telah dikaji kesesuaian untuk dikomersilkan untuk Sistem Kedudukan Global (GPS). Ciri-ciri antena sistem GPS yang penting adalah gandaan, pengutuban dan pola sinarannya. Kemajuaan teknologi di sektor elektronik kini membolehkan saiz alat penerima GPS diperkecilkan lagi. Ini telah meningkatkan lagi kemahuan orang ramai untuk sistem antena yang lebih kecil dan tipis untuk mengurangkan lagi saiz keseluruhan alat penerima GPS. Antena dwikutub berjuntai, `quadrifilar` heliks dalam bentuk asalnya dan tercetak, pilin `archiemedean`, pilin berbentuk kon, antena tercetak selinder berjalur dan antena mikrojalur telah dipilih untuk dikajiselidik umumnya kerana mempunyai ciri pengutuban membulat dan berkeupayaan menghasilkan pola sinaran yang lebar. Perbandingan prestasi kesemua struktur antena tersebut telah menunjukkan bahawa antena mikrojalur adalah yang paling sesuai untuk sistem GPS kerana rekabentuknya yang mudah dan ciri fizikalnya yang menarik.

Dua antena mikrojalur, satu berbentuk bulat dan yang satu lagi berbentuk segiempat telah dihasilkan untuk mengkaji samada prestasi antena mikrojalur akan berubah mengikut bentuk geometrinya. Toleransi dalam proses fabrikasi adalah isu penting dalam proses pengilangan komersil. Hasil ujikaji menunjukkan bahawa tiada perbezaan prestasi diantara kedua-dua geometri antena yang dihasilkan. Analisis perbandingan prestasi antena mikrojalur apabila saiznya berubah juga telah dikajiselidik menggunakan dua bahan mikrojalur yang berbeza. Satu-satunya kelemahan antena mikrojalur adalah gandaannya yang rendah. Walaubagaimanapun, kelemahan ini telah diatasi dengan menggunakan litar aktif. Gandaan sebanyak 16dB telah dapat dihasilkan tanpa mengganggu prestasi antena tersebut ataupun ciri fizikalnya yang tipis. Antena yang dicadangkan ini juga berjaya menerima isyarat satelit walaupun hampir di kaki langit.

Untuk mempertingkatkan lagi sifat pengutuban membulat antena tersebut, saiz permukaan buminya telah dikurangkan. Pada frekuensi GPS L1, didapati bahawa ciri pengutuban membulat bertambah baik apabila saiz permukaan bumi yang mengelilingi antenna tersebut diperkecilkan sebanyak mungkin. Pola sinaran menjadi bulat tetapi gandaannya berkurangan. Memasang parasitik mengelilingi antena tersebut telah dapat meningkatkan lagi ciri pengutuban membulatnya, tetapi ciri gandaanya menjadi rendah. Antena yang baru dicadangkan ini mungkin sesuai untuk aplikasi GPS semasa di laut.

Pada kesimpulannya, didapati bahawa antena aktif mikrojalur yang dicadangkan dalam tesis ini adalah calon yang sesuai untuk dikomersilkan untuk sistem GPS. Rekabentuknya mudah difabrikasi dan dihasilkan dalam kuantiti yang besar.

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LIST OF ABBREVIATIONS

2D	2-Dimensional
AMPS	Advanced Mobile Phone System
AUT	Antenna Under Test
BW	Bandwidth
C/A Code	Coarse Acquisition Code
DGPS	Differential GPS
GIS	Geographical Information Systems
GPS	Global Positioning System
HPBW	Half-Power Beamwidth
LHCP	Left-Hand Circular Polarization
LNA	Low Noise Amplifiers
MCS	Master Control Station
MMIC	Monolithic Microwave Integrated Circuits
MNM	Multiport Network Modeling
MSA	Microstrip Antenna
MTTF	Mean Time To Failure
P Code	Precision Code
PCB	Printed Circuit Board
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
QHA	Quadrifilar Helix Antenna
Q_o	Unloaded Quality Factor

RF	Radio Frequency
RHCP	Right-Hand Circular Polarization
RSSI	Received Signal Strength Indicator
SMM	Spiral-Mode Antenna
SPS	Standard Positioning Service
SS	Signal Strength
$\tan\delta$	Tangent loss
TEM	Transverse Electromagnetic
TM	Transverse Magnetic
UTC	Universal Time Clock
VSWR	Voltage Standing Wave Ratio
WLL	Wireless Local Loop
α	Groundplane Size
β	Parasitic Height
ε_r	Substrate Permittivity
σ	Conductivity
λ	Wavelength

CHAPTER I

INTRODUCTION

Global Positioning System (GPS) is a worldwide satellite-based radio-navigation system developed in the 1970's for the military but has since been adopted for various commercial applications. The United States Government still maintains the highest level of positioning accuracy for the military, but a special Civilian Access code which provides lower positioning accuracy have been developed and made available to everyone.

Navigation receivers are made for aircraft, ships, ground vehicles and even hand-portables for individuals. With the advent of electronic miniaturization, bulky GPS receivers have given way to smaller, lighter and cheaper sets thus driving the need for smaller antenna designs to improve aesthetic appearance (Fisher and Ghassemi, 1999, Enge and Misra, 1999).

This thesis investigates the microstrip antenna and other low planar radiators for a commercial land-based GPS application. The proposed antenna system should be robust enough to be mounted via a magnetic base on the roof of a vehicle and provide sufficient coverage to enable it to be used with a single channel GPS receiver.

Global Positioning System Overview

GPS can be used worldwide for navigation, positioning and time dissemination functions. Positioning can be determined by calculating the distances from at least three satellites and then using simple triangulation to calculate the receiver's current 2-Dimensional (2D) positioning, i.e. latitude and longitude. If a fourth satellite is available, then even altitude information can be provided (3D).

Positioning information is used for vehicle tracking and is popular for managing large vehicle deployments, for security and anti-theft purposes. GPS also provides accurate clocks that can be used to synchronize all clock equipment, especially useful in a Telecommunications Exchange for accurate billing records. GPS is also used for surveying, mapping and the gathering of information for Geographical Information Systems (GIS) and remote sensing applications.

GPS System Architecture

The GPS system architecture consists of a Space Segment, Control Segment and User Segment. The Space Segment is an earth-orbiting constellation of 24 NavStar satellites (21 plus 3 on-orbit operational spares) in six orbital planes. The spacing of satellites in their orbital planes are arranged such that a minimum of four satellites will be in view anywhere on and near the surface of the earth at any one time. These satellites operate in circular 20,200km (10,900 nautical miles) orbits at an inclination angle of 55° and with a 12-hour period (Dana, 1998).

The Control Segment consists of 1 Master Control Station (MCS), 5 Monitor Stations and 3 Ground Antennas. The Monitor Stations passively track all satellites in view, performing almost no processing of data. They send their raw pseudo-range measurements and a 50Hz (navigation) observation message back to the MCS for processing in real time. The MCS then determines each satellite's orbit and updates each satellite's navigational message. Updated information is transmitted to each satellite via the Ground Antennas.

The Ground Antennas are unmanned installations, remotely controlled by the MCS. They provide the Control-Space interface which enable the MCS to command and control the on-orbit NavStar satellites.

The GPS User Segment consists of the GPS receiver and its antenna. GPS receivers convert received signals into position, velocity and time estimates. There are many types of user equipment with different levels of accuracy, customized for various applications.

GPS Signal Characteristics

The satellite works by transmitting two L-band frequencies, L1 = 1575.42 MHz and L2 = 1227.6 MHz, where frequency L1 is made available to everyone. Signal L2 is available in two coded variations, one of which is scrambled for military use. The most precise information is contained in the carrier wave L1 that cannot be scrambled. The three pseudo-random noise (PRN) codes are as follows,

- The Coarse/Acquisition (C/A) code has a 1.023 MHz chip rate, a period of 1 ms and is used primarily to acquire the Precision (P) Code.
- The Precision (P) code has a 10.23 MHz rate, a period of 7 days and is the principal navigation ranging code.

- The Y-code is used instead of the P-code whenever the anti-spoofing (Selective Availability) mode of operation is activated.

The C/A code is available on the L1 while the P-code is available on both L1 and L2. Thus L1 is modulated with two signals in phase quadrature, the C/A code and the P-code, while L2 is modulated only with the P-code. All 24 orbiting satellites transmit on the same frequencies, L1 and L2, where each satellite has a unique C/A and P-code.

The C/A code modulates the L1 carrier signal, 'spreading' it over a 1 MHz bandwidth, hence providing a large margin of resistance to interference. Superimposed on these PRN codes are the navigational data that a GPS receiver uses to calculate its position. The data sent are at a much lower rate than the PRN code.

GPS Service Accuracy

GPS provides two levels of service, Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). The low accuracy of the SPS service can be further improved using a Differential Receiver. SPS is provided on the GPS frequency L1, which contains a course acquisition (C/A) code and a navigation data message. The accuracy of this service is degraded intentionally by manipulating navigation messages, orbit data (epsilon) and/or satellite clock frequency (dither).

This random effect is called Selective Availability, and it affects all civilian GPS receivers the same way. According to the USA Federal Radio-Navigation Plan (1990), SPS provides a 95% accuracy which translates into a predictable positioning accuracy of 100m horizontally, 156m vertically and a time transfer accuracy to the Universal Time Clock (UTC) within 340ns.

PPS is available on a worldwide basis to authorized users only. This service will be denied to unauthorized users by the use of cryptography. Differential GPS (DGPS) has been developed to improve GPS accuracy by adding a land-based reference receiver at an accurately surveyed site. This non-moving DGPS reference station can determine where each satellite is located in space at any given moment as well as its own location, hence the station can compute theoretical distances and the signal travel times between itself and each satellite. These theoretical measurements are compared to actual satellite transmissions and the difference represents the 'error' in the satellite's signal due to the selective availability phenomenon. This data is then used to correct the GPS receiver's own measurements. Naturally, a separate receiver is required to receive DGPS signals and the GPS receiver must be able to process DGPS data. Currently, there are two sources of corrective DGPS signals:

- Coast Guard, land-based beacon transmitters, broadcasting the data at no charge to the public, but limited primarily to coastal areas.
- FM radio sub-carriers transmissions, available in both coastal and inland areas, but limited to paid subscribers.

GPS Receivers

There are two main categories of GPS receivers, the Multiplexing Receivers and the Parallel Channel Receivers. They refer to how a receiver gets and processes information from the satellites, bearing in mind that the receiver must first capture and then measure the signals of at least three different satellites in order to navigate.

Multiplexing Receivers

Multiplexing receivers use a short cut to achieve triangulation. They establish contact with a satellite only long enough to sample its data, then hunt for another satellite to sample and acquire data, then a third and possibly a fourth. This process takes at least several seconds. In order to provide a one second update, most multiplexing receivers grab an update from a couple of satellites and make a 'best guess' at the position update.

Multiplexing receivers are the least expensive types of receivers, but provide less accurate positioning responses to changes in direction and speed. With only one channel to receive, the information has to be pieced together and then averaged. Because of all this switching, multiplexing receivers tend to have more problems finding and keeping contact with satellites in areas covered by foliage or where parts of the sky are blocked by mountains, hills, trees, cliffs, slopes or even tall buildings.

Parallel Channel Receivers

Parallel Channel Receivers maintain a constant simultaneous lock on several satellites at once, eliminating the switching inaccuracies of multiplexing receivers. Some GPS units use at least five parallel channel receivers. This means that there are five dedicated channels reserved for satellite communications. Three channels lock on to satellites to triangulate a longitude/latitude position while the fourth channel