Optical Ethernet Dash Shapes the Future for Optoelectronics Integration

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1 Introduction

This paper reviews Optical Ethernet applications, including the recent advance into the access network as Ethernet in the First Mile (EFM). The purpose of this paper is to increase awareness of applications that will drive optoelectronic integration in the future.

The aim of EFM is faster, simplified broadband services for both business and consumer markets. As far as possible, earlier Ethernet standard work at 100Mb/s and 1Gb/s is to be leveraged. However there are actually more stringent requirements to be met in some cases, notably

1. extended temperature range
2. extended reach
3. single fibre working.

These three design challenges are covered in detail later in this paper.

Examples are taken from IEEE presentations and various manufacturers' web sites and data sheets. The author is a member of the IEEE Standards Association, but is not affiliated to any device or system manufacturer.

2 History of Ethernet

2.1 Speed

Ethernet became commercially successful in its 10Mb/s shared medium configuration, using coaxial cable in the early 1980s. This was especially remarkable in view of the market failure of an earlier 1Mb/s variant. A few years later star wiring was adopted - still as a shared medium using hubs - followed shortly afterwards by switching . In 1990 the introduction of low cost category 3 twisted pair wiring - '10Base-T' - ensured that ethernet became a huge success. Many office buildings already had suitable twisted pair wiring installed for telephones, drastically reducing the cost of installation. In addition, fibre variants were being introduced at 10Mb/s to achieve longer distances.

The subsequent move to 100Mb/s still supported copper (now category 5 twisted pair) and fibre, by borrowing from FDDI specifications. Even before the 100Mb/s version was standardised, work had turned to 1Gb/s operation. Although copper operation is possible at 1Gb/s, it sees a minority of usage. 10Gb/s Ethernet finally necessitated working with only fibre and full duplex mode. Ethernet is standardised at all the above rates.

2.2 Application Space

The growth in the speed of Ethernet was matched by a simultaneous increase in reach, such that the desired application spaces were covered. These were local, metropolitan and wide area networking (LAN/MAN/WAN). Now the access network is being addressed by Ethernet since it is the one missing piece of an end-to-end Ethernet Internet solution.

The EFM standard - expected in Q2/04 - is set to bring us 'Ethernet everywhere'. Notably, EFM offers large and scaleable bandwidths for operators. EFM will include copper, point to point fibre and a passively split fibre access method called EPON, Ethernet Passive Optical Network, see Figure 1, Plextek [1].

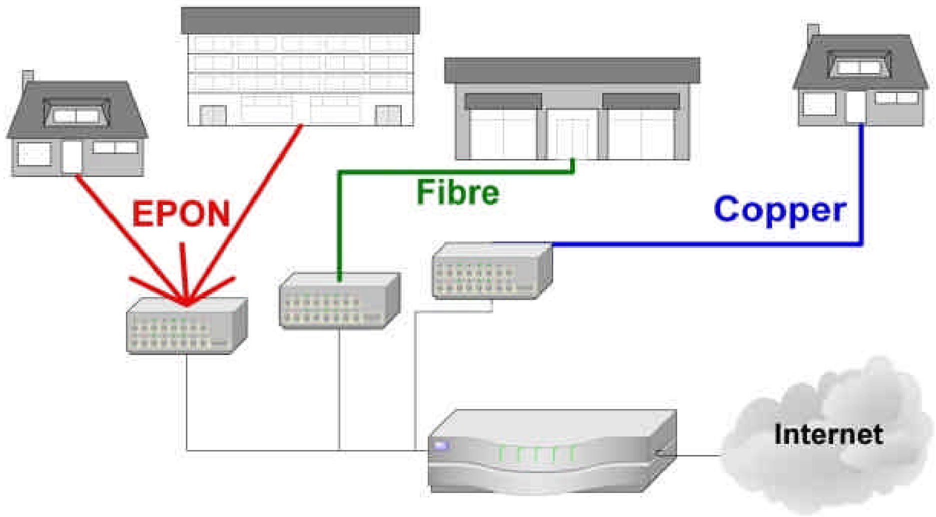

Figure 1 The three EFM access methods [1]

If the goals during the growth of Ethernet were increased speed and reach, then the value proposition that ensured it was a commercial success was the prospect of '10x speed for 3x cost'. After a while one of the other reasons for success became self fulfilling – ubiquity.

3 Fibre and Copper Approaches

For copper solutions, Ethernet has addressed coaxial cable, categories 3 and 5 twisted pair cable and shielded twisted pair cable, including twinax. As speeds have increased, more signal processing has been used to combat attenuation, and crosstalk where multiple pair solutions are concerned. The installed base of copper cabling has directed much of this effort.

For the early fibre solutions, the applicable installed base was seen to be multimode fibre. During the development of Gigabit Ethernet, it became widely realised that installed multimode fibre was far from standard and that laser launch conditions could greatly affect performance. Single mode applications have been relatively straightforward, with the focus then turning to how low cost lasers could be employed without system penalty. EFM seeks to provide a family of physical layer (PHY) specifications:

- 1000BASE-LX extended temperature range optics
- 1000BASE-X >= 10km over *single strand* of SM fibre
- PHY for PON, >= 10km, 1000Mbps, *single strand* SM fibre, >= 1:16 split
- PHY for PON, >= 20km, 1000Mbps, *single strand* SM fibre, >= 1:16 split
- 100BASE-X >= 10km over SM fibre
- PHY for single pair non-loaded voice grade copper distance >=750m and speed >=10Mbps full-duplex

The italics emphasise that this is duplex working on a single fibre.

Particularly for EFM, working with an installed fibre base is not such a concern, since the installed base of first mile fibre is so small. Installed copper is a concern, but this is not the focus of this paper.

4 Fibre methods for Ethernet in THE First Mile, IEEE 802.3ah

Before details are discussed, two new measurement metrics are described which were used during the later optical Ethernet activities: Optical Modulation Amplitude (OMA) and triple trade off curves. Used in EFM and elsewhere as *de facto* standards, they are reviewed briefly below.

4.1 Optical Modulation Amplitude

The driver for OMA is to move away from measurements of average optical power and extinction ratio penalty. OMA ties average power and extinction ratio together by looking at the peak to peak power difference between symbol 1s and 0s. It is this modulation amplitude which is a direct representation of the signal current in a system. As a caution, this does tacitly assume that average power is not so high as to overload the receiver, and that shot noise is negligible. Figure 2, Ohlen et al [2] illustrates OMA.

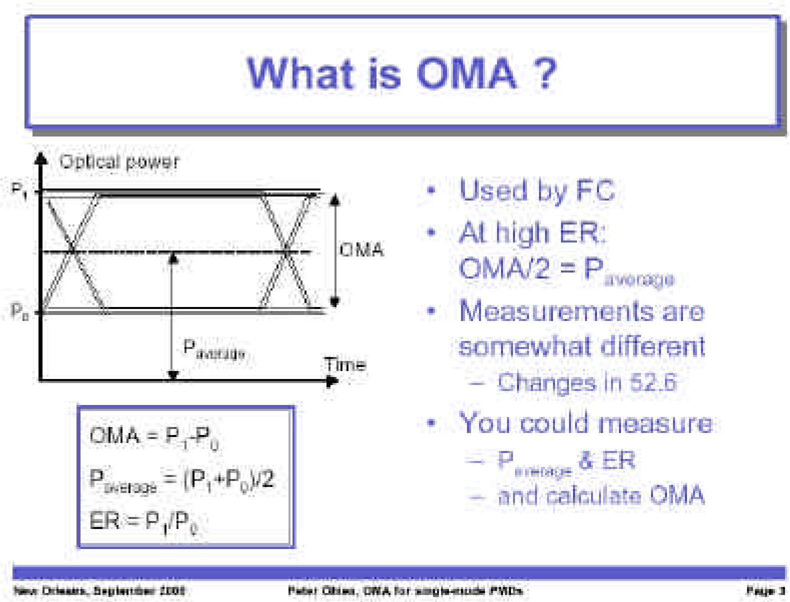

Figure 2 Optical Modulation Amplitude [2]

OMA is important because it facilitates the use of triple trade off curves, shown next.

4.2 Triple Trade Off Curves

The three way trade off is between spectral width, centre wavelength, and minimum OMA required for a certain BER. This joint representation of the analyses is very convenient for extended temperature laser selection, discussed below. See Figure 3, Tatum et al [3].

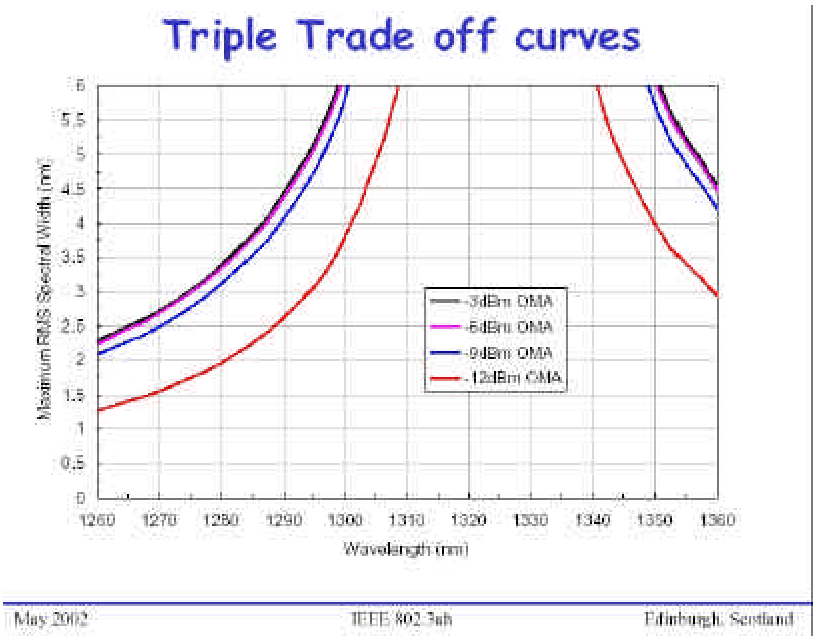

Figure 3 Triple Trade Off Curves Example [3]

5 Three Design Challenges

Three challenges which the IEEE group set themselves are extended temperautre range, extended reach and single fibre working. Along the way several other innovations have emerged from elsewhere; on board digital diagnostics to mention but one.

5.1 Extended Temperature Range

Whilst the gigabit Ethernet standard had addressed 5km, a de facto industry standard had appeared in the marketplace and was adopted for all the 10km EFM applications.

For the 10km dual fibre extended temperature range application, both upstream and downstream wavelengths are in the same band (see below for single fibre WDM). The lasers are expected to be uncooled and hence drift with a characteristic 0.4nm/degC coefficient over the expected case temperature range of –40 to +85 degC, which is a full industrial range. Peak to peak wavelength variation due to temperature is thus expected to be 50nm.

The triple trade off approach (figure 3 shows a generic example) was used to establish that a working wavelength range of 1260-1360nm was acceptable for lasers with width of up to 2.9nm rms (the model assumes Ogawa's K=0.5) and a Tx OMA of –7.6dBm. The symbol rate at 1Gb/s is 1.25 Gbaud, due to 8B10B encoding.

Extending the temperature range has packaging implications. This has had to be addressed by manufacturers in their TOSA and ROSA (transmit/receive optical subassembly) designs. Figure 4 and Figure 5 show TOSA developments from review papers by IBM [5] and NEC [6] for example.

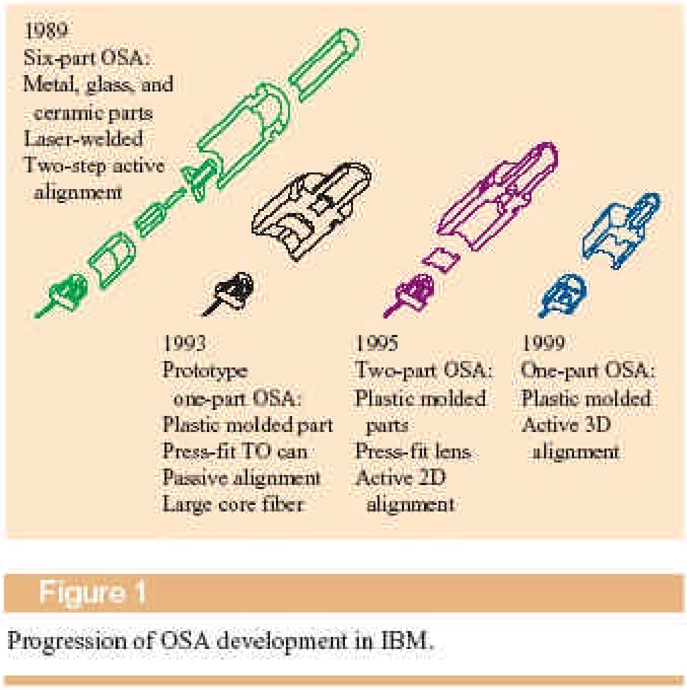

Figure 4 TOSA development example: IBM [5]

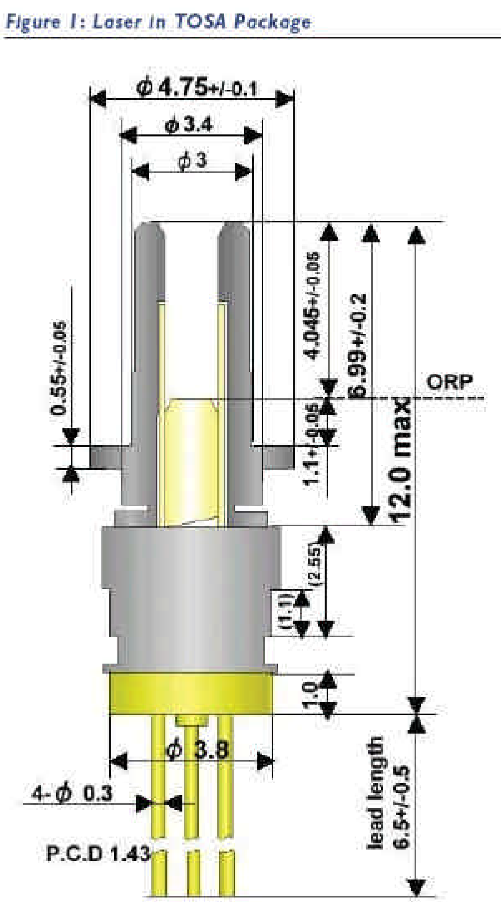

Figure 5 TOSA drawing example: NEC [6]

5.2 Extended Reach

This covers the application with the highest loss, which is the PON because of the loss of the splitter. Figure 6, Pesavento [6] shows the EPON.

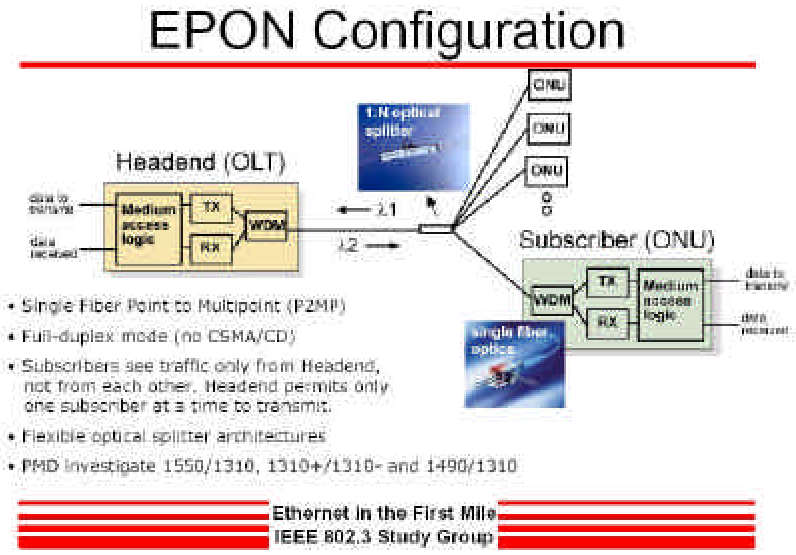

Figure 6 Ethernet Passive Optical Network [6]

Two options are available. Type A covers a 1:16 split and 10km reach by using PIN diode receivers. Type B is intended to cope with greater losses and may require a DFB subscriber transmitter. The DFB is used for better dispersion performance as well as higher launch power. The type A solution is easily implemented but does not address the whole market. Type B allows a greater proportion of the market to be reached, but is more complex.

Burst mode operation, which is required in PONs, demands special receiver electronics design considerations; the analog sections must stabilise quickly on reception of a pulse and the clock recovery must operate from a very short preamble for good system bandwidth efficiency. Downstream uses a broadcast approach and upstream uses time division multiplexing. The guard band in the TDM scheme allows for laser shutdown and prebias delays, receiver sensitivity and dc level recovery delays and clock acquisition. Upstream is thus collision free and does not fragment packets.

With respect to packaging, the TOSA is always harder than the ROSA due to component sizes and placement tolerances. Higher launch powers for extended reach may require tighter alignments and perhaps coaxial isolators.

5.3 Single Fibre Working

Bi-directional point to point links are made by using a simple two window WDM over a single strand of fibre. 1310nm is used upstream and 1490nm is used downstream. Triple trade off is used to determine the allowed centre wavelength spread and rms width of the lasers with the defined OMA. This was done for the ranges 1260–1360nm and 1480-1500nm at 1Gb/s. Single fibre working is also specified for 100Mb/s.

WDM was chosen since it offered the advantage of reduced system complexity over a single wavelength solution. It is based as closely as possible on the existing 1000Base-X standard, but over the extended temperature as already discussed. It does however bring the need to manage the differences in the transceivers at each end of the link.

Single fibre working demands either external WDM components or integrated WDM transceivers with some form of a dichroic beam splitter arrangement. This approach has been around for many years; Figure 7 shows a recent example from Luminent.

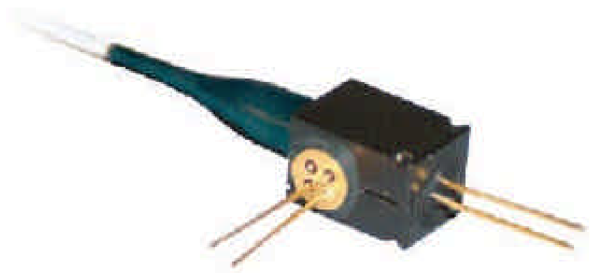

Figure 7 WDM single fibre transceiver example: Luminent [7]

6 SUMMARY

The imminent addition of EFM to the series of Ethernet standards will allow full end-to-end, standards-based Ethernet working for the first time everywhere from the access network to the WAN. This homogeneity of transport and management is expected to lead to reduced complexity and hence lower costs for users and providers alike. The potential is there for EFM to drive optoelectronics integration towards both high performance and low cost, simultaneously.

7 References

All web references accessed January 2004.

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