Integrated Circuits for Wavelength Division De-multiplexing in the Electrical Domain

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23rd September, 2013
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Outline

• Motivation

• New Proposed WDM Receivers

• Test Setups and Results
  ▪ Two channel (SSB rejection) tests
  ▪ Three channel (adjacent channel rejection) tests

• Conclusion
Motivation

- **Network Traffics / High Data Rate Demands**
  - More bandwidth
  - Higher spectral efficiency
  - Low power consumption
  - System complexity and cost
  - Long reach

→ **Toward 1Tb/s using a Single Receiver (System)**

- **System Directions:**
  - Coherent (phase/amplitude) modulations (i.e. 16QAM)
  - Dual polarizations
  - Gridless channels
  - Super-channels
  - Photonic and electronic Integrations
  - Low power / high efficiency
Conventional WDM Receivers

- **Configuration: Photonic IC + Electrical IC**
  - WDM multi-channels
  - De-multiplexing using AWG
  - Integrated LO lasers
  - 90° optical hybrids
  - Balanced photo-diodes (PDs)
  - EIC: TIAs + filters + ADCs + DSPs

**Photonic IC**

- Complex PIC
- Large die: expensive
- Many interfaces between PIC & EIC
- Fixed WDM channel spacing
Proposed WDM Receivers

- **Single-chip Multi-channel WDM Receivers:** *Toward 1Tb/s*
  - Simple PIC: one LO + one optical hybrid + one set of PDs
  - Complex EIC
    - TIAs + filters + ADCs + DSPs
    - SSB mixers
    - Electrical LOs
  - **Challenges:** high speed PDs\(^1\) and high speed EIC\(^2\)

**References:**
1) >300GHz PDs – Ishibashi et. al.
2) 1THz TRs – Jain Vibhor et. al.

- Complex EIC: **OK!!**
- Small and simple PIC
- One set of interface between PIC & EIC
- Flexible WDM channel spacing
Two-Stage Down-conversion: Optical, then Electrical

1) Optical LO for optical down conversion for all WDM channels
   → Optical WDM channels become subcarriers in the electrical domain

2) Electrical LO for selected channel with SSB mixers
   → Selected channel down-converted to near DC

3) Other channels removed by filtering
   → Then, ADC + DSP
   → DATA recovery
System Demonstration using OMA+EIC (2-channels)

OMA* as PICs
Free space optics
90° optical hybrid
& Balanced PDs

Real-time oscilloscope

OMA* blocks

As PICs

*OMA – optical modulation analyzer

Ref. Agilent N4391A Optical Modulation Analyzer Measure with confidence
Two-channel Tests: Single-side-band Suppression

**Activated channel**

**Suppressed channel**

**(+/- channels)**

**I & Q outputs**
Two-channel Tests: Single-side-band Suppression

- **EIC outputs (Electrical Spectrum Analyzer)**
  - About **25dB SSB suppression**
  - Negligible channel interference
  - $x2$ more channels within the PDs and EIC bandwidth
Three-channel Tests: Adjacent Channel Rejections

- **20GHz Spacing**
- **10GHz Spacing**
- **5GHz Spacing (no guard band)**

Tested with different channel spacing!!

*Measured spectrums by an optical spectrum analyzer*
Three-channel Tests: Adjacent Channel Rejections

- **Eye Qualities with Different Filter Combinations**

*Filter1: before optical modulators to suppress the side lobes
*Filter2: after EIC outputs to filter out the other channels

BER 1.0E-9
Future Tests: 6-channel WDM Receivers

- Concept schematics (PIC + EIC)
- EIC for 6-channel receivers is ready to test!
Future Tests: 6-channel WDM Receivers

- **6-channel WDM receiver IC**
  - *Teledyne 500 nm InP HBT: ~300GHz $f_t, f_{max}$*
  - *1st design spin: no attempt to design for low power*
  - *4.8 x 1.5 mm²*

- **Simulations (5Gb/s BPSK)**
  - *30Gb/s for BPSK, 60Gb/s for QPSK, 120Gb/s for 16QAM are feasible!*

- **6-channel initial EIC only tests (done)**
- **6-channel system demonstrations will be done (soon)!**
Conclusion

- The first concept demonstration using two channel EIC receivers
- Spectral efficiency is maximized using a minimum channel spacing
- 5Gb/s using two channel receivers
  → Using 8-channels / 25GHz spacing / 100GHz EIC / 100GHz PDs / PDM
  → 0.8Tb/s for QPSK, 1.6Tb/s for 16QAM
- 5GHz spacing data recovery
  → Flexible channel (<10GHz) designs

Future Works

- 6-channel demonstration soon
- PIC + EIC demonstration soon
- Silicon based designs in near future
  → Low power consumption
  → Small IC size
Thanks for your attention!

Questions?

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