A Novel and Economic Way to Fiber-to-the-Home (FTTH)

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***Abstract*—In the last mile of Optical Access Network, high fiber-to-the-home (FTTH) construction cost per subscriber has always been a concern for the Network Operators. In order to cost down the fiber and transceiver deployment, PONs are developed to replace Active P2P Network Access. Also the splitter placement problems are issued that make efforts to reduce fiber and splitters deployment cost. Cost down the Optical Components in PONs is one of the successful elements for building the business of FTTH. For an example, instead of traditional method, a 1x12 splitter module which is cascaded by one piece of 1x2 (67%:33% power ratio, 2.6dB:6.2dB IL) and 10 pieces of 1x2 (50%:50% power ratio, 3.7dB IL) splitters, the IL of module is 2.6+3.7x3=13.7dB; an economical 1x12 splitter module could be cascaded just by one piece of 1x3 (IL: 5.4 dB) and 3 pieces of 1x4 (IL: 7.2dB), the IL of module will be 5.4+7.2=12.6dB, 1.1dB less than the former. In the case of 1x36, an economic one is cascaded by 4 pieces of 1x3 and 9 pieces of 1x4 splitters (IL: 18dB) to replace the traditional one which is cascaded by 35 pieces of 1x2 splitters (IL: 19.9dB). Another case of 2x24, an economic one is cascaded by 1 piece of 2x2, 2 pieces of 1x3 and 6 pieces of 1x4 splitters (IL: 16.3dB) to replace the traditional one which is cascaded by 1 pieces of 2x2 and 22 piece of 1x2 splitters (IL: 17.4dB). In conclusion, bundle with less Insertion Loss, the economical multi-output splitter module can be successfully built up by this novel fiber coupler manufacturing apparatus and method.**

***Index Terms*—FTTH, PON, optical splitter, Insertion loss IL, topology of cascade.**

I. INTRODUCTION

In the last mile of Optical Access Network, high FTTH construction cost per subscriber has always been a concern for the Network Operators. In order to cost down the fiber and transceiver deployment, PONs (Passive Optical Networks) are developed to replace Active P2P (Point to Point) Network Access. Also the splitter placement problems are issued that make efforts to reduce fiber and splitters deployment cost. Cost down the Optical Components in PONs is one of the successful elements for building the business of FTTH.

1x32 and 1x64 PLC (Planar Light-wave-guide Circuit) splitters could be specified for EPON (Ethernet PON) and GPON (Giga-bit PON), nevertheless those are not able to distribute optical power unevenly. Generally, a multi-port output splitter module is built up by cascading a group of 1x2 optical splitters. The more numbers of splitters we need the more Insertion Loss (IL) will take place. It is even harder to build such as 1x12, 2x24 and 1x36 splitters whose numbers of output ports are not equal to power series of 2. By the novel US patented Fused Fiber Coupling Machine in 2007 [1], monolithic 1x2, 1x3, 1x4 and 1x5 optical splitters were made, as well as a number of successful stories in Europe and Taiwan FTTH deployment cases came true.

II. TOPOLOGY of OPTICAL SPLITTER CASCADING

Suppose there is a 1xN optical splitter module with 1 input port and N output ports in the optical cable node. The splitter module is cascaded by 1xA 1xB 1xC and 1xD splitter elements. In addition, the priority of splitter elements selection is :

1xA : the fist,

1xB : the second

1xC : the third

1xD : the last.

and $N = (A^a)(B^b)(C^c)(D^d)$

then it is able to be proved by summation of power series that the number of splitter elements in are :

$$1xA : N(A) = (A^a -1)(B^b)(C^c)(D^d) / (A -1)$$

$$1xB : N(B) = (B^b -1)(C^c)(D^d) / (B -1)$$

$$1xC : N(C) = (C^c -1)(D^d) / (C -1)$$

$$1xD : N(D) = (D^d -1) / (D -1)$$

Practically, the monolithic 1x2, 1x3, 1x4 and 1x5 splitter elements can be made by the novel US patented Fused Fiber Coupling Machine as well as considering the optical performance and economic cost the priority of selection are 1x4, 1x5, 1x3 and 1x2 in order.

III. Traditional Splitter Module Cascaded by 1x2 Components

Traditionally, a piece of 1x (2^n) optical splitter can be cascaded by (2^n-1) pieces of 1x2 splitter as shown in Fig.3-1 to Fig.3-4. For example, a piece of 1x8 splitter is cascaded by 7 pieces of 1x2 splitter; a piece of 1x16 splitter is cascaded by 15 pieces of 1x2 splitter; a piece of 1x32 splitter is cascaded by 31 pieces of 1x2 splitter; a piece of 1x64 splitter is cascaded by 63 pieces of 1x2 splitter. Nevertheless, a piece of 1xN splitter is not able to be cascaded by 1x2 splitter only, while N (the number of output ports) is not equal to the power series of two.

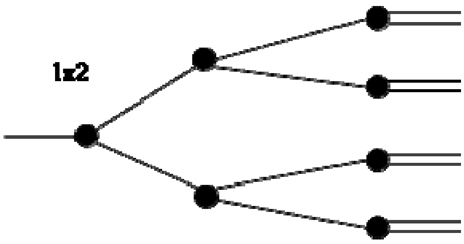

Fig.3-1 1x8 splitter by 1x2 cascading (No. of 1x2 splitter in used:1+2+4=7).

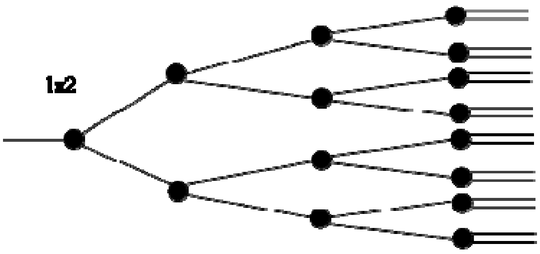

Fig.3-2 1x16 splitter by 1x2 cascading (No. of 1x2 splitter in used:1+2+4+8=15).

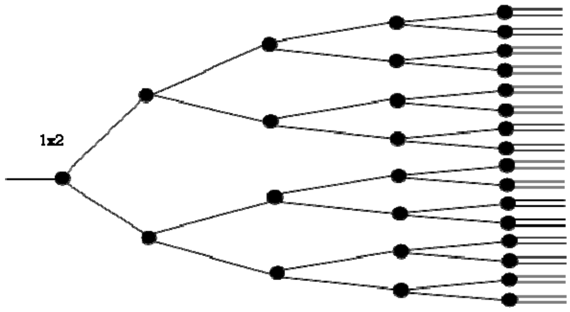

Fig.3-3 1x32 splitter by 1x2 cascading (No. of 1x2 splitter in used:1+2+4+8+16=31).

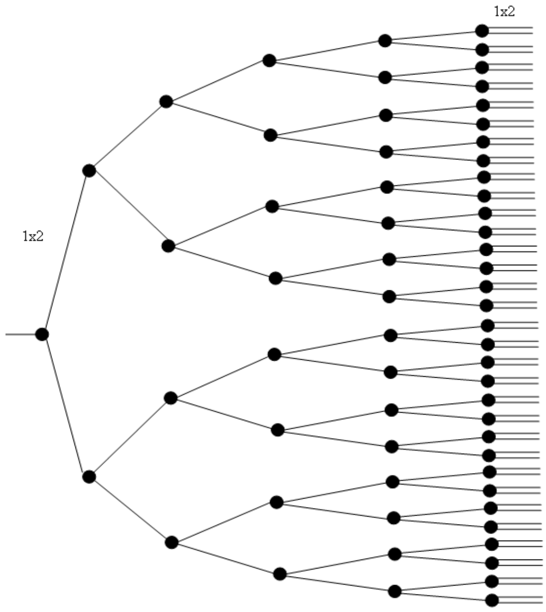

Fig.3-4 1x64 splitter by 1x2 cascading (No. of 1x2 splitter in used:1+2+4+8+16+32=63).

IV. A Novel And Economic Way Of Cascading Splitter Module

By the novel US patented Fused Fiber Coupling Machine [1] developed 2007, monolithic 1x2, 1x3, 1x4 and 1x5 optical splitters are able to be made. In case the number N of a 1xN optical splitter output-ports is a common multiple of 2; 3; 4 and 5, a novel economic cascading topology is implemented. Considering the factors of optical performance, reliability and market price, the priority of choice we have made is 1x4, 1x5, 1x3 and then 1x2. It is found a piece of 1xN optical splitter can be economically cascaded by N(4) pieces of 1x4 splitter; N(5) pieces of 1x5 splitter; N(3) pieces of 1x3 splitter and N(2) pieces of 1x2 splitter; where

$$N(4) = (4^a -1)(5^b)(3^c)(2^d) / (4-1) \quad (1)$$

$$N(5) = (5^b - 1)(3^c)(2^d) / (5-1) \quad (2)$$
$$N(3) = (3^c - 1)(2^d) / (3-1) \quad (3)$$
$$N(2) = (2^d - 1) / (2-1) \quad (4)$$
$$N = (4^a)(5^b)(3^c)(2^d) \quad (5)$$

According to ITU-T G.984 GPON Standard, the maximum number of splitter output ports is 64. For a piece of 1xN splitter module, while N is a common multiple of 2,3,4,5 and less than 64, in Fig.4-1 to Fig.4-17, the topologies of 1x6, 1x8, 1x9, 1x10, 1x18, 1x20, 1x24, 1x25, 1x27, 1x30, 1x32, 1x36, 1x40, 1x45, 1x50, 1x54, 1x60 splitter cascading are shown.

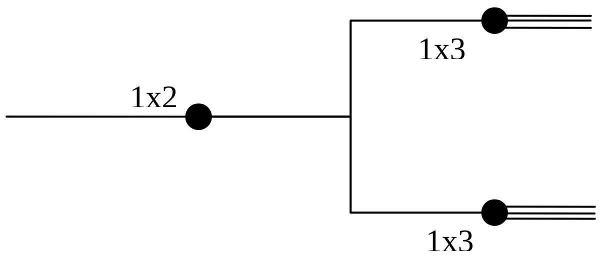

Fig.4-1 An economic 1x6 splitter module.

From Fig.4-1, $N = (4^0)(5^0)(3^1)(2^1) = 6$.

Comprising the bellow components:

1x4 : $N(4) = (4^0 - 1)(5^0)(3^1)(2^1) / (4-1) = 0$

1x5 : $N(5) = (5^0 - 1)(3^1)(2^1) / (5-1) = 0$

1x3 : $N(3) = (3^1 - 1)(2^1) / (3-1) = 2$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

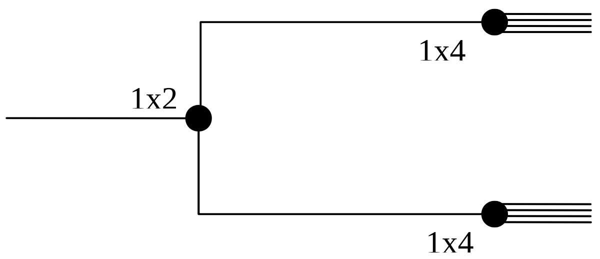

Fig.4-2 An economic 1x8 splitter module.

From Fig.4-2, $N = 8 = (4^1)(5^0)(3^0)(2^1)$

Comprising the bellow components:

1x4 : $N(4) = (4^1 - 1)(5^0)(3^0)(2^1) / (4-1) = 2$

1x5 : $N(5) = (5^0 - 1)(3^0)(2^1) / (5-1) = 0$

1x3 : $N(3) = (3^0 - 1)(2^1) / (3-1) = 0$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

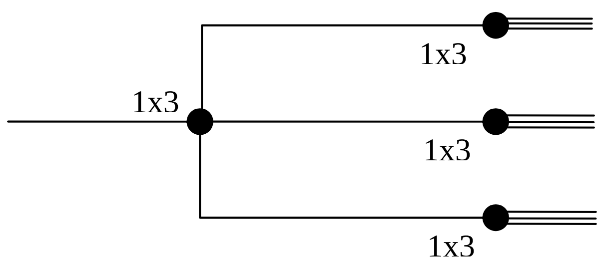

Fig.4-3 An economic 1x9 splitter module.

From Fig.4-3, $N = 9 = (4^0)(5^0)(3^2)(2^0)$

Comprising the bellow components:

1x4 : $N(4) = (4^0 - 1)(5^0)(3^2)(2^0) / (4-1) = 0$

1x5 : $N(5) = (5^0 - 1)(3^2)(2^0) / (5-1) = 0$

1x3 : $N(3) = (3^2 - 1)(2^0) / (3-1) = 4$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

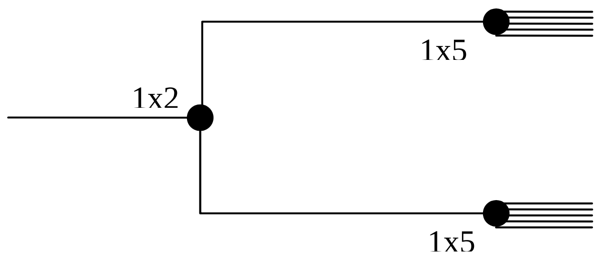

Fig.4-4 An economic 1x10 splitter module.

From Fig.4-4, $N = 10 = (4^0)(5^1)(3^0)(2^1)$

Comprising the bellow components:

1x4 : $N(4) = (4^0 - 1)(5^1)(3^0)(2^1) / (4-1) = 0$

1x5 : $N(5) = (5^1 - 1)(3^0)(2^1) / (5-1) = 2$

1x3 : $N(3) = (3^0 - 1)(2^1) / (3-1) = 0$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

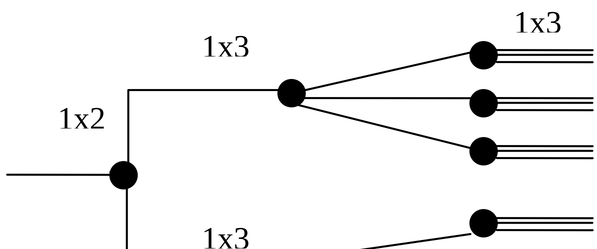

Fig.4-5 An economic 1x18 splitter module.

From Fig.4-5, N= 18 = $(4^0)(5^0)(3^2)(2^1)$

Comprising the bellow components:

1x4 : N(4) = $(4^0 -1) (5^0)(3^2)(2^1) / (4-1) = 0$

1x5 : N(5) = $(5^0 -1) (3^2)(2^1) / (5-1) = 0$

1x3 : N(3) = $(3^2 -1) (2^1) / (3-1) = 8$

1x2 : N(2) = $(2^1 -1) / (2-1) = 1$

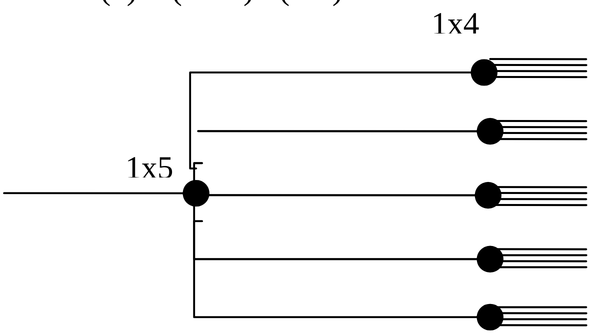

Fig.4-6 An economic 1x20 splitter module.

From Fig.4-6, N= 20 = $(4^1)(5^1)(3^0)(2^0)$

Comprising the bellow components:

1x4 : N(4) = $(4^1 -1) (5^1)(3^0)(2^0) / (4-1) = 5$

1x5 : N(5) = $(5^1 -1) (3^0)(2^0) / (5-1) = 1$

1x3 : N(3) = $(3^0 -1) (2^0) / (3-1) = 0$

1x2 : N(2) = $(2^0 -1) / (2-1) = 0$

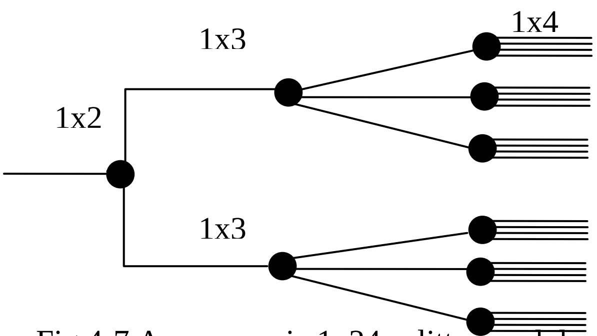

Fig.4-7 An economic 1x24 splitter module.

From Fig.4-7, N= 24 = $(4^1)(5^0)(3^1)(2^1)$

Comprising the bellow components:

1x4 : N(4) = $(4^1 -1) (5^0)(3^1)(2^1) / (4-1) = 6$

1x5 : N(5) = $(5^0 -1) (3^1)(2^1) / (5-1) = 0$

1x3 : N(3) = $(3^1 -1) (2^1) / (3-1) = 2$

1x2 : N(2) = $(2^1 -1) / (2-1) = 1$

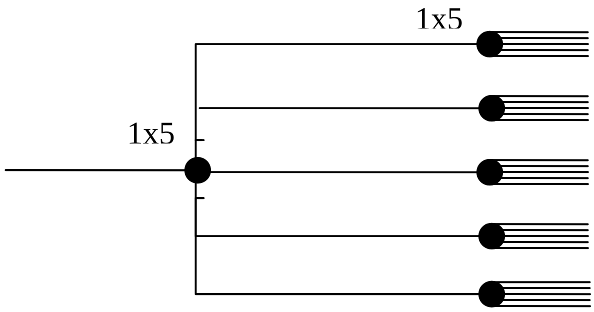

Fig.4-8 An economic 1x25 splitter module.

From Fig.4-8, N= 25 = $(4^0)(5^2)(3^0)(2^0)$

Comprising the bellow components:

1x4 : N(4) = $(4^0 -1) (5^2)(3^0)(2^0) / (4-1) = 0$

1x5 : N(5) = $(5^2 -1) (3^0)(2^0) / (5-1) = 6$

1x3 : N(3) = $(3^0 -1) (2^0) / (3-1) = 0$

1x2 : N(2) = $(2^0 -1) / (2-1) = 0$

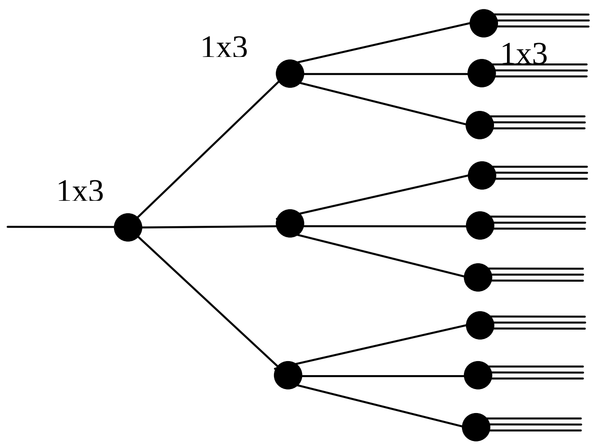

Fig.4-9 An economic 1x27 splitter module.

From Fig.4-9 N= 27 = $(4^0)(5^0)(3^3)(2^0)$

Comprising the bellow components:

1x4 : N(4) = $(4^0 -1) (5^0)(3^3)(2^0) / (4-1) = 0$

1x5 : N(5) = $(5^0 -1) (3^3)(2^0) / (5-1) = 0$

1x3 : N(3) = $(3^3 -1) (2^0) / (3-1) = 13$

1x2 : N(2) = $(2^0 - 1) / (2-1) = 0$

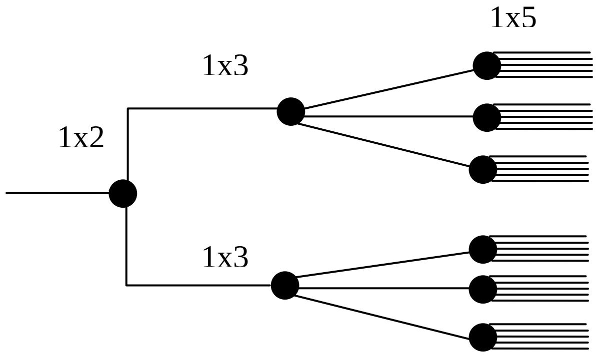

Fig.4-10 An economic 1x30 splitter module.

From Fig.4-10, N= 30 = $(4^0)(5^1)(3^1)(2^1)$
Comprising the bellow components:
1x4 : N(4) = $(4^0 - 1)(5^1)(3^1)(2^1) / (4-1) = 0$
1x5 : N(5) = $(5^1 - 1)(3^1)(2^1) / (5-1) = 6$
1x3 : N(3) = $(3^1 - 1)(2^1) / (3-1) = 2$
1x2 : N(2) = $(2^1 - 1) / (2-1) = 1$

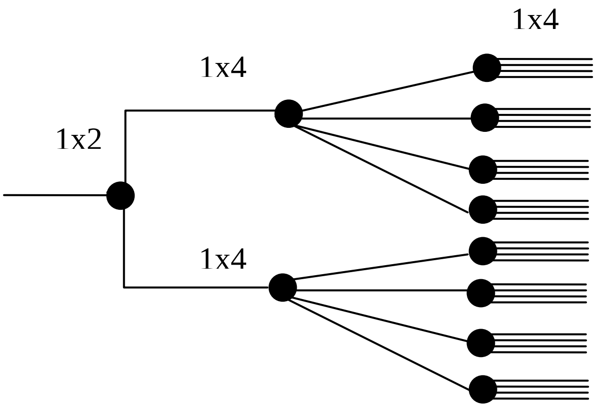

Fig.4-11 An economic 1x32 splitter module.

From Fig.4-11, N= 32 = $(4^2)(5^0)(3^0)(2^1)$
Comprising the bellow components:
1x4 : N(4) = $(4^2 - 1)(5^0)(3^0)(2^1) / (4-1) = 10$
1x5 : N(5) = $(5^0 - 1)(3^0)(2^1) / (5-1) = 0$
1x3 : N(3) = $(3^0 - 1)(2^1) / (3-1) = 0$
1x2 : N(2) = $(2^1 - 1) / (2-1) = 1$

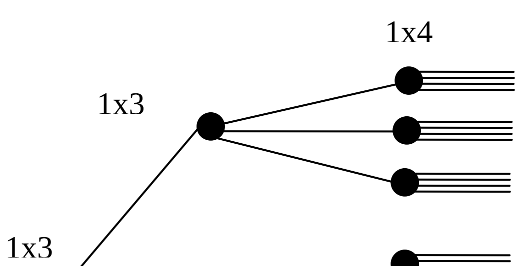

Fig.4-12 An economic 1x36 splitter module.

From Fig.4-12, N= 36 = $(4^1)(5^0)(3^2)(2^0)$
Comprising the bellow components:
1x4 : N(4) = $(4^1 - 1)(5^0)(3^2)(2^0) / (4-1) = 9$
1x5 : N(5) = $(5^0 - 1)(3^2)(2^0) / (5-1) = 0$
1x3 : N(3) = $(3^2 - 1)(2^0) / (3-1) = 4$
1x2 : N(2) = $(2^0 - 1) / (2-1) = 0$

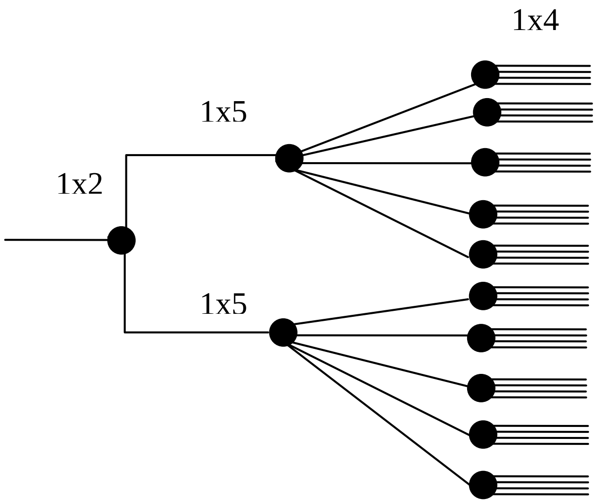

Fig.4-13 An economic 1x40 splitter module.

From Fig.4-13, N= 40 = $(4^1)(5^1)(3^0)(2^1)$
Comprising the bellow components:
1x4 : N(4) = $(4^1 - 1)(5^1)(3^0)(2^1) / (4-1) = 10$
1x5 : N(5) = $(5^1 - 1)(3^0)(2^1) / (5-1) = 2$

1x3 : $N(3) = (3^0 - 1)(2^1) / (3-1) = 0$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

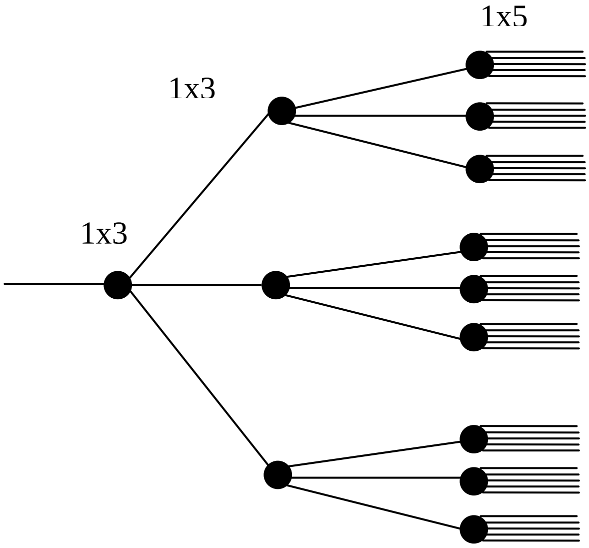

Fig.4-14 An economic 1x45 splitter module.

From Fig.4-14, $N = 45 = (4^0)(5^1)(3^2)(2^0)$

Comprising the bellow components:

1x4 : $N(4) = (4^0 - 1)(5^1)(3^2)(2^0) / (4-1) = 0$

1x5 : $N(5) = (5^1 - 1)(3^2)(2^0) / (5-1) = 9$

1x3 : $N(3) = (3^2 - 1)(2^0) / (3-1) = 4$

1x2 : $N(2) = (2^0 - 1) / (2-1) = 0$

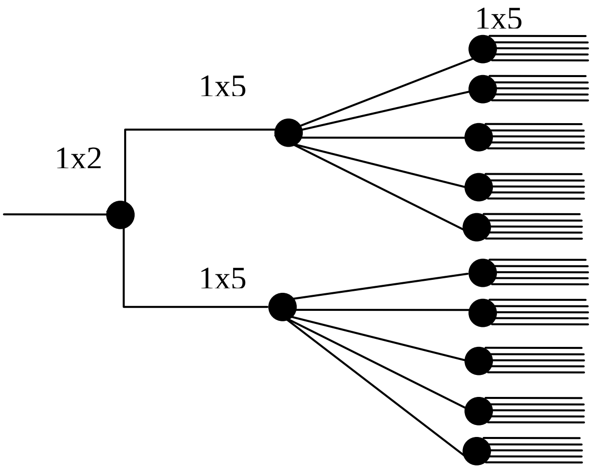

Fig.4-15 An economic 1x50 splitter module.

From Fig.4-15, $N = 50 = (4^0)(5^2)(3^0)(2^1)$

Comprising the bellow components:

1x4 : $N(4) = (4^0 - 1)(5^2)(3^0)(2^1) / (4-1) = 0$

1x5 : $N(5) = (5^2 - 1)(3^0)(2^1) / (5-1) = 12$

1x3 : $N(3) = (3^0 - 1)(2^1) / (3-1) = 0$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

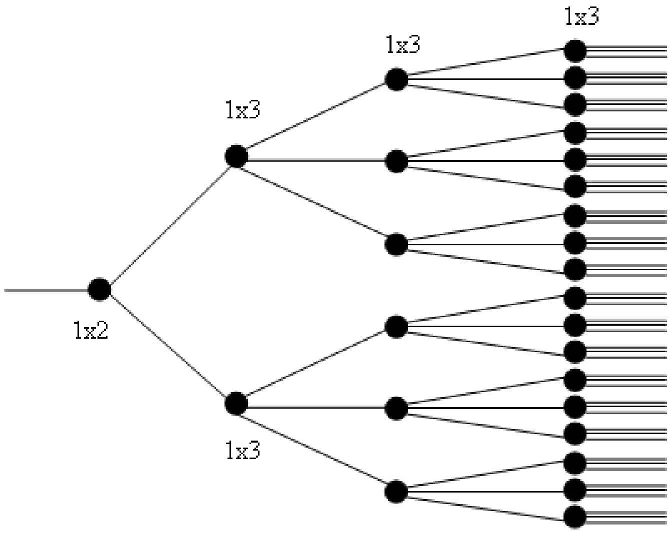

Fig.4-16 An economic 1x54 splitter module.

From Fig.4-16, $N = 54 = (4^0)(5^0)(3^3)(2^1)$

Comprising the bellow components:

1x4 : $N(4) = (4^0 - 1)(5^0)(3^3)(2^1) / (4-1) = 0$

1x5 : $N(5) = (5^0 - 1)(3^3)(2^1) / (5-1) = 0$

1x3 : $N(3) = (3^3 - 1)(2^1) / (3-1) = 26$

1x2 : $N(2) = (2^1 - 1) / (2-1) = 1$

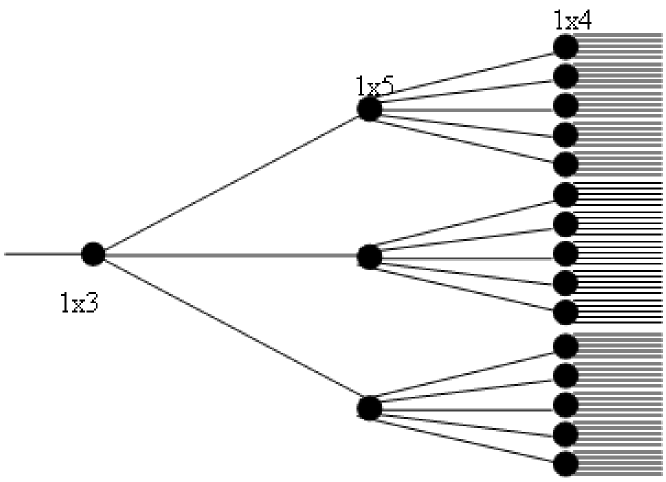

Fig.4-17 An economic 1x60 splitter module.

From Fig.4-17, $N = 60 = (4^1)(5^1)(3^1)(2^0)$

Comprising the bellow components:

1x4 : N(4) = $(4^1 - 1)(5^1)(3^1)(2^0) / (4-1) = 15$

1x5 : N(5) = $(5^1 - 1)(3^1)(2^0) / (5-1) = 3$

1x3 : N(3) = $(3^1 - 1)(2^0) / (3-1) = 1$

1x2 : N(2) = $(2^0 - 1) / (2-1) = 0$

V. Three Successful Cases

Case 1: 1x12 splitter module deployed in Switzerland

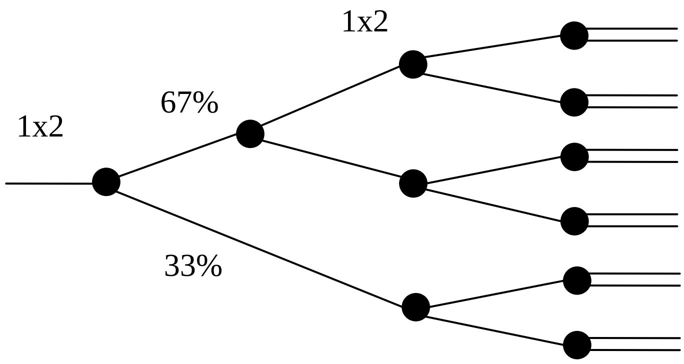

Fig. 5-1 Traditional 1x12 splitter module cascaded by 1x2 components.

As shown in Fig.5-1, normally one piece of unevenly 1x2 splitter, optical power ratio: 67% / 33%; insertion loss IL: 2.6 / 6.2 dB and 10 pieces of evenly 1x2 splitter, optical power ratio: 50% / 50%; IL: 3.7 dB are required to be cascaded. In total, the IL of this 1x12 splitter will be 13.7dB (2.6 + 3.7 × 3 = 13.7) and the market price is about 110 USD for reference.

Instead of above method, we used 1 piece of 1x3 (IL: 5.4 dB) and 3 pieces of 1x4 (IL: 7.2dB), totally 4 pieces of splitter elements to cascade a 1x12 splitter module as shown in Fig.4-2, in which the IL = 5.4 + 7.2 = 12.6 dB. It is found that 13.7 – 12.6 = 1.1 dB of optical power is saved. The market price for reference is 80 USD, cost-down more than 20%.

Fig. 5-2 An economic 1x12 splitter module.

Case 2: 1x36 splitter module deployed in the UK

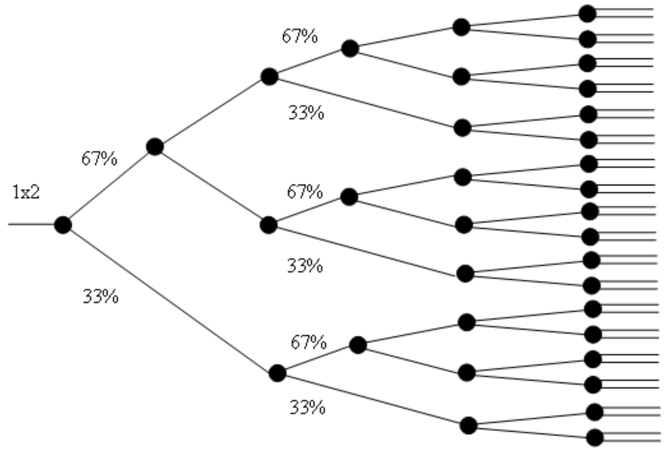

Fig. 5-3 Traditional 1x36 splitter module cascaded by 1x2 components.

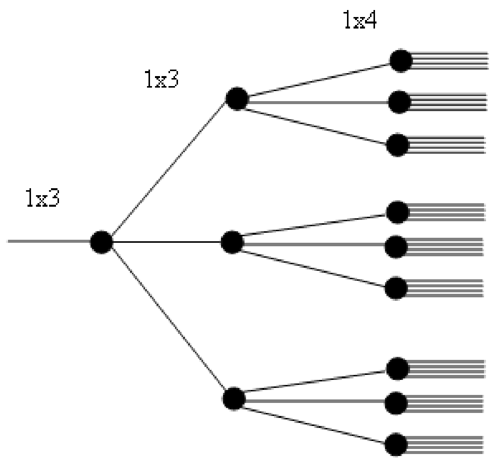

Fig. 5-4 An economic 1x36 splitter module.

Case 3: 2x24 splitter module deployed in Taiwan.

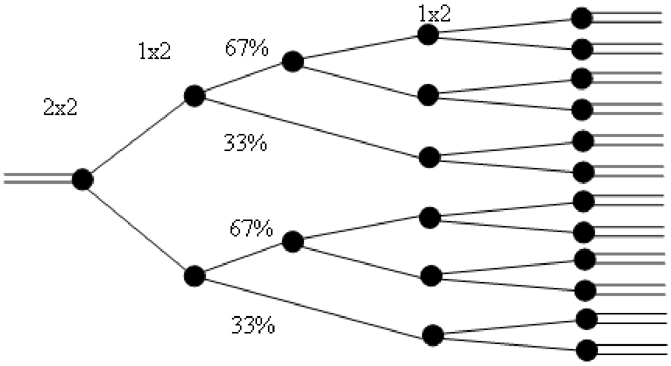

Fig. 5-5 Traditional 2x24 splitter module cascaded by 1x2 components.

Fig.5-3 shows a traditional 1x36 in this case, the 350 USD is cascaded by 35 pieces of 1x2 splitters (IL: 2.6 + 6.2 + 3.7 x3 = 19.9dB) can be replaced by a 260 USD economic one is cased by 4 pieces of 1x3 and 9 pieces of 1x4 splitters (IL: 5.4 + 5.4 + 7.2 = 18dB) as shown in Fig.5-4. 1.9dB of optical power is found and saves 90 USD.

In the case of 2x24, the 230 USD traditional is cascaded by 23 pieces of 1x2 splitters (IL: 2.6 + 3.7 x 3 = 17.4dB) as shown in Fig.4-5 is replaced by a 170 USD economic one is cased by 1 piece of 2x2, 2 pieces of 1x3 and 6 pieces of 1x4 splitters (IL: 3.7 + 5.4 + 7.2 = 16.3dB) as shown in Fig.5-6. 1.1dB of optical power is found and saves 60 USD.

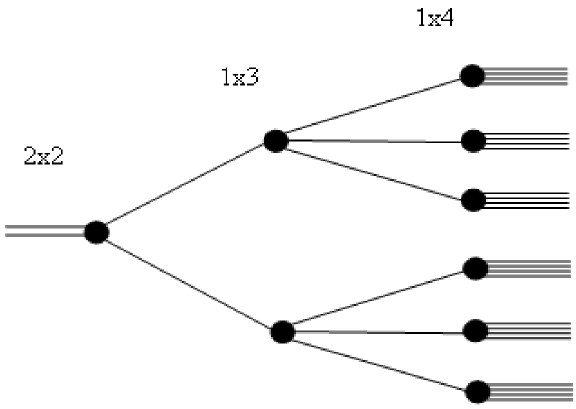

Fig.5-6 An economic 2x24 splitter module.

VI. Results And Conclusions

In conclusion, this novel topology by cascading 1x4, 1x5, 1x3 and 1x2 splitter elements are more beneficial and effectively in both optical performance and cost compare to traditional model and PLC technology. Table 6.1 lists comparison.

Table 6.1 Comparison of splitter module cascade.

Splitter Module	Novel topology	Traditional 1x2 cascading	PLC technology
1x12 module	1x4(3pcs) 1x3(1pcs)	1x2(10pcs; 50%/50%) 1x2(1pcs; 67%/33%)	1x16(1pcs) 4 ports idle
Insertion Loss	12.6dB	13.7dB	13.8dB
Price	$80	$110	$140
1x36 module	1x4(9pcs) 1x3(4pcs)	1x2(31pcs; 50%/50%) 1x2(4pcs; 67%/33%)	1x64(1pcs) 28ports idle
Insertion Loss	18dB	19.9dB	20.5dB
Price	$260	$350	$450
2x24 module	1x4(6pcs) 1x3(2pcs) 2x2(1pcs)	1x2(20pcs; 50%/50%) 1x2(2pcs; 67%/33%) 2x2(1pcs; 67%/33%)	2x32(2pcs) 8 ports idle
Insertion Loss	16.3dB	17.4dB	17.2dB
Price	$170	$230	$210

Reference

[1] "Optical fiber coupler and manufacturing apparatus and method thereof"; US Patent 7158712B2; Jan. 2, 2007