DESIGN OF SYSTEMS ON SILICON

In-Home Technology Description

Corporate Headquarters

Design of Systems on Silicon
Charles Robert Darwin, 2
46980 Paterna – Valencia
Spain

Tel: +34.96.136.6004
Fax: +34.96.136.6250
WWW: http://www.ds2.es
Email: info@ds2.es

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1 Introduction

With the DSS90XX architecture, DS2 provides a family of chips designed with the required flexibility and throughput capabilities for home networking applications using powerlines. ICs like the DSS9010 and DSS9011, which have been specially designed for audio/video in-home applications, share the same physical layer characteristics with the rest of ICs in the DSS90XX series, allowing seamless integration of access and in-home powerline networks. Advanced OFDM modulation provides the ability to cope with the changing characteristics of the powerline channel using high-density constellations that provide a throughput of up to 200 Mbps.

The DSS9001, DSS9010 and DSS9011 can be easily integrated with the DSS7700, which provides a single analog front end, perfectly adapted for PLC. The DSS7700 contains very low noise, low distortion amplifiers demanded by dense OFDM applications. Assembled in a 48-pin QFN package, the devices run from a single 5V supply, and provide advanced features such as power down control for each block and a programmable gain amplifier for automatic gain control.

Multi-Application with Multi-MAC Support

All DSS90XX ICs support multiple Medium Access Control protocols each one optimized for a different application. Support for slave mode in the DS2 Access MAC ensures that the DSS9010 can be used for low-cost customer premises equipment in PLC access and in-building deployment. Support for an In-Home AV MAC makes the device suitable for deployment in home networking, allowing networks to support multiple classes of service. Each DSS90XX in a network can be programmed to support the class of service optimized for its application.

Plug-and-Play Auto-Configuration

DSS90XX ICs support a full set of auto-configuration features ensuring that end users have an immediate out-of-the box plug-and-play experience. All aspects of network configuration can be set up automatically such as network domain and passwords, quality of service levels, frequency selection, etc.

The Only Solution with Whole House Video Coverage

Because it is not attenuated by walls, DS2 PLC technology is the only whole home coverage solution for high-speed digital video. Unlike wireless, PLC's deployment characteristics are also far more predictable improving the end-user experience.

Addressing the Triple-Play Market

The competitive pressures in the broadband market are forcing telecommunications service providers to offer more complete services. One key trend is the provision of video services by DSL providers, who are competing with cable companies to provide "Triple Play" services consisting of video, voice and data using only the telephony twisted pair.

One of the most important barriers to the provision of these services is the fact that the entry points of the twisted pair into the home is seldom close to the television, leaving the home owner and the service provider with the problem of connecting the tens of meters which separate the television with the phone socket, or more specifically the set top box with the residential gateway. This connection poses a problem for operators because potential customers are not willing to add new cabling in their home, and because the installation of customer premises wiring represents an expensive contribution to the operator's costs.

Providing a Better IPTV Service

Installing fixed wiring to distribute digital video around the home is not only expensive for operators and unappealing for subscribers, but also restricts the places in the home where subscribers can use services to those where new wiring has been installed. With DS2 PLC it is possible to enjoy Triple Play services anywhere in the home, or deploy multiple services, for example having one set top box for video in the living room and another in the bedroom.

Acceptance by Subscribers

In many cases subscribers are unwilling to upgrade to Triple Play services either because of the inconvenience of home wiring or for aesthetic reasons. Consumer resistance to new home wiring places a severe limitation on the available market for Triple Play services. DS2 PLC is a no new wires solution. This means that a complete home installation can be done without drilling a single hole or extending any structured cabling.

Adding Value through Home Networking

Many operators are currently looking at ways to make their offer more attractive, adding value to their broadband services. DS2 PLC technology allows operators to provide subscribers with building a complete home media network, allowing photos, home-movies and other content stored on a home PC, as well as IPTV and video-on-demand services, to be viewed on a TV set anywhere in the home.

Features

- 200 Mbps capacity
- QoS for simultaneous real-time multimedia applications
- Programmable bandwidth and latency allocation
- Flexible MAC for access or in-home AV applications
- Advanced networking features: 802.1q VLANs with optimized extensions
- Plug-and-play auto-configuration
- Efficient support for neighboring networks
- Multicast for video and audio distribution
- Standard, easy to use network management
- Powerful error correction system
- Integrated 802.1D Ethernet bridge
- Fast Ethernet, SPI, UART, GPIO support
- Advanced security for personal privacy and network integrity
- Flexible frequency configuration
- Flexible API and software development tools
- Designed for access/in-home coexistence
- Remotely programmable notching for global regulatory compliance

Applications

The DS390XX family has been designed for use in a variety of audio/visual home networking applications.

Figure 1: Audio/Visual Home Networking Application using DSS90XX ICs

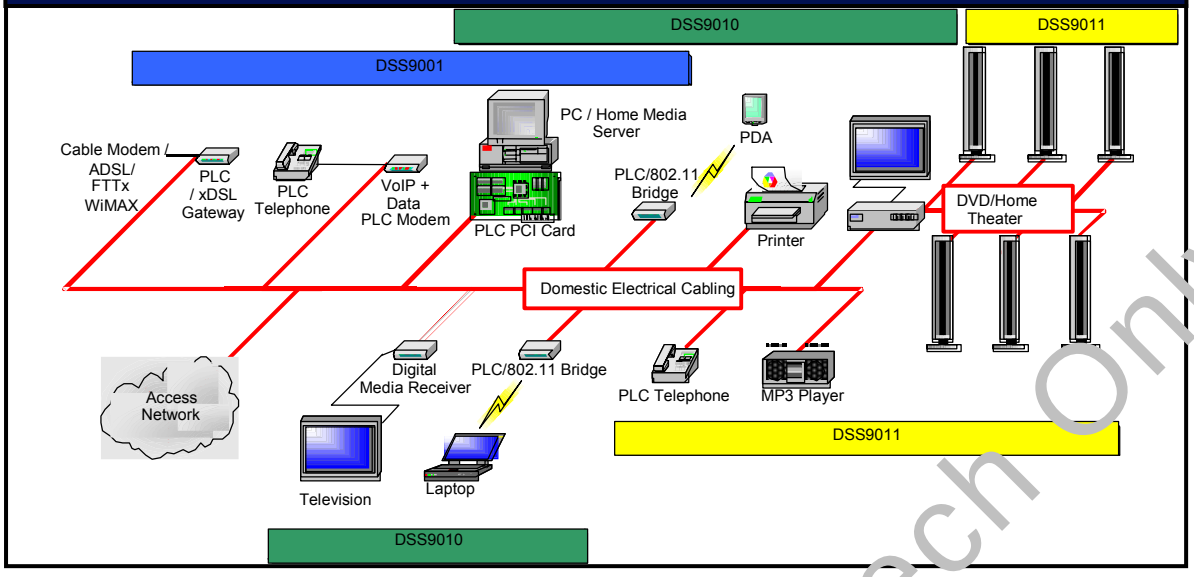


Figure 1 depicts some examples of devices and applications that can be built around the DSS90XX IC family. Possible uses range from traditional low-speed applications (like sharing a broadband Internet connection or a networked printer) to the most demanding high-speed audio/visual applications like house-wide HDTV streaming (sharing of a DVR, extension of video-over-DSL service for Triple Play applications, etc.). Simultaneously, the network can support any type of IP-based applications like VoIP, video-surveillance cameras, MP3 audio streaming, etc.

Thanks to the wide range of reference designs provided by DS2, DSS90XX ICs can be embedded in several types of devices:

- AV adapters like Ethernet-to-PLC or USB-to-PLC
- High-Definition TV distribution systems (TVs, Set Top Boxes, DVRs)
- CPEs (DSL-to-powerline or cable modem-to-powerline)
- Video-surveillance systems

2 Physical Layer Description

DS2 technology provides the highest-performance low-cost PLC solution for high-speed communications over medium and low voltage networks. DS2's fully integrated OFDM technology delivers by far the highest throughput on the market: more than 200 Mbps.

In addition to high efficiency, DS2's OFDM provides the most flexible, robust, adaptable, and controllable transmission capabilities on the market, as well as mechanisms to avoid radio-sensitive frequency ranges.

2.1 Operation Modes

DSS90XX products allow communicating by means of selecting the spectrum bandwidth and location. In this way there are three physical main operation modes (10, 20 and 30 MHz), depending on the bandwidth of the signal injected onto the powerline, whose spectral location is fully programmable between 1 and 34 MHz.

The default configuration has twelve operation modes, as is shown in Table 1. The number of modes and its location in the band can be configured using the development Application Programming Interface (API).

Table 1: Default Configuration

MODE	BANDWIDTH (MHz)	FROM (MHz)	TO (MHz)
1	10	3	13
2	10	13.5	23.5
3	10	24	34
4	20	3	23
5	20	14	34
6	30	4	34
7	5	2	7
8	5	7.85	12.85
9	20	14	34
10	10	2	12
11	26.15	7.85	34
12	20	7.85	27.85

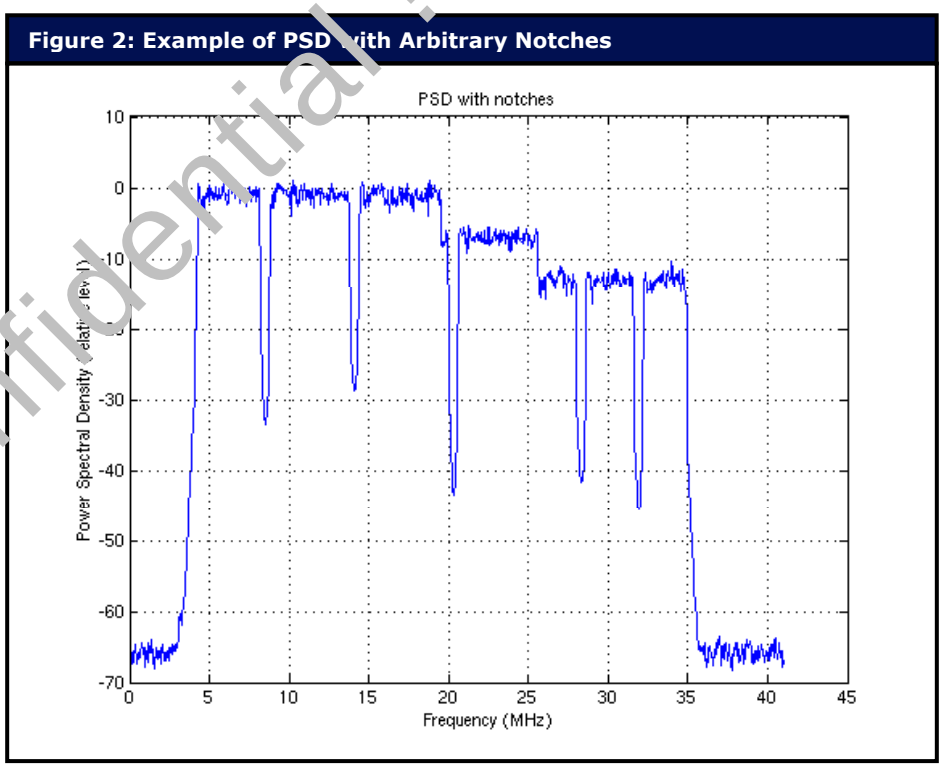
2.2 Power Levels

The physical layer is very robust to ingress noise, supporting interference levels 25dB above the received signal. It has the following characteristics:

- PSD (Power Spectral Density): ≤ -50dBm/Hz
- Transmission power step: 1 dB.
- Dynamic range: 73dB (DH10E reference design), 79 dB (DU100 reference design).
- Minimum required received power level: -70 dBm (without any environment noise)

The PSD of the signal can be modified with high precision to achieve narrow notches without impacting capacity in order to comply with regulations.

Figure 2: Example of PSD with Arbitrary Notches



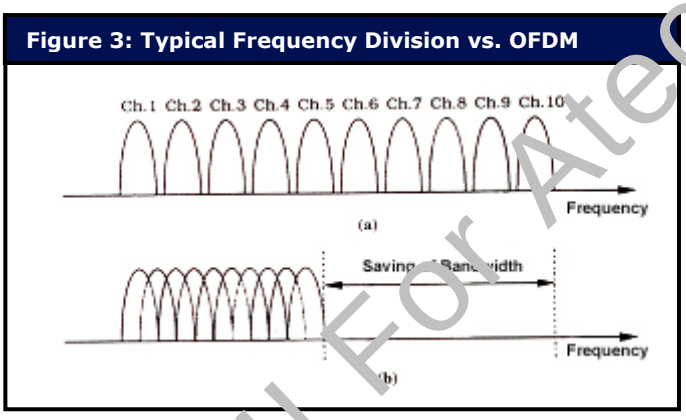
2.3 Modulation Schemes and Coding

2.3.1 Modulation

DS2 technology is based on OFDM modulation. OFDM is not a new technology and is being used in many other communication systems such as ADSL, VDSL, DAB, and DVB, to name a few. Using OFDM has allowed companies with these technologies to obtain high data rates in adverse conditions.

There are many forms of modulation that could be used over the powerline, but after sophisticated measurements DS2 identified OFDM as the most suitable because it was the most immune to powerline interference, providing the highest level of spectral efficiency and performance, as has been proved by DS2's first generation of products. Specifically, OFDM is very robust against frequency selective fading channels and large time spreads. It is a special case of multi-carrier transmission that uses several subcarriers to communicate. It is both a modulation and a multiplexing technique. Using more than 1000 carriers offers the flexibility that if a carrier is working in a space with a lot of interference on that carrier, then it can be disregarded while transmission continues on the remaining carriers, thus avoiding this interference and ensuring reliable communications.

Figure 3: Typical Frequency Division vs. OFDM



The typical frequency division data system divides the frequency band into N non-overlapping frequency channels as shown in (a) of Figure 3, and because there is no overlapping there is no inter-carrier interference. The disadvantage of this system is inefficient use of the spectrum.

On the other hand, OFDM uses overlapped sub-channels, (b) in Figure 3, and orthogonality between different modulated carriers. The orthogonality causes the carriers to be linearly independent and carrier spacing to be a multiple of 1/T. Entire number of cycles of other carriers in the symbol period T implies that there is no contribution from all but one carrier at the integration.

FFT can be used to obtain the contribution of a carrier without crosstalk; there is no need for subcarrier oscillators. OFDM is a sum of subcarriers that are modulated using any linear modulation such as Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM). The DS2 system uses a proprietary High Density Advanced Modulation at each subcarrier of the OFDM signal.

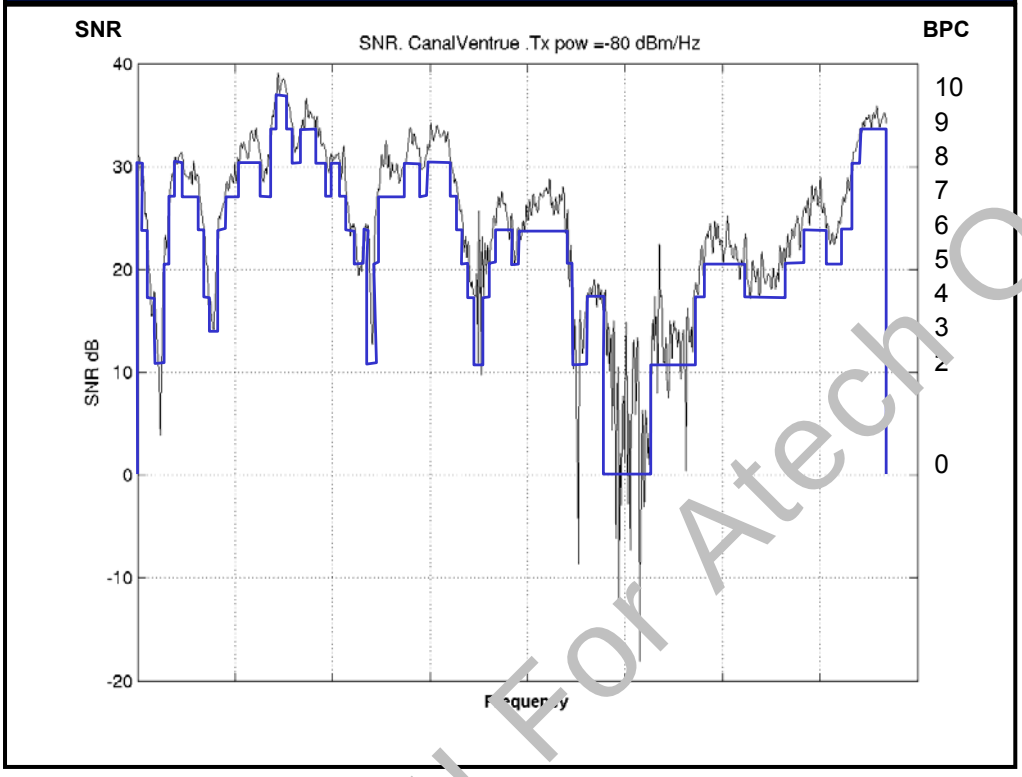
The main advantages of OFDM are:

- It is efficient in multi-path fading channels with large time spreads, i.e. powerline.
- The data rate per subcarrier is adaptable (according to the SNR detected at this subcarrier).
- Interferences (and impulsive noise) only affect some carriers while the remaining carriers ensure reliable communications.

Each operation mode (10, 20 and 30 MHz) has more than 1000 subcarriers. DS2's system uses the highest number of carriers of all competing PLC technologies.

Modulation parameters are adapted in real-time depending on channel quality parameters for each user and for each carrier. Figure 4 depicts an example of this functionality. The SNR is measured for each carrier and the optimum modulation is chosen, with the objective of achieving the maximum transmission speed while maintaining the desired BER.

Figure 4: Dynamic Adaptation of Modulation as function of Channel Quality



2.3.2 Coding and Channel Quality Monitoring

DS2 technology employs several coding mechanisms:

- Adaptive per-carrier modulation
- Reed-Solomon Forward Error Correction
- Interleaving
- 4D Trellis Coded Modulation

Optimum values for the coding mechanisms are computed by the PLC modems automatically depending on channel quality measurements (Signal-to-Noise Ratio, error packets, etc.), although they can be configured by the product manufacturer.

2.3.3 Bit Error Rate

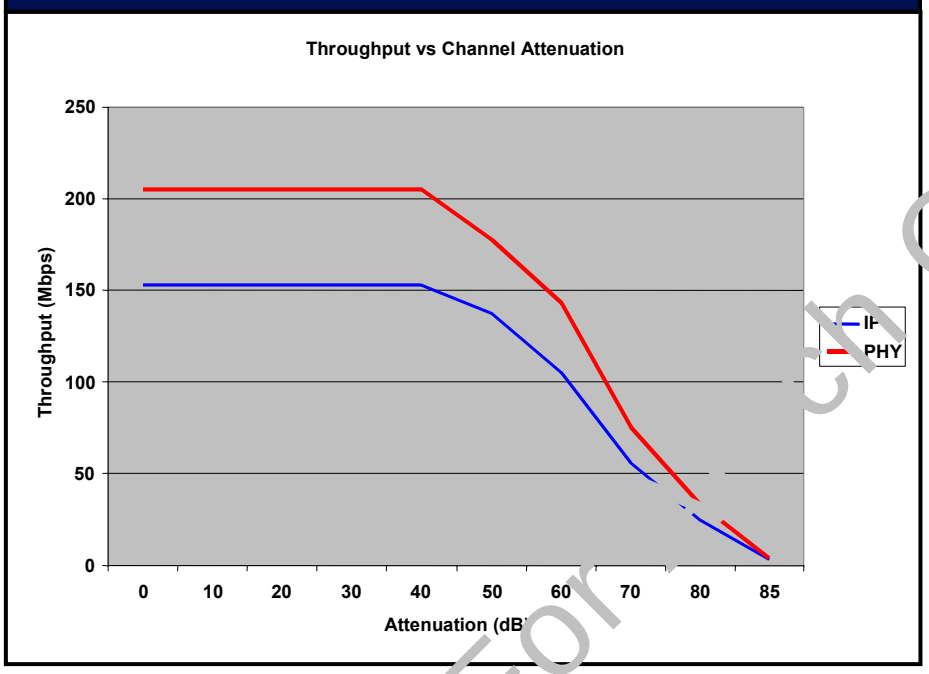
The Bit Error Rate (BER) characteristics of the technology are fully programmable in order to meet QoS requirements for any possible services. The bit-loading algorithms of each node can be configured by the product manufacturer, who can make any trade-off between BER and capacity. Default values for BER are 10^{-9} for 1500-byte packets, although the configuration can be changed for increasing or decreasing the BER as needed (typical values are 10^{-3}, 10^{-6} and 10^{-9}).

2.3.4 Performance

Performance is not only dependent on channel attenuation or noise, but also on the number of taps, so it is difficult to provide a formula that is useful for any environment.

The following figure shows laboratory measurements performed with flat-channel attenuators, a default conservative BER configuration, and an output PSD of –56 dBm and a bandwidth of 30 MHz. The graph shows performance both at the PHY level and IP level (note that in order to obtain IP-layer performance above 100Mbps, a DSS9003 chip with Gigabit Ethernet interface is required).

Figure 5: System Performance as a Function of Channel Attenuation



2.4 Channel Adaptation

The system is continuously monitoring the channel attenuation and the noise level with a very high spectral resolution. Information from these measurements is used for adapting the modulation parameters per carrier in order to optimize data capacity while keeping a bounded BER.

- Algorithm agility
- Modulation thresholds
- Desired BER
- Disabled carriers

2.5 Spectral Efficiency

The spectral efficiency is up to 9 bits/sec/Hz, the highest available on the market.

The spectral efficiency used depends on the actual channel conditions (SNR). If the SNR of the channel degrades, the system automatically decreases the spectral efficiency in order to guarantee that the BER remains below the specified limit.

3 MAC (Media Access Control)

DSS90XX chips implement layer-1 (PHY) and layer-2 (DLL and MAC) of the OSI reference model. They integrate a powerline 802.1D-based switch that supports traffic priorities for QoS policies and encryption to assure the privacy of the communications.

DS2's chips feature MAC specifically designed for QoS-demanding audio/visual applications. This MAC, called In-Home AV, is a master/slave MAC providing guaranteed bandwidth and latency, traffic priorities, Layer-2 ACKs, and support for neighboring networks.

For home networking applications, the In-Home AV MAC features enough performance and QoS levels to satisfy the most demanding multimedia application, while at the same time providing the ease-of-use and plug-and-play capabilities required by home users.

3.1.1 Multiple Network Support

Each in-home network is composed of an access point and a set of end points. The access point is in charge of sharing the channel access within the nodes of one network.

In the case that two or more networks share the same powerlines, one of the access points becomes a "QoS Controller" (QC). The QC is responsible for controlling how the different networks share the channel, avoiding collisions and interferences.

3.1.2 Maximum Number of Neighboring Nodes

In a DSS900X network, the maximum number of devices with which a given node can communicate directly (neighboring nodes) is limited. The maximum number of neighboring nodes that a node can handle at the same time is related to the amount of information that has to be stored and managed per neighbor. So, the maximum number of active neighboring nodes depends on the DSS90XX chip and is detailed in the following table.

Table 2: Max. Number of Active Neighboring Nodes

CHIPSET	MAXIMUM NEIGHBORING NODES
DSS9011	1
DSS9010	16
DSS9001	32
DSS9002	64
DSS9003	128

3.1.3 Maximum Number of MAC Addresses

DSS90XX chips perform Layer-2 frame forwarding according to the IEEE 802.1D standard. In order to do this, the embedded bridge inside each chip needs to learn the location of all MAC addresses involved in data communication. The maximum size of the learning table depends on the DSS90XX chip and is detailed in the following table.

Table 3: Max. Number of MAC Addresses

CHIPSET	MAXIMUM MAC ADDRESSES
DSS9011	1
DSS9010	16
DSS9001	64
DSS9002	1024
DSS9003	262144

4 QoS (Quality of Service)

DSS90XX advanced In-Home AV MAC includes several features that guarantee that the network can simultaneously support several applications with different levels of bandwidth and latency requirements, like Internet Access, VoIP, video streaming, etc.

Quality of Service (QoS) capabilities include multiple priority levels and strict bandwidth and latency guarantees.

In a scenario with several neighboring networks, the QoS controller distributes bandwidth amongst the different networks depending on the QoS requirements of each application. An advanced protocol that coordinates all neighboring access points makes sure that each network gets the bandwidth and latency required by QoS-demanding applications.

4.1 Traffic Prioritization

There are eight possible priority levels. Table 4 shows a list of applications and their priorities.

Table 4: Traffic Prioritization

PRIORITY	APPLICATION
P7	Firmware packets (STP, PSP, BPC, QoS management, etc.)
P6	VoIP
P5	Games
P4	Streaming Media
P3	FTP
P2	Web Browsing
P1, P0	Other

P7 is the highest priority. It should be dedicated to internal signaling. The rest of the priorities are ordered in decreasing latency requirements.

Every priority has an implicit maximum latency and jitter, which are defined by the product manufacturer. The priority-application pair, as shown in Table 4, is only an example. The product manufacturer may want to redefine its priorities, which are fully programmable.

Only DSS9001 chips support multiple priorities simultaneously. DSS9010 and DSS9011 support only one priority per device, although this priority level can be programmed. This means that, for devices that need to handle several different traffic types (for example, advanced media servers transmitting both audio, video and data), DSS9001 is recommended. For simple applications in which a single type of traffic is being transmitted, DSS9010 and DSS9011 are enough.

4.2 Multicast Support

The majority of video distribution applications, especially in the Triple Play market, make an extensive use of multicast transmission. Multicast reduces bandwidth requirements in the backbone network, thus reducing operation costs.

DSS90XX provides two methods for handling multicast traffic:

1. Broadcasting of multicast packets, sending one copy to all end points in the network.
2. Intelligent forwarding of multicast packets only to those end points "interested" in receiving the multicast contents.

The first method is the default behavior, and provides transparent handling of multicast streams without requiring any configuration.

The second method provides additional performance (as less bandwidth is used in the powerline network). The list of end points that should receive each multicast stream can be easily selected by means of HTTP commands (other interfaces, like SNMP or configuration files can also be added, if required). The advantage of the HTTP interface is that it can be used both by end users (by means of any web browser) and by automatic network provisioning tools.

5 Security

5.1 Network Isolation

Each powerline device can be configured with a network identifier. Using this network identifier, end users can make sure that their devices connect to the right network, and not with another network installed in a neighboring house (in the unlikely case that the signal from one house leaks into another house).

5.2 Encryption

In addition to the basic network isolation described above, the DSS90XX may use strong encryption. DSS90XX encryption is a combination of 3DES and DES. The procedure ensures high encryption security by using 3DES encryption for long-term information (encryption key) and short key life (one single data burst) for DES encryption, thus enabling a low-cost, high-speed hardware implementation.

5.3 Configuration and Network Management Mechanisms

All PLC devices possess a default configuration that makes them plug-and-play appliances.

In case the user or the service operator want a specific tuning of their working parameters, DS2's products based on the DSS90XX family allow for three different mechanisms of configuration and management.

The first is by means of a web page. Using the web page that DS2's products incorporate, network parameters and traffic priority, as well as security and encryption, can be configured.

The second is related to providing the service operator with the possibility of remotely controlling in-home PLC networks. Therefore, all nodes can have their networking parameters, like IP address, default gateway or subnet mask, automatically configured from a central management system using DHCP. The embedded DHCP client also supports configuration file downloading, reducing even further the effort needed to manage the network. The configuration of each node is stored in a central database, and the device downloads the updated configuration every time it boots.

The third configuration and management method is SNMP. All of the products based on the DSS90XX family can be remotely managed using SNMP. The robust SNMP agent embedded in every IC implements both standard (RFC 1213) and extended DS2 MIBs. The use of the SNMP agent is oriented towards requesting information from the nodes to check the network state, generate alarms, and help the troubleshooting process.

6 Coexistence with other Powerline Networks

Currently, powerline networks are being used for a variety of different applications. These applications may have different requirements in terms of performance, coverage, cost, flexibility, etc. Because of this, several technologies exist now, each one targeted for a different set of applications and services, all of them potentially sharing the same network at the same time. Not all of these technologies are interoperable, so in some cases, modems based on one technology cannot talk to modems based on another technology.

6.1 Classification of Powerline Technologies

The majority of applications for powerline communications in the in-home environment can be classified in the following three main groups:

- Narrowband powerline communication, for home automation applications
- Broadband powerline access, for VoIP and Internet access
- Broadband powerline in-home networking for data and audio/video applications

Narrowband powerline makes use of the lower part of the frequency spectrum (well below 1MHz), while broadband powerline uses the range between 1.6 MHz and 30 MHz. Because of this, narrowband and broadband powerline networks are typically not aware of each other, and can operate simultaneously on the same powerline with any problem related to interference or collisions.

On the other hand, both broadband access and in-home networking can use the same part of the spectrum, so there is potential for interference and collision between both networks unless coexistence mechanisms are implemented.

6.2 Coexistence between Access and In-Home

DS2 is the only company providing a PLC solution for access and in-home that supports the possibility of the coexistence mechanisms being proposed by the standardization bodies (ETSI and CENELEC).

The coexistence issue is considered to be a major issue, and therefore DS2 has taken active responsibility in proposing and promoting the technical solution. DS2's representative is responsible for the work items in ETSI PLT and in CENELEC SC205A WG10 that deal with this subject and has contributed to the documents that have been promoted by each body. Both bodies are proposing a very similar technical solution based on splitting the whole frequency band into two parts when two solutions have to coexist: the lower sub-band for access and the higher sub-band for in-home.

A Joint Task Force (JTF) between ETSI PLT and CENELEC SC205A WG10 has been created with the objective of agreeing to a common frequency split. DS2's representative is the chairman of this JTF.

As described in Section 2.2, DS2's PLC technology allows choosing the frequency bandwidth and location depending on the final definition coming from the standardization bodies. Having the most efficient technology, the highest performance is achieved for each sub-band and hence each sub-band can be used for any service application.

Other technologies that do not support this frequency split will not be compatible with this ETSI/CENELEC standard, and will probably become obsolete once these universal coexistence mechanisms are enforced.

6.3 Coexistence with Neighboring In-Home Networks

In the unlikely case in which a signal from the powerline network in one house leaks into another house, there is the potential for interference and/or collisions between networks. The DSS90XX architecture addresses this issue by means of the advanced in-home AV mechanisms described in Section 3.1.1. The In-Home AV MAC guarantees that one of the access points is elected as the QoS controller, coordinating all neighboring networks and making sure that collisions are completely avoided.

7 Radiation and EMC

7.1 EMC Levels

The strength of radiated electric fields is very dependent on the injection mode and electrical cabling type and topology. Large variations can be expected. Nevertheless, the FCC Part 15 limits are always met, even in the very worst cases.

The spectral distribution of the transmission output voltage is a flat level up to 30 MHz bandwidth that can be placed anywhere from 1 to 34 MHz. The voltage level is flexible.

The output power is programmable from –110 dBm/Hz to –50 dBm/Hz, which allows DS2 to be compliant with FCC Part 15 and other regulations.

The system has the ability to configure the output power on a carrier-by-carrier basis. That is to say, the output powermask can be programmed the way it is desired. This feature allows the system to achieve spectral notches with the bandwidth and depth required, as shown in Figure 2.

8 API (Application Programming Interface)

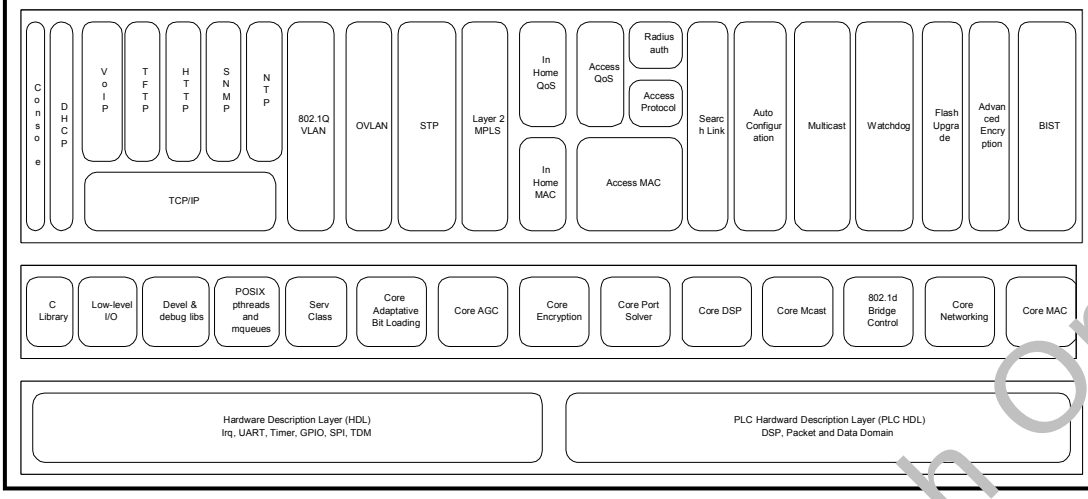
The DSS90XX contains a high-performance embedded processor, which, together with the API and development environment provided by DS2, allows manufacturers to easily create custom applications at a very low cost.

The software running in the embedded microprocessor has a layered architecture:

- **HDL (Hardware Description Library) layer:** Software components that encapsulate the access to the hardware (HW). Though this layer is mostly private, some public API is provided. Using this layer, product developers can change some HW components of the basic reference design, in order to reduce costs or add new functionality.
- **Core layer:** Software components that implement the basic functionality of a PLC modem, including the OS. Product developers may change several configuration and performance-tuning parameters of the components at the core layer without affecting the compatibility between DS2 basic reference designs.
- **Application layer:** Applications and protocols that implement all of the high-level functionality. Product developers may add or change modules at this level, adding new applications and/or networking protocols.

As Figure 6 shows, each layer is composed of several independent modules, which can be added or removed depending on specific customers needs.

Figure 6: Modular Application Programming Interface



9 DSS90XX ICs Feature Comparison

Table 5 depicts the main differences between the three DSS90XX ICs designed for the in-home market:

Table 5: Feature Comparison for DSS9001, DSS9010 and DSS9011 ICs

	DSS9011	DSS9010	DSS9001
	Access MAC Support		
Master Mode			●
TD Repeat Mode			●
Slave Mode	●	●	●
FD Repeater Support			●
	In-Home AV MAC Support		
End Point	●	●	●
Access Point		●	●
Number of Supported MACs	1	16	64
	Interfaces		
TDM Port	●		●
Single MII Interface		●	●
SPI Interface	●	●	●
UART	●	●	●
GPIO	●	●	●
	Encryption Support		
3DES Encryption	●	●	●
Multi-key Encryption			●
	QoS Support		
Programmable Priority Schemes			●
Priority Sniffing			●
Frame Rule Matching			●
Contention Based Prioritization	●	●	●
Buffer Space Allocation			●

Table 5: Feature Comparison for DSS9001, DSS9010 and DSS9011 ICs			
	DSS9011	DSS9010	DSS9001
	Traffic Engineering		
Bridge Support		●	●
Number of Supported MACs	1	16	64
MAC Filtering			●
STP	●	●	●
802.1Q VLAN		●	●
OVLAN			●

These differences in features and available interfaces make each IC suited for specific applications. Table 6 is a part selection guide that tries to help the reader chose the best IC for each specific application.

Table 6: DSS90XX Part Selection Guide			
	DSS9011	DSS9010	DSS9001
	Home Automation		
Smart Appliances		●	
Home Control		●	
	Home Theater		
Remote Speakers	●		
DVD Player		●	
	Home Media Networks		
MP3 Player	●		
Video Digital Media Receiver		●	
Home Media PCI Card		●	
Home Media Server		●	●
	Home Data Networks		
FTTh Gateway		●	●
Home Data LAN Node		●	●
WiFi Extender		●	●
	In-Building Networks		
Combined VoIP/Data Modem			●
PLC VoIP Terminal	●		
PLC Video Conferencing Terminal		●	●
Data Only CPE		●	
Second Access CPE		●	●
Access to Building Gateway			●
In-Building Signal Booster			●

10 Reference Designs

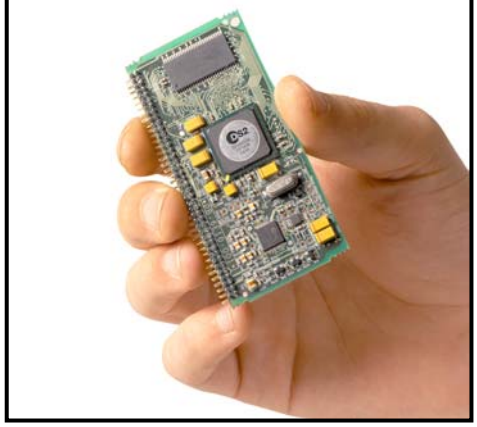
DS2 provides complete reference designs to shorten time-to-market. The following in-home reference designs are available:

- **Ethernet adapter:** This Ethernet-to-PLC external wall plug device provides one Ethernet connector as data interface and an integrated AC plug. The power supply and the coupling unit are built-in. Thermal range goes from 0 to 40° C and dissipated power is around 5W. The module is available in both wall mount and desktop format.

Figure 7: Ethernet Wall Plug

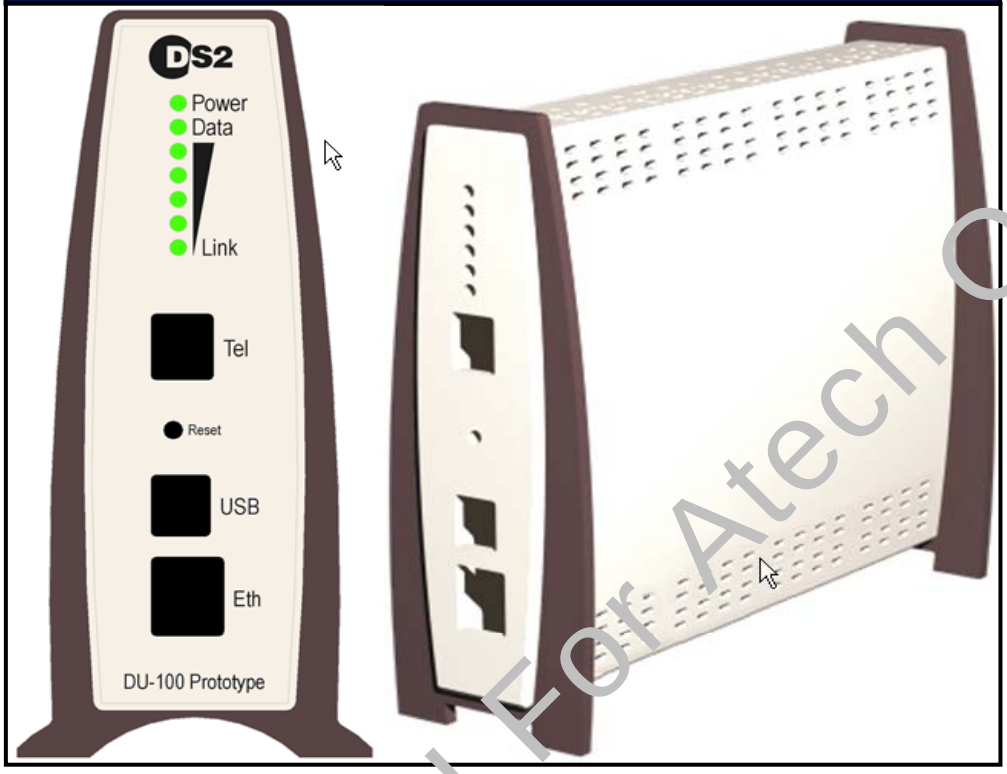
- **Embedded module:** This design eases the integration into existing applications. The module provides an MII application interface and a 2-wire analog PLC interface with integrated low-cost AFE. It accepts 5V and 3.3V power supplies.

Figure 8: Embedded Modules



- **Access CPE (Customer Premises Equipment):** This device is designed to be used as the last element in a broadband powerline access network. In addition to the Fast Ethernet port, it also features an embedded VoIP gateway, allowing operators to provide telephony services in addition to Internet Access.

Figure 9: Access CPE



10.1 Dynamic Range

System performance is highly dependent on the power level of the received signal and on the amount of noise found in the powerline. Because of differences in transmitted power levels and also in receiver sensitivity, each reference design can support a different maximum level of signal attenuation. This "maximum supported attenuation" is also known as "dynamic range".

If the channel attenuation between the transmitter and receiver is higher than the dynamic range, the systems stops working reliably.

Table 7 shows the dynamic margin for the different reference designs:

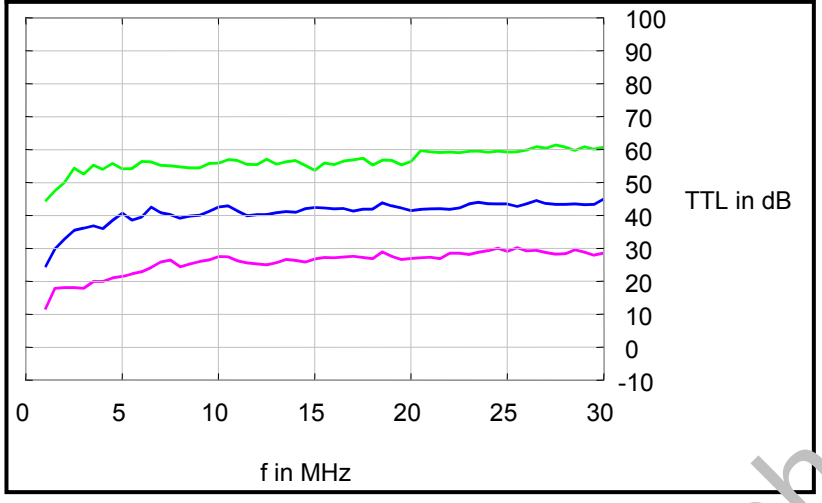
Table 7: Dynamic Margin

REFERENCE DESIGN	DYNAMIC RANGE
DH10E (Wall Mount or Desktop)	73 dB
DU100 (Access CPE)	79 dB

11 Statistical Performance Analysis (European/Asian Environments)

On December 2003, ETSI published a report (ETSI TR 102 269) with statistical information about transverse transfer loss (i.e.: attenuation) between several hundreds of outlet pairs in houses in Europe, including pairs of outlets in the same or in different flats.

Figure 10



NOTE[1]: Outlet pairs in the same flat/house independent of phase.
NOTE[2]: 80 % (green), 50 % (blue), 20 % (violet) cumulative probability.

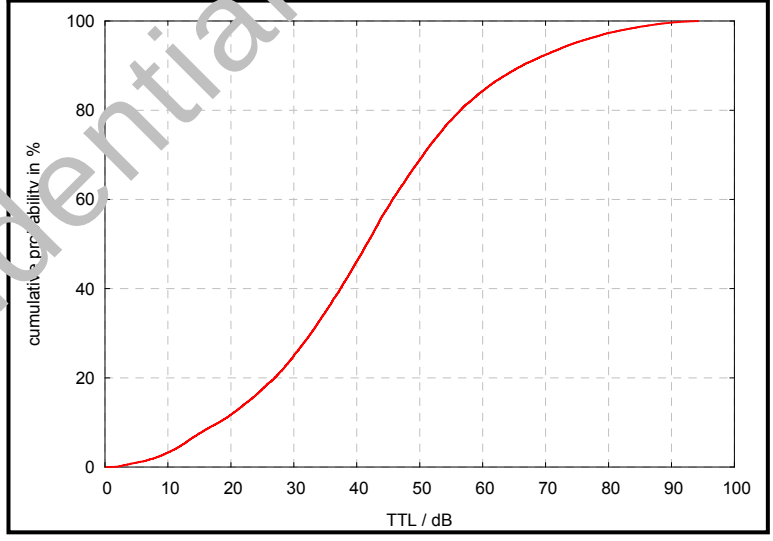
11.1 Main Figures from ETSI TR 102 269

Attenuation between outlets in the **same flat/house**:

- 80% of outlet pairs have an "almost flat" attenuation of **55dB or less.**
- 50% of outlet pairs have an "almost flat" attenuation of **45dB or less.**
- 20% of outlet pairs have an "almost flat" attenuation of **30dB or less.**

As the attenuation statistics are mainly independent of the frequency, the cumulative probability function can be described with the following graphs:

Figure 11



NOTE[1]: Group A: same flat/house independent of phase.

This means that in the majority of the cases (90%), the attenuation between outlets in the same flat is below 65dB. This information can be used to estimate the performance that end-users can expect in this type of environment (European flats).

Figure 12: System Performance as a Function of Channel Attenuation

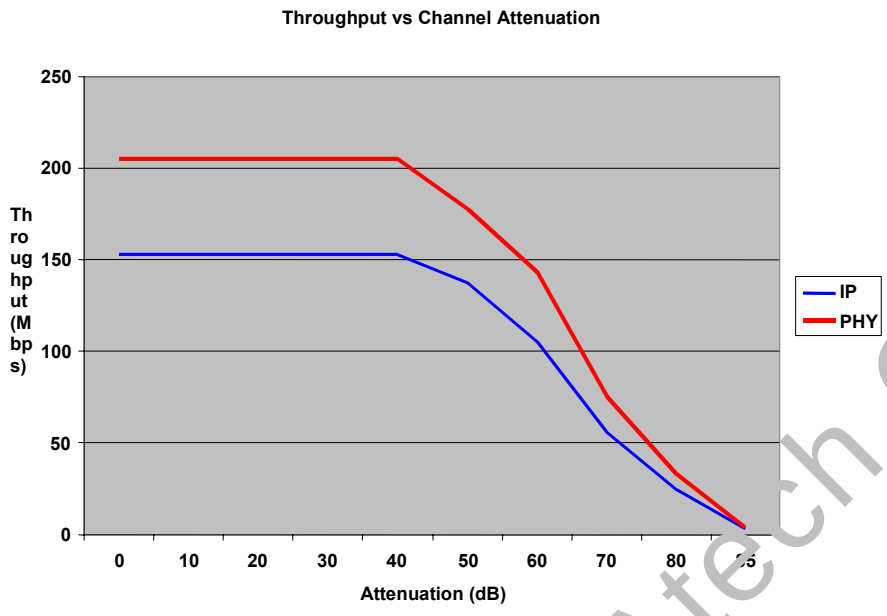


Figure 12 shows that for an attenuation level of 65dB, the expected system performance is 100Mbps at the PHY level, and 75Mbps at the IP level. **This means that in the majority of the cases (90%), end users in European flats will experience performance of 75Mbps or more at the IP level.**

These results can be extrapolated to Asian environments, where a large percentage of the population lives in medium/small-sized flats.

12 Field Results (North American Environments)

In 2004, a series of field tests were conducted in typical North American houses. Three houses of different sizes were chosen: one small house (less than 1500 square feet), one medium-sized house (1500-2500 sq feet) and one large house (more than 2500 sq feet).

For each house, seven outlets were selected, and all possible combinations of outlet pairs were tested, giving a total of 21 outlet pairs. As the throughput tests were done in both directions, the total number of 'paths' was 42. The outlets were chosen based on locations that were reasonably likely to be selected by the end user for data, audio or video applications, like a media center, bedroom TV, computer room, kitchen TV, etc. The set of outlets was selected with the aim of providing a relatively uniform distribution throughout the home, so that a good mix of long and short paths was provided.

A variety of electric and electronic devices common in the home (refrigerators, TV sets, air conditioners, heaters, etc.) were connected during the test.

Ethernet traffic was generated and measured using SmartBits. The tests were performed with the modems operating in the frequency band from 4 to 34 MHz (Mode 6).

Table 8 summarizes the results obtained for each house:

Table 8: Field Results				
HOUSE	**SPEED @ 10% OF OUTLET PAIRS**	**SPEED @ 50% OF OUTLET PAIRS**	**SPEED @ 90% OF OUTLET PAIRS**	**SPEED @ 100% OF OUTLET PAIRS**
Small House	95 Mbps	72 Mbps	52 Mbps	44.9 Mbps
Medium House	82 Mbps	44 Mbps	25 Mbps	12.39 Mbps
Large House	70 Mbps	37 Mbps	20 Mbps	12.5 Mbps

This table should be read as follows:

- 90% of outlet pairs in the small house provided an Ethernet throughput of 52 Mbps or more.
- 100% of outlet pairs in the medium house provided an Ethernet throughput of 12.39 Mbps.

Note that these numbers are "Ethernet throughput" (i.e.: real payload throughput). This needs to be taken into account when comparing them with performance numbers reported by other technologies (for example: 11Mbps for 802.11b, 54 Mbps for 802.11a/g or 14 Mbps for HomePlug 1.0), which are PHY-layer throughput numbers. These PHY layer numbers need to be reduced by 25%-50% (depending on the technology) in order to estimate actual Ethernet throughput.