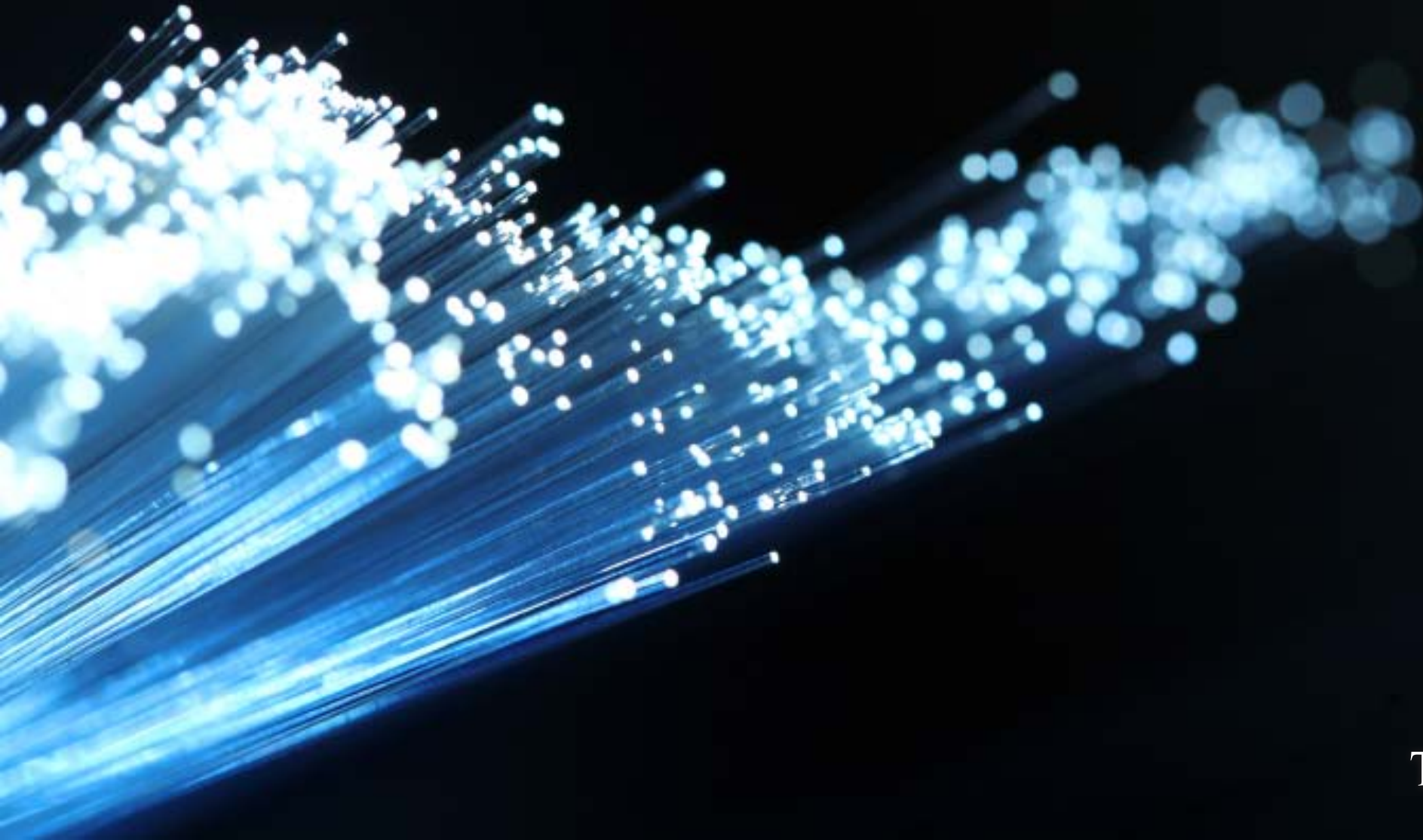


Optical Transmission Trials

Not quite as simple as they seem



Tony Frisch

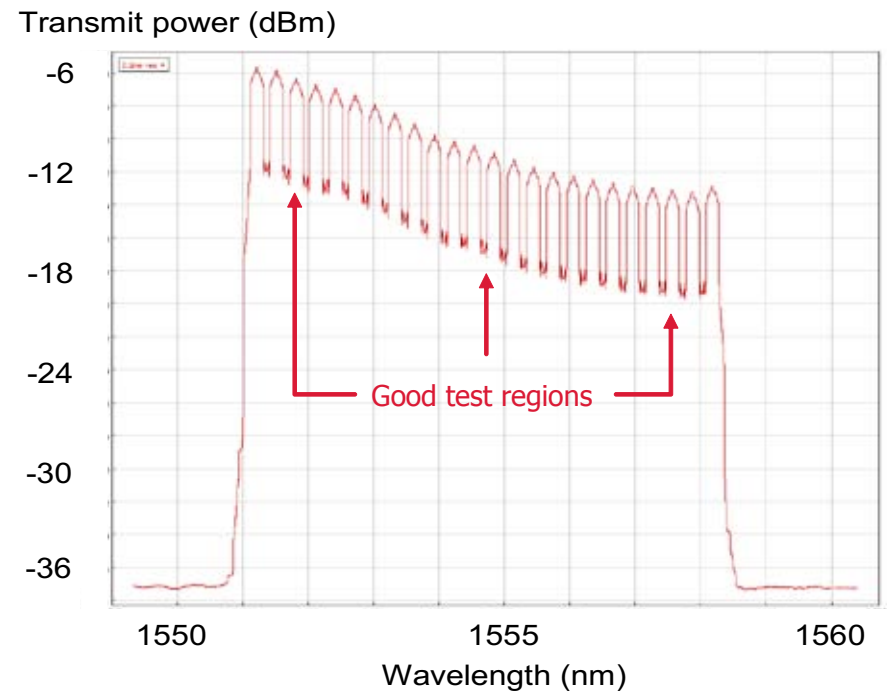
A key question for most upgrades is how much capacity can be achieved? Simulations can provide an answer, but the results are only good if the input data is correct, and potential buyers are not always able to supply what needed. Typically, the data available includes nominal values which may be deliberately a little pessimistic, or initial values which may no longer be up-to-date due to system repairs/ageing. Additionally, system owners may take the commercial position that they will not be responsible for the accuracy of data used. The value of a measurement/demonstration is that it gives the potential supplier the opportunity and responsibility for getting the data he requires and it should also demonstrate directly what capacity can really be achieved.

The reality, of course, is never quite so straightforward. There can be problems if the test fibre is carrying traffic and measurements can be done only in part of the bandwidth, or if a different, but “similar” fibre is offered for measurement – how similar is it? In the case of a network with several links it’s generally impractical to test all of them and the objective will be to test the most demanding one; in general this will be fairly obvious from a technical viewpoint, if not from a commercial one.

Assuming that a test fibre can be made available, how does one make sure that the results are meaningful? Using real terminal equipment sounds like the best

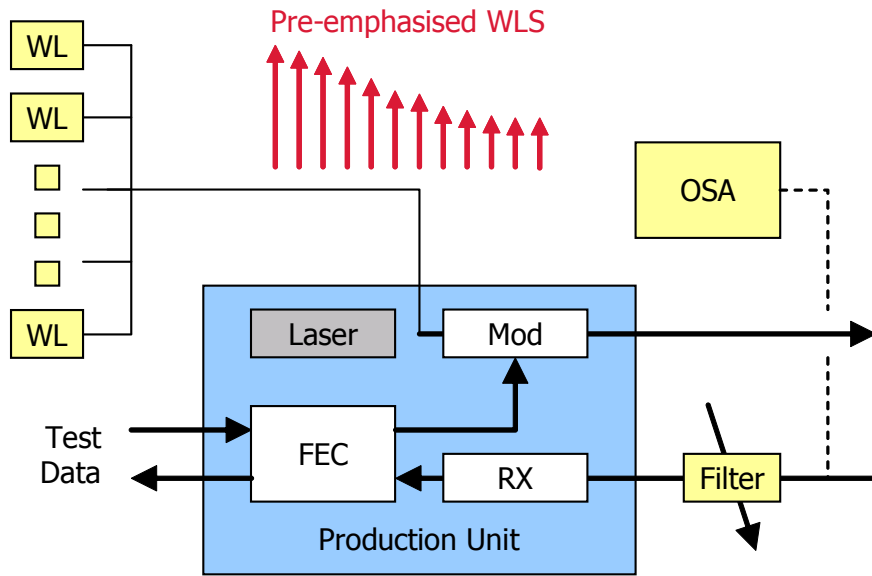
way to ensure a truly representative test, but is generally not a good solution. One operator recounted his experience of having a potential supplier ship him a complete terminal consisting of several racks, and the irritations of having to first install them and then take them down. The time taken and the disruption caused were much greater than for tests done by others who had used more compact, specialised test equipment; this approach tends to work well for all involved – for potential suppliers it reduces shipping and involves fewer people.

Given that tests will be done with specialised equipment, how can one ensure that the test results will be meaningful? Ensuring that the test equipment replicates the conditions of the proposed upgrade as closely as possible and performing tests over the full bandwidth are two key points. Experience shows that many systems show significant variations in transmission performance with wavelength, as seen in the following graph which shows how the power needed can vary with wavelength due to non-optimal gain flattening.



In this particular example, it’s clear that measurements done in the centre of the band, or at the long wavelength region, would produce a somewhat optimistic picture in terms of the power needed – in this case a 1.4 dB error using the centre point. Chromatic dispersion, non-linear effects and amplifier noise figure also tend to change across the band, with the noise figure sometimes changing quite rapidly at the edges of the band – important if the proposed upgrade puts wavelengths here. It’s worth noting, however, that the most extreme channels have only one adjacent neighbour, so they may not be the best ones to measure as they will experience less crosstalk than others.

The following diagram shows a simplified schematic of a test set-up that can get close to the ideal:



Here a number of adjustable light sources are set to the wavelengths and power levels of the proposed upgrade and then fed into a production unit which has been modified to allow the test wavelengths to connect to the modulator in place of the laser that is normally used. This ensures that the entire bandwidth can be filled with modulated signals and that the transmit and received units are representative of what will be supplied. There will usually be dispersion compensation & amplifiers, and most suppliers tend to interleave “odd” and “even” channels with different modulating signals to avoid any question that having the same traffic on adjacent signals might improve performance.

A tuneable optical filter before the receiver allows measurements to be done on any of

the wavelengths. While a Bit Error Rate Test Set (BERTS) can be used to supply test data, it cannot really measure anything because the power levels should be set close to those needed for real operation and FEC output should thus be error-free.

An Optical Spectrum Analyser (OSA) is usually needed to help with the initial set-up - checking existing wavelengths, measuring Optical Signal to Noise Ratio (OSNR) etc. to compare with predictions from simulations and (more importantly) to set power levels. Setting power levels - and sometimes establishing the best wavelengths to be used - usually represents the first day or so of a programme

which takes a few days. Getting close to the proposed upgrade conditions makes it much easier to extrapolate to what performance is really possible.

Because optical power budgets focus on Q, the parameter one needs to measure is the FEC correction rate, from which the Q value is derived using the inverse error function, and the tests need to last 12-24 hours to assess fluctuations in the performance to determine Time Varying System Performance (TVSP), Line 2 in the power budget defined by ITU-T recommendation G.977, the most used standard for submarine systems with repeaters. The following table shows the G.977 parameters and how the field measurements should relate to them:

Line	G.977 Parameter	Field measurement
1	Mean Q value (assuming no impairments)	Calculated from measured OSNR
1.1	Propagation impairments (non-linearity etc.)	Cannot be measured individually
1.2	Gain Flatness impairments	
1.3	Non-optimal optical pre-emphasis impairment	
1.4	Wavelength tolerance impairment	
1.5-7	Mean polarisation penalties	
1.8	Supervisory impairment	Should be known
1.9	Manufacturing and environmental impairment	Cannot be measured individually
2	Time Varying System Performance (5 σ rule)	Measured (5x standard deviation)
3	Line Q Value (Line 1 - Lines 1.1 to 1.9 - Line 2)	Measured - TVSP
4	Specified TTE Q value (back to back)	Known
5	Segment Q value	Calculated from Lines 3 & 4
5.1	BER corresponding to segment Q without FEC	Calculated
5.2	BER corresponding to segment Q with FEC	Calculated
5.3	Effective segment Q value with FEC	Calculated

6	Q limit after FEC correction (at 1E-13)	Known (depends on FEC gain)
7	Repairs, ageing and pump failures	Specified for the upgrade
8	Segment margin	Calculated

Line 1 is useful mainly as a comparison with predictions; if there is a noticeable difference it suggests that some of the simulation inputs may have been incorrect. A number of lines (such as individual impairments, Lines 1.1-1.9) cannot be verified, but Lines 2 and 3 can. Line 2 should be equal to 5x the standard deviation of the long-term Q, while Line 3 relates directly to the average measured Q minus - Line 2. From Line 3 one can compute Lines 5 to 8 and verify whether the margin is sufficient. Key to this calculation is the FEC gain and it's important that the Net Coding Gain (NCG) at the target BER is used.

For practical reasons, it may be hard to replicate the conditions of the proposed upgrade completely - supervisory equipment is rarely included, and getting the precise power levels may be difficult - so ultimate capacity has to be calculated by extrapolation from the tests. Most types of supervisory add 0.1-0.2 dB of penalty which should be included in the budget. More important is the extrapolation from the test conditions to those proposed for the upgrade, where it's important to be meticulous in handling the different power levels needed for different parts of the band.

If it's desired to make comparisons between potential suppliers then care needs to be taken, as the tests will almost certainly have employed different methods and equipment. For the final optical power budget all should use the same margins for repairs, ageing and operation, as these should not depend on which supplier is selected. Providing that all

measurements covered the full bandwidth, that test channels had adjacent channels and that all power levels and wavelengths are those proposed for start of life, the process is relatively straightforward. If this isn't the case, then one will need to extrapolate from the results and there is the potential for errors and uncertainty which increase with the degree of extrapolation. As an approximation a 0.5 dB error is sufficient to make around 10% difference to the prediction of ultimate capacity. Channel separation during testing also needs to be fairly close to that proposed, as penalties can rise very rapidly as the spacing is reduced and there is generally no precise formula which can be applied.

An optical transmission trial doesn't sound complex, but it represents a significant outlay in time and effort for all concerned and critical decisions may depend on the results. This short article has tried to identify some of the key issues and hopefully showed ways to minimise errors/uncertainty and make results from different suppliers comparable.



Tony started his working in British Telecom's Research labs working on early optical fibre submarine systems. After a number of years he moved to Alcatel Submarine Networks in Australia and led the system

testing team for the TASMAN 2 cable system. Following this, he spent a brief period with Bell Labs where he was involved in terminal design and troubleshooting. Family pressure took him back Alcatel Submarine Networks, spending a few years in France working in Sales and Marketing and then moving back to the UK. Most recently he moved to Azea Networks, a start-up which was acquired by Xtera Communications, where he is currently Product Line Manager for Repeated Solutions.