



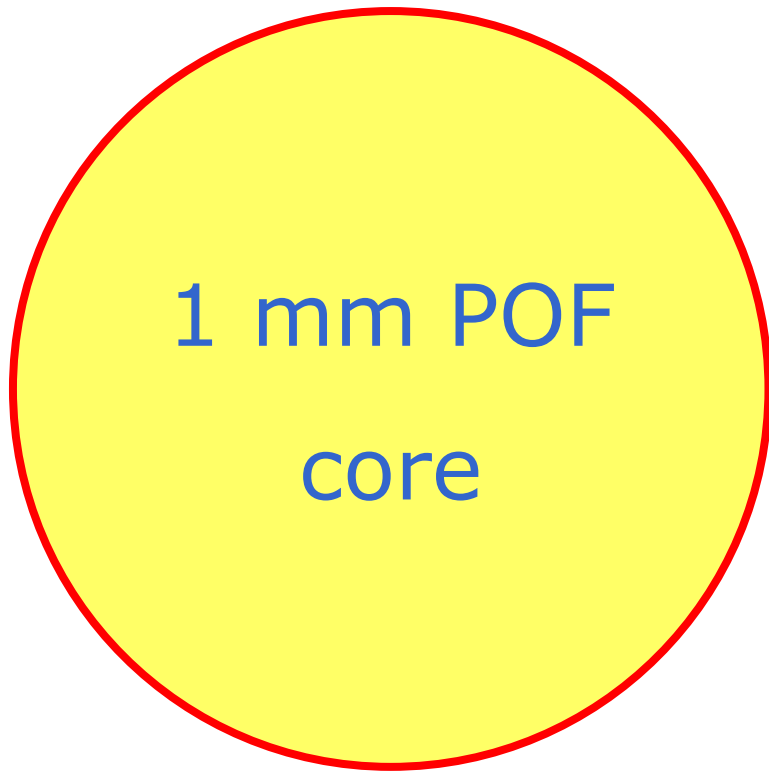
Latest results from the POF-ALL EU Project: Toward Improved Capacity over Large-Core Plastic Optical Fibers

Authors: Roberto Gaudino, A. Nocivelli, H. Kragl, O. Ziemann, N. Weber, D. Jaeger, T. Koonen, C. Lezzi, A. Bluschke, S. Randel

- The POF-ALL project: framework and goals
- The POF-ALL consortium
- Update on the latest technical achievements
- Expected impact

The POF-ALL project: framework and goals

- It's a STREP project financed by the European Community within the Sixth Framework Program (FP6)
 - POF-ALL means "Paving the Optical Future with Affordable Lightning-fast Links"
 - IST-FP6 STREP project n. 027549
 - Duration: 01/2006 – 06/2008 (30 months)
 - Total Cost: €2.6 m
 - EC Contribution: €1.6 m



- The POF-ALL project focuses on:
 - large-area POF (\emptyset 1mm)
 - PMMA-based
 - Step-Index or Graded-Index

10 μm singlemode
glass fiber



62.5 μm multimode
glass fiber

*(the three pictures show
the actual proportions)*

- The technical goal is to design and build low-cost “optical modems” based on large-core POF, operating:
 - symmetrically (upload speed = download speed)
 - at 100 Mbit/s or more
 - over distances ranging from 100 to 200 meters
 - and being simple enough to be installed by anyone with no special tools

- The potential applications are:
 - last part of telcos’ access networks (edge networks);
 - in-building networks of multi-dwelling units, condominiums and high rise buildings
 - in-apartment networks

- The use of large core POF (1mm diameter) greatly eases installation with respect to standard glass optical fiber (GOF)
 - Large core POF is mechanically resilient, easy to connectorise and tolerant to dusty environment
 - Installation can be done by unskilled personnel
 - Even “Do-it-yourself” installation is possible

BUT

- The use of POF introduces significant challenges, due to physical transmission impairments
 - POF has much higher attenuation and dispersion than GOF

- The project is organized in seven work-packages:
 - WP1 – Advanced transmission techniques for 100 Mbit/s over long distances (300+ m)
 - WP2 – Module conception and transmission experiments of high speed data (1 Gbit/s and more) over intermediate distances (100+ m)
 - WP3 – Component support
 - WP4 – Fiber support
 - WP5 – Demonstration and Test-beds
 - WP6 – Economic impact, Dissemination
 - WP7 – Management

The POF-ALL Consortium



IST-FP6 – STREP project n. 027549 – POF-ALL
Paving the Optical Future with Affordable Lightning-fast Links





1. *Istituto Superiore "Mario Boella" (Italy)*
2. *Luceat SpA (Italy)*
3. *DieMount GmbH (Germany)*
4. *Plastic Optical Fiber Application Center (Germany)*
5. *Fraunhofer Institute (Germany)*
6. *Universität Duisburg-Essen (Germany)*
7. *Technische Universiteit Eindhoven (The Netherlands)*
8. *Fastweb SpA (Italy)*
9. *STMicroelectronics (Italy) (withdrawn in 2006)*
10. *Siemens (Germany)*
11. *Teleconnect (Germany)*



Fraunhofer
Institut
Integrierte Schaltungen



- The consortium includes:
 - two ICT research institutes (ISMB and Fraunhofer)
 - two SMEs specifically devoted to POF (Luceat and Diemount)
 - One SME specialized in xDSL (Teleconnect)
 - A large optoelectronic company (Siemens)
 - one FTTH national telecom operator (Fastweb)
 - three universities (POFAC, UDE and TUE)

- The consortium was created in order to put together:
 - Basic research capabilities (through research centers and universities)
 - Small companies working in the POF market
 - Two big optoelectronic vendors (Siemens and STMicroelectronics)
 - A perspective final user (Fastweb)

Update on the latest technical achievements

- The “perceived” performance for Step-Index, PMMA, 1mm POF, is usually very low
 - Typically, most people think this medium works only over small distances (50-60 meters) at low bit-rate (100 Mbit/s max)
 - Actually, most commercial transceivers hardly perform better than this, and are today used in:
 - Industrial automation
 - Automotive (i.e., inside 6-7 million cars, as of today)

- In January 2006, the POF-ALL consortium started its work to demonstrate that large-core POF can actually provide much higher performances than what was usually perceived.

- Large area, 1mm photodiodes don't have sufficient bandwidth:
 - FALSE: we demonstrated large-area photodiode setups that are suitable for Gigabit/s transmission

- Optical transmitters are too expensive for home networking applications
 - FALSE: we demonstrated that LEDs can be easily used up to 100 Mbit/s
 - For Gigabit/s transmission, we showed that red laser dies used in commercial DVDs can be efficiently used

- Most typical: 1mm POF don't have enough bandwidth
 - FALSE: using digital signal processing (DSP), we demonstrated very high bit rates on 1mm Step-Index POF
 - We also obtained excellent performance on 1mm Graded-Index POF without DSP.

- POF-ALL developed several technical solutions in parallel
 - At the end of the project, we will compare the results and determine the most commercially viable

- 100 Mbit/s over 200+ meters on SI-POF
 - 8-PAM and adaptive equalization
 - OFDM and VDLS2 chipset
 - Alternative optical QAM schemes

- 1 Gbit/s over up to 100 meters
 - Standard modulation with GI-POF, optimizing large area components
 - OFDM with SI-POF

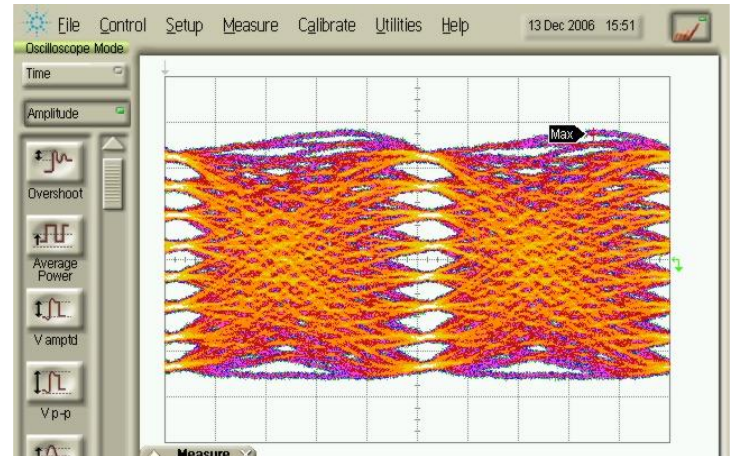
Approach #1 (ISMB group)



- Multi-level 8-PAM transmission
- Pre- and post- equalization
- Forward error correction (FEC)

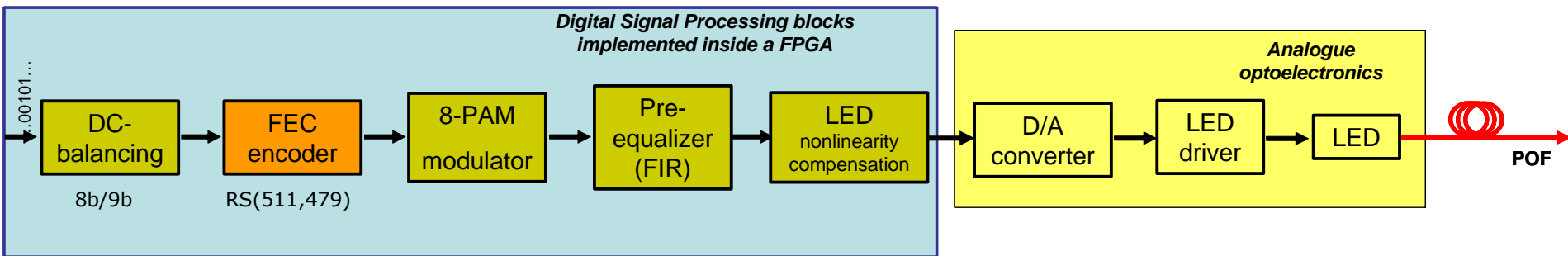
Current status:

- FPGA demonstrator available
- 200 meters error-free before FEC
- 275 meters error-free after FEC



8-PAM eye-diagram after 200 meter, 120 Mbit/s line rate

POF Link (m)	Post-Equalization alone	Pre- and Post-Equalization
200	Error free	Error free
225	$\ll 10^{-8}$	$< 10^{-8}$
250	$\sim 10^{-6}$	$\sim 10^{-5}$
275	$\sim 10^{-3}$	$\sim 10^{-2}$

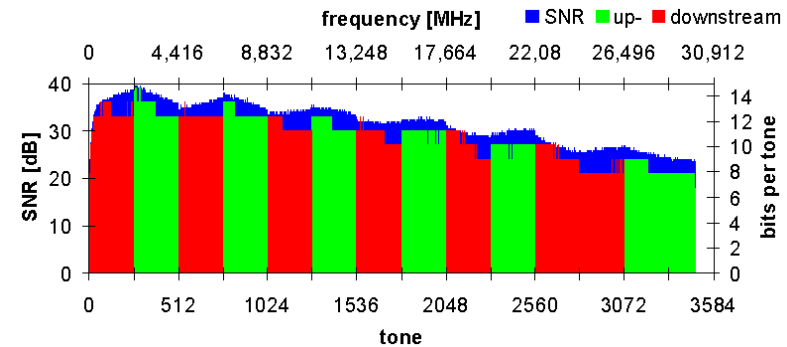


Approach #2 (Teleconnect group)

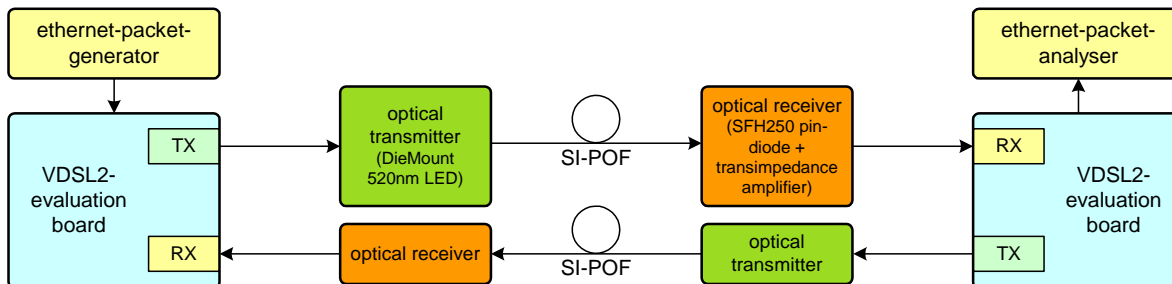
- Orthogonal Frequency Division Multiplexing (OFDM)
 - This is a modulation technique that is having huge success in other fields, such as xDSL

Current status:

- fully engineered prototype using standard VDSL2 chips
- symmetrical data rate of more then 100 Mbps over 200 meters
- excellent noise margin for shorter distances or lower data rates



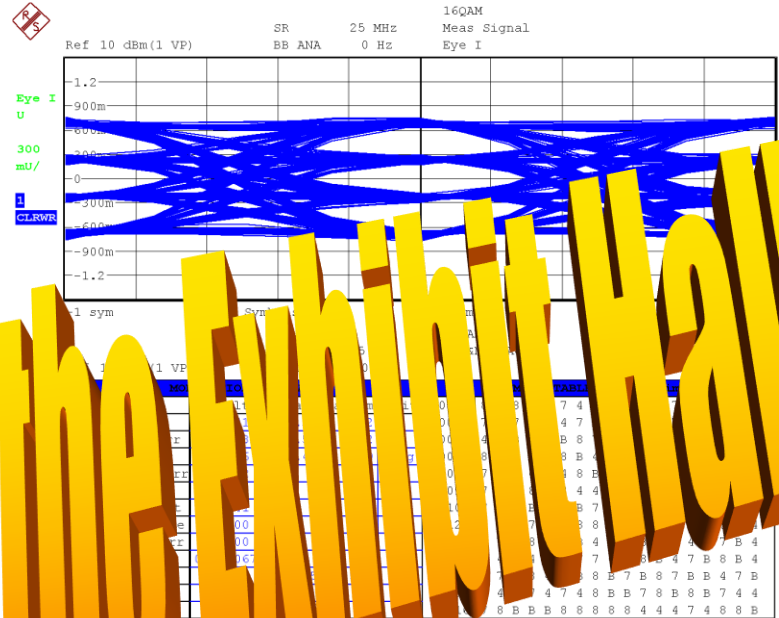
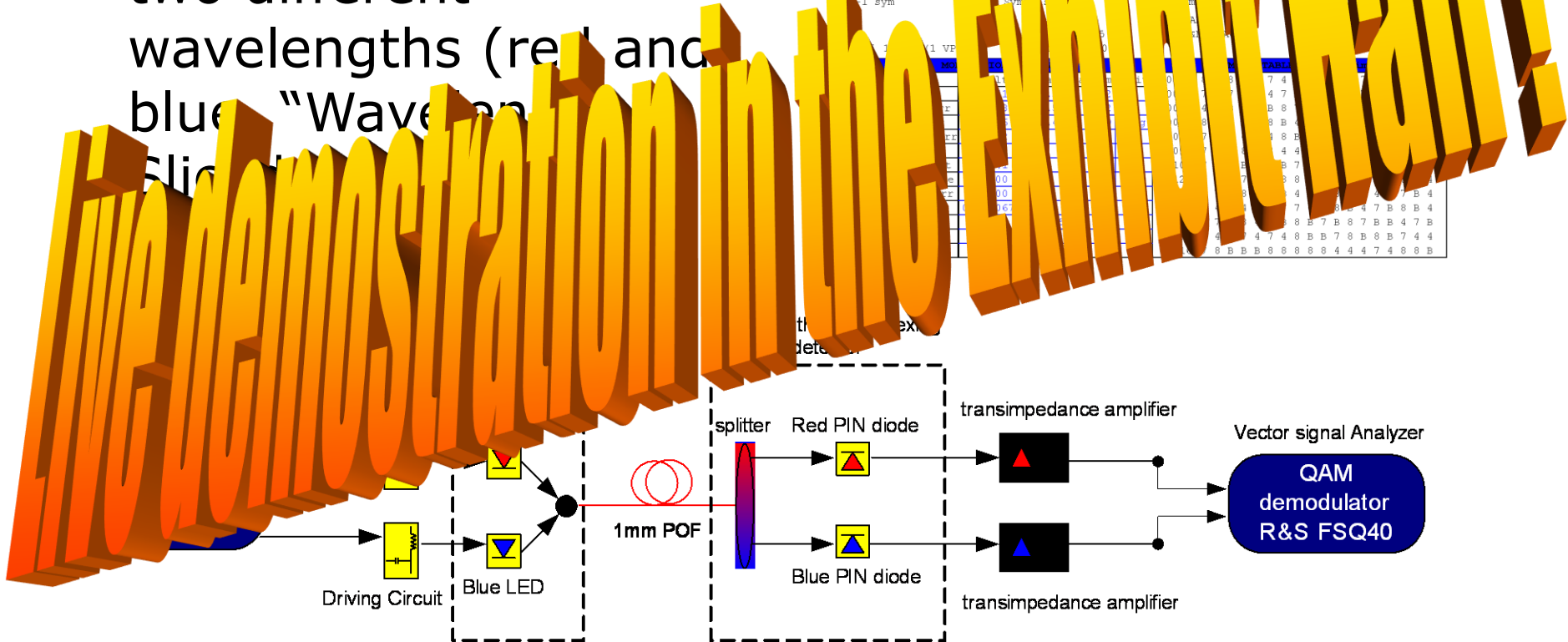
Bit-per-tone allocation in the 200 meter demonstrator using VDSL chips



TU/e technische universiteit eindhoven

Approach #3 (TUE group)

- QAM modulation over two different wavelengths (red and blue)

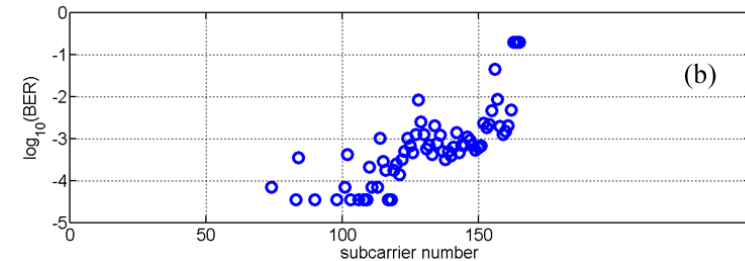
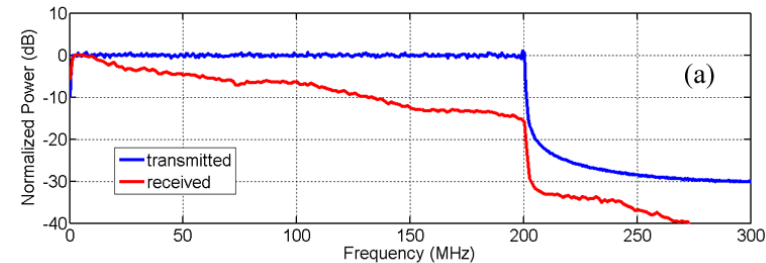


Approach #4 (Siemens/TUE group)

- Orthogonal Frequency Division Multiplexing (OFDM) up to 1 Gbit/s

Current status:

- Proof-of-concept experiments
- 1 Gbit/s over 100 meters using red DVD laser
- 1 Gbit/s over 25 meters using red LED



(a) Transmitted and received OFDM spectrum over 25 m of SI-POF. (b) Bit-error ratio per subcarrier, of 165 sub-carriers in total. No errors detected for subcarriers w/o marker.

- Preliminary results up to 10 Gbit/s (under development)

Siemens AG - Plastic cable with gigabit data rates - Microsoft Internet Explorer provided by CIO - V 3.158

Adresse http://www.siemens.com/index.jsp?sd_c_p=cfi1034571lmo1450080ps5uz38&sd_c_bcpaht=1327899.s_4%2C1034230.s_4%2C

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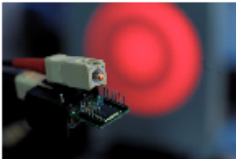
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Plastic cable with gigabit data rates

Munich, Jun 4, 2007



→ Press picture

Researchers at Siemens Corporate Technology have set a new record for data transmission in optical polymer fiber cables. Thanks to a new data transmission technique, they have succeeded in sending one gigabit per second down the plastic fibers – ten times more than with products currently on the market. This should finally enable polymer fibers to become established in the home entertainment sector and in factory automation.

Polymer fiber cables enable every layman to set up high-speed data links in their home network. Small converter boxes convert the electrical signal from the copper cable into an

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Siemens testa fibra ótica de polímero com velocidade de 1Gbps

Por John Blau, para o IDG Now!*

Publicada em 05 de junho de 2007 às 15h53
Atualizada em 05 de junho de 2007 às 16h06

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TIN TỨC Thứ Hai ngày 25/06/2007

Siemens thử nghiệm sợi quang polymer 1Gbps

Ngày đăng: 11/6/2007 10h9

Công nghệ mới mở ra khả năng dễ dàng xây dựng các mạng gia đình liên kết nhiều PC và TV độ nét cao.

Các nhà nghiên cứu tại Siemens đã truyền dữ liệu qua cáp sợi quang polymer đạt tốc độ khoảng 1Gbps, mở ra những khả năng mới cho công nghệ như dễ dàng xây dựng các mạng gia đình liên kết nhiều PC và TV độ nét cao.



Ngày 5/6/2007, giám đốc dự án Sebastian Randel cho biết, cáp polymer cho phép người dùng tự mình cài đặt. Không giống cáp sợi quang làm bằng thủy tinh, cáp sợi quang polymer chỉ dày độ 1mm, rất mềm dẻo, dễ cắt (chỉ cần một chiếc dao lam), dễ lắp vào bộ nối.

Dù cáp sợi quang làm bằng thủy tinh (hiện đang được sử dụng rất rộng rãi) có thể truyền dữ liệu với tốc độ cao hơn cáp sợi quang làm bằng polymer rất nhiều, nhưng nó dày hơn khá nhiều trong lớp vỏ bảo vệ, bị gãy nếu bị cuộn chặt, ông Randel cho biết. Muốn cắt gọn ghẽ loại cáp này để lắp vào bộ nối cần dao cắt bằng kim cương.

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西门子的项目经理塞巴斯蒂安·兰德尔 (Sebastian Randel) 称, 聚合光纤可自己安装 (DIY), 与玻璃光纤不同的是, 这种网线更为灵活

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西门子的项目经理塞巴斯蒂安·兰德尔 (Sebastian Randel) 称, 聚合光纤可以自己安装 (DIY), 与玻璃光纤不同的是, 这种网线更为灵活也更易裁减和插接。他表示, 聚合光纤直径约1毫米, 不容易折断但可用剃须刀割断。

虽然应用广泛的玻璃光纤比聚合光纤速度更快, 但保护层使其显得厚很多, 而且用力弯曲也会折断。同时要切割或连接时需要钻石刀片。当新的高速服务如IPTV出现后, 对易安装和低成本的家庭网络系统的需求日益增长。

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Geschwindigkeits- und Reichweitensprung bei Plastiklichtleitern

Lichtleiter aus preisgünstigem Kunststoff (Polymer Optical Fiber, POF) sind mittlerweile robust genug und auch simpel verlegbar, sodass sie den sperrigen Twisted-Pair-Kabeln im [Heim-LAN](#) ebenso wie in industriellen Netzwerken [Konkurrenz machen](#). Bislang ist die Fast-Ethernet-Geschwindigkeit von 100 MBit/s auch bei POF der Standard. Ein Satz aus zwei Twisted-Pair-zu-Licht-Adaptern und 30 Metern Kabel für eine Punkt-zu-Punkt-Verbindung ist mit rund 140 Euro halbwegs erschwinglich.

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1Gbit/s transmitted on plastic fiber

11 June 2007

Siemens Corporate Technology has achieved gigabit data rates on "plastic" cable.

Researchers at Siemens Corporate Technology say they have set a new record for data transmission in optical polymer fiber cables. A new data transmission technique allows the transmission of 1 Gbit/s down a plastic fiber - 10 times more than with other such products, currently available. "This achievement should finally enable polymer fibers to become established in the home entertainment sector and in factory automation," said Sebastian Randel, project manager at Siemens Corporate Technology.

Polymer fiber cables enable the establishment of high-speed data links even on a home network. Small converter boxes

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Siemens touts 1-Gbit transmission over polymer fiber cables

JUNE 6, 2007 -- Researchers at Siemens Corporate Technology (search for [Siemens](#)) say they have set a new record for data transmission in optical polymer fiber cables. Thanks to a new data transmission technique, they have succeeded in sending 1 Gbit/sec down the plastic fibers--ten times more than with products currently on the market, say Siemens representatives, who hope this milestone finally enables polymer fibers to become established in the home entertainment sector and in factory automation.

In theory, polymer fiber cables would enable every layman to set up high-speed data links in his or her home network. Small converter boxes convert the electrical signal from the copper cable into an optical signal. Thin cables, which are made of plastic and transport the optical signal to receivers anywhere in the home, can be easily connected to these boxes. Because of the very high transmission rate of these polymer fiber cables, television signals with high data volumes also

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Plastic fantastic for Siemens !!!!!
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Researchers at Siemens Corporate Technology have succeeded in transmitting data at a rate of one gigabit per second through optical polymer fibre cables, setting a new record.

A new data transmission technique allowed the fast rate, which is ten times faster than with products currently on the market. This performance sets the stage for the use of polymer cables in home entertainment and factory automation.

In polymer fibre cable transmission, small converter boxes convert the electrical signal from the copper cable into an optical signal and thin plastic cables transport the optical signal to receivers. Because of the very high transmission rate of these polymer fibre cables, television signals with high data volumes could also be transmitted within the home in this way in the future.

Until recently, polymer fibres' transmission capacity has been limited to 100Mbit/s, sufficient for DSL but not

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- All these approaches strongly rely on advanced digital signal processing
 - It's a well-established trend in all other telecommunication fields for the last 40 years
 - Even the optical transmission community recently "discovered" DSP
 - The rationale is the astonishing evolution of digital electronic capabilities and performances

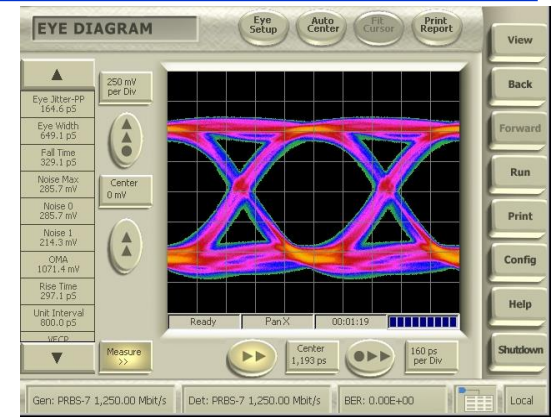
- When applied to SI-POF, our approach means increasing the system complexity in order to achieve the maximum ease of installation (do-it-yourself).

Approach #5 (Fraunhofer/POFAC/Diemount group)

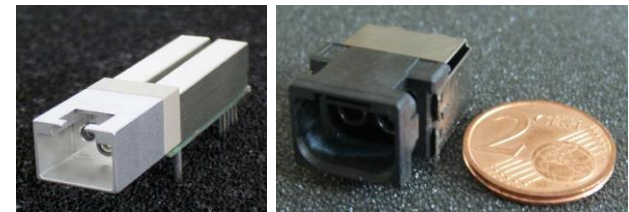
- A more traditional approach is also followed in the POF-ALL project, towards 1 Gbit/s transmission over 100 meter of 1mm GI-POF
 - Modulation is traditional binary NRZ
 - The effort is on component optimization
 - ➔ Optimization of red DVD laser driver
 - ➔ Optimization of receiver configuration for large area photodiodes

Current status:

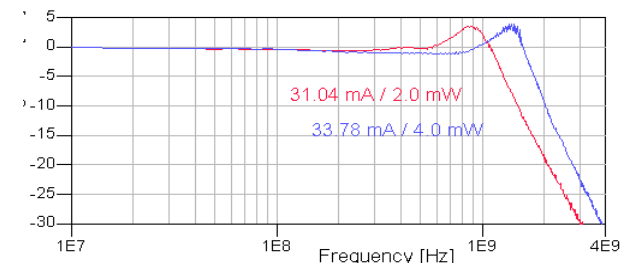
- Small form factor transceivers for 1.25 GBit/s over 30+ m available
- Laboratory demonstration over 100 meters



Eye-diagram for a 50 m GI-PMMA-POF link



Small form factor transceiver devices currently manufactured within POF-ALL



Normalized small signal frequency response of red edge emitting laser diode

■ COMPONENTS

- Sklarek, Danielzik, Vinogradov, Ziemann, Lednický, Offenbeck, Kragl, (Schott AG Mainz, POF-AC, Fraunhofer Institute for Integrated Circuits Erlangen, DieMount GmbH), "The influence of photo diode diameter on maximum data rate and sensitivity of POF systems"
- Offenbeck, Weber, (Fraunhofer Institute for Integrated Circuits IIS), "Versatile alterable gigabit transceiver for large core fibers ready for mass production"
- Moellers, Gindera, Bulters, Hung, Jager (Universitat Duisburg-Essen), "High-speed transceiver for Radio-Over-POF applications"
- Camatel, Nespola, Càrdenas, Abrate, Gaudino (Istituto Superiore Mario Boella, Politecnico di Torino), "LED non-linearity characterization and compensation"

■ DATACOM - I

- Lee, Randel, Vinogradov, Ziemann, Offenbeck, Koonen (Eindhoven University of Technology, Siemens AG, POF-AC, Fraunhofer Institute for Integrated Circuits), "10Gbit/s over large diameter polymer optical fibers using discrete multitone modulation"
- Gaudino, Nocivelli, Kragl, Ziemann, Weber, Jager, Koonen, Lezzi, Bluschke, Randel (Istituto Superiore Mario Boella, Politecnico di Torino, Luceat S.p.A., DieMount GmbH, POF-AC, Fraunhofer Institute, Universitat Duisburg-Essen, Technische Universiteit Eindhoven, Fastweb S.p.A., Teleconnect GmbH, Siemens AG), Invited paper: "Status and recent results from the POF-ALL EU project: toward improved capacity and new application of large-core POF"
- Offenbeck, Weber, Vinogradov (Fraunhofer Institute for Integrated Circuits IIS, POF-AC), "Analog GHz transmission over large core fibres for DVB satellite links of sophisticated coding schemes"
- Breyer, Lee, Randel, Hanik (Technische Universitat Munchen, Eindhoven University of Technology, Siemens AG), "10Gbit/s transmission over 220 m perfluorinated graded-index polymer optical fiber using PAM-4 modulation and simple equalization schemes"

■ DATACOM-II

- Yang, Van den Boom, Koonen (Eindhoven University of Technology), "Wavelength multiplexed quadrature amplitude modulation for low cost high capacity data transmission over plastic optical fibre"
- Randel, Lee, Breyer (Siemens AG, Eindhoven University of Technology, Technische Universitat Munchen), "1Gbit/s transmission over POF using light-emitting diodes"
- Nespola, Camatel, Abrate, Càrdenas, Gaudino (Istituto Superiore Mario Boella, Politecnico di Torino), "Fast-Ethernet transmission over extended reach SI-POF links"

■ DATACOM-III

- Kragl, Bluschke, Ziemann (DieMount GmbH, Teleconnect GmbH, POF-AC), "POF data link applications in the field of local access networks"
- Gaudino, Bosco, Bluschke, Hofmann, Kiss, Rietzsch, Randel, Lee, Breyer (Istituto Superiore Mario Boella, Politecnico di Torino, Teleconnect GmbH, Siemens AG, Eindhoven University of Technology, Technische Universitat Munchen), "On the ultimate capacity of SI-POF links and the use of OFDM: recent results from the POF-ALL project"

Expected Impact

- We have demonstrated that impressive performances can be achieved with large core POF
 - 200m are feasible at 100Mbps
 - Several tens of meters at 1 Gbps

- Some of the approaches are very close to a fully-engineered setup, namely:
 - The OFDM approach (with VDSL2+ ICs)
 - The NRZ 1 Gbps approach over 30 m GI-POF

- New applications become possible with large core POF:
 - Industrial automation (Industrial Ethernet, SERCOS III ...)
 - Video surveillance
 - Edge networks
 - Home networking

- The last point seems the most promising
 - Several national incumbent operators are currently considering POF for “optics inside the apartment”

- “TRUE” FTTH will (sooner or later) bring an extremely good digital connection up to the “apartment main door”
 - 100 Mbps per residential user is offered today in some FTTH commercial offers (Japan, Korea)
 - Higher bit rates will surely be offered in the future (up to Gbps) and people will use them!

- Some operators are being concerned on how to “distribute” this inside the apartment
 - By the way: who will install the in-apartment network?
 - The Telecom operator themselves?
 - Very expensive
 - The in-apartment network is very often reconfigured

 - The final user himself?
 - A good solution if a do-it-yourself approach is possible

- What are the options (for a mass-rollout) inside the apartment?
- Wireless
 - + Installation is trivial and unexpensive
 - - Still, it is a shared media!!
 - - Can it ever (reliably) reach the Gbps range?
- Glass fibers
 - + Very future proof!!
 - - Anyway, installation cost appears too high
- UTP Cat.5 or higher
 - - Installation is less simple than one usually think
 - - Cable is quite thick
- POF
 - + Better performance than UTP Cat.5 (similar to higher Cat)
 - + Extreme ease of installation

- WEB site:
www.ist-pof-all.org
- For any info regarding the project:
info@ist-pof-all.org
- To contact the coordinator
Dr. Roberto Gaudino
E-mail: gaudino@polito.it