



**UNIVERSITI PUTRA MALAYSIA**

**PERFORMANCE ANALYSIS OF DUTY-CYCLE DIVISION  
MULTIPLEXING FOR OPTICAL FIBER COMMUNICATION SYSTEMS**

**GHAFOUR AMOUZAD MAHDIRAJI**

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**GHAFOUR AMOUZAD MAHDIRAJI**

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**By**

**GHAFOUR AMOUZAD MAHDIRAJI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

**July 2009**



**To My Beloved Wife  
and  
Daughter**



Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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MULTIPLEXING FOR OPTICAL FIBER COMMUNICATION SYSTEMS**

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**GHAFOUR AMOUZAD MAHDIRAJI**

**July 2009**

**Chairman: Ing. Ahmad Fauzi Abas, PhD**

**Faculty: Engineering**

The ever increasing demand for network capacity motivates the explorations for new modulation formats and multiplexing techniques. Wavelength division multiplexing (WDM) channel capacity can be improved by using time division multiplexing (TDM). However, TDM requires precise bit and symbol synchronization and limited from the operating speed of electronic components. The introduction of return-to-zero (RZ) line coding facilitates TDM synchronization in high speed transmission systems. Alternatively WDM channel capacity can be doubled by using polarization division multiplexing (PDM) or differential quadrature phase-shift-keying (DQPSK) modulation format.

Duty-cycle division multiplexing (DCDM) is another multiplexing technique that can support multiple users per WDM channel. Previously, initial version of DCDM (IV-DCDM) is proposed for optical fiber communications. DCDM takes advantage of RZ and offers even better synchronization at the lower clock frequency with smaller spectral width. However, IV-DCDM is badly affected from the fiber chromatic dispersion (CD). In addition, it requires high optical signal-to-noise ratio (OSNR) and less tolerance to self-phase modulation (SPM). For implementation, the IV-

DCDM architecture required  $n$  modulators for  $n$  channels at the multiplexer and  $n + 1$  sampling circuits at the receiver, which is not economically efficient. In this study, the design of DCDM multiplexer and demultiplexer is improved. A new set of algorithm are developed for data recovery in the receiver. At the same time, a model for BER estimation based on the decision algorithms is established.

Performance of the proposed demultiplexer with the new decision algorithm is evaluated using the same multiplexer design used in IV-DCDM. Since in the improve setup the multiplexer operates in optical domain this system is referred to as O-DCDM. Using the O-DCDM, performance of IV-DCDM is improved significantly by around 40 times in terms of CD tolerance, 6.5 dB better OSNR and around 3 dB higher SPM threshold. The number of sampling circuits is also reduced by one count in the proposed demultiplexer, which leads towards design simplification.

Performance of the proposed multiplexer architecture is evaluated together with the proposed demultiplexer. Since the proposed multiplexer operates in electrical domain this system is referred to as E-DCDM. Using the E-DCDM, the numbers of required modulators are reduced to only one regardless of the number of user. Using E-DCDM, performance of IV-DCDM is improved by around 48 times in terms of CD tolerance, 1.6 dB better OSNR and around 4.5 dB higher SPM threshold. Performance of E-DCDM is improved further by using amplitude distribution controller (ADC). Using E-DCDM with ADC, referring to IV-DCDM, performance is improved by around 46 times in CD tolerance, 7.5 dB better OSNR and 3.5 dB more SPM threshold.

Based on these developments, performance of DCDM is comparable against the available multiplexing and modulation techniques with an advantage, which is simpler transmitter and receiver. DCDM can support multiple users per WDM channel without the needs of increasing the clock rate at the receiver. Using this technique,  $7 \times 10$  Gb/s is transmitted over 139 km and recovered by using 10 GHz clock.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**ANALISIS PRESTASI PEMULTIPLEKS PEMBAHAGI KITAR-TUGAS  
UNTUK SISTEM KOMUNIKASI FIBER OPTIK**

Oleh

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Peningkatan permintaan terhadap kapasiti rangkaian telah memotivasi penerokaan format-format modulasi dan teknik-teknik multipleks baru. Umumnya, kapasiti saluran pemultipleks pembahagi panjang gelombang (WDM) boleh ditingkatkan menggunakan pemultipleks pembahagi masa (TDM). Walaubagaimanapun, TDM memerlukan ketepatan penyelarasan bit dan simbol dan terhad dalam kepantasan operasi komponen elektronik. Pengenalan kepada garis kod kembali-ke-sifar (RZ) mempermudah penyelarasan TDM dalam sistem penghantaran berkelajuan tinggi. Sebagai alternatif, kapasiti saluran WDM boleh digandakan dengan menggunakan format modulasi “polarization division multiplexing” (PDM) atau “differential quadrature phase-shift-keying” (DQPSK).

“Duty-cycle division multiplexing” (DCDM) adalah satu lagi teknik multipleks yang membolehkan pengguna yang ramai dalam satu saluran WDM. Sebelum ini, versi asal DCDM (IV-DCDM) dicadangkan untuk komunikasi fiber optik. DCDM menggunakan kelebihan RZ dan menawarkan penyelarasan yang lebih baik dalam frekuensi jam yang rendah dengan lebar spektrum yang lebih kecil. Walau bagaimanapun, IV-DCDM dipengaruhi oleh penyebaran kromatik (CD). Tambahan



pula, ia memerlukan “optical signal-to-noise ratio” (OSNR) yang tinggi dan sedikit ketahanan pada “self-phase modulation” (SPM). Untuk melaksanakannya, senibina IV-DCDM memerlukan pengatur  $n$  untuk saluran  $n$  pada pemultipleks, dan  $n + 1$  litar-litar persampelan di penerima, yang mana tidak efisien dari segi ekonomi. Dalam kajian ini, rekaan pemultipleks dan penyahmultipleks DCDM telah ditambah baik. Satu set algoritma yang baru telah dibangunkan untuk pemulihan data pada penerima. Pada masa yang sama, satu model untuk penganggaran BER berpandukan keputusan algoritma telah ditentukan.

Prestasi penyahmultipleks yang dicadangkan dengan algoritma yang baru telah dinilai menggunakan rekabentuk pemultipleks yang sama dengan yang digunakan dalam IV-DCDM. Oleh sebab pemultipleks dalam IV-DCDM beroperasi dalam media optik, sistem ini dikenali sebagai O-DCDM. Dengan menggunakan O-DCDM, prestasi IV-DCDM bertambah dalam lingkungan 40 kali lebih baik dalam CD, 6.5 dB lebih baik OSNR dan dalam 3 dB lebih tinggi ambang SPM. Jumlah litar-litar “sampling” juga dikurangkan satu kiraan dalam penyahmultipleks yang dicadangkan, yang membawa kepada rekaan yang lebih mudah.

Prestasi rekaan pemultipleks yang dicadangkan, dinilai bersama-sama dengan penyahmultipleks yang dicadangkan. Oleh kerana pemultipleks yang dicadangkan beroperasi dalam medium elektrik, sistem ini dipanggil E-DCDM. Dengan menggunakan E-DCDM, jumlah pengatur yang diperlukan dikurangkan kepada satu sahaja. Dengan menggunakan E-DCDM, prestasi IV-DCDM telah bertambah 48 kali lebih baik dalam CD, 1.6 dB OSNR lebih baik dan lebih 4.5 dB ambang SPM. Prestasi E-DCDM telah bertambah lebih baik dengan menggunakan pengatur

penyebaran amplitud (ADC). Dengan menggunakan E-DCDM bersama ADC, berbanding IV-DCDM, prestasinya bertambah baik dalam 46 kali dalam toleransi CD, 7.5 dB OSNR yang lebih baik dan 3.5 dB lebih ambang SPM.

Berbandukan perkembangan dan pembangunan ini, prestasi DCDM adalah sefanding dengan sistem sedia ada di samping mempunyai satu kelebihan, dimana keperluan terhadap pemancar dan penerima adalah lebih ringkas. DCDM boleh menyokong pengguna yang ramai dalam satu saluran WDM tanpa perlu menaikkan kadar jam pada penerima. Dengan menggunakan teknik ini,  $7 \times 10$  Gb/s dihantar sepanjang 139 km dan dihasilkan semula di penerima menggunakan kelajuan jam 10 GHz.

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I certify that a Thesis Examination Committee has met on 3 July 2009 to conduct the final examination of Ghafour Amouzad Mahdiraji on his thesis entitled "Performance Analysis of Duty-Cycle Division Multiplexing for Optical Fiber Communication systems" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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## **DECLARATION**

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

---

**Ghafour Amouzad Mahdiraji**

Date: 15 August 2009

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