1550nm Direct Modulated Transmitter for Network Upgrading

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1 Summary

The Spanish network operator ONO has upgraded its network at the end of 2004 and the beginning of 2005. For that purpose new 1550nm direct modulated transmitters have been applied to cost-effectively upgrade an HFC network for 2 million homes passed.

We describe the used technology and report about applications and experiences.

We firstly introduce the conventional optical transmitter types for CATV (Cable Television) broadcasting. Then 1550nm direct modulation transmission is explained. The main challenges were finding solutions for the chirp problem and for the restricted linearity of lasers with 1550nm wavelength. Technology and lab measurements of the new transmitter are presented.

Finally we describe applications and report about field tests and the network operator's experiences with the new transmitter. 1550nm direct modulated re-transmission servicing optical fibre nodes in up to 25 km distance has been demonstrated for an AM (Amplitude Modulation, analogue video carrier modulation) and digital full spectrum multiplex. In addition, fibre distances up to 40 km are possible for a pure digital load with no noticeable service performance degradation.

2 Introduction

1550nm directly modulated transmitters are already well-known for QAM (Quadrature Amplitude Modulation) transmission but are not yet well-known for analogue, CATV broadcasting. The conventional concepts for CATV broadcasting are as follows:

1. The direct modulation concept is cost-efficient and applied for 1310nm transmitters. 1310nm directly modulated transmitters can cover distances up to 30 km. At higher distances there are problems with fibre noise and especially fibre attenuation since 1310nm can not be amplified by optical amplifiers (EDFAs – Erbium Doped Fibre Amplifiers).
2. The external modulation concept is more expensive, which is its disadvantage, but externally modulated transmitters can cover distances up to 120km by using optical EDFA amplification.

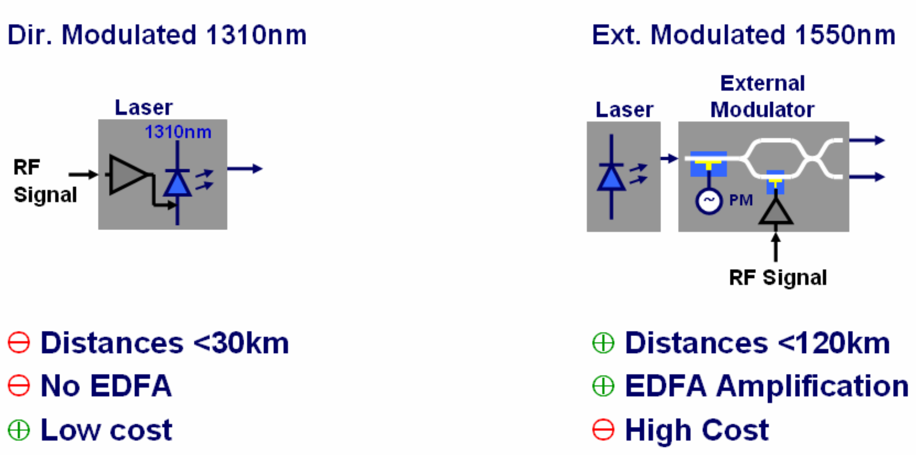


Figure 2-1: Conventional Concepts for Optical Transmitters

Figure 2-1 provides a closer look at the two concepts. The direct modulation concept is a straight forward solution. The RF input signal is amplified and added to the laser current. Thus, the optical power varies according to the RF input signal.

The more sophisticated concept of external modulation uses an external modulator to attenuate the optical signal of a constant-power-laser according to the RF input signal. This concept has a big advantage: there is no laser chirp. Laser chirp occurs with directly modulated transmitters and means that the emitted wavelength is not constant but depends on laser current. This effect causes distortions at 1550nm. So, typically externally modulated transmitters are applied for 1550nm transmission.

In this paper, a 1550nm directly modulated transmitter is presented and its features and applications are clarified. The transmitter is using 1550nm wavelength but is somehow dealing with the chirp effect.

3 Technological Challenges of 1550nm Direct Modulation

Laser chirp is causing CSO (Composite Second Order) distortions at 1550nm because of fibre optic chromatic dispersion. The graph in Figure 3-1 explains this relationship in more detail. It depicts dispersion which is dependent on wavelength. There is no dispersion at 1310nm and therefore laser chirp does not matter for 1310nm transmitters.

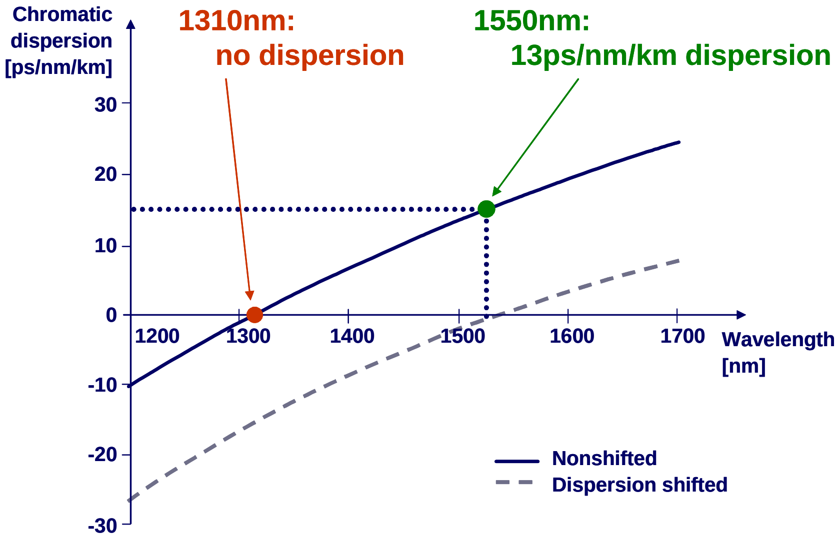


Figure 3-1: Fibre Optic Chromatic Dispersion Coefficient k_{Disp}

But there is dispersion unlike zero at 1550nm wavelength for non dispersion shifted glass fibres that are typically used in HFC fibre optic networks.

Dispersion means: When the 1550nm transmitter chirps and slightly changes its wavelength by $\Delta\lambda$ because of varying RF input signal x,

Chirp: $$\Delta\lambda = k_{Chirp} \cdot x$$

propagation speed also changes and signal delay τ varies proportional to fibre length L.

Dispersion: $$\tau = \tau_0 + k_{Disp} \cdot \Delta\lambda \cdot L$$

Receiver output signal y calculates as delayed input signal x:

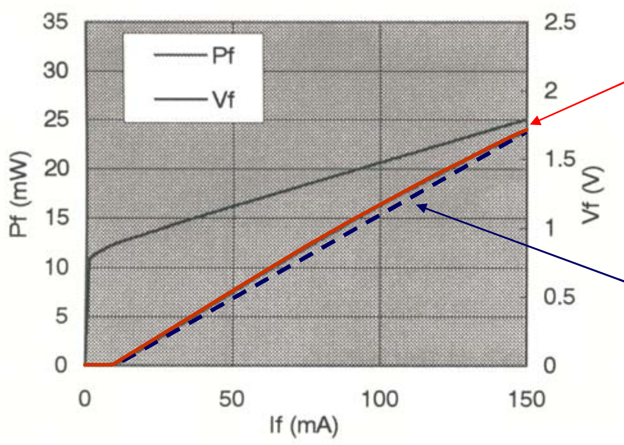
Receiver: $$\begin{aligned} y(t) &= x(t-\tau) \\ &= x(t-\tau_0 - k_{Disp} \cdot \Delta\lambda \cdot L) \\ &= x\big(t-\tau_0 - k_{Disp} \cdot k_{Chirp} \cdot L \cdot x(t-\tau)\big) \end{aligned}$$

The type of distortion becomes apparent by considering the term $\varepsilon = k_{Disp} k_{Chirp} L \cdot x$ to be quite small so that we can approximate the receiver output signal with the help of the first differential $\dot{x}$.

$$\text{Receiver:} \quad \begin{aligned} y(t) &= x(t - \tau_0 - \varepsilon) \\ &\approx x(t - \tau_0) - \varepsilon \cdot \dot{x}(t - \tau_0) \\ &\approx x(t - \tau_0) - k_{Disp} k_{Chirp} L \cdot x(t - \tau_0) \cdot \dot{x}(t - \tau_0) \end{aligned}$$

It turns out that the receiver signal contains second order distortion products $x \cdot \dot{x}$ measured as CSO. Distortion is worse the higher the considered carrier frequency due to the differential element $\dot{x}$. Since the distortion products can become very strong especially for higher carrier frequencies, we will have to find a solution for the chirp and fibre optic dispersion issue.

Moreover, there is a second challenge, laser nonlinearity, which is also known from 1310nm lasers. But it is even more problematic in 1550nm lasers. Figure 3-2 depicts the dependence between laser input current I_f (horizontal axis) and the laser output power P_f (vertical axis).



Real P–I curve:
Nonlinear slope of optical output power P with rising current I

Ideal P–I curve:
Strictly linear

Figure 3-2: Laser Characteristics

The red curve is not a straight line like the ideal strictly linear (dashed blue) curve. Detailed examination reveals an additional component of second order affecting laser characteristics:

$$\text{Laser:} \quad P_f(I_f) = \eta \cdot (I_f - I_{th}) - \eta_{CSO} \cdot (I_f - I_{op})^2$$

For the formulae, we need to introduce two constants, the threshold current I_{th} and the operating current I_{op}. This nonlinear laser behaviour described above also leads to second order distortions measured as CSO.

4 1550nm Directly Modulated Transmitter

For building a 1550nm directly modulated transmitter, measures against both challenges, laser nonlinearity and laser chirp in combination with fibre optic dispersion, have to be set. Figure 4-1 depicts the block diagram of the new transmitter.

It is quite common to solve the second order nonlinearity problem by applying linearization circuitries. A linearization circuitry adds second order products equal to the laser nonlinearity but with a different sign. Thus, laser and established linearization circuitry distortions compensate each other. Therefore, we denoted our linearization circuitry “CSO Compensation” (see Figure 4-1).

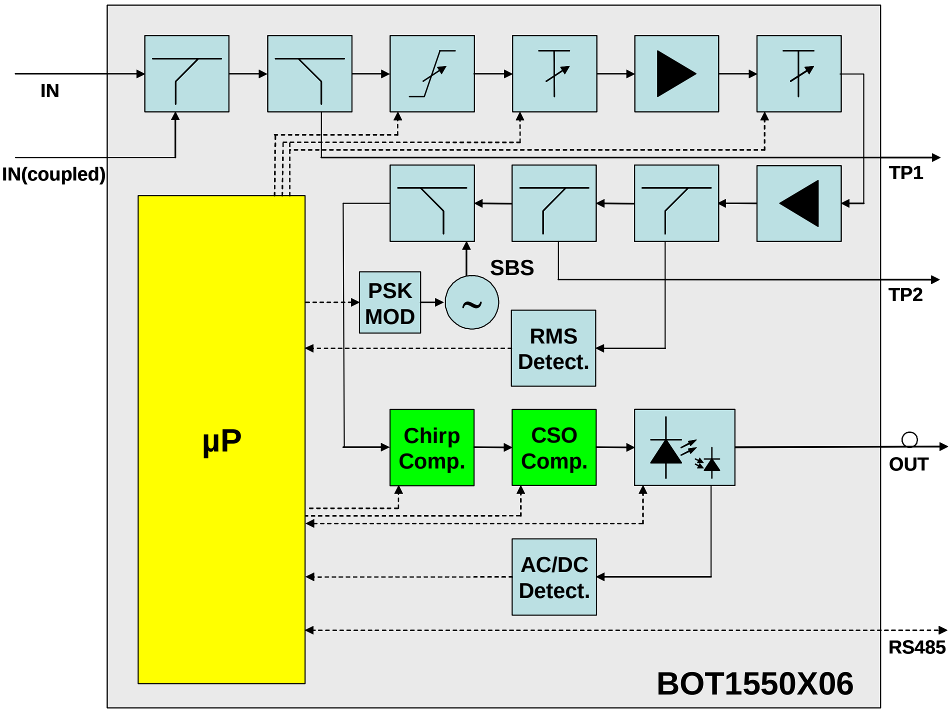


Figure 4-1: Block Diagram of 1550nm Directly Modulated Transmitter

In a very similar way, we implemented a second compensation circuitry called “Chirp Compensation”. It compensates the second order nonlinearities produced by laser chirp and fibre optic dispersion.

Figure 4-2 shows the achieved CSO performance of this concept dependent on fibre length. CSO performance is measured by using the particular fibre length and an optical attenuator to drive an optical receiver (of neglectable nonlinearity) at 0 dBm input power.

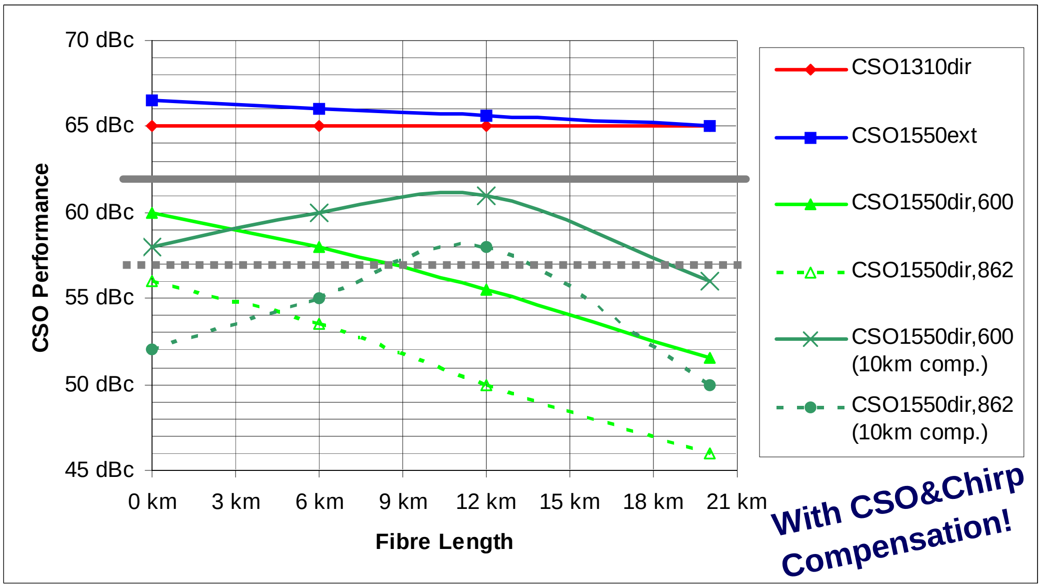


Figure 4-2: CSO Performance (Cenelec 42) of 1550nm Directly Modulated Transmitter

The red and the blue curves depict the CSO performance of conventional transmitter concepts. The conventional concepts achieve minimum (worst case) CSO of more than 62 dBc. For CSO measurement we applied the common Cenelec test channel allocation of 42 sine carriers with defined carrier frequency between 48.25 and 855.25 MHz.

The light green curves hold for the new 1550nm directly modulated transmitter. Performance seems disappointing although we have already switched on CSO Compensation: the dashed line stands for Cenelec 42 CSO performance, which is about 56dBc at 0 km fibre length and becomes even worse with higher fibre lengths due to chirp and dispersion effect.

The situation looks a bit better when we only consider CSO performance up to 600 MHz. Cenelec 42 channel allocation has carriers from 48.25 to 855.25 MHz. We take into account that practically all applied channel allocations used to have AM carrier frequencies up to 600 MHz and digital carriers in the range of 600 to 862 MHz, where CSO is of no interest. The green straight curve tells us that CSO performance between 48.25 and 599.25 MHz is a minimum of 4 dB better. Up to 600 MHz we have a CSO performance that is sufficient for subscriber near network applications. Nevertheless after 9 km, performance drops below 57 dBc which is kind of really the absolute minimum requirement.

But we have one joker left: the Chirp Compensation. For the dark green curves, the chirp compensation circuitry has been set to compensate 10km-fibre distortions. Therefore, CSO performance at 10 km fibre length is best and drops for shorter and for longer fibre lengths. With chirp compensation circuitry switched on, we can cover distances of about 20 km with a minimum performance of 57 dBc thereby doubling the covered distance by Chirp Compensation.

Figure 4-3 depicts CNR (Carrier-to-Noise Ratio) and CTB (Composite Triple Beat) performance dependent on fibre length. We note that CNR and CTB performance is roughly comparable and only a bit weaker than performance of conventional optical CATV transmitters. Again, Cenelec channel allocation with 42 carriers of frequencies between 48.25 and 855.25 MHz has been used. The optical receiver had a thermal noise equivalent current of 7 pA/√Hz, and CNR noise bandwidth was 5 MHz.

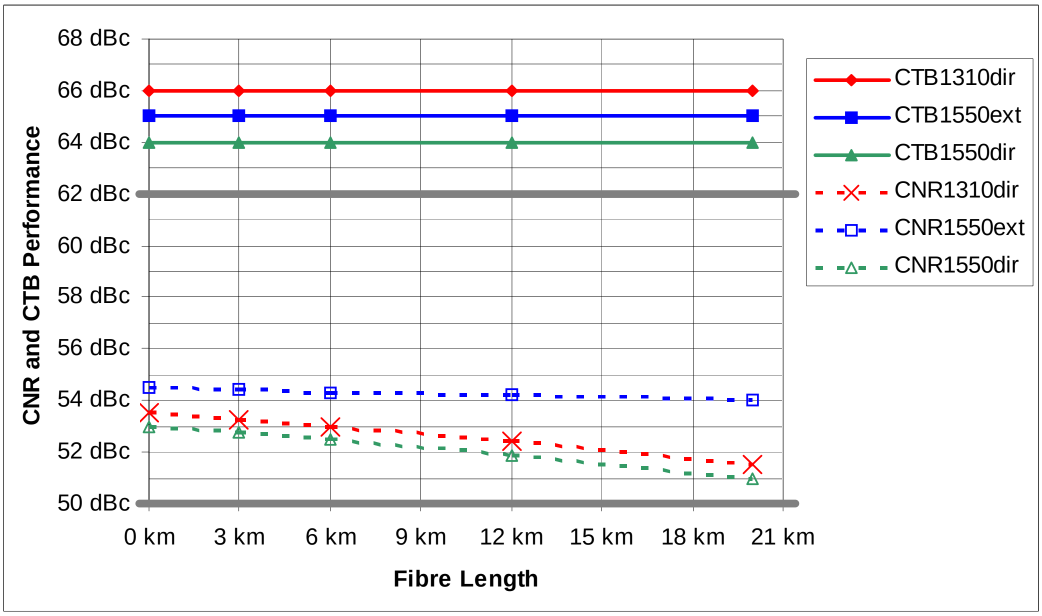


Figure 4-3: CNR and CTB Performance (Cenelec 42) of 1550nm Directly Modulated Transmitter

5 Applications and Field Experiences

Figure 5-1 shows the summary feature list of the new transmitter. The transmitter combines the advantages of EDFA amplification and low costs. But it is restricted to distances up to approximately 20 km for AM carrier frequencies up to 600 MHz:

- Consequently, the 1550nm directly modulated transmitter is applicable in subscriber near network sections for the network upgrade of 1550nm CATV networks.
- A second application field is FTTx (Fiber To The Home/Building/Curb/…) network with CATV overlay.

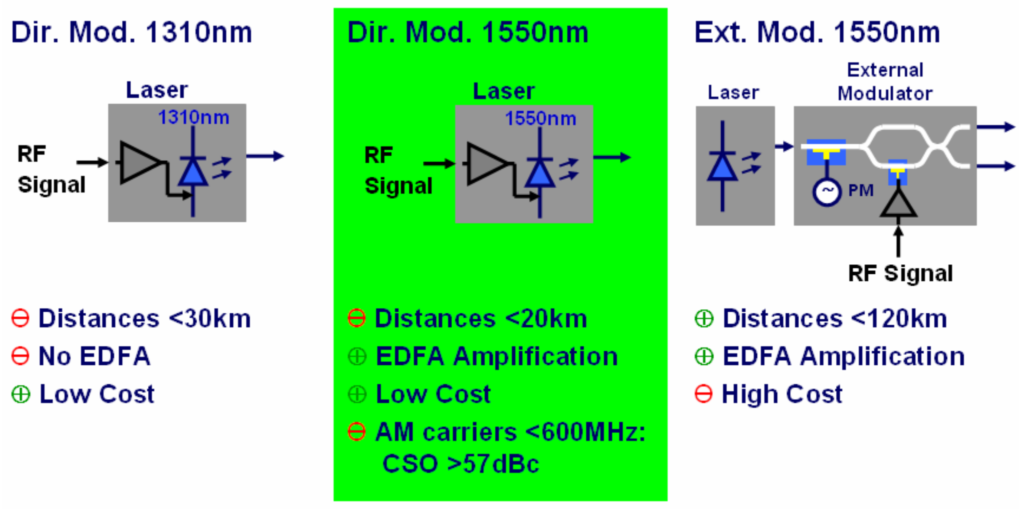


Figure 5-1: Conventional and New Concepts for Optical Transmitters

In the following we describe the network upgrade application in more detail since a recent project of the Spanish network operator ONO yields field experiences. Figure 5-2 depicts the former network topology. It is a countrywide network with 12 head ends and about 2 millions homes passed. One head end is sketched with hubs and fibre nodes. The hubs house optical amplifiers and splitters.

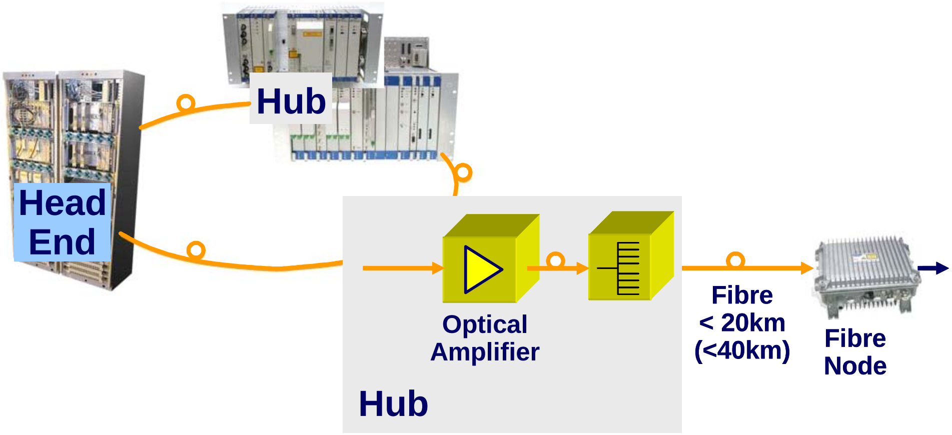


Figure 5-2: Former 1550nm Network Architecture

If huge individual traffic is demanded by subscribers, the available transmission spectrum (85 to 862 MHz) is not sufficient to be shared among all connected homes. The spectrum must be reused by dividing connected homes into clusters (e.g. group of fibre nodes). In each cluster (group of fibre nodes) individual traffic only dedicated to the connected homes is injected in the available spectrum. Thus, the available spectrum can be reused for each cluster.

ONO’s formerly narrowcast solution, which is not sketched for simplicity in the figure above, was based on optical 1310/1550nm WDM (Wavelength Division Multiplexing) at the hub which led to a strong limitation in carrier capacity: both the number and the modulation were not suitable for the exploding Internet (cable modem) demand. Neither for the expected penetration of VoD (Video on Demand) service where up to twelve 256QAM carriers per 8,000 homes passed are needed during the first stages of the rollout[1].

The network was to provide more interactive capacity requiring opto-electrical conversion, narrowcasting and electro-optical reconversion in the hub as sketched in Figure 5-3. New BKtel 1550nm directly modulated transmitters allow cost-effective narrowcast with minor architecture and minor service impact. Former EDFA investment could be reused to provide optical output power. About 400 transmitters have been installed in the field during the rollout at the end of 2004 and the beginning of 2005.

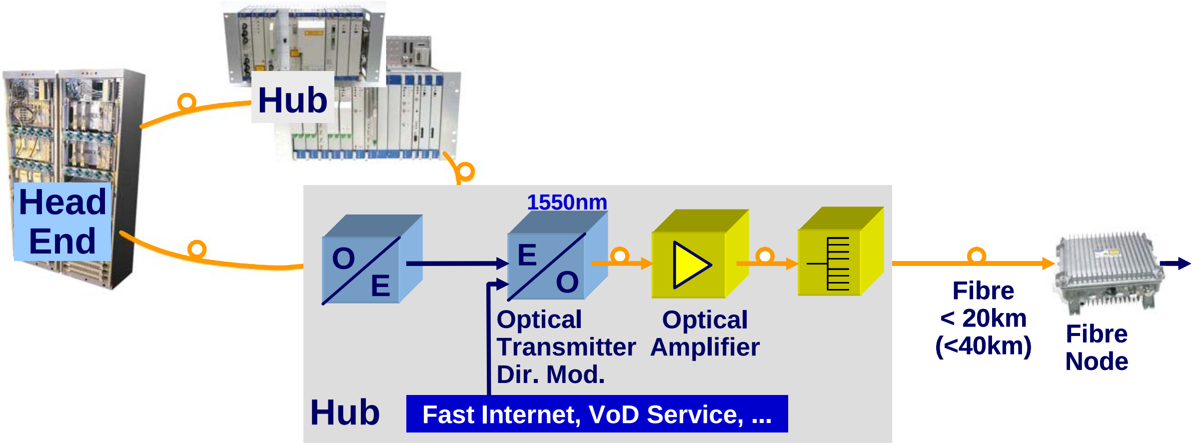


Figure 5-3: Upgraded 1550nm Network Architecture

The upgraded network will be in full service by the 2nd quarter of 2005. It successfully demonstrates operation of 1550nm direct modulated re-transmission servicing up to 25 km long optical fibre nodes for an AM plus digital full spectrum multiplex.

Successful lab tests and field tests in Palma de Mallorca and Valencia with up to 40 km fibre transmission for a purely digital load with no noticeable service performance degradation provide the basis for future upgrade strategies.

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[1] Today, typically one transmitter serves 8,000 homes passed. But the architecture is straight-forward scalable to 4,000 and subsequently 2,000 homes passed narrowcast clusters by only reducing the split degree when increased penetration requires so. Actually, ONO is about to split nearly 50 clusters of 8,000 homes passed each into 4,000 homes passed clusters in the Valencia region alone, which demonstrates today's great demand for narrowcast service penetration.