Contents

INTRODUCTION ix

CHAPTER 1. DESIGN AND PERFORMANCES OF UHF TAG INTEGRATED CIRCUITS 1

1.1. Introduction. 1
1.2. Integrated circuit architecture 2
1.3. RF to DC conversion: modeling the system. 3
1.3.1. Determination of the ideal DC output voltage 3
1.3.2. Determination of the "real" DC voltage. 6
1.3.3. Effects of parasitics and capacitances on the output voltage. 8
1.3.4. Matching considerations. 14
1.3.5. Results obtained. 19
1.4. RF to DC conversion: proposed circuits and performances. 21
1.4.1. Threshold-voltage cancellation circuit 21
1.4.2. Cross-coupled differential drive with automatic bridge structure cancellation circuit 23
1.4.3. Cross-coupled differential drive with controlled tuning voltages 24
1.4.4. Results 25
1.5. Voltage limiter and regulator 26
1.6. Demodulator 27
1.7. Oscillator 29
1.8. Modulator. 30
1.9. Digital blocks. 31
1.9.1. Memory 32
1.10. Technology, performances and trends 32
1.10.1. Technology choice 33
1.10.2. Design optimization 34

1.10.3. Circuit performances 35
1.11. Bibliography 36

CHAPTER 2. DESIGN OF UHF RFID TAGS 41

2.1. Tag antenna design 41
2.1.1. Fundamental circuit parameters of the dipole antenna 41
2.1.2. Fat antennas and tip loading 49
2.1.3. Meandered dipoles 52
2.1.4. Influence of dielectric and metallic materials – losses and detuning. 58
2.1.5. Near-field/far-field behavior of UHF RFID tags 64
2.2. Matching between the antenna impedance and the microchip impedance. 65
2.2.1. Matching conditions 65
2.2.2. L-matching basics 67
2.2.3. Equivalent electrical circuits 68
2.2.4. Double-tuned matching 69
2.2.5. Synthesis of a double-tuned tag and a naïve tag 71
2.2.6. Alternative implementation of the optimum double-tuned match 75
2.2.7. Example of a double-tuned match tag and use in variable environments 76
2.3. RFID tag antennas using an inductively coupled feed 79
2.3.1. Analytical model 80
2.3.2. Antenna design and results 82
2.4. Combined RFID tag antenna for recipients containing liquids. 83
2.4.1. Module description 84
2.4.2. Inductive coupling and antenna matching 84
2.4.3. Antenna design 85
2.4.4. Measurements of the initial tag. 86
2.4.5. Measurements with an empty and filled plastic recipient 86
2.4.6. Combined antenna 87
2.4.7. Discussion relative to the respect of the matching conditions 88
2.5. Tag on metal 89
2.5.1. Radiation efficiency of low-profile patch antennas 90
2.5.2. Ultra-thin metal tags 92
2.5.3. Thick metal tags. 99
2.5.4. Improved dipole designs on metallic surfaces 103
2.6. Bibliography 106

CHAPTER 3. THE BACKSCATTERING TECHNIQUE AND ITS APPLICATION 111

3.1. Backscattering principle of communication by between-base station and tag 112
3.1.1. The forward link: communication from the base station to the tag 112
3.1.2. The return link: communication from the tag to the base station 113
3.2. The merit factor of a tag, $\Delta\sigma_{es}$ or ΔRCS 116
3.2.1. Definition of the variation of the radar cross section, σe s or ΔRCS 116
3.2.2. Estimation of $\Delta\sigma_{e\,s}$ as a function of ΔΓ 117
3.2.3. The variation $\Delta\sigma_{e\,s} = f(\Delta\Gamma,\Gamma_1)$ 119
3.3. Variations of $\Delta\sigma_{es} = f(a)$ 128
3.4. After the theory, RFID at UHF and SHF realities 128
3.5. Measuring ΔRCS 138
3.5.1. Example of a method for measuring ΔRCS 138
3.6. The "Radar" equation 144
3.7. Appendix: summary of the principal formulas 145

CHAPTER 4. RFID MARKETS 149

4.1. Introduction 149
4.2. Market inflection point: users 149
4.3. RFID: what for? 150
4.4. Open- and closed-loop applications 152
4.4.1. Closed-loop applications 152
4.4.2. Open-loop applications 152
4.5. RFID return on investment 153
4.5.1. Introduction 153
4.5.2. Cost reduction 155
4.5.3. Sales increase 156
4.6. Many RFID technologies 156
4.7. Examples 157
4.8. Next RFID: product-embedded and seamless infrastructure 160
4.8.1. Introduction 160
4.8.2. RFID: "Slap and Ship" 160
4.8.3. Next RFID: from cradle to grave 161
4.8.4. Embedded RFID 161
4.8.5. Seamless and ubiquitous infrastructure 166
4.8.6. Software for business decisions 167

INDEX 169