PMD and CD Measurement on Optical Cables for Bandwidth Computation

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1. Abstract

Bearing in mind the transmission bandwidth determination for single-mode optical fibres, this paper reports chromatic dispersion (CD) and polarization mode dispersion (PMD) field measurements on OPGW cables. Using a characterised EDFA, we achieved an increase on measurement dynamical range from 15 dB to 25 dB (depending on the configuration setup implemented). Contrary to CD, the PMD measurements technique we were implementing presented some new challenges regarding OPGW aerial cables. It's discussed briefly the main factors causing the problems we are reporting and the possibility of using polarisation state monitorisation as a sensor for studding stresses in OPGW cables due to wind, electromagnetic forces, installation abnormalities, and even ageing. It is presented, for comparison purposes, PMD measurements on an underground optical cable also.

2. Introduction

The implementation and improvement of optical telecommunication links represents a very important driving factor for economic and social development for every communities and countries worldwide. Several high bandwidth consuming services will be available to the end user shortly, such as HDTV and IPTV, VoIP, new fixed and mobile multimedia services, among other services. People living in the big cities are, for obvious reasons, which first benefit from those technologies. The enlargement to the whole countrywide requires a very high investment with a ROI not in short time. For that reason, it is an advantage to use fibre optics infrastructures already done or in construction countrywide. We can mention, for example, the construction of road and railways, gas and water distribution networks and electrical power lines, where is usual to install optical fibre cables for immediate and future use.

The electrical energy distribution networks are an important infrastructure that covers (almost) whole countries area (see figure 1, for Portuguese example). For that reason, those networks are properly shaped for being a candidates for nationwide high bandwidth optical networks supporters. This evolution is performed substituting the traditional ground wire cable by an OPtical Ground Wire (OPGW) cable. The OPGW cable is in, appearance, identical to the conventional one, but has a set of optical fibres inside of it (typically 16 to 48 fibres). By design considerations, those links are abnormally large. A typical distance between nodes can be larger then 120 km.

In long optical links, the characterization of transmission parameters, such as polarisation mode dispersion (PMD), implies adequate measurement capacity (dynamical range). That capacity determines the maximum measuring length that can be measured at once. Using the EDFA as a booster or as a pre-amplifier (or both) we can increase the measurement dynamical range. But, for computing the fibre's PMD, we have to account first for EDFA's intrinsic PMD.

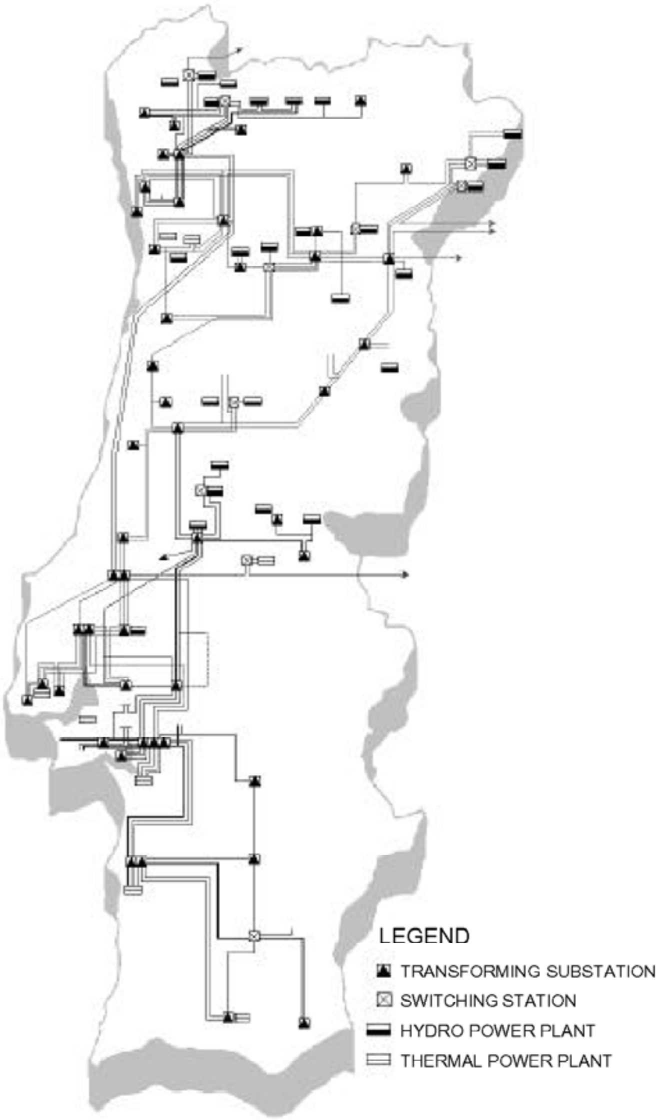


Figure 1 Portuguese electrical energy transmission and interconnection network map (150 kV, 220 kV and 400 kV lines), which is being progressively upgraded with OPGW cables (figure obtained at the EDP internet site: www.edp.pt).

A communication link with single-mode fibres as a transmission medium has a bandwidth constrains essentially imposed by chromatic dispersion (D_{CRO}) and *PMD*. Contrary to the chromatic dispersion measurement techniques, some of the established measurement methods for PMD are sensitive to the fibres movements, which in fact are present in aerial cables and are totally unavoidable. At the time we performed our measurements, because the distance limitation, we had to use a monochromatic source (tuneable laser) and optical amplifier (EDFA) with a Stokes vectors analyzer equipment.

3. PMD and chromatic dispersion measurements on OPGW cables

As we said, the fieldwork reported here aimed the transmission bandwidth computing on some OPGW cables, from D_{CRO} and PMD measurements. In addition, we performed attenuation and continuity measurement testes.

As we have mentioned already, in the PMD measurements we faced some interesting problems. At this work, we used a very well known commercial equipment EG&G Fiber Optics CD300 for D_{CRO} and HP 8509B (Lightwave Polarisation Analyser) for PMD. The HP 8509B allows measurements of PMD using either wavelength scanning with fixed analyser (WSFA) [1-3] or Jones Matrix Eigenanalysis (JME) [2-6] methods. Both methods are highly sensitive to the fibre movements. Let's remark, surely using the interferometric measurement technique [7], which was unavailable at that time, we wouldn't face the problems reported here. At same time we wouldn't be able to report the results we found with JME and Poincaré sphere.

3.1 Transmission bandwidth

In some cases we encounter enough stability for measuring PMD with the JME method. It was the case of a link 13.6 km long. The stability is ensured by the excellent repeatability obtained performing two successive measurements (figure 2b).

Considering that the transmission rate is 2.5 Gbit/s (which implies a modulation rise fall time of $B_M = 10$ GHz), assuming Gaussian pulses, a single-mode regime and a radiation signal source linewidth of $\sigma_\lambda = 0.01$ nm (DFB laser), we can determine the transmission bandwidth of that link.

The effective source linewidth, $\Delta\lambda$, is calculated by equation

$$\frac{\Delta\lambda}{\lambda} = \sqrt{\left(\frac{\sigma_\lambda}{\lambda}\right)^2 + \left(\frac{B_M}{f}\right)^2} ,$$

which gives, for 1310 nm and 1550 nm, $\Delta\lambda_{1310} = 0.058 \text{ nm}$ and $\Delta\lambda_{1550} = 0.081 \text{ nm}$.

The transmission bandwidth, *B*, of a fibre of length *L*, is calculated recurring to the equation

$$B^{-2} = B_{PMD}^{-2} + B_{CRO}^{-2} ,$$

where $B_{PMD} = \dfrac{0{,}44}{\sqrt{L}\ PMD}$ and $B_{CRO} = \dfrac{0{,}44}{L\Delta\lambda\left|D_{CRO}\right|}$

From the measurements performed (graphs shown in figure 2), $D_{CRO}^{1310} = -0.51 \text{ ps nm}^{-1} \text{ km}^{-1}$, $D_{CRO}^{1550} = 16.95 \text{ ps nm}^{-1} \text{ km}^{-1}$, and $PMD = 0.295 \text{ ps km}^{-1/2}$. The transmission bandwidths at 1310 nm and 1550 nm for the real situation (13.6 km of single-mode fibre), and for 50 km and 100 km of the same fibre, for comparison purposes, are presented in Table 1.

13.6 km fibre length *real situation*	50 km fibre length	100 km fibre length
$B_{1310} = 253$ GHz $B_{1550} = 11$ GHz	$B_{1310} = 172$ GHz $B_{1550} = 6.4$ GHz	$B_{1310} = 105$ GHz $B_{1550} = 3.2$ GHz

Table 1: Computation of transmission bandwidth for 1310 nm and 1550 nm.

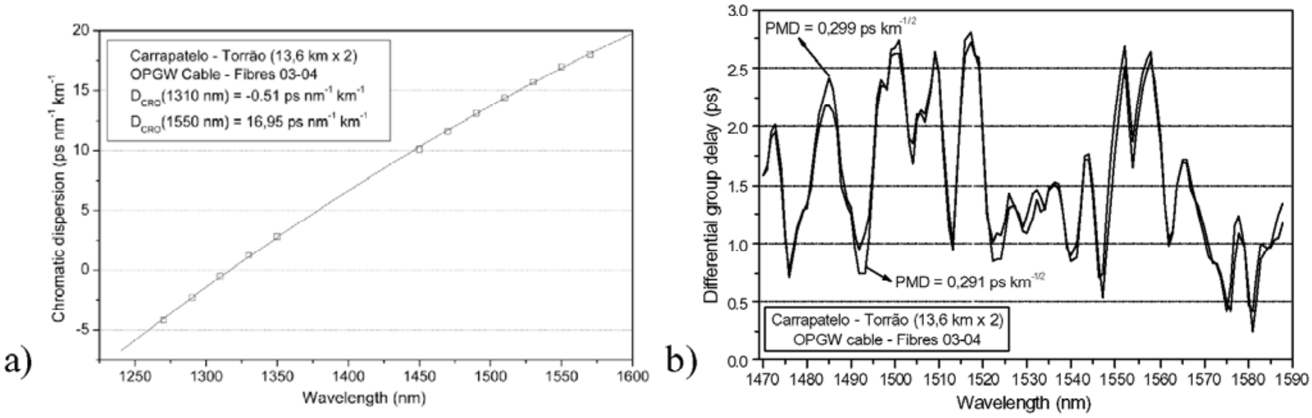


Figure 2 Measurements performed: a) chromatic dispersion and b) PMD.

3.2 The underground case

We performed PMD measurements on underground cables too. In general, we obtained very high polarisation stability, allowing PMD measurements with an excellent repeatability (< 0.01 ps for DGD). However, it is presented here a situation for which some temporary instability happened. Figure 3 shows four different measurements of PMD on an underground optical cable having 15.2 km of length. The second measurement have some "peaks", resulting from perturbations occurred somewhere in the link. The PMD value obtained was about 0.005 ps km$^{-1/2}$.

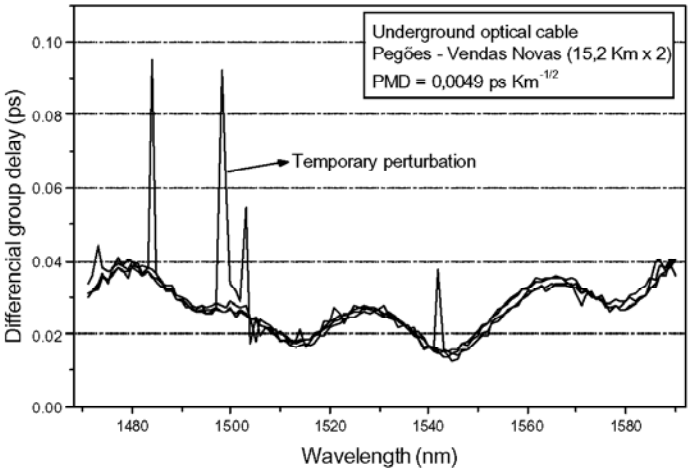


Figure 3 PMD measurements on a 15.2 km underground optical cable.

4. Introduction of EDFA for PMD measurements: Improvement of dynamic range

In a very long optical fibre links the dynamical range of the measuring system is an important limitation, forcing, sometimes, to cut the fibres at the middle of the link. This has important economical costs and is time consuming. By using an optical amplifier, such as an EDFA, as a booster or as a pre-amplifier the dynamical range of the instrument can be improved by an amount that depends on the configuration used. The input power at EDFA has influence on its saturated state level with direct consequence in the gain. Figure 4 shows the set-up used with the EDFA as a booster, having been obtained an increase in dynamical range of 15 dB. As a pre-amplifier that value raises to 25 dB.

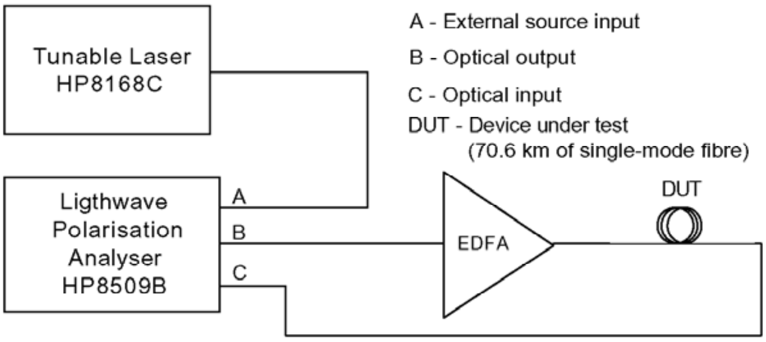


Figure 4 *Introduction of an EDFA for PMD measurement on an OPGW cable.*

The graphics of figure 5 show a very good agreement between the measurements with and without the use of an EDFA. The penalty is in accuracy, because the wavelength range that can be used with an EDFA is much lower due to the restricted positive gain range.

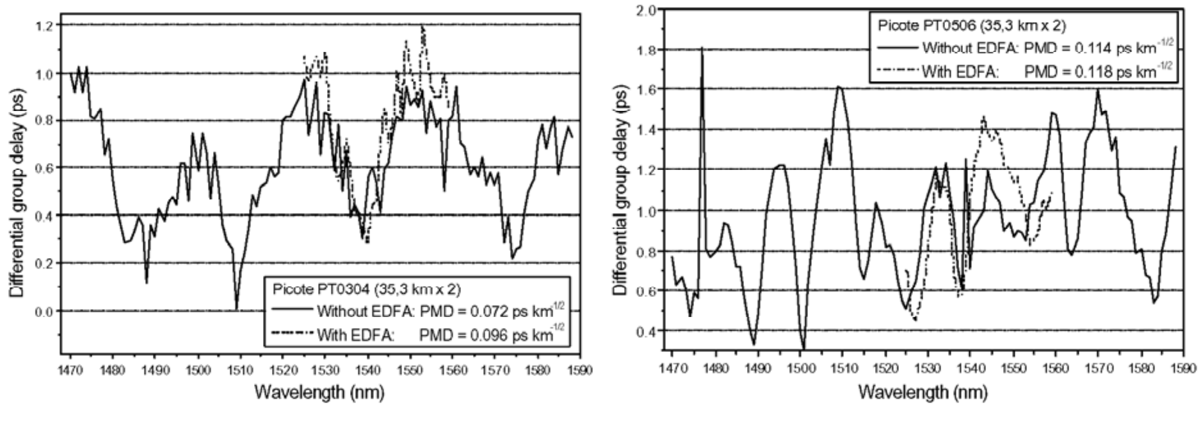


Figure 5 *Comparison of the differential group delay obtained using the JME method and setup of figure 4, with and without the EDFA, for two different fibre pairs of the same OPGW cable.*

5. Polarisation instabilities on OPGW cables

The measurement equipment can perform sampling of radiation polarisation states at very high acquisition rates. This feature provided us with a lot of information about time variation of polarisation states at one end of an OPGW cable, when coupling radiation with constant wavelength and polarisation state, at the other end. The figure 6 shows, at the Poincaré sphere [6], the three situations observed in our experiments: a) the polarisation state varies covering only a region of the sphere, so we can consider a mean state of polarisation; b) the polarisation state varies covering the whole sphere, and in this case we can not identify a mean state of polarisation; and c) is identical to the last one, but the sphere is fulfilled quicker.

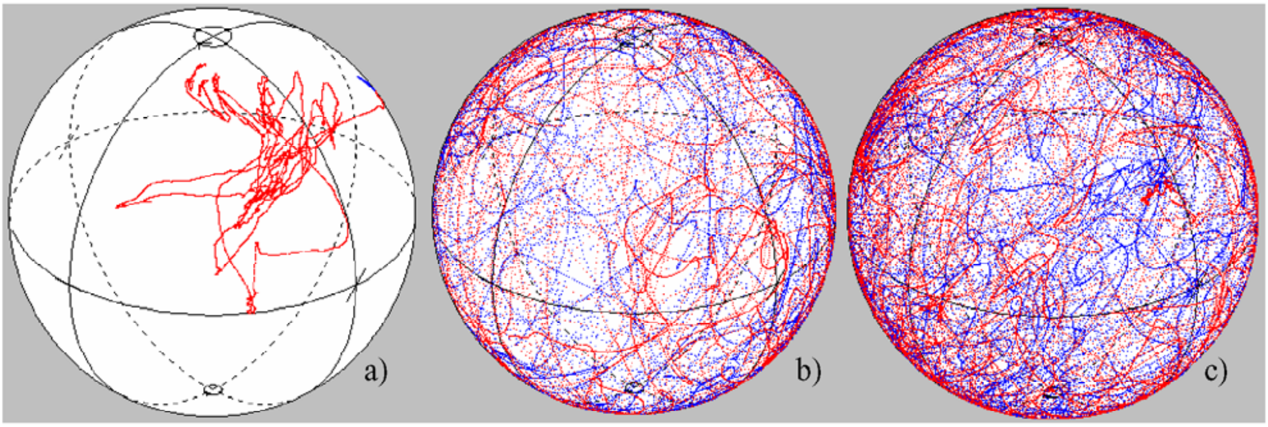
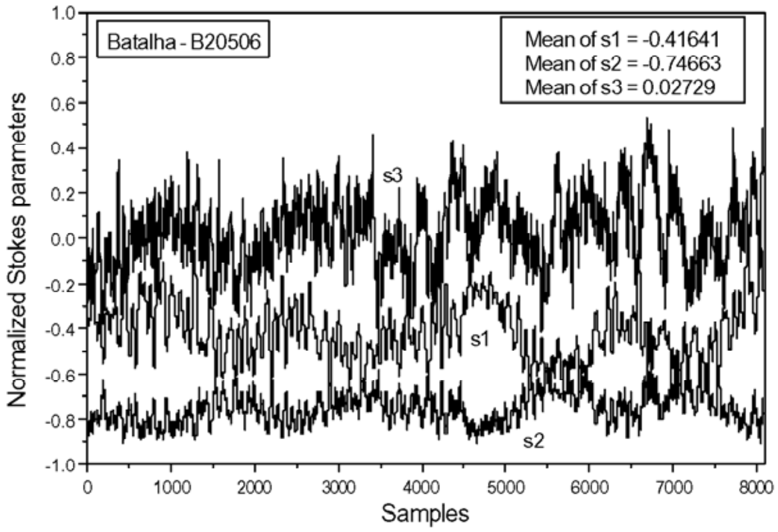


Figure 6 Polarisation states at the Poincaré sphere observed at the end of a fibre of an OPGW cable by injecting, at the other end, light with constant polarisation state.

The time of acquisition was 32,76 s for 16381 samples, which gives a sampling interval of 0.002 s, and, according the Nyquist criterion [8], we can "see" frequencies up to 250 Hz. This limit seems to be enough because the expected frequencies are lower, because we can "follow" the variation on the polarisation state at the sphere.



a)

Frequency spectrum
Batalha – B20506 – s1

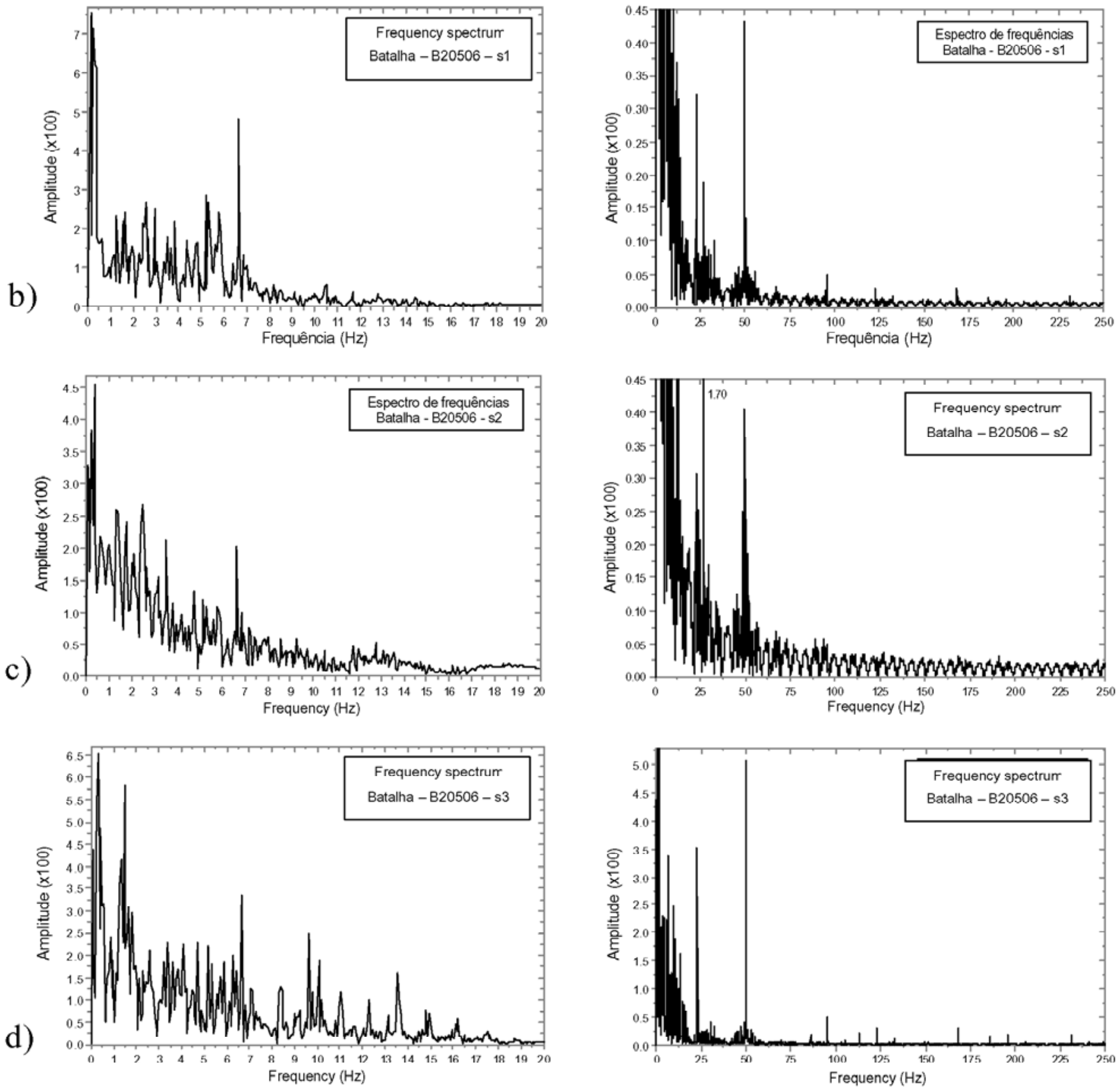


Figure 7 a) Time variation of the normalized Stokes parameters. Its frequency spectrum: b) s_1, c) s_2, and d) s_3.

Figure 7 shows the evolution of the polarisation state through the normalised Stokes parameters and their discrete Fourier transforms, in a situation of large instability, for which it is not, surely, applicable the established PMD measurement methods. All the three Stokes parameters very randomly. Performing their discrete Fourier transforms, we obtain some characteristics frequencies. The lower frequencies correspond to the fibre movements due, mainly, to wind and are strongest components of spectrum. Remarkably, the network voltage frequency (50 Hz) is present. This is due to mechanical stresses caused by electromagnetic interactions between the OPGW and other cables. It may occur also that the OPWG cable passes near or through some vibrating structures, as a voltage transformer. This problem presents a new challenge for development of alternative measurement methods and could be used for studding stresses at the OPGW due to wind, electromagnetic forces, installation abnormalities, and even ageing.

6. Conclusions

The transmission bandwidth of an aerial OPGW cable can be calculated by chromatic and polarisation mode dispersion measurements.

The measurements in long optical links imply adequate dynamical range of the measuring system. For an OPGW aerial cable additional problems were raised for measurements in the field due to polarisation instability resulting from complex movements caused by wind and mechanical stress induced by installation process. Other reasons are now being investigated in the field and also in the laboratory. The laboratory studies and simulations provide coherent explanation but do rise new challenges.

In spite of these problems, in some exceptional situations, we have determined the transmission bandwidth (by performing chromatic dispersion and PMD measurements) and demonstrated the increase of the dynamical range of 15 dB to 25 dB using an EDFA, for a PMD measurement of an OPGW aerial cable with 35 km long.

Nowadays, for very high bit rate systems like 40Gbps, would be necessary to compensate, more then CD, de PMD. As we can see from figure 3 de variation of DGD on underground cables is slow (in 60 minutes of observation). That also means the polarization states behaves in a very steady way. But, in differently, the PMD results coming from OPGW cables could be much more unstable (see polarization states variation in figures 6). That means, it will be much more difficult to establish a PMD compensation mechanism!

The polarisation instabilities observed on installed OPGW cables are due to wind and mechanical vibration occurring at some structures, and possibly could be used for behaviour investigation of OPGW cables.

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