View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Universiti Putra Malaysia Institutional Repository

UNIVERSITI PUTRA MALAYSIA

DESIGN AND ANALYSIS OF PHASED ARRAY ANTENNA BEAM STEERING FOR SATELLITE TRACKING

NG CHEE KYUN

FK 2002 7

DESIGN AND ANALYSIS OF PHASED ARRAY ANTENNA BEAM STEERING FOR SATELLITE TRACKING

By

NG CHEE KYUN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of Requirement for the Degree of Master of Science

March 2002

UPM

DEDICATION

To my beloved parents who have guided me with endless patience

my brothers and sister for their presence in my life.

Thank you.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

PHASED ARRAY ANTENNA BEAM STEERING FOR SATELLITE TRACKING

By

NG CHEE KYUN

March 2002

Chairperson: **Nor Kamariah Noordin, M.Sc.**

Faculty: **Engineering**

Nowadays achievements on mobile satellite system (MSS) communication give a great concern for research in global wireless communication fields. This has prompted the development of several Non Geostationary Earth Orbit (Non-GEO) satellite systems that promises worldwide connectivity for real-time communications. The mobility of Non-GEO satellite systems require a high directivity satellite tracking technique and a reliable inter satellite handover algorithm to ensure that connectivity between two end users are not interrupted as a result of satellite movement.

In this thesis, phased array antenna has been proposed to obtain high directivity beam for satellite tracking. In order to do this, the phased array antenna mathematical model has been developed. This mathematical model has demonstrated that a narrow beam with high directivity could be generated. By changing the phase of the exciting currents in each element of antenna array, the radiation pattern could be varied through space. Thus, the generation of multiple and steerable beams also could be depicted by varying the phase shift of phase shifter with appropriate spacing between each elements

to be sufficiently large. It is also shown here that the generated radiation beamwidth can be controlled by varying the number of antenna elements. It was found that the beamwidth reduces exponentially with the increment of the number of antenna elements.

A new algorithm called Soft Dual Beam (SDB) algorithm has been developed to provide a solution to handle the inter satellite handover process. SDB is derived from a number of various Non-GEO satellite orbital parameters such as satellite orbital period, satellite visibility period and inter satellite period. A high directivity beam from phased array antenna will be generated and steered to link up with incoming ascending satellite at one end when the connected outgoing descending satellite exceeded the defined critical elevation angle at the other end. The SDB algorithm helps to lower the inter satellite handover delay by accurately tracking the position of the satellite with the same signal level before the handover. Simulations have been done to measure the performance of the SDB algorithm.

It is concluded that the proposed SDB algorithm provides low delay in handover between satellites process. Thus, the possibility of communication connection dropping during handover will be significantly low. This is due to the algorithm which uses elevation angle in initiating inter satellite handover, instead of measuring signal link level to the satellites. With the introduction of SDB algorithm, the quality of service (QoS) for the next generation MSS communication system is expected to be improved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANTENA TATASUSUNAN FASA ALUR KEMUDIAN UNTUK JEJAKAN SATELIT

Oleh

NG CHEE KYUN

Mac 2002

Pengerusi: **Nor Kamariah Noordin, M.Sc.**

Fakulti: **Kejuruteraan**

Pencapaian sistem komunikasi satelit bergerak (MSS) masa kini telah memberi banyak tumpuan bagi penyelidikan dalam bidang komunikasi wayarles sedunia. Ini telah merangsangkan pembangunan pada beberapa sistem satelit Bukan Orbit Geopegun Bumi (Non-GEO) yang menjanjikan perhubungan ke seluruh dunia bagi komunikasi masa nyata. Pergerakan sistem satelit Non-GEO memerlukan teknik jejakan satelit yang berketerarahan tinggi dan satu algoritma pengambilalihan antara satelit yang konsisten bagi memastikan perhubungan antara dua pengguna akhir tidak diganggu akibat daripada pergerakan satelit itu.

Dalam tesis ini, antena tatasusunan fasa telah dicadangkan bagi memperoleh alur berketerarahan tinggi untuk jejakan satelit. Untuk tujuan ini, model matematik untuk antena tatasusunan fasa telah dibangunkan. Model matematik ini telah menunjukkan satu alur halus berketerarahan tinggi dapat dijanakan. Dengan menukarkan fasa arus teruja dalam setiap unsur antena tatasusunan, corak alur dapat diubah menerusi ruang. Oleh itu, penjanaan alur yang berbilang dan berkebolehkemudian juga dapat ditunjukkan dengan

mengubah fasa pada penganjak fasa dengan peruntukan ruang antara setiap unsur yang cukup luas. Ini juga menunjukkan lebar jalur sinaran yang dijanakan dapat dikawal dengan mengubah bilangan unsur antena. Didapati bahawa lebar jalur menyusut secara exponen dengan tokokan bilangan unsur antena.

Satu algoritma baru yang dikenali sebagai algoritma Dwi Alur Halus (SDB) telah dibangunkan untuk memberi satu penyelesaian bagi mengendalikan proses pengambilalihan antara satelit. Algoritma SDB diterbit daripada pelbagai orbit satelit Non-GEO parameter seperti tempoh orbit satelit, tempoh kebolehlihatan satelit dan tempoh antara satelit. Satu alur berketerarahan tinggi dari antena tatasusunan fasa akan dijanakan dan dikemudikan bagi menyambungkan kedatangan satelit yang menaik pada satu hujung apabila sambungan keluaran satelit yang menurun pada satu hujung yang lain melebihi sudut dongakan takrifan yang kritikal. Algoritma SDB membantu mengurangkan masa kelengahan pengambilalihan antara satelit dengan kejituan jejak kedudukan satelit pada aras isyarat yang sama sebelum pengambilalihan. Simulasi telah dijalankan untuk mengukur prestasi algoritma SDB.

Ini dapat disimpulkan bahawa algoritma SDB yang telah dicadangkan memberi masa kelengahan yang rendah dalam proses pangambilalihan antara satelit. Dengan itu, kebarangkalian rangkaian komunikasi tercicir semasa pengambilalihan akan menjadi rendah. Ini disebabkan algoritma yang mengunakan sudut dongakan dalam memulakan pengambilalihan antara satelit, sebagai mengganti bagi mengukur paras isyarat sambungan pada satelit. Dengan pengenalan algoritma SDB, kualiti perkhidmatan untuk sistem komunikasi MSS pada generasi akan datang dijangka dapat dipertingkatkan.

ACKNOWLEDGEMENTS

Firstly, I wish to express my sincere appreciation and gratitude to my supervisor, Pn. Nor Kamariah Noordin, for her counsel, guidance and inspiration throughout my research period. She was always available for providing useful direction and advice when I needed. Also I extend my grateful appreciation to other supervisors, Assoc. Prof. Dr. Borhanuddin Mohd. Ali and Pn. Ratna Kalos Zakiah Sahbudin, for their invaluable experience, knowledge and support to me.

Special thanks also extend to my former supervisors, Mr. Ashraf Gasim Elsid Abdalla and Dr. Sabira Khatun for their ideas and suggestions that have contributed to this work. I would like to take this opportunity to thank other colleagues who have contributed directly or indirectly to this work. To Choong Khong Neng, Tan Kee Leong, Yem Poh Cheang and Prihandoko, my helpful seniors, for their encouragement and support. To Aduwati Sali and Angeline Anthony, my research members, for their ideas, knowledge and advices. To others especially in Wireless and Photonic Groups, thanks for their assistance and cooperation throughout my research period.

Finally, to my family, especially both my parents, thanks for their endless love and support. To my brothers and sister, thanks for their encouragement and support to me.

I certify that an Examination Committee met on 28th March 2002 to conduct the final examination of Ng Chee Kyun on his Master of Science thesis entitled "Phased Array Antenna Beam Steering for Satellite Tracking" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

MOHAMAD KHAZANI ABDULLAH, Ph.D.
Associate Professor,
Department of Computer and Communication Systems Engineering,
Faculty of Engineering,
Universiti Putra Malaysia.
(Chairman)

NOR KAMARIAH NOORDIN, M.Sc.
Department of Computer and Communication Systems Engineering,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

BORHANUDDIN MOHD ALI, Ph.D.
Associate Professor,
Department of Computer and Communication Systems Engineering,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

RATNA KALOS ZAKIAH SAHBUDIN, M.Sc.
Department of Computer and Communication Systems Engineering,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

SHAMSHER MOHAMAD RAMADILI, Ph.D.
Professor / Deputy Dean,
School of Graduate Studies,
Universiti Putra Malaysia.

Date: 15 APR 2002

The thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

AINI IDERIS, Ph.D.
Professor / Dean,
School of Graduate Studies,
Universiti Putra Malaysia.

Date: 13 JUN 2002

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NG CHEE KYUN

Date: 2nd April 2002

TABLE OF CONTENTS

		Page
DEDICATION		ii
ABSTRACT		iii
ABSTRAK		v
ACKNOWLEDGEMENTS		vii
APPROVAL SHEETS		viii
DECLARATION		x
LIST OF TABLES		xiv
LIST OF FIGURES		xv
LIST OF ABBREVIATIONS		xviii
LIST OF NOTATIONS		xx
CHAPTER		
I	INTRODUCTION	1
	Mobile Satellite Communication Systems Overview	1
	Appropriate Antenna Systems for Satellite Tracking	4
	Non-GEO Satellites Mobility Routing Management	5
	Description Mobile Satellite Communications Scenarios and Challenges	7
	Objectives	9
	Organisation	10
II	LITERATURE REVIEW	11
	Propagation of Sinusoidally Plane Waves in Free Space	13
	Antenna Radiation Power Density	15
	Isotropic Radiation	15
	Directivity Radiation	16
	Principle of Antenna Array	17
	MSS's Portable Vehicle Phased Array Antenna	20
	Lens Fed Array Approach for MSS Applications	21
	Two Ring Circular Phased Array Antenna for MSS Communication	23
	Self Steering Planar Array Antenna for Satellite Broadcast Reception	26
	Appropriate Phase Shifter Used in Phased Array Antenna	28
	Ferrite Phase Shifter	28
	Semiconductor Diode Phase Shifter	30
	Monolithic Microwave Integrated Circuit	31
	Analog Phase Shifter Circuts	32
	Phase Locked Loops	33
	Microeletromechanical System	35

	Optoelectronic Phase Locked Loops	35
	Non-GEO Satellite Network System	37
	Non-GEO Satellite Constellation	38
	Odyssey	38
	ICO Global Communications	40
	Globalstar	40
	Iridium	41
	Teledesic	42
	Inter Satellite Handover Techniques and Algorithms	43
	Position and Signal Strength Algorithm	44
	Footprint Handover Rerouting Protocol	45
	Multiple Diversity Link Technique	46
III	METHODOLOGY	48
	Mathematical Model of Phased Array Antenna Design	48
	Array Antenna with Two Elements	49
	Array Antenna with *N* Elements	53
	Spacing Distance between Elements over Beam Frequency	55
	Phased Array Antenna Beamwidth	56
	Selection Criteria of Compatible Phase Shifter	57
	Insertion Loss	57
	Switching Time	57
	Drive Power	57
	Non-GEO Satellite Constellation Parameters	58
	Velocity of Non-GEO Satellites	58
	Satellite Constellation Orbital Period	60
	Satellite Visibility Period	61
	Inter Satellite Period	63
	New Algorithm for Inter Satellite Handover	64
	Inter Satellite Handover using SDB Algorithm	66
IV	SIMULATION RESULTS	70
	Mathematical Model of Phased Array Antenna Beam Forming Simulation	70
	Electronic Beam Steering	70
	Antenna System Beamwidth	76
	Multiple Beams Generation	81
	Performance of Phase Shift over Antenna Elevation Angle	86
	Non-GEO Satellite Constellation Systems	88
	Odyssey Satellite System	89
	ICO Satellite System	90
	Globalstar Satellite System	91
	Iridium Satellite System	92
	Teledesic Satellite System	93
	SDB Algorithm for Non-Geo Satellites Tracking	94
	Odyssey Satellite	96

ICO Satellite 97
Globalstar Satellite 98
Iridium Satellite 99
Teledesic Satellite 100

V. DISCUSSIONS 102
The Performance of Non-GEO Satellite Characteristics 102
The Speed of Satellite Varies with Altitude of Satellite 103
The Satellite Orbital Period over the Altitude of Satellite 104
The Satellite Visibility Durations 105
Beam Radiation Propagation Delay of Non-GEO Satellite Systems 106
The Performance of SDB Algorithm in Inter Satellite Handover 107
Signal Strength Level 107
Multiple Diversity Management 108
Rerouting Management 109
Alternative Solution in SDB Algorithm for Inter Satellite Handover 110
Conclusions 111

VI. CONCLUSIONS AND FUTURE WORKS 114
The Significances and Contributions 114
Future Works 116
Hardware Implementation 116
Inter Orbit Satellite Tracking System 117

REFERENCES 118
BIODATA OF THE AUTHOR 122

LIST OF TABLES

Table		Page
4.1	The performance of several type phase shifters.	87
4.2	Summary of various satellite constellation system parameters.	94
4.3	Performance of SDB algorithm for Non-GEO satellites tracking.	101

LIST OF FIGURES

Figure		Page
1.1	Handover management operations.	7
2.1	Infinite plane sheet in the xy-plane carrying surface current of uniform density.	13
2.2	Time history of uniform plane electromagnetic wave radiating away from an infinite plane current sheet in free space.	14
2.3	Isotropic radiation in free space with the isotrope at the centre.	15
2.4	Time history of individual fields and the total field due to an array of two infinite plane parallel current sheets.	19
2.5	Lens fed array antenna geometry.	21
2.6	Lens switching network.	22
2.7	A block diagram of a two ring phased array antenna.	24
2.8	The assembly configuration of the two-ring phased array.	25
2.9	A transparent layout of the two-ring phased array.	25
2.10	Example of use of self-steering planar array antenna for DBS reception.	26
2.11	Multilayer substrate architecture for a self phasing active planar array.	27
2.12	The block diagram of the self-phasing planar array antenna.	28
2.13	Schematic of transmission 4 bit phase shifter.	30
2.14	Inter satellite handover scenario.	43
3.1	Phased array antenna with *N* elements.	49
3.2	Computing the radiation field due to an array of two elements.	50
3.3	A uniform linear array of n antennas.	53
3.4	Depiction of satellite speed over Earth's gravity.	58

3.5	Depiction of how to obtain satellite visibility period.	61
3.6	SDB algorithm phenomena.	68
3.7	Flow chart of SDB algorithm.	69
4.1a	Plot of beam steer with directivity, ψ of 0^o for phase shift, $\alpha = -180^0$.	71
4.1b	Plot of beam steer with directivity, ψ of 60^o for phase shift, $\alpha = -90^0$.	72
4.1c	Plot of beam steer with directivity, ψ of 90^o for phase shift, $\alpha = 0^0$.	73
4.1d	Plot of beam steer with directivity, ψ of 120^o for phase shift, $\alpha = 90^0$.	74
4.1e	Plot of beam steer with directivity, ψ of 0^o and 180^o for phase shift, $\alpha = 180^0$.	75
4.2a	Plot of phased array antenna with one element.	76
4.2b	Plot of phased array antenna with two elements.	77
4.2c	Plot of phased array antenna with 8 elements.	78
4.2d	Plot of phased array antenna with 50 elements.	79
4.2e	Plot of phased array antenna beamwidth over several number of elements.	80
4.3a	Plot of phased array antenna with SLR = 0.3 with -60^o phase shift.	81
4.3b	Plot of phased array antenna with SLR = 1 with 0^o phase shift.	82
4.3c	Plot of phased array antenna with SLR = 0.7071 with 180^o phase shift.	83
4.3d	Plot of phased array antenna with SLR = 2 with -120^o phase shift.	84
4.3e	Plot of the number of generated beams over the SLR.	85
4.4	Plot of antenna elevation angle versus phase shift.	86
4.5	Calculation of handover critical angle.	95
4.6a	Odyssey inter satellite handover.	96
4.6b	ICO inter satellite handover.	97
4.6c	Globalstar inter satellite handover.	98

4.6d	Iridium inter satellite handover.	99
4.6e	Teledesic inter satellite handover.	100
5.1	The speed of satellite varies with satellite altitude.	103
5.2	Satellite orbital period versus altitude of satellite.	104
5.3	The satellite visibility duration for specific altitude of satellite.	105
5.4	Beam radiation propagation delay of satellite in various altitudes.	106
5.5a	Soft dual beam of Odyssey satellite at 25.75° and 154.25°.	112
5.5b	Soft dual beam of ICO satellite at 40.35° and 139.65°.	112
5.5c	Soft dual beam of Iridium satellite at 22.6° and 157.4°.	113
5.5d	Soft dual beam of Teledesic satellite at 55.65° and 124.35°.	113

LIST OF ABBREVIATIONS

BS	-	Base Station
BW	-	Beamwidth
CDMA	-	Code Division Multiple Access
CPW	-	Coplanar Waveguide
DBS	-	Direct Broadcast Satellite
ES	-	Earth Station
FHRP	-	Footprint Handover Reroute Protocol
FR	-	Footprint Rerouting
GEO	-	Geostationary Earth Orbit
GSLD	-	Gain Switched Laser Diode
HTS	-	High Temperature Superconductor
IL	-	Insertion Loss
IF	-	Intermediate Frequency
IMT-2000	-	International Mobile Telecommunications year 2000
ISL	-	Inter Satellite Link
LEO	-	Low Earth Orbit
LF	-	Loop Filter
MAHO	-	Mobile-Assisted Handoff
MCHO	-	Mobile-Controlled Handoff
MEMS	-	Microelectromechanical System
MEO	-	Medium Earth Orbit

MIC	-	Microwave Integrated Circuit
MMIC	-	Monolithic Microwave Integrated Circuit
MSS	-	Mobile Satellite System
MT	-	Mobile Terminal
NCHO	-	Network-Controlled Handoff
Non-GEO	-	Non-Geostationary Earth Orbit
OEPLL	-	Optoelectronic Phase Locked Loop
PCS	-	Personal Communication System
PLL	-	Phase Locked Loop
PSK	-	Phase Shift Keying
PSTN	-	Public Switched Telephone Network
QoS	-	Quality of Service
SDB	-	Soft Dual Beams
SLR	-	Spacing Distance over Wavelength Ratio
TTD	-	True Time Delay
VCO	-	Voltage-Controlled Oscillator
YBCO	-	Yttrium Barium Copper Oxide

LIST OF NOTATIONS

h_G	-	Altitude of GEO Satellite
h_N	-	Altitude of Non-GEO Satellite
α	-	Angular Phase Shift
J_{SO}	-	Current Amplitude
J_S	-	Current Density
G	-	Directive Gain
ω	-	Earth Angular Rotation Speed
E	-	Electric Field
ε_o	-	Electric Permittivity
ψ	-	Elevation Angle
R_E	-	Equatorial Radius of the Earth
η_O	-	Free Space Wave Impedance
R_G	-	GEO Satellite Orbit Radius
v_G	-	GEO Satellite Speed
$T_{satellite}$	-	Inter Satellite Period
H	-	Magnetic Field
μ_o	-	Magnetic Permeability
v_N	-	Non-GEO Satellite Speed
T_N	-	Non-GEO Satellite Orbital Period

R_N	-	Non-GEO Satellite Orbit Radius
S_o	-	Orbit Length
v_p	-	Phase Velocity
$P_{isotrope}$	-	Power Density of Isotrope
$P_{semi\text{-}isotrope}$	-	Power Density of Semi-Isotrope
β	-	Propagation Constant
T_{visit}	-	Satellite Visibility Period
d	-	Spacing Between Antenna Elements
c	-	Speed of Light
λ	-	Wavelength

CHAPTER I

INTRODUCTION

The commercial proliferations of cellular voice and limited data service have created a great demand for mobile communications and computing. Current voice, fax, email, and paging services will give way to data transfer, video conferencing, image transfer, and video delivery. Achieving such an advanced level of tetherless mobile multimedia service requires the development of a wireless network that can provide not only the integrated services, but also dynamic relocation of mobile terminals. As a result, next generation mobile communication systems are currently being researched worldwide (Akyildiz, 1999).

Mobile Satellite Communication Systems Overview

Nowadays private companies are striving to provide truly seamless global communications to the public, making today's personal communication systems (PCS) a proving ground for new technologies. Recent years have witnessed the introduction of a large number of mobile satellite systems (MSS). The integration of MSS with terrestrial cellular networks will pave the way for future next generation mobile communication systems. Several satellite orbital constellations have been proposed for MSS (Re, 1999). Currently, there are more than 333 communication satellites in orbit at an altitude ranging from 780 km to 36,000 km away from earth (Boeke, 1999). Depending on the distance between the satellite and the earth, these systems are grouped into Low Earth

Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO) systems. The LEO satellite systems use orbits with altitudes in the range of 1000 km above the earth's surface. This is followed by MEO satellite systems, with their orbit altitudes between 2000 km and 10,000 km, and then by GEO satellite systems, with the orbit at 36,000 km above the earth's surface (Bialkowski, 1999).

GEO satellites are fixed with respect to a terrestrial observer and they are on an equatorial circular orbit at about 36,000 km of altitude. Theoretically, only three GEO satellites are required to serve all the Earth coverage (Re, 1995). GEO satellite systems allow full earth coverage below 70 degrees latitude with as few as three satellites. However, the GEO satellites may cause a significant transmission delay with more than 250 ms due to their high altitude. Therefore it could be a problem especially when there is a concatenation of networks. Some of these delay problems associated with satellite transmissions are avoided by going to wireline fiber and LEO or MEO communication satellites (Pattan, 2000). This has prompted the development of several Non-Geostationary Earth Orbit (Non-GEO) satellite systems which consists of LEO and MEO that promise worldwide connectivity and real-time voice communications.

Since LEO and MEO satellites are usually defined for those with altitude between 500 and 10,000 km above the Earth's surface, these low altitude satellites systems are seen as a means of providing truly global ubiquitous hand-held low delay real time communication systems with only low power requirements, and ensure the earth coverage with smaller cells, so achieving a higher traffic capacity. This global approach has sparked the development of several new communication satellite systems,

which abandoned the traditional use of GEO in favour of LEO and MEO satellite systems (Uzunalioğlu, 1997; Pratt, 1999).

The Non-GEO satellites are not stationary with respect to a fixed point on the Earth with a constant speed where the satellite ground-track speed is far greater than the earth rotation speed and the user speed (Ganz, 1994). In contrast to terrestrial mobile cellular systems, when the mobile network is based on Non-Geo satellites, these satellites behave like moving base stations with respect to land users. The satellite footprints (or cells) therefore move through the user space and the period of visibility for an individual satellite is typically only a few minutes. These satellite cells move at such a high speed that the movement of the mobile terminal (MT) can usually be neglected (Carter, 1995; Ruiz, 1998).

Global coverage at any time is possible if a certain number orbits and satellites are used (Uzunalioğlu, 1997). Besides that, inter satellite links (ISL) make it possible to route a connection through the satellite network without using any terrestrial resources. As an example, the Iridium system uses 6 polar orbits with 11 satellites in each orbit (Pratt, 1999). Construction of these satellite constellations for global wireless communication has begun with the launch of a number of Motorola's Iridium satellites in 1997, and the building of a number of Qualcomm's Globalstar satellites launched in 1998. These early constellations, and their competitors, aim to provide low bandwidth satellite telephony world wide, including paging, faxing and high speed modern services. Future satellite constellations have been proposed for high bandwidth wireless data transmission such as Teledesic satellites (Wood, 1998).