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# IN-BAND DISPERSION LIMITATIONS OF UNIFORM APODISED FIBRE GRATINGS

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*Abstract:. Apodisation-generated in-band dispersion can limit the useful bandwidth of gratings. We discuss how a trade-off in reflection squareness may be necessary in order to increase the useful bandwidth.*

## Introduction

Wavelength-division multiplexing (WDM) is widely recognised as the technology of choice to utilise the fibre bandwidth. The key enabling technology for WDM is grating-based filters, offering low insertion loss over a wide bandwidth and good suppression of neighbouring channels when properly designed /1/. It has recently been discussed how the dispersion on the edges of the photonic bandgap of a grating both in-band and out-of-band can cause the reflected and transmitted signals to be significantly distorted /2,3/.

In this paper we show that apodisation-induced in-band dispersion can limit the useful bandwidth of gratings considered for current transmission systems. We discuss design rules depending on apodisation and length for an optimisation of the useful bandwidth.

## Grating design criteria

Fig. 1 highlights some of the issues required for gratings to be suitable candidates for e.g add-drop multiplexing in a WDM scheme. These include at least 30 dB sidelobe suppression to minimise cross talk between adjacent channels. At least 30 dB rejection for a sufficient channel drop, less than 1 dB variation in the reflection spectrum and low in-band dispersion to minimise power penalties at the reciever.

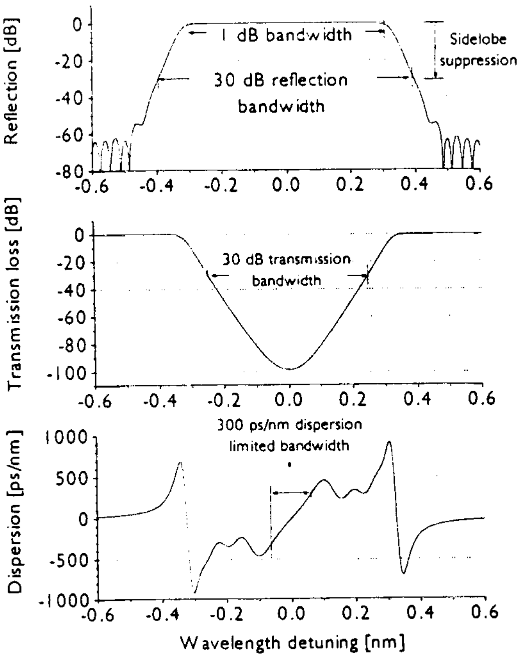

**Figure 1: Calculated reflection, transmission and dispersion characteristics of a 25 mm long Gaussian apodised grating**

We define the following parameters to quantify the useful bandwidth of a grating.

a) **Relative reflection bandwidth;** The 1 dB reflection bandwidth relative to the 30 dB reflection bandwidth (Fig. 1a).

b) **Relative transmission bandwidth;** The 30 dB transmission bandwidth relative to the 30 dB reflection bandwidth (Fig. 1b & 1a).

c) **Relative dispersion limited bandwidth;** The minimum bandwidth at which a tolerable dispersion is present relative to the 30 dB reflection bandwidth (Fig. 1c & 1a).

The smallest of a)-c) is then going to determine the relative useful bandwidth on a given grid of the grating to allow for error-free operation.

As Gaussian apodised uniform gratings are considered to be the ideal add-drop multiplexing filter /1/, and some grating filters already have been installed in real world systems, we base this study on gratings apodised with that particular profile. Different degrees of apodisation are simulated by varying the FWHM of this profile and to make use of the full ITU channel bandwidth, the 30 dB bandwidth of the gratings is kept constant at 100 GHz. This is achieved by varying the refractive index modulation accordingly.

The grating spectra in this study are generated using a transfer matrix formalism. Assumptions are based on operation in a single mode fibre with an effective index $n_{eff}$=1.45, a mode confinement factor $\eta$=0.78, and an operation wavelength of 1550 nm.

## Analysis and discussion

Fig. 2 shows the relative reflection, transmission and dispersion limited bandwidths plotted against $L_{FWHM}$ of the grating. The gratings considered are 25 mm long and have a constant 30 dB bandwidth of 100 GHz. It is seen that an increase in the degree of apodisation (a reduction in the FWHM length) first of all reduces the relative reflection and transmission bandwidths of the gratings. However it is seen to increases the relative dispersion bandwidth.

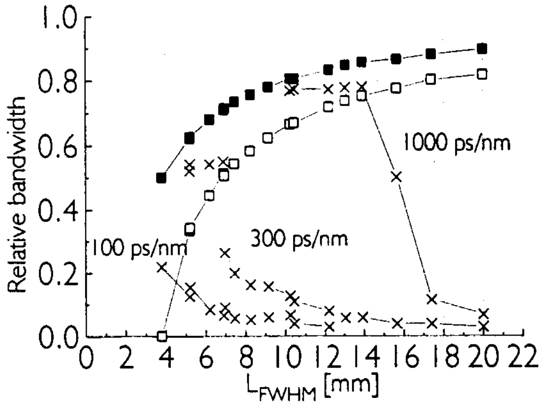

**Figure 2. Relative bandwidths of reflection (■), transmission (□) and dispersion (x) vs FWHM grating length. The gratings are Gaussian apodised with 30 dB reflection bandwidths of 100 GHz.**

Further calculations suggest, although not illustrated here due to limited space, that smaller channel spacings of 25-50 GHz are going to be useful bandwidth limited even further. Reducing the 30 dB bandwidth to less than the channel spacing shows that the useful bandwidth on that grid is reduced even further. This suggests that in order to obtain the maximum useful bandwidth on a given grid the grating also must be designed to have a 30 dB bandwidth identical to or slightly larger than the channel spacing.

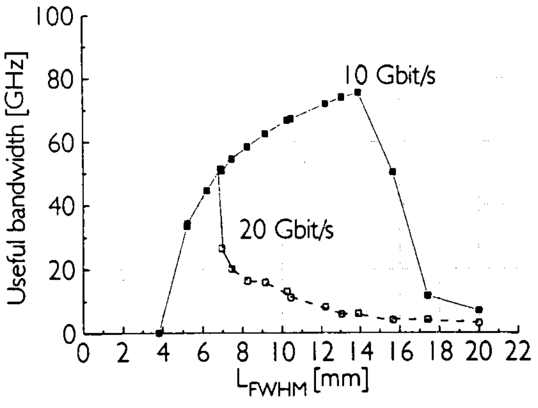

**Figure 3. Useful bandwidth for different bit-rates vs FWHM length of a uniform Gaussian apodised grating with a constant 30 dB reflection bandwidth of 100 GHz.**

Fig. 3 plots the resultant useful bandwidth on a 100 GHz grid for different maximum tolerable dispersion values plotted against the FWHM length for a single add-drop uniform apodised grating with a constant 30 dB reflection bandwidth.

In a 10 Gbit/s system based on NRZ coding, the maximum tolerable dispersion /4/ before experiencing a 1 dB power penalty is ~1000 ps/nm. It can be seen from Fig. 3 that for this dispersion value the grating has to be carefully designed with a FWHM length of ~14 mm to optimise the useful bandwidth to a maximum of ~ 75 GHz. Proposed higher (20 Gbit/s) bit-rate systems will experience increased penalty because they can only tolerate dispersions of up to 300 ps/nm before they experience dispersion induced power penalties. In this case the maximum useful bandwidth is reduced to 55 GHz. To meet this maximum useful bandwidth the grating must be carefully designed to have a FWHM length of ~ 7mm. Considering even higher bit-rates of 40 Gbit/s and above, tolerable dispersion values are less than 100 ps/nm. This useful bandwidth is from Fig. 2 seen to be smaller than the actual spectral width of a 40 Gbit/s NRZ pulse, a fact that may prove to be fatal for the use of uniform apodised gratings in high-bit rate DWDM systems.

## Conclusions

We show that although square filter characteristics of the grating are desirable in order to optimise the relative reflection bandwidth, the apodisation generated in-band dispersion can lead to a significant reduction of the useful bandwidth. We conclude that gratings considered for use in WDM systems must be carefully designed to optimise the useful bandwidth and point out that the use of 'traditionally' apodised uniform gratings in systems operated above 20 Gbit/s may be limited. It has however recently been demonstrated that gratings with low in-band dispersion values and high filling factor values are possible to manufacture [5]. The low transmission loss through these filters at present is the only limiting factor to use these.

We will at the conference present results of other apodisation profiles and give guidelines for an optimisation of the useful bandwidth.

## Acknowledgements

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