Whitepaper

High Data Rates over Long Copper Loops – SHDSL Goes the Extra Mile(s)

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Dr. Andreas Bluschke, Michael Matthews
and Philipp Rietzsch, Teleconnect GmbH

Teleconnect
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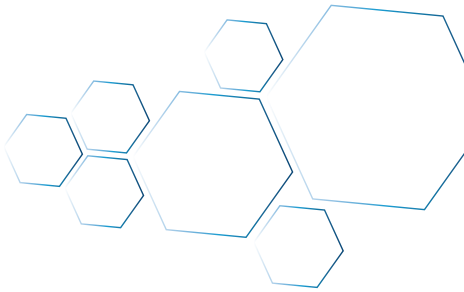

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Abstract

Nothing beats SHDSL when it comes to high data rate requirements on long copper loops. Adding kilometers of TDM or Ethernet connectivity can be as easy as adding an Ethernet PHY. Design houses like Teleconnect GmbH and Lantiq's experienced customer support can help to get new designs to market in record time. The Lantiq SOCRATES™ single-chip solution features standard MII and TDM interfaces and a 4-pair bonding engine that enables up to 60 Mbps symmetrical throughput. Its unique rate/reach performance makes it the product of choice in an ever more diversified field of applications ranging from business broadband access, to enterprise networks and industrial communications.

Introduction

More than fifteen years after its first market introduction as broadband access technology for businesses, SHDSL has gained a second life in industrial and enterprise applications. Built on features defined in ISDN, MDSL and HDSL/HDSL2/SHDSL, which stands for Single-Pair High Speed Digital Subscriber Lines, is a global ITU standard. In more than a decade of use, equipment providers and carriers have gone beyond the "single-pair" concept to achieve high data rates over bonded lines, while specialized modes of operation have extended reach far beyond the typical distance of copper technology. Today, SHDSL-based transceivers can achieve data rates up to 15 Mbps per copper pair or reach far beyond 15 kilometers (9.3 miles). This is why SHDSL today is better known as Symmetrical High Speed DSL. It is the technology of choice whenever long copper loops are already deployed or are required in new installations that use them for remote power feeding. A growing number of industrial applications rely on SHDSL as a robust long-reach communication technology. Examples are surveillance cameras, vending machines, public displays, infotainment systems, traffic control and industrial communication and sense & control applications. Even the traditional business broadband access application profile is evolving. Often marketed as Metro Ethernet, EFM, Long Reach Ethernet or IP/Ethernet Access, SHDSL based services provide a tremendous value add to deployed copper lines. Small businesses that may be out of fiber reach – like hotels, banks, offices or shops – can get state-of-the-art 100 Mbps symmetrical rates over bonded phone lines.

Global SHDSL Recommendation

The ITU-T recommendation G.991.2 describes a data transmission method for access networks, often dubbed G.shdsl. The recommendation was formally published in 2003, one erratum and some amendments were published in 2005. In short, SHDSL is a very stable recommendation. A big part of the G.991.2 originally was developed by ETSI Technical Committee Transmission and Multiplexing and published as TS 101 524 under the name SDSL (Symmetric single pair high bitrate DSL).

SHDSL transceivers are designed for duplex operation over mixed gauge 1-pair (single pair, 2-wire) twisted pairs. Optional multi-pair operation is supported for extended reach or extended data rate applications. SHDSL transceivers are designed to be spectrally compatible with other transmission technologies deployed in the broadband access network. SHDSL transceivers are capable of supporting selected symmetric user data rates in the range of 192 kbps to 2312 kbps using a Trellis Coded Pulse Amplitude Modulation (TC-PAM) line code. Optional extensions described in Annex F allow user data rates up to 5696 kbps in some cases – traditionally called ESHDSL (Enhanced or Extended SHDSL) or G.shdsl.bis. Regional requirements, including both operational differences and performance requirements, are specified in Annexes A, B and C. Regenerators for both 1-pair and multi-pair operation are specified in Annex D. Annex E describes application-specific framing modes that may be supported by SHDSL transceivers.

EFM Standard – Long Reach Ethernet PHY

A second relevant standard for SHDSL was produced by a working group of the Institute of Electrical and Electronics Engineers (IEEE) and became a part of the standard IEEE 802.3ah (EFM, Ethernet First Mile) in 2004. Later on this standard was included in the standard IEEE 802.3-2008, where it is named 2BASE-TL and described in clauses 61 and 63.

A 2BASE-TL transceiver supports data rates from 196 kbps (3 x 64 kbps) to 3840 kbps (60 x 64 kbps) using 16-TCPAM and data rates from 768 kbps (12 x 64 kbps) to 5696 kbps (89 x 64 kbps) using 32-TCPAM. A transceiver may also support an aggregation or bonding of multiple pairs, called PME Aggregation Function (PAF), to form a single logical Ethernet link.

SHDSL/EFM Physical Layer

SHDSL is a baseband technology which utilizes the frequency band down to 0 Hz. Figure 1 sketches examples of a PSD mask of SHDSL. The PSD mask depends on the symbol rate of the connection. This symbol rate for a target data rate can be influenced by the use of different TC-PAM levels. The SHDSL standard specifies 16 and 32 PAM levels for data rates up to 2.312 and 5.696 Mbps. The Lantiq SOCRATES™ SHDSL chip supports a proprietary extended PAM rate feature to increase the number of PAM levels up to 128, pushing data rates up to 15 Mbps per copper pair, or reduce PAM levels down to 4 and get substantially enhanced reach of basic data rates. The more levels the more bits per symbol, which reduces the required symbol rate

for a given rate and thereby also the effective attenuation in the cable, but this comes with lower noise resistance due to the smaller distance between the different PAM signal levels. SHDSL framing adds an overhead of 8 kbps in terms of sync words, special indicator bits for defects and power loss and an embedded operational channel (EOC) for exchange of physical performance data, but also usable for proprietary information exchange or remote firmware updates.

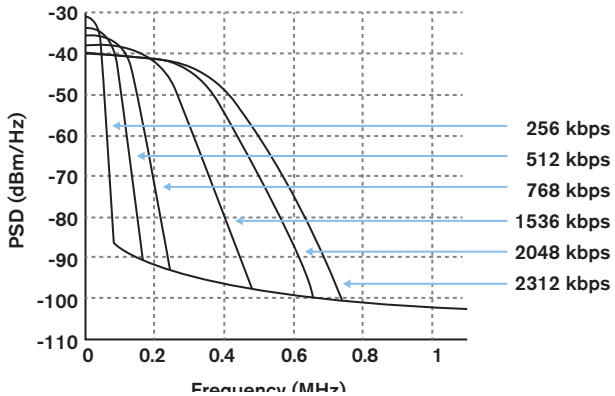


Figure 1:
TC-PAM coding examples with PSDs for different data rates.

Lantiq SOCRATES™ Goes Beyond the Standard

In recent years, the Lantiq SOCRATES™ SHDSL and EFM solution have become a de-facto standard and synonym for SHDSL communication. It is by far the most innovative product in the market and has gained a very strong market position. The product is not only the best implementation of the SHDSL and EFM standard; it also offers unique features that go far beyond the standard.

Its worst case power consumption of 650 mW per line is only half that of the nearest competitive product. Digital and analog front ends are combined in one single 19 x 19 mm LBGA package and require only two supply voltages. SOCRATES™ does not require separate memory and can be configured with a simple 8-bit micro controller. An integrated bonding engine distributes data streams from TDM, UTOPIA, MII and SS-SMII interfaces to up to four SHDSL lines; in Dual Bearer mode, TDM data and Ethernet packets can even coexist on the same lines.

Lantiq SOCRATES™ is 100% SHDSL and EFM standard compliant and offers best in class interoperability with legacy equipment based on other vendor's chipsets. But this isn't where it ends. Lantiq goes beyond the standards and offers proprietary modes with substantially enhanced rate/reach performance. SOCRATES™ offers configuration options for TC-PAM levels from 4 to 128 which are fully backward compatible with legacy equipment due to an automatic fallback into the standardized range. This means, with one SOCRATES™ on each end, symmetrical rates up to 60 Mbps (15 Mbps per pair) are possible. Typical rate/reach characteristics are shown in Figure 2a. Reach can be extended further on thicker copper cables. For example, 300 kbps data rates were demonstrated over several tens of kilometers on one single pair with a wire gauge

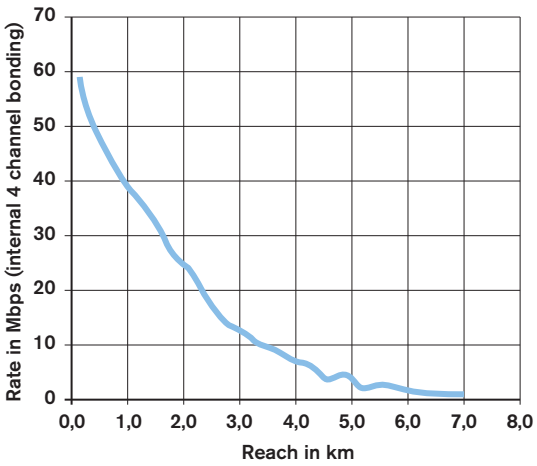


Figure 2a:
Rate/Reach Performance Measurement of Lantiq SOCRATES™-4e V1.2. Extended PAM, cross-talk-cancelled, sequential startup, 4-pair bonding, standard twisted copper pair phone cables, no alien noise

of 1.5 mm.

Today, hundreds of Lantiq SOCRATES™ based applications are readily available in the market. New applications benefit from the maturity of the technology and the rich experience of design houses around the world. Teleconnect, with more than 20 years of experience in hard- and software-development for xDSL systems, can provide ODMs and OEMs customized designs and fast time-to-market. Today, new SHDSL designs can have record time-to-market and three months from start to volume ramp are not unusual.

SOCRATES™ has two incarnations: SDFE and –e. SOCRATES™ SDFE is optimized for TDM traffic dedicated TDM interfaces and SOCRATES™-e offers a MII, UTOPIA and TDM interfaces for Ethernet (EFM) and ATM traffic. In Dual Bearer mode SOCRATES™-e can also handle MII and TDM traffic in parallel. Both, SDFE and –e feature an integrated four channel bonding engine. 3rd party bonding and line aggregation solutions are readily available in the market if reach and data rate extensions are desired. 100 Mbps symmetrical rates with 8-pair bonding have seen significant traction in the market in recent years.

Rate/reach improvements for multi-pair applications or multiple single-pair connections which share the same cable binder can be realized with the integrated crosstalk canceller in the Lantiq SOCRATES™ (CTC) which can cancel near-end self-next crosstalk between neighbored SHDSL lines. This works so nicely that crosstalk is nearly completely eliminated and almost noise free performance can be realized. Near-end crosstalk of up to 7 other lines can be eliminated. Crosstalk cancellation does not require support on both ends to show performance improvements. It is fully compatible with legacy equipment.

Lantiq SOCRATES™ also connects ATM and EFM world with integrated interworking functionality. Several interworking scenarios are supported. These include ATM on the local loop and Ethernet on the System Interface for BOM optimized CPE designs with low featured network processors (NWPs) as well as interworking with ATM on the System Interface and Ethernet on the local loop for EFM support out of an ATM based DLSAM/network. LLC (Logical Link Control) encapsulation and VC multiplexing as described in RFC2684.

Lantiq continues to invest in the SOCRATES™ business line. Future proof manufacturing processes and frequent firmware updates enhance the lifetime particularly of the popular four channel products. This is critical particularly in industrial markets, where equipment makers need to provide their customers with long-term supply assurances.

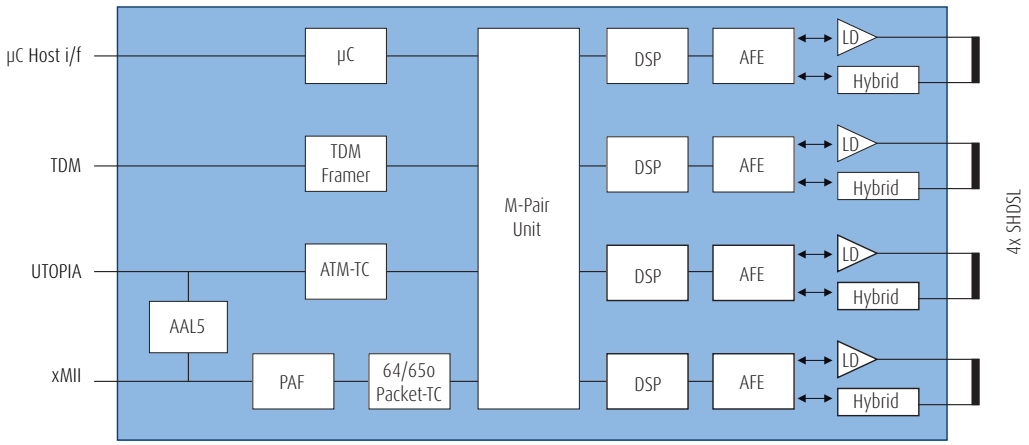


Figure 2b:
Interfaces of Lantiq SOCRATES™ 4e (not shown here: SOCRATES™ SDFE offers additional TDM interfaces instead of UTOPIA or MII)

Applications

Today, SHDSL is used in a very broad range of telecom, enterprise, security and industrial applications. SHDSL is the best alternative wherever reach is critical and symmetrical rates are required, particularly if copper pairs are already deployed or even required for remote power feeding. Today, SHDSL is frequently used in combination with remote power feeding schemes. While this is not a SHDSL feature per-se, it has become a popular use case as the power feeder and the data transceiver may share the same single pair. The following non-exhaustive list outlines the impressive variety of applications using SHDSL today.

- **Infotainment systems** are obvious applications for SHDSL. High resolution displays require broadband data connections and often need to be supplied with power over the same copper wire. While on short copper loops, Power-over-Ethernet (PoE) and VDSL2 are alternatives, SHDSL is the technology of choice beyond 200 – 500 meters up to kilometers of reach. Examples range from multi-media screens in planes and trains to larger infotainment and advertising screens in public places like airports, train and metro stations, outdoors on buildings and along streets.

- **Video surveillance** often requires connecting IP cameras in locations beyond the reach of PoE. SHDSL can replace traditional technologies and use the established infrastructure. Examples are parking garages, campuses and public places; here IP cams are replacing traditional analog cameras sing SHDSL.

- **Vending machines** and banking terminals like ATMs increasingly rely on SHDSL for robust, low latency and extended reach data connections .

- **Traffic control** systems are another area. In particular, traffic lights and traffic flow control and information systems rely on low latency, high robustness and long reach data connections.

- **Emergency communication** systems need long reach broadband data connections for voice and video communication. Traditionally analog voice technologies and ISDN have been used to connect the caller with an emergency call center. Today, these systems are more and more replaced with combined voice, video and (sensor) data communication systems based on SHDSL over leased lines or for example for private lines along highways, in train stations, elevators, etc.

- **Industrial voice and video** communication in mines, along pipelines and powerlines or in disaster communication systems

- **Sense and control** applications in industrial manufacturing equipment and geological and meteorological equipment like weather forecasting and earthquake/tsunami pre-warning systems.

- **Reach extenders and repeaters.** SHDSL has become popular as a reach extension technology for TDM and packet based data transmission. Anything from POTS, ISDN, T1/E1, ATM, Ethernet, ADSL, VDSL2, … can be extended with the help of SHDSL repeaters/extenders

SHDSL was originally designed as a broadband access technology for businesses and base transceiver stations replacing T1/E1 and ISDN access lines. The standard compliant and the proprietary data rates of the Lantiq SOCRATES™ with 4- and 8-pair bonding remain the only alternative for high data rate business access lines out of fiber reach.

Point-to-Point Applications

The most common applications for SHDSL are Point-to-Point (P2P) applications using two SOCRATES™ chips connected via twisted pairs. In such a case, one SOCRATES™ should be configured in CO mode (also called STU-C) and the other SOCRATES™ in CPE mode (also called STU-R). This very easy application is shown in Figure 3.

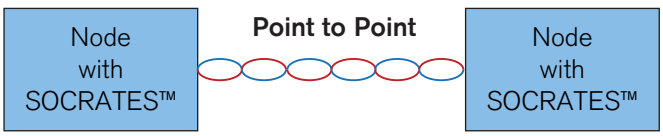


Figure 3:
Two SOCRATES™ in P2P application

Such a P2P application can be realized over different cable types and over different distances, for example, as a (higher bit rate) ISDN- or leased-line-replacement.

Figure 4 shows a lower bandwidth P2P application example for 1-pair and an application with 4 pairs for long reach/high performance. Depending on the SOCRATES™ type, different amounts of pairs can be supported. If one SOCRATES™ supports more than one pair, every pair can be used independently for data transmission or they can be combined to get higher sum bit rates using Bonding.

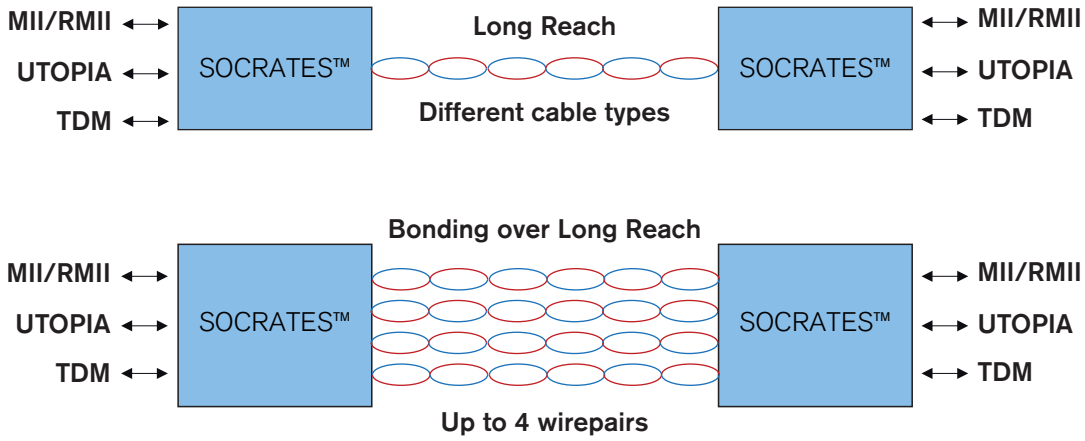


Figure 4:
Possible P2P applications

On the customer side, the SOCRATES™ has different possibilities to connect interface circuits:

- MII/RMII to connect an Ethernet PHY or Ethernet Switch,
- UTOPIA for the connection to an ATM-based device or
- TDM to interface PDH or other equipment.

The combination of different interfaces types are allowed in the so-called Dual Bearer mode.

Reach Extenders and Repeaters

If the required line length is higher than supported with direct P2P connections, so-called reach extenders or repeaters can be integrated (see Fig. 5). Doing this, extremely long reach applications can be realized. A repeater can be realized with one SOCRATES™. Functionally it is based on two SOCRATES™ connected back-to-back, whereby one SOCRATES™ is working in CO mode and the other in CPE mode. However, one physical multi-channel device is enough as two SHDSL channels of the same device can always be connected back-to-back and act as a repeater. Every P2P SHDSL segment should consist of a CO-mode-configured and a CPE-mode-configured SOCRATES™. Typically SOCRATES™ SDFE is used for repeater applications. In this case the repeater is fully transparent and does not care what kind of data stream is repeated.

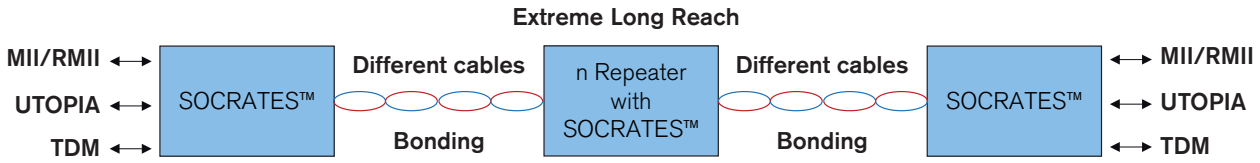


Figure 5:
SHDSL connection with repeater

A big advantage of SHDSL is that Remote Power Feeding (RPF) can be implemented.

In Figure 6 two possibilities for RPF of two repeaters are demonstrated. In the first case, the SHDSL node on the left side feeds power to both repeaters and the SHDSL node on the right side.

In the second case both repeaters are remotely powered by the nearest SHDSL node. The line segment between both repeaters is used only for data transmission.

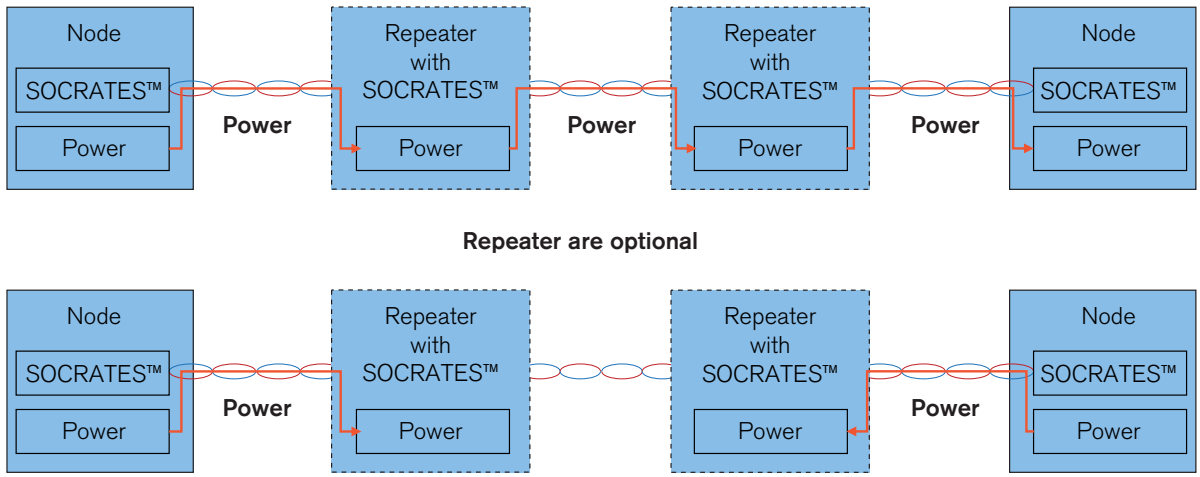


Figure 6:
RPF-examples for SHDSL repeaters

Party Line Applications

In addition to the simple P2P application, party line application with data add and drop functionalities in every node as shown in Figure 7 can also be created.

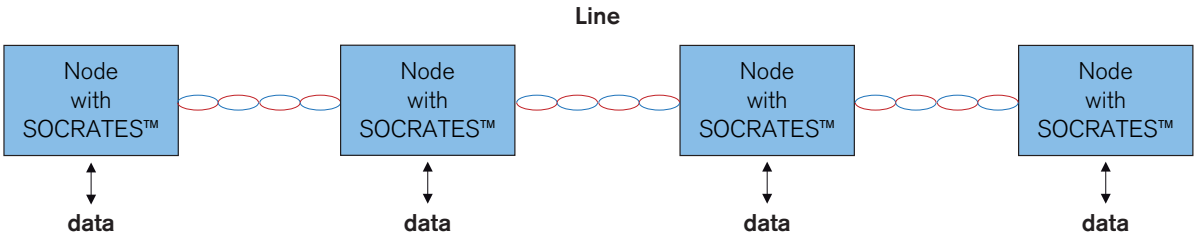


Figure 7:
SHDSL party line application

Point-to-Multipoint Applications (DSLAM)

In telecommunication access networks P2MP applications are well known. The "point" is the CO and the "multipoints" are the CPEs. The structure of such a network is shown in Figure 8.

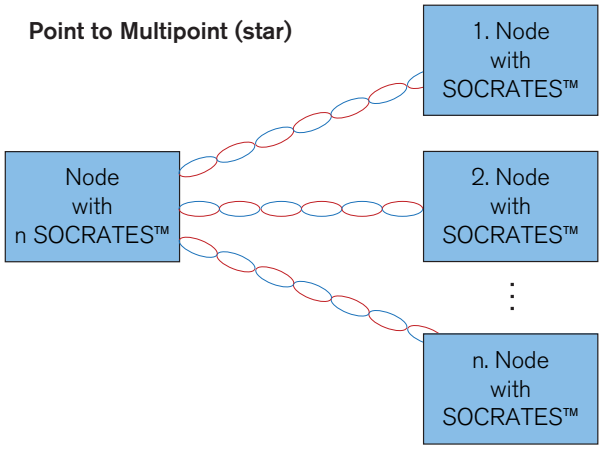


Figure 8:
SHDSL P2MP application

The connections between the central node and the other SHDSL nodes can be realized also as multi-pair lines (including repeaters and RPF). RPF may realize with typical power feeding equipment. Figure 9 shows an application example where PoE equipment is used for the power supply.

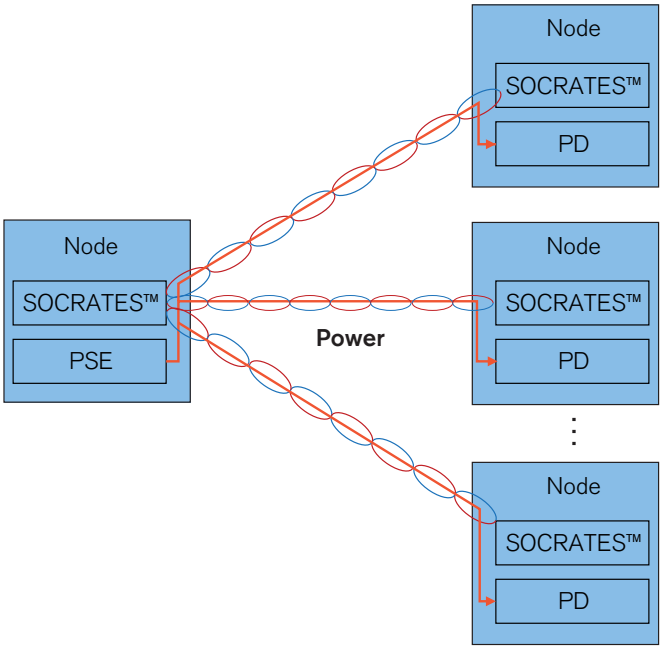


Figure 9:
SHDSL P2MP application example with PoE (PSE – Power Source Equipment; PD – Powered Device)

Ring Applications

SHDSL allows also applications not only in P2P or P2MP structures. For illustration a ring application is shown in Figure 10. All nodes can be a part of a ring structure, so that redundant structures can be built.

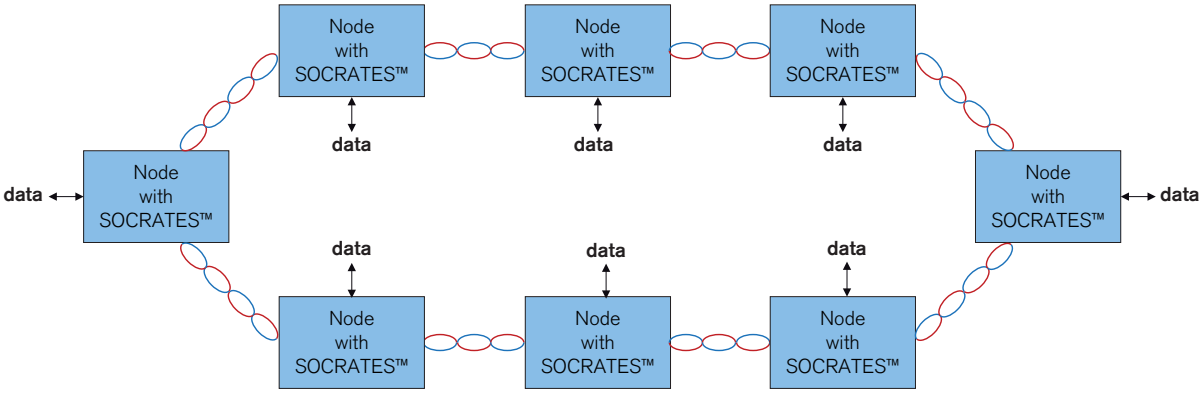
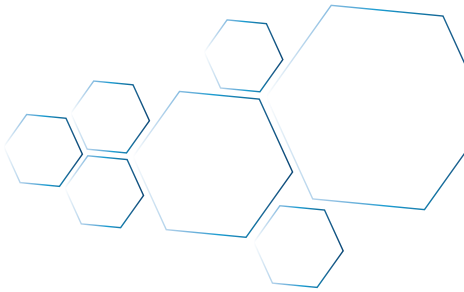


Figure 10:
SHDSL ring application with Add-drop capabilities (e.g. Ethernet forward, add, drop via standard Ethernet Switch)

The SHDSL Market

Worldwide SHDSL port shipments are growing. Operators remain committed to SHDSL-based business access services to this day, and growth in emerging markets is a big driver of worldwide sales in recent times. With the proliferation of SHDSL into industrial and enterprise markets,



the technology has returned to the impressive market growth rates of the early days. The Lantiq SOCRATES™ SHDSL chip has become the de-facto SHDSL standard and gained a very strong market position in recent years. It's a natural solution of choice for new designs.

Be Inspired

The unique data rate and reach capabilities of the Lantiq SOCRATES™ provides broadband connectivity beyond the reach of other technologies in the market. Teleconnect and Lantiq can help equipment makers, operators and enterprises to add the technology to their applications. We also want to inspire experienced SHDSL designers to diversify into new markets. More than fifteen years after its first market introduction as broadband access technology, SHDSL has gained a second life in industrial and enterprise applications.

Get in Touch

We are at the heart of the SHDSL ecosystem. We can help anybody find the right solution for long reach broadband connectivity and the best OEM, ODM, EMS and design partner. Please contact

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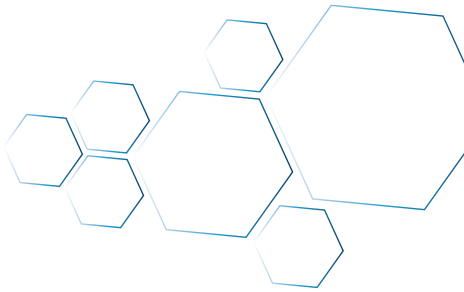
Terminology

A	
ATM	Asynchronous Transfer Mode
C	
CO	Central Office
CPE	Customer Premises Equipment
CTC	Crosstalk Canceller
D	
DSL	Digital Subscriber Line
E	
EFM	Ethernet First Mile according to IEEE 802.3-2004
EOC	Embedded Operational Channel
H	
HDSL	High Data Rate DSL
I	
IEEE	Institute of Electrical and Electronics Engineers
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
L	
LBGA	Low-Profile Ball Grid Array
LLC	Logical Link Control
MMII	Media Independent Interface
N	
NWP	Network Processor
P	
P2MP	Point-to-Multipoint
P2P	Point-to-Point
PAF	PME Aggregation Function according to IEEE 802.3-2004
PD	Powered Device
PDH	Plesiochronous Digital Hierarchy
PHY	Physical Layer Device
PoE	Power over Ethernet



POTS	Plain Old Telephone Service
PSD	Power Spectral Density
PSE	Power Source Equipment
R	
RFC	Request for Comment
RPF	Remote Power Feeding
S	
SDSL	Symmetric single pair high bitrate DSL
SHDSL	Single-Pair High Speed DSL
SRU-R	SHDSL Regenerator Unit RT side
SS-SMII	Source Synchronous Serial MII
STU	SHDSL Terminal Unit
STU-C	SHDSL Terminal Unit COT side
STU-R	SHDSL Terminal Unit RT side
T	
TC-PAM	Trellis Coded Pulse Amplitude Modulation
TDM	Time Division Multiplexing
U	
UTOPIA	Universal Test and Operations Physical Layer Interface for ATM