

Athermal Performance  
of  
Bulk Grating Wavelength Division Multiplexers/Demultiplexers

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## I. Introduction

With increasing economics and applications, Dense Wave Division Multiplexing (DWDM) has become a viable means of lowering costs while increasing capacity and flexibility on fiber optic networks. The demand for equipment to enable DWDM continues to increase. This demand has led to the introduction of a variety of new DWDM technologies into the marketplace. Ironically, bulk diffraction gratings, one of the most mature technologies, is now one of the newest technological forerunners in the field of DWDM.

A bulk diffraction grating is a classical optics technology that has been in existence for over 100 years. Historically, the polarization dependent loss (PDL) of diffraction gratings restricted its use in the telecommunications field. This is because the state of polarization (SOP) of light in an optical media is indeterminate, technology that is sensitive to PDL can experience significant signal loss, rendering it useless in an optical transmission system. However, recent technological advances have overcome this problem. There now exist two approaches to diffraction grating technology to overcome the problem of PDL. One is a dual or split path design and the other is a unitary path design. The unitary path design is more efficient because the grating design takes PDL into account and there is no need for multiple optical paths. The split path design requires the light to be split and sent through polarization control elements and then recombined at the grating interface. This design requires multiple optical components to “handle” the polarization states independently, and thus is plagued by issues of inefficiency, costs, complexity, and reliability. The unitary path structure, which greatly improves the design, is made possible by recent grating breakthroughs within the grating itself.

Diffraction grating based mux/demuxes offer significant performance advantages compared to competing technologies. Their parallel optical architecture provides extremely low insertion loss, low ripple, excellent channel-to-channel uniformity, and low polarization dependent loss while operating over a wide temperature range. More importantly, this performance is achieved without the added complication of external active thermal stabilization (e.g., thermo-electric heaters or coolers), thereby making the design truly passive, less complex, and inherently much more reliable.

The performance of a truly passive unitary path grating based device is described in this paper. A Lightchip 20 channel 200 GHz spaced mux/demux (OWR2020) was selected for this paper. This device is representative of a product that is currently being manufactured and shipped to existing customers. The choice of product is independent of channel spacing or number of channels for purposes of evaluation.

## II. Understanding Optical Performance over Temperature

Perhaps the most challenging requirement in optical mux/demux design is to ensure meeting the reliability and performance criteria over a wide operating temperature range. To do so without the need for external temperature control (athermal design) is highly desirable due to improved cost and reliability implications. A truly passive athermal mux/demux is simple yet elegant, performing a complex function with picometer accuracy while remaining relatively insensitive to variations in center wavelength and insertion loss over temperature. In evaluating the thermal performance of a mux/demux, maintaining the maximum insertion loss stability over the operating temperature becomes the primary objective. Having a clear understanding of how the insertion loss is measured is a mandatory point of reference<sup>1</sup>. All of the insertion loss measurements described herein are made relative to the ITU grid wavelengths within defined pass band edges to the left or right of the respective wavelength of the mux/demux channel under test. For visual purposes, figure 1 depicts a single spectral response from a connectorized grating-based multiplexer with 200 GHz channel spacing measured at 25 °C. The parallel vertical lines form the pass band edges from which the loss values are derived. In this example, the pass band edges are positioned  $\pm 0.25$  nm from the ITU grid wavelength, yielding a pass bandwidth of 0.5 nm, centered on the ITU grid wavelength. In this case there is a maximum insertion loss of

2.77 dB measured at the right band edge. The minimum insertion loss of 2.50 dB is measured at the peak of the spectrum. The difference between the maximum and minimum insertion loss yields a ripple of 0.27 dB.

The insertion loss and ripple of the spectral response shown in Figure 1, will vary if a significant shift in wavelength occurs. Figure 3 represents the same spectral response shown in Figure 1 artificially shifted by +80 pm, simulating a high, unacceptable wavelength temperature dependence. Assume the +80 pm center wavelength shift occurred when going from 25 °C to 70 °C. This would yield a center wavelength temperature dependence of 1.8 pm/°C shown in Figure 2. The graph consists of simulated center wavelength (CWL) measurements made at 25 °C, -5 °C, and 70 °C over three cycles. The CWL hysteresis at each of the three temperatures is shown as < 10 pm.

Figure 1 – Well Centered Spectral Response at 25 °C

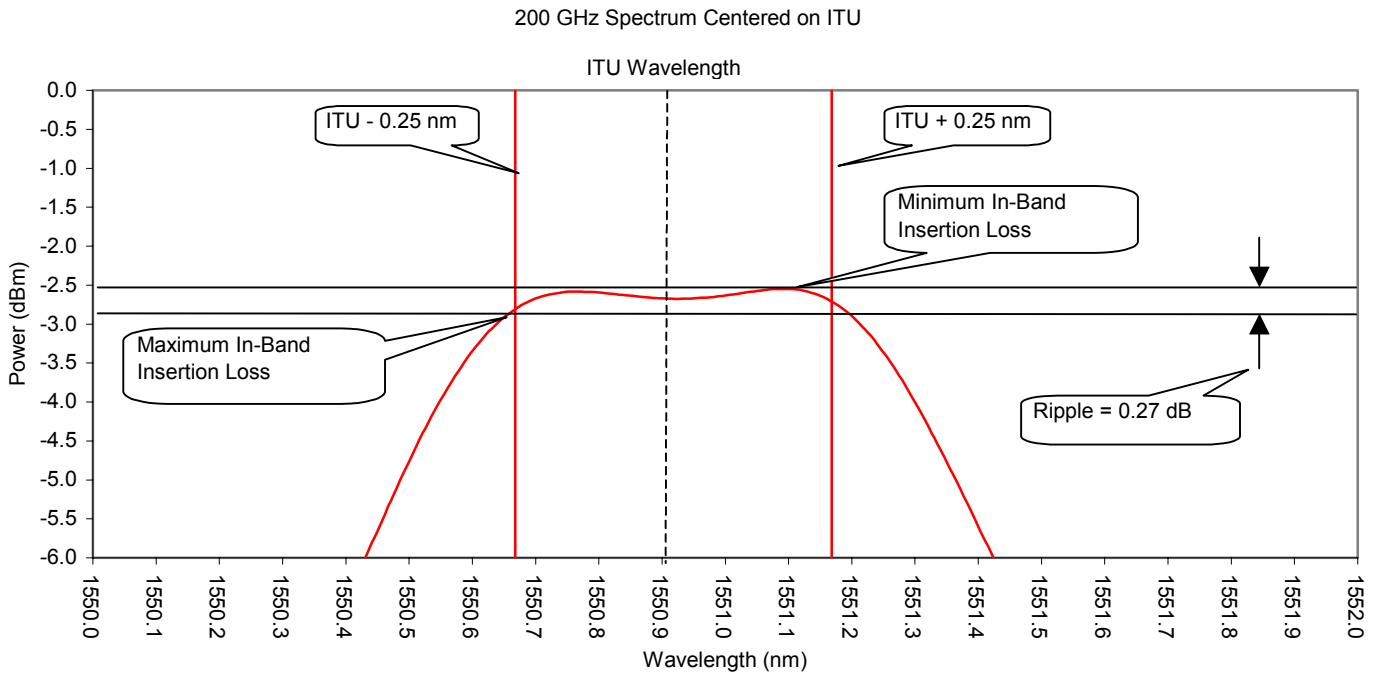
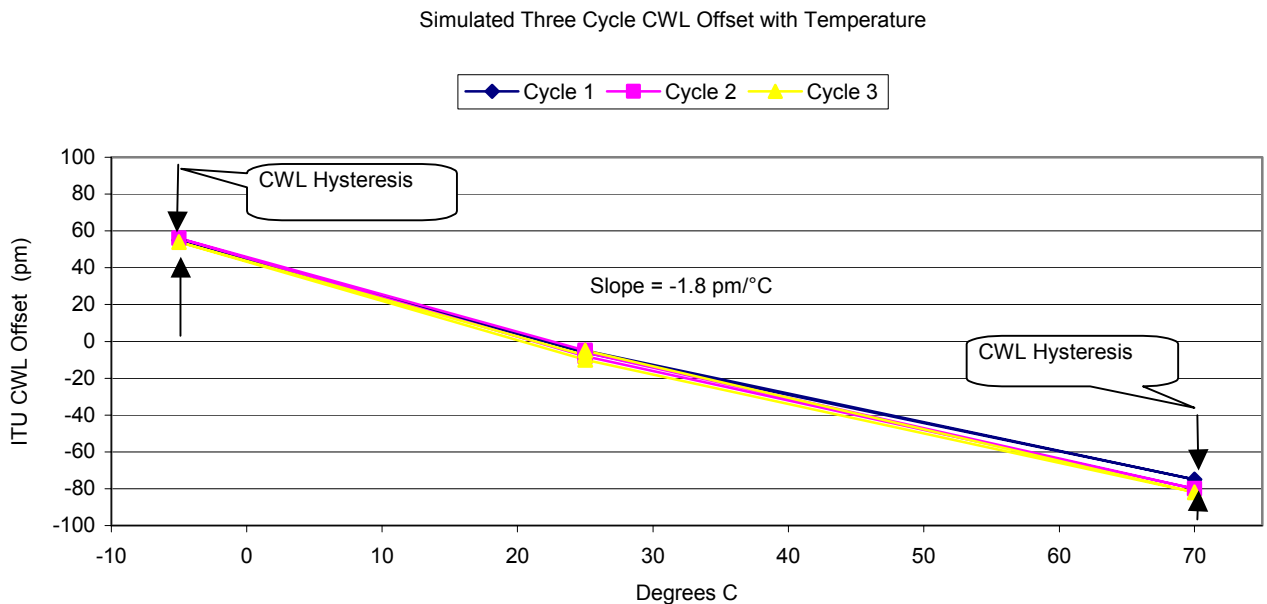
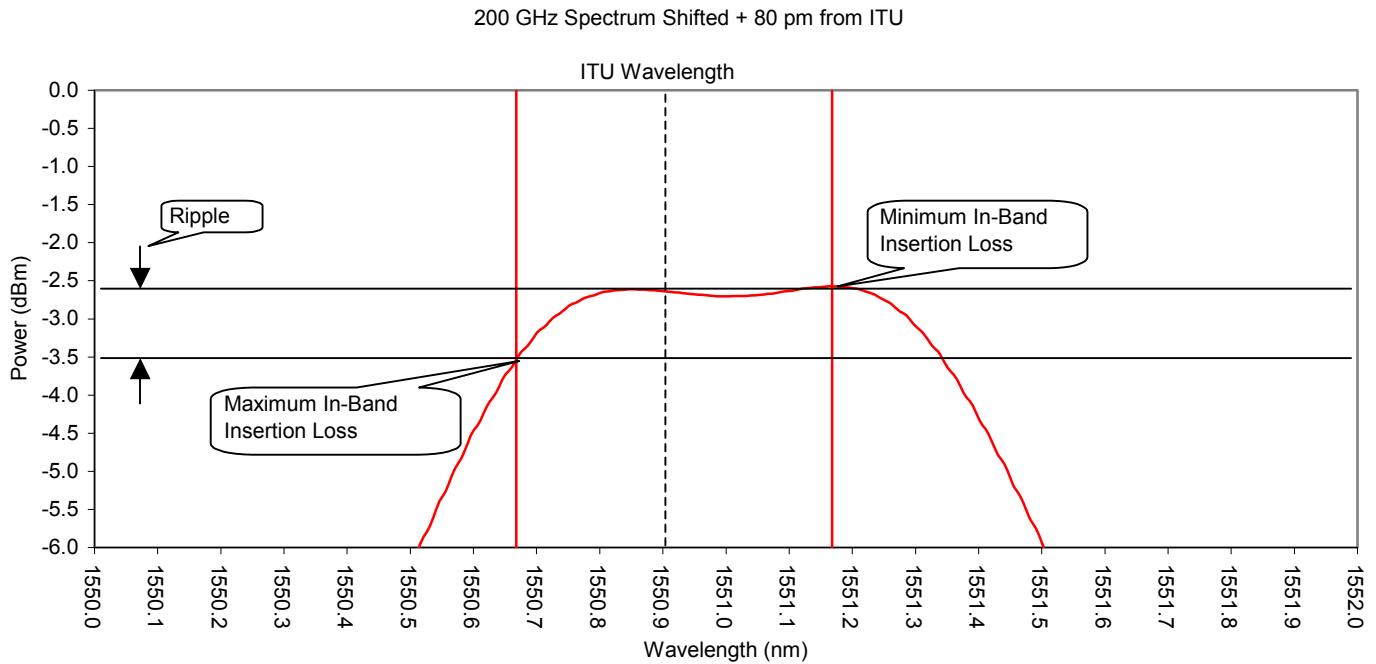


Figure 2 – Simulated Center Wavelength Temperature Dependence



The result of this high wavelength thermal dependence of (1.8 pm/°C) on the spectral response is shown in Figure 3. As you can see, the insertion loss increases to 3.5 dB with a ripple of 0.94 dB as the spectral response moves out of band. This is an unacceptable increase for both the 0.75 dB in maximum insertion loss and the increase of 0.75 dB in ripple from the 25 °C reference measurements.

Figure 3 – Simulated Spectrum Shift to Demonstrate Center Wavelength Temperature Dependence of 1.8 pm/°C and Resulting Increase in Insertion Loss and Ripple



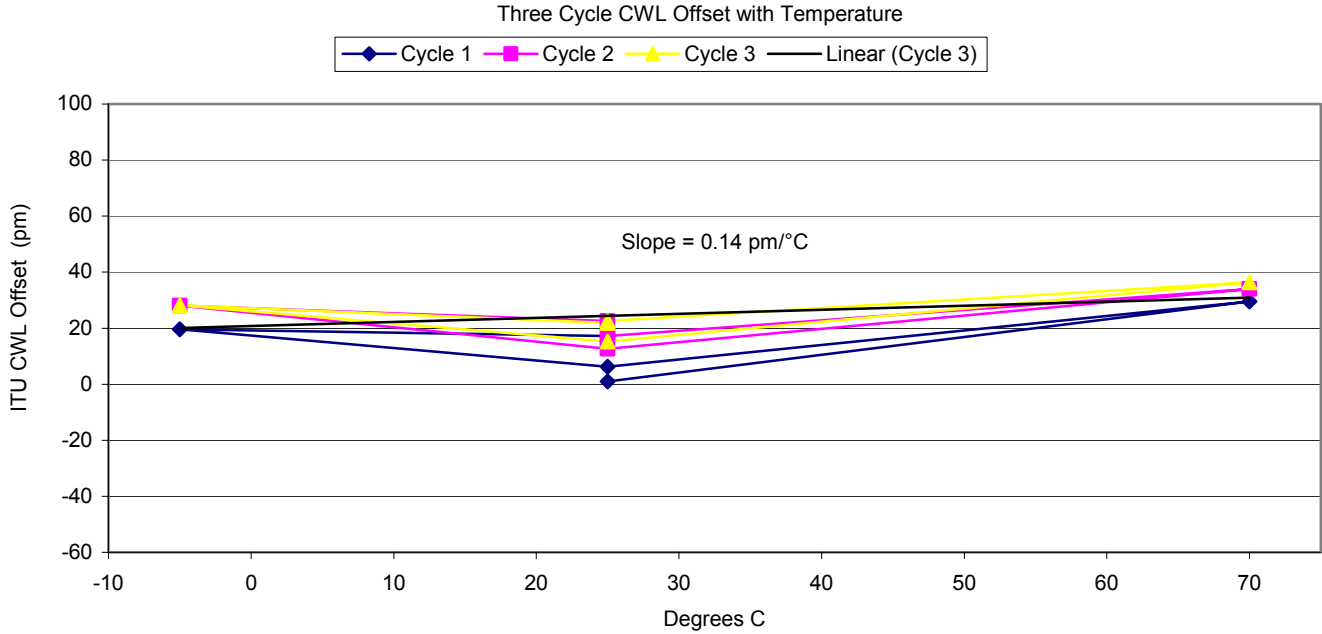
As illustrated in Figures 1 and 3, center wavelength shift is a major concern when heating or cooling a mux/demux. The allowable insertion loss variation over operating temperature, according to Telcordia GR-1209-CORE, is 0.5 dB, so wavelength shift combined with other sources of loss must be negligible. An athermal mux/demux must have a low wavelength temperature dependence and less than 0.5 dB of insertion loss variation over the defined operational temperature range, in this case -5 °C to 70 °C, while remaining within specification for all the other optical parameters on a specification sheet.

To consistently achieve a high degree of athermality, the design must have; 1) small center wavelength temperature dependence, 2) a wide filter width and, 3) a well centered spectral response with respect to the ITU grid wavelength.

### III. Evaluating the Lightchip 200 GHz mux/demux (OWR2020)

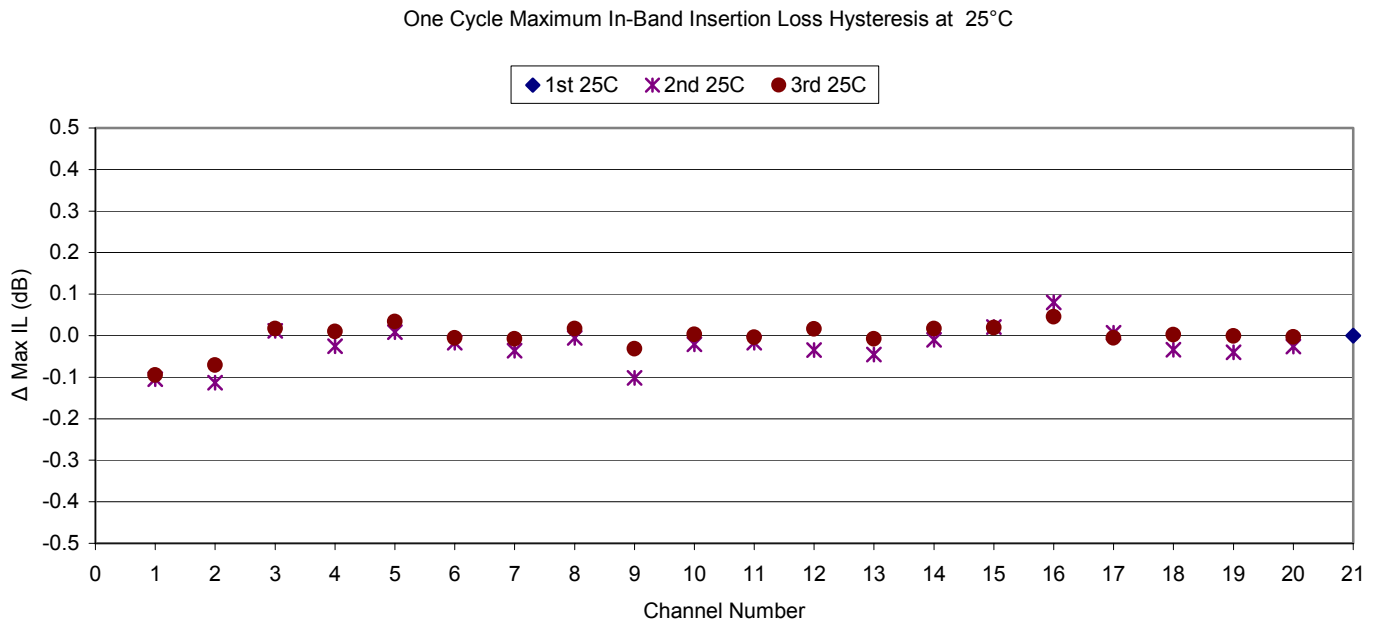
Clearly, an intrinsic low temperature dependence is indicative of superior optical design. The graph in Figure 4 depicts the performance of the Lightchip 20 channel, 200 GHz spaced mux/demux (OWR2020), measured over three temperature cycles. The thermal dependence slope is very small at 0.15 pm/°C - essentially no change in center wavelength over the operating temperature. The CWL hysteresis at 25 °C is 20 pm, and 10 pm at -5 °C and 70 °C.

Figure 4 – Lightchip OWR2020 Wavelength Temperature Dependence



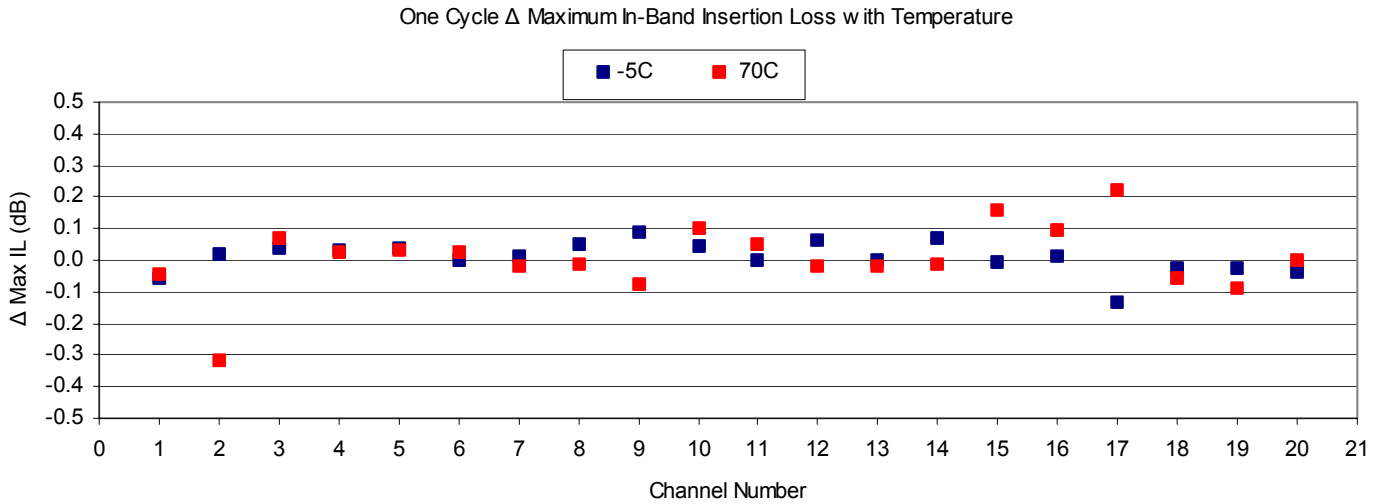
Insertion loss hysteresis is a measure of the repeatability of the insertion loss at 25 °C after returning from a dwell period at the temperature extremes. Insertion loss hysteresis can be an accumulation of CWL hysteresis and other sources of loss. The graph in Figure 5 shows the insertion loss hysteresis to be 0.1 dB on an OWR2020 at 25 °C after returning from a one-hour dwell at the temperature extremes of -5 °C and 70 °C.

Figure 5 – 20 Channel Maximum In-Band Insertion Loss Hysteresis at 25 °C



The total insertion loss excursion is a measure of the change in the maximum in-band insertion loss at  $-5\text{ }^{\circ}\text{C}$  and  $70\text{ }^{\circ}\text{C}$  relative to  $25\text{ }^{\circ}\text{C}$ . Total excursion can result from accumulation of CWL shift and other sources of loss. The graph in Figure 6 shows the worst case insertion loss total excursion of 0.32 dB on an OWR202 at  $25\text{ }^{\circ}\text{C}$  after dwelling at  $-5\text{ }^{\circ}\text{C}$  and  $70\text{ }^{\circ}\text{C}$ . This total excursion easily satisfies the Telcordia GR-1209-CORE requirement of  $\leq 0.5\text{ dB}$ .

Figure 6 – 20 Channel Total Excursion of Maximum In-Band Insertion Loss



The enhanced performance of low temperature dependence is clearly illustrated in the spectral response shown in Figure 7. There are several important considerations to interpreting the spectral response. First, notice how well the spectra are centered between the pass band edges. This centering provides ultra-low maximum insertion loss of  $< 3.5\text{ dB}$  and low ripple of  $< 0.5\text{ dB}$ . Second, the wavelength shift over a total  $75\text{ }^{\circ}\text{C}$  range is  $10\text{ pm}$  yielding a center wavelength temperature dependence of  $0.1\text{ pm}/^{\circ}\text{C}$ . The center wavelength temperature dependence is also critical to adjacent channel isolation or crosstalk. As a spectral response shifts to the left or to the right of the ITU CWL, adjacent channel crosstalk can be severely impacted. However, due to the low CWL thermal dependence, the effects on adjacent channel isolation are negligible (Figure 8). Most importantly, the total excursion of maximum insertion loss is  $0.25\text{ dB}$  while the ripple remains  $< 0.5\text{ dB}$  with no effect on isolation. Essentially, from  $-5\text{ }^{\circ}\text{C}$  to  $70\text{ }^{\circ}\text{C}$ , the maximum transmitted laser power fluctuation over the entire  $0.5\text{ nm}$  pass band width would be  $0.5\text{ dB}$ , governed by the wavelength stability of the laser.

Figure 7 – Spectra Illustrating Total Excursion of Wavelength, Insertion Loss and Ripple over a -5 °C to 70 °C Operating Range

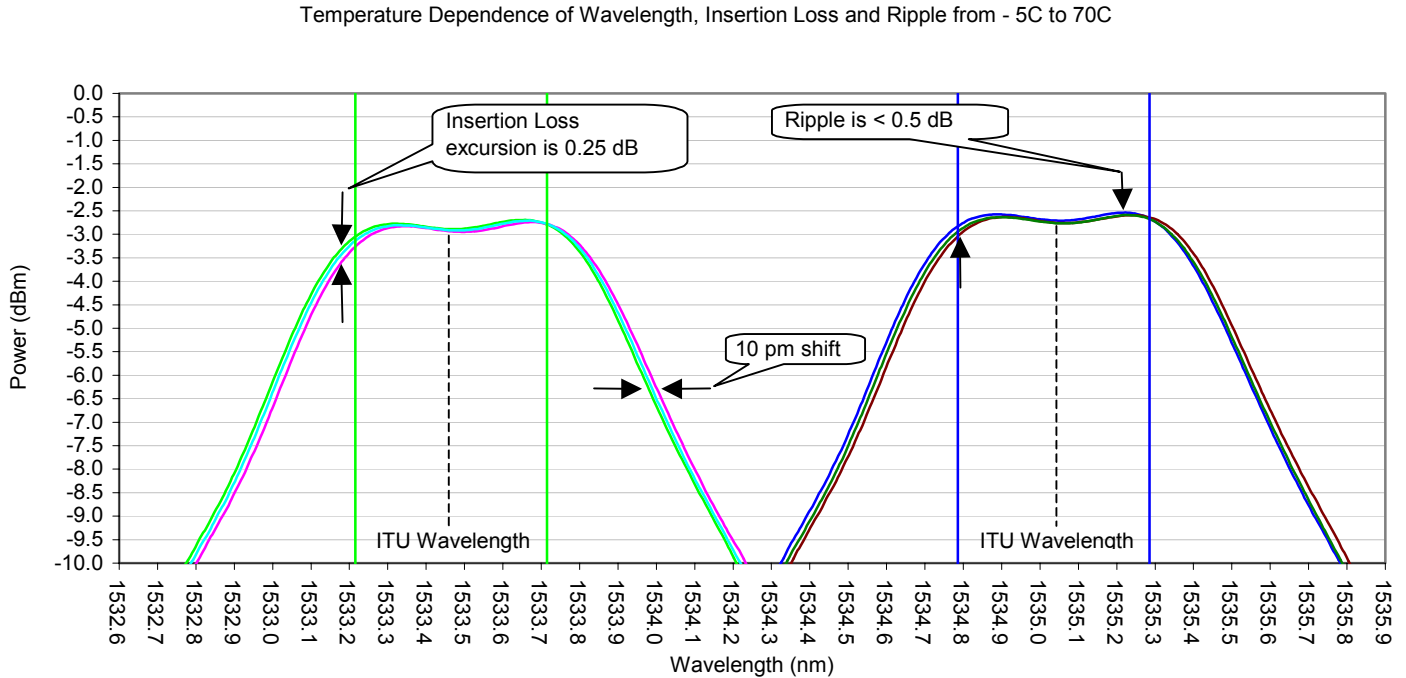
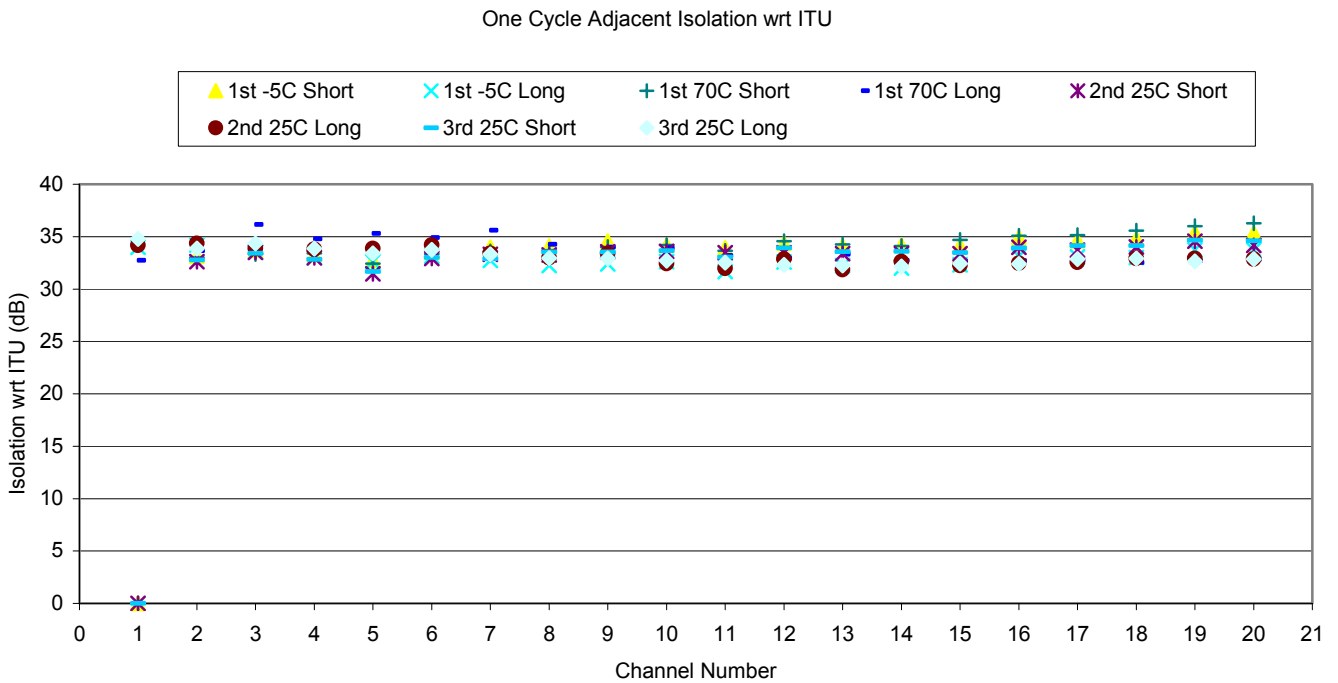


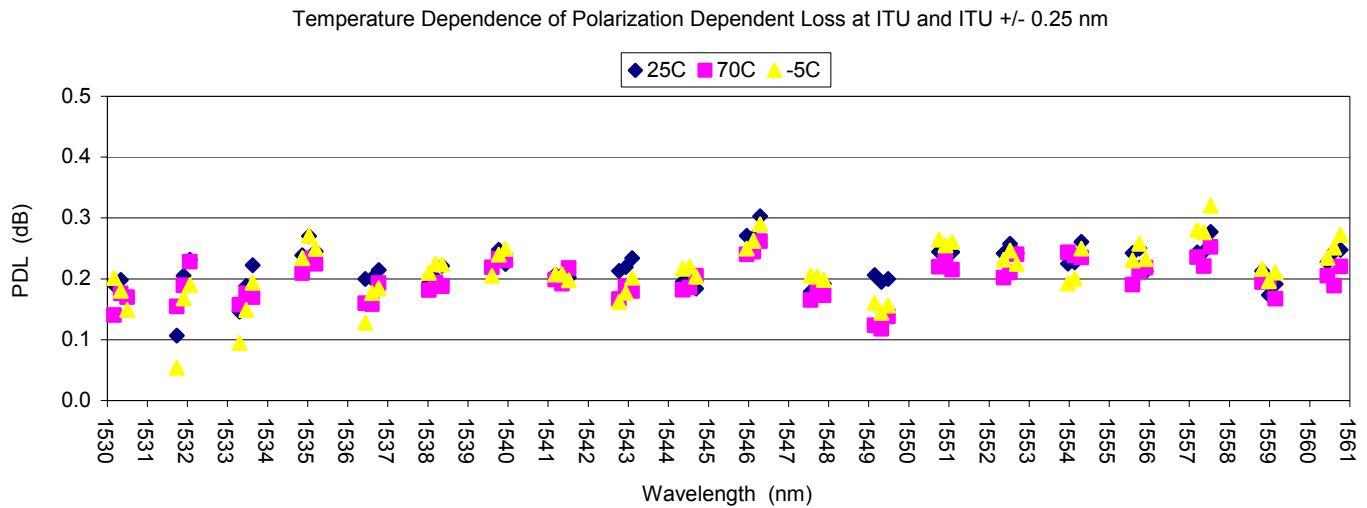
Figure 8 – Temperature Dependence of Adjacent Channel Isolation due to Spectral Response Shift



Polarization Dependent Loss (PDL) is another performance parameter that must be considered in a mux/demux as it has an affect on the overall insertion loss of the device. As the state of polarization is varied at a fixed wavelength, the insertion loss varies by an amount equal to the PDL of the channel under test. The PDL must therefore be low, and remain within specification over operating temperature. Figure 9 shows the PDL of the

OWR2020 measured at 25 °C, -5 °C and 70 °C. The PDL was measured at the ITU wavelength and at each of the pass band edges with a worst-case measurement of 0.31 dB.

Figure 9 – Temperature Dependence of PDL over a -5 °C to 70 °C Operating Range



#### IV. Conclusion

It has been demonstrated that the athermal optical performance of grating based mux/demux devices are at the forefront of high channel count DWDM technology. Not only do they exhibit excellent performance, but they are also inherently more reliable. The need for no temperature control not only increases reliability, but simplifies design and reduces cost through the elimination of additional circuitry and electrical power requirements.

As a result of low center wavelength dependence over temperature, the Lightchip mux/demux devices specifications experience very little change at temperature extremes. Furthermore, the patented design of Lightchip’s product addresses PDL concerns once associated with grating based devices. This unitary path free-space structure also allows for more design flexibility to control spectral response shape. Consequently, it is easy to widen the spectral response or provide a flat top or gaussian shape with virtually no penalty in insertion loss. With the ultra-low insertion loss through the unitary path design, optical amplifiers and their costs can be eliminated or reduced in a system. The unitary path design inherently allows the Lightchip device to act as either a mux or demux. The ability of the device to have identical specifications for both a mux and demux mode is known as a symmetrical device. Utilizing a symmetrical device in DWDM system design offers a significant advantage when the system needs to be reconfigured or expanded. A symmetrical device can be interchanged at any point in the network without suffering any type of system penalty (i.e. insertion loss). However, a mux/demux device, which is not symmetrical, can greatly impact a system budget when changes are needed which can lend itself to a costly network redesign. In examining a Lightchip mux/demux, it has been shown that the athermal and unitary path design results in overall superior optical performance whether the application is a mux, demux, or both.

## **References**

1. Mux/DeMux Optical Specifications and Measurements, G. M. Colachino, [www.lightreading.com](http://www.lightreading.com). 2001 July 24

## **Acknowledgements**

1. Bill Emkey, V.P. Product Marketing
2. Frank Hiatt, Director Customer Development
3. R. Greg Dudgeon, Application Engineer