

Table of Contents

1	Introduction	1
1.1	Historical OWC Applications	1
1.2	OWC Applications	1
1.3	Advantages of VLC	2
1.4	Technical Problems of VLC	3
1.5	Latency of VLC	4
1.6	VLC Applications.....	4
1.7	Camera-Based VLC	6
2	Fundamentals of Illumination Engineering	7
2.1	Electromagnetic Pollution.....	7
2.2	Daylight Harvesting	8
2.3	CIE 1931 XYZ, RGB, and HSV Color Spaces	8
2.4	CIE 1931 xy Chromaticity Diagram, Part I	10
2.5	CIE 1931 xy Chromaticity Diagram, Part II	12
2.6	Eye Sensitivity Function	14
2.7	Color Blindness	15
2.8	Efficiency Measures of Light Sources	16
3	VLC and IR/UV Channel Modeling.....	18
3.1	Generalized Lambertian Source	18
3.2	Line-of-Sight Channel Modeling	19
3.3	Non-Line-of-Sight Channel Modeling	20
3.4	Optical Underwater Channel Modeling	20
3.5	Crest Factor for Intensity Modulation.....	21
3.6	Shot Noise, Thermal Noise, and Dark Current.....	22
3.7	Signal-to-Noise Ratio of OWC Systems	23

4	Modulation Schemes for Optical Wireless Communications	24
4.1	Intensity Modulation with Direct Detection	24
4.2	Linear Modulation Schemes	25
4.3	On-Off Keying	26
4.4	Amplitude Shift Keying	27
4.5	Pulse Position Modulation	28
4.6	Carrierless Amplitude and Phase Modulation	29
4.7	Color-Domain Modulation Schemes	30
4.8	Multi-Carrier Modulation Schemes	31
4.9	Code-Division Multiplexing	32
4.10	Superposition Modulation	33
4.11	Optical Camera Communication	33
5	Optical Multiple-Input Multiple-Output (MIMO) Techniques	34
5.1	Optical MIMO Channel Modeling	34
5.2	Optical Space-Time Block Codes	35
5.3	Spatial Diversity	35
5.4	Spatial Optical Multi-Carrier Modulation	36
5.5	Superposition Modulation	37
5.6	Interference-Avoidance Modulation Techniques	38
5.7	Optical Camera Communication	39
6	OWC Standardization	40
6.1	Infrared Standardization	40
6.2	Current Standardization Efforts	41
6.3	Flicker Mitigation and Dimming Assistance	41
6.4	Color Shift Keying	43
7	Software-Defined Radio Concept and its Applications in OWC	46
7.1	Software-Defined Radio Concept	46
7.2	Strengths and Weaknesses of the Software-Defined Radio Concept	46
7.3	Adaptive, Cognitive, and Intelligent Radio	47
7.4	Hardware-Friendly Modulation Schemes	48
7.5	Hardware Platforms for OWC Applications	48
8	Photonic Devices and High-Speed Amplifiers	50
8.1	DC and AC Behavior of III-V LEDs	50
8.2	Organic LEDs	51
8.3	Micro-LEDs and Laser Diodes	51

8.4	Silicon Photodiodes	52
8.5	Noise-Equivalent Power of a Photodiode.....	53
8.6	Equivalent Circuit Model of a Photodetector	54
8.7	Operational Amplifiers.....	54
9	Circuit Design Rules for OWC Transmitters and Receivers	58
9.1	Elementary LED Driver	58
9.2	Constant-Current Source	59
9.3	Buck Converter.....	60
9.4	Multi-String LED Driver.....	61
9.5	Basic Design Criteria for LED Drivers	62
9.6	Transimpedance Amplifier	62
9.7	Ambient Light Compensation	63
10	Selected VLC and FSO Applications	66
10.1	Light Fidelity.....	66
10.2	Optical Underwater Communication.....	68
10.3	Wireless Ethernet	69
10.4	Optical Relaying.....	71
10.5	Hybrid Microwave/Free-Space Optical Communication	72
11	Optical Ranging and Visible Light Positioning.....	74
11.1	Distance Estimation by Runtime Measurements	74
11.2	Distance Estimation by Triangulation	77
11.3	Time-of-Arrival Localization	78
11.4	Time-Difference-of-Arrival Localization	78
11.5	Angle-of-Arrival Localization	79
11.6	Hybrid Localization	80