Analysis of the optical spectrum in the communications by means of optical fibre

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The origins. Colours discovery

→ 380 - 700 nm

Summer of 1665. A terrible disease whips London region. The University of Cambribge is forced to close their classrooms and to send the students and teachers to their homes.

One of these students is a young person of 22 years, **Isaac Newton**, who is going to stay in his native town, Woolsthorpe, two years of unavoidable vacations.

The most fruitful vacations of the science history.

Throughout these months Newton is going to conceive, to experience and to develop his brilliant ideas about the nature of the light, the universal gravitation and on the method of fluxions.

At the beginning of **1666**, using a prism and a hole in the window shutter of his room is going to demonstrate that the sun light is a mixture of spectrum colours.

Isaac Newton (1643 - 1727)

In the present optical fibre networks the spectral analysis in any network point is more and more necessary. Systems WDM convert optical fibres to freeways of information with capacities up to 1Tb/s (1x10^{12}b/s). This thanks to a greater advantage of the optical fibre spectral band. At the moment, up to 200 lasers of different wavelength can be transmitted in a same fibre. For the test and maintenance of these networks it is fundamental to handle portable equipment working in the wavelength dominion. A new generation of optical measuring equipment in field, is now raising.

Discovery of the infrared

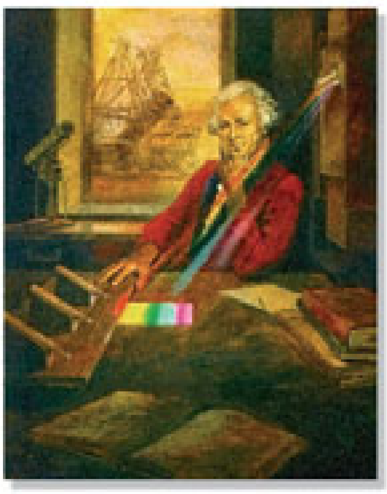
→ 700 - 1 000 000 nm

In 1800 **Sir Frederick Herschel** sent the sunlight through a prism to create a spectrum and measured the temperature of each colour.

Once measured the temperature of colours violet, blue, green, yellow, orange and red, he noticed that the temperature of the colours was increased from the violet to the red part of the spectrum.

After noticing this pattern, Herschel decided to measure the temperature beyond the red spectrum portion, in an apparently lacking region of sun light. Surprisingly, he found that this region had the highest temperature than all.

That William Herschel had discovered was a form of energy beyond the red light. These "calorific rays" were renamed **infrared rays**.



Frederick William Herschel (1738 - 1822)

“In the 30 years since our discovery of the fibre with low-loss, more than 300 million km of optical fibre has been deployed world-wide around. These single fibres can handle more information than all the thousands million kilometers of installed copper cables during the last century. Two metric tons of copper wire would be necessary to transmit the information that needs a little more than 1 lb of fibre. In laboratory today, a single fibre can transmit the equivalent of 60 million of simultaneous telephone calls.”

Dr. Donald Keck, 1999

The way to optical fibre

→ 1 550 nm

By years 40 of XIX century, the swiss physicist Daniel Collodon and the french Jacques Babinet, demonstrated that the light could be guided throughout the water jets of a source. John Tyndall popularised the idea in 1854 on the basis of an experiment that used a water jet flowing from a tank.

In 1954, Van Heel of Holland and Hopking presented a study about an optical conductor in the "Nature" publication. Their articles **caused that the optical fibre began to be developed**. Towards 1960, fibres with glass cover had been already developed with losses of 1 dB by meter.

A **fundamental step** in the attainment of the communications by optical fibre was the discovery of the laser by Theodore Maiman. In the 1962 the first semiconducting lasers were developed.

The **great advance** took place in 1970 in Corning Glass Works, when Donald Keck, Peter Schultz and Robert Maurer managed successfully to make an optical fibre with length of hundreds of meters and with the crystalline clarity that Kao and Hockham had proposed.

Shortly after, Panish and Hayashi, from Bell labs, showed a laser of semiconductors that could work continuously to room temperature, and John MacChesney and his collaborators, also from Bell labs, independently developed fibre preparation methods.

Evolution of the optical fibre

→ 1 300 nm

The first test was carried out in AT&T in Atlanta on **1976**.

The work teams installed two optical fibre cables, each one of which measured 630 meters in length with 144 fibres, throwing them through underground standard tubes, for which it was required that the cables could draw extreme curves. The commercial service began the following year in Chicago, where an optical fibre system transported voice, data and video signals through 2.4 km of subterranean cables that connected two telephone company commutation offices from Illinois Bell Telephone Company.

These first generations of systems could transmit light to several kilometers without repeater, but they were limited by an attenuation of approximately 2 dB/km. Soon appeared one **second fibre generation**, using the new InGaAsP lasers emitting at 1.3 micrometers, where the attenuation of the fibre was as low as 0.5 dB/km, and the dispersion of the pulse reduced to 850 nm.

In 1983 MCI, one of the big companies of long distance in USA was first in tending a **National Optical fibre Network** in the United States.

By the end of the eighties, the systems tended to operate to greater wavelengths. The Dispersion Shifted Fibre (DSF), was introduced in 1985, and announced a new era in the optical communications. Uniting the minimum of attenuation in the window of 1.550nm with dispersion zero in the same wavelength, greater data rates could take to greater distances.

In 1978, the amount of installed optical fibre in the world was only of 960 km. In 1980, AT&T presented to the USA FCC. (Federal Communications Commission) a project of a system that would connect the main towns from Boston to Washington path. Four years later, when the system began to work, the cable with less than 1 inch (2.5 cm) of diameter, provided 80,000 voice channels for simultaneous telephone conversations. By then, the length overall of fibre cables in the United States solely reached **400,000 km**, sufficient to arrive at the Moon.

Soon, similar cables crossed the oceans of the world. The first **transatlantic cable** began to operate in **1988**, using a so transparent crystal that the amplifiers to regenerate the weak signals could be placed for distances longer than 64 km. Three years later, another transatlantic cable duplicated the capacity of first one. The cables that also cross the Pacific have entered in operation offering a easy telephone service for the commerce increasing between the United States and Asia.

In 1990, the Bell labs transmit a signal of 2.5 Gb/s through 7,500 km without feedback. The system used a laser soliton and an amplifier EDFA that allowed the light wave to maintain its form and dens.

In 1998, such Bell labs transmitted 100 optical signals of 10 Gb/s using a single fibre of 400 km. In this experiment, thanks to WDM techniques (wave-division multiplexing) that allows to combine many lengths wave in a single optical signal, increase the fibre capacity of transmission in a Tbits/sec (10^{12} b/s).

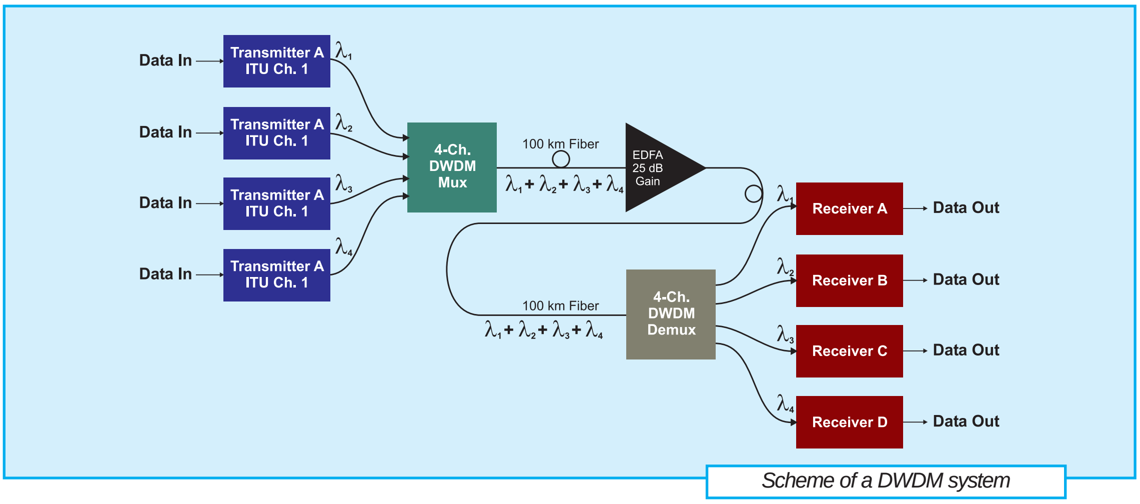
DWDM Technology

→ 1 530 - 1 610 nm

In the decade of the 90, an incredible growth of requirements about communications **capacity** is done, as much in terms of speed as in geographic cover. The transmission of **digital TV**, **voice**, **data**, the **mobile telephony** and the arrival of the **Internet** phenomenon have caused that traffic information requires high capacity means. The optical fibres in the field of the communications began to apply in voice telephony, but at the moment is present total or partially in any communication system.

However, the index of growth in the capacity of transmission demanded by these new services is exponential and the only technology that at the moment can respond to this growth is the dense wavelength division multiplexing (DWDM).

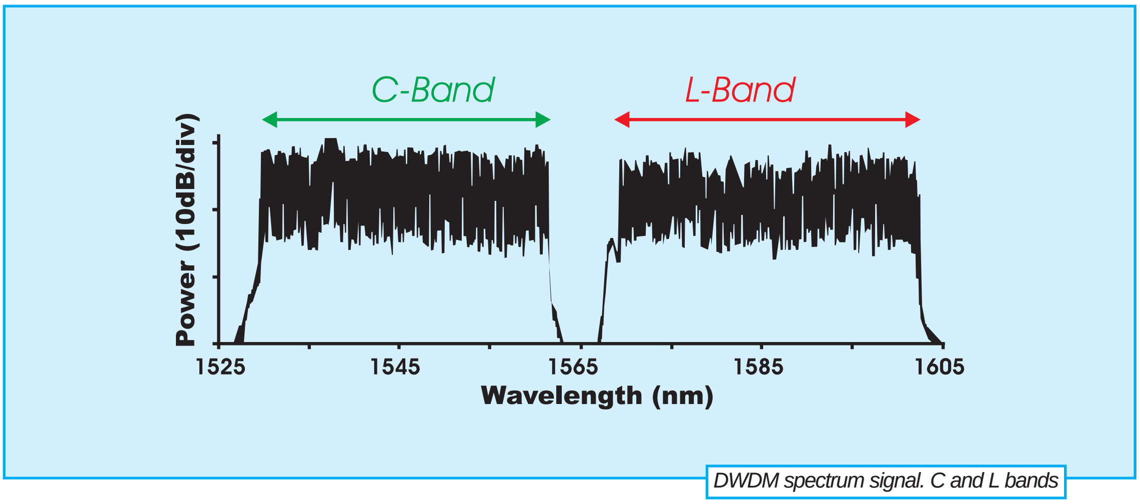
These systems are based on the capacity of the fibre in transporting different wavelengths (colours) without simultaneously mutual interference. Each wavelength represents an optical channel within the fibre.



Scheme of a DWDM system

The development of the non-zero dispersion shifted fibre industry (**NZDSF**) is a direct answer to the non-linear effects propagation. The zero-dispersion wavelength outside the operation window is changed, introducing therefore a small but finite amount of dispersion to reduce the non-linear effects in DWDM.

First NZDSF cables with a great effective area were commercially available in 1998. By means of increasing the effective area of the field mode within the fibre and the non-linear effects can be reduced. The technical benefits are immediate: the capacity for handling the power is higher, the signal/noise relation is greater and the space between amplifiers is also greater.



DWDM spectrum signal. C and L bands

CWDM Technology

→ 1 250 - 1 625 nm

The transmission by **CWDM** (coarse wavelength division multiplex) is gaining popularity in applications such as metropolitan access 10 GbE, CATV, FTTH-PON, and other systems with short covering point to point over transparent services, using protocols such as ESCON, FICON, Fibre Channel, Gigabit and Fast Ethernet.

The multiplexing technique CWDM consists of 18 defined wavelengths in the interval from 1270 to 1610 nm with 20 nm spacing.

The multiplexing by coarse wavelength division, a WDM technology, is characterised by a **wider spacing** of channels than the dense division of wavelength (DWDM). Systems CWDM are more profitable for metropolitan networks applications.

The plan of wavelengths described in the new recommendation UIT-T G.694.2 has channel a spacing of **20 nm** as need the lasers of great spectral width and/or considerable thermal drifts. This wide spacing of channels is based on economic considerations related to the cost of the lasers and filters, that vary according to that spacing. In order to accommodate numerous channels in each fibre, the plan of wavelengths established cover most of the bands from lower than 1300 nm to higher than 1600 nm of the monomode optical fibre spectrum, recently approved.

Systems CWDM admit transmission ranges up to **50 km** and they do not use optical amplification. Between those distances, technology CWDM can admit different topologies: ring with distributor (hubbed ring), point to point and passive optical networks. In addition, can be adapted correctly to the metropolitan network applications (for example, CWDM local ring connecting central offices with the express DWDM metropolitan main rings) and to the applications relative to the access, like the access ring and the passive optical networks.

CWDM systems can be used as an integrated platform for many clients, services and protocols destined to commercial clients. The channels in CWDM can have different binary speeds. This technique adapts itself more easily to the variations of the traffic demand, since channels can be added in the systems and be released.

CWDM can be a low cost alternative to the dense wavelength division multiplexing systems (DWDM) for optical transport in short distances (less than 50 km) from the companies facilities to the main metropolitan service suppliers.

The price of a DWDM transceiver is typically four or five times more expensive that the equivalent CWDM.

Measurements in optical networks

→ 1 250 - 1 650 nm

The priority for the worldwide telecommunication operators is to **make profitable the already existing optical networks**. For it the first step is to **increase its capacity**. Current DWDM systems, can increase in one or two orders of magnitude the capacity from an already existing fibre.

One of the **greater limitations** for this type of systems, it is the cost of measuring equipments needed in the starting up process and along the network maintenance. When several wavelengths share a same fibre, the optical power meters do not report information about the composed signal that it is being transmitted, since the measurements are not selective in wavelength.

For the measurement and monitoring of WDM systems it is required to characterise components and to take measurements in points of the network based on the wavelength. The **optical spectrum analysers** become the protagonists of any test of this type of systems.

These equipments are essential as much during the manufacture and the network components installation processes (multiplexers, filters, commutators, amplifiers, etc.) as well as in the maintenance processes of the own network.

The basic measurements in the frequency dominion required in WDM systems are:

- Measurement of channel power
- Measurement of the channel central wavelength
- Measurement of the spacing between signals
- Measurement of the relation signal noise (OSNR)
- Total power for the optical signal

The spectrum analyser

In order to analyse the individual carriers optical spectrum analysers **with resolutions below 1 nm** are required. In the most advanced facilities, the separation between carriers goes from 0.8 nm (100 GHz of spacing channel) to 0.2 nm (25 GHz).

These measurements based on a hi-res optical spectral analysis and also with high accuracy have to be able to be carried out **in any point of the network**. By all it, the equipment for measuring, and more specifically, the spectrum analyser (OSA) that is oriented to applications in WDM networks, must be a **handheld equipment**, robust, quickly and easily of operating and with a moderate price. Do not forget that until the arrival of WDM systems, the spectrum analysers were basically laboratory equipments, **non portable** and **high cost**. Systems WDM demand multitude of field optical measurements and the laboratory optical analysers are not suitable for outdoor measurements.

Another necessary feature in meter equipment focused on WDM networks is to have **procedures for specialised measurements** facilitating and simultaneously doing agile the technical service operations. The **PROLITE-60** instrument, developed by Promax Electronica S.A., is designed with dedicated algorithms for each application.

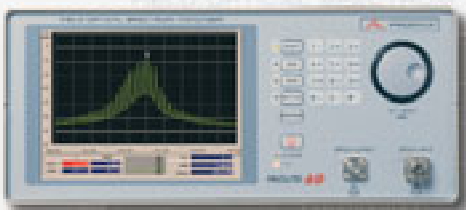
Field measurements using a PROLITE-60 from PROMAX Electronica, S.A.

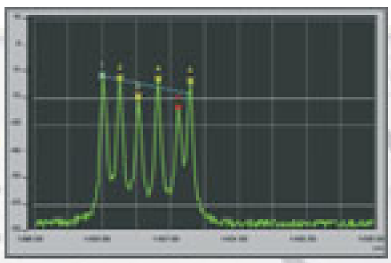
Based on a spectrum analyser platform, the equipment allows to carry out automatic measurements in all the scopes of application, as much in the analysis of the WDM signal **in any point of the network** as the characterisation of network components: Filters, amplifiers, multiplexers, DFB lasers, FB lasers and LEDs.

PROLITE 60 optical spectrum analyser from PROMAX

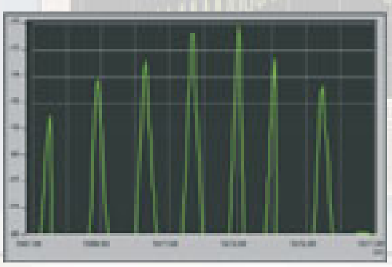
PROLITE-60 is the first optical spectrum analyser truly portable, rough and batteries operated available at a really attractive cost.

The **PROLITE-60** is also suitable for many other applications. Using the various available options it is suitable for reflectometry, analysis of materials, fibre sensors, testing of photonic devices such as filters, attenuators, couplers, isolators and other optical components.

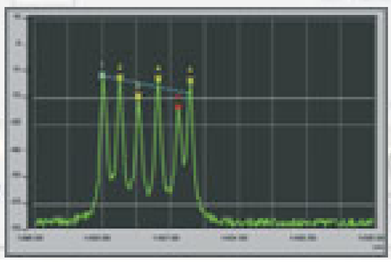




Automatic measurement of a system WDM using a PROLITE-60 from PROMAX



Spectrum of a measured WDM system using a PROLITE-60 from PROMAX



Measurement of an optical amplifier using a PROLITE-60 from PROMAX

Conclusion

The increase of the transmission capacity is unstoppable, in fact always it has been thus throughout history, but now it is significantly growing.

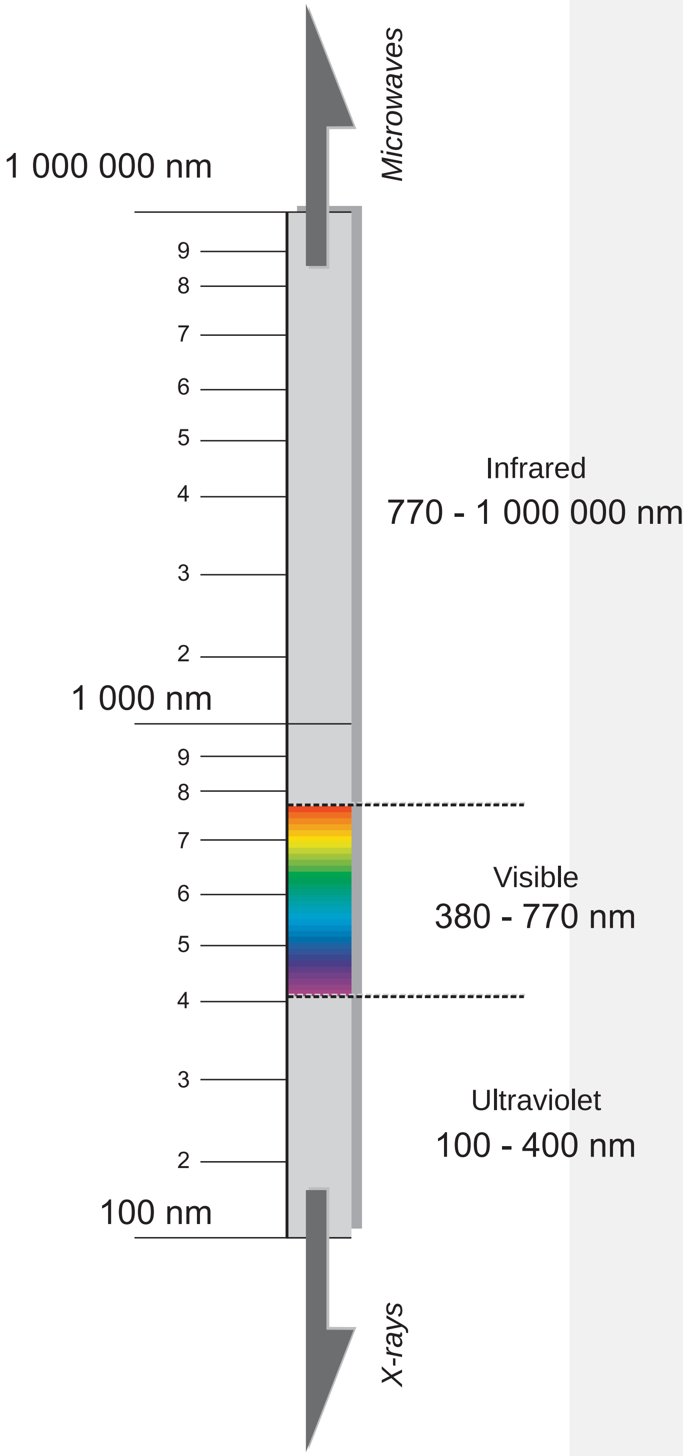
The rate of growth of the transmission capacity is multiplied by ten every four years. This means that **within eight years the capacity of transmission required by the main networks could surpass 100 Tb/s**.

At the moment, in the experimental scope, optical link systems are being test at tens of Tb/s for distances of thousands km using soliton lasers, special fibres that reduce the nonlinear effects, new optical amplifiers and of course WDM techniques (ultraDWDM). The spectral analysis for these systems is a requirement as necessary as it is for other means of transmission like coaxial or aerial that use UHF or microwave frequencies.

Since we have seen in the article, the first transmissions in F.O has used light at **850 nm**, soon were at **1300 nm** and at **1550nm** looking for the minimum transmission losses. Current WDM systems work in the **C** and **L** bands (1530-1610 n) but already fibres are being developed that work in the fourth window (1625 nm).

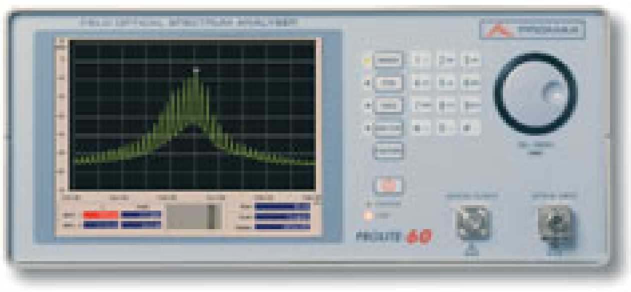
The trend, forced by the necessity of increasing to the maximum the transmission capacity is to use a greater part of the optical spectrum. In this sense already are manufacturing optical fibres that diminish the losses due to the absorption of water molecules in the 1470 nm area, so that also it is possible to use this band (fifth window).

In fact at the current time the band used by optical fibres is growing to be able to cover the exigencies of increasing the transmission capacity. In the future probably it will be very necessary to go up to zones of the electromagnetic spectrum with much greater capacity of transmission, towards **lower wavelengths to the visible light** (ultraviolet, X-rays.), which would allow to reach a big advance on transmission capacity. The current fibres do not allow the transmission of these wavelengths since the losses would be highest to these lengths. Perhaps in the future new materials will be discovered that can lead that type of radiation.



Optical spectrum diagram

PROLITE-60



The **PROLITE-60** is the first optical spectrum analyser truly portable, rough and battery operated available in the market at an attractive price. It is suitable for many applications. The first and may be the most interesting today is WDM/CWDM telecom system test but using the various options and accessories available it is adequate for reflectometry, analysis of materials, fibre sensors, testing of photonic devices such as filters, attenuators, couplers, isolators and other optical components.

SPECIFICATIONS	PROLITE-60
Wavelength	
Range	From 1250 nm to 1650 nm
Span	From 400 nm to 10 nm
Resolution	0.150 nm
Accuracy	± 0.8 nm
Stability	± 0.2 nm
Power	
Dinamic range	From -60 dBm to 10 dBm
Accuracy	± 1 dB
Flatness	± 0.5 dB
Stability	± 0.2 nm
OSNR	
(Selectivity at 1550 nm)	
At 25 GHz (± 0.2 nm)	18 dB
At 50 GHz (± 0.4 nm)	25 dB
At 100 GHz (± 0.8 nm)	30 dB
Polarisation dependancy	<1dB
Cycle time	5 s
Optical connector	FC/PC
Display	6.4" TFT color
Power supply	
Mains supply	100-240 V AC
Autonomy	3 h approx.
Mechanical features	
Dimensions	294 W.x 126 H. x 274 D.
Weight	5.7 k
Broadband source (optional)	1550 nm SLED light source (please ask for other wavelengths)
Universal optical connector (optional)	SC, FC, E-2000, ST, DIN

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