# TESTING 40 Gbit/s NETWORKS: THE DAWN OF A NEW ERA

031

TECHNICAL NOTE

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Though 40 Gbit/s transmission technology has been in existence for more than a decade, until recently, it has mainly been confined to system-vendor laboratories. As the telecom industry continues to recover from troubles past, research and development of this technology have made considerable progress thanks to the market's renewed interest in the subject. The first commercial 40 Gbit/s system was successfully deployed in 2005. Carriers are seeing the obvious advantages of this technology and the demand is steadily growing.

40 Gbit/s networks, however, still pose a vexing financial challenge. In order for it to be accepted as a feasible upgrade from 10 Gbit/s transmission, the 40 Gbit/s system would have to be four times less expensive. Even though this is not yet the case, some tier-1 carriers that envision substantial growth have turned to 40 Gbit/s to provide them with vastly superior traffic capacity. Most of these network operators are considering the possibility of implementing of 40 Gbit/s networks within a year or two. If it is determined that the transmission technology is cost-effective and efficient, operators will need to be ready to confront the potential issues involved in the infrastructure and deployment.

**40 Gbit/s: Higher Speed Brings New Issues**

Unlike the 10 Gbit/s transmission model, which operates on non-return-to-zero on/off keying (NRZ-OOK), the 40 Gbit/s transmission model does not properly support that technique.

When NRZ-OOK is used in 10 Gbit/s applications, the transmitter, via an external modulator, produces 1 and 0 databits, but the light stays on when successive 1 values occur. This provides higher average power than if the 1 were to return to 0 between two successive 1s:

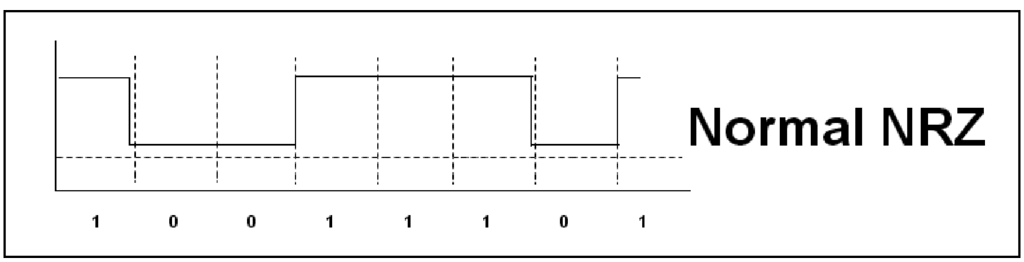


***Figure 1:*** *. Bit pattern of 10 Gbit/s transmission using non-return-to-zero on/off keying (NRZ-OOK)*

However, when used at 40 Gbit/s the NRZ-OOK technique can lead to several potential problems:

- All network components such as multiplexers and filters must be four times larger to accommodate the increase in speed. Accordingly, four times more noise enters the system, resulting in an optical signal-to-noise ratio (OSNR) that is 6 dB lower.
- Non-linear effects, such as self-phase and cross-phase modulation, will occur from signal boosting.
- At 40 Gbit/s, dispersion (both CD and PMD) becomes a serious issue, as the effects are amplified manifold.

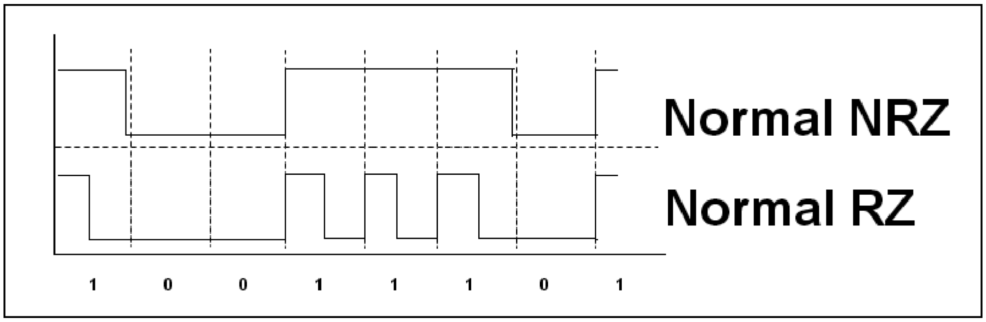


***Figure 2:*** *Comparative bit patterns of 40 Gbit/s transmission: non-return-to-zero on/off keying (NRZ-OOK) vs. return-to-zero on/off keying (RZ-OOK)*

To surmount these issues, several innovative modulation schemes have been developed, the most common of which are outlined in the table below, along with their advantages and disadvantages.

| Modulation technique | Advantage | Disadvantage |
|---|---|---|
| Carrier-suppressed return-to-zero on/off keying (CS-RZ-OOK) | • Relatively inexpensive | • Does not resist well against dispersion<br>• Wavelength spacing limited to 100 GHz<br>• Suitable for short-haul transmissions only |
| Duo-binary | • 50 GHz transmission is possible, and therefore, it's cost-effective<br>• Somewhat more resistant against dispersion | • Duty cycle is low, so sensitivity is degraded<br>• Suitable for short-haul transmissions only. |
| Differential phase-shift keying (DPSK) | • Offers the best sensitivity<br>• Extremely resistant to dispersion effects<br>• Most suitable method for long-haul 40 Gbit/s transmission. | • Implementation is complex and expensive |

**DWDM and Optical Spectrum Analysis**

The broader pulse of the 40 Gbit/s scheme leads to four main issues.

a) For a similar total power, peak power will be much lower on a broader pulse.

b) OSNR, which in 10 Gbit/s transmission is approximately the difference between the peak power and the noise floor, must be calculated differently for 40 Gbit/s.

c) Full-width half maximum (FWHM) obviously has a different meaning and different implications on a broader pulse.

d) The larger response not only means that the power must be monitored (like in most system-integrated OPMs), the spectral width and central wavelength must also be carefully monitored. Any deviation or enlargement may result in crosstalk.

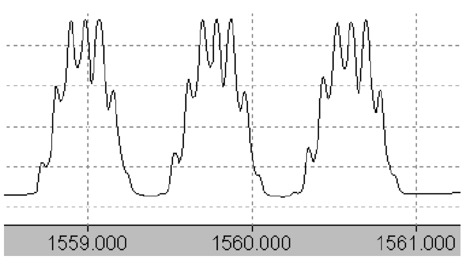


***Figure 3:*** *40 Gbit/s transmission signal pulses (broader than those of 10 Gbit/s)*

Due to the larger spectral response of 40 Gbit/s systems, more noise may contaminate the signal and, therefore, require low-noise amplifiers. Accordingly, amplifiers are also key in making

40 Gbit/s and 10 Gbit/s signals copropagate along a single fiber. Since the power distribution in these two formats is quite different, it is all the more critical to use amplifiers to add some restraints to the gain flatness and gain-flattening filters. To properly test 40 Gbit/s networks during installation and commissioning, a highly accurate optical spectrum analyzer that can also characterize amplifiers is a must.

**Raman Amplification**

For configurations such as long-haul networks, Raman amplification makes it possible to achieve longer distances, thanks to flattening and low-noise amplifiers. This technique uses the fiber itself as a gain medium by applying a counter-propagating pump at about 100 nm below the region of desired gain. Several pumps can be used to cover a greater gain spectrum.

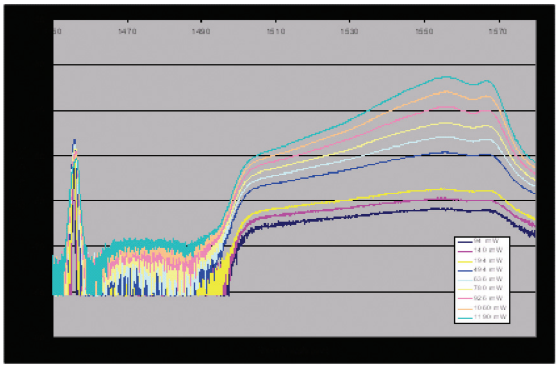


***Figure 4:*** *Gain as a function of pump power*

Unlike erbium-doped fiber amplifiers (EDFAs), Raman amplifiers have no isolator. Rayleigh backscattering and connector/splice reflection coming back toward the transmitter will benefit from the gain the Raman amplifier provides. The high-power counter-propagating signal will be subject to Rayleigh backscattering as well as reflection. It will then propagate once again in the original direction and will be reamplified in the Raman amplifier.

**Multipath Interference**

The downside of Raman amplifiers is that it results in a ghost image and creates interference with the ongoing transmission; i.e., MPI. This can prove problematic because the MPI generates RF noise (signal intensity noise), which is not detectable with an OSA. As such, numerous tests can be performed (power, OTDR, CD, PMD, OSNR), without MPI ever being detected, when in fact, the network may be experiencing very high BER levels. In Raman-amplified systems, MPI can cause several problems and it best not be overlooked, as MPI can be easily and cost-effectively monitored using a multipath interference meter.

**Addressing Chromatic Dispersion**

As mentioned previously, the effects of dispersion have many implications, especially in high-speed transmissions. Chromatic dispersion (CD), i.e., the spreading of a pulse through the time domain, is particularly harmful because all of its frequencies travel at different speeds. Although sophisticated modulation techniques can reduce its impact, it can never be entirely eliminated. Nonetheless, proper compensation techniques are essential (e.g., with granularity attaining about 5 km of G.652 fiber).

When considering some of the compensatory modulation techniques such as the traditional RZ-OOK, the duty cycle is reduced in an attempt to improve resistance to CD, but to compensate for the decrease in average power, peak power must be increased, thus amplifying the impact of non-linear effects.

Since chromatic dispersion is wavelength-dependent, compensation techniques must include accurate slope compensation (per wavelength). Three techniques can be considered:

- **Compensation fine-tuning**
  When add/drop multiplexers are present, some may prefer to fine-tune the compensation at every possible occasion (i.e., at every repeater site in addition to the receiver end) but, either way, fine-tuning requires accurate measurements.
- **Negative pre-chirping**
  This means red-shifting high frequencies and blue-shifting low ones. Although this is a helpful method, it does have limitations and some sort of compensation must be applied to the negative pre-chirp.
- **Phase-shift and differential phase-shift**
  These are the only approaches that offer the required accuracy to ensure proper transmission and adequate compensation at 40 Gbit/s.

**Controlling PMD**

Most long-haul network infrastructures may contain older fibers that are more subject to polarization mode dispersion (PMD), i.e., pulse spreading caused by the impurities and local stresses on a fiber. Many of these older fiber networks are not capable of running 10 Gbit/s transmission, let alone 40 Gbit/s. The modulation schemes alone are simply not enough to offset the PMD effects of transmitting at such speeds. The only way to ensure error-free transmission is to properly test for PMD, as recommended by the various standards organizations. Although there are several ways to do so, it is essential to select the most appropriate one for the application (i.e., fieldwork vs. lab), as opting for the wrong technique can lead to expensive errors.

In addition, there is the issue of second-order PMD, which essentially adds a random and changing value to the CD value, thus reemphasizing the importance of accurate CD and second-order PMD measurements.

In conclusion, the coming wave of 40 Gbit/s technology will require more rigorous testing and emphasis on splice connections rather than connectors to prevent unnecessary power loss and to minimize the impact of MPI. All testing issues that affect today's 10 Gbit/s network will apply to tomorrow's 40 Gbit/s but these issues will become more critical than ever. Several new parameters may also arise and gain significance, as high-performance and capacity testing are likely to become increasingly important, as network operators strive to meet users' ever-evolving needs and requirements.

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