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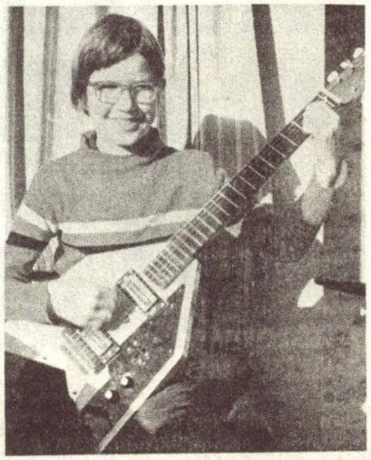
Creativity in Electrical and Electronic Engineering:

My Inspirations from the Physical World

Prof Arthur Lowery, *Fellow IEEE*

Director, Monash Electro-Photonics Group
Director, Monash Vision Group
Science Leader, CUDOS
Chief Investigator, Centre for Integrative Brain Function
Department of Electrical and Electronic Engineering
Monash University, Clayton, Australia

Arthur Lowery, Yorkshire.



Everyday Electronics, February 1975

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Summary

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- Hypothesis: Inspiration comes from many places
  - Semiconductor laser models: a guitar and a 100-W stack (and a bucket of water)
  - VPIphotonics.com (my first company) and frustrating guitar stomp boxes
  - Cool Jazz and Orthogonal Division Multiplexing
  - Enhancing optical communications by analysing garage bands
  - Bionic vision & steam engines: both are boiler-making and energy inefficient (Monash Vision Group)
- Conclusion
- Questions and Discussion

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Semiconductor Laser Modes & Guitars

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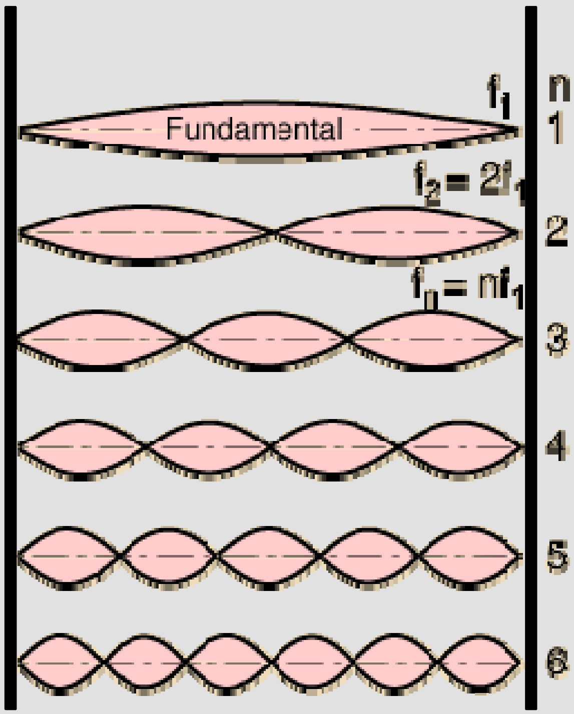
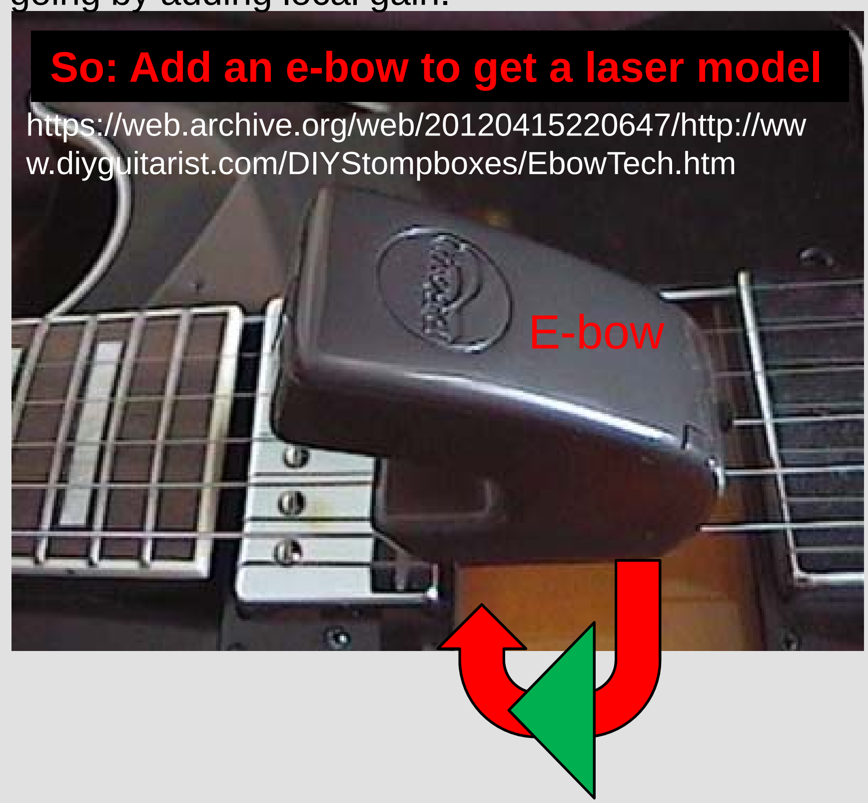
1) The modes in a Fabry-Perot Laser mimic the vibrational modes of a guitar string



http://hyperphysics.phy-astr.gsu.edu/hbase/waves/string.html

2) The gain within a laser cavity keeps the vibrations going. The E-bow kept guitar notes going by adding local gain.



The E-bow has a pick up to monitor the string, and amplifier, and a transducer to stimulate the string

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Transmission-Line Laser Model (TLLM)

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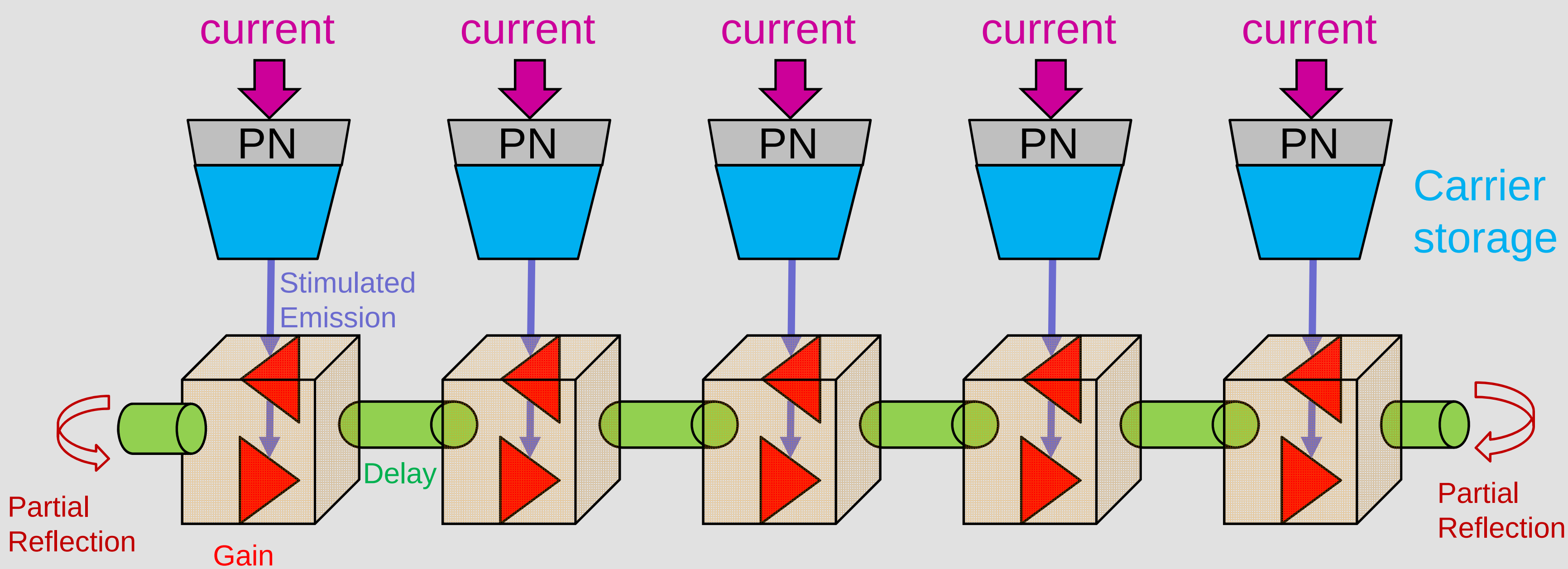

- Laser is divided into sections: samples of the optical field pass between them on "transmission lines". *Very numerically efficient*
- Reflections create a resonant cavity supporting only certain modes
- (Frequency Selective) Gain amplifies some modes more than others
- The output powers of the amplifiers are limited by the injected current

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Arthur Lowery, "*New dynamic semiconductor laser model based on the transmission-line modelling method,*" IEE/IET Proc J Optoelectronics, Vol. 135, No. 5, 1987 pp.281-289

VPIphotonics & Stomp Boxes

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One of my teenage hobbies was to make guitar effects boxes for a session musician. These could be strung together in many different ways to get interesting sounds.

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OPALS allowed models of photonic components to be strung together

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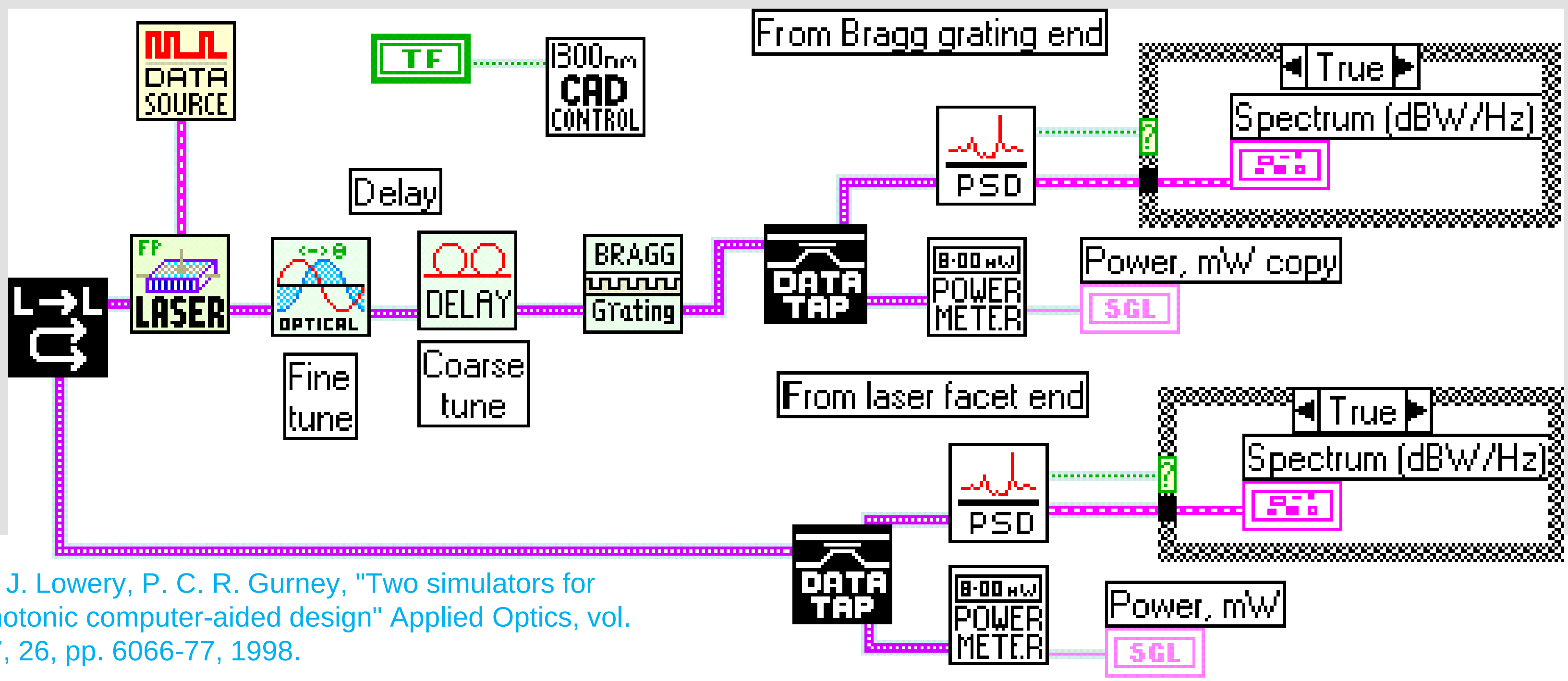
Optoelectronic
Photonic, and
Advanced
Laser
Simulator

the first Photonic 'systems' simulator

- Detailed laser models in the time domain
- Bidirectional interfaces communicate every picosecond
- easy Graphical User Interface (based on LabVIEW)
- First released February 1996
- Sold to Fujitsu as first customer (IBM second)



A. J. Lowery, P. C. R. Gurney, "Two simulators for photonic computer-aided design" Applied Optics, vol. 37, 26, pp. 6066-77, 1998.

VPIphotonics incorporated OPALS's and systems models

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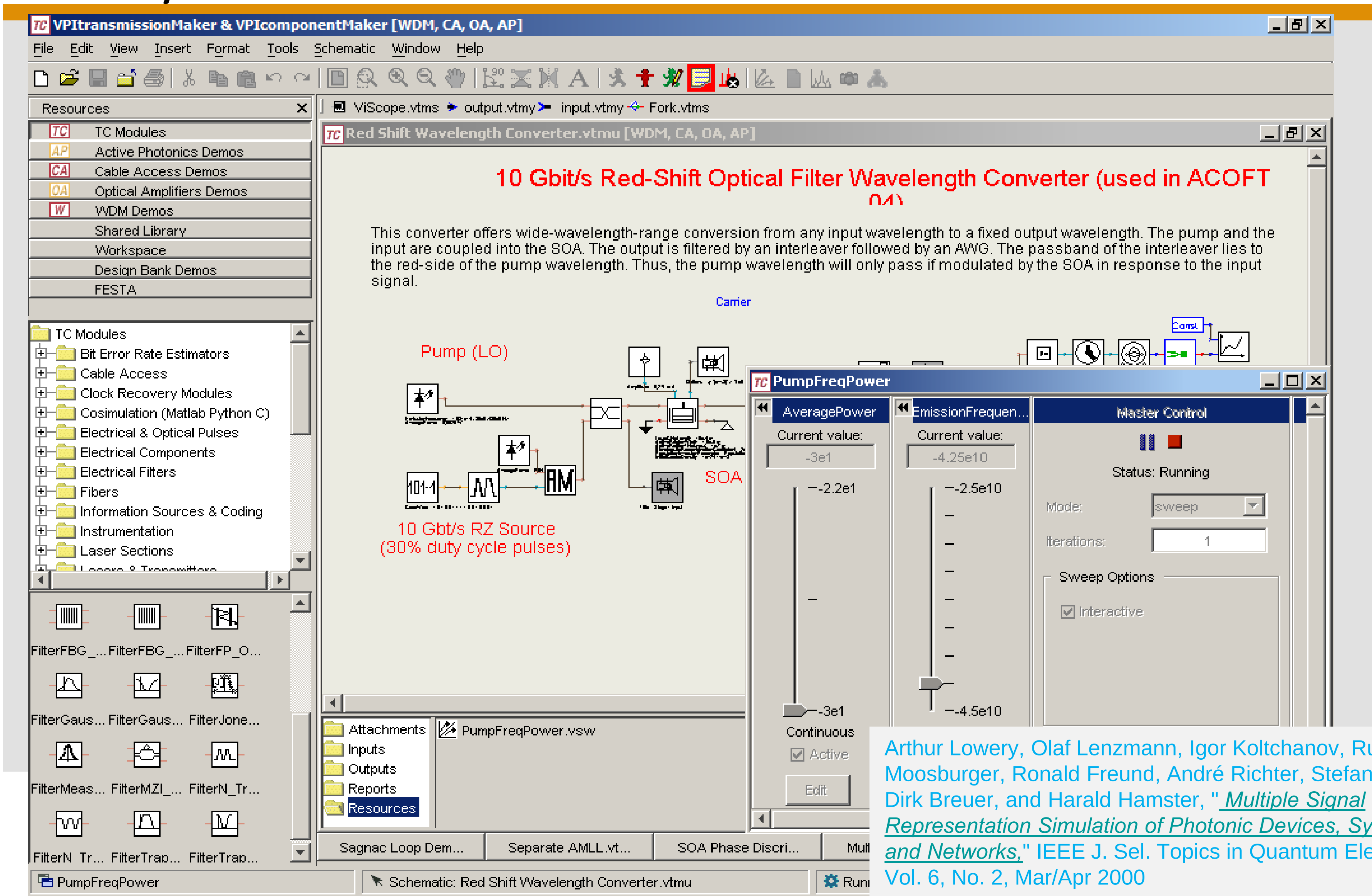

Arthur Lowery, Olaf Lenzmann, Igor Koltchanov, Rudi Moosburger, Ronald Freund, André Richter, Stefan Georgi, Dirk Breuer, and Harald Hamster, "*Multiple Signal Representation Simulation of Photonic Devices, Systems, and Networks,*" IEEE J. Sel. Topics in Quantum Electronics, Vol. 6, No. 2, Mar/Apr 2000

VPIphotonics' customers in 2000

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Cool Jazz and OFDM

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- Play slow music in large buildings
- The complexity is in the chords
    - The complexity carries the Information

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A. J. Lowery and Liang B. Du, "Optical orthogonal division multiplexing for long haul optical communications: A review of the last five years" An invited review article for Optical Fiber Technology special edition "100G and Beyond (Ed. M. Chbat)", 17, 421-438 (2011)

Cool Jazz and OFDM

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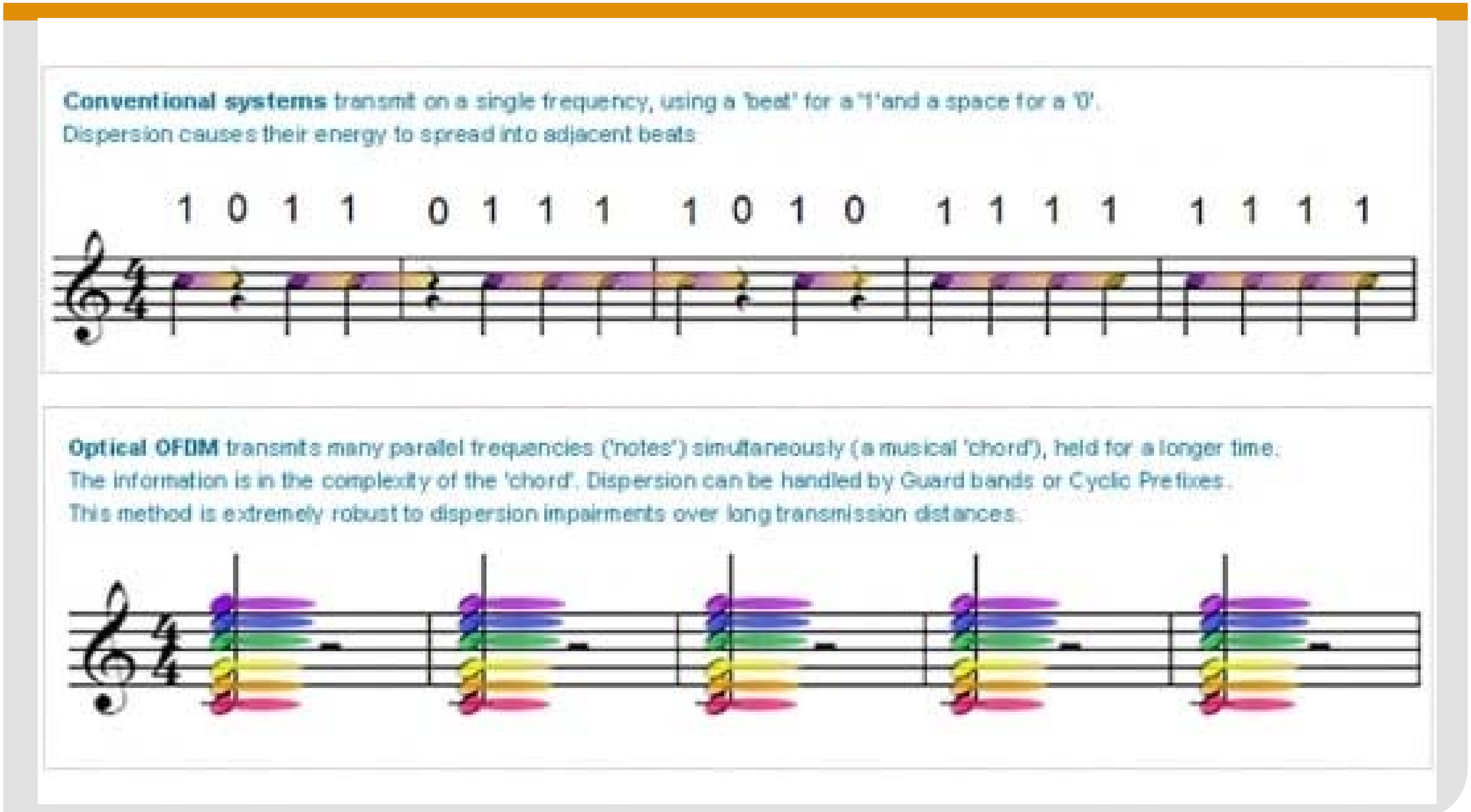

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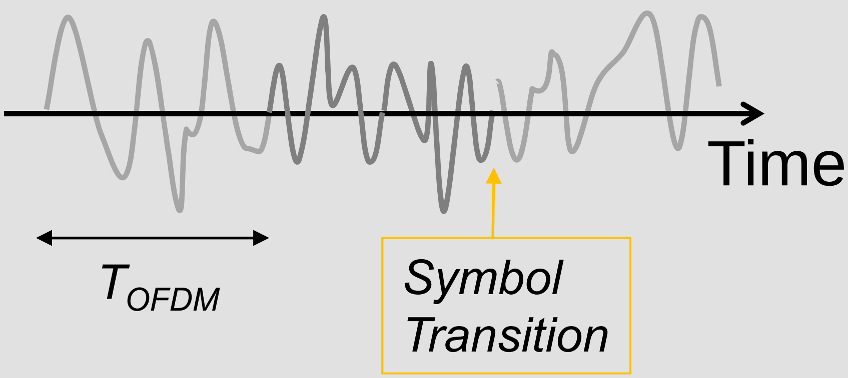
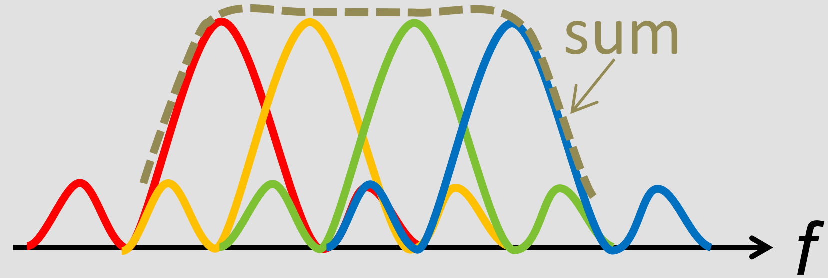
OFDM

At the Transmitter

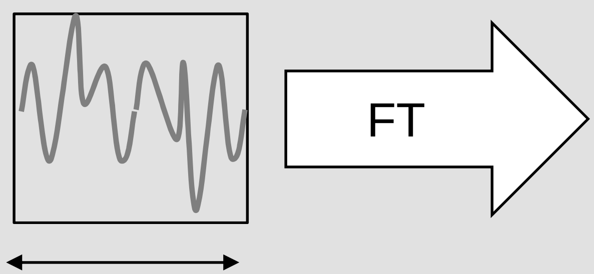
(multiple subcarriers shown in each symbol)



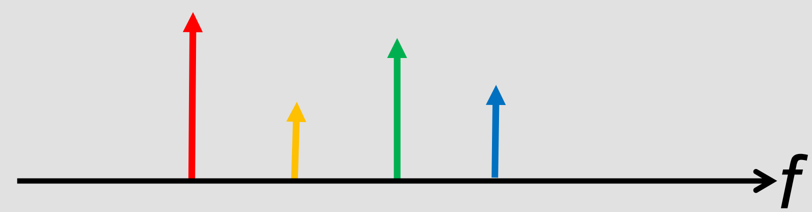


No CP: $T_{OFDM} = 1/R$

At the Receiver….



Fourier Transform window



Delta Functions
(no spectral leakage)

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Enhancing OFDM with clipping

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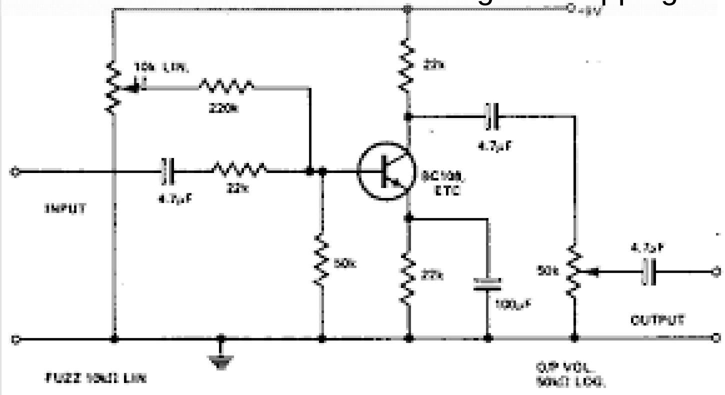
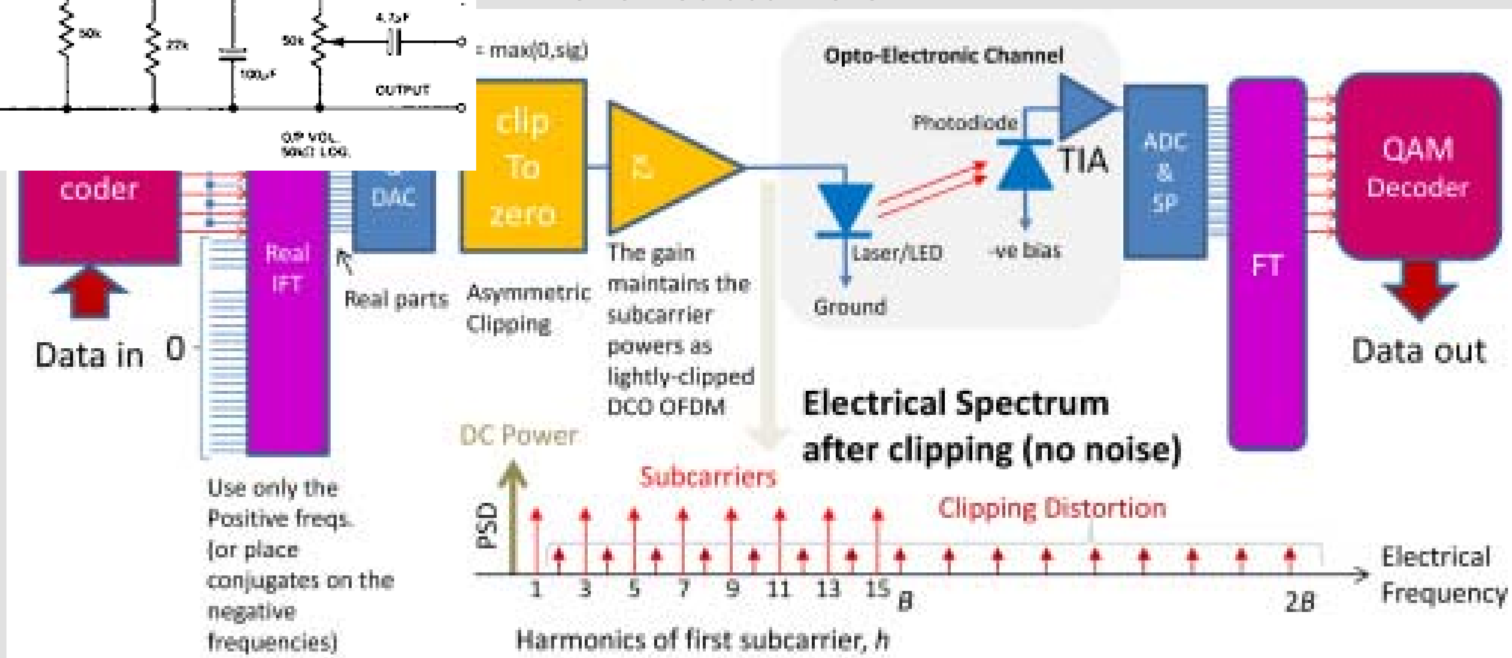
Guitar “fuzz” box with variable negative clipping



- ACO-OFDM – asymmetrically clipped optical orthogonal frequency division multiplexing
- Reduces DC content – less optical power
- BUT: only uses half of the subcarriers (odds) because of harmonic distortion falling on the even subcarriers



A. J. Lowery and J. Armstrong, “10 Gbit/s multimode fiber link using power-efficient orthogonal-frequency division multiplexing,” Opt. Express 13(25), 10003–10009 (2005).
J. Armstrong and A. J. Lowery, “Power efficient optical OFDM,” Electron. Lett. 42(6), 370–371 (2006).

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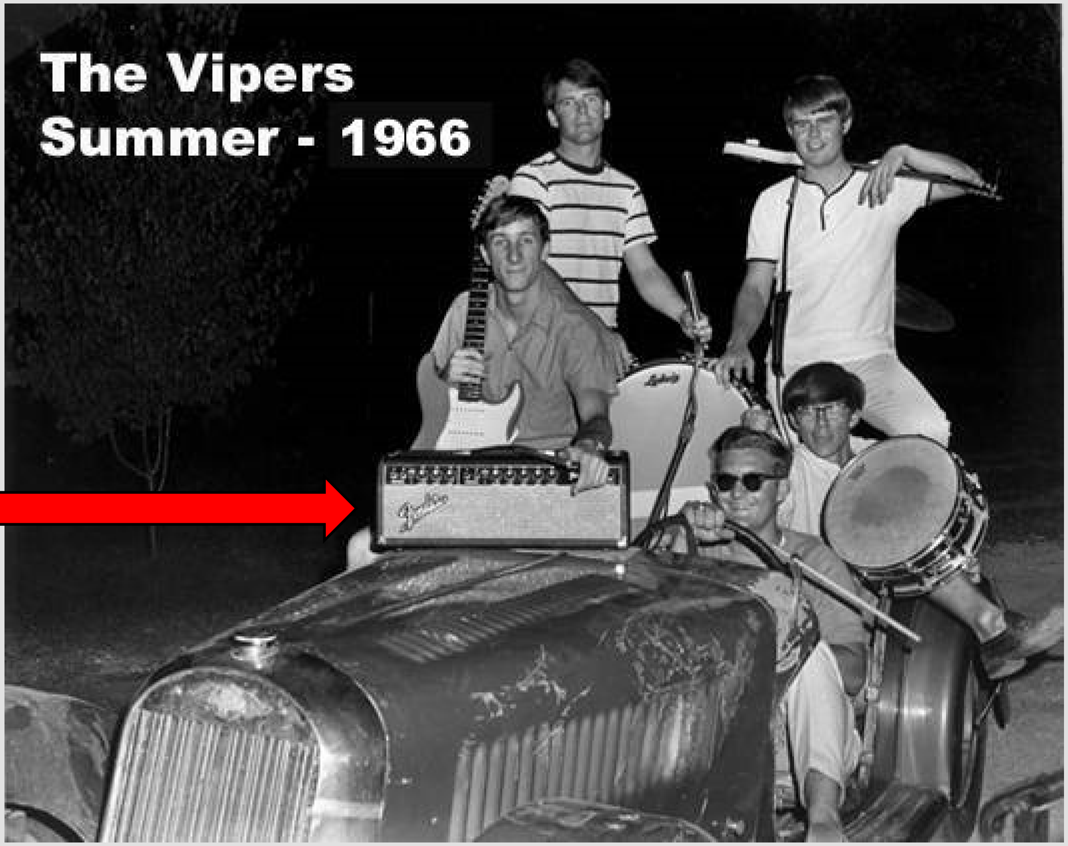
Enhancing OFDM & Garage Bands

A poor band – one amplifier (well, they had a car!):

All instruments through one amplifier: This gives serious and unpleasant intermodulation distortion when amplifier clips, even if they are playing the same chords (but at octaves).



http://home.unet.nl/kesteloo/vipers.html

Enhancing OFDM & Garage Bands

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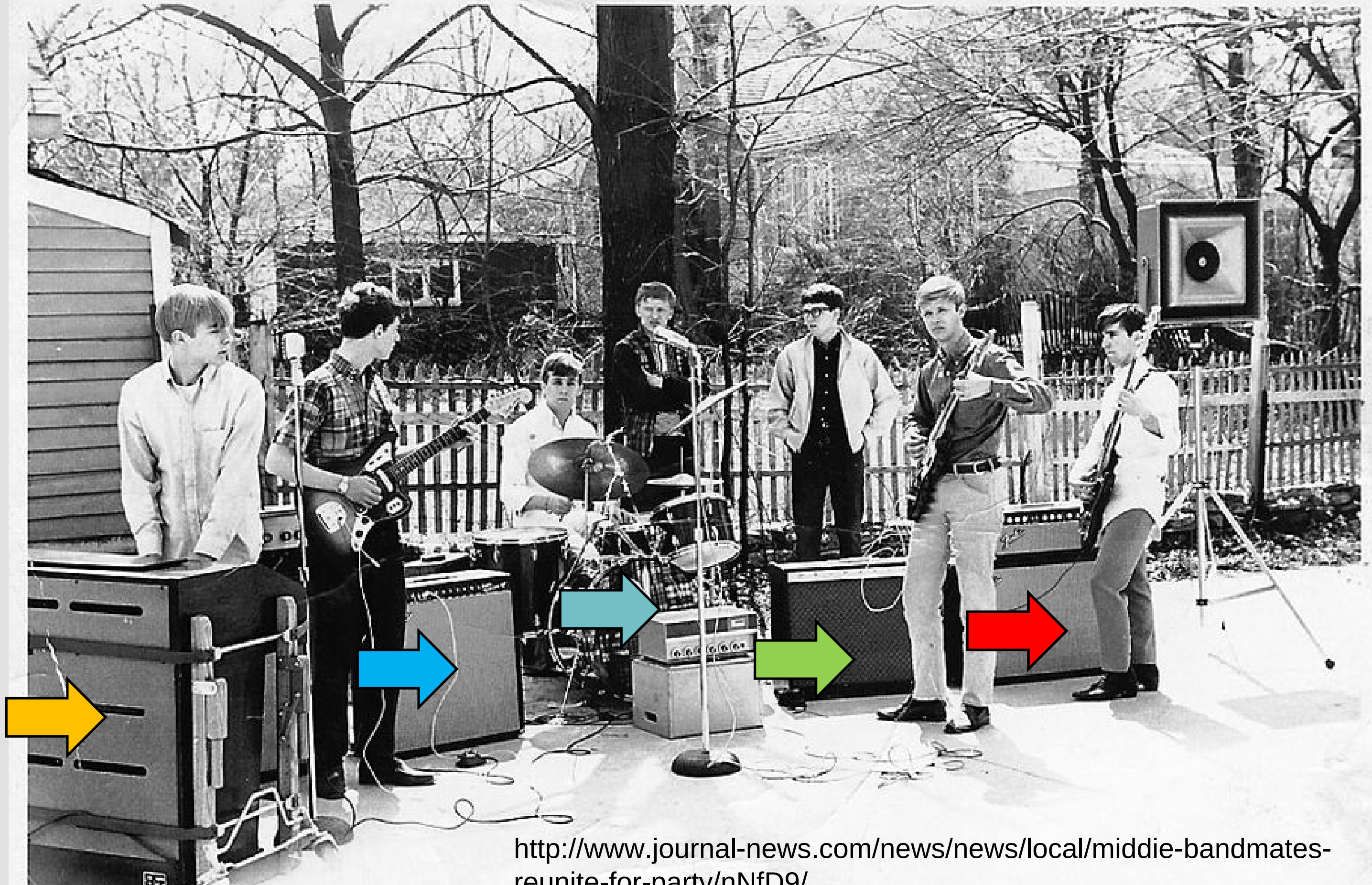
A richer band:

Separate amplifiers for each instrument:

The clipping within each amplifier only causes pleasant distortion.

The sound is combined in the air.



http://www.journal-news.com/news/news/local/middie-bandmates-reunite-for-party/nNfD9/

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Enhancing OFDM with separate clipping for each chord

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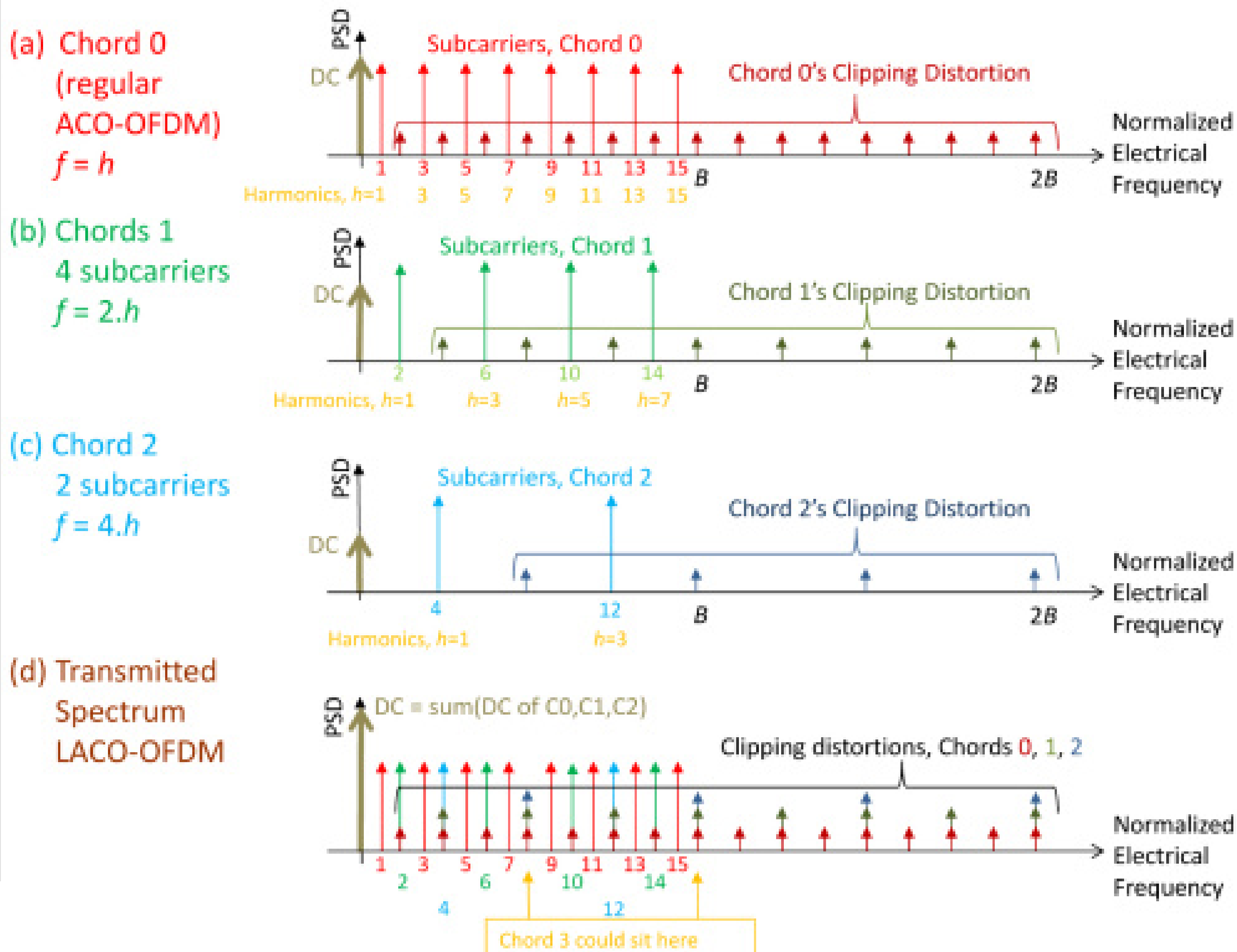
This trick* can be used to enhance the spectral efficiency of optical OFDM signals

**clipping the instruments separately, then adding the results*

Arthur James Lowery, "Comparisons of spectrally-enhanced asymmetrically-clipped optical OFDM systems," Optics Express 24(4) pp. 3950-3966, (2016) and papers referenced therein.



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Enhancing OFDM & Garage Bands

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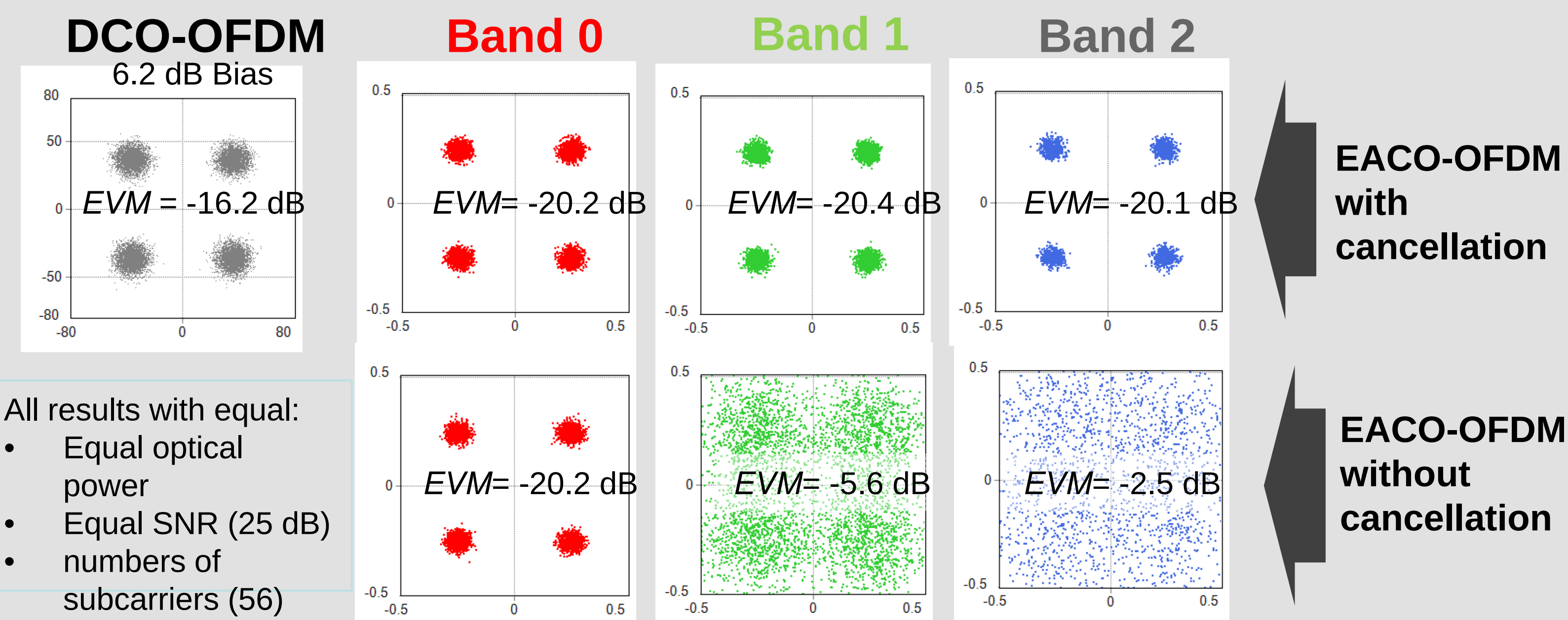
Successive interference cancelation at the receiver reveals the chords. The error vector magnitude (EVM) is less than any other (unlayered) modulation format, for the same optical power.



All results with equal:

- Equal optical power
- Equal SNR (25 dB)
- numbers of subcarriers (56)

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Enhancing OFDM & Garage Bands

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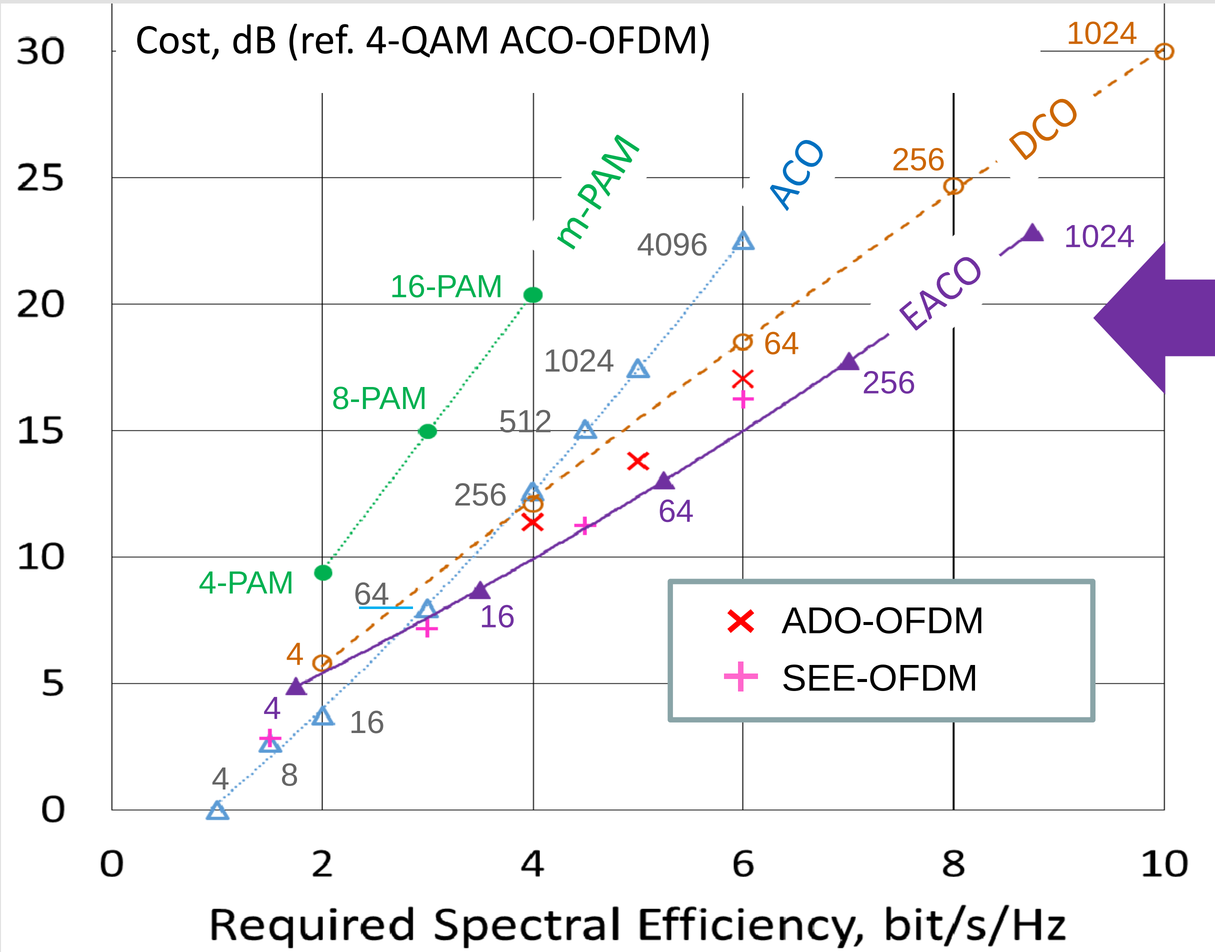

Enhanced/Layered ACO-OFDM outperforms other methods (i.e. needs the lowest optical power for a given spectral efficiency) at spectral efficiencies above 3 bit/s/Hz.

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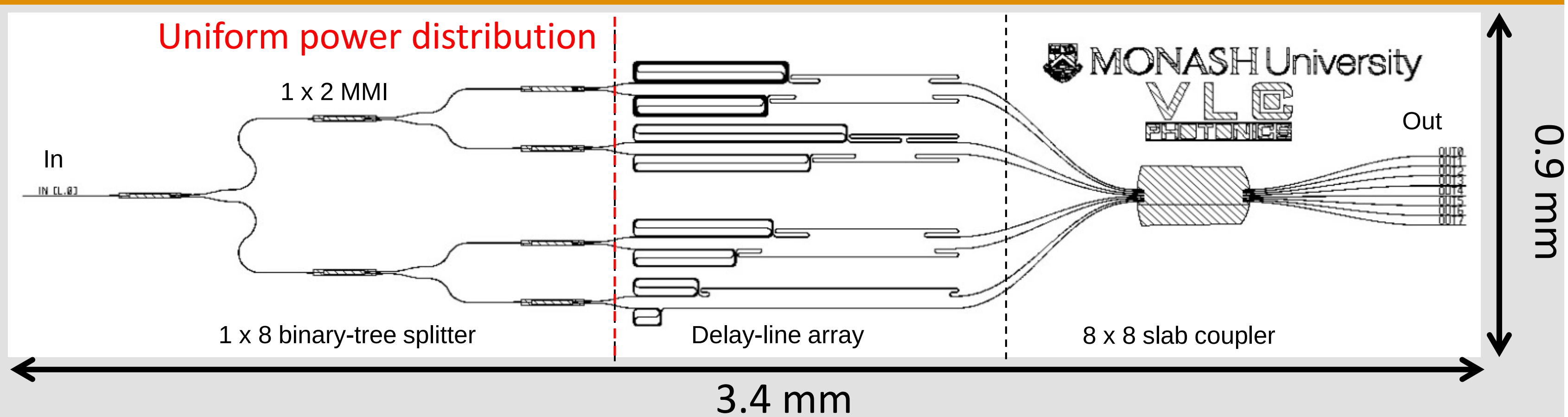
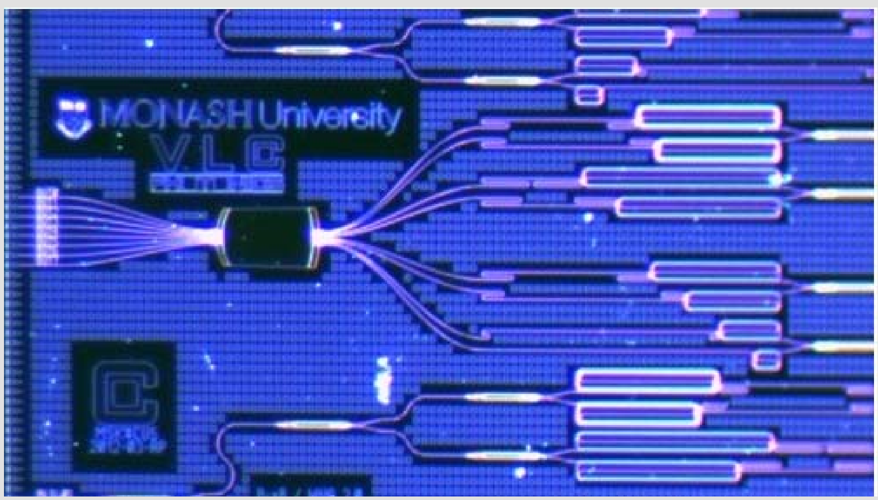
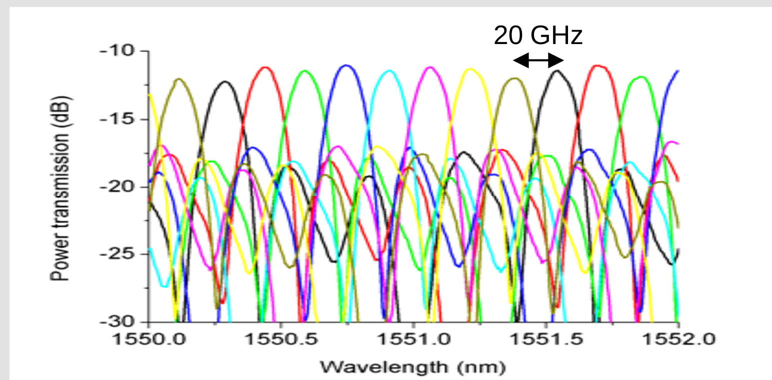
Implementing OFDM All-Optically
(Optical Fourier transforms)







A. Lowery, L. Zhuang, B. Corcoran, C. Zhu, and Y. Xie, "Photonic Circuit Topologies for Optical OFDM and Nyquist WDM," J. Lightwave Technology, DOI: 10.1109/JLT.2016.2618388

Also see M. E. Marhic, "Discrete Fourier transforms by single-mode star networks," Opt. Lett., vol. 12, pp. 63-65, 198 for a design with cross-overs

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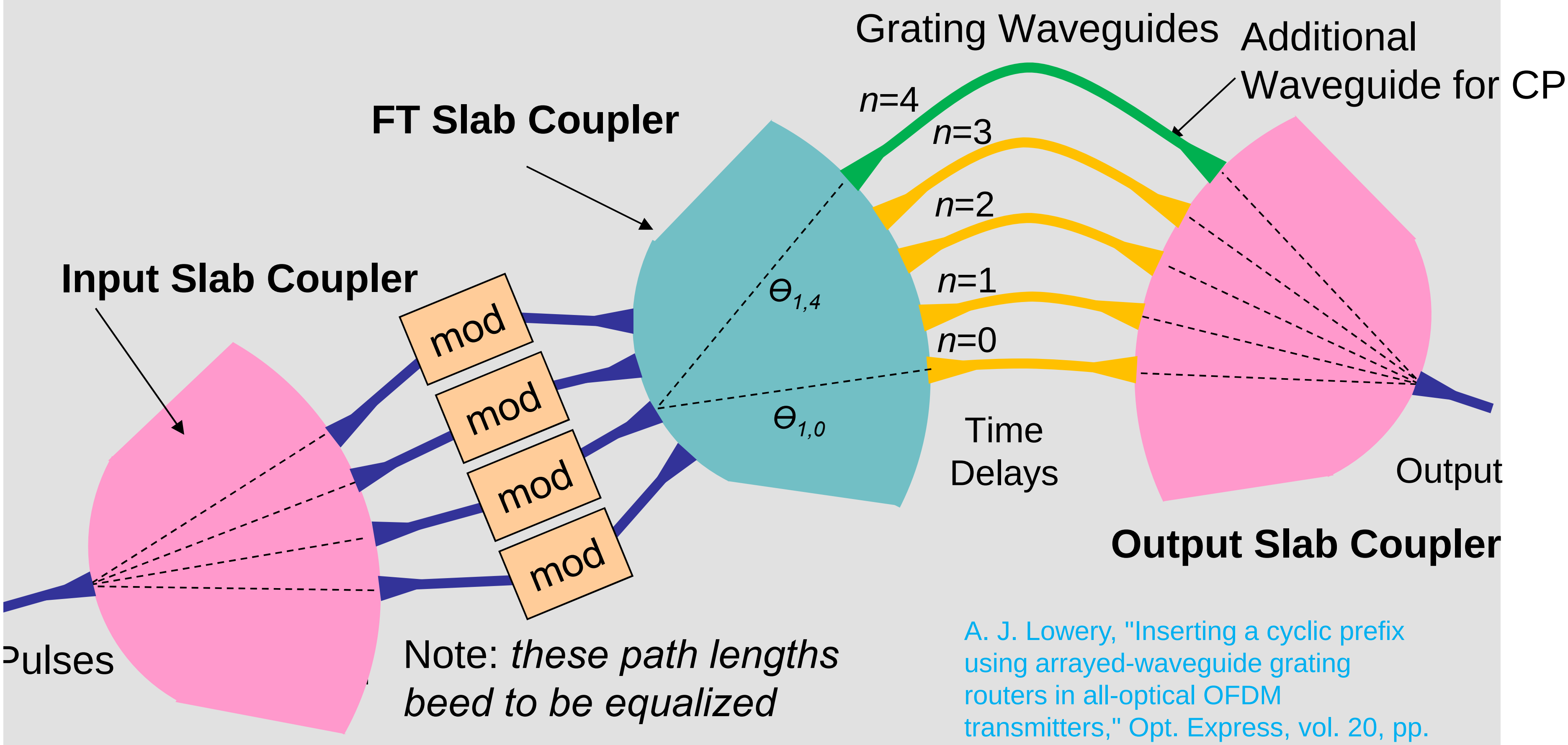
The AWGR as an Inverse FT (with a Cyclic Prefix)



Note: *these path lengths beed to be equalized*

A. J. Lowery, "Inserting a cyclic prefix using arrayed-waveguide grating routers in all-optical OFDM transmitters," Opt. Express, vol. 20, pp. 9742-9754, 2012.

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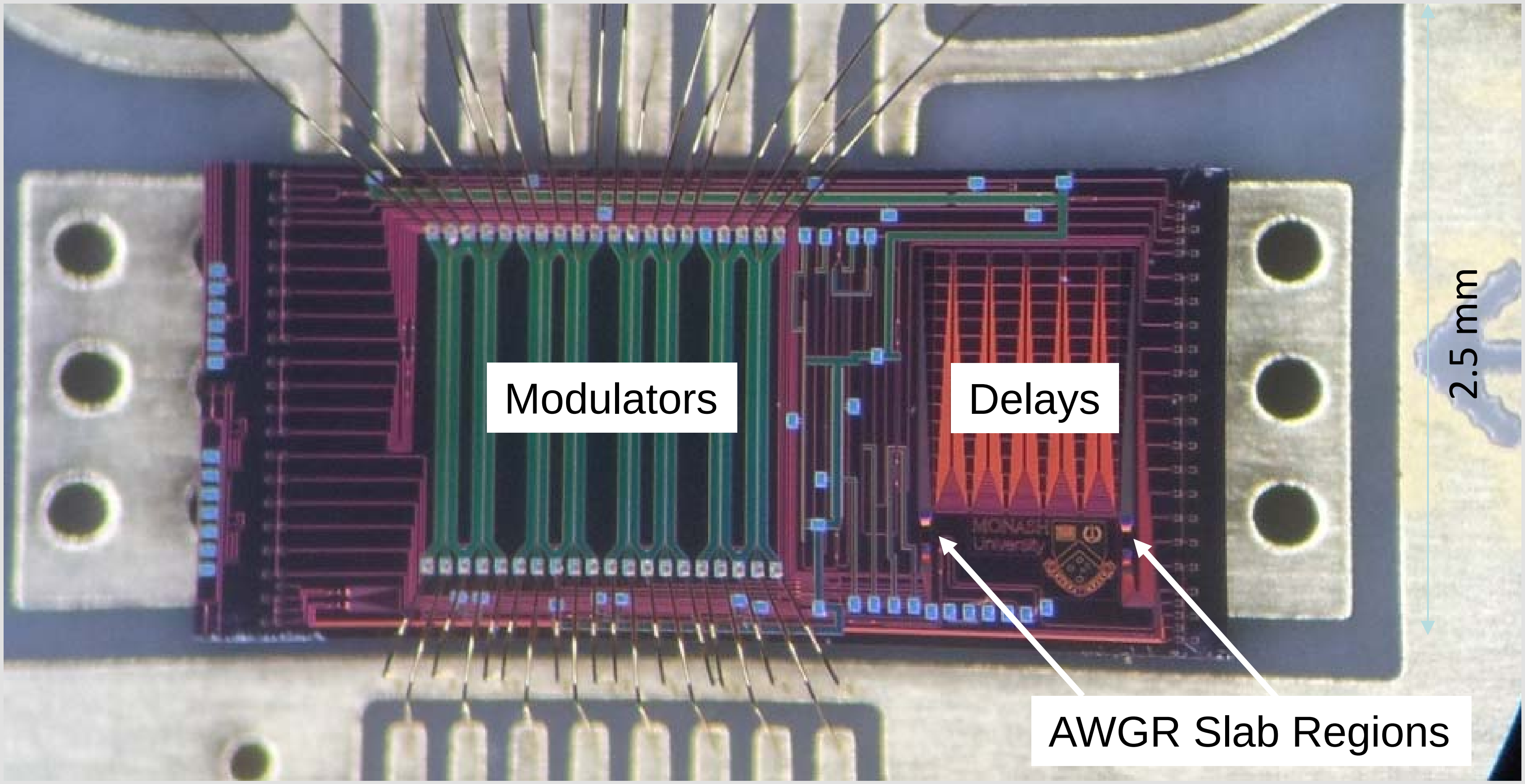
OFDM Photonic Integrated Circuit: Monash I



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IMEC OFDM Tx chip in Silicon-on-insulator (SOI) with modulators and AWGR-based IFT

Conclusions

- Many of my ideas have come from:
  - Musical instruments
  - Sound
  - Analog electronics/ effects boxes
  - Railway track layouts (photonic circuits)
- I then usually simulate the ideas using software
- I have needed mathematics to create models to optimise and communicate these ideas, and physics to ensure that they are grounded
- “Engineering-Inspired-Engineering”
- Questions and Discussion