CORNING

揭秘单通道 100G 多模光纤传输的带宽需求

Demystifying the Bandwidth Requirements for 100G/lane Multimode Fiber Operation

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引言

行业通常将 100 米的 OM4 和 70 米的 OM3 作为数据中心短距多模光纤链路长度的指导基准。这些基准在过去为行业提供了良好的支持，然而，随着单通道 100G 或更高数据速率应用时代的到来，必须重新评估多模光纤的带宽需求，以确保多模光纤在高速应用中能继续支持同样的距离。

For multimode fiber (MMF) applications, the industry has traditionally adhered to 100-meter OM4 and 70-meter OM3 as link guidance for fiber deployment selections in short-reach data center applications. While these benchmarks served industries well in the past, as we move into an era of 100G/lane or higher data rate applications, it's time to reassess MMF bandwidth requirements to sustain MMF's role in such applications.

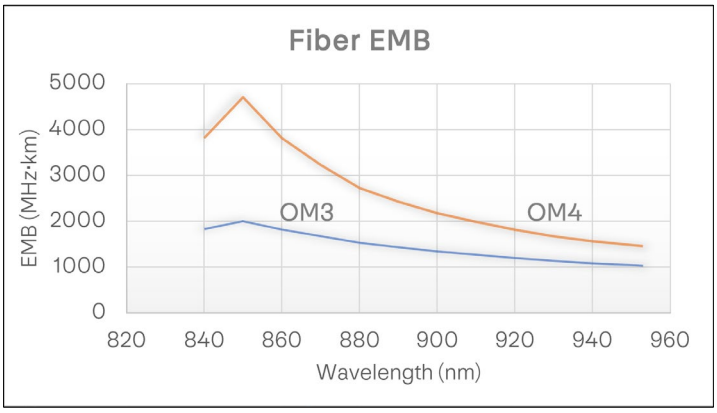

图 1: 标准 OM3 和 OM4 光纤的有效模式带宽（EMB）与波长的关系

EMB Standard OM3 and OM4 EMB wavelength dependance.

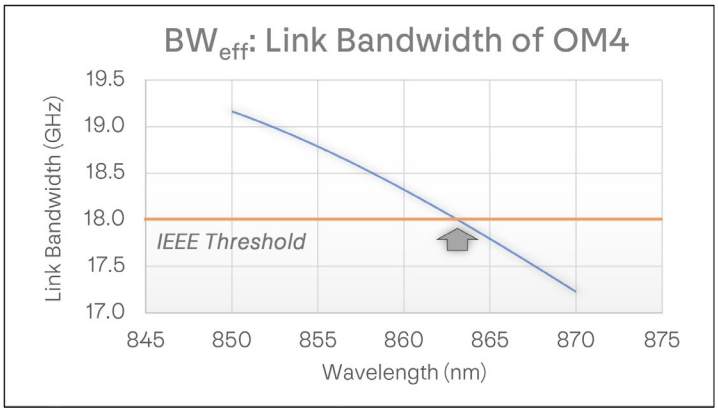

图 2: 使用标准 OM4 光纤时，链路带宽可能会下降到低于 18GHz

Link bandwidth may fall below 18GHz by using standard OM4.

在单通道 100G 或更高数据速率的多模应用时代，技术范式已经发生了转变。很多高速 VCSEL（垂直腔面发射激光器）通过在量子阱中引入铟来提升器件带宽，导致激光器工作波长从 850 nm 上移至 860-870 nm。这种工作波长的变化可能会影响标准 OM4 光纤在该波长处的有效模式带宽（EMB）值，从而引发关于光纤带宽是否能有效支持 100G 每通道速率下的 100 米传输距离的问题。

In the era of 100G/lane or higher-data-rate multimode applications, the paradigm has shifted. In practice, many of the high-speed VCSEL transceivers available in the market incorporate Indium into the quantum well to enhance device bandwidth, which effectively shifts the operating wavelength upward from 850 nm to the 860-870 nm range. This shift can affect the EMB value at 860-870 nm when using standard OM4 fiber, raising questions about whether the fiber bandwidth can support 100 m reach at 100G/lane speed.

在多模光纤（MMF）传输系统中，传输性能由有效链路带宽（BW_{eff}）决定，其定义为：$\boldsymbol{BW_{eff} = \left(\frac{1}{EMB^2} + \frac{1}{BW_{CD}{}^2}\right)^{-1/2}}$

对于单通道 100G 的传输，所需的链路带宽被规定为 18GHz [2]。随着 VCSEL 的工作波长向 860 nm 至 870 nm 范围偏移，链路带宽通常会下降到低于 18GHz，如图 2 所示。

In MMF transmission systems, the transmission performance is driven by the effective link bandwidth BW_{eff}, which is defined as $\boldsymbol{BW_{eff} = \left(\frac{1}{EMB^2} + \frac{1}{BW_{CD}{}^2}\right)^{-1/2}}$. For 100G/lane transmission, the required link bandwidth is specified as 18GHz [2]. As the VCSEL wavelength shifts toward the 860 nm-870 nm range, the link bandwidth typically declines below 18GHz, as is shown in Fig 2.

Intuitively, one may suppose the EMB must increase to bring the performance (link bandwidth) back to 18GHz.

链路带宽（BWeff）是评估传输性能的关键指标。需要注意的是，链路带宽（BW_{eff}）不仅是模式带宽（EMB）的函数，还与色散带宽（BW_{CD}）相关。而色散带宽与多模光纤的色散值和激光器的均方根（RMS）线宽相关。大多数商业部署的垂直腔面发射激光器（VCSEL）均方根线宽通常规定为 0.6 nm。

However, it's important to note that the effective link bandwidth BW_{eff} is a function of not only EMB, but also chromatic dispersion and laser linewidth-contributed bandwidth (BW_{CD}). Here BW_{CD} is related to both the chromatic dispersion value and the root mean square (RMS) linewidth. For most of the commercially deployed VCSEL transmission applications, the RMS linewidth is primarily specified at 0.6 nm.

随着波长的增加，光纤的色散会减小，BW_{CD} 对链路带宽的贡献增大，如图 3 所示。因此，随着波长的增加，较低的有效模式带宽（EMB）值也可以实现相同的链路带宽。

As the wavelength increases, chromatic dispersion drops, resulting in a higher BW_{CD}, as demonstrated in Fig.3. This implies that a lower EMB value might be sufficient to achieve the same link bandwidth as the wavelength increases. Since link bandwidth BW_{eff} is the measure that affects the transmission performance, it's more effective to assess link performance based on BW_{eff} rather than solely on the EMB value.

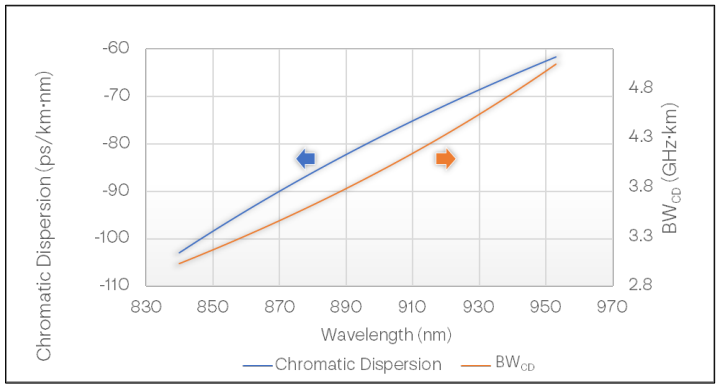

Figure 3: 随着波长向更长波长偏移，色散带宽（BW_{CD}）对链路带宽的贡献会增加

CD contributed bandwidth BW_{CD} increases as wavelength shifts to longer wavelength.

同时考虑模式带宽和色散影响，可以计算满足 100 米传输距离要求所需的有效模式带宽（EMB）值（见表 1）。By considering both modal bandwidth and chromatic dispersion, required EMB values to meet 100 m reach capability can be calculated (Table 1).

SPEC 规格	OPERATIONS 操作		
波长	850 nm	860 nm	870 nm
有效模式带宽 MHz·km	4700	4500	4200
BW_{eff} 裕量 GHz	1.2	1.5	1.5

表 1: 在不同波长下实现 100 米距离的单通道 100G 传输所需的光纤模式带宽
Fiber bandwidth requirement for 100 m 100G/lane operation at various wavelengths.

为了在单通道 100G 速率下实现 100 米的传输距离，并提供足够的裕量（*相对于链路带宽需求的 18 GHz 裕量）以确保传输性能，多模光纤在 860 nm 波长时必须提供最低 4500 MHz·km 的有效模式带宽（EMB）值，在 870 nm 波长时则需提供最低 4200 MHz·km 的 EMB 值。Clearly, to achieve a 100-meter reach at 100G/lane, the multimode fiber must deliver a minimum EMB value of 4500 MHz·km at 860 nm and 4200 MHz·km at 870 nm. This ensures optimal performance with sufficient margin (*margin over 18 GHz of link bandwidth requirement).

使用康宁® ClearCurve®多模光纤满足并超越带宽需求
Meeting and exceeding bandwidth requirements with Corning® ClearCurve® multimode optical fiber

康宁是否提供能够满足甚至超越短距离数据中心应用带宽需求的多模光纤？答案是肯定的。康宁可以提供带宽优化的 ClearCurve® OM4 光纤，是单通道 100G 应用的理想解决方案，满足 870 nm 工作波长偏移的要求。Does Corning offer a multimode fiber that can meet or even exceed bandwidth requirements for short-reach data center applications? The answer is yes. An optimized ClearCurve® OM4 fiber is the ideal solution for the 100G/lane applications, readily accommodating any potential wavelength shift toward 870 nm operation.

此外，康宁在 2023 年推出了一种针对高数据速率优化的多模光纤——ClearCurve® OM4 XT 光纤，该光纤在 850 nm 波长处定义的有效模式带宽（EMB）值为 4700 MHz·km，在 910 nm 波长处的 EMB 值为 3100 MHz·km。通过蒙特卡罗模拟，我们分析了 ClearCurve® OM4 XT 光纤的 EMB 分布，重点研究了该多模光纤的带宽随波长分布曲线 [3]。Additionally, Corning introduced a high-data-rate optimized multimode fiber in 2023, ClearCurve® OM4 XT fiber, which defines EMB values of 4700 MHz·km for 850 nm and 3100 MHz·km for 910 nm. Through Monte Carlo simulation, we analyze the EMB distribution of ClearCurve® OM4 XT fiber, focusing on the wavelength dependence curve of this MMF [3].

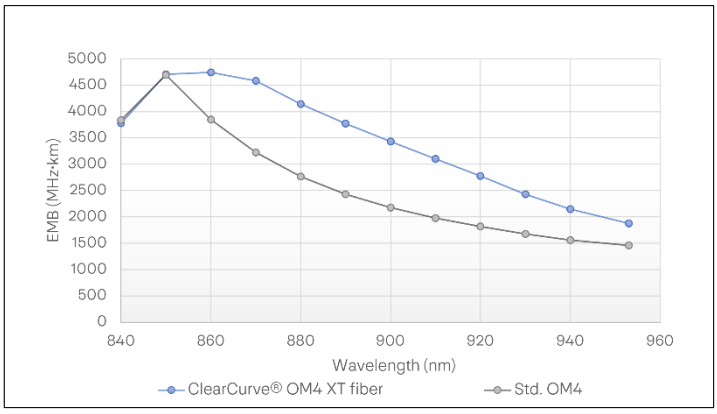

图 4: ClearCurve® OM4 XT 光纤的带宽随波长分布曲线 ClearCurve® OM4 XT fiber wavelength dependence curve.

如图 4 所示的曲线表明，ClearCurve® OM4 XT 光纤具有远高于表 1 中所列要求的带宽裕量。因此康宁 ClearCurve®多模光纤产品（性能优化的 OM4 光纤和 OM4 XT 光纤）都可以帮助客户在数据中心或 AI 集群连接中以单通道 100G 速率实现最长 100 米的传输，同时保持低成本和低功耗的运行模式。The wavelength dependence curve, illustrated in Fig.4, indicates that ClearCurve® OM4 XT fiber has much higher bandwidth margins than the requirements shown in Table 1 above. Ultimately, Corning ClearCurve® Multimode fiber

assists customers in delivering the necessary performance for up to 100 m in data center or AI cluster links at 100G/lane multimode, while maintaining low-cost and low-power operation.

参考文献 References

[1] IEC guidance: IEC document with EMB guidance curves 60793-2-10_ed7_2019.pdf.

[2] IEEE Std 802.3dbTM-2022.

[3] Xin Chen et al. Wavelength Dependence of Modal Bandwidth of Multimode Fibers for High Data Rate Transmission and Its Implications, Photonics 2024, 11(7).