PRECISE METHOD OF BALANCING PASSIVE OPTICAL NETWORKS WITH IRREGULAR SPLITTER WITH TWO OR MORE OUTPUTS

Oleksiy Nedashkivskiy, Anatoly Semenko, prof.
State University of Telecommunications, Kyiv, Ukraine

1. INTRODUCTION

Recent advances in fiber optic technology, in particular in the field of passive optical networks (PON - Passive Optical Network), open opportunities to cover broadband Internet services and other telecommunications services. Today, there are several generations of PON [1, 2, 3, 4] speeds up to 10 Gbit/s per PON-tree. Many articles and materials devoted to problems of implementation of such networks [5, 6, 7, 8, 9, 10, 11]. Thus, the problem of balancing the branches of PON-tree, more or less accurately solved only splitters type 1: 2 (one input - two outputs), which built the corresponding two-dimensional table [7, 8, 9], and the solution to the problem boils down to a simple search from a list of possible values. These tables for splitters with three or more outputs do not build because following table for splitter with three outputs are three-dimensional! For four outputs splitters they are four- dimensional tables, etc. As a result, designed and calculated PON often negates the potential for passive optical networks because network topology approach the "star" instead of "tree" or "bus". In this no economy of fibers, increased requirements for automatic gain control, reduced maximum range of PON-tree that together leads to reduction of technical and economic efficiency of PON.

So the search for analytical solutions to the problem of balancing passive optical network is scientific problem. But advances in the manufacture of passive optical splitters, couplers that can make increments dividing the input power at 1% make finding solution relevant and timely.

2. BALANCING PON BRANCHES BY 1:2 SPLITTERS

Consider the model of optical splitter 1:2 with a scheme of connection of two remote users with relevant optical network terminals (ONT - Optical Network Terminal): ONT1 and ONT2 (Figure 1).

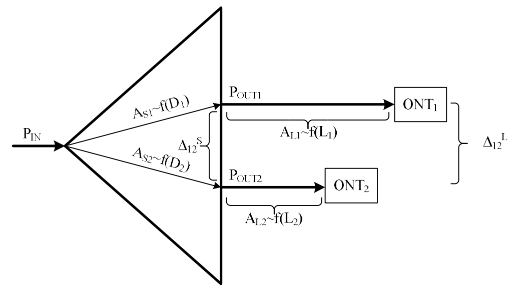

Figure 1. Model of optical splitter 1:2.

In general, subscribers are in different places, that is, the length of individual optical fibers, the number and characteristics of connectors and welding points are different. This leads to losses A_{Li}~$f(L_i)$, that are made by individual optical paths in areas from splitter to the ONT are not equal. So there is a difference ONT of optical power levels of signals in ONT inputs:

$$\Delta_{12}{}^{L} = A_{L1} - A_{L2} \tag{1}$$

where: A_{L1}, A_{L2} - individual total loss of the optical path for ONT_1 and ONT_2, respectively;

$\Delta_{12}{}^{L}$ - the difference between power levels of optical signals between ONT_1 and ONT_2.

For maximum efficiency (range, reliability, stability, error rate) of PON networks it is need to provide the same power level at the inputs of all ONT's, and this can be done with unequal distribution of power between the splitter outputs.

The scheme (Figure 1) shows that the losses of optical splitter depends on the rate of capacity, which is displayed in the corresponding output, while the outputs of the splitter can be such a difference of insertion loss $\Delta_{12}{}^{S}$ that will offset the inequality of power levels of optical signals $\Delta_{12}{}^{L}$, taken with a minus sign:

$$\Delta_{12}{}^{S} = A_{S1} - A_{S2} =$$

$$= -\Delta_{12}{}^{L} = -(A_{L1} - A_{L2}) = A_{L2} - A_{L1} \tag{2}$$

where: A_{S1}, A_{S2} - optical splitters loss towards outputs OUT_1 and OUT_2;

$\Delta_{12}{}^{S}$ - difference of insertion loss between ONT_1 and ONT_2 due to the irregular distribution of input power PIN.

It is known [9] that the losses being made by optical couplers of any type may be approximated by:

$$A_{Si} = 10\lg(\frac{100\%}{D_i\%}) +$$

$$+\log(N-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100\%}{D_i\%}) \quad , \tag{3}$$

where: A_{Si} - optical splitters loss towards outputs i;

D_i - percentage of power transmitted from the splitter input in the direction of the output i;

N - number of splitter output.

Then, with (1), (2), (3) and the fact that the sum of all D_i is 100%:

$$\sum_{i=1}^{N} D_i \ , \tag{4}$$

we can write the following system of equations:

$$\begin{cases} \Delta_{12}{}^{S} = A_{L2} - A_{L1} \\ D_1 + D_2 = 100 \\ A_{S1} = 10\lg(\frac{100}{D_1}) + \log(2-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_1}) \\ A_{S2} = 10\lg(\frac{100}{D_2}) + \log(2-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_2}) \end{cases} \tag{5}$$

Substituting the third and fourth equation of (5) in the first, which takes the form:

$$\Delta_{12}{}^{S} = 11.5\lg(\tfrac{D_1}{D_2}) \ . \tag{6}$$

From the second equation of (5) terms D_1 and substitute it in (6), we obtain:

$$\Delta_{12}{}^{S} = 11.5\lg(\tfrac{100-D_2}{D_2}) \ . \tag{7}$$

Result of (7) will be:

$$D_2 = \frac{100}{1+10^{\frac{\Delta_{12}{}^{S}}{11.5}}} \tag{8}$$

Finally for D_1 and D_2:

$$\begin{cases} D_1 = \dfrac{100}{1+10^{\frac{-\Delta_{12}{}^{S}}{11.5}}} \\ D_2 = \dfrac{100}{1+10^{\frac{\Delta_{12}{}^{S}}{11.5}}} \end{cases} . \tag{9}$$

Analyzing the expression (9) it is possible to simplify it form. Thus, if the exponent $-\Delta_{12}{}^{S}$ substitute by $\Delta_{21}{}^{S}$, where the difference is taken in the opposite direction and one's in the denominator of the first and second equation of (9) replace by the relevant expressions $10^{\frac{\Delta_{11}{}^{S}}{11.5}}$ and $10^{\frac{\Delta_{22}{}^{S}}{11.5}}$ we get:

$$\begin{cases} D_1 = \dfrac{100}{10^{\frac{\Delta_{11}{}^{S}}{11.5}} + 10^{\frac{\Delta_{21}{}^{S}}{11.5}}} \\ D_2 = \dfrac{100}{10^{\frac{\Delta_{22}{}^{S}}{11.5}} 1 + 10^{\frac{\Delta_{12}{}^{S}}{11.5}}} \end{cases} . \tag{10)}$$

Next, change the order of summation in the second equation of (10):

$$\begin{cases} D_1 = \dfrac{100}{10^{\frac{\Delta_{11}{}^{S}}{11.5}} + 10^{\frac{\Delta_{21}{}^{S}}{11.5}}} \\ D_2 = \dfrac{100}{10^{\frac{\Delta_{12}{}^{S}}{11.5}} + 10^{\frac{\Delta_{22}{}^{S}}{11.5}}} \end{cases} . \tag{11}$$

Which shows that the overall solution can finally be written as:

$$\begin{cases} D_i = \dfrac{100}{\sum_{n=1}^{2} 10^{\frac{\Delta_{ni}{}^{S}}{11.5}}} \\ i = 1 \cdots 2 \end{cases} . \tag{12}$$

3. BALANCING PON BRANCHES BY 1:3 SPLITTERS

Consider the model of optical splitter 1:3 with a scheme of connection of three remote users with relevant ONT_1, ONT_2 and ONT_3.

In general, subscribers are in different places, so on the ONT inputs there is not one, like in splitters 1:2, but three difference power levels of optical signals that can described as:

$$\begin{cases} \Delta_{12}{}^{L} = A_{L1} - A_{L2} \\ \Delta_{23}{}^{L} = A_{L2} - A_{L3} \\ \Delta_{13}{}^{L} = A_{L1} - A_{L3} \end{cases} , \tag{13}$$

where: A_{L1}, A_{L2}, A_{L3} - individual total loss of the optical path for ONT_1, ONT_2 and ONT_3, respectively;

$\Delta_{12}{}^{L}$ - the difference between power levels of optical signals between ONT_1 and ONT_2;

$\Delta_{23}{}^{L}$ - the difference between power levels of optical signals between ONT_2 andONT_3;

$\Delta_{13}{}^{L}$ - the difference between power levels of optical signals between ONT_1 and ONT_3.

The scheme (Figure 2) shows that the losses of optical splitter depends on the rate of capacity, which is displayed in the corresponding output, while the outputs of the splitter can be such a difference of insertion loss $\Delta_{12}{}^{S}$, $\Delta_{23}{}^{S}$, $\Delta_{13}{}^{S}$, that will offset the inequality of power levels of optical signals $\Delta_{12}{}^{L}$, $\Delta_{23}{}^{L}$, $\Delta_{13}{}^{L}$, taken with a minus sign:

$$\begin{cases} \Delta_{12}{}^{S} = A_{S1} - A_{S2} = -\Delta_{12}{}^{L} = -(A_{L1} - A_{L2}) = A_{L2} - A_{L1} \\ \Delta_{23}{}^{S} = A_{S2} - A_{S3} = -\Delta_{23}{}^{L} = -(A_{L2} - A_{L3}) = A_{L3} - A_{L2} \\ \Delta_{13}{}^{S} = A_{S1} - A_{S3} = -\Delta_{13}{}^{L} = -(A_{L1} - A_{L3}) = A_{L3} - A_{L1} \end{cases}. \quad (14)$$

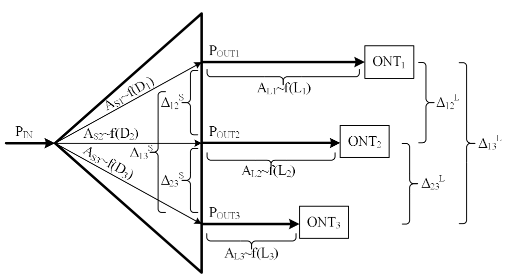

Figure 2. Model of optical splitter 1:3.

where: A_{S1}, A_{S2}, A_{S3} - optical splitters loss towards outputs OUT_1, OUT_2 and OUT_3 respectively;

$\Delta_{12}{}^{S}$ - difference of insertion loss between ONT_1 and ONT_2 due to the irregular distribution of input power PIN;

$\Delta_{23}{}^{S}$ - difference of insertion loss between ONT_2 and ONT_3 due to the irregular distribution of input power PIN;

$\Delta_{13}{}^{S}$ - difference of insertion loss between ONT_1 and ONT_3 due to the irregular distribution of input power PIN.

Then, with (13), (14), (3) and (4) we can write the following system of equations:

$$\begin{cases} \Delta_{12}{}^{S} = A_{L2} - A_{L1} \\ \Delta_{23}{}^{S} = A_{L3} - A_{L2} \\ \Delta_{13}{}^{S} = A_{L3} - A_{L1} \\ D_1 + D_2 + D_3 = 100 \\ A_{S1} = 10\lg(\frac{100}{D_1}) + \log(3-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_1}) \\ A_{S2} = 10\lg(\frac{100}{D_2}) + \log(3-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_2}) \\ A_{S3} = 10\lg(\frac{100}{D_3}) + \log(3-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_3}) \end{cases} \quad (15)$$

Substitute fifth and sixth equation of (15) in the first equation, sixth and seventh in the second and fifth and seventh in the third and after transformations we obtain:

$$\begin{cases} \Delta_{12}{}^{S} = 11.5\lg\frac{D_1}{D_2} \\ \Delta_{23}{}^{S} = 11.5\lg\frac{D_2}{D_3} \\ \Delta_{13}{}^{S} = 11.5\lg\frac{D_1}{D_3} \\ D_1 + D_2 + D_3 = 100 \\ A_{S1} = 10\lg(\frac{100}{D_1}) + \log(3-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_1}) \\ A_{S2} = 10\lg(\frac{100}{D_2}) + \log(3-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_2}) \\ A_{S3} = 10\lg(\frac{100}{D_3}) + \log(3-1)\cdot 0.4 + 0.2 + 1.5\lg(\frac{100}{D_3}) \end{cases} \quad (16)$$

Result of (16) will be:

$$\begin{cases} D_1 = \dfrac{100}{1 + 10^{\frac{-\Delta_{12}{}^{S}}{11.5}} + 10^{\frac{-\Delta_{13}{}^{S}}{11.5}}} \\ D_2 = \dfrac{100}{1 + 10^{\frac{\Delta_{12}{}^{S}}{11.5}} + 10^{\frac{-\Delta_{23}{}^{S}}{11.5}}} \\ D_3 = \dfrac{100}{1 + 10^{\frac{\Delta_{13}{}^{S}}{11.5}} + 10^{\frac{\Delta_{23}{}^{S}}{11.5}}} \end{cases}. \quad (17)$$

Analyzing the expression (17) it is possible to simplify it form. Thus, if the exponent $-\Delta_{12}{}^{S}$, $-\Delta_{13}{}^{S}$, $-\Delta_{23}{}^{S}$ substitute by $\Delta_{21}{}^{S}$, $\Delta_{31}{}^{S}$, $\Delta_{32}{}^{S}$, where the difference is taken in the opposite direction and one’s in the denominator of the first, second and third equation of (9) replace by the relevant expressions $10^{\frac{\Delta_{11}{}^{S}}{11.5}}$, $10^{\frac{\Delta_{22}{}^{S}}{11.5}}$ and $10^{\frac{\Delta_{11}{}^{S}}{11.5}}$ we get:

$$\begin{cases} D_1 = \dfrac{100}{10^{\frac{\Delta_{11}{}^S}{11.5}} + 10^{\frac{\Delta_{21}{}^S}{11.5}} + 10^{\frac{\Delta_{31}{}^S}{11.5}}} \\ D_2 = \dfrac{100}{10^{\frac{\Delta_{22}{}^S}{11.5}} + 10^{\frac{\Delta_{12}{}^S}{11.5}} + 10^{\frac{\Delta_{32}{}^S}{11.5}}} \\ D_3 = \dfrac{100}{10^{\frac{\Delta_{33}{}^S}{11.5}} + 10^{\frac{\Delta_{13}{}^S}{11.5}} + 10^{\frac{\Delta_{23}{}^S}{11.5}}} \end{cases}. \quad (18)$$

Further, changing the order of summation in the second and third equations of system (18), similar to the formula (12), finally we get a compact form of solution for determine the rate of distribution of power between the outputs of splitters 1:3 for precise balancing of PON branches:

$$\begin{cases} D_i = \dfrac{100}{\sum\limits_{n=1}^{3} 10^{\frac{\Delta_{ni}{}^S}{11.5}}} \\ i = 1 \cdots 3 \end{cases}. \quad (19)$$

4. BALANCING EQUATION OF PON BRANCHES BY SPLITTERS OF GENERAL TYPE 1:N

Comparing (12) and (19) shows that they have the same form exactly the number of outputs of optical splitter, that is the type of splitter.

Thus it can be argued that for precise balancing of optical splitters 1:N (Figure 3), where N is a positive integer and is equal to the number of outputs, can be used one compact general formula:

$$\begin{cases} D_i = \dfrac{100}{\sum\limits_{n=1}^{N} 10^{\frac{\Delta_{ni}{}^S}{11.5}}} \\ i = 1 \cdots N \end{cases}. \quad (20)$$

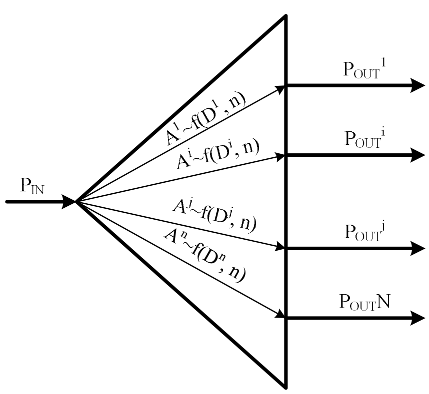

Figure 3. Model of optical splitter 1:N

5. CONCLUSION

1. The mathematical model of PON of complex structure can be used while implementing passive optical access networks and cable TV networks, where the physical processes in the couplers and splitters are very similar.

2. By using precise analytical solution of the problem of balancing make it possible in practice to approach the maximum theoretical advantages inherent in the PON technology.

References

1. ITU-T Rec. G.983.1. Broadband Optical Access Systems based on Passive Optical Networks (PON), 10/1998.

2. ITU-T Rec. G.983.3. A broadband optical access system with increased service capability by wavelength allocation, 03/2001.

3. ITU-T Rec. G.984.3. Gigabit Capable Passive Optical Networks (G-PON): Transmission Convergence Layer Specification, 10/2003.

4. ITU-T Rec. G.987.10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms, 06/2012.

*5. **Sklyarov A.K.** Optical fiber network and communication systems. St. Petersburg., 2010, p. 272.*

*6. **Rusakov E.A.** Designing of access network base on PON technology. Ekaterinburg, 2015, p. 40.*

*7. **Glushchenko D.B., Uryadov V.N.** PON optical budget calculation with uniform splitter. Modern means of communication: materials XV Intern. Scientific-techn. Conf., 28-30 Sept. 2010, Minsk, Republic of Rep. Belarus. - Minsk: VGKS, 2010. – p. 28.*

*8. **Glushchenko D.B., Uryadov V.N.** PON optical budget calculation with ununiform splitters. Modern means of communication: materials XV Intern. Scientific-techn. Conf., 28-30 Sept. 2010, Minsk, Republic of Rep. Belarus. Minsk: VGKS, 2010. p.29.*

*9. **Glushchenko D.B., Uryadov V.N.** Methods for estimating the budget based on the application of technical solutions using a component of passive optical networks. Communications Networks, No. 2 (108), 2011, pp. 43-45.*

*10. **Petrenko I.I., Ubaidullaev R.R.** Passive Optical Networks PON, Part 1. Architecture and Standards. Lightwave russian edition No. 1 2004, pp. 22-28.*

*11. **Ubaidullaev R.R.** Fiber-optic networks. Eco-Trends, Moscow, 2001, p. 267.*

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