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Polarization effects in KAT-7 telescope optical fibre network: Towards the distribution of frequency and timing references in the MeerKAT telescope

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ABSTRACT

Polarization mode dispersion (PMD) is one of the key effects in optical fibre communication that distorts the transmitted signal. The effect of birefringence on the polarization states of an optical signal leads to broadening of the pulses in an optical fibre. The difference in propagation time of the orthogonal modes in a fibre results in differential group delay (DGD). For proper functioning of a telescope, accurate and stable clock signals will be distributed via an optical fibre network to each of the dishes. This paper presents field PMD measurement that is essential in estimating the expected phase change of the clock signal. The average DGD of a 10.2 km fibre link established to be about 62.1 fs. This study serves to address the applicability of optical fibre network transmission in the distribution of frequency and timing reference signals in the MeerKAT and later phases of the square kilometre array (SKA) telescope.

1. Introduction

Optical fibre networks have been used to transfer both radio and optical frequency references with high stability [1–4]. Distribution of highly coherent, stable frequencies over an optical fibre network is an important enabling tool in a variety of applications such as radio astronomy. The Expanded Very Large Array (EVLA) comprising of 27 antennas relies on a single centralized hydrogen maser for reference tone generation, optical fibres for transfer to all antennas for the purpose of timing and frequency distribution [5]. Atacama Large Millimetre Array (ALMA) through the use of photonic system over fibre network distributes it timing across all the antennas [6,7]. Square kilometre array (SKA) is a radio telescope which will comprise 3000 mid-frequency dish antennas with planned baselines ranging from 10 km up to 3000 km or more. The effective collection area of all the antennas will amount to about one square kilometre, making it the world's largest radio Telescope. MeerKAT Telescope, which is a precursor for SKA, will have 64 dishes. Its construction at the Karoo, Northern Cape, South Africa is expected to be complete and operational in 2017. The farthest dish in the MeerKAT is expected to be 12 km from the central processing station [8].

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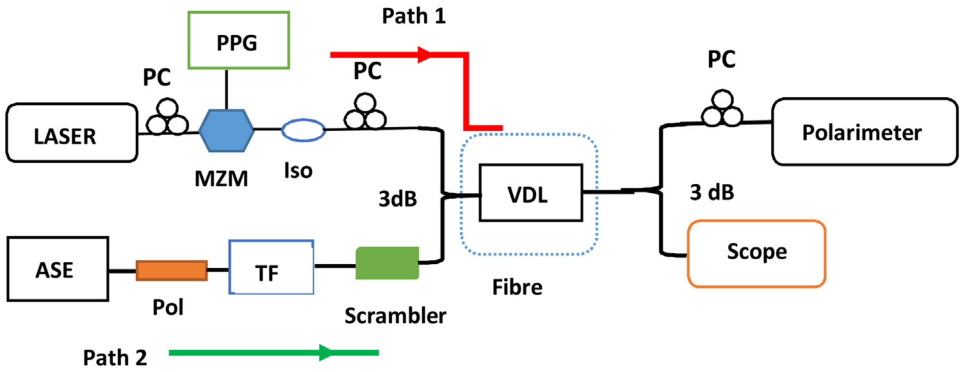

Fig. 1. Experimental set-up used to study the effects of Differential group delay on a clock signal. PC is polarization controller, PPG is programmable pattern generator, MZM is Mach-Zehnder modulator, Iso is an isolator, ASE is a broadband source, Pol is a polarizer, TF is a tuneable filter and VDL is a variable delay line.

Polarization mode dispersion (PMD) is a measure of differential group delay (DGD). This is the difference in the propagation velocity of two orthogonal polarization modes of a light wave within the fibre. PMD leads to pulse broadening and system impairment thus limiting the transmission capacity of the fibre [9,10]. PMD has its origin in optical birefringence and complicated by mode coupling in the fibre link. Birefringence is caused by both intrinsic and extrinsic changes in the fibre network. Intrinsic perturbations result from manufacturing process while extrinsic perturbations are due to stress and environmental changes such as temperature, wind and pressure. In long fibre lengths composed of a large number of segments, each segment has its own slow and fast modes and a portion of the signal propagates on each of them. At the boundary between these sections, the polarization vectors will be resolved into new pairs of local modes belonging to the next segment. The process of rotating the polarization vector into the new modes of the following segment is known as mode coupling. This mode coupling complicates PMD making it wavelength dependent [11]. As the polarization of the light wave drifts between the birefringent axes, the phase of the signal will be altered by an amount corresponding to the DGD. This in turn affects the time and frequency distribution in the telescope array. Radio Telescopes on the other hand, need accurate clock signals for data digitization, instrument synchronization, control and monitoring. PMD in optical fibre networks affect the signal accuracy in time and frequency reference.

This work presents polarization mode dispersion (PMD) measurements in KAT-7 telescope. KAT 7 telescope comprises of 7 operational telescope dishes situated at Karoo, Northern Cape of South Africa. KAT 7 is a pathfinder for the MeerKAT telescope. The KAT-7 study is relevant to the MeerKAT telescope network because of similar dish dynamics in addition to the environmental conditions arising from the same geographical area. The study provides values for allocation in the design of the MeerKAT telescope array. This paper is arranged as follows: Section 1 is the introduction, Section 2 illustrates fibre's birefringence and Section 3 gives the findings of the investigation.

2. Illustration of fibre's birefringence effect on the phase of a clock signal

Fig. 1 depicts the experimental set-up used to study birefringence in an optical fibre network. For path 1, a tuneable laser source was externally modulated with a 4.25 GHz clock signal and a variable delay line (VDL) was used to vary the DGD of the link. Polarization controllers (PCs) were used to align the input polarization with the VDL, while the isolator prevented back reflection on to the MZM. Path 2 was used to determine the principal state of polarization (PSP). The broadband source generates an unpolarized light. The generated signal is then polarized before it is being filtered. The filtered signal is then scrambled and coupled into the variable delay line. To set the fast and slow axes; a Poincaré sphere (polarimeter) was utilized to visualize the polarization changes. After the delay line, a 3 dB splitter was used so as to monitor the polarization state of the signal on a polarimeter while analysing the DGD effects on the oscilloscope.

In our experimental test, the DGD was introduced using an optical variable delay line (VDL). The VDL emulates a fibre under test in the link. The received clock signal via path 1 was studied on a high-resolution oscilloscope. The DGD values on the VDL were set to 10 ps and 20 ps and the shift on the clock signal phase monitored. These DGD values are however not realistic as expected in a normal fibre network. But we use high values for illustrative purposes to clearly show what happens to the phase of a clock signal. The overall phase shift measured corresponds to the introduced DGD i.e. 10 ps DGD introduced a shift of 10 ps (0.27 rad) [12].

The illustration of the introduced DGD variation with the time delay on the scope is shown in Fig. 2. The phase shift depicted in the figure shows the birefringent axes of the transmitted clock signal. The angular values, 0° and 180° on the figure refer to the Poincaré sphere angle that the state of polarization (SOP) of the light wave makes with the delay line axes. At 0° the light wave is aligned with the slow axis while at 180°, it is aligned with the fast axis. The phase shift is seen to increase with an increase in DGD. PMD is a stochastic parameter which does not linearly increase with length. Instead, the PMD is proportional to the square root of the fibre length, due to mode coupling [13].