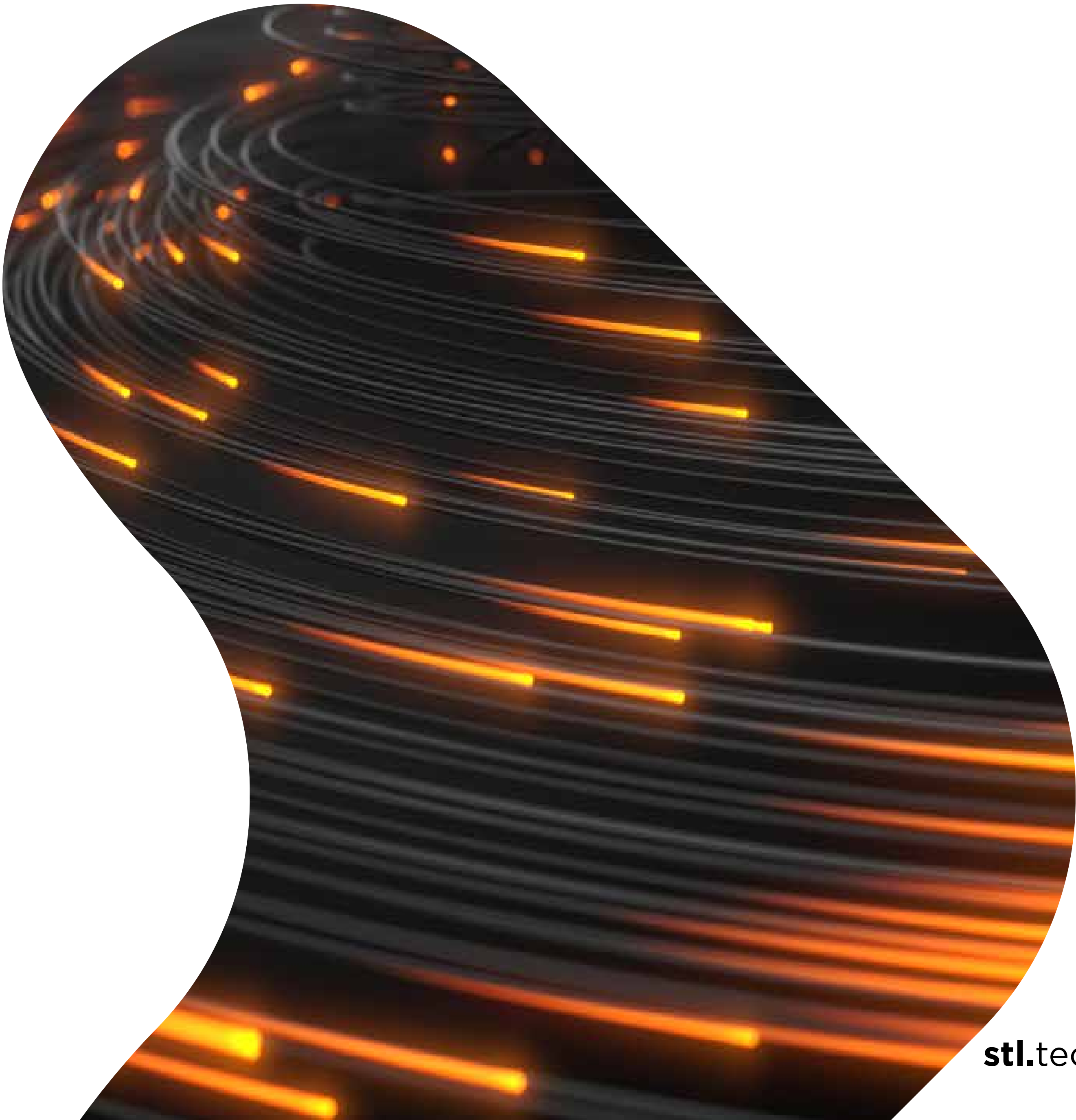
Whitepaper

Fibre speed limiters – the history and latest disruption

Peter Arnoff Nielsen
PLM Head, Optical Fibre and Cable, STL



While optical fibre is a fantastic means of transportation of data it does have its limitations. There are a range of optical parameters that limit how far a given transmission system can transmit a signal before optical-electrical-optical regeneration is required. As transmission systems and fibres have developed over the last 25 years, we have also seen those limitations shift amongst the fibre parameters.

Let’s take quick look at the history that led to the present situation. In doing so we follow the evolution of the ITU standards.

G.652

Still referred to as standard transmission fibre and still making up for the absolute bulk of optical fibre cable installations. The fibre has a relatively high Chromatic Dispersion and in the early days of manufacturing no particular efforts were made to avoid Polarization Mode Dispersion. The main speed/length limiting parameter up to the 10 Gb/s systems was attenuation.

G.653

As Chromatic Dispersion was an issue even at single channel transmission the G.653 was an excellent answer with its zero-dispersion wavelength at 1550 nm. This fibre had a very short technological lifetime and manufacturing has been discontinued long ago.

G.655

With the introduction of Dense Wavelength Division Multiplexing (DWDM) zero-dispersion does not work well. Four Wave Mixing amongst the transmission channels became a new limiter. So Chromatic Dispersion was reintroduced in the fibre although at much less numbers than in the G.652 fibre.

Chromatic Dispersion could be repaired by means of Dispersion Compensating Modules – in essence a short spool of fibre with a very steep reversed Chromatic Dispersion. Polarization Mode Dispersion could not be repaired and a lot of different initiatives were taken to limit it both in fibre and cable production. These Dispersion Compensating Modules are also installed in great numbers in G.652 networks. While they work splendidly, they have three drawbacks: added price, added attenuation and added PMD.

Key optical parameters of G.655 were Chromatic Dispersion and dispersion slope as well as Polarization Mode dispersion. It remained the optimal choice until RAMAN based amplifier systems came around.

G.656

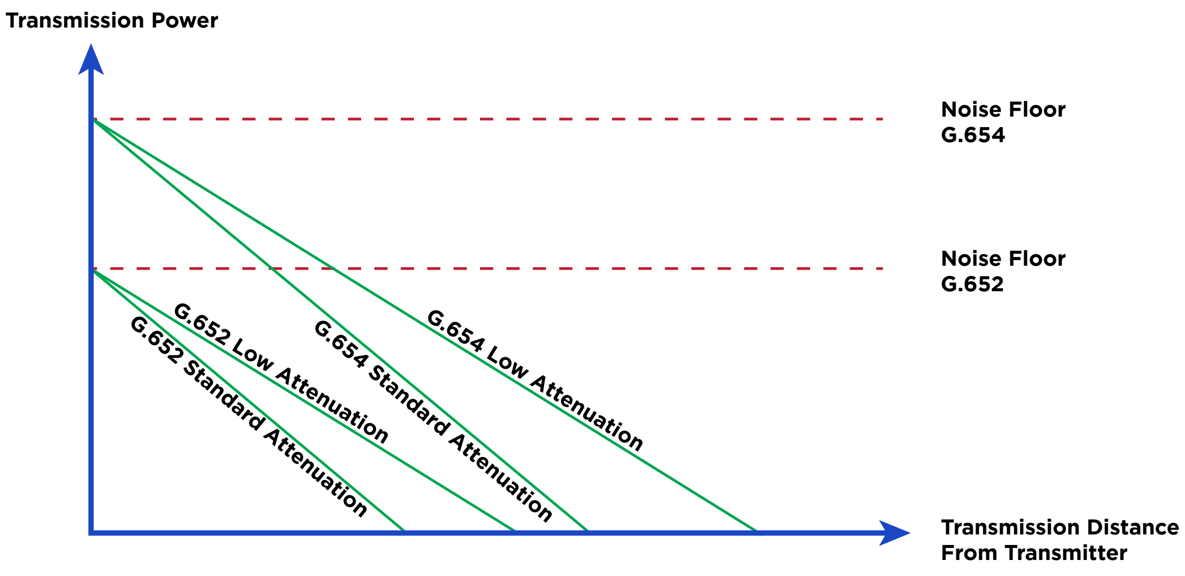
The RAMAN based amplifier pumps light into the fibre at approximately 100 nm below the wavelength it shall amplify. Since the G.655 fibres have a Zero Dispersion Wavelength between the pump and the transmission, Four Wave Mixing occurred frequently between the two limiting the transmission range. The G.656 was the answer. Not only does it place its Zero Dispersion Wavelength below the pump light, some manufacturers choose a lower Mode Field Diameter, which counter intuitively – in fact is an advantage for RAMAN based systems.

G.654

The observant reader will notice that I address G.654 after G.656. Indeed the G.654 was invented and standardized by ITU after G.653. The terminology in the naming of the standards follows chronology. However, the G.654 fibre was originally developed especially for transoceanic cables. The design rules of these cables are significantly different from terrestrial applications for a range of reasons like availability of electrical power, number of submarine repeater stations, dispersion management etc.

And since we discuss terrestrial cables here the G.654 is a new fibre. This fibre is characterized by having a very large effective area.

With the introduction of coherent transmission there was an actual disruption in the long haul / high speed optical world. Earlier Chromatic Dispersion and Polarization Dispersion were the major speed limiters in the optical network. With coherent transmission systems taking care of these previously troublesome optical distortions, today's speed limiter becomes the amount of optical power that can be inserted into the fibre without hitting the noise floor limit.



The illustration is based upon 4 fibres and their individual performance.

- G.652 with standard attenuation around 0.2 dB/km. This fibre has an effective area of 85 μ^2. The dotted line represents the maximum power that can be inserted into a fibre without causing noise. The x-axis represents the distance from the transmitter. Once the power drops below the x-axis axe the signal is no longer readable.
- The simple way of extending the transmission length is a similar fibre with less loss.
- Alternatively, by increasing the effective area of the fibre more power can be inserted due to the associated higher noise floor tolerance. That is the property of the G.654 fibre.
- Finally – as with the G.652 fibre – the attenuation can be lowered for maximum transmission length.

Please take note that the illustration is not to scale; it purely illustrates ordinal differences.

The new limiter is the amount of power you can insert into the fibre without reaching the noise floor. So, the speed/length transmission span limiter shifts from CD and PMD to Effective Area.

That has been known for many years in transoceanic systems and now we build on the experience as large area fibres crawl ashore.

In submarine cables effective areas of above 150 μ^2 have been installed. For terrestrial cable applications a new limit must be considered. As the effective area is increased in parallel the micro bend sensitivity increases. Trials have set the limit for an acceptable manufacturing and handling performance at 125 μ^2.

As always, the lower the loss the more ideal. Again, the transoceanic fibre has led the game with loss in the 0.15 dB/km range. In order to keep the manufacturing cost down the target for terrestrial applications have been set at 0.17 dB/km by several manufacturers.

Today we can summarize the history of speed/un-regenerated transmission length limiters as follows:

Transmission system, Gb/s	2.5	10	40	100*	400*	1200+*
Transmission span limiter	Att.	Disp.	Disp.	OSNR ***	OSNR ***	OSNR ***
Transmission span limiter**	G.652	G.655	G.655	G.654	G.654	G.654

** Coherent*
*** While other fibres are optimal G.652 can also be used and is the preferred choice of many operators.*
**** OSNR in reality covers a combination of Effective Area and loss*

G.654 future terrestrial application fields

The combination of coherent transmission systems and low loss high effective area fibre have attracted a lot of attention amongst especially long-haul operators. Extensive studies and fields test have been done especially in China.

The general conclusion is that while the solution is most interesting from a technical perspective the associated business case has not yet proven attractive. So far unfortunately, this has prevented the terrestrial deployment of G.654 fibre-based cables.

beyond tomorrow

stl.tech