Mixing Single-Mode fibre types

The aim of this article is to show what happens when different types of single-mode (SM) fibres are fusion spliced together - but just before we do though, let's kick-off with a brief introduction: Nowadays there happens to be no shortage of optical fibre submarine cables terminated in landing stations on our shores. Not to begrudge consumers access to this abundance of high-speed broadband capacity - top of the to-do list of network operators is to build terrestrial optical fibre routes in and between cities and the subsea cables that connect us to the global Internet. To accomplish this - it turns out that predominantly, 4-types of single-mode (SM) fibres (see table 1) are currently being deployed and the smart money is on the fact that it is inevitable that every-so-often, different types of SM fibres will need to be fusion spliced together. As it happens, the deployment of hybrid cables containing both G.652 and G.655/6 type fibres, has become a popular option. Sadly, there still is a view, a minority view but a prominent one none the less, that you can do whatever-you-want using standard SM G.652D fibre - but we are all particularly thrilled that we know better, hey?

Table 1.

Fibre type	**Ideally suited for…**
ITU-T G.655E	Long-haul and metro
ITU-T G.656	Between cities and metro
ITU-T G.652D	Metro and access networks
ITU-T G.657A	Local access / last drop

Background

With the increasing number of optical fibres being spliced in today's long-haul and access networks, it is important to have a better-than-average understanding of the aspects surrounding fusion splice loss verification and interpretation. It goes without saying, of course, that an optical time-domain reflectometer (OTDR) is the best device to use for measuring fusion splice loss. As wonderful as an OTDR is cracked up to be, there is no denying that it is limited in some respects - to which occasionally, a splice technician's stock response is a shake of the head, a frown, and a mutter of "Huh?"

What is an OTDR? In very simple terms an OTDR combines a laser light source and an optical detector, together with electronic and software driven controls. The OTDR injects an accurately timed light pulse into the fibre core and the optical detector observes the small proportion of light that is reflected backwards (backscatter) as the forward propagating pulse travels along the fibre being measured. There happens to be clear evidence that unidirectional OTDR measurements can be misleading and do not reflect the true loss of a splice. You see, an OTDR measures backscattered power not transmitted power and at a splice point, it is possible for the amount of backscattered light before the splice, to be greater than that after the splice or vice versa - which oddly enough, bewilders an OTDR. Despite an OTDR taking a punch in the soft parts with unidirectional testing - when doing bi-directional testing, as we will see shortly - this mood of defeatism will disappear.

As noted above, an OTDR measures reflected light and is therefore an indirect measurement - in other words, an estimate of the total amount of loss or attenuation in a fibre span. Quite clearly, a direct measurement method, such as the Optical Loss Test Set (OLTS) - which measures insertion loss (IL), is more accurate for total end-to-end loss measurements. Equally clear, an OLTS test is the best way to make sure that a link meets the power budget requirement, which without doubt is the number-one criterion.

It might be worth mentioning at this stage that we used state-of-the-art OTDR's and fusion splicers in the form of EXFO FTB-200's, Fujikura's and Sumitomo's to do this research - and another important point to be made is that here is no obvious difference in the obtained splice results between these two types of splicing machines used.

As far as I’m concerned, I could not have asked for a more experienced and fibre-savvy bunch of fibre experts (pictured below) to assist with this research. With all their fusion splicers set on auto mode they went about the business of splicing and testing with well-organised urgency. It is well documented that splicing standard G.652D onto G.652D consistently delivers ridiculously low splice losses without any obvious effort - to the tune of 0.04 dB or lower. So far so good? But wait, there is more, much more and better to come.

Front L-R: M. Sampson, L. Van Eden, M. Nkabini, J. Daniel, S. Makhubu, P. Breedt, C. Jordan, T. Carstens
Back L-R: D. Reddy, J. Botha, T. Huber, E. De Jager, M. Pike, A. Dutton, JC Potgieter, R. Visser

In what follows, we will look at what happens when we mix them:

I ought to point out here and now that with this research, attenuated attention was paid to meet the criteria of comparable validity. Anyway, moving right along, the sample size was 15 fusion splices per fibre type.

Table 2. G.652 - G.656 splice loss

G.652 →	**← G.656**	Bi-directional Average (dB)
-0.659 dB	0.852 dB	**0.096**

Table 3. G.652 - G.655 splice loss

G.652 →	**← G.655**	Bi-directional Average (dB)
-0.386 dB	0.580 dB	**0.097**

Shown in both tables 2 and 3 is a decent-sized loss when testing from G.656 or G.655 onto G.652 with an OTDR and although cushioned by ultra-low negative contribution from the other end; your colleagues are still likely to look at you with pity. I was just as surprised as you might have been to discover that both G.655 and G.656 spliced onto G.652 produced almost the exact same bi-directional average. I can immediately confirm that everything was perfectly above-board. The fibre parameter responsible for these somewhat strange readings is the Mode Field Diameter (MFD). A MFD is the diameter of the light-carrying region of the fibre - with the range of nominal MFD values for G.656 and G.655 being larger than that of G.652D - this despite the fact that they share the same core size.

The amount of OTDR backscattered light is inversely proportional to the mode field diameter (MFD) and therefore a fibre with a smaller-MFD carries a larger optical power density in the core and an OTDR detector will see proportionally more backscattered light than in a larger-MFD fibre. As has now been made apparent - a smaller-MFD spliced to a larger-MFD will register less backscattered light immediately after the splice, making it seem that power was actually gained at the splice (often called a “gainer”). Conversely, if light goes from a larger-MFD into a smaller-MFD, more light is scattered back and displayed will be a loss greater than what it really is. It is important to remember that the gainer is “apparent” and the loss is “exaggerated”. So what now? The industry recognizes the fact that the most accurate measurement of actual splice loss is the average of bi-directional testing. Fibre techs are not usually too slow to boast about their achievements, but I'm afraid that a 0.09 dB splice loss average heavily implies that there is nothing much to write home about for any self-respecting fibre tech.

Table 4. G.657 - G.652 splice loss

G.657 →	**← G.652**	Bi-directional Average (dB)
-0.256 dB	0.333 dB	**0.039**

The recent emergence of SM fibres with improved bending performance for the access network has been driven by the penetration of optical fibre into buildings (FTTB) and homes (FTTH). As a result, optical fibre cables are now subject to tight bends around corners, some as tight as 90 degrees. SM fibres complying with ITU-T G.657A was developed to replace G.652D for the purpose of use at FTTH sites. G.657A fibres contain a nano-engineered ring in the cladding, which prevents light escaping through the cladding when faced with tight bends. Curiously enough, G.657A has a slightly lower range of MFD values than G.652D. On the face of it, it would be perfectly possible to assume that with light going from G.652D onto G.657A, a fictitious negative contribution or gainer is imminent, right? Wrong! In fact it happens to be the other way around - thanks to G.657's nano-engineered ring. At any rate, we shouldn't dwell on this any further as a 0.039 dB bi-directional average loss clearly suggests that these two fibre types are compatible.

Table 5. G.656 - G.657 splice loss

G.656 →	**← G.657**	Bi-directional Average (dB)
-0.279 dB	0.355 dB	0.038

Table 6. G.655 - G.657 splice loss

G.655 →	**← G.657**	Bi-directional Average (dB)
-0.234 dB	0.312 dB	0.039

Illustrated in both tables 4 and 5 are the considerable OTDR unidirectional variations (i.e. negative contribution vs. exaggerated loss) found when splicing a fibre with a bigger MFD (G.655/6) onto one with a smaller MFD (G.657). None the less, with a bi-directional average loss of only 0.038 and 0.039 dB, it is obvious that these three fibre types are compatible.

Table 7. G.655 - G.656 splice loss

G.655 →	**← G.656**	Bi-directional Average (dB)
0.516	-0.410	**0.053**

G.655 and G.656, both variants of non-zero dispersion-shifted fibre (NZ-DSF) – again produce the same OTDR unidirectional variations we've seen when splicing fibres with different size MFD's onto each other (i.e. G.655 has a larger MFD than G.656). Despite this MFD-related issue, the result clearly suggests that they are compatible.

Conclusion

At this point, I suspect that we all agree that it would be an act of gigantic dim-wittedness to perform OTDR tests for certification, from one direction only. I am of the opinion that a 0.1 dB bi-directional average splice loss is entirely appropriate and, engaging in behavior calculated to enforce a much more stringent splice loss spec, is likely to prove counter-productive i.e. unnecessary remakes. Remember that system performance is dependent on overall link loss, not individual splice losses. And let us also not forget that in reality, splicing is often done in haste, and in somewhat less than ideal conditions. Well, where does this leave us then? Simply put, G.652, G.655, G.656 and G.657 are all compatible! Even though G.652 spliced onto G.656 or G.655 snuck home only by a whisker.

Table 8. OTDR bi-directional splice loss average - summary

Fibre type	**dB**
G.652 - G.656	0.096
G.652 - G.655	0.097
G.657 - G.652	0.039
G.656 - G.657	0.038
G.655 - G.657	0.039
G.655 - G.656	0.053