Space-Time Optical Systems for Encryption of Ultrafast Optical Data

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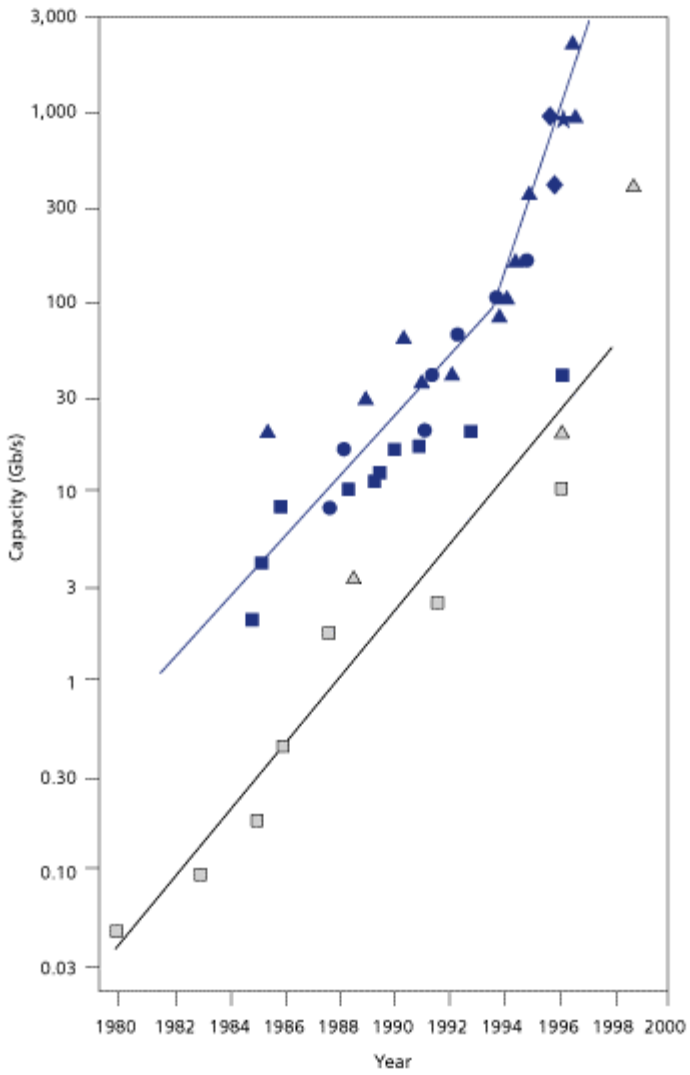
Ultrahigh-Speed Optical Communications

- **CAPACITY** increased at over 4 dB per year.
  - Experiments with **1 Tb/s** and higher.
  - Commercial systems with **400-Gb/s.**
- **ELECTRONIC ENCRYPTION** has difficulties above **~ 10Gbit/s**.
- Our research aims at **OPTICAL ENCRYPTION BOXES AT PHYSICAL LAYER** for such high speeds.

Progress in Speed

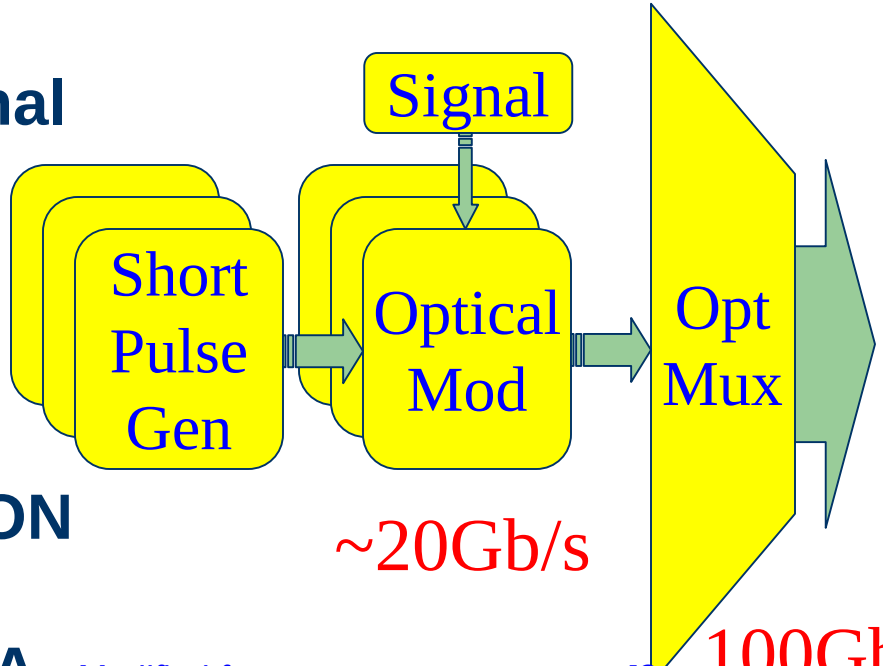
Transmission capacity (though SMF) versus year



[A. R. Chraplyvy; Bell Labs Technical Journal, Vol. 4, No. 1, 1999]

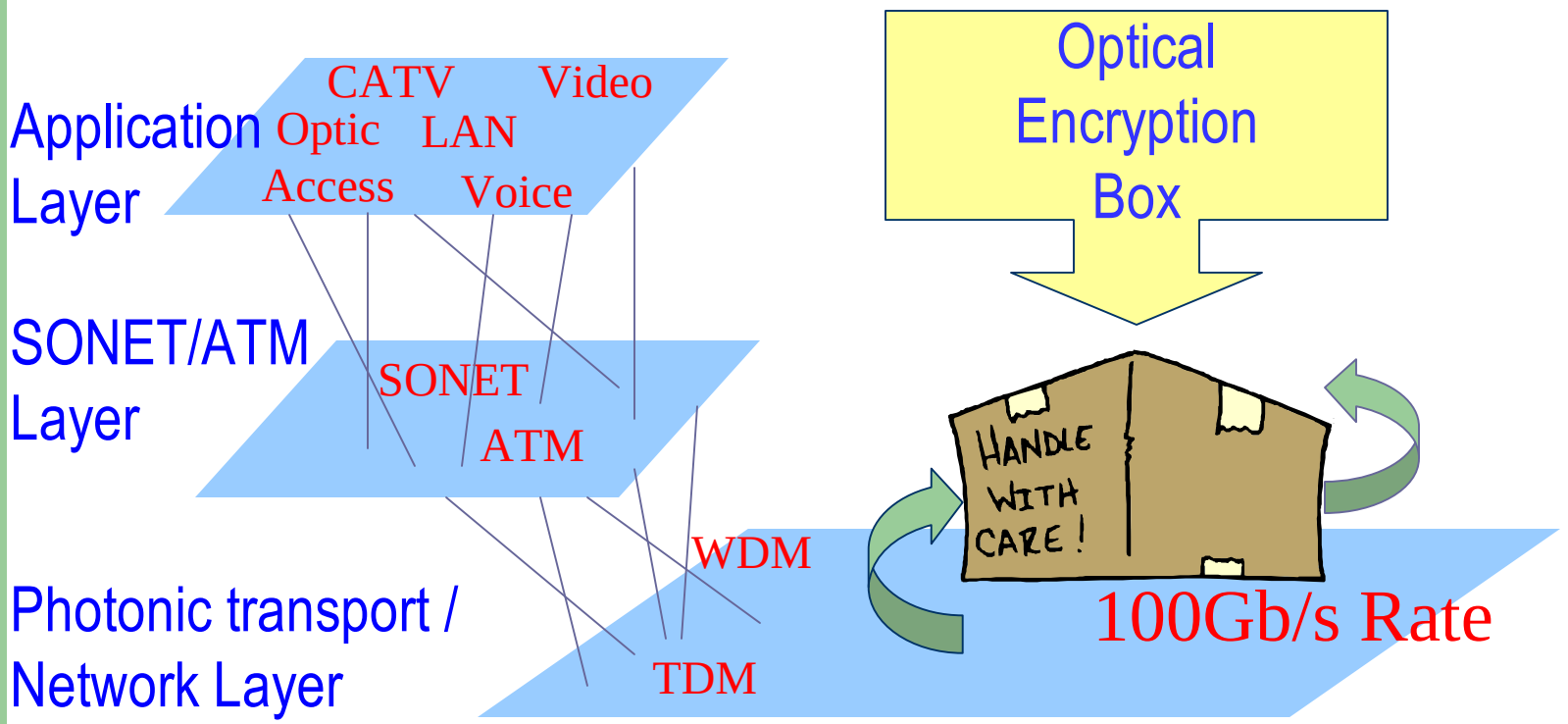
Optical Time-Division-Multiplexed (TDM) Transmission

- Resembles **conventional electronic networks**.
- Focus on packet processing including **HEADER RECOGNITION** and **ENCRYPTION** of **TDM OPTICAL DATA** at **100 Gb/s** and beyond.



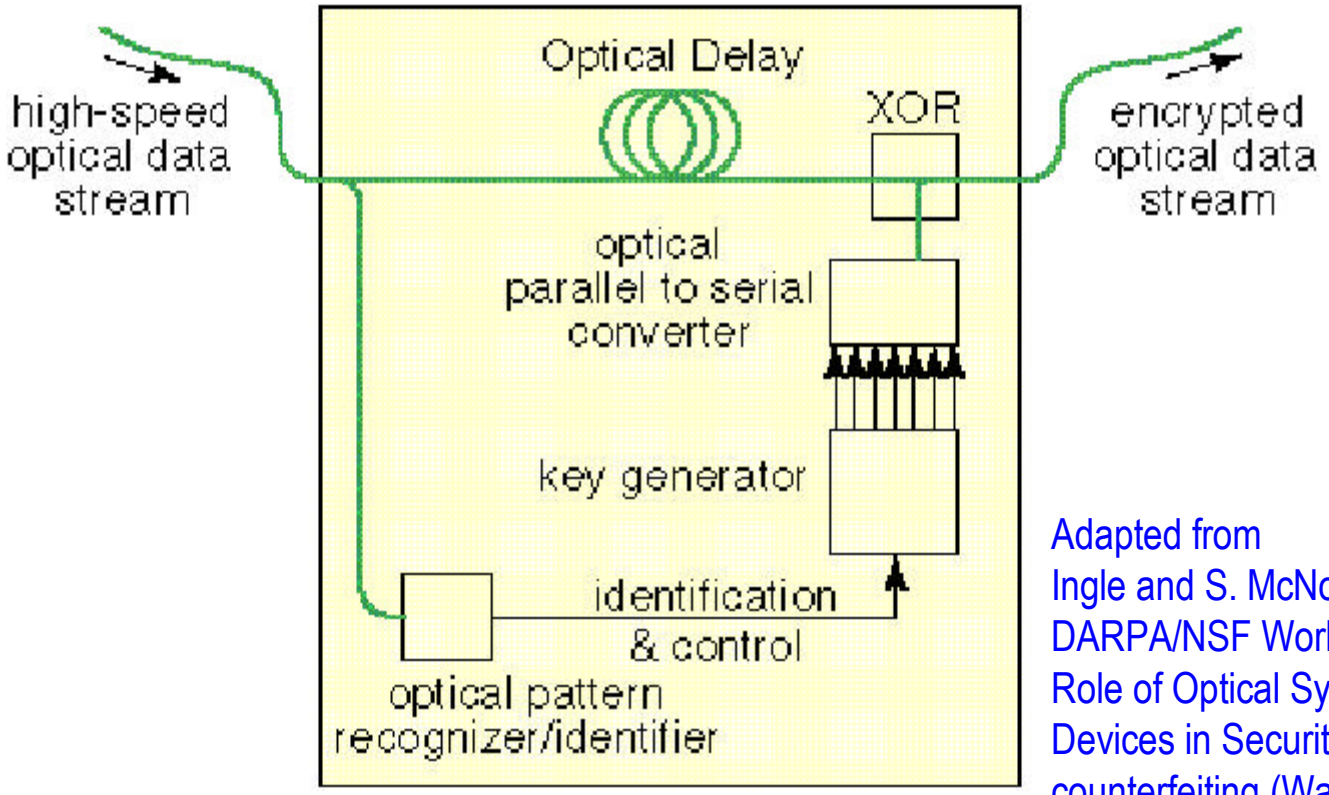
Modified from [S. Kawanishi, NTT; IEEE Journal of Quantum Electronics, Vol. 34, No. 11, Nov. 1998]

Optical Encryption at Physical Layer



Modified from [D. Salameh *et al.*; Bell Labs Technical Journal, Vol. 3, No. 1, 1998]

High-Speed Optical Encryption Box



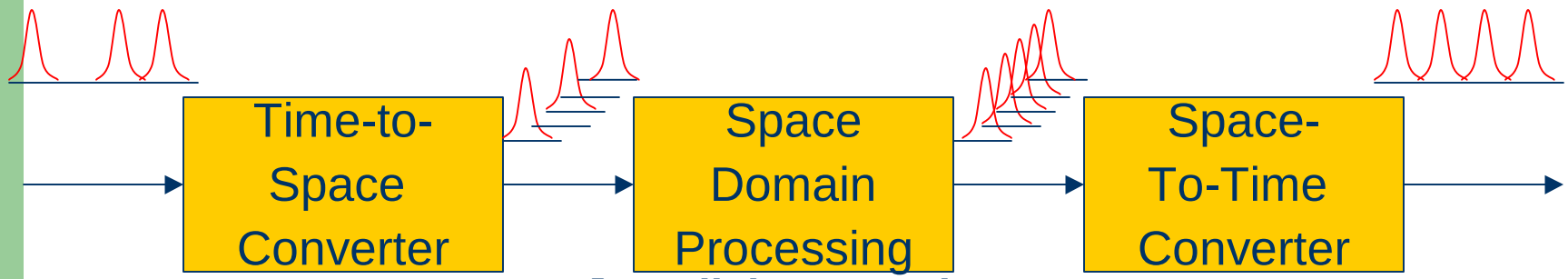
Adapted from [J. Ingle and S. McNown, DARPA/NSF Workshop on the Role of Optical Systems and Devices in Security and Anti-counterfeiting (Washington, D.C., 1996)]

Subsystems for Ultrahigh-Speed Optical Encryption

- **Serial-to-parallel converter** to allow header recognition and packet processing at rates compatible with electronics
- **Key generator array**
- Ultrahigh-speed **optical XOR gate** or array of high-speed **optoelectronic XOR gates** for stream cipher (for example)
- **Parallel-to-serial converter** to reform the ultrahigh-speed TDM data stream

We are working on novel parallel optical/optoelectronic subsystems to implement the serial-to-parallel conversion, parallel XOR gating, and parallel-to-serial conversion subsystems.

Approach of Space-Time Processing

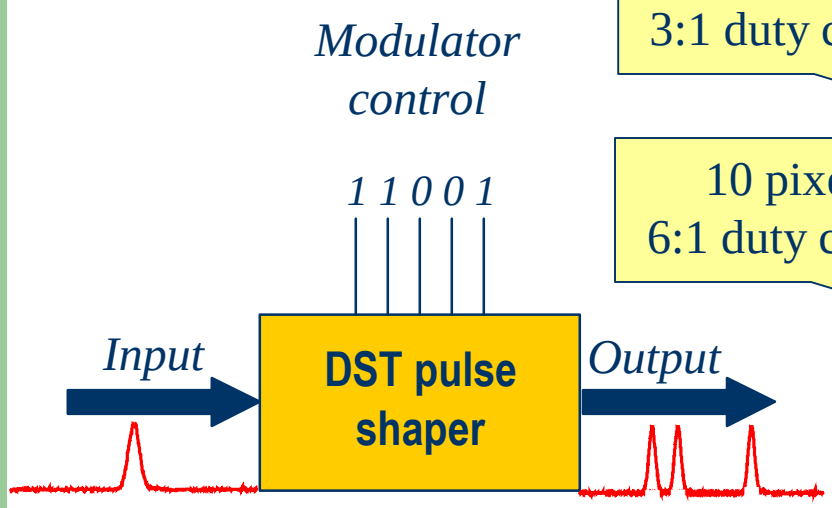


[Serial-to-parallel] **[Parallel processing Using optoelectronic Smart Pixels]** **[Parallel-to-serial]**

- Manipulates optical data in parallel to keep up with high speed stream.
- **Pulse shaper**: generate ultrafast test waveforms
- **Time-to-space converter**: Serial stream => Parallel data input
- **Smart Pixel optoelectronic array**: Digital logic operations like header recognition
- **Space-to-time converter**: Parallel data output => Serial stream

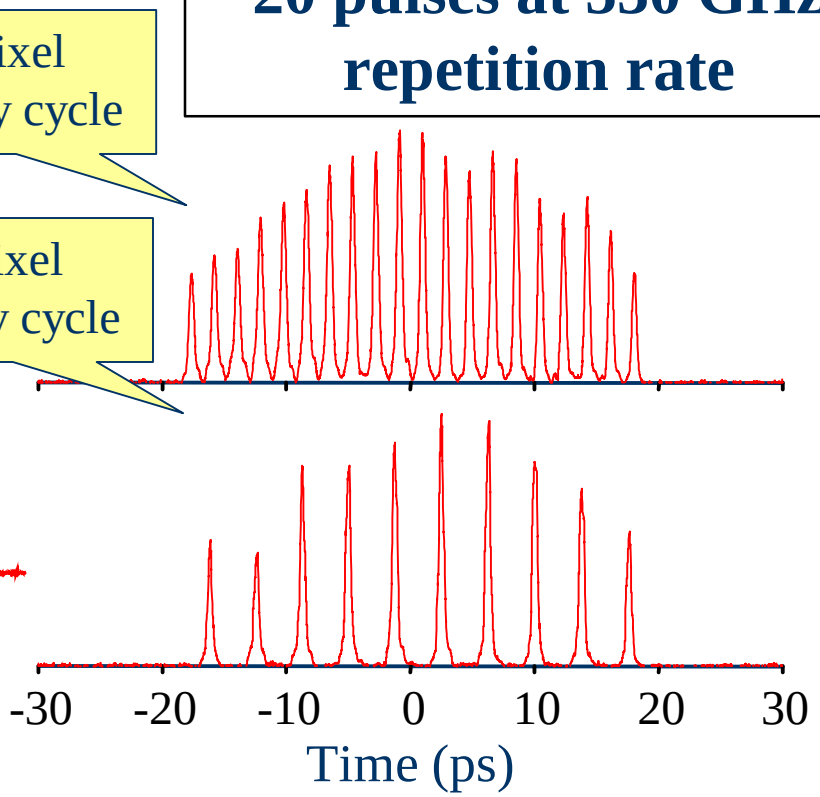
Direct Space-To-Time Pulse Shaper (Space-To-Time Converter)

Scheme

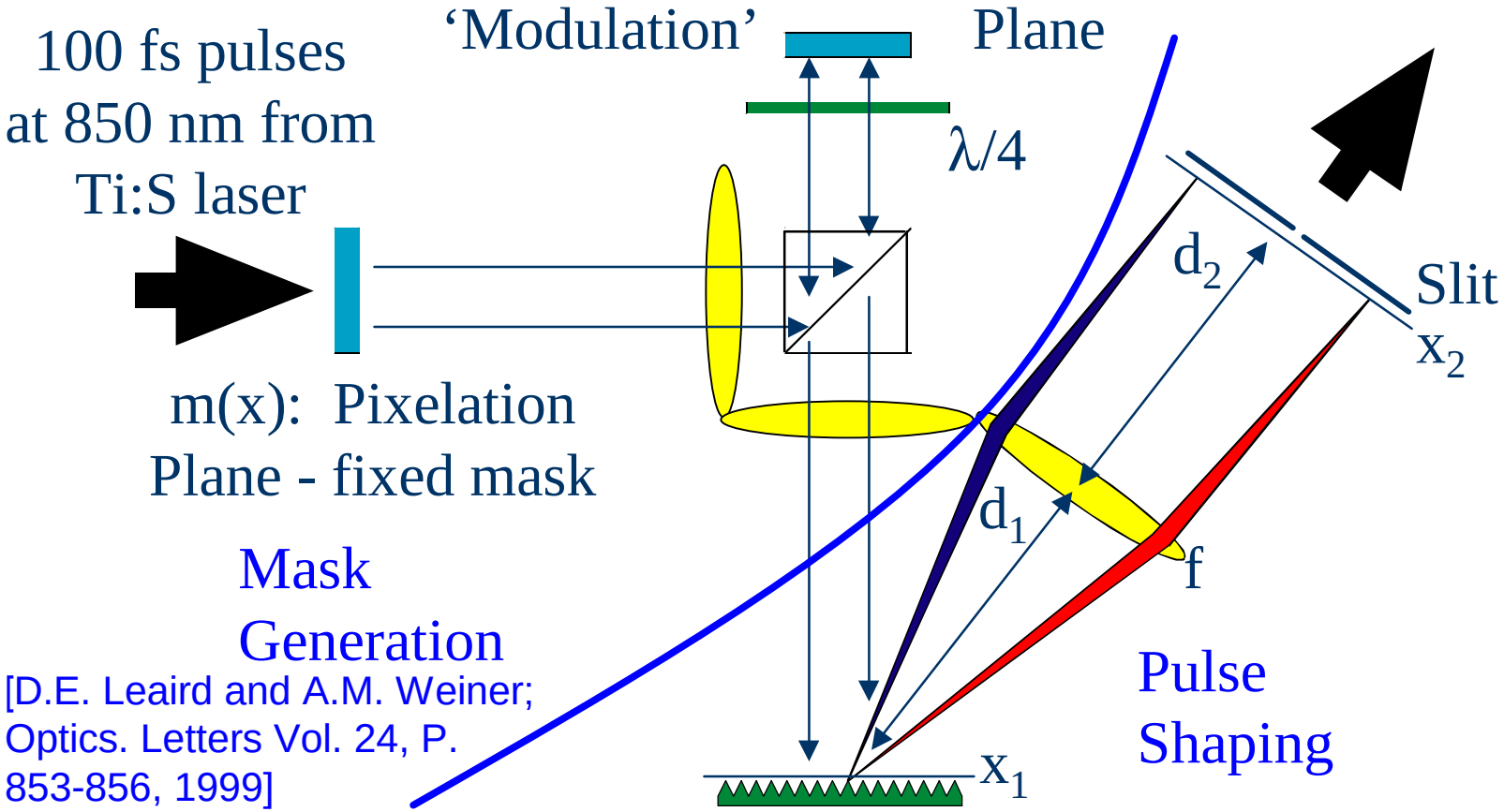


[D.E. Leaird and A.M. Weiner; Optics. Letters Vol. 24, P. 853-856, 1999]

20 pulses at 530 GHz repetition rate

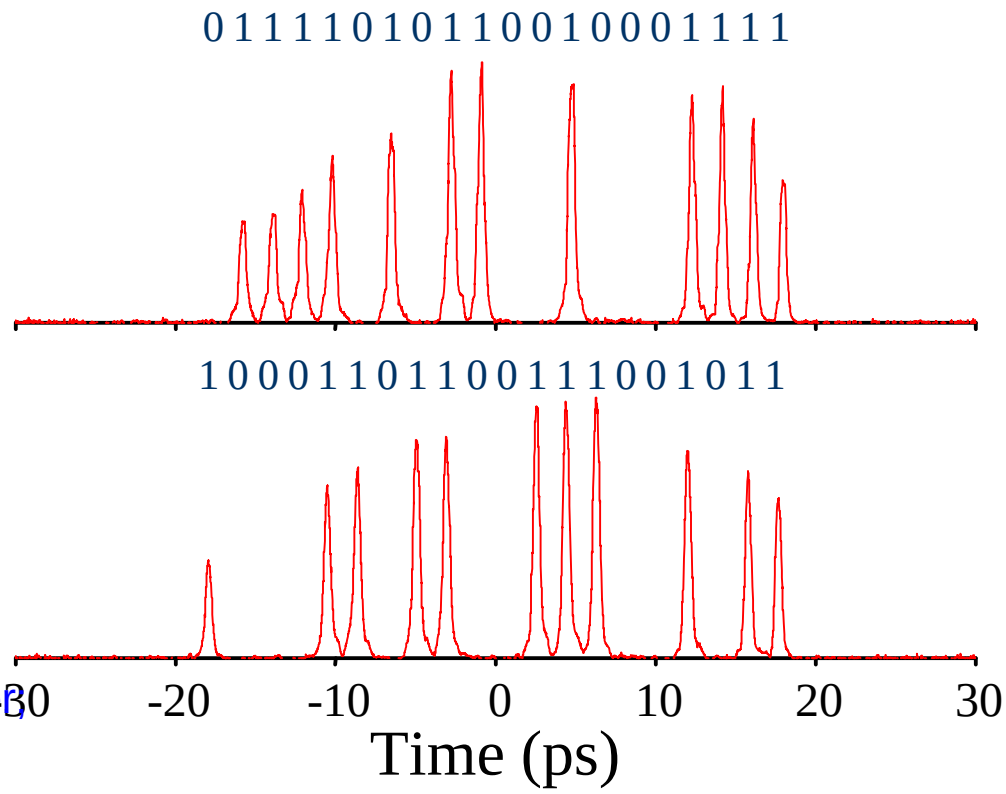


Direct Space-To-Time Pulse Shaper Apparatus



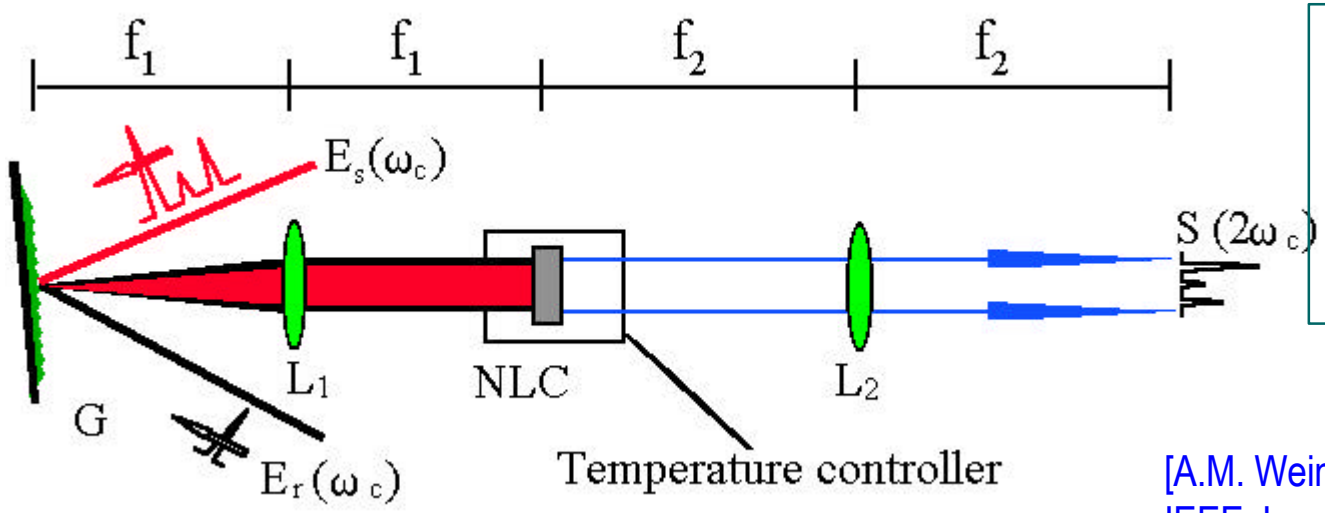
Femtosecond Data Packets

- Target application of DST.
- The ‘state’ of each temporal pulse is determined by the transmission at a unique spatial location.



[D.E. Leaird and A.M. Weiner, Optics. Letters Vol. 24, P. 853-856, 1999]

Time-to-Space Converter



NLC: Nonlinear crystal
G: Grating
L: Lens
E_s: Signal beam
E_p: Pump beam
S: Spatial replica after a Fourier-transform lens

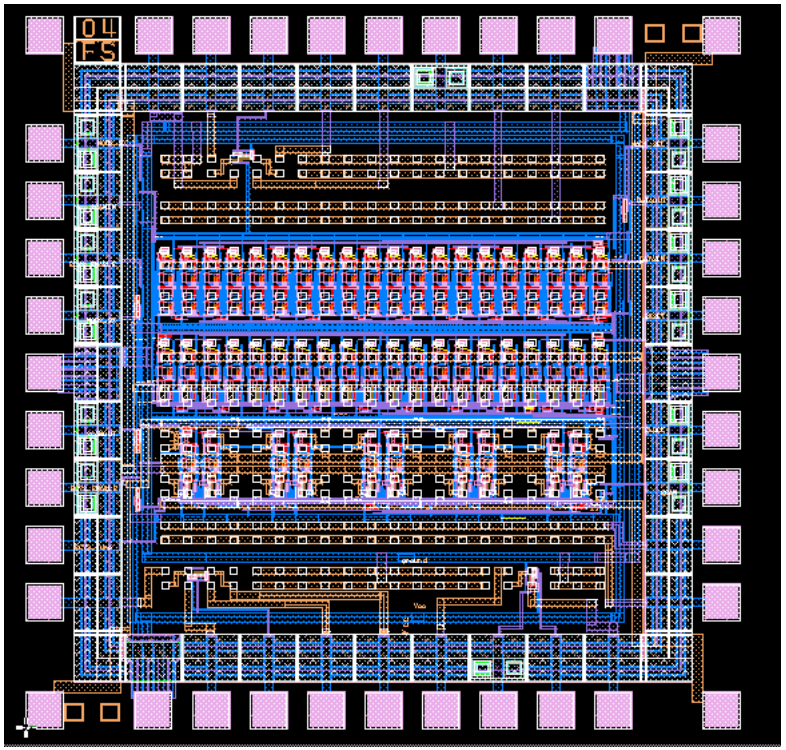
• Using a reference pulse, make Spatial replica of input signal pulses.

•We have demonstrated 500 times sensitivity improvement, which is key for operation at realistic power budgets in high-speed systems.

[A.M. Weiner and A.M. Kan'an; IEEE Journal of Selected Topics In Quantum Electronics, Vol. 4, No. 2, Mar/Apr. 1998]]

Modified form [P.C.Sun, Y.T. Mazurenko and Y. Fainman; Journal of the Optical Society of America A, Vol. 14, P. 1159, 1997]

Optoelectric-VLSI Smart Pixel Array



- Hybrid CMOS/GaAs from Lucent foundry
- 200 Optical I/O's
- High-speed modulator array functionality for ultrafast optical packet generation
- AND gate array functionality for experiments on ultrafast optical header recognition
- XOR gate array functionality for experiments on ultrafast optical stream cipher

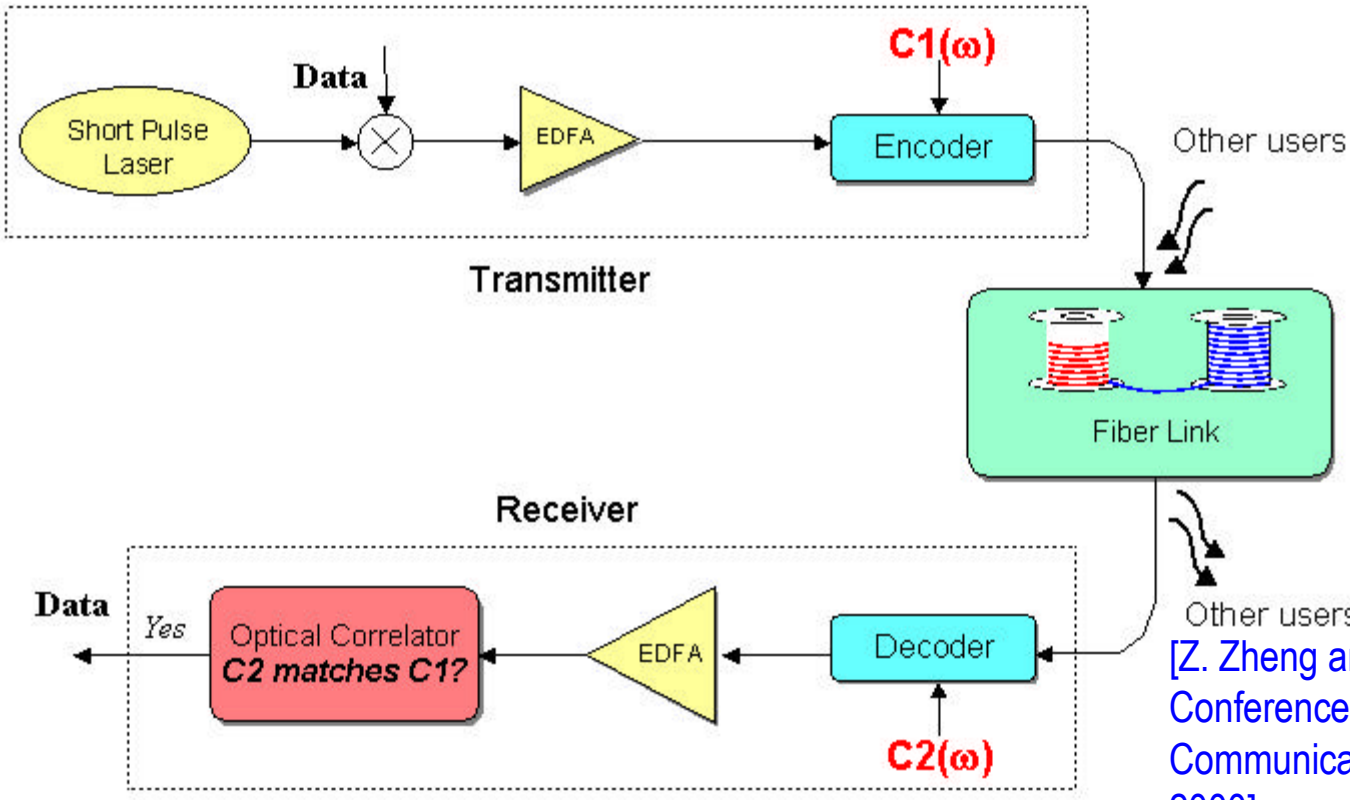
Digital Logic Operation of Smart Pixel Array

- Processes the spatially-converted data in parallel, using an array of detectors
- The data would be XORed electronically with a stored key, to implement a stream cipher.
- The processed data then drives an optoelectronic modulator array inserted in a suitable space-to-time converter to get back to a serial ultrafast optical signal.
- Works out to frame rates of a few Gb/s to be able to achieve overall data rates exceeding 100 Gb/s.

Other Approach to Encryption: Optical CDMA

- Encoding/decoding of ultrafast waveforms at the bit level
- Provide security at the physical layer
  - Keep unauthorized users without key from getting access to the bitway.
- Can circumvent electronics bottlenecks and potentially implement directly in the optical domain certain network operations, such as addressing and security, which traditionally have been performed electronically

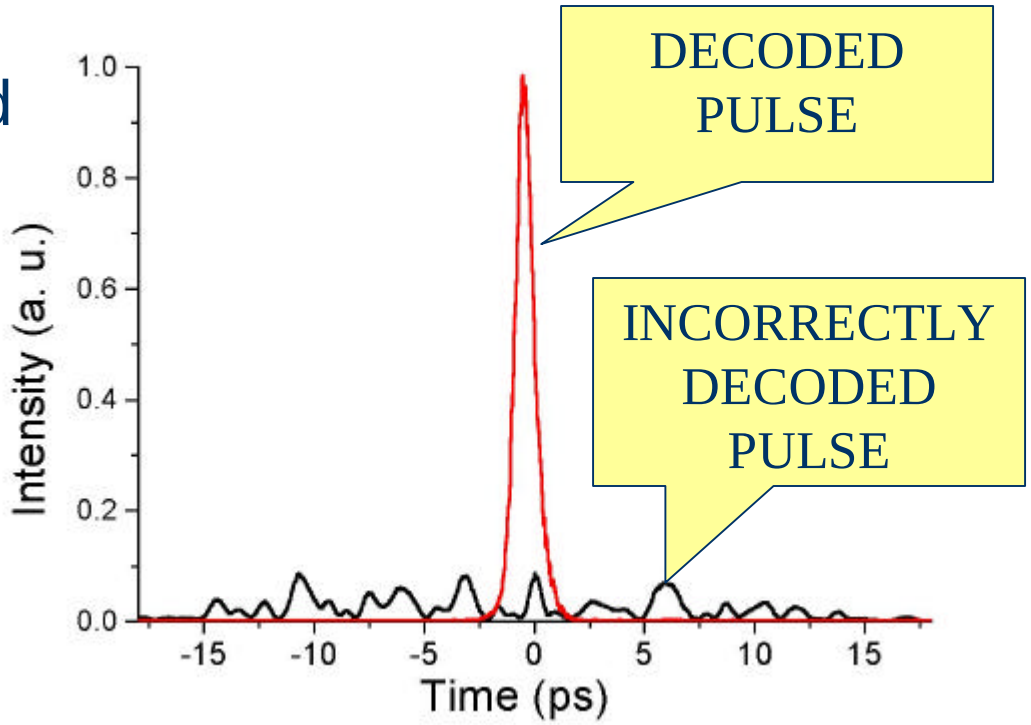
Schematic of Ultrashort Pulse Optical CDMA



[Z. Zheng and A.M. Weiner, Conference for Optical Fiber Communication, Baltimore, Mar. 2000]

Decoding a Pulse

We have demonstrated coding, transmission, decoding, and optical correlation of femto-second pulses over multi-kilometer fiber spans.



Modified from [Z. Zheng, S. Shen, H. Sardesai, C.-C. Chang, J.H. Marsh, M.M. Karhkhanehchi, and A.M. Weiner, Optics Communications Vol. 167, P. 225, Aug. 1999]

Conclusion

- Using space-time processing technique, we can perform encryption operation on optical data at the physical layer, especially in the high-speed optical TDM transmission.
- Optical CDMA scheme can also encode and decode optical data at the physical layer for the purposes of addressing and security.