Application of a Refined Error Model of Turning Point Monitoring to the Simulation of Narrow Bandpass Filter Production

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ABSTRACT

We have previously reported on the hypersensitivity to layer thickness errors of DWDM and similar narrow band filter coatings. We further simulated how well certain natural error compensation effects work to mitigate the effects of these errors. We here refine the model to even better simulate what is likely to occur in actual practice. We show examples of the effects of various types and levels of error on typical turning point monitoring yields in the presence of error compensating mechanisms.

INTRODUCTION

The effects of noise in the optical monitoring signal and errors in the termination of the layers at their design thicknesses for narrow bandpass (NBP) filters have been described previously [1,2]. We have taken as an example filters such as might be used in communications Dense Wavelength Division Multiplexing (DWDM) through fiber optics, etc. We discussed the sensitivity of different layers in such a design represented by: (1H 1L)9 4H (1L 1H)9 1L (1H 1L)9 4H (1L 1H)9 1L (1H 1L)9 4H (1L 1H)8 1L .52072H .86628L. A modeling of errors and compensation as it actually occurs in practice was recently reported [3]. Zhou, et al. [4] briefly reported work of this type with limited conclusions.

In a previous work [3], the effects of random errors in layer termination were simulated, with and without the natural error compensation properties of the commonly used monitoring technique. A three cavity filter design as given above has 114 layers. The requirements for a typical NBP filter for DWDM have been illustrated [1,2]. The common monitoring technique is to terminate each new layer at the "turning point" (TP) where the transmittance of the piece being monitored changes direction. This is normally at points of integral quarter wave optical thickness (QWOT). If a previous termination was in error before or after the TP, the current layer will be correspondingly thicker or thinner than a QWOT when the layer is terminated at the TP. When this technique is used, errors from previous layer terminations are largely compensated [1,2], and we have discussed the necessary conditions to take advantage of this effect.

In the most recent work [3], the errors were simulated as having a random distribution as a percentage of a QWOT imposed at each TP in sequence, and then the next TP was found. Three types of cases were simulated: 1) where the errors were symmetrically distributed about the ideal turning point; 2) where the errors extend from the turning point to greater thickness (long side), as might be more typical of an actual case; and 3) where the errors are entirely before the turning point (short side). These short side errors have a more detrimental effect than the long side errors, but an explanation for this difference has not yet been found. It was shown that uncompensated random errors of 0.01% of a QWOT would totally destroy the yield of useful filters for such DWDM applications, but it was concluded that 2% to 4% of a QWOT might be adequate with turning point compensation.

In this extended work, we refine the model to simulate what should be a still more realistic representation of actual practice. In attempting to terminate a layer at the TP, it is necessary to sense the changes in the transmittance of the monitoring signal at the TP. The errors that occur with respect to the monitoring signal at the TP are more likely to be measured "vertically" in errors of percent transmittance (%T) than "horizontally" in percent of a QWOT. The %T is a quadratic function of the layer thickness about a TP. As seen in previous papers, the change in %T from one TP to the next varies greatly from layer to layer. The change in %T is the smallest, and therefore most sensitive, at the layers nearest the spacer layers. We here use a random %T error in a defined range for each layer in the sequence, convert that to an equivalent QWOT error based on the sensitivity of each layer, and apply that error as each new TP is found.

The three types of cases previously simulated were also used here: centered errors about the TP, all of the errors after, and all before the TP. Similar behavior was found to the previous investigation, but the range of "probably satisfactory" results was found to be less than 0.15%T random errors as compared to 2-4% of a QWOT errors in the earlier work. In that case with errors applied as a percent of a QWOT, the magnitude of the errors were uniform throughout all of the layers, which is not likely to be the case due to the differing sensitivities of the layers. In the present case, the %T errors are uniform (randomly) throughout all of the layers, but the impact on thickness errors is greatest near the spacer layers where the sensitivity to %T errors is the greatest.

Figure 1 shows the effects on the filter dB transmittance of random %T monitoring errors. The three curves are for 0.075, 0.10, and 0.15 %T errors from the highest to the lowest on the plot. All of the random errors in this first case are after the TP. Each of these curves is the result of an average of 20 runs as seen in Figure 2 for the 0.10% case from which Figure 1 was derived. Figure 3 shows the effects at the same %T cases when the errors are symmetrically distributed about the TP. Figure 4 shows the effects where all the errors are before the TP.

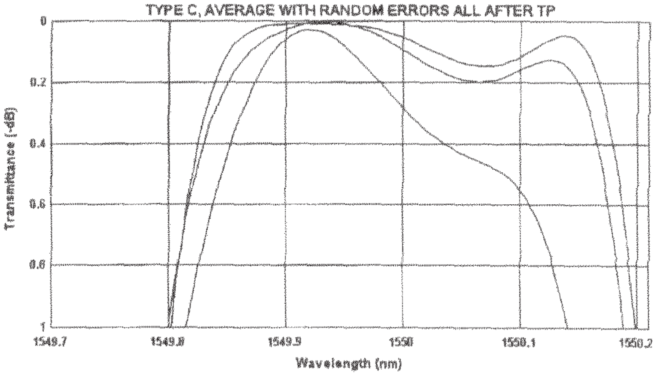

Figure 1: Effects on the filter dB transmittance of random %T monitoring errors where the three curves are for 0.075, 0.10, and 0.15 %T errors from the highest to the lowest on the plot. All of the random errors in this case are after the Turning Point. Each of these curves is the result of an average of 20 runs.

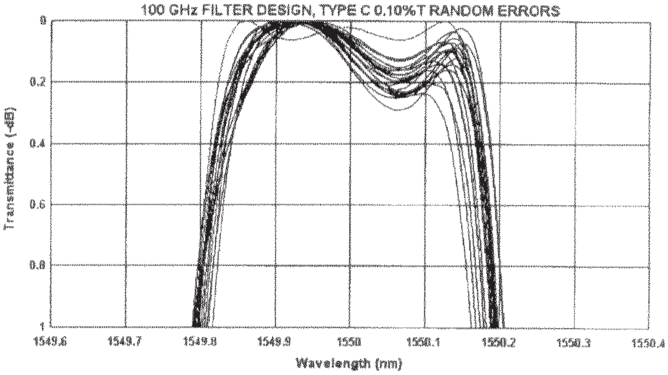

Figure 2: Results of 20 runs for the 0.10% case from which Figure 1 was derived.

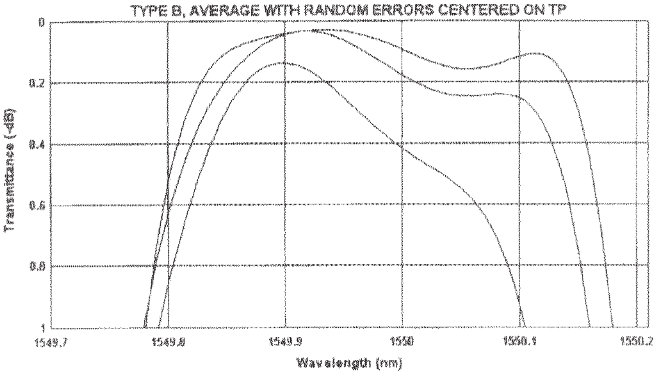

Figure 3: Effects at the same %T cases as Figure 1 when the errors are symmetrically distributed about the Turning Point.

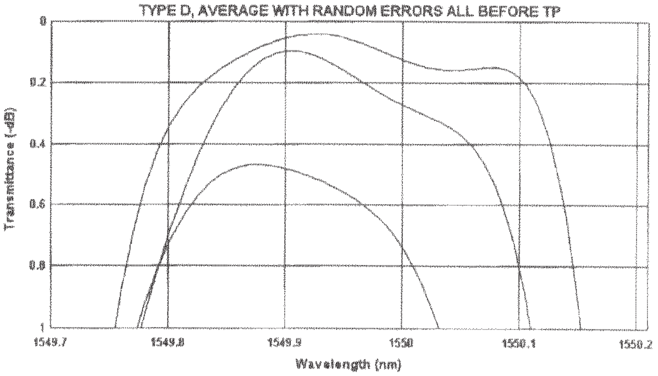

Figure 4: Effects where all the errors are before the Turning Point at the same %T cases as Figure 1.

The data which generated these figures were then used in design of experiments (DOE) software [5,6] to summarize the behavior and allow visualization and prediction of the effects of different magnitude errors on dB transmittance loss, bandwidth, and central wavelength shift. Figure 5 shows the average dB loss in transmittance over the band which is 80% of the 1.0 dB band edge points versus the random %T error bounds and the amount or fraction of the error which is after the TP. This amount ranges from 1 to 1 for 100% of the error before to 100% after the TP in each of these three figures. As might be expected, the loss increases with error and is somewhat greater as the errors are before the TP. Figure 6 shows the average bandwidth in nanometers at the 0.5 dB points. Here the bandwidth above 0.5 dB narrows rapidly as the errors become greater than 0.10%T. Figure 7 shows the percent shift in the center wavelength of the passband versus error and amount after the TP. This is a strong function of both error and whether the errors are before or after the TP. Clearly, if all of the errors were on the long side of the TP, the center wavelength of the filter would be greater than the nominal and vice versa.

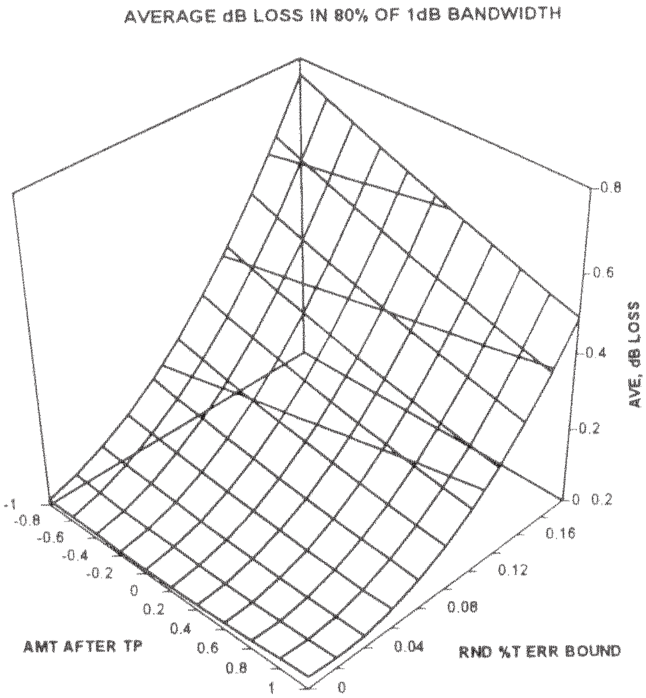

Figure 5: Average dB loss in transmittance over the band versus the random %T error bounds and the fraction of the error which is after the Turning Point. This fraction ranges from 1 to 1 for 100% of the error before to 100% after the Turning Point.

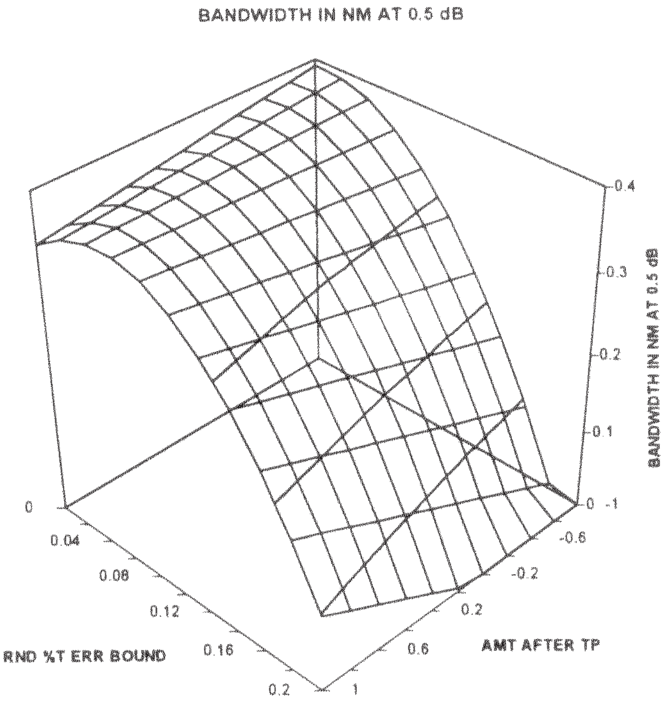

Figure 6: Average bandwidth in nanometers at the 0.5 dB points versus the random %T error bounds and the fraction of the error which is after the Turning Point.

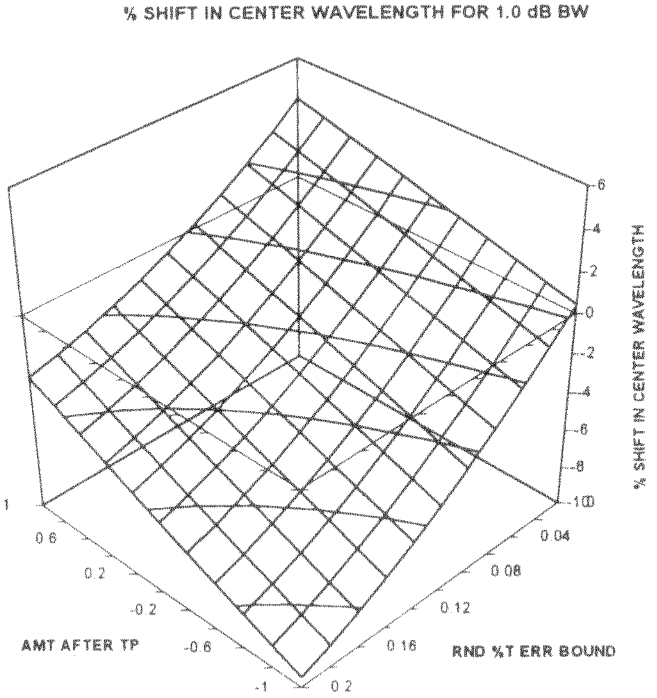

Figure 7: Percent shift in the center wavelength of the passband versus % T error and fraction of the error which is after the Turning Point.

CONCLUSIONS

The effect of turning point monitoring errors on the yield and performance of NBP filters has been simulated to a new degree of realism. We conclude in examining these results that the random errors in %T at the turning points need to be on the order of 0.10% or less in order to obtain a reasonable yield for such a 100 GHz DWDM filter with a 0.3 dB specification on losses in the passband.

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