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Experiments on 40 Gb/s Transmission with Wavelength Conversion: Results from the IST ATLAS Project

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In this article we report the main experimental results obtained in the framework of the IST ATLAS project regarding the transmission at 40 Gb/s over long terrestrial links, including the frequency conversion of a signal. We report the single-channel 40 Gb/s transmission over a link 500 km long with an amplifier spacing of 100 km, both with G.652 fibers and G.653 fibers by periodically compensating the chromatic dispersion with dispersion-compensating fibers. We report the single-channel transmission at 40 Gb/s, also, after the wavelength conversion of a channel with both PPLN and semiconductor optical amplifier devices. In particular, 500 km distances are obtained with PPLN wavelength conversion and 300 km distances with semiconductor optical amplifiers. Some results have been reported for electronic devices operating at 40 Gb/s.

Keywords networks, optical systems, WDM, wavelength, 40 Gb/s

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The aim of the Information Society Technology (IST) ATLAS (All-optical Terbit per second LAmbda Shifted transmission) project is to investigate transmission techniques at very high capacity [1–5] over long distances (500–1000 km), taking into account the behavior of some fundamental devices that will be used in the future Terabit/s networks, such as the optical wavelength converters that perform routing operations in the network nodes.

Even though experiments have demonstrated that enormous transmission capacities can be achieved over thousands of kilometers [4], the signal behavior in propagating through optical telecommunication high-capacity networks has not been deeply investigated yet, especially with information fluxes of 40 Gb/s or more, as will be required if the predictions about the traffic growth materialize.

Project ATLAS is aimed at answering some general questions concerning very high capacity networks, namely, what is the maximum capacity-length product attainable in a connection and what are the requirements for switching cross-connecting nodes. Experimental investigations are projected for 4×40 Gb/s and 2×80 Gb/s, which should be obtained by the end of 2001 and in the middle of 2002, respectively.

A detailed investigation has been projected for the All Optical Wavelength Converters (AOWC), which are likely to be key devices in future networks, in which they will perform operations of routing and restoration. The typical configuration is a generic point-to-point link with one AOWC inserted along the path. Some of the Wavelength Division Multiplexing (WDM) channels entering the AOWC will be converted to different channels, while the others will continue to the final destination.

Four different types of AOWCs were studied: three of them are based on nonlinear wave interactions in a Semiconductor Optical Amplifier (SOA), a Periodically Poled Lithium Niobate (PPLN) waveguide, and DS fiber (DSF), respectively, while the fourth has a novel design based on nonlinear effects, such as Nonlinear Polarization Rotation (NPR) in quantum well semiconductors.

In this article we report the main results from laboratory experiments performed in the framework of this project, in particular we present the results obtained in single-channel transmission at 40 Gb/s in links up to 500 km long and in the presence of a wavelength conversion of the signal.

Design of the Line to Achieve the Longest Distance at 40 Gb/s

In the literature there are several articles dealing with 40 Gb/s transmission on single-channel or on WDM systems [1–2]. These articles focus generally on Dispersion Managed (DM) links with different kinds of maps on nonzero dispersion (ITU G.655) fibers.

However, the great part of fibers already installed are conventional single-mode fibers, (ITU G.652) that have a high value of chromatic dispersion, and it would be very important to be able to improve the capacity of systems with such fibers.

A preliminary analysis should deal with the choice of the signal format. However, it is recognized [3] that for terrestrial 40 Gb/s systems on G.652 and long amplifier spacing (>80 km), the return to zero (RZ) format guarantees the best performances. As a consequence, we have limited our analysis to RZ systems and, among the compensation methods presented in literature, we focus our analysis on two of them: periodic compensation and all-at-the-end compensation. Periodic compensation has been already investigated [1–3], coming to the conclusion that the system's best performances can be achieved introducing a small prechirp at the beginning of the link. On the other hand, the all-at-the-end compensation scheme has been introduced quite recently [3] and is based on the transmission of very short RZ pulses that are rapidly dispersed and permit reduction of the effects of self-phase modulation (SPM). From theoretical studies, it has been observed that the best DM configurations to achieve the highest capacity are the ones reported in Figure 1.

Figure 1(a) refers to periodic post dispersion compensation, which can be modified adding an initial prechirp and a final postchirp, shown in Figure 1(b). Figure 1(c) corresponds to the all-at-the-end dispersion compensation scheme.

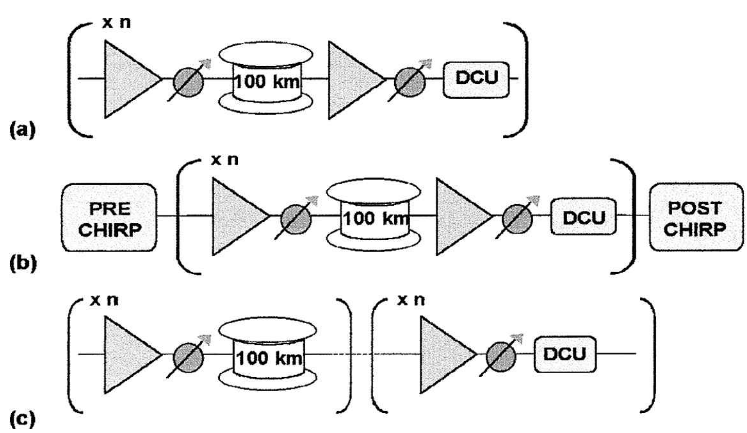

Figure 1. Schematic of the link. DCU stands for dispersion compensation unit. Variable optical attenuators are placed after the amplifiers to change input power. (a) Periodic post compensation scheme; (b) periodic post compensation with prechirp and postchirp; (c) all at the end compensation.

Numerical simulations have shown that scheme (b) is the one that produces the best performance. However very good results can be achieved by using scheme (c), which is much more easily reached in practice.

The amplifier spacing was chosen as 100 km since it is a standard requirement for high-capacity terrestrial systems.

Experiments on Single-Channel OTDM Transmission at 40 Gb/s

Laboratory experiments have been performed in Pirelli Labs, and so far the investigation has involved the transmission with Optical Time Division Multiplexing (OTDM) technique, in which an optical signal at 10 Gb/s is optically multiplexed at 40 Gb/s using a bit interleaver device as shown in Figure 2. In the last year of the project (2002), a 4×10 Gbit/s to 1×40 Gbit/s Electrical Multiplexer (EMUX) will be used; this device has been fabricated, packaged, tested, and is ready to be inserted in the transmission experiment as described in Section 5.

The OTDM receiver, shown in Figure 2, consists of three main parts: an electro-adsorption modulator, a 10 Gb/s receiver, and a 40 Gb/s clock recovery. The clock recovery consists of a photodiode and electronics circuits that are able to produce a signal clock at 40 Gb/s that drives the electro-absorbtion modulator, permitting it to extract, at optical level, a signal at 10 Gb/s from a 40 Gb/s one. The resulting 10 Gb/s signal is detected by a conventional 10 Gb/s receiver. Also this OTDM receiver will be replaced by one based on the Electrical Time Division Multiplexity (ETDM) when the Electrical Demultiplexing (EDEMUX) will be packaged and tested.

We have considered the transmission over two kinds of fibers: G.652 step-index fibers ($\beta_2 = -20$ ps^2/km, $\gamma = 1.3$ W^{-1}km^{-1}, $\alpha = 0.25$ dB/km), and G.655 nonzero dispersion ones ($\beta_2 = -5$ ps^2/km, $\gamma = 1.5$ W^{-1}km^{-1}, $\alpha = 0.25$ dB/km).

We mounted Sumitomo N-DCFM and Lucent HSDK as compensating fibers in G.652 and G.655 links, respectively. The mean characteristics of each nominal 100-km span composing the laboratory link are reported in Table 1. In both the G.652 and G.655 links, -23 ps/nm is the minimum available compensating step, thus we compensated for chromatic dispersion within 0.3% and 1% accuracy for G.652 and G.655, respectively.

In the case of periodic postcompensation, the optimum prechirp values turned out to be -78 and -47 ps/nm for G.652 and G.655, respectively; in terms of β_2, they correspond to 60 and 100 ps^2/km, which are in good accordance with the numerical results reported

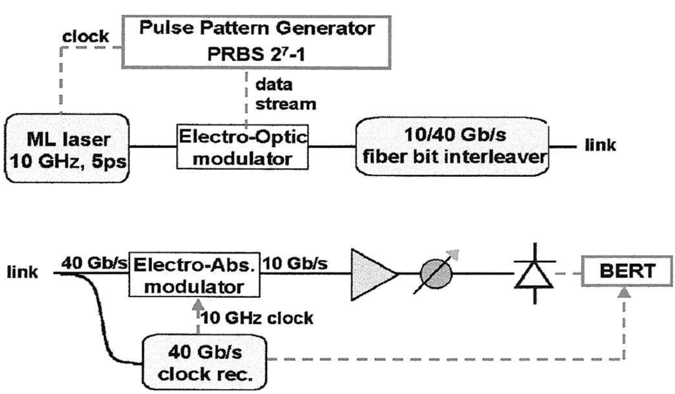

Figure 2. Schematic of the OTDM transmitter (upper part) and of the receiver (lower part).

Table 1
Mean characteristic values of each span with the respective compensating section (the reference wavelength is 1552.52 nm)

		G.652	G.655
Line span	Loss (dB)	22	22
	Dispersion (ps/nm)	1675	434
	Dispersion slope (ps/nm^2)	6.7	8.5
Compensating section	Loss (dB)	14	5
	Dispersion (ps/nm)	−1677	−439
	Dispersion slope (ps/nm^2)	−3.8	−2.4

in Zitelli et al. [2]. The experiment was performed with a Pritel source having 10 Gb/s pulse train with a T_{FWHM} pulse duration equal to 5 ps.

The signal average power at 40 Gbit/s along the line was optimized to achieve the best performance. In particular, the EDFA at the input of each fiber span (see Figure 1) were set to give an average power of 8 dBm, the optimum value found by numerical simulation results reported in Zitelli et al. [2]. The input power at each of the DCF fibers in case (a) and (b) was set to 2 dBm. Higher input power cannot be used due to the manifestation of Kerr impairment in DCF fibers.

In Figure 3 we report the Bit Error Rate (BER) versus the received power for different link distances of the G.652 link by using scheme (b). For (a) and (c) results are not shown since the performance was in worse agreement with the theoretical results of Zitelli et al.

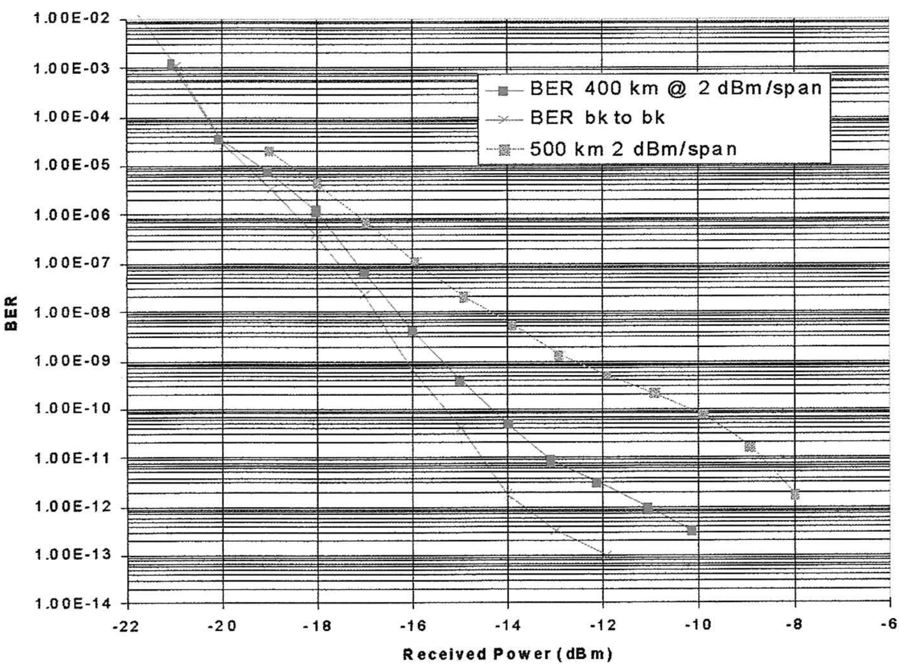

Figure 3. BER versus received power for different lengths of G.652 link.

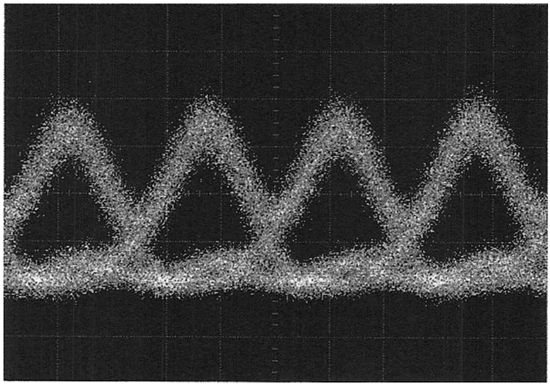

Figure 4. Eye diagram at the 500 km output of the link with G.652 fibers.

[2]. We can see that at 400 km only a small penalty is present with respect to the back-to-back case, while at 500 km the penalty is larger (about 2 dB), even if no error floor behavior is observed. In Figure 4, the eye diagram is reported for the 500 km distance.

Experiments were performed also on the G.655 High End Fibers (HEF), and the results are reported in Figure 5. Due to the lower chromatic dispersion value of the G.655 fibers and to the shortest distance of the Dispersion Compensating Fibers (DCF) the performance was much better and at 500 km only a weak penalty was present as shown in Figure 5. In Figure 6 the eye diagram after 500 km is reported.

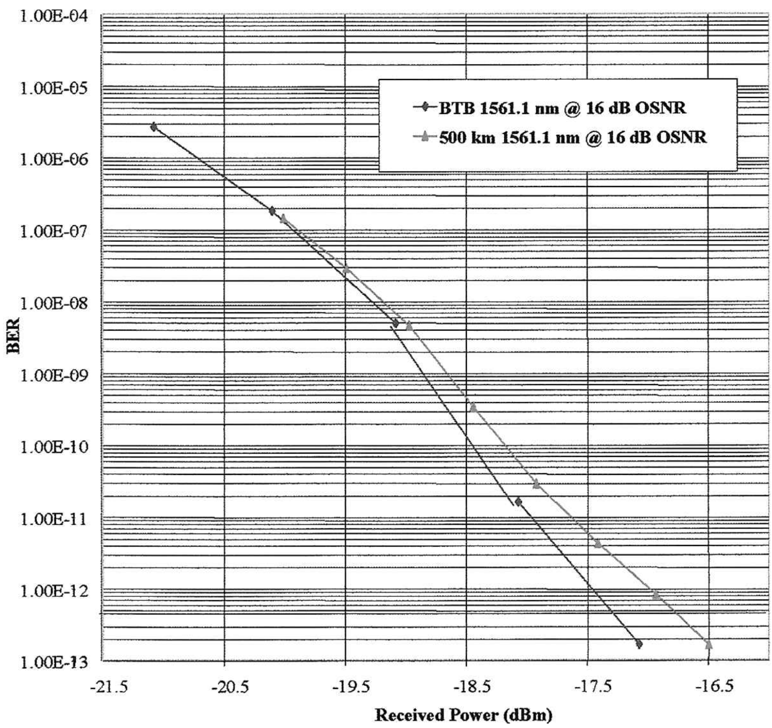

Figure 5. BER versus received power for a link encompassing G.655 fibers.

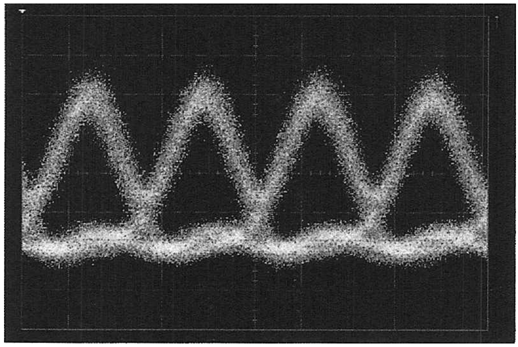

Figure 6. Eye diagram at the output of a G.655 link 500 km long.

It has to be pointed out that we did not use any kind of forward error correction and, as a consequence, we expect that an improvement in the transmission performance could be obtained by using such a technique.

40 Gb/s Transmission with Wavelength Conversion

It is well known that wavelength conversion will be one of the fundamental techniques for the implementation of future networks. As reported in the introductory section, in this project four different AOWCs are investigated. While the NPR and DSF devices are still in too preliminary a state for the test at 40 Gb/s, devices based on SOA and on PPLN have already shown fantastic results in the transmission tests. In the following discussion, we report results on the transmission of a signal after its wavelength conversion.

Wavelength Conversion Based on PPLN

Figure 7 is the photograph of the PPLN AOWC and Figure 8 presents its efficiency. In Figure 9, we report the BER versus received power at different distances for a signal that is wavelength converted by a PPLN at the link input. The link consists of G.655 fiber compensated by means of DCF fibers and optical amplifiers located every 100 km. As shown in Figure 9, after 500 km the performance is very good and no floor behavior is observed.

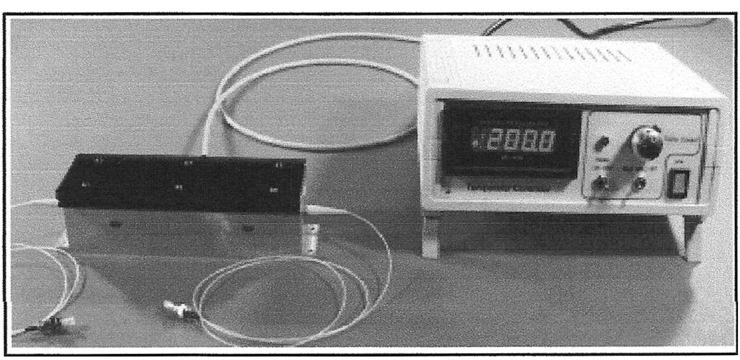

Figure 7. PPLN wavelength converter.

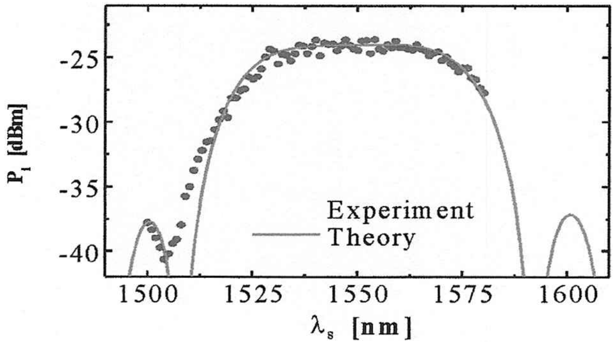

Figure 8. Efficiency of a PPLN wavelength converter.

Wavelength Conversion Based on SOA

A simple scheme of the wavelength converter is depicted in Figure 10. The modulated signal is coupled with a cw pump source and injected into the SOA. A band pass filter selects the converted field prior to injecting it into the transmission line. The mean intensities used for the experiment have been $P_s = 2$ dBm at 1557 nm and $P_p = 12$ dBm at 1555.1 nm. The pulse Full Width Half Maximum (FWHM) is 5 ps. The output spectrum of the SOA is shown in Figure 11. The three marked peaks are the signal (right), the pump (center), and the converted signal (left). It is worth noting that the signal is broadened by self-phase modulation experienced as the signal passes through the SOA, and the

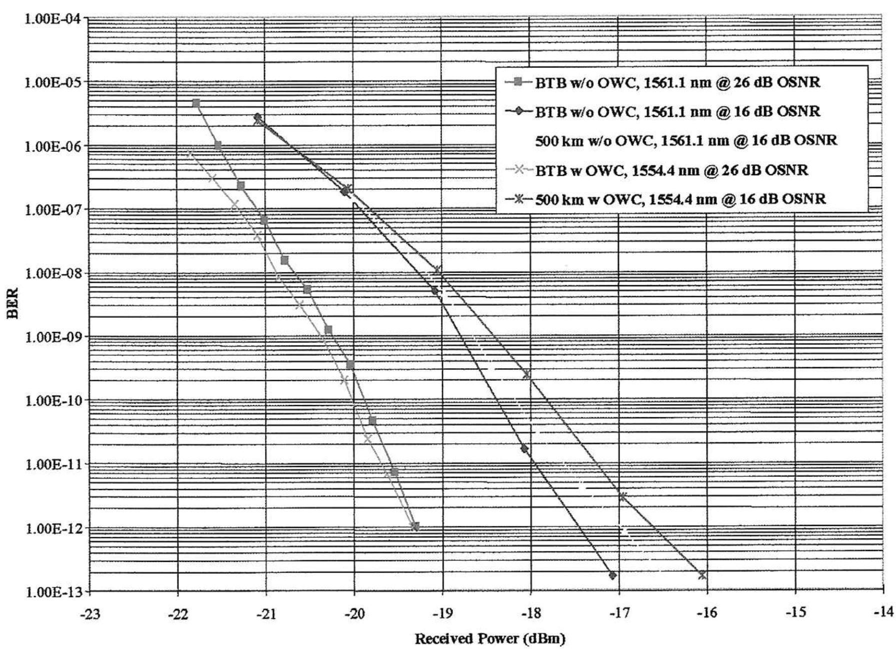

Figure 9. BER versus received power at different distances for a signal that is wavelength converted by a PPLN at the link input.

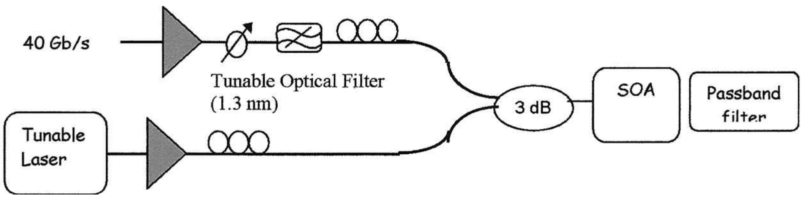

Figure 10. Scheme of the wavelength conversion configuration used for the transmission measure.

pump shows over-imposed peaks spaced by 40 GHz, probably originated by cross-phase modulation induced by the strong modulated signal. Measured over a band of 2 nm, the converted signal has an intensity of $P_c = -12.8$ dBm at 1553.4 nm.

Once filtered, the converted signal injected into the transmission line is as in the righthand part of Figure 12. The lefthand side of Figure 12 is the eye diagram of the incoming signal at 40 Gb/s. In the righthand part of the same figure, the eye diagram of the converted signal at 40 Gb/s is shown together with one of its 10 Gb/s demultiplexed tributaries.

In Figure 13, we report the eye diagrams of the converted signal at 40 Gb/s after 100 km (left) and 3×100 km (right) transmission over the HEF (G.655) fiber link. The launch mean power was about 8 dBm of optical input in each span and the chromatic compensation ratio, obtained by means of dispersion compensating fiber (DCF), was set to 100%. The signal-to-noise ratio at the receiver was in the two cases 21 dB and 18 dB over 2 nm optical bandwidth, respectively.

In Figure 14, we finally show the measured bit-error-rate after the propagation over 1×100 km, 2×100 km, and 3×100 km of HEF fiber. The two BTB Pritel curves are two baselines taken for two different signal-to-noise ratios of the original signal at the receiver input. The penalty introduced by the conversion method (BTB 23.5 dB) is 1.5 dB with respect to the baseline; a 2 dB penalty is introduced by the transmission of the converted signal up to 300 km.

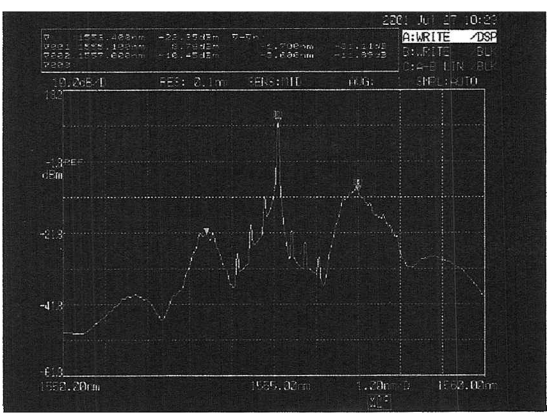

Figure 11. Optical spectrum analyzer trace of the SOA output, the total output recorded with an optical bandwidth of 0.1 nm.

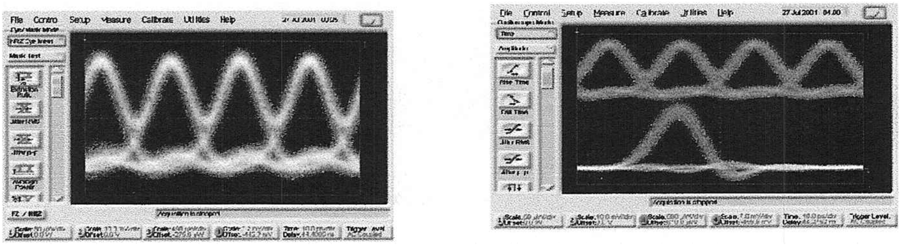

Figure 12. Optical eye diagrams. The 40 Gb/s input signal (left); the converted signal with one of the demultiplexed 10 Gb/s component (right).

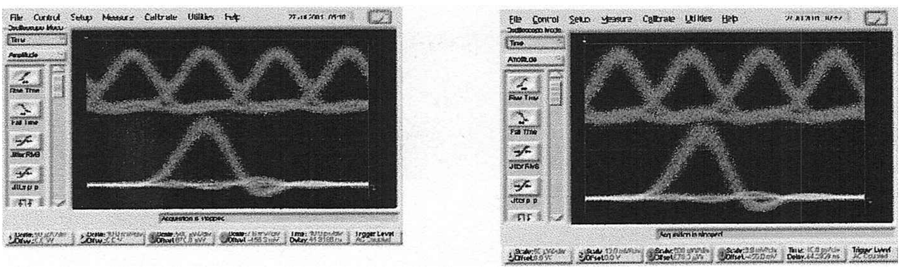

Figure 13. Optical eye diagrams at 40 and 10 Gb/s for the converted signal after 100 km (left) and 300 km (right) transmission.

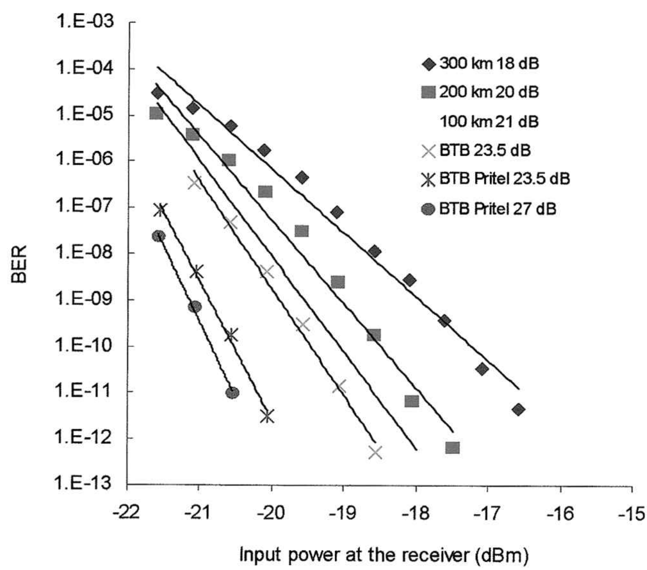

Figure 14. BER curves. In the legend, BTB indicates the back-to-back curves taken at different signal-to-noise ratios. The signal-to-noise ratio after each transmission distance is also indicated.

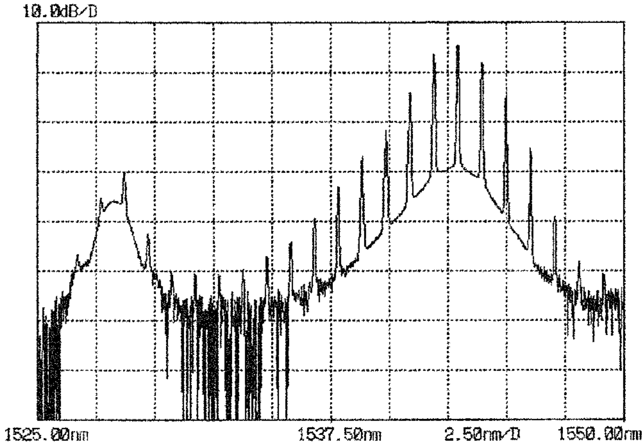

Figure 15. Wavelength conversion based on the Kerr effect in DS fiber at 2.5 Gb/s.

Preliminary Results of the Wavelength Conversion Based on DSF

Wavelength conversion of a signal can be achieved by exploiting the nonlinear Kerr effect in DS fibers. The most interesting result, which has been experimentally demonstrated in this investigation, is that, by propagating the signal at zero chromatic dispersion, it is possible to have simultaneously several replicas of the signal that can cover practically the whole ITU grid as shown in Figure 15, in which a 2.5 Gb/s signal was converted after 10 km of DS fiber. Another important result shown by the experiments is that the signal after the conversion presents a reshaping behavior, indicating that such a device can be also used as a 2R device.

Preliminary Results on the Wavelength Conversion Based on Quantum Well Nonlinearities

Three all-optical switching mechanisms for wavelength conversion in multiple quantum well (MQW) devices have been considered [4–6]:

- field screening in reverse biased p-$i(MQW)$-n devices,
- excitonic absorption bleaching in ion-implanted MQWs, and
- nonlinear polarization rotation (NPR).

The transmission (or reflection) of an all-optical switch transiently increases on the application of an optical control pulse. For the purpose of wavelength conversion the control pulses are the data stream at the input wavelength, and the transmission change is used to modulate a CW signal at the output wavelength, which is incident on the same device. The switching mechanisms used are noninstantaneous, resulting in varying degrees of pulse reshaping.

Field screening wavelength conversion in a resonant p-$i(MQW)$-n device with a 200 μm diameter optical window fabricated from a wafer incorporating a 50-period Q1.6/Q1.1 InGaAsP MQW and a 16-period distributed Bragg reflector (DBR) has been demonstrated at the University College of London (UCL). A sample result, with the output wavelength at the cavity antiresonance, is illustrated in Figure 16(a). The device was excited with 2 ps control pulses. CW light was simultaneously reflected from the same

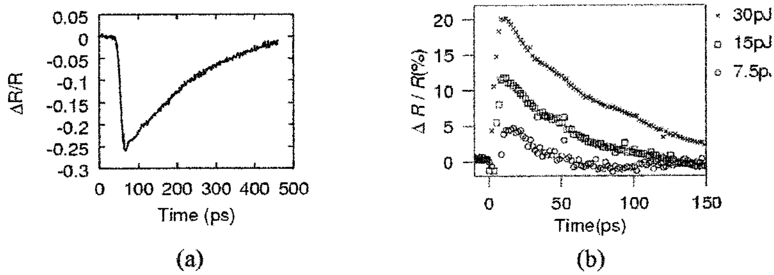

Figure 16. Measurements of field screening devices. (a) Wavelength conversion in a 200 μm diameter optical window device with 16 V reverse bias and 3.4 pJ control pulses at 1542 nm. The output wavelength was 1542 nm; (b) time resolved recovery of a 20 μm diameter optical window device measured at 1539.2 m with 20 V reverse bias.

point on the device. The reflected CW light was observed with a fast photodetector and a 20 GHz bandwidth sampling oscilloscope. At output wavelengths away from the cavity antiresonance wavelength the magnitude of the transmission change decreased, and magnitudes 18% and 10% were measured at 1538 nm and 1544 nm, respectively. Figure 16(b) shows dynamic transmission change measurements of a resonant p-$i(MQW)$-n device with a 200 μm diameter optical window. A standard pump-probe configuration was used. The device was fabricated from the same wafer as that used for the wavelength conversion experiment described above. The 50% recovery time with 2.5 pJ pump pulses in 30 ps. This is comparable to the 28 ps time which we have previously reported in a nonresonant p-$i(MQW)$-n device [6], to our knowledge the fastest yet reported in this material system.

Faster recovery times can be obtained using excitonic bleaching in ion-implanted MQW material, and we have obtained recovery times of less that 3 ps in such devices, showing excellent potential for 80 Gb/s operation.

NPR-based optical switching relies on the circular birefringence which is induced in a MQW layer when it is excited by a circularly polarized control pulse. This birefringence is a consequence of the selective excitation of either spin-up or spin-down carriers by the control pulse. Following such an excitation, the carrier population relaxes to a spin balanced state. For wavelength conversion linearly polarized CW light at the required output wavelength is transmitted through the MQW layer and then, under small signal conditions, blocked by an appropriately aligned analyzer. Birefringence due to excitation of the MQW by a circularly polarized pulse at the input wavelength will rotate the CW signal such that some part of it is transmitted through the analyzer. Switching based on this technique has been demonstrated at UCL in a 60 period Q1.6/Q1.1 InGaAsP transmission structure. Results are shown in Figure 17.

Electronics Devices Operating at 40 Gb/s

In the ATLAS project several electronic devices have been foreseen to be fabricated for 40 Gb/s transmission. Since all test signals adopted in this project will be tributaries at 10 Gbit/s, several electronic components not yet available on the market have been developed, including single XOR gates and D FlipFlops, and complete 40 Gbit/s multiplex and demultiplex MMICs. All those parts made an InP HBT technology directly compatible with photodiodes working beyond 40 Gbit/s. In a first step, specific chips have been

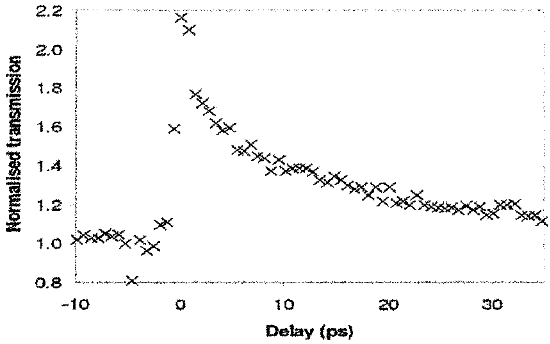

Figure 17. Time resolved measurements of NPR switching.

fabricated and then hybridized in a package. In a second step, the specific parts will be monolithically integrated in order to provide more complex functions on a single chip.

The complete experimental setup for 40 Gb/s ETDM transmission foresees the following electronics devices: 40 Gb/s EMUX, a 40 Gb/s PRBS generator (that drives the EMUX) for the transmitter, and 40 Gb/s receiver with 40 to 10 Gb/s electrical demultiplexer (EDEMUX).

Now we report the main results on some electronics key devices that have been already tested.

Packaged 4 × 10:1 × 40 Gbit/s Multiplexer with Clock Multiplier

A complete 4 × 10:1 × 40 Gbit/s multiplexer with clock multiplier has been fabricated and tested.

An SMB connector was chosen for the power supply connection instead of using soldering lids as usual. It allows the module to be a self-containing component and there is no need of soldering irons to make the power supply connection. All the other connectors are K type which provide a bandwidth larger than 40 GHz to all signal paths. The position of the pads on the chip was chosen in such a way that the connections in the final package can be more easily manipulated, i.e., inputs are in one side of the package, outputs in the other side, and clock signals in the middle. This arrangement helps in the reduction of cross talk between outputs and inputs.

In Figure 18, we report the 40 Gb/s eye obtained at the output of a 4-to-1 multiplexer chip when applying 4 noncorrelated 10 Gb/s PRBS patterns (32 bits) at the 4 inputs. Time scale: 10 ps/div; amplitude scale: 100 mV/div.

40 Gbit/s DEMUX

A chip performing the electronics demultiplexing of a 40 Gb/s signal in four 10 Gb/s has been fabricated and tested. The demultiplexer chip was developed to be fully compatible with the multiplexer chip described in the previous section.

A 40 Gb/s measurement setup was specially built for the characterization of the 1-to-4 demultiplexer. All four outputs could be monitored simultaneously. The generated 40 Gb/s pattern was greatly corrupted with noise due to limitations of the Fraunhofer 2-to-1 multiplexer specially used in this case. The demultiplexer was able to extract the four 10 Gb/s sequences having a very close 40 Gb/s input eye, $Q < 3$.

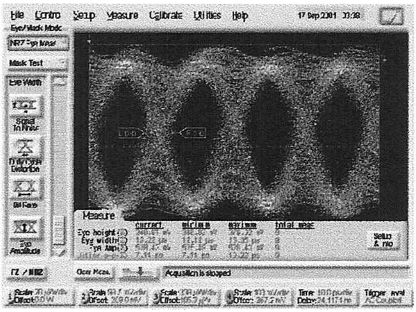

Figure 18. Eye diagram at the output of the multiplexer (40 Gb/s).

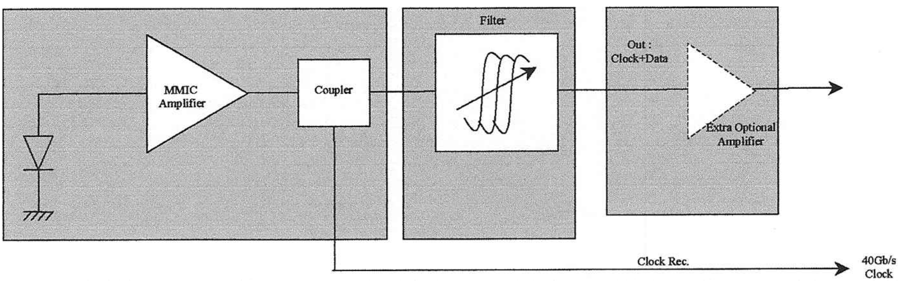

Figure 19. Scheme of the 40 Gb/s receiver.

40 Gb/s Receiver

The 40 Gb/s receiver consists of four main parts: photodiode, an amplifier with a clock output, an active filter [7], and a post amplifier. We have foreseen three different packages as reported in Figure 19.

Photographs of three fabricated packages of the receiver are reported in Figures 20 and 21. The complete receiver is now under test.

Other Activities in the Framework of the ATLAS Project

Other optoelectronics devices have been fabricated or are under study in this project with the main aim of improving transmission. Among these, we note the fabrication of a bit interleaver and a study for the fabrication of a polarization mode dispersion compensator (PMDC). Polarization mode dispersion (PMD) is one of the most critical impairments for 40 Gb/s transmission and, hence, an important investigation has been conducted on this topic and in particular on its measurement. A novel instrument to measure the PMD has been fabricated and is based on the reflectometric process. Such an instrument has the advantage of requiring only one end of the fiber link and, as a consequence, is particularly suitable for field measurements.

For 40 Gbit/s a differential group delay higher than 5 ps could be strongly degrading for our transmission. However, measurements made on our fibers showed values much lower than 5 ps.

Another activity in the framework of the ATLAS project is the preparation of novel normative for the ITU regarding system and networks operating at 40 Gb/s.

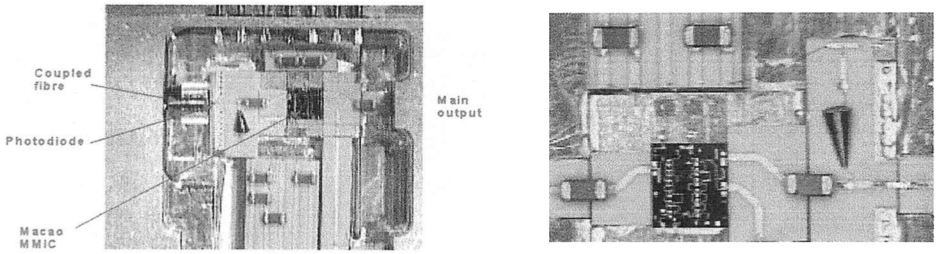

Figure 20. Photograph of the photodiode (left) and of the first amplifier (right).

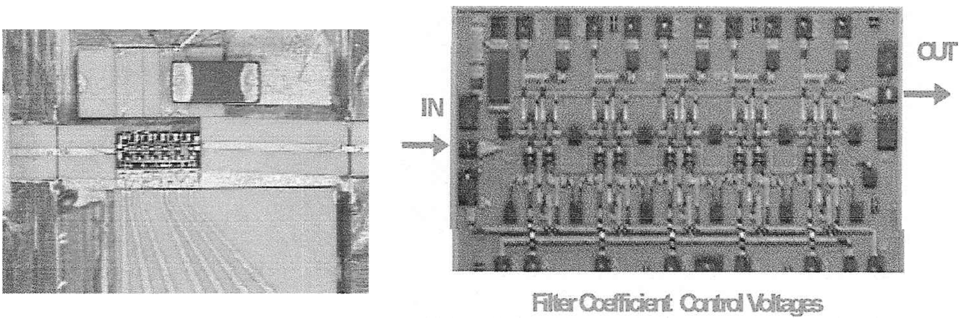

Figure 21. Photograph of the filter with detail of the GaAs MMIC filter on the right.

Conclusion

In this work we have shown the main experimental results on the transmission at 40 Gb/s including the wavelength conversion process. The results show that the transmission of 40 Gb/s signals, after their wavelength conversion, can be achieved up to 500 km in links with long amplifier spacing (100 km). Such preliminary results show the possibility of implementing wide transport networks based on the transmission at 40 Gb/s with wavelength conversion.

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Biographies

Francesco Matera was born in Rome, Italy, on May 1, 1961. He received the Laurea degree in Electronics Engineering from the University La Sapienza in Rome, Italy, in 1985. In 1986, he was granted a fellowship at Fondazione Ugo Bordoni, Rome, Italy on optical fibers. Since 1988, he has been a Researcher at Fondazione Ugo Bordoni where he works on nonlinear effects on optical fibres, optical systems, and optical networks. His main works are in the field of the polarization mode dispersion and in the numerical models to evaluate the performance of optical telecommunication systems.

Franco Curti received his Electronics Engineering degree (laurea cum laude) in 1975. From 1977–1985 he was a research engineer with ITT-FACE Standard R&D Lab. In 1985 he became a Research Scientist with Fondazione Ugo Bordoni in Rome and in 1990 he became a Senior Research Scientist. At present his research activity in FUB concerns the all-optical reshaping and conversion.

Alessandro Schiffini was born in Ivrea (TO), Italy, in 1970. He took his Physics degree from the University of Torino in 1995. From 1994 he attended the Cselt Laboratories studying Soliton Mode-Locked Fiber lasers and in 1997 he joined Pirelli Cavi e Sistemi, working in Pirelli advanced Photonics research group on high-speed transmission systems. In particular his main areas of activity involve theory, design, and experimental investigation on 40–80 Gb/s telecommunications systems. Dr. Schiffini has authored and co-authored more than 20 scientific papers in international journals and conferences. Since 2001, he has moved in the WDM System Technology Lab of Pirelli Labs—Optical Innovation.

Arianna Paoletti was born in Livorno, Italy, in 1971. She graduated in Telecommunications Engineering at the Politecnico of Milan in 1997. She spent her last university year in Pirelli Cavi e Sistemi, at the Research and Development Department, working on her degree thesis about ultra-short soliton pulses generation and propagation along fiber link. From 1998–2000 she joined Alcatel, at the Optics Lab unit of the R&D department in charge of the development of 10 Gb/s electro-optical interfaces. In 2000 she moved to Pirelli Advanced Photonics Research Group, dealing with the experimental investigations into high-speed (40–80 Gb/s) transmission systems. Since 2001 she has been working in the WDM System Technology Lab of Pirelli Labs Optical Innovation.

Francesco Alberti was born in Saronno (VA), Italy, in 1969. He took his degree in Electronic Engineering at Politecnico of Milan in 2000. From 1998–1999 he worked at Instrumentation Devices in the field of measurements for automotive and avionics applications. In 1999 he joined Pirelli Cavi e Sistemi for a stage at the Speciality Fibres Group, studying an all-optical switch based on resonant nonlinear effects in doped fibers. Since 2000 he has been working with the Pirelli Advanced Photonics Research on the theoretical and experimental investigations on high-speed (40–80 Gb/s) telecommunications systems.

Maurice Gloanec was born in Tremeven, France in January 1945. He received the Electrical Engineering Degree from the Conservatoire National des Arts et Métiers Paris in 1975. He joined the Thomson-CSF Central Research Laboratory in Orsay in 1969 and from 1974 to 1977; he investigated digital applications of GaAs Planar Transferred Electron Devices (TED). Since 1978, he has been involved in GaAs MESFET IC Design (frequency divider, D flipflop, etc.) and in 1984 became Manager of the Thomson GaAs Analog IC Group which developed a family of Gigabit Data Conversion Circuits, e.g., S/H, ADC, and DAC ICs. Since 1993, he has been the Head of the MMIC Engineering Group in Thomson GaAs Activity and Head in Product Lines since 1996, date of creation of United Monolithic Semiconductors (UMS), a joint venture of THALES and EADS companies. Since 1999 he has served as Business Development Manager in charge of Defense, Space, and Opticom activities in UMS.

He is coauthor of about thirty publications and holds more than 10 patents in the field of GaAs MMICs.

Raimond Bauknecht received his PhD on InP HBTs from the Swiss Federal Institue of Technology (ETH) in 1998. He joined Opto Speed in 1999, where he is leading the InP HBT group, focusing on the development of optical receivers for high bitrate applications.

Marcos Gaspar was born in Rio de Janeiro, Brazil in 1962. He has received his MSc and BS degrees in Electrical Engineering from the Federal University of Rio de Janeiro, Brazil, in 1995 and 1991, respectively. Since 2000 he is an Electronics Engineer at Opto Speed, Switzerland where he has been performing research and development of optoelectronic components for high-speed optical communications. He has also worked in various projects as a Research Associate from 1991 to 1999 at CERN (European Organization for Nuclear Research) and at CEA/Saclay (Commissariat a l'Energie Atomique) where he developed high-speed electronics for nuclear and particle physics detectors. His current interests are in the research and development of high-speed electronics for the new generation of optical communications systems.

Eric Leclerc was born in France in 1962. He received a research degree in Physics in 1984 and a Solid State Physics DEA in 1985 at Paris XI University. He worked on the GaAs Czochralski growing method in the Thomson DAG Group and studied the influence of defects on active devices performances. In 1992 he joined the Modeling Department of Thomson-TCS and was in charge of nonlinear modeling for high frequency GaAs processes. He joined UMS at its creation in 1996 to work on new devices development and characterization, and since 2001 he has been the UMS Foundry Manager.

Paulo P. Monteiro was born in Coimbra, Portugal in 1964. He received the diploma and doctoral degrees in Electronics and Telecommunications from the University of Aveiro and the MSc (Eng.) degree from the University of Wales, U.K. He is an Assistant Professor at the University of Aveiro where he has been teaching courses of telecommunications and computer science. He is also a Senior Research Scientist at the Instituto de Telecomunicações. His main research interests include high-speed synchronization and signal processing for gigabit-per-second optical communications systems. Participation in various projects included in the following European Union (EU) Telecommunications R&D programs: RACE (R1051), RACE II (R2011), ACTS (ESTHER, UPGRADE, SPEED), and IST (ATLAS). He is also the research coordinator of the FCT project TOBLU—Single Side Band Optical Transmission. He has published more than 30 research papers in journals and international conferences.

M. Violas received his degree in electronics and telecommunications engineering from the University of Aveiro, Portugal, in 1982, his MSc from University of Coimbra Portugal, in 1988, and his PhD degree in electrical engineering from University of Aveiro in 1999. Since 1982, he has been with the Department of Electronics and Telecommunications at the University of Aveiro, Portugal. His research interests are optical receivers for high speed lightwave applications and low noise microwave signal processing.

Armando Nolasco Pinto is an assistant professor in the Electronic and Telecommunications Department of Aveiro University. His main research interests focus on performance evaluation of optical communication systems, nonlinear transmission, multiwavelength optical communication systems, optical receivers, and components for optical networks.

Costantino de Angelis was born in Padova, Italy in 1964. He received his laurea degree (cum laude) in Electronic Engineering and his PhD degree in telecommunications from the University of Padova, Padova, Italy, in 1989 and 1992, respectively. Since 1998 he is Professor of Electromagnetic Fields at the University of Brescia, Brescia, Italy. His fields of technical interest are optical communications, soliton propagation, and photonics. He has authored or coauthored about 120 papers and conference contributions.

Alwyn Seeds received his PhD degree from the University of London in 1980. From 1980–1983 he was a staff member at Lincoln Laboratory, Massachusetts Institute of Technology, where he worked on GaAs monolithic millimeter-wave integrated circuits for use in phased-array radar. He returned to England in 1983 to take up a lectureship in telecommunications at Queen Mary College, University of London, moving to University College London in 1986, where he is now Professor of Opto-Electronics and Head of the Opto-Electronics and Optical Networks Group. He has published over 200 papers on microwave and opto-electronic devices and their systems applications.