

UNIVERSITE C



.IS

ECOLE DOCTORALE STIC
SCIENCES ET TECHNOLOGIES DE L'INFORMATION ET DE LA COMMUNICATION

T H E S E

pour l'obtention du grade de

Docteur en Sciences

de l'Université Nice-Sophia Antipolis

Mention : Électronique

présentée et soutenue par

Muhammad Nazrol BIN ZAWAWI

New Antenna for Millimetre Wave Radar

Thèse dirigée par *Claire MIGLIACCIO*

Jury :

Mauro ETTORRE

HDR, CR1-CNRS, IETR UMR 6164,
Université de Rennes 1

Rapporteur

Thierry MONEDIERE

Professeur, Université de Limoges

Rapporteur

Claire MIGLIACCIO

Professeur, Univ. Nice Sophia Antipolis

Directeur de thèse

Jérôme LANTERI

MCF, Univ. Nice Sophia Antipolis

Encadrant

Acknowledgments

Foremost, I would like to express my sincere gratitude to my supervisor, Claire Migliaccio for her continuous support in my study and research. Her patience, motivation, enthusiasm and immense knowledge had greatly influenced me. Her guidance helped me in all the time of research and writing of this study. I could not have imagined having a better supervisor for my electronic path study and my academic career progress.

Besides my supervisor, I would like to thank my assistant supervisor Jerome Lanteri for his idea, views and technical knowledge in RF field. Not to forget my classmate and officemate Philippe Perissol for his great help. My sincere thanks also go to all lecturers in Electronic Department of University Nice Sophia Antipolis, Christian Pichot, Jean Yves Dauvignac, Geoges Kossiavas and Jean Marc Ribero for their professional support and knowledge during my academic studies.

I am greatly indebted to Lutfi Arif Bin Ngah and Raja Fazliza Binti Raja Suleiman for their stimulating discussions, great opinions, insightful comments and guidance in writing. I also would like to thank my fellow batch mates and the rest of colleagues in LEAT.

Last but not least, I am eternally indebted to my beloved mother and the rest of my family members for their spiritually endless support.

Contents

1. Introduction	1
2. Bibliography	3
2.1. Overview	3
2.2. Introduction to reflectarray	4
2.2.1. History	4
2.2.2. Main components	4
2.2.3. Working principle	7
2.2.4. Phase-shift distribution	10
2.2.5. Beam scanning	13
2.2.5.1. 2x2 antenna array using Butler matrix	13
2.2.5.2. Focal plane array based on microfluid	16
2.2.5.3. Reflectarray with single bit phase shifter	18
2.2.6. Advantages & Disadvantages	20
2.3. Elementary cell	21
2.3.1. Single layer	21
2.3.2. Multi layer	22
2.4. Active Reflectarray	24
2.4.1. Active elementary cell	24
2.4.2. RF MEMS	25
2.4.3. Varicap diode	27
2.4.4. Liquid Crystal	30
2.4.5. Ferroelectric	33
2.4.6. PIN diode	35
2.5. Fresnel Reflectarray	37
2.6. Application	39
2.7. Conclusion	39
3. Reflectarray modelisation	41
3.1. Theoretical analysis	42
3.2. Parameters definitions	45
3.3. Directivity calculation	47
3.3.1. Power received at the elementary cell	47
3.3.2. Incident wave at the elementary cell	47
3.3.3. Reflected wave at the elementary cell	48
3.3.4. Total radiated wave	50

3.3.5. Power density and directivity	52
3.4. Simulation program	53
3.4.1. Functionalities	54
3.4.1.1. Feed gain radiation pattern file	55
3.4.1.2. Reflection coefficient (S_{11}) file for passive reflectarray	55
3.4.2. Ansoft HFSS elementary cell simulation model	56
3.4.3. Environment and structure	59
3.5. Simulation analysis	60
3.5.1. Results comparison	62
3.5.2. Order of the phase correction	66
3.6. Conclusion	70
4. Active fresnel reflectarray (AFR)	71
4.1. Elementary cell design	71
4.1.1. Passive cell	72
4.1.2. Frequency adaptation	74
4.1.3. Diode integration	80
4.1.4. The diode DC polarization circuit	85
4.1.5. Dielectric standardization using RT/duroid® 6002	92
4.1.6. Dielectric standardization using Meteorwave™ 2000	105
4.2. Reflectarray simulations	120
4.2.1. Optimal frequency of the AFR	120
4.2.2. Beam scanning capability	125
4.2.3. Result comparison against CST	128
4.2.4. Improvement using optimized elementary cell design	130
4.3. Conclusion	133
5. Diode controller	135
5.1. Circuit conception	135
5.2. Working mechanism	138
5.3. Components	139
5.3.1. Micro-controller (Arduino board)	141
5.3.2. Matrix sub-circuit	142
5.3.2.1. Serial to parallel output circuit	145
5.3.2.2. Digital to analog switch circuit	149
5.4. Test and validation	152
5.5. Conclusion	157
6. General conclusion	159
7. Resume (French)	161
A. Object oriented programming in Matlab	163
References	169

Contents

Publications	177
Curriculum Vitae	179

References

- [1] A. Tamminen, S. Makela, J. Ala-Laurinaho, J. Hakli, P. Koivisto, P. Rantakari, J. Saily, A. Luukanen, and A. Raisanen, "Reflectarray design for 120-ghz radar application: Measurement results," *Antennas and Propagation, IEEE Transactions on*, vol. 61, no. 10, pp. 5036–5047, Oct 2013.
- [2] P. Siegel, "Terahertz technology," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 50, no. 3, pp. 910–928, Mar 2002.
- [3] P. de Maagt and G. Crone, "(Sub)millimetre wave antenna technology for upcoming ESA missions," in *Proc. P2000, Millennium Conf. Antennas Propag., Davos, Switzerland*, April 2000.
- [4] N.A.Salmon, "Scene simulation for passive and active millimeter and submillimetre-wave imaging for security scanning and medical applications," in *Proc. SPIE 8th Int. Symp. Remote Sens.*, vol. 5619, December 2004, pp. 129–135.
- [5] G. M.C.Beard and C.A.Schmittenmaer, "Terahertz spectroscopy," in *J. Phys. Chem. B*, vol. 106, 2002, pp. 7149–7159.
- [6] A. Raisanen, J. Ala-Laurinaho, D. Chicherin, Z. Du, A. Generalov, A. Karttunen, D. Lioubtchenko, J. Mallat, A. Tamminen, and T. Zvolensky, "Antennas for electronic beam steering and focusing at millimeter wavelengths," in *Electromagnetics in Advanced Applications (ICEAA), 2012 International Conference on*, Sept 2012, pp. 1235–1237.
- [7] S. B. Kang, M. H. Kwak, M. Choi, S. Kim, T. Kim, E. J. Cha, and K.-Y. Kang, "Terahertz dielectric response of ferroelectric Ba(x)Sr(1-x)TiO₃ thin films," *Ultrasonics, Ferroelectrics, and Frequency Control, IEEE Transactions on*, vol. 58, no. 11, pp. 2276–2280, November 2011.
- [8] B. S. M. M. N. Vieweg, M. K. Shakfa and M. Koch, "Thz properties of nematic liquid crystals," in *J. Infr. Millim. Terahertz Waves*, vol. 31, 2010, pp. 1312–1320.
- [9] R. Munson, H. Haddad, and J. Hanlen, "Microstrip reflectarray for satellite communication and radar cross-section enhancement or reduction," Aug. 4 1987, uS Patent 4,684,952.
- [10] D. Chang and M. Huang, "Microstrip reflectarray antenna with offset feed," *Electronics Letters*, vol. 28, no. 16, pp. 1489–1491, July 1992.

-
- [11] D. M. Pozar, "Microstrip reflectarrays myths and realities," in *JINA 2004, International Symposium on Antennas, Nice, France*, November 2004, pp. 175–179.
- [12] J. Lanteri, C. Migliaccio, J.-Y. Dauvignac, and C. Pichot, "Reflectarray using an offset prolate feed at 94 ghz," in *Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE*, July 2008, pp. 1–4.
- [13] K. Zhang, J. Li, G. Wei, Y. Fan, J. Xu, and S. Gao, "Design and optimization of broadband single-layer reflectarray," in *Antennas Propagation (ISAP), 2013 Proceedings of the International Symposium on*, vol. 02, Oct 2013, pp. 1226–1229.
- [14] D. M. Pozar, S. D. Targonski, and H. D. Syrigos, "Design of millimeter wave microstrip reflectarrays," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 287–295, February 1997.
- [15] K. Sze and L. Shafai, "Microstrip patches for a reflectarray," *Antennas and Propagation Society International Symposium, 1999. IEEE*, vol. 3, pp. 1666–1669, August 1999.
- [16] K. Konno, Q. Chen, K. Sawaya, S. Kameda, and N. Suematsu, "Reflectarray design by induced electromotive force method," in *Antennas and Propagation Society International Symposium (APSURSI), 2013 IEEE*, July 2013, pp. 1342–1343.
- [17] L. Guo, P.-K. Tan, and T.-H. Chio, "Design of an x-band reflectarray using double circular ring elements," in *Antennas and Propagation (EuCAP), 2013 7th European Conference on*, April 2013, pp. 2947–2950.
- [18] D. Oloumi, S. Ebadi, A. Kordzadeh, A. Semnani, P. Mousavi, and X. Gong, "Miniaturized reflectarray unit cell using fractal-shaped patch-slot configuration," *Antennas and Wireless Propagation Letters, IEEE*, vol. 11, pp. 10–13, 2012.
- [19] T. Smith, U. Gothelf, O. Kim, and O. Breinbjerg, "An fss-backed 20/30 ghz circularly polarized reflectarray for a shared aperture l- and ka-band satellite communication antenna," *Antennas and Propagation, IEEE Transactions on*, vol. 62, no. 2, pp. 661–668, Feb 2014.
- [20] J. Huang and J. A. Encinar, *Reflectarray antennas*. Hoboken, New Jersey: John Wiley & Sons, Inc., 2008, ISBN: 978-0-470-08491-5.
- [21] A. Gheethan, M. C. Jo, R. Guldiken, and G. Mumcu, "Microfluidic based ka-band beam-scanning focal plane array," *Antennas and Wireless Propagation Letters, IEEE*, vol. 12, pp. 1638–1641, 2013.
- [22] A. Guntupalli, T. Djerafi, and K. Wu, "Two-dimensional scanning antenna array driven by integrated waveguide phase shifter," *Antennas and Propagation, IEEE Transactions on*, vol. 62, no. 3, pp. 1117–1124, March 2014.

- [23] H. Kamoda, T. Iwasaki, J. Tsumochi, T. Kuki, and O. Hashimoto, "60-ghz electronically reconfigurable large reflectarray using single-bit phase shifters," *Antennas and Propagation, IEEE Transactions on*, vol. 59, no. 7, pp. 2524–2531, July 2011.
- [24] S. Targonski and D. Pozar, "Analysis and design of a microstrip reflectarray using patches of variable size," in *Antennas and Propagation Society International Symposium, 1994. AP-S. Digest*, vol. 3, June 1994, pp. 1820–1823 vol.3.
- [25] D. Pozar and T. Metzler, "Analysis of a reflectarray antenna using microstrip patches of variable size," *Electronics Letters*, vol. 29, no. 8, pp. 657–658, April 1993.
- [26] K. Sze and L. Shafal, "Analysis of phase variation due to varying patch length in a microstrip reflectarray," in *Antennas and Propagation Society International Symposium, 1998. IEEE*, vol. 2, June 1998, pp. 1134–1137 vol.2.
- [27] D.-C. Chang and M.-C. Huang, "Multiple-polarization microstrip reflectarray antenna with high efficiency and low cross-polarization," *Antennas and Propagation, IEEE Transactions on*, vol. 43, no. 8, pp. 829–834, Aug 1995.
- [28] J. Huang and R. Pogorzelski, "A ka-band microstrip reflectarray with elements having variable rotation angles," *Antennas and Propagation, IEEE Transactions on*, vol. 46, no. 5, pp. 650–656, May 1998.
- [29] J. Huang, "Bandwidth study of microstrip reflectarray and a novel phased reflectarray concept," in *Antennas and Propagation Society International Symposium, 1995. AP-S. Digest*, vol. 1, June 1995, pp. 582–585 vol.1.
- [30] J. A. Encinar, "Design of two layer printed reflectarrays using patches of variable size," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 1403–1410, October 2001.
- [31] M. B. E. Carrasco and J. A. Encinar, "Aperture-coupled reflectarray element with wide range of phase delay," *Electronics Letters*, vol. 42, pp. 667–668, June 2006.
- [32] J. A. Encinar and J. A. Zornoza, "Broadband design of three - layer printed reflectarrays," *IEEE Trans. Antennas Propagat.*, vol. 51, pp. 1662–1664, July 2003.
- [33] E. Carrasco, J. Encinar, and M. Barba, "Dual linear polarized reflectarray element with true-time delay," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, March 2009, pp. 3733–3737.
- [34] H. H. Meinel, "Automotive millimeterwave radar history and present status," in *Microwave Conference, 1998. 28th European*, vol. 1, Oct 1998, pp. 619–629.
- [35] C.-H. Tsai, L.-H. Kan, H.-H. Chen, and S.-J. Chung, "A co-design of dielectric lens and folded reflectarray antenna with the application to 77 ghz long-range mode forward-looking vehicle collision warning radar system," in *Microwave Conference Proceedings (APMC), 2012 Asia-Pacific*, Dec 2012, pp. 676–678.

- [36] I. Gresham, N. Jain, T. Budka, A. Alexanian, N. Kinayman, B. Ziegner, S. Brown, and P. Staecker, "A compact manufacturable 76-77-ghz radar module for commercial acc applications," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 49, no. 1, pp. 44–58, Jan 2001.
- [37] E. Carrasco, M. Barba, B. Reig, J. Encinar, and P. Charvet, "Demonstration of a gathered element for reconfigurable-beam reflectarrays based on ohmic mems," in *Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference on*, April 2011, pp. 1413–1416.
- [38] R. Sorrentino, R. Gatti, and L. Marcaccioli, "Recent advances on millimetre wave reconfigurable reflectarrays," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, March 2009, pp. 2527–2531.
- [39] M. Hajian, B. Kuijpers, K. Buisman, A. Akhnoukh, M. Plek, L. C. N. De Vreede, J. Zijdeveld, and L. Ligthart, "Active scan-beam reflectarray antenna loaded with tunable capacitor," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, March 2009, pp. 1158–1161.
- [40] K. Buisman, L. C. N. De Vreede, L. Larson, M. Spirito, A. Akhnoukh, Y. Lin, X. Liu, and L. Nanver, "Low-distortion, low-loss varactor-based adaptive matching networks, implemented in a silicon-on-glass technology," in *Radio Frequency integrated Circuits (RFIC) Symposium, 2005. Digest of Papers. 2005 IEEE*, June 2005, pp. 389–392.
- [41] K. Buisman, L. de Vreede, L. Larson, M. Spirito, A. Akhnoukh, T. Scholtes, and L. Nanver, "Distortion-free varactor diode topologies for rf adaptivity," in *Microwave Symposium Digest, 2005 IEEE MTT-S International*, June 2005, pp. 157–160.
- [42] M. Ismail, W. Hu, R. Cahill, V. Fusco, H. Gamble, D. Linton, R. Dickie, S. Rea, and N. Grant, "Phase agile reflectarray cells based on liquid crystals," *Microwaves, Antennas Propagation, IET*, vol. 1, no. 4, pp. 809–814, Aug 2007.
- [43] A. Moessinger, R. Marin, J. Freese, S. Mueller, A. Manabe, and R. Jakoby, "Investigations on 77 ghz tunable reflectarray unit cells with liquid crystal," in *Antennas and Propagation, 2006. EuCAP 2006. First European Conference on*, Nov 2006, pp. 1–4.
- [44] W. Hu, R. Cahill, J. Encinar, R. Dickie, H. Gamble, V. Fusco, and N. Grant, "Design and measurement of reconfigurable millimeter wave reflectarray cells with nematic liquid crystal," *Antennas and Propagation, IEEE Transactions on*, vol. 56, no. 10, pp. 3112–3117, Oct 2008.
- [45] W. Hu, R. Dickie, R. Cahill, H. Gamble, Y. Ismail, V. Fusco, D. Linton, N. Grant, and S. Rea, "Liquid crystal tunable mm wave frequency selective surface," *Microwave and Wireless Components Letters, IEEE*, vol. 17, no. 9, pp. 667–669, Sept 2007.

- [46] W. Hu, M. Ismail, R. Cahill, H. Gamble, R. Dickie, V. Fusco, D. Linton, S. Rea, and N. Grant, "Tunable liquid crystal reflectarray patch element," *Electronics Letters*, vol. 42, no. 9, pp. 509–511, April 2006.
- [47] G. Perez-Palomino, P. Baine, R. Dickie, M. Bain, J. Encinar, R. Cahill, M. Barba, and G. Toso, "Design and experimental validation of liquid crystal-based reconfigurable reflectarray elements with improved bandwidth in f-band," *Antennas and Propagation, IEEE Transactions on*, vol. 61, no. 4, pp. 1704–1713, April 2013.
- [48] F. Seitz and D. Turnbull, *Solid State Physics*. Elsevier Science, 1957, no. v. 4, ISBN: 9780080864686.
- [49] M. Lines and A. Glass, *Principles and Applications of Ferroelectrics and Related Materials*, ser. Oxford classic texts in the physical sciences. Clarendon Press, 2001, ISBN: 2001268331.
- [50] J. Nath, D. Ghosh, J.-P. Maria, A. I. Kingon, W. Fathelbab, P. Franzon, and M. Steer, "An electronically tunable microstrip bandpass filter using thin-film barium-strontium-titanate (bst) varactors," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 53, no. 9, pp. 2707–2712, Sept 2005.
- [51] A. Tombak, J.-P. Maria, F. Ayguavives, Z. Jin, G. T. Stauf, A. I. Kingon, and A. Mortazawi, "Voltage-controlled rf filters employing thin-film barium-strontium-titanate tunable capacitors," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 51, no. 2, pp. 462–467, Feb 2003.
- [52] M. Nikfalazar, M. Sazegar, Y. Zheng, A. Wiens, R. Jakoby, A. Friederich, C. Kohler, and J. Binder, "Compact tunable phase shifter based on inkjet printed bst thick-films for phased-array application," in *Microwave Conference (EuMC), 2013 European*, Oct 2013, pp. 432–435.
- [53] M. Sazegar, A. Giere, Y. Zheng, H. Maune, A. Moessinger, and R. Jakoby, "Reconfigurable unit cell for reflectarray antenna based on barium-strontium-titanate thick-film ceramic," in *Microwave Conference, 2009. EuMC 2009. European*, Sept 2009, pp. 598–601.
- [54] A. Kanareykin, E. Nenasheva, S. Karmanenko, A. Dedyk, and V. Yakovlev, "Low-loss ferroelectric for accelerator applications," in *Particle Accelerator Conference, 2005. PAC 2005. Proceedings of the*, May 2005, pp. 4305–4307.
- [55] B. D. Nguyen, K. T. Pham, V.-S. Tran, L. Mai, N. Yonemoto, A. Kohmura, and S. Futatsumori, "Electronically tunable reflectarray element based on c-patch coupled to delay line," *Electronics Letters*, vol. 50, no. 16, pp. 1114–1116, July 2014.
- [56] M. Inam, M. Ismail, A. Zain, and N. Misran, "Multi-state frequency switchable reflectarray antenna design," in *Space Science and Communication (IconSpace), 2013 IEEE International Conference on*, July 2013, pp. 253–256.

- [57] A. Kohmura, J. Lanteri, F. Ferrero, C. Migliaccio, P. Ratajczak, S. Futatsumori, and N. Yonemoto, "Ka-band dual frequency switchable reflectarray," in *Antennas and Propagation (EUCAP), 2012 6th European Conference on*, March 2012, pp. 3230–3233.
- [58] C. Menudier and T. Koleck, "Sub-reflectarrays performances for reconfigurable coverages," *Antennas and Propagation, IEEE Transactions on*, vol. 60, no. 7, pp. 3476–3481, July 2012.
- [59] E. Carrasco, M. Barba, and J. Encinar, "X-band reflectarray antenna with switching-beam using pin diodes and gathered elements," *Antennas and Propagation, IEEE Transactions on*, vol. 60, no. 12, pp. 5700–5708, Dec 2012.
- [60] B. D. Nguyen, J. Lanteri, J. Dauvignac, C. Pichot, and C. Migliaccio, "94 ghz folded fresnel reflector using c-patch elements," *Antennas and Propagation, IEEE Transactions on*, vol. 56, no. 11, pp. 3373–3381, Nov 2008.
- [61] A. Kohmura, J. Lanteri, F. Ferrero, C. Migliaccio, S. Futatsumori, and N. Yonemoto, "Ka-band beam switchable fresnel reflector," in *Antennas and Propagation (ISAP), 2012 International Symposium on*, Oct 2012, pp. 535–538.
- [62] S. Mener, R. Gillard, R. SAULEAU, C. Cheymol, and P. Potier, "Unit cell for reflectarrays operating with independent dual circular polarizations," *Antennas and Wireless Propagation Letters, IEEE*, vol. 13, pp. 1176–1179, 2014.
- [63] E. Carrasco, M. Barba, B. Reig, C. Dieppedale, and J. Encinar, "Characterization of a reflectarray gathered element with electronic control using ohmic rf mems and patches aperture-coupled to a delay line," *Antennas and Propagation, IEEE Transactions on*, vol. 60, no. 9, pp. 4190–4201, Sept 2012.
- [64] S. Ebadi, R. Gatti, and R. Sorrentino, "Linear reflectarray antenna design using 1-bit digital phase shifters," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, March 2009, pp. 3729–3732.
- [65] B. Wu, A. Sutinjo, M. Potter, and M. Okoniewski, "On the selection of the number of bits to control a dynamic digital mems reflectarray," *Antennas and Wireless Propagation Letters, IEEE*, vol. 7, pp. 183–186, 2008.
- [66] C.-C. Cheng and A. Abbaspour-Tamijani, "Study of 2-bit antenna-filter-antenna elements for reconfigurable millimeter-wave lens arrays," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 54, no. 12, pp. 4498–4506, Dec 2006.
- [67] S. Ebadi, R. Gatti, L. Marcaccioli, and R. Sorrentino, "Near field focusing in large reflectarray antennas using 1-bit digital phase shifters," in *Microwave Conference, 2009. EuMC 2009. European*, Sept 2009, pp. 1029–1032.
- [68] H. Yang, Y. Mao, S. Xu, F. Yang, and A. Elsherbeni, "Analysis and optimization of the scanning performance of 1-bit reconfigurable reflectarrays," in *Antennas and Propagation Society International Symposium (APSURSI), 2014 IEEE*, July 2014, pp. 1029–1030.

- [69] E. Plaza, G. Leon, S. Loredó, and F. Las-Heras, "Dual polarized transmitarray lens," in *Antennas and Propagation (EuCAP), 2014 8th European Conference*, The Hague, The Netherlands, April 2014, pp. 2305–2308.
- [70] W. An, S. Xu, and F. Yang, "A two-layer transmitarray antenna," in *Antennas and Propagation Society International Symposium (APSURSI), 2014 IEEE*, Tennessee, USA, July 2014, pp. 864–865.
- [71] H. Kaouach, "Antennes quasi-optiques reconfigurables à grande ouverture aux fréquences millimétriques," Ph.D. dissertation, Université Rennes, 2009.
- [72] H. T. Friis, "Noise figure of radio receivers," in *Proc. IRE*, vol. 3, no. 7, July 1944, pp. 419–422.
- [73] M. Hajian, J. Dickhof, C. Trampuz, and L. Ligthart, "Design of hollow patch microstrip reflectarray and measuring phase of reflection coefficient at ka-band using waveguide simulator," in *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference*, Barcelona, Spain, April 2010, pp. 1–5.
- [74] S. McGarrity. (2009, February) Introduction to object-oriented programming in MATLAB. [Online]. Available: <http://www.mathworks.fr/company/newsletters/articles/introduction-to-object-oriented-programming-in-matlab.html>
- [75] C. Migliaccio, K. Mazouni, A. Breard, A. Zeitler, J. Lanteri, J.-Y. Dauvignac, C. Pichot, N. Yonemoto, A. Kohmura, and S. Futatsumori, "Reflectarrays for mm-wave radar applications," in *Antennas and Propagation (APSURSI), 2011 IEEE International Symposium*, Spokane, USA, July 2011, pp. 105–108.
- [76] A. Clemente, "Conception d'antennes à réseaux transmetteurs à depointage et formation de faisceau," Ph.D. dissertation, Université Rennes, 2012.
- [77] J. Weiner and F. Nunes, *Light-Matter Interaction: Physics and Engineering at the Nanoscale*. OUP Oxford, 2012, ISBN: 9780191650093.
- [78] A. Ahmadi, S. Ghadarghadr, and H. Mosallaei, "An optical reflectarray nanoantenna: The concept and design," *Opt. Express*, vol. 18, no. 1, pp. 123–133, Jan 2010. [Online]. Available: <http://www.opticsexpress.org/abstract.cfm?URI=oe-18-1-123>

Publications

- [79] M. Bin Zawawi, J. Lanteri, and C. Migliaccio, “20-ghz single-bit active elementary cell,” in *Antennas and Propagation (EuCAP), 2013 7th European Conference*, Gothenburg, Sweden, April 2013, pp. 1304–1307.
- [80] M. Binzawawi, J. Lanteri, and C. Migliaccio, “Réseau réflecteur actif à base de déphaseurs 1-bit à 20GHz,” in *18èmes Journées Nationales Microondes (JNM)*, Paris, France, May 2013, pp. J2-AP-P13.pdf. [Online]. Available: <https://hal.archives-ouvertes.fr/hal-00862583>
- [81] M. Bin Zawawi, J. Lanteri, C. Migliaccio, and C. Pichot, “20 ghz active reflectarray using 1-bit phase shifter,” in *Antennas and Propagation Society (AP-SURSI), 2013 IEEE International Symposium*, Florida, USA, July 2013, pp. 1668–1669.
- [82] M. Bin Zawawi, J. Lanteri, and C. Migliaccio, “20-ghz 1-bit slotted active elementary cell,” in *Antennas and Propagation (EuCAP), 2014 8th European Conference*, The Hague, Netherlands, April 2014, pp. 1944–1947.