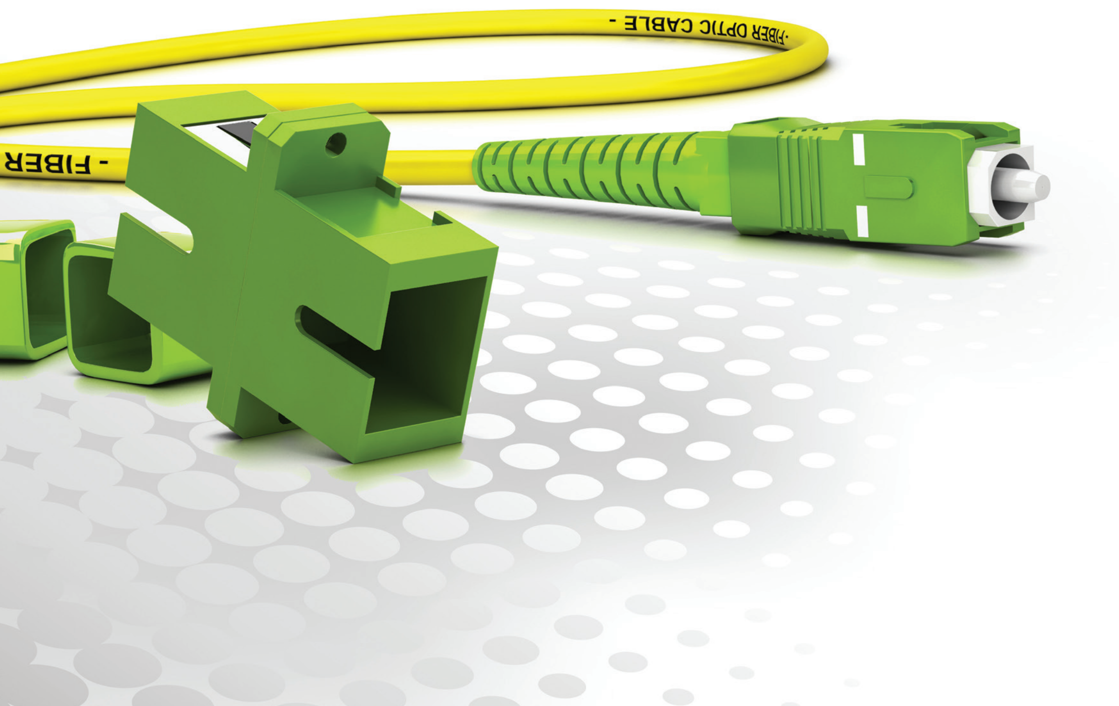
Anritsu
envision : ensure

Understanding PON

Measurements and fault finding



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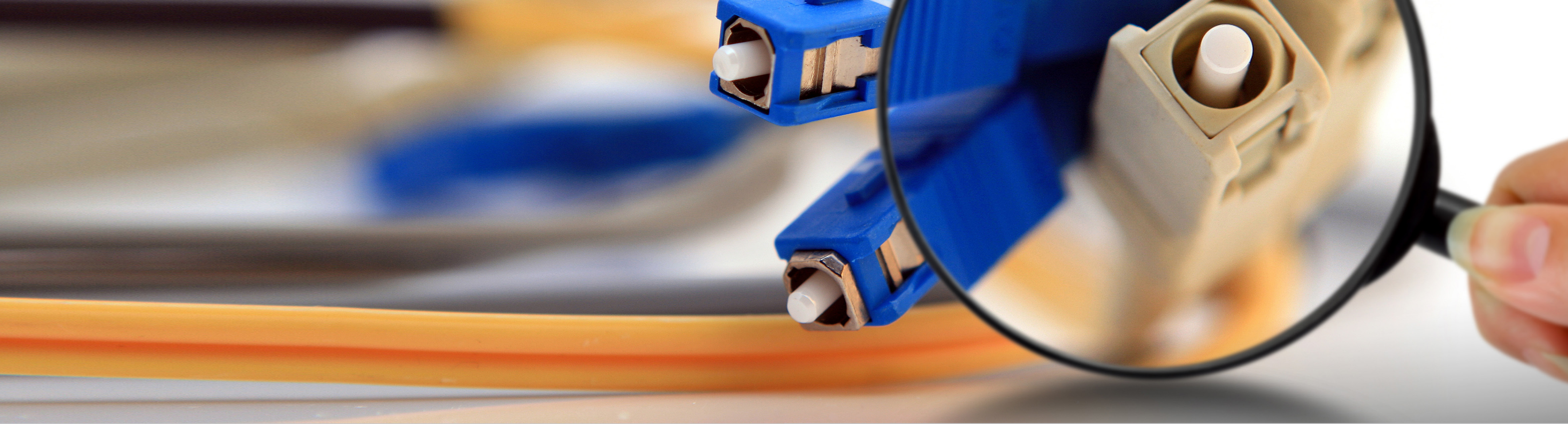

Introduction

The NGAN projects are currently being implemented by many network providers and are introducing fibre optics into the network on a massive scale, often with a solution of the PON (Passive Optical Network) type.

The measurements and fault-finding procedures on these networks are mainly based on the use of OTDRs (Optical Time Domain Reflectometers). These measurements are made more complex by the heavy local losses due to the passive optical splitters and by the presence of the "n" branches downstream of the splitters themselves. These produce a superimposition of the signals that are often difficult to discriminate, being represented on the screen of the OTDR by a single trace called a "composite".

In this work we turn to a PON network for a solution of the FTTH (Fiber To The Home) type, implemented with a double level of passive splitting, to cover a high number of ONTs (Optical Network Termination) starting from a central OLT (Optical Line Termination).

The first part describes the problems with measurement connected with use of the OTDR on PON networks, checked on a test plant set up in the laboratory.

The second part however looks at the possible causes of faults and the relative localization procedures on the PON networks, with an analysis of the possible case studies and the choice of the most effective remedies.

Preliminary Technical Considerations Regarding the Measurement of Backscattering in Optical Splitters

As we know, the attenuation of backscattering A_{bs} measured at any concentrated discontinuity along an optical fibre is given by the equation:

$$A_{bs}\ (dB) = -\frac{1}{2}\left[10\log_{10}\left(\frac{P_{bs}}{P_i}\right)\right] \qquad (1)$$

Where P_i represents the relative incident power and P_{bs} the power scattered back by the discontinuity itself. The factor 1/2 results from the propagation back and forth of backscattering on the fibre of the signal.

The backscattering attenuation given by (1) also applies to a 1:n splitter measured in the input-output direction with its output branches connected to leads of sufficient length. In the case of a 1:n splitter account must be taken, for any point-point concentrated discontinuity, of all the backscattering contributions generated by the output branches, that are in turn superimposed by the OTDR in a single backscattering trace ("composite" trace). So the attenuation provided by (1) measured in line with a 1:n splitter is defined as apparent attenuation, not always the same as the insertion attenuation of the splitter itself; this attenuation is in fact influenced both by the direction of the propagation of the measurement signal and by the "loading" of its output branches (connections).

The theoretical apparent attenuation ($A_{apparent}$) of a splitter generally varies according to how many output branches are connected to separate optical leads. The range of values is given by the following equation (2):

$$\frac{Insertion\ Loss}{2} \leq A_{apparent} \leq Insertion\ Loss \qquad (2)$$

The theoretical Insertion Loss (IL) of a 1:n splitter is however expressed as follows (3):

$$IL\ (dB) = 3\,\frac{\ln(n)}{\ln 2} = 3\log_2 n \qquad (3)$$

We will now consider the behaviour of an ideal 1:n splitter (balanced), in the input-output direction, with all its output branches connected to leads of progressively increasing length according to the diagram in Figure 1. The corresponding backscattering trace is also shown.

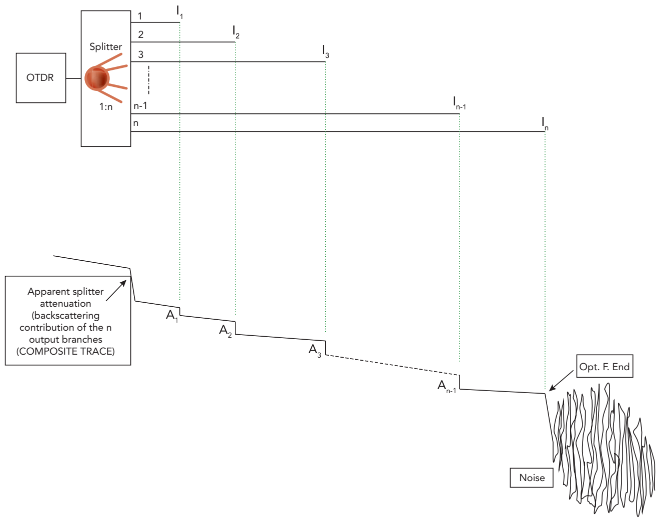

Figure 1 – Theoretical backscattering trace of a 1:n splitter measured in the input-output direction with all its output branches connected.

For different values of the spatial x-coordinate l, the OTDR measures the following backscattering contributions (A_{bs}):

$l \leq l_1$ — $A_{bs,\,n} = A_{apparent\ splitter}$ = Backscattering contribution of all the output branches

$l_1 < l \leq l_2$ — $A_{bs,\,n-1} = A_{apparent\ splitter} + A_1$ = Backscattering contribution of the n - 1 output branches (from no. 2 to no. n);

$l_2 < l \leq l_3$ — $A_{bs,\,n-2} = A_{apparent\ splitter} + A_1 + A_2$ = Backscattering contribution of the n - 2 output branches (from no. 3 to no. n);

and so on up to the spatial coordinates made up of:

$l_{n-1} < l \leq l_n$ — $A_{bs,\,1} = A_{apparent\ splitter} + A_1 + A_2 + A_3 + \ldots + A_{n-1}$ = Backscattering contribution of just the nth output branch (longest branch).

The last significant backscattering contribution represents the typical attenuation of a branch of the splitter with respect to the level of optical power at its input or strictly speaking the IL of the splitter. We can see that the individual attenuation contributions A_1, A_2, A_3 ….. A_{n-1} increase progressively.

In order to measure the IL of a splitter with an OTDR it is therefore necessary to isolate the contribution of just one branch from the superimposition of all the backscattering contributions of its branches. From the operational point of view it is enough for this measurement to make a branch sufficiently longer than all the other branches of the splitter. This can easily be arranged by connecting a tail coil to one and only one of the n output branches of the splitter.

The behaviour of a splitter measured by an OTDR in the output-input direction is different. In the case of a 1:n splitter the attenuation measured is equivalent to its insertion loss, obviously according to the method of measuring the backscattering.

However in the case of a 2:n splitter, that is a typical primary FTTH splitter in the presence of two-way and with both the input branches connected, the attenuation measured (in the output-input direction) is an apparent attenuation, less than the insertion loss.

Finally the use of an OTDR for acceptance testing of a multi-splitting FTTH network is connected both with the network elements, that can be measured individually, and with the direction of the measurement used.

We can see below that measurement with OTDR by the OLT strictly enables one of the following two parameters to be measured:

- Total attenuation just of the primary network excluding the insertion loss of the primary splitter;
- Total attenuation of the primary network including the insertion loss of the primary splitter.

The latter parameter can be measured to the extent described, in the presence of just one secondary branch of sufficient length or in the case of extension of one of the outputs of the primary splitter with a suitable tail coil.

Although more favourable for the measurable contributions, the use of the OTDR in the ONT-OLT direction however places a limit on the measurement of the insertion loss of the primary splitter if the latter is type 2:n. In fact the two backscattering contributions of the direct route and the reserve route show the apparent attenuation of the primary splitter to be less than its insertion loss, as far as has been observed.

In reality and for information's sake, the measurement of the apparent attenuation of a 1:n (or 2:n) splitter will provide a value greater than the theoretical value because its "excess loss" is not zero. In reality in fact the sum of the optical powers in the output branches is always less than the input power to the splitter.

Finally the combined effect of all the fibres makes the reflectometer measurement, although indispensable for characterizing a PON, particularly insensitive and difficult to interpret.

In fact it is only possible to evaluate the events if:

- The event to be evaluated has a very accentuated attenuation;
- The output fibres from the splitter are of different lengths;
- The network was accurately documented before the anomalous event, that is at the network deployment stage.

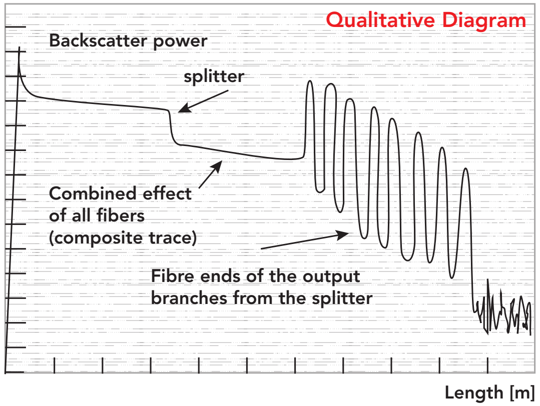

Figure 2

For example, in a 1:8 splitter, an interrupted fibre causes an increase in attenuation in the point of interruption of just 0.29 dB!

In fact:

Loss = 5 Log [N/(N-1)] = 5 Log (8/7) = 0.29 dB (4)

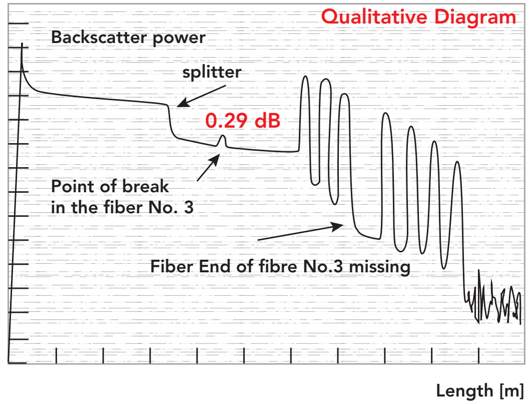

Figure 3

As the typical attenuation of the above splitter is about 10 dB, a similar attenuation value significantly reduces the S/N ratio after the event affecting the splitter itself. So, to have an ideal S/N ratio and hence a trace that is less noisy after the splitter event, an OTDR is needed with the following salient characteristics:

- High energy of the signal launched in fibre (high dynamics with narrow pulses)
- High receiver sensitivity (limited "recovery time" of the RF receiver)

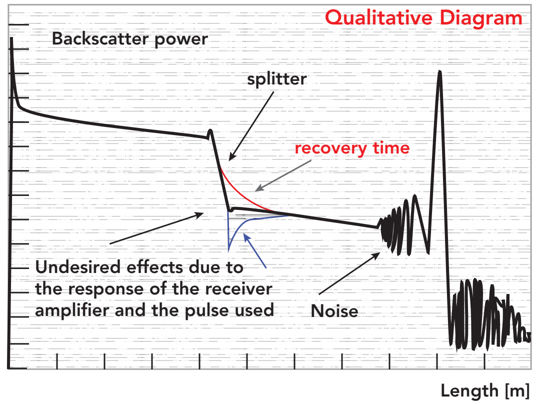

Figure 4

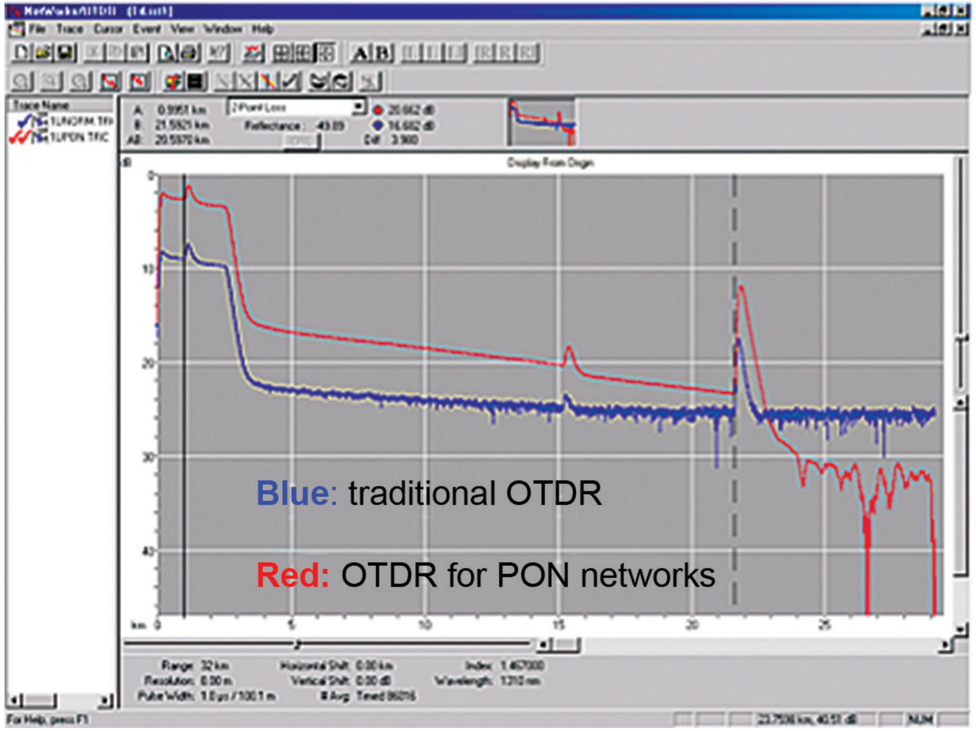

Figure 5

Measurement Test Plant: THE COMPONENTS

The following components are used to make up the test plant:

- SMF optical fibres (ITU-T G.652D) joined together in cascade, and so as to represent, in terms of length, a realistic optical access network;
- PLC (Planar Light Circuit) type splitters: Primary 2:8 and secondary 2:16;
- Bragg filter (FBG) with l = 1650 nm in an SC/PC brace;
- Refraction index adaptor bulbs.

Measurement Test Plant: THE SCHEDULE

The test plant is constructed to as to enable:

- Connection in cascade of the 2:8 (primary) and 2:16 (secondary) splitters connecting the latter to branch 1 of the 2:8 splitter;
- Connection of the Bragg filter with λ=1650 nm to just one of the two input ports of the primary 2:8 splitter (port corresponding to optical fiber 1A' optic line number 2).

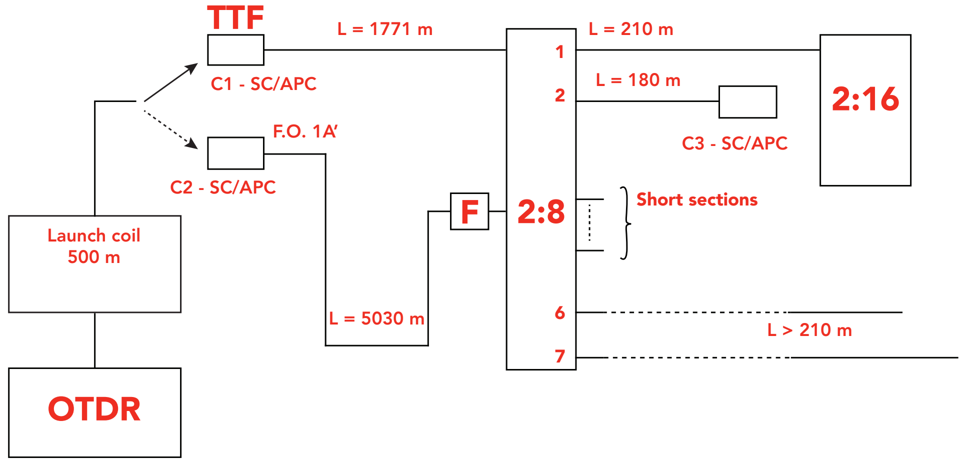

Figure 6

With reference to the figure above, the measurement schedule in this case requires the OTDR to be connected to C1, of SC/APC type; in fact in order to significantly reduce the reflections of the individual output branches of the splitter all the SP/PC type terminations have been connected to mixed SC/PC – SC/APC braces. The Bragg filters, with λ=1650 nm, initially provided at all the user terminations, have however been eliminated. The only filter used was inserted on one of the two input branches to the primary 2:8 splitter. This filter (inserted in the SC-PC brace) was connected to the above port by means of an SC coupling and an SC-PC semi-brace; this point of flexibility enables the measurement at λ=1650 nm to be conducted with or without the filter.

The measurement schedule in figure 6 shows a branch of the primary 2:8 splitter (branch 2) of a shorter length (180 m) than the distance between primary splitter and secondary splitter (equal to 210 m); branches 6 and 7 are of greater length, the remaining branches are very short.

The Measurements of Test 1

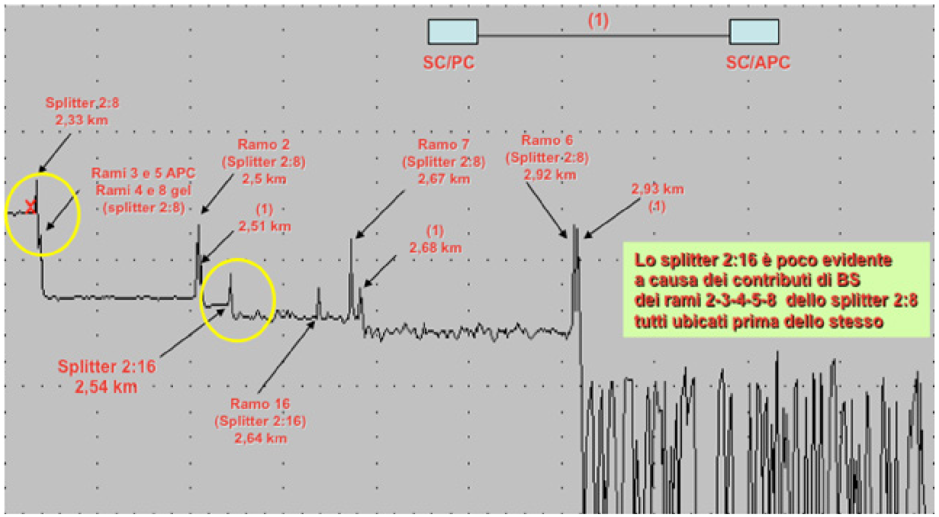

Figure 7 - Test 1 All the branches are terminated with APC braces

Ramo = branch

The 2:16 splitter is less evident because of the backscatter contributions of branches 2-3-4-5-8 of the 2:8 splitter all located before it

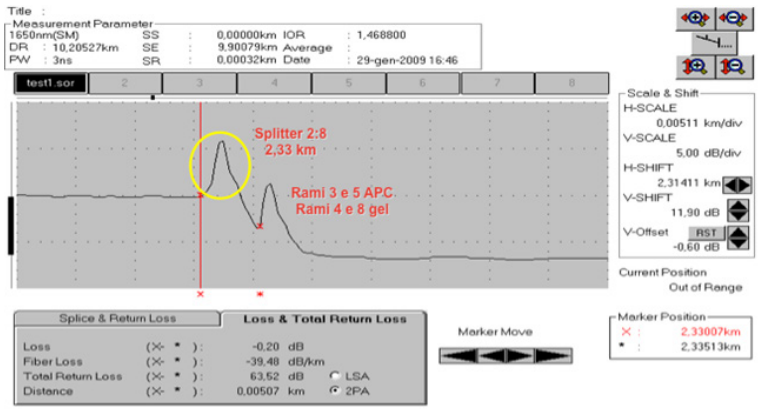

Figure 8 - Test 1 Events 1 and 2

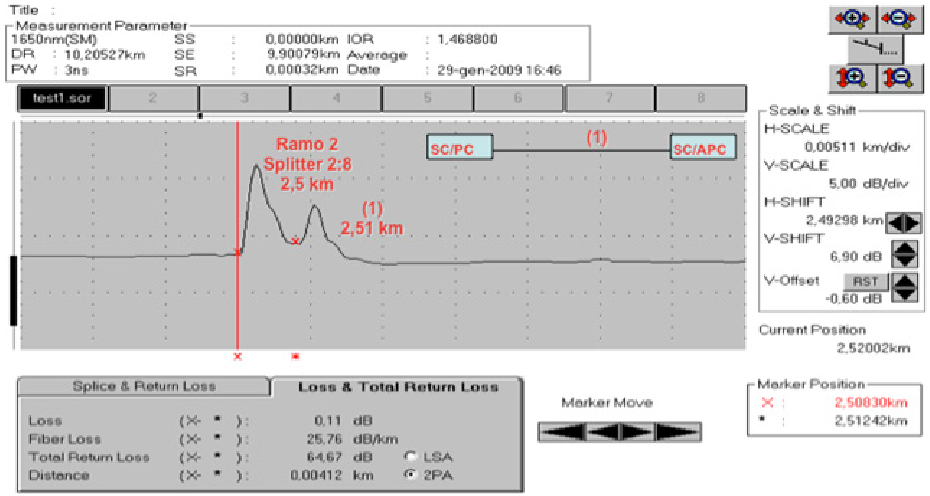

Figure 9 - Test 1 Evenst 2 and 4

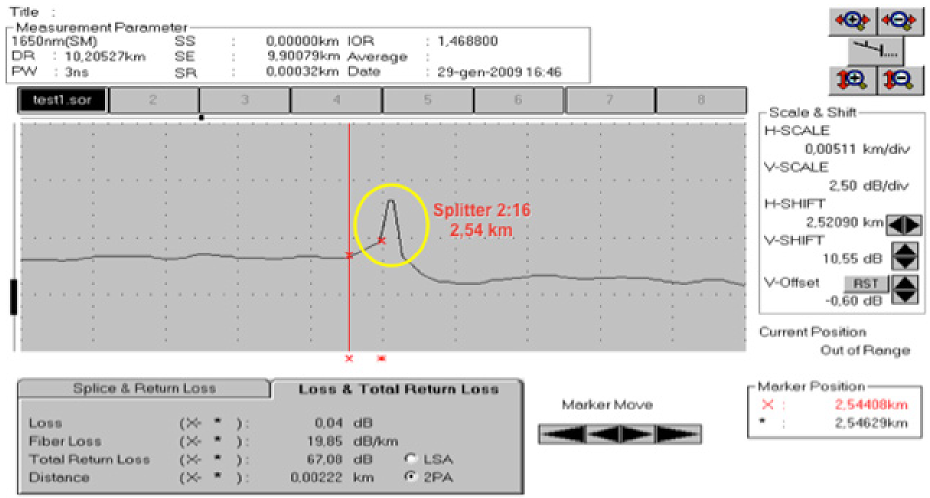

Figure 10 - Test 1 Event 5

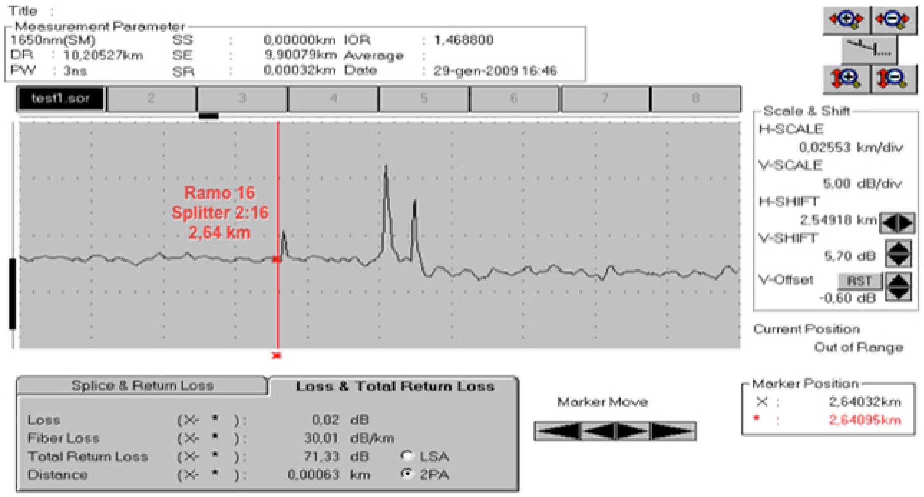

Figure 11 - Test 1 Event 6

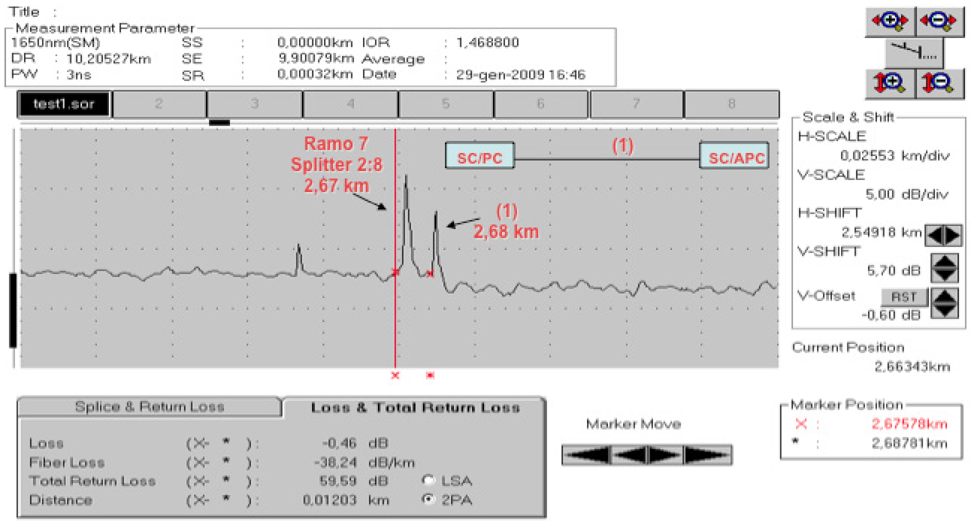

Figure 12 - Test 1 Event 7 and 8

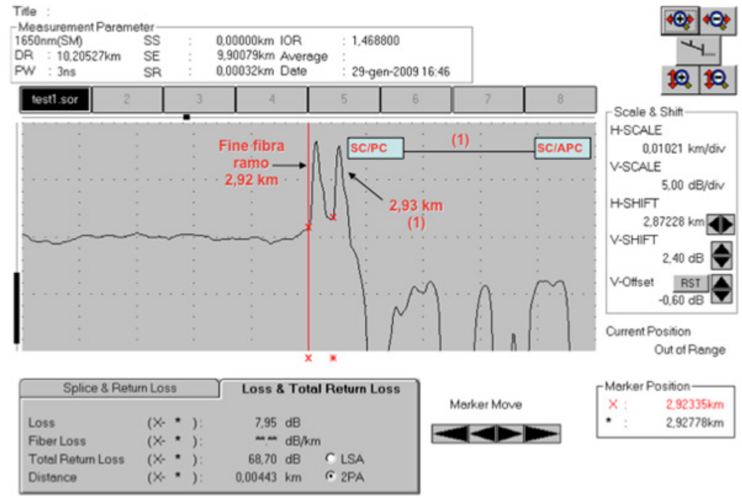

Figure 13 - Test 1 Events 9 and 10

Conclusions of Test 1

As can be seen from analysis of figures 7 to 13, according to the lengths of the output branches from the primary splitter and the output ones from the secondary splitters, the trace shows a succession of reflections belonging both to the branches of the primary and to those of the secondary, strictly connected to their distance from the point of measurement.

In particular, in the backscattering trace shown in figure 14, we can see the reflections of the primary (2:8) splitter, located downstream of the reflection of the secondary (2:16) splitter!

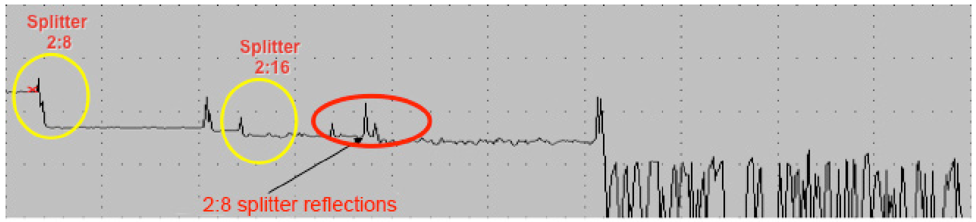

Figure 14

Practical Example

If the 16 buildings served by the same secondary splitter are 40 m apart from one another and in each building the fibres have a maximum length of 30 m, the trace first shows the 16 reflections connected to the shortest branch, then those of the branch 40 m longer and so on. In any other case the reflections of the various branches are superimposed!

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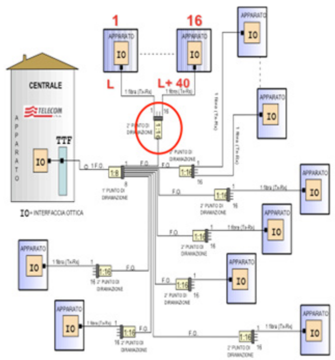

Figure 15 (Punto di diramazione = splitter point)

These situations are found in the FTTH architecture that provides for a spatial distribution of the secondary splitters that is hard to keep uniform and such as to guarantee that the nearest user connection is after the last secondary splitter, that is the one furthest from the primary splitter

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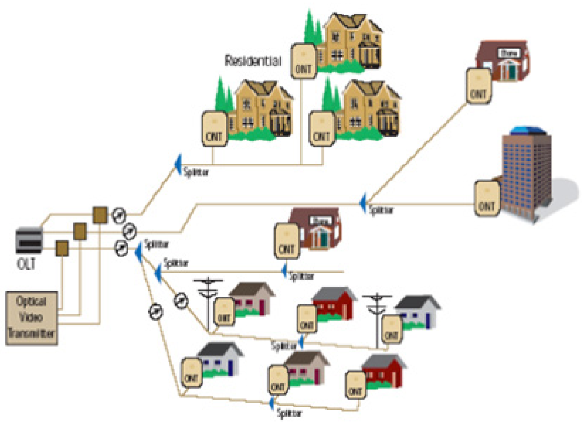

Figure 16

The Measurements of Test 2

In test 2, first of all branch 7 of the primary 2:8 splitter was terminated on an SC/PC connector to be able to observe its reflection, then the influence of the Bragg filter with λ =1650 nm, positioned at the input to the primary 2:8 splitter, on the backscattering measurement was analysed.

The OTDR was connected to the optical fibre 1A' of the TTF according to the measurement schedule in Figure 17.

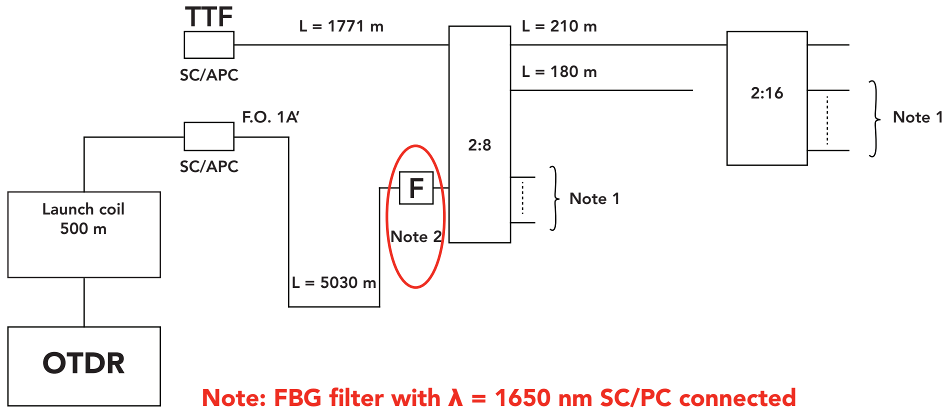

Figure 17

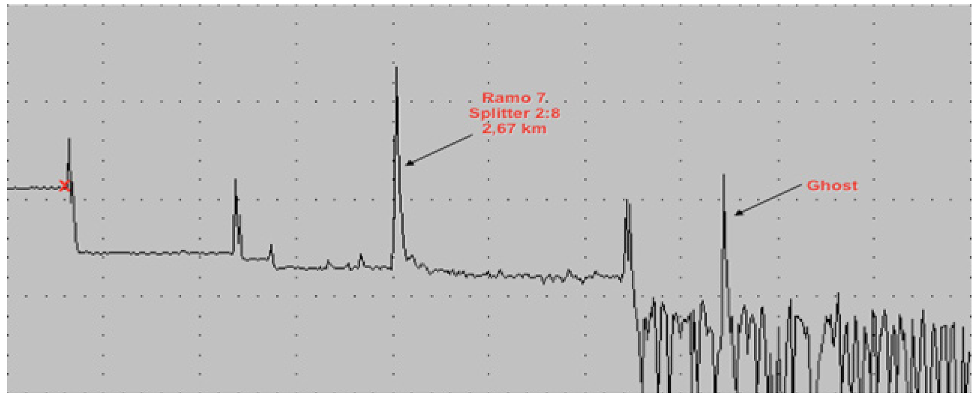

Figure 18 - TEST 2 Branch 7 Splitter 2:8 terminated SC/PC

The dead zone and the width of the reflections of the various branches are wider if these are not terminated with APC connectors or even with bulbs filled with index adjusting gel spurious reflections are also seen.

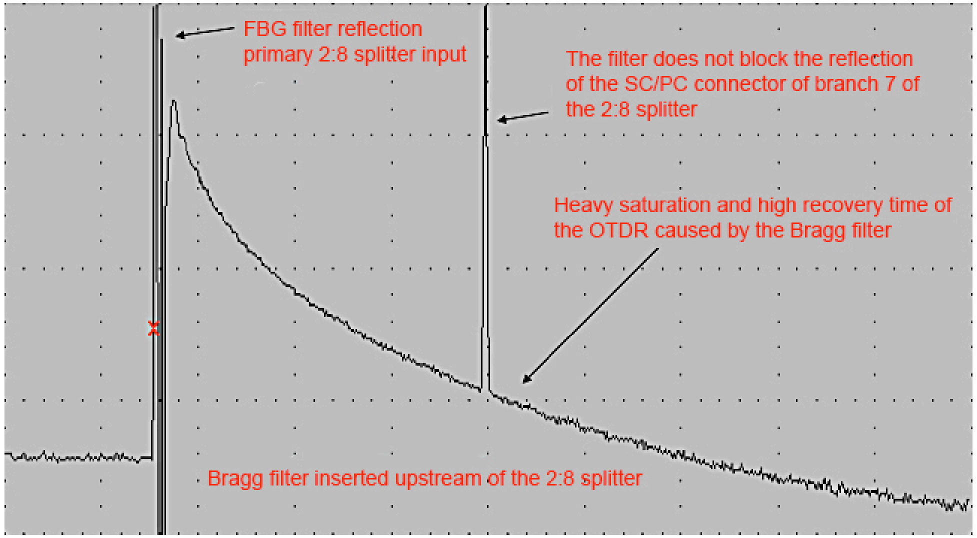

Figure 19 - TEST 2 Branch 7 Splitter 2:8 terminated SC/PC

The diagram shows how a highly reflective element like the Bragg filter with a λ =1650 nm (IL > 20 dB; RL < 5 dB) disturbs the measurement downstream of its positioning. Therefore it is only correct to insert these filters in plants in the presence of automatic monitoring systems that use an OTDR with λ = 1650 nm. In this case in fact the purpose of the Bragg filter is to block the λ= 1650 nm at the input of the ONT.

The Measurement of Test 3

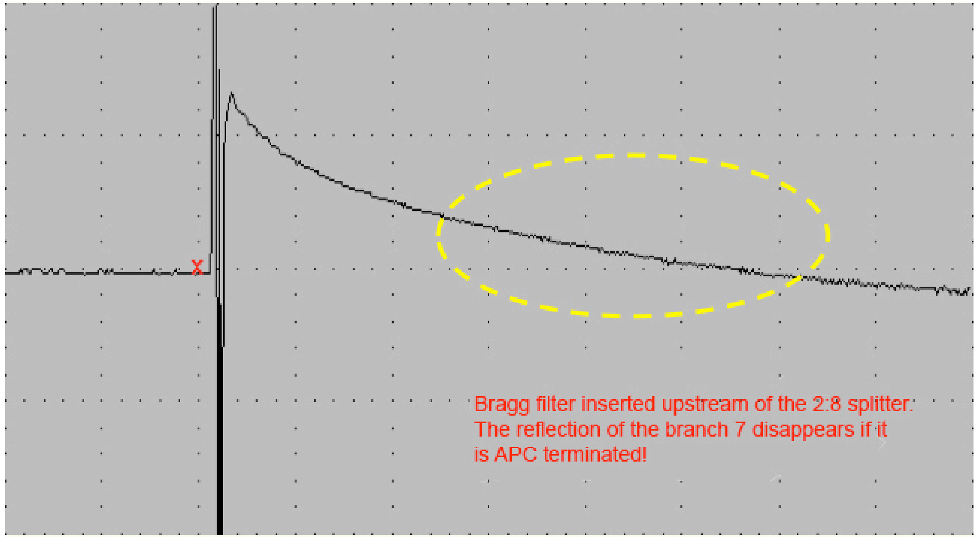

Figure 20 - Test 3 Branch 7 of the 2:8 Splitter terminated SC/APC

The high RL value of an APC connector > 60 dB is such that its reflection is not seen downstream of the Bragg filter.

Conclusions of Tests 2 and 3

The particular nature of a passive optical network requires careful adjustment of the measurement configuration of the OTDR to be able to reconcile the requirements to be dynamic with those of resolution. In this article the problems have been discussed and demonstrated that are encountered in the use of these instruments for acceptance testing and operation of the PON networks and the results of the measurements conducted on an experimental test plant have been set out. A comparison was also made between certain instruments available on the market, generally recording good measurement results but with substantial and important differences in performance according to the manufacturer of the instrument itself.

Salient Characteristics of an OTDR for PON Networks

As mentioned above in the case of point to point connections, the use of the OTDR technique in the analysis of PON networks is more complex, mainly due to the presence of the optical splitters. These devices in fact introduce a strong localised attenuation and if the OTDR does not have sufficient dynamic range. It may not be able to distinguish the trace downstream of the splitter from the noise level, may interpret this strong localised attenuation as "end of fibre", and may neither be able to evaluate the attenuation of the splitter nor capable to analyse the events downstream of same splitter. Moreover the superimposition of the backscattering signals coming from the various user branches makes it difficult to identify the individual traces downstream of the splitter and hence the location of any fault. If the lengths of two or more branches are equal, it as happens in reality, matters are further complicated because, as well as having the total superimposition of the traces, the reflection peaks of the connectors coincide, making it difficult to evaluate any stress on the cable because of the reduction in the level of these reflections.

These considerations apply in the case of measurements conducted by the OLT; to obtain complete information on the network and in particular to localise any fault on the secondary section, the measurements must also be conducted on the ONT side. In the case of FTTH architecture with a high splitting factor (64, 128 and above), the situation gets even worse in that the section downstream of the primary splitter is difficult to interpret.

An OTDR optimised for measurements on PON networks must have the following salient characteristics:

- Source of pulses with a wavelength of 1625/1650 nm to guarantee the continuity of the service during the measurements on live networks, with receiver filtered at the operating wavelengths (1310, 1490, 1550 nm);
- High spatial resolution to localise the events accurately;
- Highly dynamic, even for short pulses, to be able to investigate the maximum distance possible downstream of the highly concentrated attenuation introduced by the splitters;
- Dead zone after the splitter limited as much as possible (limited recovery time of the RF receiver).

By suitably adjusting the parameters of the OTDR it is possible to carry out measurements on PON networks, both at the stage of acceptance testing and during corrective and preventative maintenance, even if with the limitations described above. A point worth considering is the fact that the spatial resolution is more accurate for shorter pulses, while the dynamic range of the instrument is greater for longer pulses. It is therefore necessary to carefully determine what information we want to obtain from the measurement and adjust the parameters of the OTDR accordingly, so to reach the best compromise between resolution and dynamics. An OTDR for PON networks must therefore achieve a good compromise between resolution and dynamic range.

The analysis of PON networks by means of OTDR, although difficult to interpret, is fundamental and must be carried out both on the OLT side to display the primary section and on the ONT side for the secondary.

The measurement of the 1490 nm wavelength, used on the PON in the downstream direction, is not needed in that the attenuation at 1490 nm is on average only 0.02 dB higher that at 1550 nm. This is true for the most recently built fibres and particularly for the G.652 C fibres (low water peak fibres), but not however for fibres produced before 1990.

The availability of a very wide range of pulses in the interval from zero to 500 ns enables the measurement to be optimised according to the various attenuation conditions with the most appropriate resolution (e.g.: 3/5; 10; 20/30; 50; 100; 200; 500 ns). The pulse from 500 ns is very important in that it allows, when it is not necessary to characterise the individual elements of the plant, the attenuation between OLT and ONU to be determined directly with a good speed of measurement.

Operating the PON Networks

The network problems that can arise most frequently in the operation of a PON are:

- The level of power received in one or more ONT is insufficient;
- No signal received at the ONT, increased BER or degraded signal;
- Component faults at the ONT, along the line and at the OLT.

As all the line components are passive, the problems are generally due to lack of cleaning, to damage or to misalignment of connectors, or to interruptions and/or micro and macro curvature of the optical fibres. These problems can affect one, some or all of the customers of the network according to the location and type of fault encountered.

To locate a fault on a PON we can therefore operate as follows:

Primary network fault (lack of service for all the users affected by the particular primary splitter):

- Use of a common OTDR operating at any l for localisation by the OLT;

All the users of a secondary splitter are without service:

- Probable causes of faults and corresponding actions:
  - Interruption of the branch connecting to the primary splitter:
    - Use of OTDR at any λ by one of the output ports of the secondary splitter; in this case no filter is required and the signal of the OTDR will not in fact be transmitted to the OLT (fibre interrupted).
  - Secondary splitter completely faulty (not very likely):
    - Replacement of the splitter.

One or more users of as secondary splitter are without service:

- Probable causes of faults and corresponding actions:
  - Optical fiber of the vertical connection cable interrupted;
- Ports corresponding to the secondary splitter faulty;
- Splitter side and/or user side connectors dirty or faulty.

In the above cases the ONT/ONT's does/do not receive any signal from the OLT!

Fault-finding will require:

- Visual fault Locator (VFL);
- Receiver/transmitter to measure the attenuation;
- OTDR.

One or more customers of a secondary splitter report a reduction in the quality of the service:

- Probable causes of faults and corresponding actions:
  - Optical fibre of the vertical connection cable stressed;
- Ports corresponding to the secondary splitter faulty;
- Splitter side and/or user side connectors dirty or faulty.
- The ONT/ONT's receives/receive a low level of signal from the OLT.

Fault-finding will require:

- A power-meter;
- An OTDR.

Check the level received by OLT at the outputs of the secondary splitter; if the level is still low the port of the splitter is faulty and if a spare is available replace the port.

If the level of the signal received by OLT is nominal, after cleaning the terminals, connect the OTDR towards the ONT (after detachment of the user equipment) in order to locate any stresses on the user connection and/or degradation of the terminations.

Test Equipment for the Optical Communications Industry

MT9090 Network Master

With its four independent modules the MT9090 finally addresses the need of providing all the features and performance required for installation and maintenance of FTTx access networks. The very compact battery-powered Network Master is a comprehensive solution for OTDR, 10 Mb/100 Mb & Gigabit Ethernet, Drop Cable Fault Locator and Optical Channel Analyzer.

Modules Available include:

- MU909011A Drop Cable Fault Locator
- MU909014x/15x µOTDR Module
- MU909020A Optical Channel Analyzer
- MU909060A Gigabit Ethernet Module

Base Model	Wavelength (nm)[1]	Dynamic Range (dB)	Supported feature				
			APC[2]	OPM	PON-PM	LS	VLD
MU909014C	Triple wavelength 1310/1550, filtered 1625 or 1650	32.5/31/32.5	●	●			
MU909014C6			●	●	●	●	
MU909015C		38/37/35	●	●			
MU909015C6			●	●	●	●	
MU909015C-059	Triple wavelength 1310/1490/1550	36/35/35	●	●			
MU909015C6-059			●	●	●	●	
MU909014B	Dual wavelength 1310/1550	32.5/31	●	●			
MU909014B1			●	●			●
MU909015B		37/36	●	●			
MU9090 15B1			●				●
MU909014A1	Single wavelength filtered 1625, or 1650	32.5	●	●			●
MU909014A6			●	●	●	●	

1 - Wavelengh should be specified at option, deatiled models are described in MT9090 brochure.

2 - All models are supported APC, detailed models are described in MT9090 brochure.

MT9090A/MU909014/15 Network Master µOTDR

- High-end OTDR performance in a pocket-size package with unique battery operation
- Full AUTO mode simplifies operation, no OTDR knowledge needed
- Complete PON testing through splitters up to 1 × 64
- Built-in PON Power Meter, Loss Test Set and Light Source
- Verify connector quality (Pass/Fail) with Video Inspection Probe

The new MU909014x/15x µOTDR Module series for the MT9090A Network Master platform provides all of the features and performance required for installation and maintenance of optical fibers in a compact, modular test set. The MT9090A represents an unmatched level of value and ease of use, while not compromising performance. Data sampling of five centimeters, dead zones of less than one meter and dynamic range up to 38 dB ensure accurate and complete fiber evaluation of any network type – premise to access, metro to core…including PON-based FTTx networks featuring up to a 1 × 64 split.

MT9083A2/B2/C2 ACCESS Master™ OTDR

- Test ultra-long fibers spans (>200 km)
- Rapid testing of PON based networks up to 128 splits
- Up to 150,000 data points for superior fiber detail
- Battery operation time up to 12 hours
- SCPI remote command support
- Fiber visualizer application apply easy graphical summary & PDF reporting
- Verify connector quality (Pass/Fail) with Video Inspection Probe

The MT9083C2 test sets are designed to make your measurement experience simple and error-free with true one-button fault location, pass/fail classification, automated file saving and naming and also a macrobend detection feature for identifying installation issues. They feature multiple wavelengths and options to satisfy any network testing requirement: access or metro, FTTx or LAN...all without straining your budget. For customers installing and maintaining metro area or core networks, the ACCESS Master offers an automated fiber construction application and multiple wavelengths.

Model	Wavelength (nm)	Dynamic Range (dB)	Options
MT9083A2-073	1310/1550	39/37.5	Protector kit - display cover & bumpers (-010)39/37.5
MT9083B2-053	1310/1550	42/41	Visible laser diode (-002)
MT9083C2-053	1310/1550	46/46	Optical power meter - CATV, Single mode, +23 to -50 dBm (-004)
MT9083A2-057	1310/1550/1625	37/35.5/32.5	Optical power meter - Single mode/multimode +6 to -67 dBm (-007)
MT9083B2-057	1310/1550/1625	40/39/38	Optical power meter - High power, Single mode, +30 to -43 dBm (-005)
MT9083C2-057	1310/1550/1625	46/46/44	
MT9083A2-055	1310/1550, filtered 1650	38.5/37/34.5	LC connector (-033)
MT9083B2-055	1310/1550, filtered 1650	42/41/35	FC connector (-037)
MT9083A2-063	1310/1550 SM	39/37.5	ST connector (-038)
MT9083B2-063	850/1300 MM	29/28	SC connector (-040)
MT9083B2-056	1310/1490/1550	42/41/41	FC/APC connector (-025)
MT9083B2-058	1310/1490/1550/1625	42/41/41/40	SC/APC connector (-026)

USB 200/400X Video Inspection Kit OPTION-545VIP

- Interchangeable adapters for all popular connector styles including angled polish
- Compact, one cable design with standard USB interface
- Ability to view back panel fiber connectors through the bulkhead without removing them
- "Pass" or "Fail" evaluation of connectors based on pre-determined criteria (CMA4500/5000/a and PC only)
- Compatible with most Anritsu field test sets and Windows based Laptop PCs

The Video Inspection Probe (VIP) application for Anritsu field testing platforms gives operators a safe, easy way to analyze and document connector conditions. With today's high data rates, high definition services, connector quality and inspection has never been so important. Research reveals that up to 75% of all optical network failures are attributed to poor connector quality - reduce your installation time and ensure your network is reaching its full potential.

Connector images are captured digitally and displayed on the test set screen. The images can then be viewed or saved as a variety of common graphics files for later review or documentation of connector quality. Various adapters are available to allow direct viewing of patch cord end faces, as well as, for viewing of end faces already installed in patch panels. Furthermore, since there is no path to the human eye the VIP application eliminates the possibility of injury as with traditional connector microscopes.

Conclusions

- If there is non-active spare capacity, the priority will be to activate the reserve fibre in the shortest time possible and any locating of the fault can be conducted afterwards with a common OTDR at any λ;
- With a double splitter level and high splitting ratios, the measurement by the OLT is significant only for the part of the network upstream of the primary splitter. In fact downstream of the primary splitter it is possible to identify the reflections that can be attributed to the various elements under examination, that can be identified based on the measured progression compared to the point of insertion of the signal.
- Clearly it is difficult to identify the reflections of the various branches of the secondary splitter, which can be confused with the reflections of the branches of the primary splitter;
- The situation is much more complex if all the branches of the primary splitter are connected to secondary splitters in that the backscattering trace does not just show the spatial contributions of the splitter but also those of all the output branches from the latter.
- The terminations of an angular type (APC) have a better RL value, give rise to more regular Backscattering diagrams and, for equal pulse width, to narrower reflections that are unsaturated and with greater resolution power than the non-angular terminations (PC). Therefore it is good practice to terminate the output branches from the splitters on APC type connectors.
- The presence of the Bragg filters (FBG) is a cause of saturation of the backscattering trace and the use of these filters does not give any advantage, so it is not recommended to use them on the network, except in cases of clear need (automatic fibre optics monitoring systems).

Nicola Ferrari Profile

Nicola Ferrari has been with Telecom Italia for about 36 years and was employed initially on operation, maintenance and testing in the "Special cables" department.

He has been co-writer of the following decree theses at the faculty of Electronic Engineering of L'Aquila:

- *Specialist degree "Polarisation mode dispersion: theoretical models and measurement methods", L'Aquila, 2002.*
- *Specialist degree "Backscattering measurements on PON networks: implementation of an automatic system for the analysis and monitoring of the fibres", L'Aquila, 2008.*
- *Specialist decree "Optimisation of a system of automatic monitoring of PON networks", L'Aquila, 2009.*

He has been the author of numerous press articles on the subject and publications including the text "Fibre optics in telecommunications" and "Echo-sounding applied to cable telecommunications".

Specifications are subject to change without notice.

- **United States**

Anritsu Company
1155 East Collins Blvd., Suite 100, Richardson,
TX 75081, U.S.A.
Toll Free: 1-800-267-4878
Phone: +1-972-644-1777
Fax: +1-972-671-1877

- **Canada**

Anritsu Electronics Ltd.
700 Silver Seven Road, Suite 120, Kanata,
Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

- **Brazil**

Anritsu Eletrônica Ltda.
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - São Paulo - SP - Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

- **Mexico**

Anritsu Company, S.A. de C.V.
Av. Ejército Nacional No. 579 Piso 9, Col. Granada
11520 México, D.F., México
Phone: +52-55-1101-2370
Fax: +52-55-5254-3147

- **United Kingdom**

Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire, LU1 3LU, U.K.
Phone: +44-1582-433200
Fax: +44-1582-731303

- **France**

Anritsu S.A.
12 avenue du Québec, Bâtiment Iris 1- Silic 612,
91140 VILLEBON SUR YVETTE, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

- **Germany**

Anritsu GmbH
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

- **Italy**

Anritsu S.r.l.
Via Elio Vittorini 129, 00144 Roma, Italy
Phone: +39-6-509-9711
Fax: +39-6-502-2425

- **Sweden**

Anritsu AB
Kistagången 20B, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00
Fax: +46-8-534-707-30

- **Finland**

Anritsu AB
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

- **Denmark**

Anritsu A/S (Service Assurance)
Anritsu AB (Test & Measurement)
Kay Fiskers Plads 9, 2300 Copenhagen S, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

- **Russia**

Anritsu EMEA Ltd.
Representation Office in Russia
Tverskaya str. 16/2, bld. 1, 7th floor.
Russia, 125009, Moscow
Phone: +7-495-363-1694
Fax: +7-495-935-8962

- **United Arab Emirates**

Anritsu EMEA Ltd.
Dubai Liaison Office
P O Box 500413 - Dubai Internet City
Al Thuraya Building, Tower 1, Suit 701, 7th Floor
Dubai, United Arab Emirates
Phone: +971-4-3670352
Fax: +971-4-3688460

- **India**

Anritsu India Private Limited
2nd & 3rd Floor, #837/1, Binnamangla 1st Stage,
Indiranagar, 100ft Road, Bangalore - 560038, India
Phone: +91-80-4058-1300
Fax: +91-80-4058-1301

- **Singapore**

Anritsu Pte. Ltd.
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

- **P.R. China (Shanghai)**

Anritsu (China) Co., Ltd.
Room 2701-2705, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

- **P.R. China (Hong Kong)**

Anritsu Company Ltd.
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P.R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

- **Japan**

Anritsu Corporation
8-5, Tamura-cho, Atsugi-shi, Kanagawa, 243-0016 Japan
Phone: +81-46-296-1221
Fax: +81-46-296-1238

- **Korea**

Anritsu Corporation, Ltd.
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 463-400 Korea,
Phone: +82-31-696-7750
Fax: +82-31-696-7751

- **Australia**

Anritsu Pty. Ltd.
Unit 21/270 Ferntree Gully Road, Notting Hill,
Victoria 3168, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

- **Taiwan**

Anritsu Company Inc.
7F, No. 316, Sec. 1, NeiHu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817

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Please Contact:

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