Benes Configurations Of Circuit In Node With Space Cross Connections For Transparent Optical Networks

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Abstract: **There is a consideration of the transparent optical network with space cross connections in nodes realized with Benes configuration of circuit. The equations for the Benes configuration are recalculated and improved for relations among number of entrances and exits in circuit N and number of direct symmetric two channel couplers C, number of voltage electrode circuits V, characteristic of attenuation A and characteristic of signal to noise ratio SNR. The numerical analyze has been performed for Benes configuration of direct two channel symmetric couplers on circuit for space division multiplexing and cross connecting relating to specified essential characteristics.**

Index terms – Benes configuration, optical nodes, optical cross-connections, space optical cross-connections, space division multiplexing

I. INTRODUCTION

The transparent optical networks are in first phase of its development. Those networks have been realized from certain number of optical communication systems, which operate with synchronization, less or more, relating to the wavelength and power of optical signals.
The simplest degree of transparency is transparency for digital signal modulated by intensity, with standard single mode fiber as transmission media. There are more difficulties for creation of other degrees of transparencies for other types of modulations of optical signals, analog and digital, too.
Entirely transparent optical network would request the transparency for any optical signal. One of boundary factor is defined with configuration of circuits in nodes of network, for different manipulations with optical signals.

II. CROSS CONNECTIONS

The core of transparent optical networks are composed of those networks which operate with optical signals realized with wavelength division multiplexing (WDM), time division multiplexing (TDM) and space division multiplexing (SDM). In development of transparent optical networks, it was evidenced the mentioned progressions in use. The next phase in multiplexing schemes understands utilization of previously used, and so, space multiplexed optical signal can be those which are previously multiplexed by wavelength or by time.
The cross connection in node of transparent optical network is method of assigning of optical signal from entrance(s) to exit(s) of node.
Anyhow, realized optical networks, with any degree of transparency, and with any concept of nodes implementation, can not fulfill demands for increasing of capacities of communication systems.
It is a reason for applying of nodes with space multiplexing and cross connections of previously multiplexed or unmultiplexed optical signals.

III. BENES CONFIGURATION IN NODES WITH SPACE CROSS CONNECTIONS

Very different solutions of nodes with space cross connections would request, in most general case, different schemes of circuit connection, and each circuit realized with different number of direct two channel symmetric couplers.
The direct two channel couplers are widely researched in various realizations, as integrated optoelectronic circuits, or with fused fibers. The general scheme of integrated two channel couplers on $LiNbO_3$, which is here in consideration, is presented on Fig. 1.

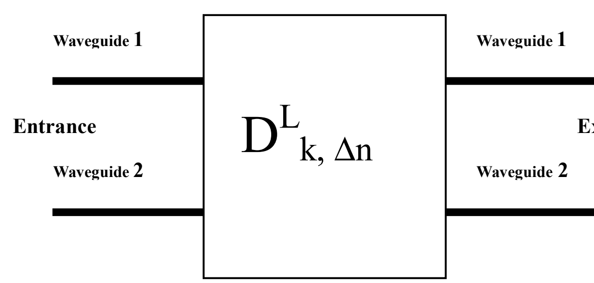
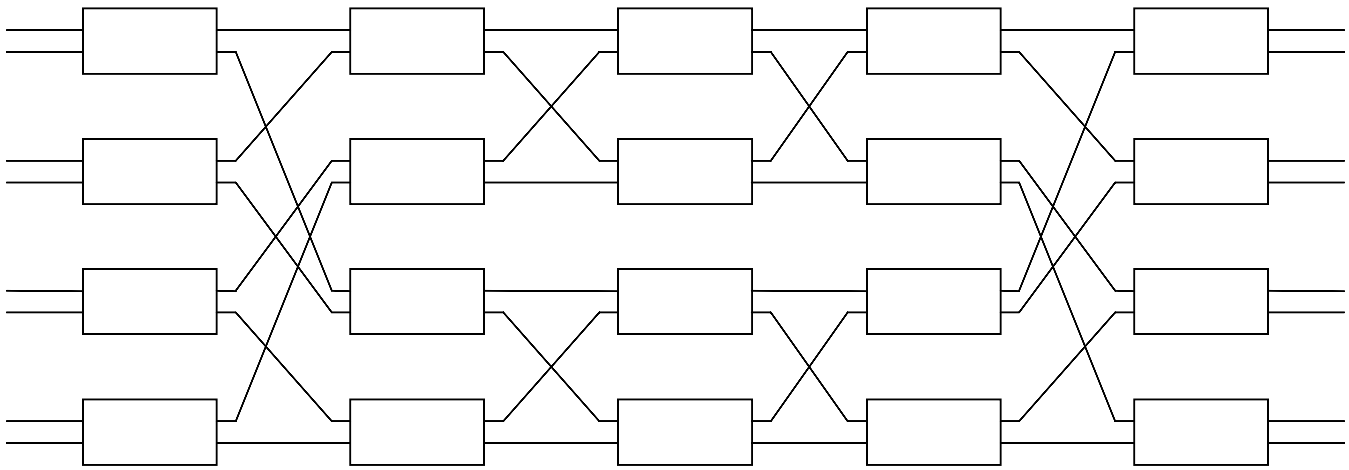


Fig. 1. Scheme of integrated direct symmetric two channel coupler
D – Transmit function of four (4) pole circuit, L – Coupling length, k – Coupling coefficient, Δn – Induced changes of



Entrances 1-8 Fig. 2. Benes configuration of circuit **Exits 1-8**

refraction index of electro optical materials on which the coupler was integrated.

The basic coupler circuit, with two entrances (inputs) and two exits (outputs) [1], has had great influence to development of transparent optical networks.
Any more detailed analyze of architecture of node with space cross connection can recognize Benes configuration of circuits utilized in construction of node [2, 3]. The configuration of circuit for space optical cross connection is placement of several two channel direct symmetric couplers relating to entrances and exits between couplers in circuit. The placement of direct two channel symmetric couplers for Benes configuration is presented on Fig. 2., for number of entrances and exits to circuit N≤8.
It will be performed basic analyze of specified Benes configuration relating to essential characteristics.

IV. BASIC ELEMENTS FOR ANALYZE OF WORK OF CIRCUITS FOR SPACE CROSS CONNECTIONS

There is a presentation of basic and well known elements for analyze of works of circuits for space cross connections in nodes of transparent optical networks. The numeric analyze has been performed according to object that circuits have been realized with integrated symmetric two channel directional couplers on $LiNbO_3$, each one with electrodes of same form and size. Also, there is presumption that circuits can be used for one directional and two directional transmissions. The number of entrances and exits to circuit with Benes configuration for this numeric analyze is N≤8.

1. Characteristic of blockade and broadcasting:
This characteristic describes Benes configuration of circuit for space cross connection relating to conformity of work of transparent optical network in which node operates, according to number and type of user services. This characteristic for Benes configuration is as following:

Table 1: BLOCKADE AND BROADCASTING	
1. Benes configuration of circuit	a) Rearrangable nonblocking b) Point-to-Point

2. Number of entrances and exits in circuit N:
This number depends on number of circuits with Benes configuration utilized in architecture of node in transparent optical network for rearrangable nonblocking connections, point-to-point. This number is limited, on one hand, with spectral width of transmit optoelectronic element (laser diode, or more rare LED), spectral characteristics of waveguides of couplers, and with sensitivity of receiver optoelectronic element (PIN, APD), on other hand. All other constraints as result of characteristics of coupler itself will not be considered.

3. Number of direct symmetric two channel couplers C:
This number for Benes configuration is defined with number of entrances and exits on circuit, or with number of optical signals for cross connections.
The number of two channel symmetric direct couplers C for considered configuration is presented (Table 2 and Fig. 3.), and in the equation as following:

$$C = ABS\{INT[(N/2)\cdot(2\cdot\log_2(N)-1)]\} \quad (1)$$

The number of couplers increases exponentially relating to number of entrances and exits to circuit. But, those problems can be overcome in technological procedures in manufacturing of circuit in presented configuration.

Table 2: Numerical analyze of work of Benes configuration of circuit in node for space cross connection				
Number of entrances or exits of circuit	**Number of couplers**	**Number of electrode circuit**	**Attenuation (dB)**	**Signal to noise ratio SNR (dB))**
N	**C**	**V**	**A; Ac=5; A_d=0.5**	**SNR; X=20**
	$C=ABS(INT((N/2)\cdot(2\cdot\log_2(N)-1)))$	**V=C**	**$A=ABS((2\cdot\log_2(N)-1)\cdot Ac+A_d)$**	**$SNR=X-10\cdot\log_{10}(2\cdot\log_2(N)-1)$**
1	**1**	**1**	**4.50**	**20.00**
2	**1**	**1**	**5.50**	**20.00**
3	**3**	**3**	**11.35**	**16.64**
4	**6**	**6**	**15.50**	**15.23**
5	**9**	**9**	**18.72**	**14.38**
6	**12**	**12**	**21.35**	**13.80**
7	**16**	**16**	**23.57**	**13.36**
8	**20**	**20**	**25.50**	**13.01**

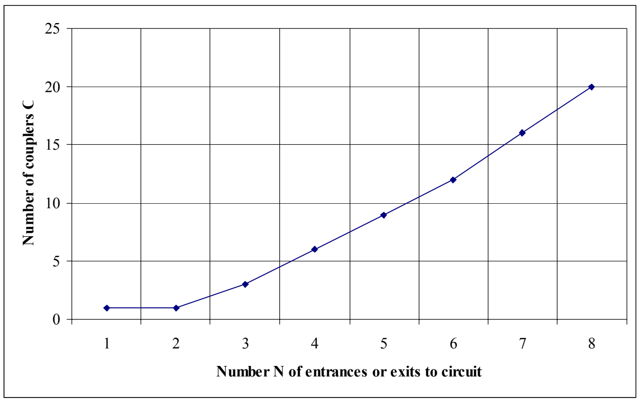


Fig. 3. Benes configuration - Number of couplers C

4. Number of voltage electrode circuits V:

With presumption that each coupler has electrode of same form and size, this number is same to the number of couplers C. The reason for such number of electrodes is presented with fact that every coupler has possibility to work in cross state and bar state, too, for realization of rearrangable nonblocking connections, point-to-point.

The number of voltage electrode circuit V for considered configuration is presented (Table 2), according to the equation as following:

$$V=ABS\{INT[(N/2)\cdot(2\cdot\log_2(N)-1)]\} \quad (2)$$

The number of voltage electrode circuit increases exponentially relating to number of entrances and exits to circuit. But, there is a possibility to have voltage on electrode of coupler in value of voltage for use in micro processing, so, it makes this configuration programmable for eventual reconfiguration in node.

5. Characteristic of attenuation A:

The attenuation of optical signal which will be space cross connected in node with Benes configuration of circuit is conditioned with number of couplers optical signal is passing through according to the placement of couplers on integrated circuit as well as according to the method of connections among couplers. The connections between couplers on circuit are realized (Fig. 2.) with crossing of waveguides and without crossing of waveguides, which is favorable case. Any crossing of waveguides will result with undesired coupling of optical signals which will be space cross connected. The resulting attenuation of optical signal on circuit for space cross connection has been composed of components as following:

a) Internal losses in one integrated coupler, size of $A_c \in [2, 10]$ dB, with in calculated losses caused by scattering, as well as with losses caused with realization of waveguides with curves. The amount of total attenuation on one circuit that can be in calculated in attenuation plan in one link is A_{cmax}=30 dB. Also, it is adopted that the value of attenuation in any coupler is A_c=5 dB.

b) There are additional losses when circuit with Benes configuration is coupled to fibers as transmission media in optical transparent networks. It includes different losses, for example, those caused with Fresnel reflection, as well as caused by method of coupling fiber to circuit (end but coupling or coupling with grove etched in GaAs or SiO_2, with or without micro lenses, etc.). Typical values of this attenuation for two (2) coupling fiber – circuit is $A_d \in [0.2, 2]$ dB, with possibility to reduce this attenuation with use of materials for having better matching of refraction indexes of fiber and waveguide of coupler, and with better technological conditions in process of coupling.
It is adopted, in further calculations, the value of this attenuation for two (2) coupling fiber - circuit to be A_d=0.5 dB.

The characteristic of attenuation A for Benes configuration is presented (Table 2 and Fig. 4.), according to the equation as following:

$$A=ABS[(2\cdot\log_2(N)-1)\cdot A_c+A_d] \quad (3)$$

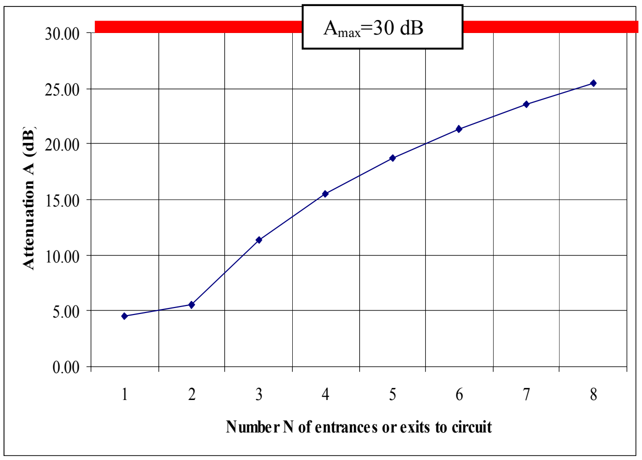


Fig.4. Benes configuration - Attenuation A (dB) of circuits

The attenuation can be a limiting factor for use of this configuration of circuit, because of exponential growth of number of couplers in realization of Benes configuration relating to number of entrances and exits N. The solution can be found in better technological condition in realization of particular coupler with lower level of attenuation.

6. Characteristic of signal to noise ratio SNR:

Each two channel symmetric direct coupler causes crosstalk between optical signals passing through its waveguides. This characteristic is especially noticeable in case of two directional communication links through one waveguide.

Because of that, it is more simple to have space cross connection of optical signals already organized with time division multiplexing. With better extinction ratio X of material which has been used as substrate for integration of circuit for space cross connection, it will be better SNR of whole circuit. It is adopted, in calculations, that an extinction ratio for $LiNbO_3$ is X=20 dB [2]. Also, it is adopted, in further considerations, that the value of SNR≥11 dB will be enough to have $BER=10^{-9}$ between two users connected in transparent optical network. The characteristic SNR for Benes configuration is presented (Table 2 and Fig. 5.), and in the equation as following:

$$SNR=X-10\cdot\log_{10}[2\cdot\log_2(N)-1] \quad (4)$$

The signal to noise ratio is not limited factor for utilization of Benes configuration for N≤ 8.

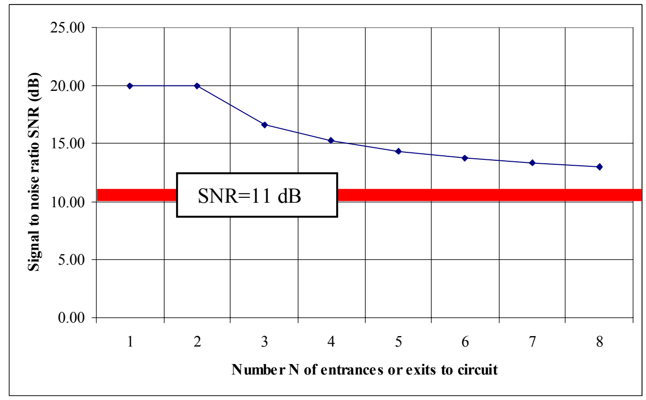


Fig. 5. Benes configuration - Signal to noise ratio SNR (dB) of circuits

V. CONCLUSION

The real potentials of presented Benes configuration of circuits for space cross connection in nodes of transparent optical networks have not been investigated enough, yet. It would be necessary to analyze and to investigate the behavior of Benes configuration with couplers realized with fused fibers, and with belonging parameters.

The limiting factor in realization of presented configuration of bigger number of couplers would come from increased attenuation as well as from fact of crossing waveguides on circuit in connection of particular couplers, because of coupling of optical signals, which would be able to be avoided with use of, previously, time multiplexed optical signal, which would pass through crossed waveguides in different time period.

The real knowledge of characteristics of presented circuit configurations will come with more utilization of transparent optical network of high capacities, for different area of usage, which will not be, only, public network, but networks utilized for needs of functional communication systems for other public utility networks, in mining industry, in medical purposes, closed video supervision systems, etc..

It is expected the development of transparent optical network with nodes realized with circuits for space cross connection according to Benes configuration, not only for end users, but for experience and making of statistics about technological conditions of work of such one node and network entirely.

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