DSP in the home
using Plastic Optical Fibers (POF)

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OFC workhosp
"DSP for Short Reach Applications: Why Bother?"
2014, March 10th

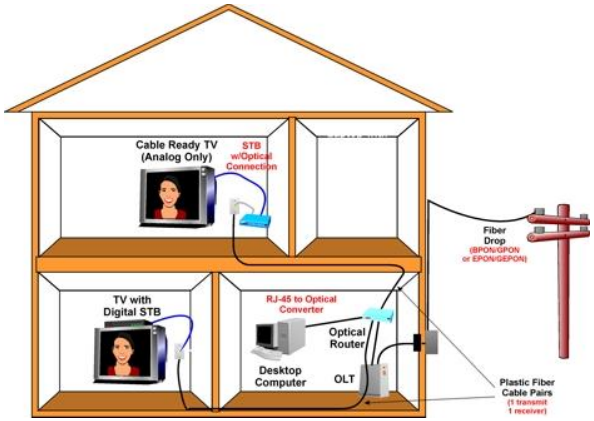
OFC 2014
The future of optical networking and communications is here.

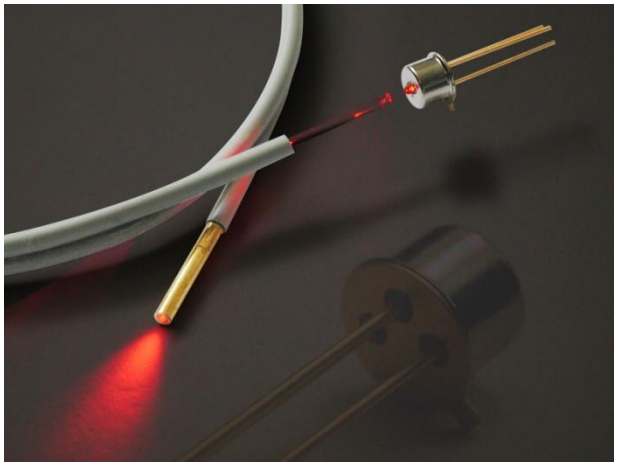
Why am I here?

OPTCOM

POF-ALL

- I was the coordinator of two EU-funded projects (POF-ALL and POF-PLUS) that investigated the use of PLASTIC OPTICAL FIBERS (POF) in home networking
  - http://www.ict-pof-plus.eu/





Focus of the presentation

- POF for High-speed home networking
- The need for DSP-based solutions
- Today situation at the commercial level

Which type of POF? Why POF?

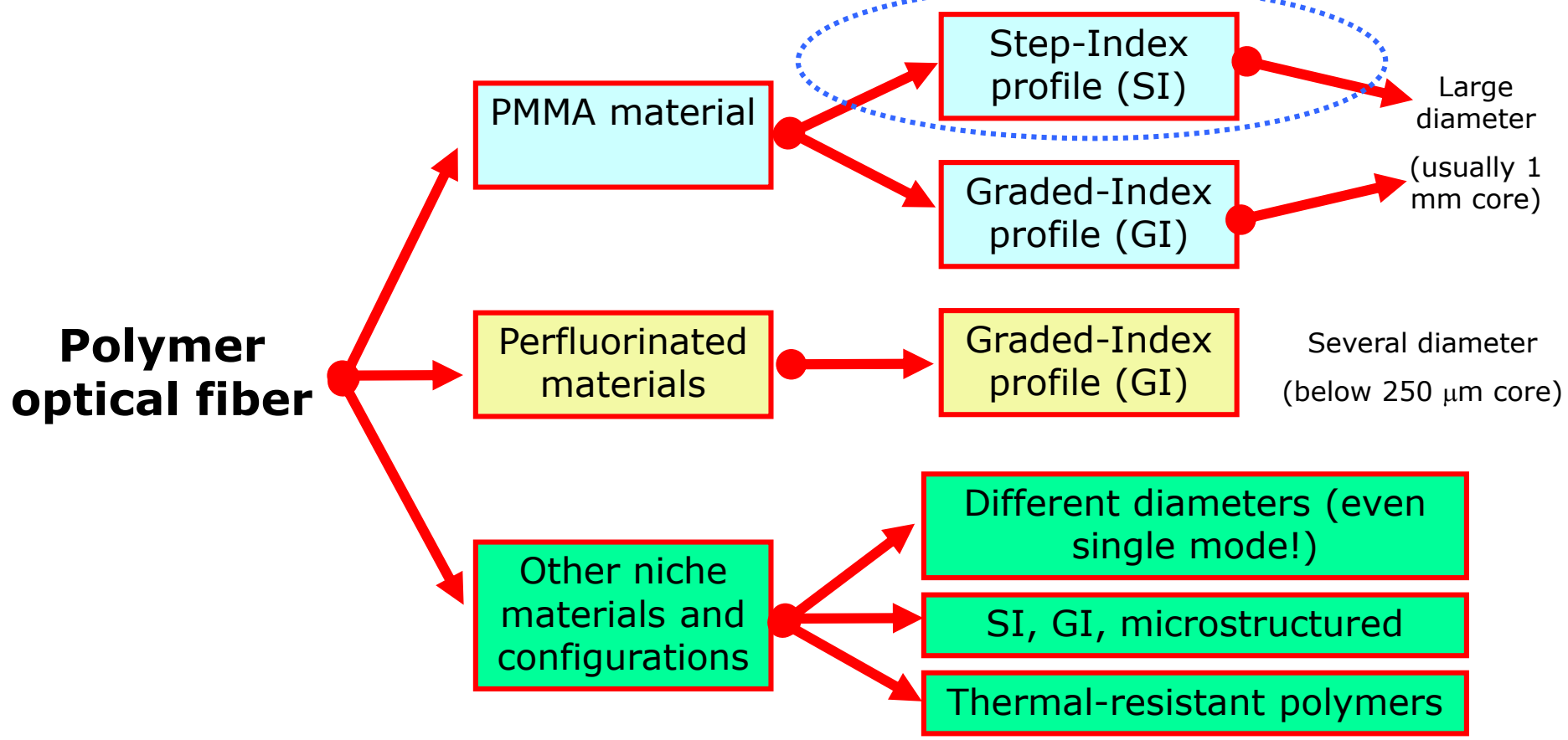
- "Standard POF" used today for industrial automation and for infotainment in car systems is:
  - Step-index POF
  - PMMA material
  - 1mm core diameter
  - Standardized in IEC as **A4a.2**

- Very robust, easy to be installed

- In home networking:
  - Can be installed in power ducts
  - Completely EMI free (advantage toward wireless or powerline solutions)

POF is actually a large family...

... but I will focus mostly on these ones, calling them simply "POF"



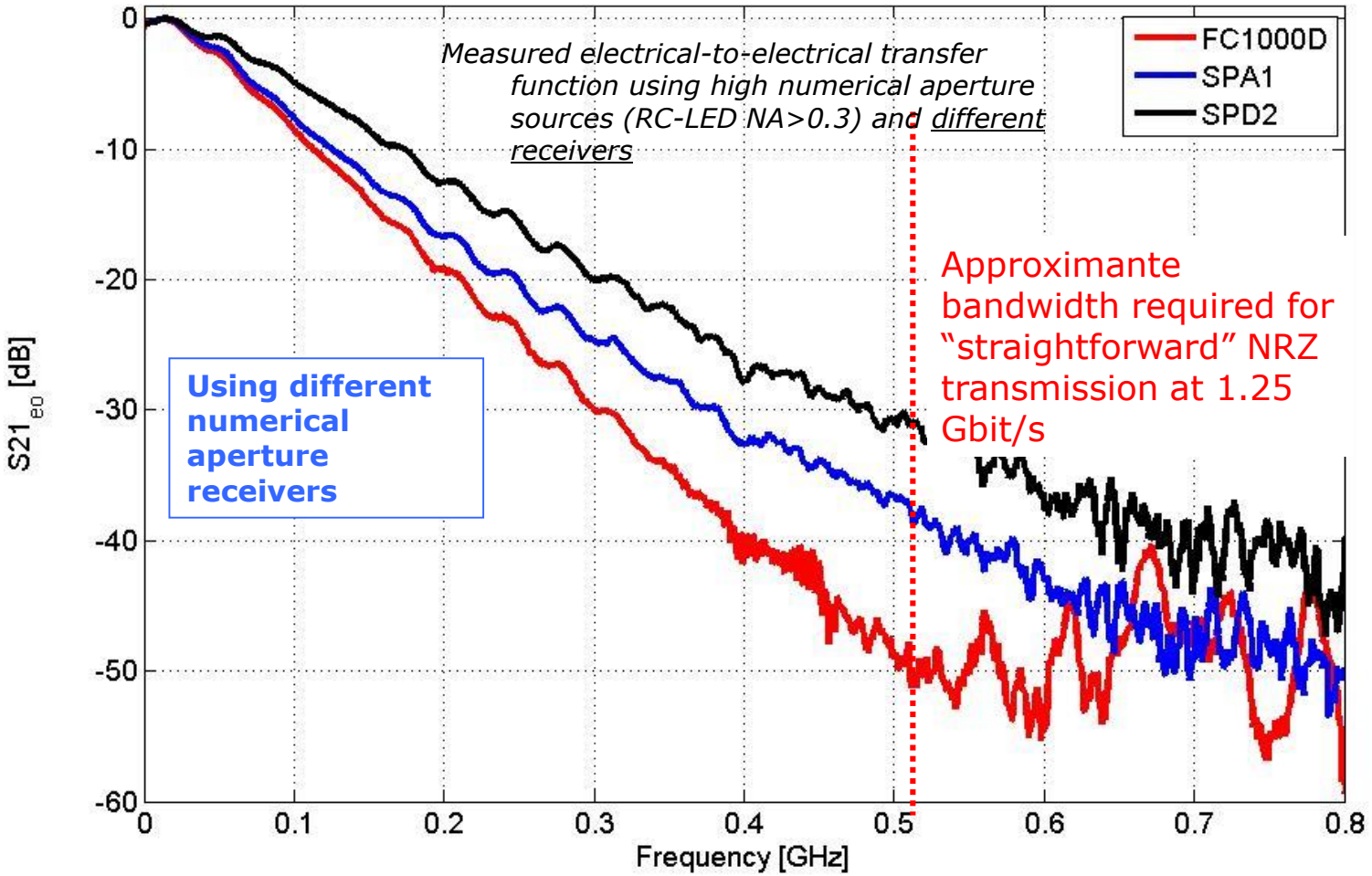
Why DSP for POF?

- Most commercial POF transceivers available today use binary NRZ modulation and very simple receivers (PIN+TIA+limiting amplifiers, NO DSP) for POF distances about 50 meters
- The resulting bit rate is at most 100 Mbit/s
  - This is because 50 meters of POF gives an electrical-to-electrical bandwidth that is less than 100 MHz
    - Very strong multi-mode dispersion due to high numerical aperture (NA=0.5)

- DSP for POF was thus proposed starting from 2006 by many research projects, and today it is the target of some companies of the field, the goal being:

at least 1 Gbit/s over at least 50 meters of POF

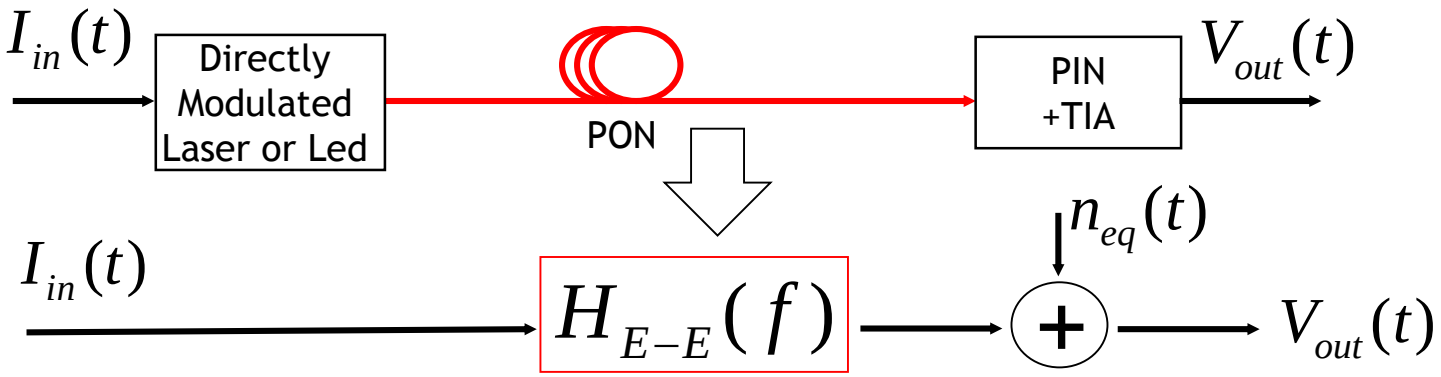
Bandwidth over 50m POF



On top of limited bandwidth, there is also a significant attenuation in POF (of the order of 0.2 dB/m at red wavelengths)

What type of DSP?

- The “POF channel” is an intensity modulation and direct detection (IM-DD) channel
  - Most relevant noise source is electrical noise at the TIA stage

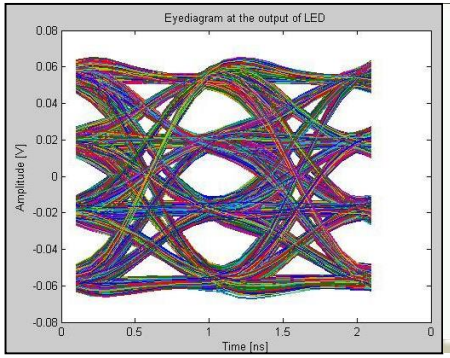


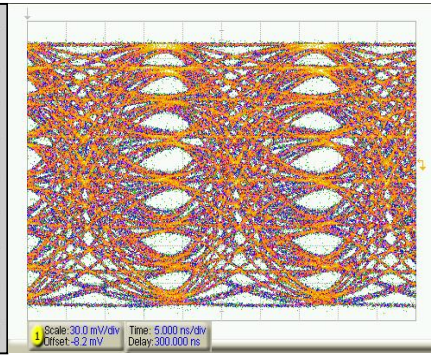
Resulting “Informatio theory” modelling

- Real baseband channel, bandwidth-limited
- Input signal is peak-to-peak limited (and not average power limited)
- Additive Gaussian noise at RX

The options that have been investigated

1. Multilevel modulation
   - 4-PAM or 8-PAM
   - Pre-emphasis at the TX



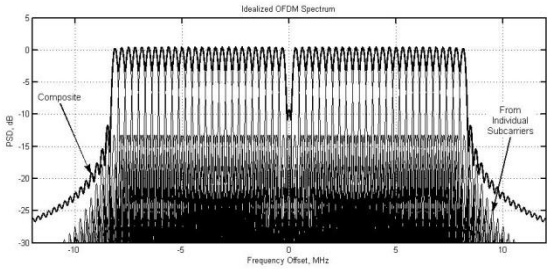


2. Adaptive equalization at the receiver
   - Feed-forward MMSE FIR filters
   - Decision-feedback filters

   but also:

   - Simple analog equalizers

3. OFDM/DMT modulations
   - Adaptive bit loading



NRZ vs. M-PAM vs. DMT

Comparison of Modulation Schemes for 10.7 Gb/s Transmission Over Large-Core 1 mm PMMA Polymer Optical Fiber

Sven Loquai, Roman Kruglov, Bernhard Schmauss, *Member, IEEE*, C.-A. Bunge, *Member, IEEE*, Florian Winkler, Olaf Ziemann, Engelbert Hartl, and Theodor Kupfer

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 31, NO. 13, JULY 1, 2013

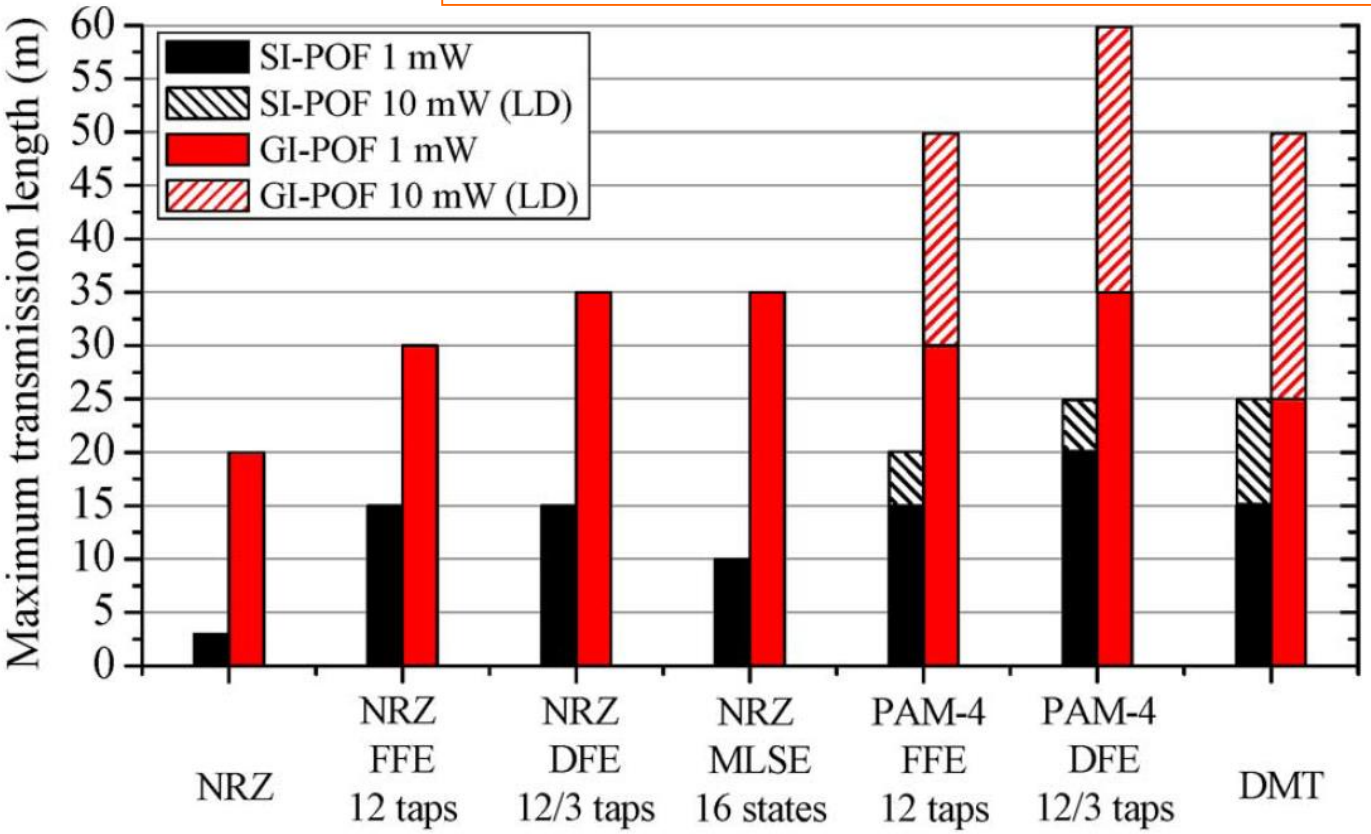
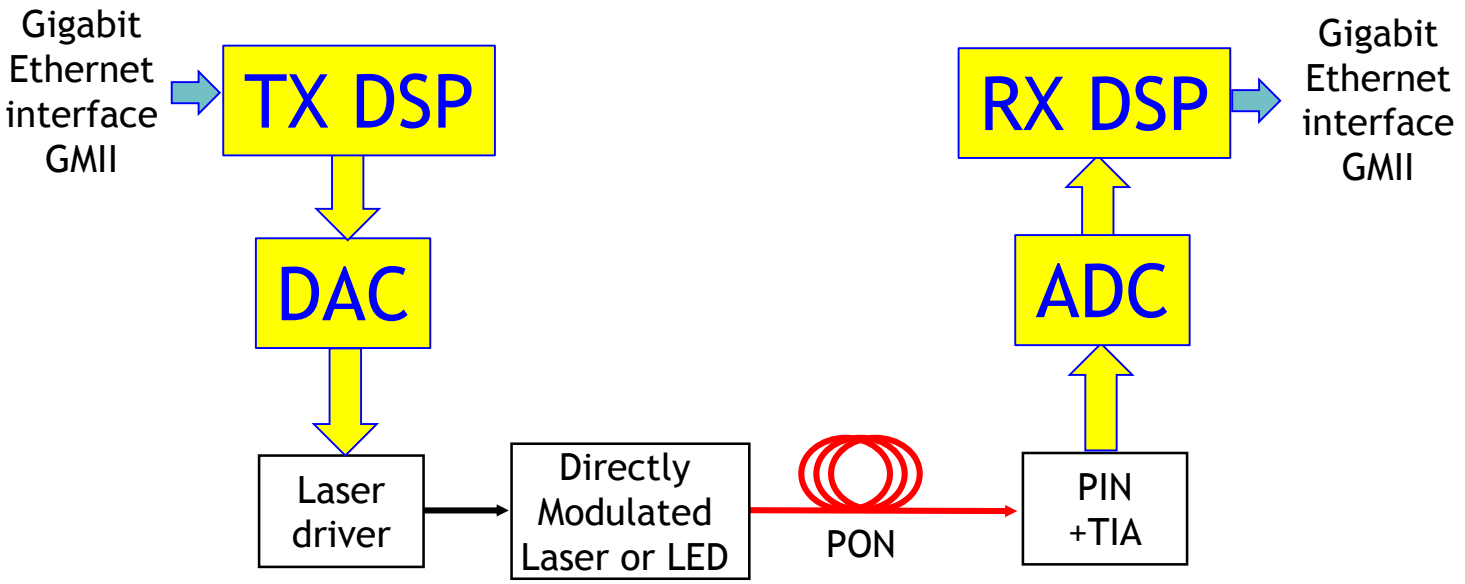


Fig. 20. Maximum transmission lengths at 10.7 Gb/s for 1 mm PMMA SI-POF and GI-POF ($\mathrm{BER} < 10^{-3}$). (laser-based transmitter)

Setup toward "Gigabit over POF"



- Specific goals for POF
  - Keep the DAC and ADC sampling rate as low as possible, to allow very low cost CMOS converters

A review of the proposed solutions for Gigabit Ethernet over POF

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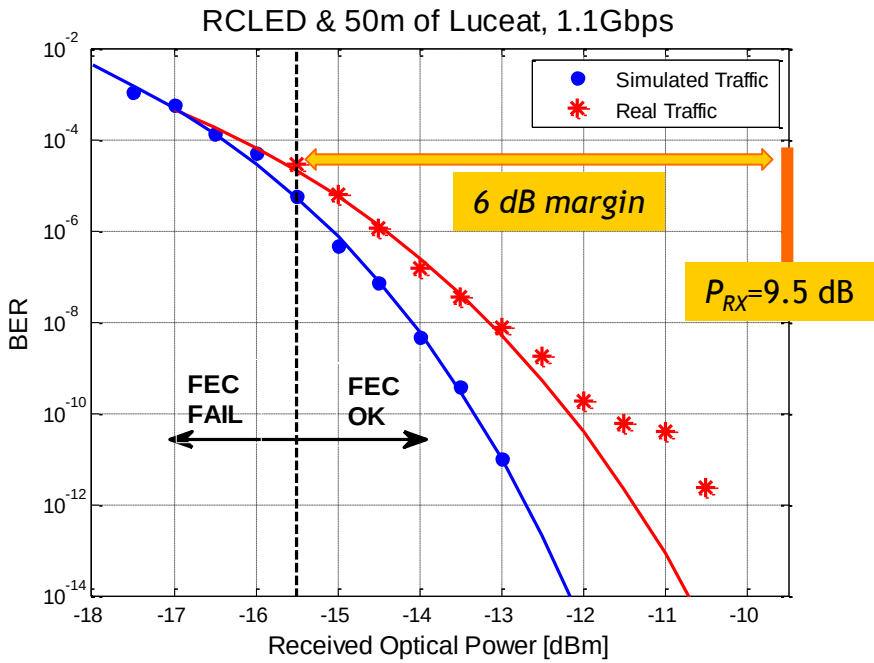
EU project POF-PLUS

Solution proposed in POF-PLUS by my group:

- RC-LED based setup
- Optimized RC-LED driver (by Fraunhofer Institute)
- Pure NRZ at transmitter (i.e., basically no DSP at TX)
- Adaptive DFE equalization at receiver
- Simple Reed-Solomon FEC

- We achieved 1 Gbps (net data rate, compliant with Gigabit Ethernet) over 50 meters POF with 6 dB system margin



Knowledge Development for Plastic Optical Fibres

KD-POF solution

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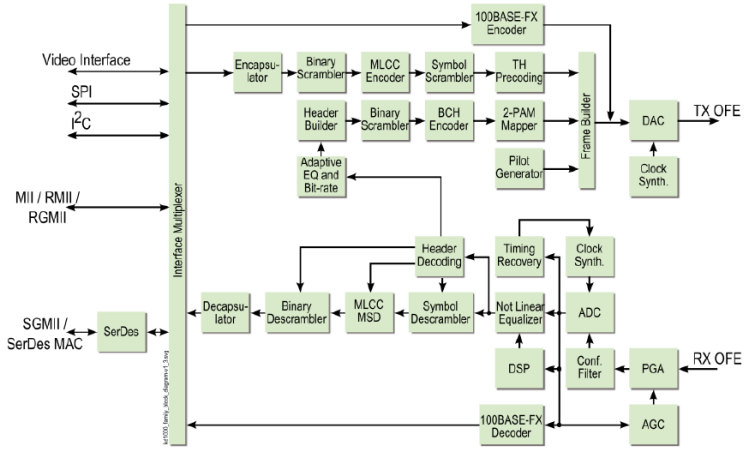
KDPOF (company focused specifically on DSP for POF):

- M-PAM with adaptive M (up to 16-PAM)
- Adaptive bit rate (ABR)
- Tomlinson-Harashima precoding at TX
- Strong (and adaptive) FEC

From http://www.kdpof.com/:

- KD1000 ASIC family to achieve 1 Gbps over POF



KD-POF solution performance

Home Networking 50 m @ 1 Gbps	25ºC			70ºC		
	Fiber 1	Fiber 2	Fiber 3	Fiber 1	Fiber 2	Fiber 3
AOP at TX (dBm)	-3.15	-3.15	-3.15	-5	-5	-5
POF attenuation (dBo)	-8.5	-9.6	-11.5	-8.5	-9.6	-11.5
RX lens coupling loss (dBo)	-2	-2	-2	-2	-2	-2
Sensitivity at PD (dBm)	-19	-19.6	-21	-18.7	-19.3	-20.7
Link budget (dBo)	13.85	14.45	15.85	11.7	12.3	13.7
Link margin (dBo)	5.35	4.85	4.35	3.2	2.7	2.2

Industrial (Long Reach) 50 m @ 100 Mbps	25ºC			85ºC		
	Fiber 1	Fiber 2	Fiber 3	Fiber 1	Fiber 2	Fiber 3
AOP at TX (dBm)	-3.15	-3.15	-3.15	-6	-6	-6
POF attenuation (dBo)	-8.5	-9.6	-11.5	-8.5	-9.6	-11.5
RX lens coupling loss (dBo)	-2	-2	-2	-2	-2	-2
Sensitivity at PD (dBm)	-33	-33.1	-33.2	-32.6	-32.7	-32.8
Link budget (dBo)	27.85	27.95	28.05	24.6	24.7	24.8
Link margin (dBo)	19.35	18.35	16.55	16.1	15.1	13.3

- Power consumption: less than 1W per port
- ASIC developed with 65nm technology

OFDM/DMT based solutions

- Large research work in this field by the Technical University of Eindhoven (TUE) group

- Companies working on OFMD-based ASICS for POF:
  - **Teleconnect**
    - Proposed to re-use the G.hn OFDM-based standard for powerline home networking
  - **Innodul**

OFDM/DMT based solutions

- Teleconnect GmbH and other semiconductor companies adopted Powerline-oriented standard G.hn also for POF
  - ITU-T G.9960 Annex F (aka G.hn) is the only international recommendation for high bitrate POF transmission; promoted by the HomeGrid Forum (more than 70 members)
  - OFDM is used with the following selected parameters:
    - 100 MHz profile: tone spacing 195 kHz, 512 tones, FEC 20/21, LDPC, 12 bit/s/Hz
    - 200 MHz profile: two times more tones: 1024

OFDM/DMT based solutions

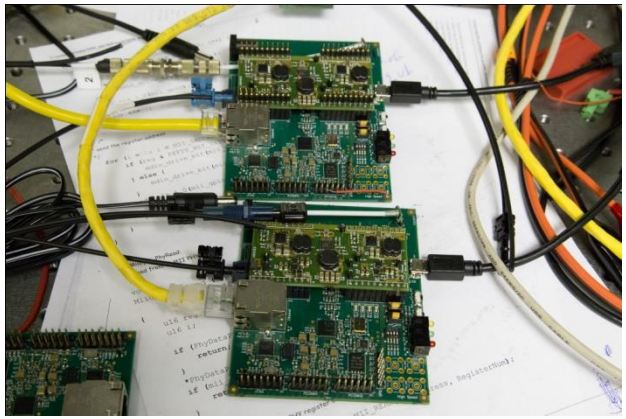
- The Pros of “G.hn over POF”:
  - Global with not only one chipset manufacturer behind the solution (can be used for “any media”) (second source)
  - Guaranteed interoperability between different chipsets
  - Fulfill all the requirement of service providers organized in the Broadband Forum (for instance: TR-069, IGMP, QoS, cost effective)
  - Flexible network structures can be realized: P-t-P, P-t-MP and MP-t-MP (so can be realized the same advantages which has PON for access networks in comparison to AON also for home networks) (see: http://www.genexis.eu/medialib/552/ghn-over-pof.pdf)
  - Simplex transmission can be done very easy

OFDM/DMT based solutions

- "G.hn POF" prototypes are today available from different manufacturers
  - With bandwidth of 88 MHz PHY rates of more than 900 Mbps are possible (throughput more than 800 Mbps) for P-t-P optical connections.
  - For 2014 solutions for 200 MHz are expected.

ISMB 10/100 long reach prototype

- Combines previous POF-ALL and POF-PLUS experiences from 10, 100 and 1000baseT to POF converters, focusing mostly on extending the reach to hundreds of meters
- A custom prototype ready for field trials was developed



- 10/100 Ethernet support
- Up to 275m @100Mb/s and 425m@10Mb/s
- Use a simple LED with On/OFF modulation (NO DAC, no multilevel, only analog peaking)
- Low power (achieved about 3.6W)

Conclusions

- DSP in POF needed for any next generation transceivers going above 100 Mbit/s over 50 m
- Commercial solutions for “Gigabit over POF” started to appear recently
- Applications may pop up in other fields, such as:
  - Next generation MOST standard for cars
  - Industrial automation

DSP in the home

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Thank you for your attention!

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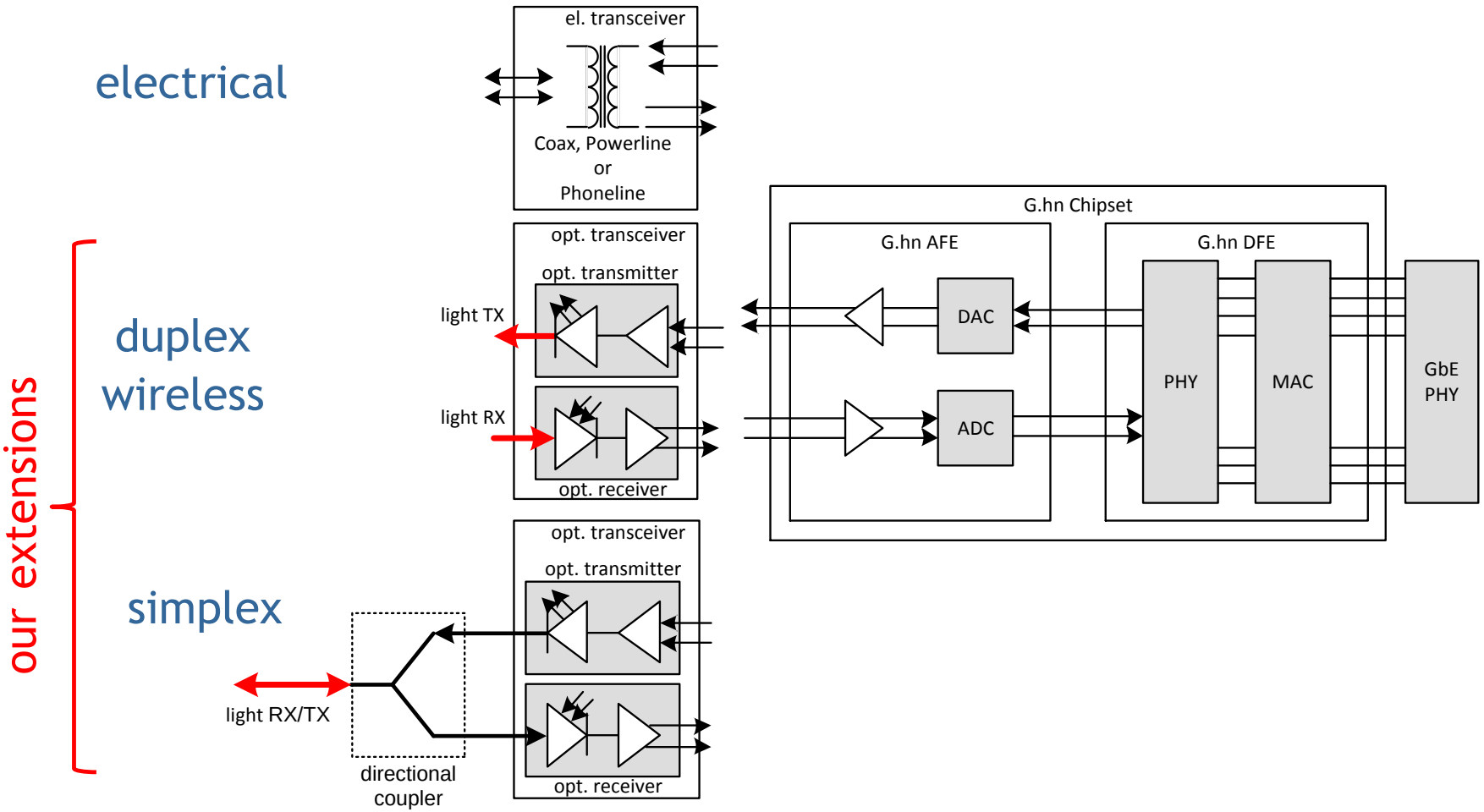
ADDITIONAL INFORMATION BY TELECONNECT

G.hn - transceiver

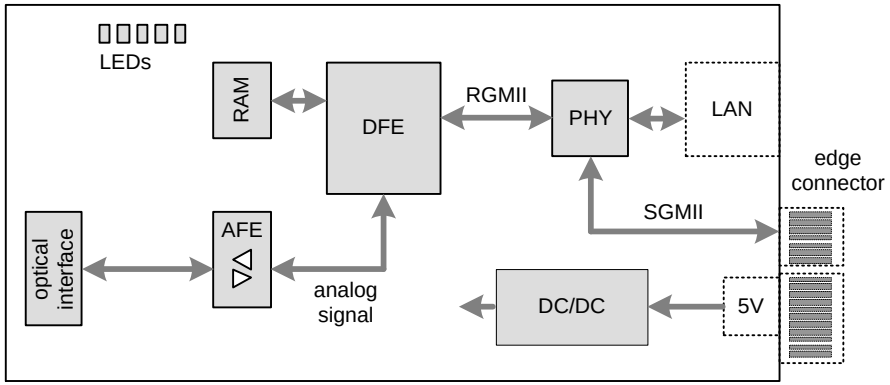


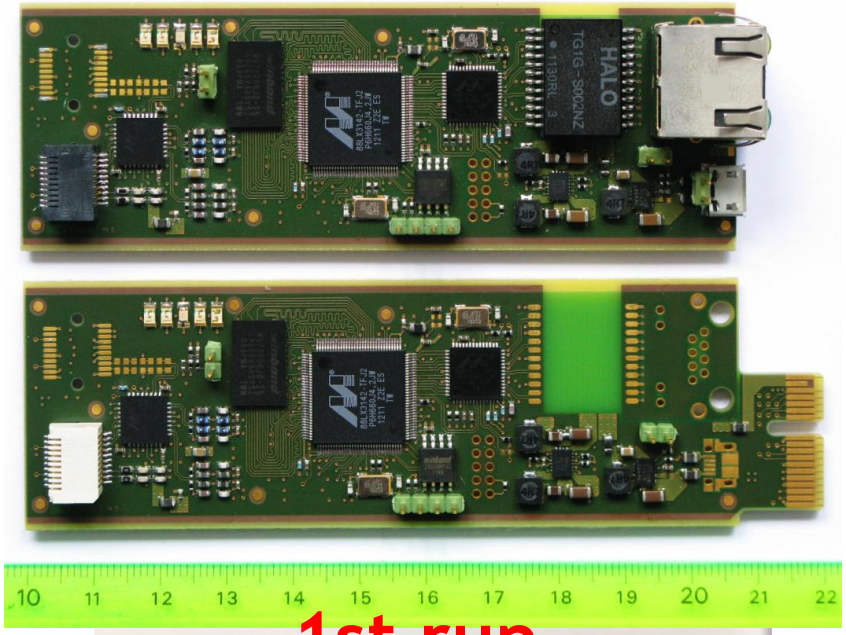
G.hn - transceiver by Teleconnect

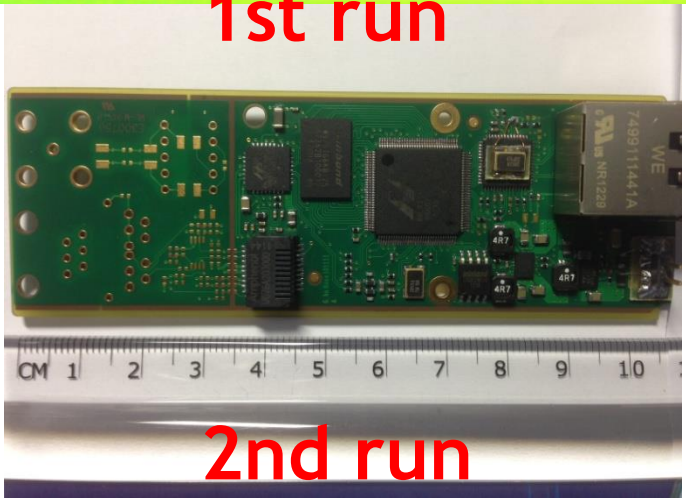
(HSPOF project)

OPTCOM

- Current profile: 2-80 MHz, 24.4 kHz tone spacing (2-100 MHz, 195 kHz)
- Prepared for all optical and electrical interfaces!
- Board usable as omniPOF™ module or as stand-alone mediaconverter.
- We reached the max. electrical PHY rate of 660 (> 900) Mbps.

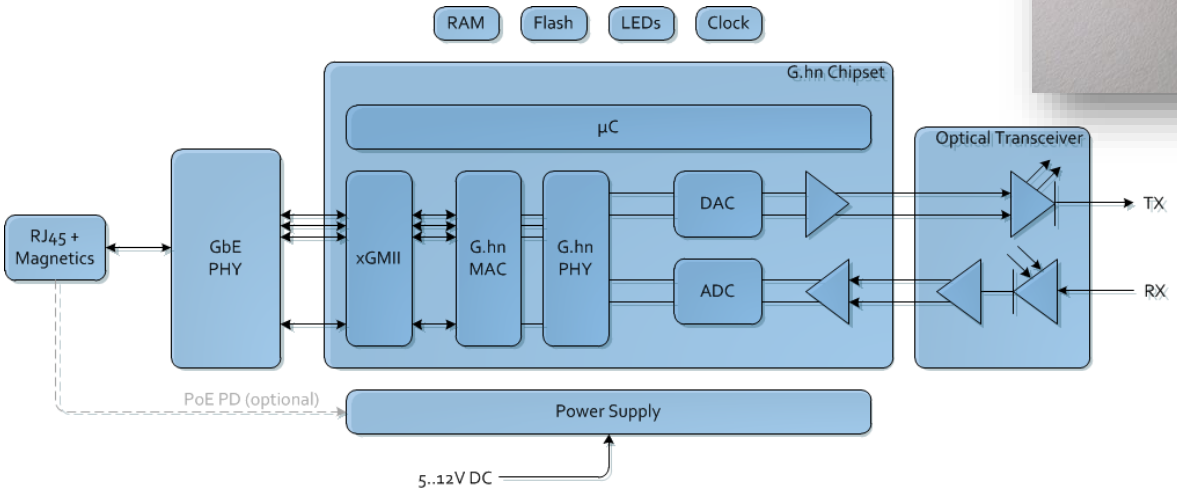






G.hn - transceiver by Teleconnect
(CoolPOF project)

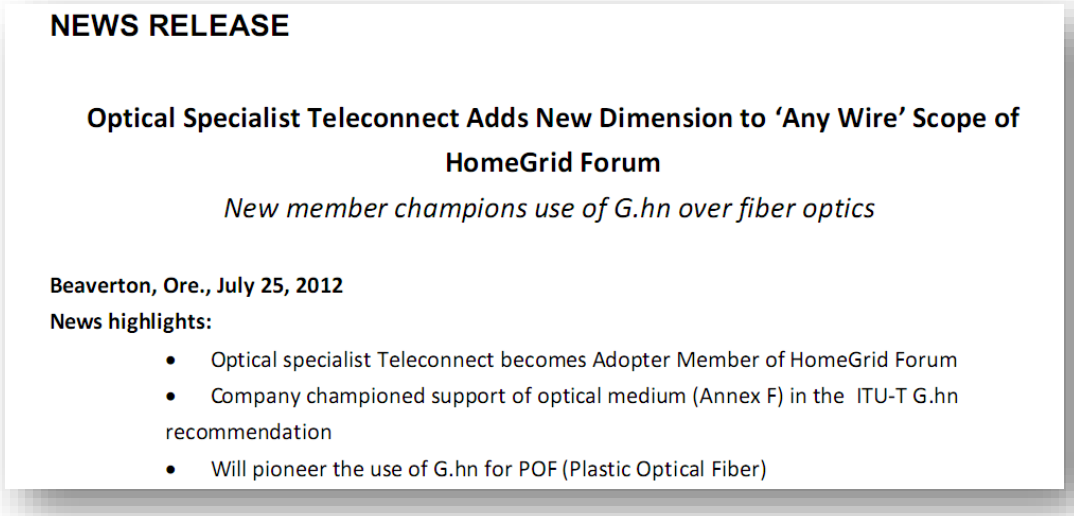
- Current profile: 2-80 MHz, 24.4 kHz tone spacing.
- Prepared for all optical and electrical interfaces!
- Board usable as module for RG or as stand-alone mediaconverter



- Power consumption: @5V 2,5 W (CoC 2015/2016 - 2,8 W)

Additional activities

- Since May 2012, Teleconnect is member of the HomeGrid Forum.



NEWS RELEASE

Optical Specialist Teleconnect Adds New Dimension to 'Any Wire' Scope of HomeGrid Forum

New member champions use of G.hn over fiber optics

Beaverton, Ore., July 25, 2012

News highlights:

- Optical specialist Teleconnect becomes Adopter Member of HomeGrid Forum
- Company championed support of optical medium (Annex F) in the ITU-T G.hn recommendation
- Will pioneer the use of G.hn for POF (Plastic Optical Fiber)

- Teleconnect is involved in standardization activities in Germany (VDE DKE) and is a member of ETSI since 2013 (to push POF-PON based on G.hn).

In the Press

Home Company News Release

Marvell and Global Tier-1 OEMs Deliver Products for the New Era of the Connected Lifestyle at CES 2013

Smart Connectivity Solutions

G.hn Wireline Deployments – Marvell's award-winning and first-to-be-certified G.hn wireline technologies are being deployed with top manufacturers such as COMTREND, Cambridge Industries Group (CIG), Teleconnect and Woxter. Marvell is providing connectivity at 1 Gbit/s over any home wiring, including electrical wires, coaxial cables, twisted pair and optical fiber. Marvell will also showcase additional G.hn solutions from Billion, Delta Networks Inc., T&W and ZTE at CES.

Home Company News Release

Teleconnect Selects Marvell's G.hn Silicon to Power Optical Home Networks

Extensible Marvell chipset enables G.hn over any wire in the connected home

Las Vegas and Santa Clara, California (January 8, 2013) – Marvell (NASDAQ: MRVL) today announced that its G.hn silicon chipset is powering the core of Teleconnect's omniPOF™ modules for home networking applications using plastic optical fiber (POF). Teleconnect joins the growing list of ODM and OEM partners in the second wave of G.hn design wins for Marvell, accelerating the global adoption of the extensible ITU-T standard designed to provide connectivity at data rates up to 1 Gbit/s over standard home wiring, including electrical wires, coaxial cables, twisted pair and, now with Teleconnect, optical fiber.

COMPUTEX Taipeh, BBWF 2013 – HomeGrid Forum booth