A 40 Gbps Wavelength Division Multiplexing (WDM) Optical Network for Data Transmission for MeerKAT

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Abstract – The MeerKAT telescope, as a precursor to the Square Kilometre Array (SKA), is expected to have 64 dish antennas, each delivering data rates up to 40Gbps. This paper reviews the optical wavelength division multiplexing technique (WDM) and how the method can be used to drive the 40Gbps links required for each of the MeerKAT dish antennas. We report on a-8x5Gbps WDM optical system simulated under VPIphotonics, which led to bit-error-rates (BER) estimations for each channel that met the telecommunications target of $< 10^{-9}$ at an optical sensitivity of -22dBm for all 8 WDM channels considered. The results obtained show error free transmission for the 8 channels considered in the system. This demonstrates that the presented WDM setup could be successfully implemented for the optical data transport network of the MeerKAT telescope.

I. INTRODUCTION

The WDM technique is considered one of the most efficient methods for delivering high data rates over single mode optical fibres. For the purpose of the MeerKAT telescope, data multiplexing will be used to transfer data from the antenna dishes to the central processing building over an approximate distance of 12 Km. We expect each antenna to deliver data to the central processing building at an aggregate rate of 40Gbps. In this paper, we present simulation results for an optical network designed to implement the WDM technique. Simulation results have shown acceptable BER values for each of the 8 channels considered on the optical links of the telescope with received sensitivities varying between -22dBm and -23dBm.

II. MULTIPLEXING TECHNIQUES

There are several methods of data multiplexing for optical networking. These include Optical Time Division Multiplexing (OTDM), Wavelength Division Multiplexing (WDM), and Code Division Multiplexing (CDM). All of which have been designed to increase the bandwidth capacity of a single mode optical fibre.

The Optical Time Division Multiplexing (OTDM) technique is one of the available methods for optical data multiplexing. An OTDM multiplexer takes in a select number of inputs or channels and interleaves them to distribute the aggregate signal in a serial fashion over an optical fibre [1]. The OTDM technique effectively works as shown in Figure 1, where the inputs are interleaved and sent over an SMF fibre, demultiplexed, and distributed to the corresponding channels. There are two major types of OTDM techniques: the deterministic (or synchronous) OTDM technique, and the statistical (asynchronous) OTDM technique. For deterministic OTDM, time slots have equal finite lengths and can be used in a periodical fashion [2]. While for statistical OTDM, time slots have variable time lengths and are used on demand, in part depending on the statistics of each individual channel considered [3].

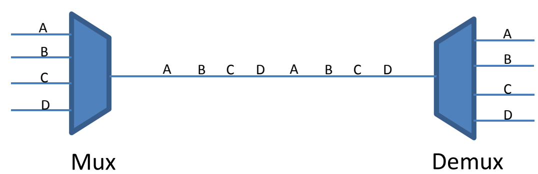

Figure 1 – Optical Time division multiplexing technique (deterministic)

The Wavelength Division Multiplexing technique relies on the wavelength properties of electromagnetic radiation to support several channels capable of considerably increasing the carrying capacity of a single mode optical fibre. In WDM, each channel has a set wavelength to operate on, and all information transferred on that given channel remains specific to the assigned wavelength or channel [4]. All wavelengths or channels are then multiplexed onto a single fibre and then demultiplexed to give out the same amount of channels used at the transmitter end. A more detailed overview of WDM is presented in the next section.

The Code Division Multiplexing (CDM) technique allows to transmit several channels simultaneously and at the same frequency. In this technique, channels are time-shared in a greater rate channel by overlaying a high rate coded sequence [5]. Each channel is also assigned a specific coded sequence that can be demultiplexed at the receiver.

III. WAVELENGTH DIVISION MULTI-PLEXING

The WDM technique is a preferred method of optical data multiplexing used in particular for long haul telecommunication optical networks [6]. As indicated by the name, the method relies on the creation and distribution of channels having different wavelengths over a single mode optical fibre. Figure 2 outlines the operating principle of a WDM system. A select number of channels are selected to make up the frequency bands to be considered for data transfer. The channel spacing can be chosen depending on the number of channels to use, and on the type of setup required, although channel spacings of 50GHz, 100GHz, or 200GHz are common. For the purpose of this simulation, a-100GHz channel spacing was used for the WDM channels with channel frequencies varying from 192.8THz to 193.5THz.

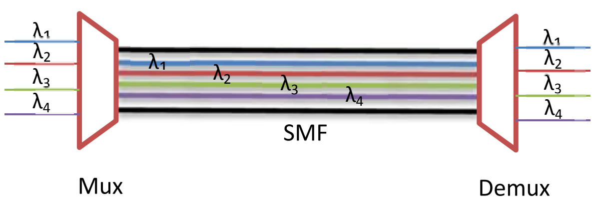

Figure 2 – Wavelength division multiplexing technique

Coarse Wavelength Division Multiplexing (CWDM) is a term established by the International Telecommunications Union (ITU) to depict a WDM system which has channel spacing of 20nm [7]. The spectral grid for CWDM is specified in the ITU-T G.694.2 document for WDM systems. Because of the greater channel spacing, CWDM usually has fewer channels in comparison to Dense Wavelength Division Multiplexing (DWDM). 0.4nm or 0.8nm channel spacing is common in DWDM systems which can carry a considerable number of channels. The ITU-T G.964.1 document for DWDM systems stipulates that channel spacings of 12.5GHz (0.1nm), 25GHz (0.2nm), 50GHz (0.4nm), 100GHz (0.8nm) and above are available for DWDM systems which can contain up to 80 channels [8]. In our simulation, we relied on a-100GHz channel spacing for 8 channels therefore operating under the DWDM ITU grid.

IV. EXPERIMENTAL SETUP

The experimental setup is shown in Figure 3. The setup consists of 8 lasers for each of the channels considered, a multiplexer, a 12 Km single mode optical fibre, a demultiplexer, and a receiver for each of the channels.

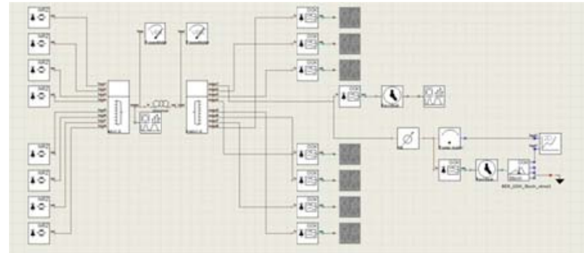

Figure 3 – Data multiplexing simulation setup (VPIphotronics)

The lasers shown on the far left of the figure are simulation components that each contains: a continuous wave (CW) laser, a pseudo-random-bit-sequence (PRBS) generator, a non-return-to-zero (NRZ) Coder, a rise-time adjustment mechanism, and a Mach-Zehnder modulator [9]. Each unit is given a specific channel wavelength to operate on. The channels considered have a channel spacing of 100GHz or an equivalent spacing of 0.8nm. The optical frequencies considered for the DWDM system therefore vary from 193.5 THz (Channel 1) to 192.8THz (Channel 8) as shown in Figure 4. The simulated Optical Spectrum Analyzer (OSA) denotes a maximum intensity on each channel of about -3.79dBm and a noise floor at about -170 dBm.

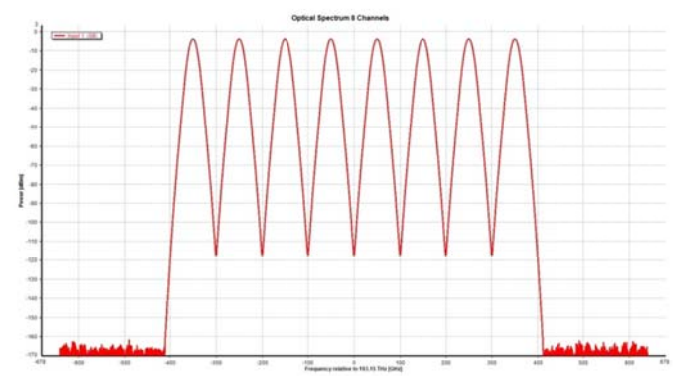

Figure 4 – 8 Channel WDM Spectrum

V. MEASUREMENT RESULTS

For telecommunication purposes we expect BER of 10^{-9} or better, so this is also the expected requirement for the receiver on each of the WDM channels we simulated here. The optical fibre used is a universal single mode fibre of 12 Km in length with negligible insertion loss.

The attenuation in the optical fibre is estimated at 0.2 dB per Km for a distance of 12 Km or an expected channel loss of 2.4dBm. The demultiplexer adds a subsequent loss for expected received power levels around -22.0 dBm to -23dBm, indicating the need for an array of Avalanche Photodiodes (APD).

From our setup shown in Figure 3, we can notice a few probes that allow us to analyse the received signals and evaluate the corresponding BER. The top arm is made of a photodiode receiver, an ideal clock recovery item, and a spectrum analyser. This part of the setup allows us to review the spectrum of the channel considered at the receiving end. The bottom arm is made up of: an optical attenuator, a power meter, a photodiode receiver with clock recovery, a BER calculator, and a 2D plot analyser that allows to plot BER curves of each channel with respect to the received power.

The eye diagrams for Channel 1 and Channel 8 are shown below displaying an open eye with an eye width of about 200ps, an eye height of about 0.57x 10^{-3} a.u, a rise and fall times of about 105ps each, and an estimated jitter of 21.82ps. Similar values for the eye diagrams of the other channels (Channels 2-7) were obtained through the simulation, indicating that there were virtually no errors in the transfer of data over the optical network constructed. Any signal degradation would reflect with a closing of the eye. The simulation results show perfectly opened eyes for each of the 8 channels considered, which is also the result we expect in for the implementation of a DWDM optical network for data transfer on the MeerKAT project.

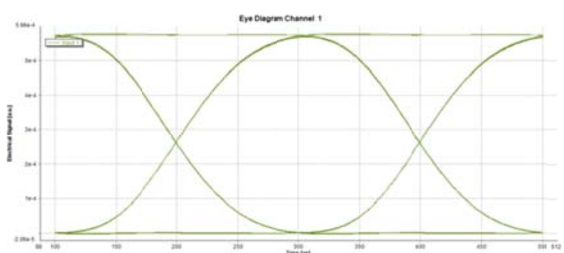

Figure 5 – Eye diagram for Channel 1

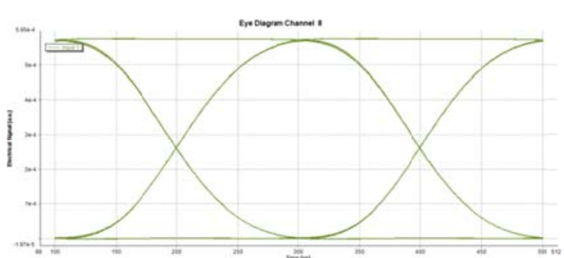

Figure 6 - Eye diagram for Channel 8

BER curves were measured in our simulation for each of the 8 channels considered in the WDM setup. To meet telecommunications requirements, it is imperative to arrive at a BER per Channel that is equivalent to 10^{-9} or better. The BER curves shown in Figure 5 show that a BER of 10^{-9} is attainable on each channel with a received sensitivity varying from -22.55dBm for channel 1 to -22.5 dBm for channel 8.

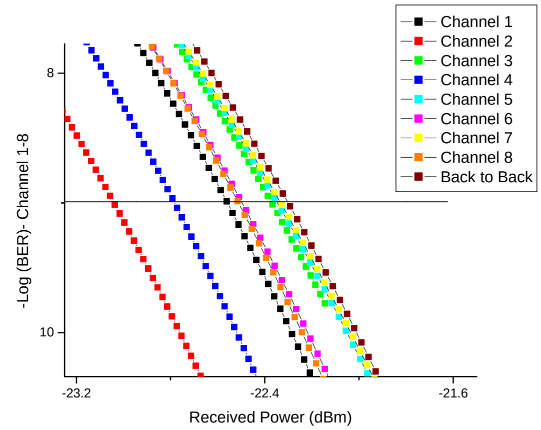

Figure 7 – BER Vs. received power for all channels

The following figure describes transmission penalty with respect to each of the channels considered. The transmission penalty is estimated by evaluating and comparing BER values of a given channel with BER values of the back to back signal. A maximum penalty of 0.74 dB is attributed on Channel 2, with a minimal penalty of 0.03dB which occurs on channels 5 and 7.

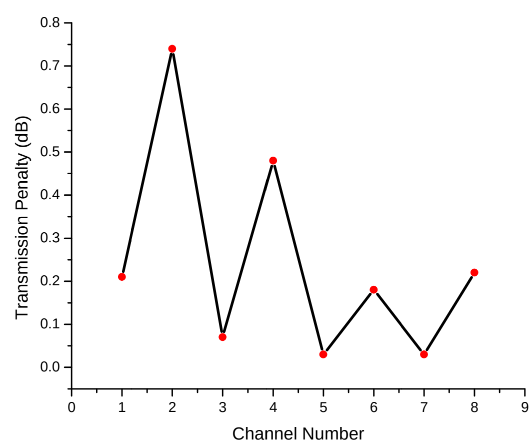

Figure 8 – Transmission penalty per WDM channel

VI. CONCLUSION

In this letter, a DWDM system has been simulated to deliver up to 40Gbps data rates via an optical fibre network from each of the MeerKAT dishes. The system is made up of 8 channels of 5Gbps each connected to an SMF via an optical multiplexer/demultiplexer system. The signals carried through the fibre are demultiplexed after 12Km of fibre to reach the receivers. We analysed the results and evaluated the BER measurements for each of the channels. We were able to obtain acceptable BER values for each of the channels considered in this DWDM implementation. The BER curves show a BER value of 10^{-9} for all channels corresponding to a receiver sensitivity varying from -22 dBm to -23 dBm. This simulation depicts a suitable DWDM implementation for the data transfer required for the MeerKAT project.

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