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Abstract

This deliverable summarizes the different options for a Gigabit space grade Ethernet transceiver. The existing standard (1000BASE-T) as well as standards that are currently under development in IEEE 802.3 are discussed and compared. Then the advantages and disadvantages of each of them are summarized. Finally, a first order approximation of the main requirements for the main analog and digital blocks is given. This will serve as an initial input to the deliverable D7.2 Report on Technical feasibility of space grade 1Gbps Ethernet transceivers.

[1] Dissemination level: **PU** = Public; **PP** = Restricted to other programme participants (including the Commission Services); **RE** = Restricted to a group specified by the consortium (including the Commission Services); **CO** = Confidential, only for members of the consortium (including the Commission Services).
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Disclosure Statement

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List of Acronyms

ACRONYM	MEANING
SEPHY	Space Ethernet PHY
PAM	Pulse Amplitude Modulation
UTP	Unshielded Twisted Pair

Table 1 – List of acronyms.

Executive Summary

This deliverable summarizes the different options for a Gigabit space grade Ethernet transceiver. The existing standard (1000BASE-T) as well as standards that are currently under development in IEEE 802.3 are discussed and compared. Then the advantages and disadvantages of each of them are summarized. Finally, a first order approximation of the main requirements for the main analog and digital blocks is given. This will serve as an initial input to the deliverable D7.2 Report on Technical feasibility of space grade 1Gbps Ethernet transceivers

1 Options

The following Ethernet standards could potentially be used to achieve 1Gbps or more in space:

- 1000BASE-T (IEEE 802.3ab ,1999).
- 1000BASE-T1 PHY Task Force (IEEE P802.3bp).
- Gigabit Ethernet Over Plastic Optical Fiber Task Force (IEEE P802.3bv).
- 2.5/5GBASE-T (IEEE P802.3bz).

The first one, is a proven standard currently used in computing and consumer electronics while the rest are ongoing standardization efforts that will produce a standard before the end of the SEPHY project (although the 2.5G is derived from the field proven 10GBASE-T). Each of them is briefly described in the following subsections.

1.1 1000BASE-T (IEEE 802.3ab)

This standard also known as Gigabit Ethernet was completed in 1999 and hundreds of millions of devices have been installed in a wide variety of systems. It was the UTP standard that followed 100BASE-TX and shares some elements with it. The idea was that a 1000BASE-T transceiver will also implement 100BASE-TX and 10BASE-T to achieve backward compatibility. In fact most commercial PHYs are currently 10/100/1000.
The transmission takes place on four UTP pairs in a full duplex mode as illustrated on Figure 1. This means that four transmitters and receivers are needed. The cable can be up to 100 meters. The signal modulation has five levels (PAM5).

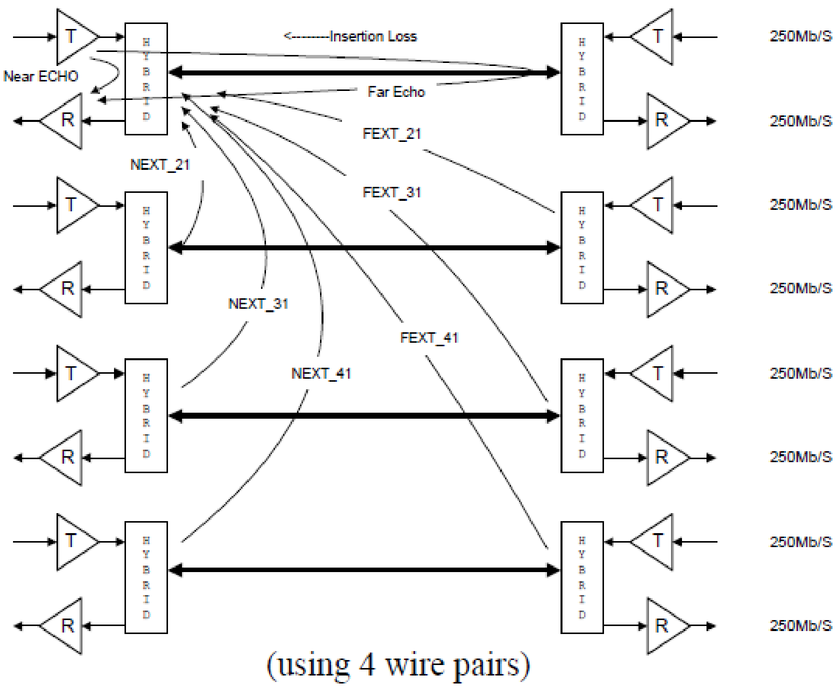
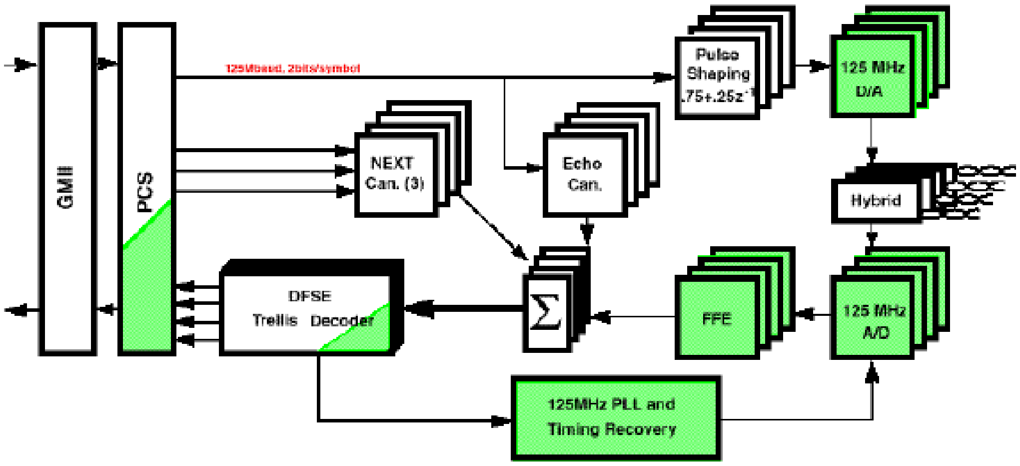


Figure 1 – Transmission environment for 1000BASE-T[3]

[3] From "802.3ab a tutorial presentation" form IEEE 802.3 available online http://grouper.ieee.org/groups/802/3/tutorial/march98/mick_170398.pdf

The block diagram of a 1000BASE-T transceiver is shown in the Figure 2 highlighting the blocks that are shared with a 100BASE-TX transceiver. This is an important point as some blocks from SEPHY can be reused and a dual 100/1000 transceiver will be easier to implement. The sampling frequency is 125Mhz as in 100BASE-TX. The main blocks of the transceivers are:

- 4 ADCs and 4 DACs.
- 4 Hybrid circuits and PGAs.
- 4 Feed Forward Equalizers (FFEs)
- 4 Decision Feedback Equalizers (DFEs)
- 4 Echo cancellers
- 12 Near End Crosstalk (NEXT) cancellers
- A Viterbi decoder.



: Blocks common between a Quad 100Base- TX and a 1000BASE-T transceiver. NEXT and Echo cancellers are the major blocks contributing to the added complexity over a Fully digital Quad-TX.

Figure 2 – Block Diagram of a 1000BASE-T transceiver[4]

1.2 1000BASE-T1 (IEEE P802.3bp)

The IEEE 802.3bp project is developing a standard that will provide 1Gbps over one UTP pair. The baseline technical solution is fixed and now the task force is refining all the details. The target market is mostly automotive and thus there is an interest in reducing weight and

[4] From "802.3ab a tutorial presentation" form IEEE 802.3 available online http://grouper.ieee.org/groups/802/3/tutorial/march98/mick_170398.pdf

cabling. The cable length will be up to 15m with an optional support of up to 40m (targeting larger vehicles such as buses or trucks).
The sampling frequency is 750Mhz and transmission uses three levels (PAM3). A Reed Solomon code is used for error correction.

The main blocks of the transceiver are:

- 1 ADC and 1 DAC.
- 1 Hybrid circuit and PGA.
- 1 Feed Forward Equalizer (FFE).
- 1 Decision Feedback Equalizers (DFE).
- 1 Echo canceller.
- A Reed Solomon Decoder.

1.3 1000BASE-RH (IEEE P802.3bv)

The IEEE P802.3bv project is developing a standard that will provide 1Gbps over up to 50 meters of Plastic Optical Fibre (POF). The target markets are automotive and home networking. The baseline technical solution is fixed and now the task force is refining all the details. The main advantages of POF are reduced weight and increased immunity against electrical noise and hazards. This standard was original presented at VDE but then it was withdrawn and brought to IEEE 802.3.
For space applications there may be a limiting factor as the use of POF is not common on space and may not be possible.

The sampling frequency is 325 Mhz and transmission uses sixteen levels (PAM16). Several BCH codes are combined with the modulation using the Multilevel Coset Coding (MLCC) technique. This is similar to the solution used in 10GBASE-T. However, the light sources may be non-linear and therefore the receiver may need a nonlinear equalizer.

The main blocks of the transceiver are:

- 1 ADC and 1 DAC.
- 1 Hybrid circuit and PGA.
- 1 Non-linear equalizer.
- 1 Feed Forward Equalizer (FFE).
- 1 Decision Feedback Equalizers (DFE) combined with Tomlinson-Harashima Precoding (THP).
- A BCH Decoder.

1.4 2.5/5GBASE-T (IEEE P802.3bz)

The aim of this project is to reuse existing 10GBASE-T technology to provide solutions for 2.5G and 10G. This is mainly done by scaling the sampling frequency. The transmission takes place on four UTP pairs in a full duplex mode using PAM16 and LDPC coding. For 200Mhz, the sampling frequency is 200Mhz. An advantage of this option is that it would enable a smooth evolution of transceiver speed (to 5G and 10G) reusing most of the components.

The block diagram of a transceiver is shown in **Figure 3**

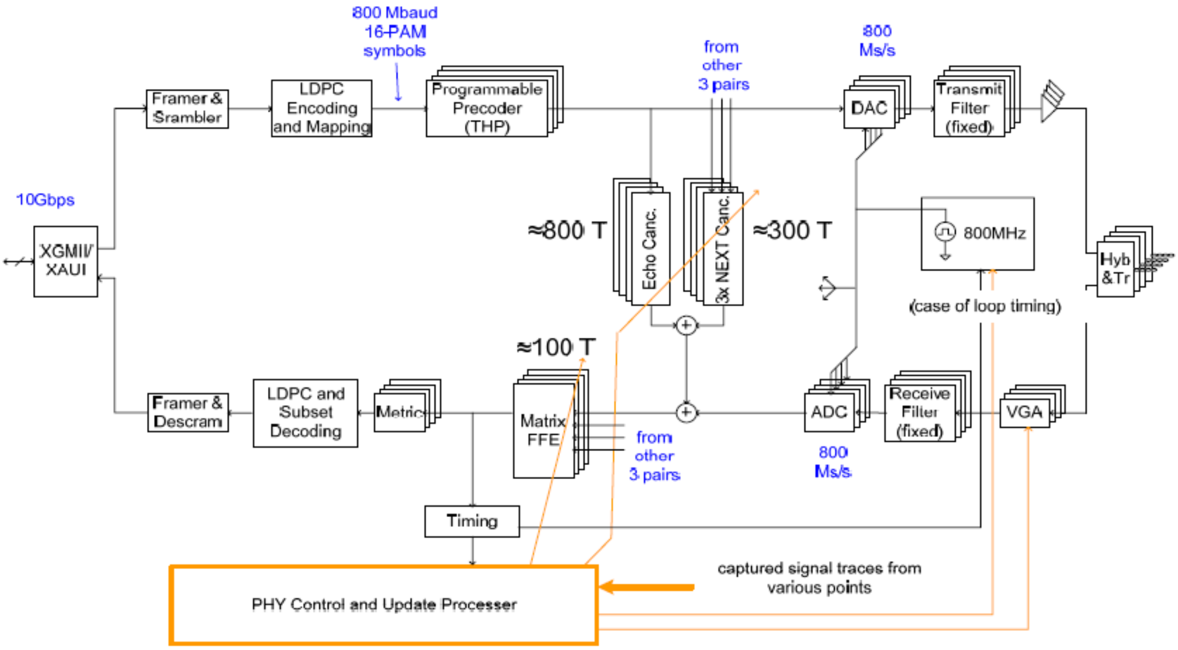


Figure 3 – Block Diagram of a 10GBASE-T transceiver[5]

The main blocks of the transceivers are:

- 4 ADCs and 4 DACs.
- 4 Hybrid circuits and PGAs.
- 4 Feed Forward Equalizers (FFEs)
- 4 Decision Feedback Equalizers (DFEs) combined with Tomlinson-Harashima Precoding (THP).
- 4 Echo cancellers.
- 12 Near End Crosstalk (NEXT) cancellers.
- 12 Far End Crosstalk (FEXT) cancellers (part of a multidimensional FFE).
- An LDPC decoder.

2 Analysis and Comparison

The best way to compare the four alternatives is to put their main features on a table and discuss the advantages and disadvantages. The features considered are:

- Medium: UTP provides backward compatibility to the SEPHY transceiver and POF does not seem to be qualified for space use. However, the POF standard is included for completeness.

[5] From G. Ungerboeck "10GBASE-T: 10Gbit/s Ethernet over copper" NEWCOM-ACoRN Joint Workshop.

- Number of pairs: this impacts the weight of the solution and also the number of blocks needed in the transceiver.
- Reach: this may limit the applicability of the PHY.
- Sampling frequency: This provides a very rough estimate to select the technology node for implementation.
- Synergy with 100BASE-TX: this highlights if there are shared blocks with 100BASE-TX so that the SEPHY development can be reused to some extent.
- Synergy with 5G and 10G: this highlights if there are blocks that could be reused for a 5G or 10G PHY. This is interesting to enable the development of future generations beyond 1G.
- Overall complexity of the solution taking into account the modulation and coding scheme and the use of advanced techniques such as adaptive pre-equalization or nonlinear equalization.

Those are summarized for the different alternatives in the table below.

Standard	Medium	Number of pairs	Reach	Sampling Frequency	Synergies with 100BASE-TX	Synergies with 10G	Complexity
1000Base-T	UTP	4	100m	125Mhz	Yes	No	High
1000BASE-T1	UTP	1	15/40m	750Mhz	No	No	Medium
1000BASE-RH	POF	1 (POF)	15/40/50m	325Mhz	No	No	Medium-High
2.5GBASE-T	UTP	4	100m	200Mhz	No	Yes	Very High

Table 2 – Comparison of the four options

It can be seen that there is no clear winner. Let us discuss each option in more detail:

- The 1000BASE-T option is a mature technology that supports 100m and has the same sampling frequency as 100BASE-TX. This means that some analog blocks can be reused. The same to a lesser extend applies to digital blocks. The main drawbacks are that four pairs are required and that this PHY does not allow reuse for speeds beyond 1Gbps. The overall complexity of the PHY is high as a sophisticated Viterbi and many adaptive filters are needed.
- The 1000BASE-T1 option is targeted to automotive applications and has the advantage of requiring only one pair. However, it requires a high sampling frequency that does not seem feasible for ATM 150nm process. The reach is also limited to 15/40m and there are no synergies with the previous (100Mbps) or the future (2.5/5G) PHY generations. The overall complexity of the PHY is medium as the use of one pair eliminates the need for crosstalk cancellation and simplifies the equalization and processing.
- The 1000BASE-RH option uses Plastic Optical Fiber (POF) as the transmission medium. This reduces the weight but POF is not qualified for space used. There are also no synergies with the previous (100Mbps) or the future (5/10G) PHY generations although the technology can be extended to support higher rates (not included in the standard). The sampling frequency can be a challenge. Reach is also limited to 50m. The overall complexity of the PHY is medium-high as the use of one pair eliminates the need for crosstalk cancellation and simplifies the equalization and processing but there is a need to perform non-linear equalization to compensate the light source.

- The 2.5GBASE-T option uses a frequency scaled version of 10GBASE-T. The 10GBASE-T standard uses an 800Mhz sampling that is reduced to 400Mhz to achieve 5G or to 200Mhz to achieve 2.5G. This can be of interest as once a 2.5GBASE-T transceiver is developed, part of the effort can be reused to target 5G or 10G. The goal is to support 100m thus covering a wide range of space applications. The overall complexity of the PHY is very high as a sophisticated LDPC decoder is needed combined with a complex Multilevel Coset Coding. The use of a larger frequency than in 1000BASE-T (200Mhz compared to 125Mhz also implies more complex filters for echo and crosstalk cancellation).

3 Initial Requirements

After this initial analysis, we now summarize some initial requirements for each of the options. At this stage the goal is to be able to determine if the implementation is feasible for the available space grade technologies. This first step should allow us to reduce the number of options to study in more detail and also the target technology for each case.

The key parameters selected at this phase are:

- The ADC sampling frequency and effective number of bits (ENOB).
- The number of digital filter taps.

In both cases, the requirements are a first order approximation that should be refined in D7.2. The estimated range of values are shown in Table 3
.

Standard	ADC frequency	ADC ENOB	Number of filter taps
1000Base-T	125Mhz	5-7	1000-1500
1000BASE-T1	750Mhz	5-7	200
1000BASE-RH	325Mhz	5-7	40
2.5GBASE-T	200Mhz	5-7	1500-3000

Table 3 – Key parameters for the fourth options

These requirements have been evaluated by ARQ (analog) and IHP (digital). The conclusions are:

From Arquimea point of view, the forward step should be done in the direction of 1000BASE-T standard for several reasons such as that it is a well-proved working mode for 150nm technologies and some analog blocks of the current design might be reusable, reducing the time to have a final product. Moreover, the rest of the standards present some problems not solved in the current SEPHY technology, so 1GBASE-T1, 5GBASE-T and 10GBASE-T should need, at least, a 65nm rad-hard technology (which is not provided by ATM nowadays) in order to get the required sampling rate. 2.5GBASE-T might be achievable in terms of sampling frequency with the current provided technology, but a complete and more complex redesign should be required. Finally, the 1000BASE-RH (POF) standard is not suitable for space applications due to radiation tolerance.

From IHP, the concerns about 1GBASE-T1, 5GBASE-T and 10GBASE-T are shared and those should be implemented in a 65nm rad-hard technology due to the high clock frequency. As for 1000BASE-T, implementation is challenging due to the large number of filter taps. However, the implementation of the echo and crosstalk cancellers can be optimized as the incoming signal to the filters has only five levels.

After this initial analysis the candidates for the next generation SEPHY can be narrowed to 1000BASE-T and 2.5GBASE-T. The first has the advantage that some blocks developed in SEPHY can be reused (for example the ADC and the FFE) as the frequency is the same. Another key advantage is that the sampling frequency (125Mhz) is lower than for 2.5GBASE-T (200Mhz) this facilitates the implementation in speed technology nodes. Another benefit is that less taps are required in the adaptive filters. The modulation and coding is also simpler in 1000BASE-T. Therefore we can estimate that the cost and complexity of 1000BASE-T can be 2/4 times lower than that of 2.5GBASE-T. The main benefit of 2.5GBASE-T are its synergies with 5G and 10G.

An important consideration for the next generation of SEPHY is the development cost. The cost of developing a commercial transceiver for 1000BASE-T was around 30 million dollars as noted in these press releases from two start-up companies that developed PHYs:

- Press note “Massana Raises $16.5 Million in Second Round of Venture Financing” http://www.design-reuse.com/news/1142/massana-raises-16-5-million-round-venture-financing.html
- Press note: “Cicada gets $17 million more for growth plan” http://www.eetimes.com/document.asp?doc_id=1177949

The cost for 2.5GBASE-T would be even larger. Given the size of the space market, these costs need to be reduced. This can be done by reusing as much technology as possible and also as some features are not needed in space (for example auto-negotiation). In any case, implementing the next generation of SEPHY will require a detailed cost-benefit analysis and a careful planning to ensure that the PHY can be implemented with the funds that can be obtained for the development.

Based on all these considerations, as of May 2016, the best candidate for the next generation SEPHY is the 1000BASE-T standard. This is mainly due to reduced implementation cost and complexity compared to 2.5GBASE-T. A more detailed analysis will be done in D7.2: Report on Technical feasibility of space grade 1Gbps Ethernet transceivers.