國　立　交　通　大　學
光電工程研究所

博士論文

先進光調變與多工技術在直接偵測光傳輸系統上的性能評估與分析

Advanced Modulation and Multiplexing Techniques for Direct Detection Optical Transmission Systems

研 究 生 ： 彭煒仁
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國立交通大學 電機學院

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摘要

在本論文中我們將簡介數種已提之先進光調變格式以及光多工技術，其工作原理以及目前所遇到的議題將一併於論文中予以討論以及部分解決。其中光多工技術包含光正交頻分多工 (OFDM) 以及光碼分多工 (OCDMA) 兩種技術，而光調變格式主要是高頻譜效能(>1 bit/symbol) 之格式包含多階相位或多階振幅調變格式 。

針對直接偵測 OFDM 下我們提出射頻輔助正交分頻多工(RF-tone assisted OFDM)以及廣義虛擬單邊帶正交頻分多工(Generalized Virtual SSB-OFDM)等兩種技術。此技術置放一射頻次載波於信號頻帶邊緣作為遠端直接偵測參考信號之用。使用我們的技術後，和同性質的直接升頻(direct up-conversion) 調變器相比，可節省一半數位轉類比器 (DAC) 的取樣速度，而其 DAC 有限的取樣速度在高容量 (≥ 10 Gbps) 的光通訊傳輸下目前乃是主要瓶頸。此外，我們成功地傳輸 10 Gbps OFDM 訊號經過 1600 km 的標準單模光纖後僅 3 dB 的損傷，驗證此技術在未來光通訊的應用潛力。

於光調變格式中，我們實驗以及理論驗證其使用簡易、低廉的單顆光調變器產生數種複雜傳輸訊號的可能性。這在未來講求低價格，高效能的光通訊網路上是一大躍進。除此之外我們更進而分析數種不同調變格式的性能理論上限: 量子限制 (quantum limit)。此一限制給出最佳性能指標以簡化工程應用上所能達成的最佳性能。

最後我們研究光碼分多工技術在局部網路(LAN)上的應用。我們使用費比布洛自注入雷射以及光纖光柵串列提出廉價光碼分多工光源。藉著針對每一個光柵施以溫度或應

力的控制我們可以改變所要傳送地點的用戶碼。接著提出交叉頻率分組方式以降低在多用戶光碼分多工系統下所遭遇到的多重存取干擾。最後，我們首次實驗驗證多載波碼分多工系統於光接取網路上的應用可能。

Advanced Modulation and Multiplexing Techniques for Direct Detection Optical Transmission Systems

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ABSTRACT

In this dissertation, we review and propose several new approaches for orthogonal frequency division multiplexing (OFDM), advanced modulation formats, and code division multiplexing (OCDM) techniques in optical transmission systems.

For OFDM, we propose an RF-tone assisted OFDM and virtual single-sideband OFDM (VSSB-OFDM) systems for direct detected optical transmission. With an RF tone inserted at the edge of the signal band, the sensitivity and CD tolerance are both improved compared to the previous power modulated SSB-OFDM. Besides, our approach also relaxes the bandwidth requirement for digital to analog converter (DAC) which would be very critical in a high speed transmission with a data rate of ≥ 10 Gbps. In addition, we firstly propose a 2x2 matrix equalization technique to jointly compensate the distortions resulted from both the transmission and the imbalances of the optical modulator. Moreover, we successfully transmit a 4-QAM, 10-Gbps signal through 1600 km uncompensated standard single mode fiber (SSMF) with only ~ 3 dB penalty, which is smaller than any other proposed direct-detected transmission systems.

For advanced modulation formats, we numerically evaluate and experimentally demonstrate the generation of complex modulation formats by using one dual-drive

Mach-Zehnder modulator (DD-MZM). We also analyze the performance bound, i.e. quantum limit, of 4ASK format. We further propose a phase modulated 4ASK (PM4ASK) format which shows a better CD, PMD and filtering tolerances compared to conventional 4ASK format.

For CDMA, we propose a simple and cost-effective fast frequency hopping CDMA (FFH-CDMA) light source which uses a self-injected Fabry Perot laser and one string of fiber Bragg grating array (FBGA). By tuning the stress of each individual grating, we can encode the transmitted data by the destination codeword. Aimed to eliminate the inherent multiple access interference (MAI) in optical FFH-CDMA, we propose a frequency-interleaved multi-group approach which fully uses the frequency gap between the gratings to reduce the spectrum overlapping among different users, and design the new codeword searched by computers which is suitable for this proposed technique. Finally we versify this technique by some simulation results.

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List of Acronyms

Acronyms	Descriptions
AABN	ASE-ASE Beat Noise
ADC	Analog to Digital Converter
ASE	Accumulated Spontaneous Emission
ASK	Amplitude Shift Keying
AWG	Array Waveguide Grating
BER	Bit Error Rate
BERT	Bit-Error-Ratio Tester
BPF	Band-Pass Filter
CD	Semiconductor Optical Amplifier
CDMA	Code Division Multiple Access
CDR	Clock and Data Recovery
CO-OFDM	Coherent Optical OFDM
CSPR	Carrier to Signal Power Ratio
CW	Continuous Wave
DAC	Digital to Analog Converter
DCF	Dispersion Compensating Fiber
DCM	Dispersion Compensating Module
DD-MZM	Dual Drive MZM
DFB-LD	Distributed Feedback Laser Diode
DFG	Difference Frequency Generation
DPSK	Differential Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
DSC	Digital Self-Coherent

DS-CDMA	Direct Sequence CDMA
DSP	Digital Signal Processing
EDFA	Erbium-Doped Fiber Amplifier
EOM	Electric Optical Modulator
ER	Extinction Ratio
EVM	Error Vector Magnitude
FBG	Fiber Bragg Grating
FBGA	Fiber Bragg Grating Array
FDL	Fiber Delay Line
FEC	Forward Error Correction
FFH-CDMA	Fast Frequency Hopping CDMA
FFT	Fast Fourier Transform
FP-LD	Fabry-Pérot Laser Diode
FWM	Four Wave Mixing
GVSSB-OFDM	Generalized Virtual Single Sideband OFDM
IFFT	Inverse FFT
KLSE	Karhunen-Loeve Series Expansion
LAN	Local Access Network
LO	Local Oscillator
MAI	Multiple Access Interference
MAN	Metropolitan Area Network
MC-CDMA	Multi-Carrier CDMA
MGF	Moment Generating Function
MLSE	Maximum Likelihood Sequence Estimation
MZM	Mach-Zehnder Modulator
NRZ	Non-Return to Zero

OBW	Optical Filter Bandwidth
OC	Optical Circulator
OCDMA	Optical CDMA
ODI	Optical Delay Interferometer
OFDM	Orthogonal Frequency Division Multiplexing
OMI	Optical Modulation Index
ONU	Optical Network Unit
OOK	On Off Keying
OSA	Optical Spectrum Analyzer
OSNR	Optical Signal to Noise Ratio
PBS	Polarization Beam Splitter
PC	Polarization Controller
PDM	Polarization Division Multiplexing
PMD	Electro-Absorber Modulator
PON	Passive Optical Network
PPLN	Periodically Poled Lithium Niobate
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectra Density
QAM	Quadrature Amplitude Modulation
QPM	Quasi-Phase Matching
ROF	Radio over Fiber
RZ	Return to Zero
SABN	Signal-ASE Beat Noise
SC	Super Continuum
SCM	Subcarrier Multiplexing
SE-CDMA	Spectra Encoding CDMA

SFG	Sum Frequency Generation
SMSR	Side Mode Suppression Ratio
SPM	Self-Phase Modulation
SSBI	Signal-Signal Beat Interference
SSFBG	Super-Structured Fiber Bragg Grating
SSMF	Standard Single Mode Fiber
TDM	Time Division Multiplexing
VOA	Variable Optical Attenuator
VSSB-OFDM	Virtual Single Sideband OFDM
WDM	Wavelength Division Multiplexing
WH	Walsh-Hadamard
XPM	Cross Phase Modulation