Optical Networks FTTx and Reduced Attenuation Balance with Passive Optical Splitter

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***Abstract*—- Article is focused on hybrid access networks FTTx (Fiber to the x) and use of a passive optical splitter in passive optical networks (PON). It analyses the properties of optical splitters Planar Lightwave Circuit (PLC) and Fused Bionic Taper (FBT) presents formulas for splitter attenuation computing. Experimental passive optical network of TUKE, (Technical University of Košice) with 1:8 PLC passive optical splitter have been evaluated by OTDR (Optical Time Domain Reflectometer) measurements. The measured results have been compared with calculated data based on the theoretical evaluation of the experimental network.**

Keywords*— *FTTx, PLC splitter, FBT splitter, experimental measurements OTDR

I. Introduction

FTTx is a family of network solutions, which are typical representatives of hybrid access networks. The term FTTx (Fiber to the x) indicates the replacement of the original metallic part of network with the optical fiber, where the x can be the most often one of these options:

- **H** - Home (user, home),
- **O** - Office (corporate and office premises),
- **P** - Premises (premises permitting summary of **H** and **O**),
- **B** - Building (building),
- **C** - Curb (settlement),
- **N** - Node (general termination, node),
- **Ex-** Exchange (control panel).

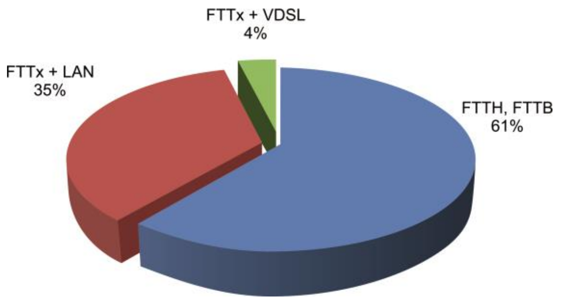

Fig. 1. Global representation of individual variants FTTx [2].

In Fig. 1 is shown a graph representing the individual variants FTTx. The FTTx + LAN variant is the most common combination of the optical connection FTTC with local data networks based on metallic Ethernet. This combination is particularly widespread in East Asia, not like FTTH or FTTB. The FTTx + VDSL presents a combination of optical connection FTTN often used in United States [1, 2].

In Fig. 2 are shown most common variants of FTTx connections. Generally, the connections can be divided into purely optical (FTTH and FTTO), hybrid optical-metallic (FTTB, FTTC and FTTN) and optical-radio. The main task of FTTx is to ensure sufficient transmission rate for the end points of the network. It allows the access to multimedia services and realize the high-speed data transfers using only one shared optical fiber.

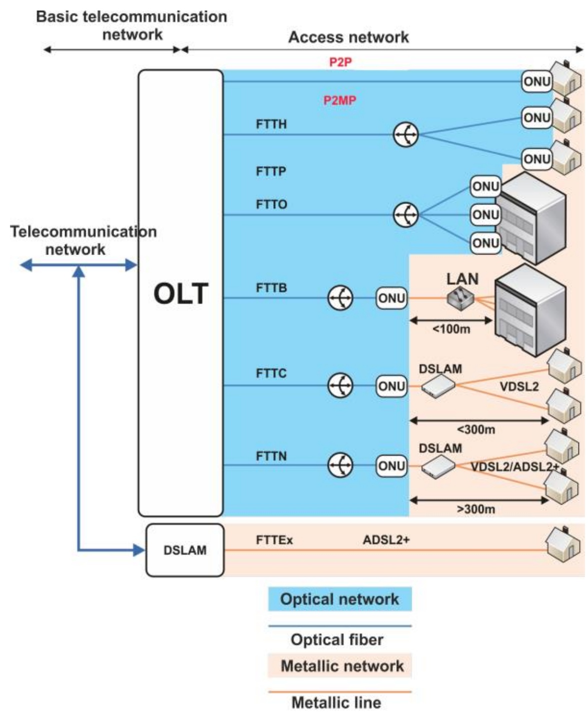

Fig. 2. Scheme of the architectures FTTx [4].

II. SPLITTER

The fiber splitter is a passive network element specifically designed for PON networks. In FTTH systems, which are operated in PON networks, are generally a two-way passive elements that have one input port and several output ports (2-128) [9,14]. The function of the splitter is to split the optical signal from input to several outputs and in the reverse direction to merge it. The splitter can be designed for a specific wavelength, or works with all wavelengths commonly used in optical transmission. Splitter is the largest insertion loss across the optical path. It is necessary to take into account the allowed optical signal attenuation due to a path attenuation, which is considered for EPON about 25 dB [3].

The exclusive advantage of splitters is that merging and splitting of optical signals happens passively, thus eliminates the need for the implementation supply network and overall equipment reliability is very high. According to the production technology, splitters can be divided into Fused Bionic Taper (FBT) or Planar Lightwave Circuit (PLC) [6].

A. Fused Bionic Taper (FBT)

FBT splitters are made by connecting the optical fibers at high temperature and pressure, when the fiber coats are melted and connected fibers cores get close to each other. This technology makes fiber bundles 2 to 4, which are cascaded for achieving more output ports. The technology is used primarily for smaller number of output ports [3,4].

Fig. 3 shows a splitter FBT where x is the connection for determining the degree of flattening and z are common parts.

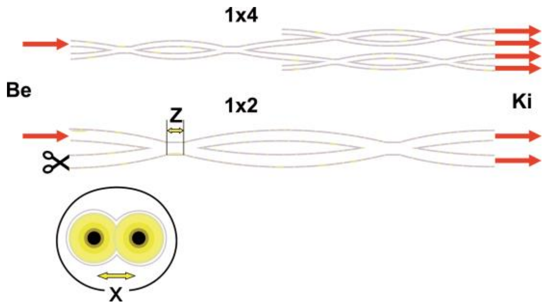

Fig. 3. Principle of FBT technology splitter.

B. Planar Lightwave Circuit (PLC)

PLC splitters are produced by planar technology. The desired structure is formed by technological process on a silicon substrate [8,14]. The splitter with up to 128 output ports can be produced by this technology. It is used mainly for splitters with a higher number of output ports [3].

Fig. 4 shows the principle of a splitter manufactured by PLC technology.

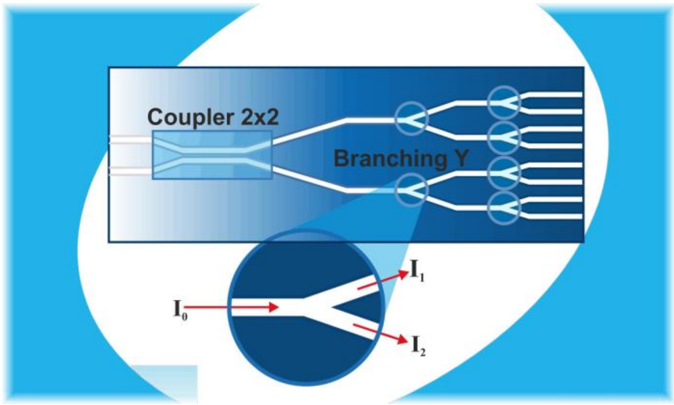

Fig. 4. Principle of splitter manufactured by PLC technology.

For splitters can be defined these basic parameters [4,8,11]:

- **Branching ratio**. It is a mathematical expression of the splitter outputs N, which is usually given as a ratio 1: N. Typical passive optical splitters achieve a splitting ratio of 1:2, 1:4, 1:8, 1:16, 1:32, 1:64 or 1:128.
- **The splitting ratio.** It expresses the rate at which the power of optical signals at the outputs of the splitter is to each other. We distinguish symmetric splitters, which outputs in terms of separation performance are identical and asymmetric, having various optical performances on its outputs.
- **Insertion loss.** Splitter attenuation depends on the number of outputs and each output channel attenuation depends on whether the splitter is symmetrical or asymmetrical [12].

In TABLE I. are shown the splitter attenuations, which value depends on the number of splitter output ports.

TABLE I. TYPICAL PARAMETERS OF PLC SPLITTERS

Branching ratio	1:2	1:3	1:4	1:8	1:16	1:32	1:64	1:128
The split ratio	symmetric							
Maximum insertion loss [dB]	3.9	6.2	7.4	10.8	14.1	17.3	21	25.3
Typical insertion loss [dB]	3.5	5.8	6.9	9.8	13.5	16.5	20	23.5
Maximum uniformity [dB]	0.5	0.6	0.6	1.0	1.3	1.6	2	2.8
Polarization loss [dB]	≤0.15						≤0.2	
Directivity [dB]	≥55							
Reflection attenuation [dB]	≥55							
Guaranteed range of wavelengths [nm]	1260-1650							
Guaranteed operating temperature range [° C]	-40 to +85							

- **Uniformity of splitter.** This parameter is related to the insertion loss of splitter. It represents a attenuation variation between the individual outputs of the symmetrical splitter, or variations of attenuation produced by splitter from the ideal state of asymmetricity [13]. Impact of manufacturing uncertainties creates minor deviations from the ideal attenuation of the proposal and the final real splitter. These variations represent an additional insertion loss, with which it is necessary to calculate the ODN design [6]. Today, manufacturers often indicate an average or maximum uniformity; thereby guarantee that purchased splitter does not exceed this value.

Connecting splitters to the optical infrastructure ODN can be realized by connectors, welds or joints. It is often placed along with cartridges with stored reserves of optical fiber cables and pigtails in stands of optical distributors in van with standardized height in multiples U (Rack Unit = 45 mm) [11].

C. Calculation of splitter attenuation

A_D attenuation separation depends on the splitter ratio 1: N. Its calculation is based on the following situation for basic Y-segment (splitter) shown in Fig. 5.

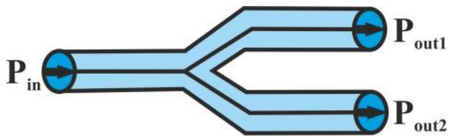

Fig. 5. Derivation of splitter attenuation.

For this Y-segment relationship can be defined [7]:

$$A_{D1} = 10\log\left(\frac{P_{in}}{P_{out1}}\right)[\text{dB;W,W}] \quad (1)$$

$$A_{D2} = 10\log\left(\frac{P_{in}}{P_{out2}}\right)[\text{dB;W,W}] \quad (2)$$

At the same time with the ideal Y-segment, the sum of the output optical power is equal to the input power.

$$P_{in} = P_{out1} + P_{out2}[\text{W;W, W}] \quad (3)$$

1) Calculation of symmetric splitter attenuation

In the case of the symmetrical splitter is optical power on all outputs same and can be generally written as [13]:

$$P_{out1} = P_{out2} = P_{out3} .. = P_{outN} \ [\text{W;W;W;W}] \quad (4)$$

For a simple Y-segment with a ratio 1:2 is (Fig. 5) [8]:

$$P_{out1} = P_{out2} = \frac{Pin}{2}[\text{W;W;W}] \quad (5)$$

Substituting (5) into (1) and (2):

$$A_{D1} = A_{D2} = 10\log\left(\frac{P_{in}}{0{,}5*P_{in}}\right) = 10\log(2) = 3.01\text{dB} \quad (6)$$

Similarly, the attenuation of the symmetrical splitter with a ratio 1:4 can be determined (Fig. 6):

$$P_{out1} = P_{out2} = P_{out3} = P_{out4} = \frac{P_{in}}{4}\text{W} \quad (7)$$

Substituting into (1) and (2):

$$A_D = 10\log\left(\frac{P_{in}}{0.25\times P_{in}}\right) = 10\log(4) = 6.02\text{dB} \quad (8)$$

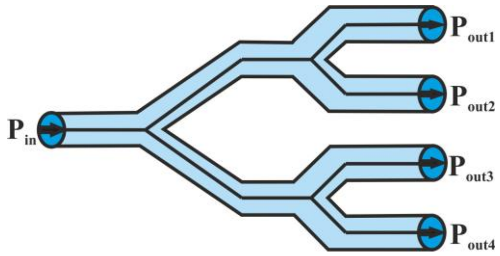

Fig. 6. 1:4 splitter attenuation.

For symmetrical splitters are two basic rules that can be derived:

- Attenuation dividing AD is the same for all branches, and generally it can be expressed as:

$$P_{out1} = P_{out2} = P_{out3} \dots = P_{outN} = \frac{P_{in}}{N}\text{W} \quad (9)$$

$$A_{D1} = A_{D2} = A_{D3} \dots . = A_{DN} = A_D \quad (10)$$

$$A_D = 10\log\left(\frac{P_{in}}{\frac{1}{N}*P_{in}}\right) = 10\log(N)\ \text{dB} \quad (11)$$

where N is with a splitter ratio 1: N.

- Doubling the number of the symmetrical splitter outputs represents increasing attenuation division of 3 dB. It is expressed:

$$A_D = 10\log(N) = 10\log_2(N) \times \log(2) =$$
$$n \times 10\log(2) = n \times 3.01\ [\text{dB}] \quad (12)$$

2) The calculation of asymmetric splitter attenuation

The asymmetric splitter generally achieves varying power distribution on its outputs. This is expressed through:

$$P_{out1} \neq P_{out2} \neq P_{ot3} \dots \neq P_{outN} \quad (13)$$

The total input power is divided in a partial relation between the individual inputs, and in practice is often used expression in percentage e.g. : 2% -98%, 5% -95%, 10% -90%, 20% -80%, 40% -60%.

Therefore the fundamental condition is (3) and has a sum of 100%, the following applies:

$$100 \times P_{in} = D_1 \times P_{out1} + D_2 \times P_{out2} + \dots D_N \times P_{outN}\ [\%,\text{W}] \quad (14)$$

$$100 = D_1 + D2 + \dots D_N\ [\%] \quad (15)$$

While D_1 is the splitting ratio for the first branch and D2 for the second branch of splitter etc., the attenuation division for the asymmetrical splitter k-branch can be expressed as:

$$A_{Dk} = 10\log\left(\frac{P_{in}}{\frac{D_k}{100}\times P_{in}}\right) = 10\log\left(\frac{100}{D_k}\right)\text{dB} \quad (16)$$

$$A_{Dk} = 10\log(100) - 10\log(D_k) = 20 - 10\log(D_k)\text{dB} \quad (17)$$

While D_k is the attenuation ratio for the splitter k-branch.

III. OTDR Splitter Measurements

Optical network was measured by OTDR (Optical Time Domain Reflectometer) [16]. Fig. 7 shows the variances that can be detected using OTDR.

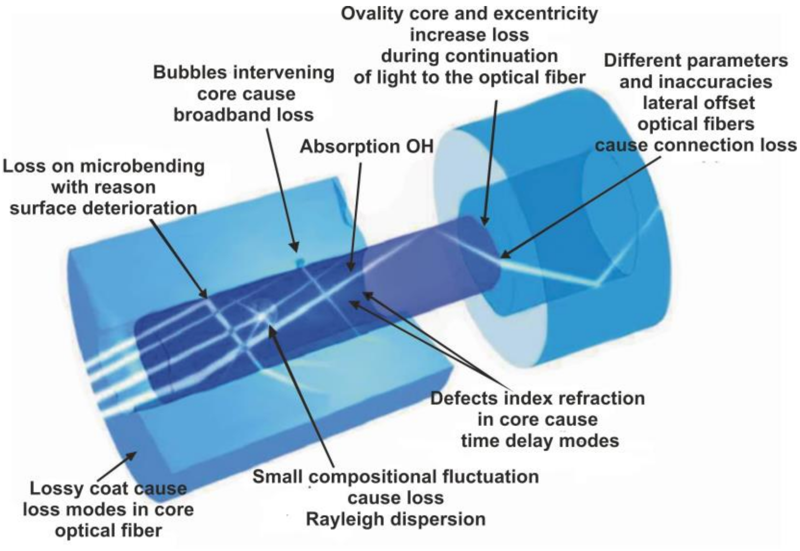

Fig. 7. Some variances which can be detected using OTDR.

To check the splitter attenuation, the passive optical network PON has been set, and includes PLC splitter splitting the optical power 1: 8 in Fig. 8. For the measurement was used an optic cable with a length of 721 meters. Type of optical cable is SAMSUNG 12FO SM.B. The optical fiber cable 12 with SM fiber type ITU-T G.652.B. It is used for external wiring, the construction of telecommunication lines, or installation of LAN. For the optical fiber cable termination, we used an optical distributor type WMDB.

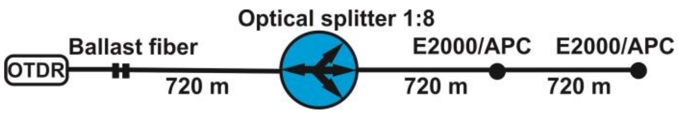

Fig. 8. Test connection for OTDR measuring.

For measuring was used the meter OTDR FTB-200, ideal for measuring the insertion loss, connector attenuation, reflection attenuation and couplings route length attenuation [16]. It was designed for super technological areas and problem solutions analysis for FTTx network [5]. These parameters have been chosen for the measurement, the resulting curve is in Fig. 9, and the values are in TABLE II.:

- Wavelength 1310 nm and 1550 nm,
- Measuring pulse width 100 ns,
- Set length of the route 2500 m,
- Averaging measurement time 30 s.

WMDB distributor, in which the connectors E2000 / APC, SC / PC and FC / PC are placed by their respective adapters, 40 mm, welds protection and PLC splitter 1:8 is shown in Fig. 10.

Optical fibers G.652.B have a specific attenuation at a wavelength of 1310 nm 0.4 dB and 0.35 dB at 1550 nm [10]. For the calculation of reduced balance these components are entered [4, 15]:

- Splitter 1:8 - maximum insertion loss 10.8 dB,
- Connectors- insertion loss 0.3 dB, 3 pcs, 0.9 dB,
- Optical welds – 0.05 dB, 8 pcs, 0.4 dB,
- Specific attenuation – 0.4 dB / km – 2.5 km, 1 dB.

The sum of the individual attenuations equals 13.1 dB.

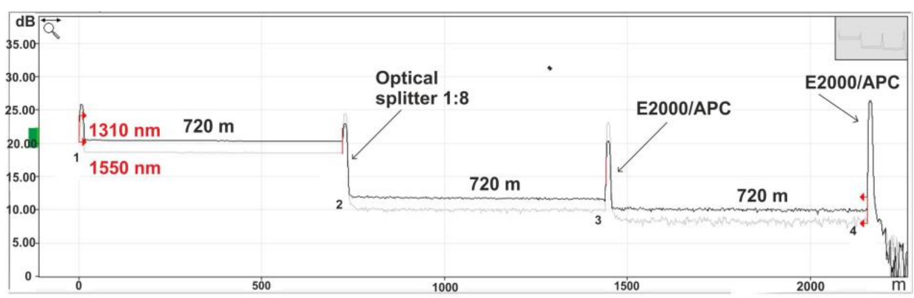

Fig. 9. Reflectometer OTDR measurement result.

TABLE II. OTDR MEASURED VALUES

No	Loc. (km)	Event Type	Loss (dB)	Refl. (dB)	Att. (dB/km)	Cumul. (dB)
1310 nm						
1	0.0000	Launch Level	---	-49.0		0.000
		Fiber Section (0.7215 km)	0.240		0.332	0.240
2	0.7215	Reflective Fault	8.350	-55.3		8.590
		Fiber Section (0.7193 km)	0.317		0.441	8.907
3	1.4408	Reflective Fault	1.426	-42.0		10.333
		Fiber Section (0.7159 km)	0.279		0.389	10.612
4	2.1567	Reflective Fault	---	-26.5		10.612
1550 nm						
1	0.0000	Launch Level	---	-53.5		0.000
		Fiber Section (0.7211 km)	0.127		0.176	0.127
2	0.7211	Reflective Fault	8.452	-50.2		8.580
		Fiber Section (0.7194 km)	0.188		0.262	8.768
3	1.4405	Reflective Fault	1.483	-35.5		10.251
		Fiber Section (0.7161 km)	0.271		0.378	10.522
4	2.1566	Reflective Fault	---	-25.8		10.522

Fig. 10. Experimental FTTH network terminal at Technical University of Košice.

IV. CONCLUSIONS

This article contains the information about networking solutions, where the optical fiber is fed directly to the actual user (FTTH) or is located 300 m between the optical fiber termination point and individual end-users (FTTN). The PLC splitter has been described and used exclusively in the PON networks. During the implementing, the experimental measurements have proved that the wavelength attenuation of 1310 nm is 10.612 dB, while with the 1550 nm was measured 10.522 dB. The optical fiber length was 2156 meters. The maximum attenuation of 13.1 dB was measured in the optical network.. The difference between maximum attenuation and measured value was 2.5 dB, which is smaller than expected.

ACKNOWLEDGMENT

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REFERENCES

[1] P. Lafata, P. Vodrážka, "ROZVOJ PŘÍPOJEK FTTX " , 31.03.2010 , Department of Telecommunication Engineering, FEE, CTU in Praque, 2010 ,volume 23, number 2, elektrorevue ISSN1213-1539. Available on the internet: http://elektrorevue.cz/cz/clanky/komunikacni-technologie/0/rozvoj-pripojek-fttx/

[2] IDATE Consulting & Research: "World FTTx Markets" , FTTx Market Report. IDATE, 2009, [cit.17.09.2014]. Available on the internet: http://www.telecomasia.net/pdf/ZTE/ZTE_093009.pdf.

[3] M. Filka, "Optoelektronika pro telekomunikace a informatika" , Brno, 2009,1st edition, ISBN 978-80-86785-14-1, 369 pp.

[4] P. Lafata, J. Vodrážka, " Optické Přistupové sítě a přípojky FTTx" , CTU in Praque – publishing CVUT, Praque 2014, ISBN 978-80-01-05463-5, 294 pp.

[5] EXFO| "Telecom Test and Service Assurance", Canada 10/09, User Guide.

[6] S. Varghese, "Fabrication and Characterization of All-Fiber Components for Optical Access Networks", International School of Photonics Cochin University of Science and Technology, Cochin, 682 022, Kerala, India, December, 2008, [cit.29.09.2014]. Available on the internet: http://dyuthi.cusat.ac.in/xmlui/bitstream/handle/purl/1917/Dyuthi-T0408.pdf?sequence=18.

[7] P. Lafata, "Optimization of asymmetric passive optical splitters", Applied Electronics (AE), International Conference 2012 , IEEE Conference Publictions, [cit.5.10.2014]. Available on the internet: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6328850.

[8] G. Keiser, "FTTx Concepts and Applications", Wiley Series in Telecommunications and Signal Processing, 2006, ISBN: 978-0-471-70420-1, 285 pp.

[9] P. E. Green, "Fiber to the Home", The New Empowerment, Wiley Survival Guides in Engineering and Science, 2006, ISBN-13: 978-0471742470 John Wiley & Sons, Inc. Hoboken New Jersey, 139 pp.

[10] E. Radius, "Fiber to the home technology", OS3 Fiber Day, May 22, 2013, The Netherlands, [cit.29.09.2014]. Available on the internet: https://www.os3.nl/_media/2012-2013/courses/an/sne_lecture_2013_erikradius.pdf.

[11] LEONI | " Fiber Optics", 452 pp. [cit.2.10.2014]. Available on the internet:http://www.leoni-fiber-optics.com/uploads/tx_downloadleoni/en_fiber_optics2_02.pdf.

[12] A. Girard," Fttx PON", Technology and testing. Quebec city: EXFO Electro-Optical Engineering Inc.,2005. ISBN 1-55342-006-3, 190 pp.

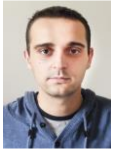
[13] S. Grady ,“ The Book on FTTX (From Design to Deployment: A Pratical Guide to FTTX Infrastructure)“, Publication of ADC Telecommunications, Inc., 2005, 161 pp.

[14] A. M. J. Koonen, “Fiber to the home/fiber to the premises: what, where, and when?, ,” Proceedings of the IEEE, Vol. 94, No. 5, pp. 911-934, May 2006. [cit.28.10.2014]. Available on the internet: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1634534.

[15] ITU-T.G.652 – “Characteristics of a single-mode optical fibre and cable”, [online],[cit. 01.11.2014]. ITU-T, November 2009. Available on the internet: http://www.itu.int/rec/T-REC-G.652-200911-I

[16] Mai, T.V.; Molnar, J.A.; Tran, L.H., "Fiber optic test equipment - evaluation of OTDR dead zones and ORLM return loss," AUTOTESTCON 2004. Proceedings , vol., no., pp.94-98, 20-23 Sept. 2004. [cit.05.11.2014]. Available on the internet: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1436782&isnumber=30947.

BIOGRAPHIES



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