

# **Broadband Planar Antennas with Improved Radiation Patterns for Satellite Reception**

Zur Erlangung des akademischen Grades

**DOKTOR-INGENIEUR**

vom Fachbereich Elektrotechnik der  
Universität - GH Paderborn

genehmigte Dissertation  
von

**DEA Leïla Bekraoui**

aus Rabat, Marokko

Referent : Prof. Dr.-Ing. Wido Kumm  
Korreferent : Prof. Dr.-Ing. Andreas Thiede

Tag der mündlichen Prüfung: 10. April 2001

Paderborn 2001  
D 14 - 165

Berichte aus der Kommunikationstechnik

**Leïla Bekraoui**

**Broadband Planar Antennas  
with Improved Radiation Patterns  
for Satellite Reception**

D 466 (Diss. Universität-GH Paderborn)

Shaker Verlag  
Aachen 2001

Die Deutsche Bibliothek - CIP-Einheitsaufnahme

*Bekraoui, Leïla:*

Broadband Planar Antennas with Improved Radiation Patterns  
for Satellite Reception / Leïla Bekraoui.

Aachen : Shaker, 2001

(Berichte aus der Kommunikationstechnik)

Zugl.: Paderborn, Univ., Diss., 2001

ISBN 3-8265-9541-6

Copyright Shaker Verlag 2001

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 3-8265-9541-6

ISSN 0945-0823

Shaker Verlag GmbH • P.O. BOX 1290 • D-52013 Aachen

Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9

Internet: [www.shaker.de](http://www.shaker.de) • eMail: [info@shaker.de](mailto:info@shaker.de)

# Contents

<b>Symbols and Abbreviations</b>	<b>4</b>
<b>1 Introduction</b>	<b>11</b>
<b>2 Direct Broadcasting Satellite Reception</b>	<b>14</b>
2.1 Historical .....	14
2.2 From the reflector to the planar antenna.....	14
2.3 Fundamental parameters and requirements .....	19
2.3.1 Radiation pattern .....	19
2.3.2 Gain and efficiency.....	20
2.3.3 Antenna noise temperature .....	22
2.3.4 Polarisation.....	24
2.3.5 Frequency band and relative bandwidth.....	25
<b>3 Microstrip Antennas as Planar Antennas</b>	<b>28</b>
3.1 Fundamentals.....	28
3.2 Advances in feeding techniques .....	31
3.2.1 Introduction .....	31
3.2.2 Contacting feeds .....	31
3.2.3 Requirements for antenna and its feeding .....	33
3.2.4 Non-contacting feeds .....	34
3.3 Existing methods for improvement of characteristics.....	36
3.3.1 Bandwidth .....	36
3.3.2 Cross-polarisation.....	41
3.4 Proper used methods for improvement of characteristics .....	45
3.4.1 Bandwidth .....	45
3.4.2 Cross-polarisation.....	47
3.5 Analysis and modelling.....	49

3.5.1	Introduction.....	49
3.5.2	Analysis of chosen configuration .....	49
3.5.3	Modelling by Method of Moments.....	51
<b>4</b>	<b>Aperture Coupled Microstrip Antenna as Basic Element .....</b>	<b>54</b>
4.1	Introduction.....	54
4.2	Structure of antenna element .....	54
4.2.1	Choice of substrates .....	54
4.2.2	Positioning and characteristics of structure components.....	57
4.2.3	Perforated patch .....	59
4.3	Dimensioning and optimisation .....	61
4.3.1	Procedure.....	61
4.3.2	Resonances .....	62
4.3.3	Impedance matching .....	72
4.3.4	Perforated patch .....	80
4.4	Measurement results.....	84
4.4.1	Bandwidth and port isolation .....	84
4.4.2	Radiation pattern and gain.....	86
4.4.3	Evaluation of parallel plate mode .....	88
<b>5</b>	<b>Array Antenna with Low Side Lobes Level Capabilities.....</b>	<b>90</b>
5.1	Conventional arrays.....	90
5.2	Developed antenna structure.....	94
5.2.1	Introduction.....	94
5.2.2	Structure principle.....	94
5.2.3	Simulation results.....	98
5.3	Novel feeding technique.....	100
5.3.1	Choice of feeding network type.....	100
5.3.2	Feeding of symmetrical subarrays .....	101
5.3.3	Feeding of complete antenna.....	106

5.4	Measurement results .....	109
5.4.1	Preliminaries.....	109
5.4.2	Bandwidth and port isolation .....	110
5.4.3	Radiation pattern and gain .....	112
5.4.4	Reception quality.....	116
<b>6</b>	<b>Conclusions</b>	<b>118</b>
<b>A</b>	<b>Appendices</b>	<b>121</b>
A.1	Relation between gains of two array antennas.....	121
A.1.1	Gain of array antenna based on gain of single antenna element .....	121
A.2.1	Generalisation.....	122
A.2	Requirements catalogue for realisation .....	124
A.3	Photos of realised antennas and feeding networks.....	126
	<b>Bibliography</b>	<b>130</b>

## Symbols and Abbreviations

### Symbols

$(a, b, c)$	Spherical coordinates of patch
$a_n$	Unknown constant
$B$	Transponder bandwidth
$B_w$	Antenna relative bandwidth
$C / N$	Carrier-to-noise ratio
$D$	Largest dimension of antenna
$d_x$	Spacing between antenna elements in $x$ -direction
$d_y$	Spacing between antenna elements in $y$ -direction
$E$	Electric field
$E_x$	$x$ -component of $E$
$E_y$	$y$ -component of $E$
$E_z$	$z$ -component of $E$
$E(z, t)$	Instantaneous electric field
$E_x(z, t)$	$x$ -instantaneous component of $E(z, t)$
$E_y(z, t)$	$y$ -instantaneous component of $E(z, t)$
$E_{x0}$	Maximum magnitude of $E_x(z, t)$
$E_{y0}$	Maximum magnitude of $E_y(z, t)$
$E_A(\theta_0, \phi_0)$	Far-zone electric field of an array antenna in the direction $(\theta_0, \phi_0)$
$e_A$	Efficiency of an array antenna
$e_a$	Efficiency accounting for losses of array structure

$e_o$	Total efficiency
$e_c$	Conduction efficiency
$e_d$	Dielectric efficiency
$e_{qp}$	Efficiency accounting for losses inserted by the extension of an array from $Q$ to $P$ elements
$e_r$	Reflection efficiency
$e_s$	Efficiency of a single antenna element
$F$	Linear integral operator
$f$	Frequency
$f_h$	Upper boundary of simulated or measured frequency band
$f_l$	Lower boundary of simulated or measured frequency band
$G$	Gain
$G_A$	Gain of an array antenna
$G_P$	Gain of an array antenna composed of $P$ antenna elements
$G_Q$	Gain of an array antenna composed of $Q$ antenna elements
$G_S$	Gain of a single antenna element
$G/T$	Gain-to-noise ratio
$\overline{G/T}$	Mean value of $G/T$
$g$	Response function to excitation
$g_n$	Basis function
$H_y$	$y$ -component of magnetic field
$h$	Excitation current function
$h_m$	Test function
$I_{nm}$	Excitation factor of the element $(n, m)$



$ I_{nm} $	Amplitude of $I_{nm}$
$I(x)$	Current at the position $x$
$\mathbf{J}_t$	Surface current on patch
$\mathbf{J}_x$	$x$ -component of $\mathbf{J}_t$
$\mathbf{J}_y$	$y$ -component of $\mathbf{J}_t$
$K$	Boltzmann's constant
$k$	Wave number
$k_0$	Free-space wave number
$L$	Patch length
$L_a$	Atmospheric attenuation
$L_d$	Free-space attenuation
$L_{o1}$	Feeding line overlap at Port 1
$L_{o2}$	Feeding line overlap at Port 2
$L_{p1}$	Resonant length of perforated patch at Port 1
$L_{p2}$	Resonant length of perforated patch at Port 2
$L_{s1}$	Aperture resonant length at Port 1
$L_{s2}$	Aperture resonant length at Port 2
$L_1$	Patch resonant length at Port 1
$L_2$	Patch resonant length at Port 2
$L_{10}, L_{11}, L_{12}$	Transmission lines lengths of impedance matching network at Port 1
$L_{20}, L_{21}, L_{22}$	Transmission lines lengths of impedance matching network at Port 2
$M$	Number of array elements in $y$ -direction
$\mathbf{M}$	Equivalent magnetic current of aperture
$M_y$	Magnetic polarisation current
$N$	Number of array elements in $x$ -direction

$N_1$	Number of perforated patch strips at Port 1
$N_2$	Number of perforated patch strips at Port 2
$P_C$	Carrier power level
$P_{EIRP}$	Effective isotropically radiated power
$P_{NA}$	Antenna noise power
$P_{NS}$	System noise power
$P_{in}$	Input power
$P_{inA}$	Input power of an array antenna
$P_r$	Radiated power
$P_{rA}$	Radiated power from an array antenna
$P_{rS}$	Radiated power from a single antenna element
$P_z$	Electric polarisation current
$Q$	Quality factor
$q$	Fraction of power entering an antenna
$R(\theta, \phi)$	Radiation pattern of single antenna element in the direction $(\theta, \phi)$
$R$	Amplitude of $R(\theta, \phi)$
$R_A(\theta, \phi)$	Radiation pattern of array antenna
$R_A$	Amplitude of $R_A(\theta, \phi)$
$R_{AF}(\theta, \phi)$	Array factor
$R_{AF}$	Amplitude of $R_{AF}(\theta, \phi)$
$R_s$	Radius of sphere enclosing antenna
$S_{LL}$	Side lobe level
$S_v$	Voltage standing wave ratio
$S_1$	Spacing between perforated patch strips at Port 1
$S_2$	Spacing between perforated patch strips at Port 2

$S_{11}$	Scattering parameter corresponding to input impedance
$S_{12}$	Scattering parameter corresponding to port isolation
$T_A$	Antenna noise temperature
$T_R$	Receiver noise temperature
$T(\theta, \phi)$	Temperature distribution in the direction $(\theta, \phi)$
$t$	Substrate thickness
$t_0$	Thickness of foil supporting patch
$t_1$	Thickness of patch substrate
$t_2$	Thickness of feeding substrate
$t_3$	Thickness of space foam
$\tan\delta$	Substrate loss
$\tan\delta_1$	Loss of patch substrate
$\tan\delta_2$	Loss of feeding substrate
$\tan\delta_{eff}$	Effective substrate loss
$U(\theta, \phi)$	Radiation intensity in the direction $(\theta, \phi)$
$U_A(\theta_0, \phi_0)$	Radiation intensity of an array antenna in the direction $(\theta_0, \phi_0)$
$U_S(\theta_0, \phi_0)$	Radiation intensity of a single antenna element in the direction $(\theta_0, \phi_0)$
$V(x)$	Voltage at the position $x$
$W$	Patch width
$W_1$	Width of perforated patch strips at Port 1
$W_2$	Width of perforated patch strips at Port 2
$W_{11}, W_{12}$	Transmission lines widths of impedance matching network at Port 1
$W_{21}, W_{22}$	Transmission lines widths of impedance matching network at Port 2

$x_0$	$x$ -coordinate of aperture
$\hat{x}$	Unit vector in the $x$ -direction
$\hat{y}$	Unit vector in the $y$ -direction
$Z_{in}$	Input impedance
$Z_{in}(x)$	Input impedance at the position $x$
$\alpha_e$	Electric polarisability
$\alpha_m$	Magnetic polarisability
$\Delta f$	Receiver bandwidth
$\Delta P$	Wasted power
$\Delta\phi$	Time-phase difference
$\Delta\theta_{3dB}$	Half power beamwidth
$\epsilon_0$	Air dielectric constant
$\epsilon_r$	Substrate dielectric constant also called relative permittivity
$\epsilon_{r1}$	Substrate dielectric constant of patch
$\epsilon_{r2}$	Substrate dielectric constant of feeding
$\phi_x$	$x$ -component of phase
$\phi_y$	$y$ -component of phase
$\Gamma$	Reflection coefficient
$\varphi_{nm}$	Phase of $I_{nm}$
$\eta$	Constant
$\lambda_0$	Free-space wavelength
$\lambda_g$	Guided wavelength
$(\theta, \phi)$	Direction of radiation
$(\theta_0, \phi_0)$	Direction of maximum radiation
$\theta_p$	Angle of wave propagation

## Abbreviations

ACM	Aperture Coupled Microstrip
CEM	Computational Electromagnetics
DBS	Direct Broadcasting Satellite
DSR	Digital Satellite Radio
DTH	Direct To Home
LNB	Low Noise Block converter
MoM	Method of Moments
MPIE	Mixed Potential Integral Equation
PTFE	Polytetrafluoroethylene
SMA	Sub-Miniatur-A
TEM	Transverse Electromagnetic
VSWR	Voltage Standing Wave Ratio