

# Single-Chip Integrated Transmitters and Receivers

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**Abstract**—After many years in the research lab, photonic integrated circuits are emerging into practical commercial products with advantages not only in size, weight and power, but also in cost and performance. Recent advances in semiconductor-based devices will be reviewed.

As illustrated in Fig. 1, data traffic on the core fiber optic network and within data centers as well as the processing power of supercomputers has been growing exponentially for many years at a rate of between 100 to 500 times per decade [1]. This is faster than Moore's Law, and just as in the circuit design case, effectively parallel communication paths have been sought to keep up with the demand.

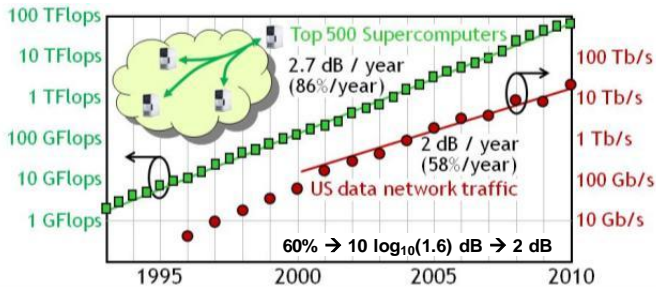


Fig. 1. Rate of growth in computer processing power and communication network bit-rate.

One common approach used in the rf-world has been to use advanced modulation formats that provide higher spectral efficiency, possibly leading to multiple bits/s of information transmission per Hz of bandwidth. This generally requires vector modulation approaches, acting on both the amplitude and phase of the optical field, as well as coherent receivers that recover the full vector field.

As it turns out coherent communication was intensively investigated some years ago (1980s), and this work stimulated work on photonic integration, because only with photonic integration could the various components be held together with enough stability and proximity. In those days, the primary goal was to increase receiver sensitivity and repeater spacing in fiber systems [2]. However, when wavelength division multiplexing (WDM) systems became more practical and inexpensive with the advent of the erbium-doped fiber amplifier (EDFA) these relatively costly and temperamental coherent communication approaches were put on the shelf for such fiber optic systems [3].

Nevertheless, the photonic integrated circuit (PIC) work they stimulated found new applications in the new WDM systems. For example, as illustrated in Fig. 2, widely-tunable (universal)

transmitters were widely desired. In fact, the integration of the sampled-grating distributed-Bragg-reflector (SGDBR) laser [4], with or without a Mach-Zehnder modulator, and some related products have been major success stories commercially, accounting for a large portion of dense WDM sources incorporated into systems over the past several years.

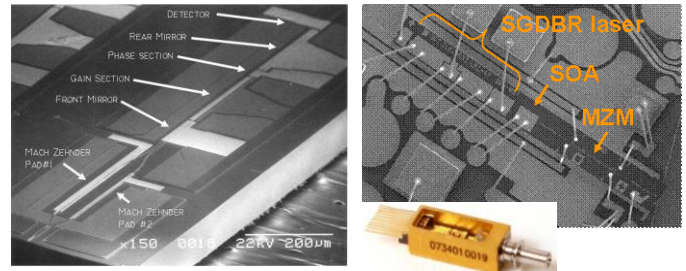


Fig 2. SEMs of SGDBR lasers integrated with Mach-Zehnder modulators (MZM)—left, early research result[5]; right, recent JDSU product, chip and TOSA[6].

Efforts on the technology to integrate more complex PICs have continued over the years, driven by the desire to make WDM more viable, the interest in “all photonic” networks, and most recently, a renewed interest in coherent, now mainly driven by spectral efficiency. Figure 3 shows an 8 x 8 photonic space switch that incorporates 8 all-optical wavelength-converters together with an arrayed waveguide grating router (AWGR). When first presented [7], this represented a major advance in the level and complexity of photonic integration.

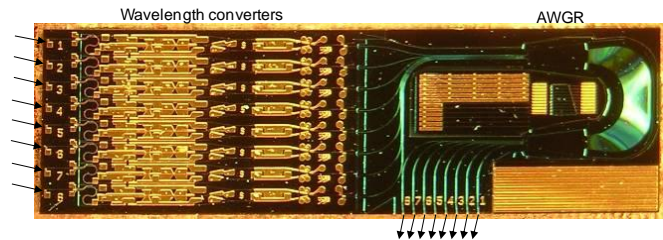


Fig. 3. Monolithic tunable optical router (MOTOR) chip with 8 SGDBR tuned wavelength converters feeding an AWGR to provide 8 spatially separated output, each operating at 40 Gb/s.

Figure 4 shows the layout of an advanced transmitter chip for polarization-multiplexed (PM) QPSK optical coherent communication demonstrated by Infinera. It has 10 parallel [x 2 for (PM)] channels operating at 10 GBaud for a net of 400 Gbits/s from one chip [8]. They have since demonstrated a single-chip with over 1 Tbit/s of net data transmission [9].

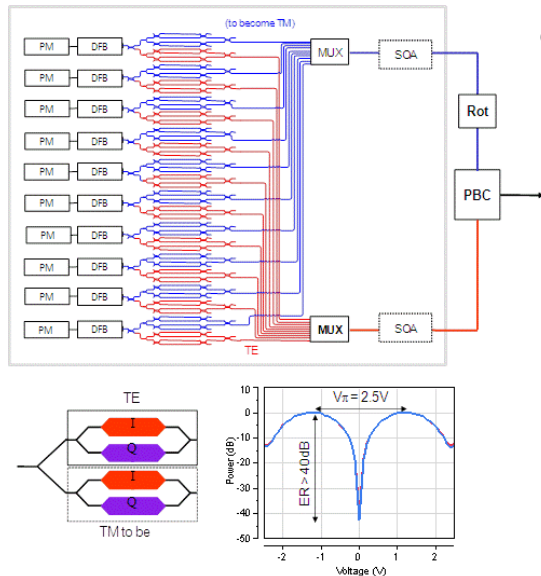


Fig. 4. Infinera PM-QPSK (10 x 40G) – 10 GBaud x 4/λ—transmitter chip layout[8].

The recent resurgence of coherent techniques is mainly driven by social networking, HD video, and other exponentially growing data demands on the network [10,11]. This has driven a variety of research including our efforts, which differs from the mainstream in that we have been exploring integrated phase-locked loops (OPLL) in both our transmitters and receivers[12-15].

The common approach today is to use a loosely frequency-locked local oscillator at the receiver, which must have a fairly narrow linewidth, and then let a Digital Signal Processor (DSP) electronic chip track the phase and also perform a number of other signal conditioning functions. The problem with this approach is that the ADC and DSP combination require a lot of power to operate, and they are also relatively expensive to design and fabricate, if the market being served is relatively small.

As mentioned above, our efforts have focused on OPLL approaches which promise much higher efficiency operation, and much lower design and production costs. Again, as in the past, photonic integration as well as close integration with electronic ICs (or no ICs at all) [12-15] have the potential to vastly simplify coherent transmitters and receivers and make them much more robust. Environmental controls are relaxed, locking and capture ranges increased, and overall stability is significantly improved in a much smaller, lighter, less costly, and lower power package.

Figure 5 shows a block diagram of a phase-locked coherent receiver, which contains photos of the PIC and EIC. The PIC contains a widely-tunable SGDBR LO laser (40 nm range) and a 90 degree hybrid along with monitoring detectors and adjustment amplifiers [13,14]. The EIC is a Costa's loop design for frequency and phase locking. In operation, the linewidth of the SGDBR laser was significantly narrowed by locking it to a narrow linewidth reference laser.

Figure 6 compares receiver output when the LO SGDBR laser is unlocked relative to a narrow linewidth input cw signal vs. the case of phase locking with a 100 MHz offset. A vast reduction in phase noise as well as a 'clean' 100 MHz optical

CW1K.1.pdf . interference waveform is observed. In fact, the linewidth of the reference laser is matched. CLEO Technical Digest © OSA 2012.

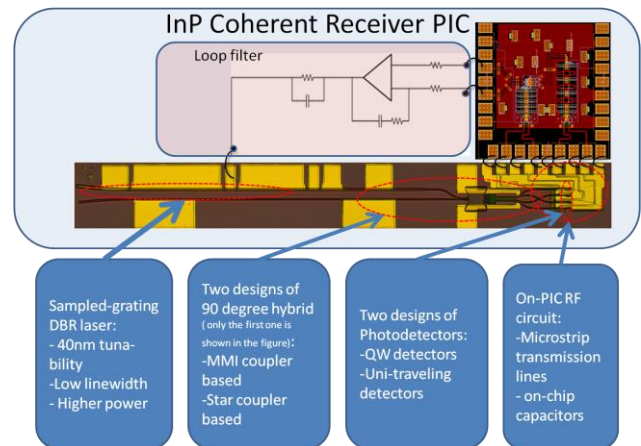


Fig. 5. OPLL coherent receiver.

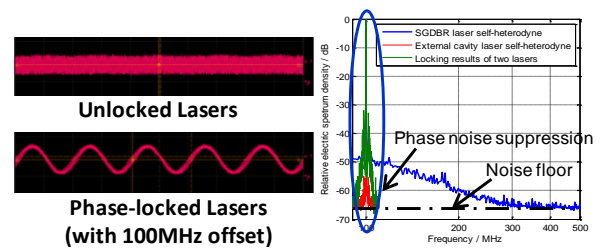


Fig. 6. Optical phase locked loop results.

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