Analysis of Optical Device Models Designed for Antenna Array Management Operability

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ABSTRACT

This paper studies engineering design and modeling of an optical device intended for Radio-over-Fiber (RoF) antenna array radio emitting management. Design and assembled models of the device are based on either profiled multiple-wave interferometer or long-haul ring topology FOCL. To construct the interferential type OSCD (optical signal splitting and chirping device) models optical ceramic glass mixer processed with the ITHP (intense twist under high pressure) method was used. Loss and transmission coefficients with account of splitting for all the prototype units were measured – on frame-controller equipment and on RoF segment test bench equipment. Satisfactory measurement results obtained allow to make conclusion on OSCD models applicability for RoF test segments. The designed models and test bench pictures are also illustrated in this article.

Keywords

Optical signal splitting and chirping device, fiber optic communication line, optical signal chirp, modeling, Radio-over-Fiber.

1. INTRODUCTION

In recent times the Radio-over-Fiber technology of the broadband transmission is well developed (RoF – Radio-over-Fiber – radio link within 3÷11 GHz [1]). RoF is appropriate for subscriber line segments, it is also of a great interest for special application modeling, for example, GLONASS radio extender. Apart from the broad passband there are basic advantages of the technology, such as the component hardware diminutiveness which is explained analogue signal transmission assuming transform circuit and digital signal processing absence. Then comes sufficient concealment due to low power radio signal (~-50…55 dBm) determined with the necessity to comply with the spectral mask [1] for wideband radio links. However, this feature is also a disadvantage of the RoF – its transmission distance remains short that considerably limits the applicability of such systems.

To increase RoF wideband radio link it is better to use a direct radiation antenna array (AA) [2] instead of separate omnidirectional emitters. This will allow to increase and adapt the RoF segments – which has a great applicability and is one of the coordinated directions in constructing 5G type networks. However, taking into consideration the frequency signal diapason, the AA management is preferred to produce not with the electronic (with the UHF circuits) but with the optic method. The latter suggests specific optical devices that compensate signal distortions brought to the AA input, as well as distribution of the signal onto outputs of the AA radio emitters providing their phase shifting.

2. OPTICAL SIGNAL SPLITTING AND CHIRPING DEVICE MODELS

The optical signal splitting and chirping device (OSCD) was suggested as such an optical device [3], could be designed either on the basis of a profiled multiple resonator interferometer, Fig.1, or on the basis of a long-haul fiber optic scheme, Fig.2. Both suggested options of the OSCD are shown Fig.3 and Fig.4, respectively.

Model #1 and model #2 were assembled with the ceramic glass mixer processed with the intense twist under high pressure (ITHP) method [4]. Model #1 contains additional light guides that also contain EDFA light guides. Additional light guides are intended for signal phase shifting fed on different groups of AA radio emitters. It allows managing radio lobe positioning. Model #2 is constructed without additional light guides and is intended for AA with fixed radio lobe positioning. Both models have one informational input (λ_{inf}) and one input for pump emission feed (λ_{pump}). The number of output light guides is equal to 44 – corresponding to the number of AA radio emitters.

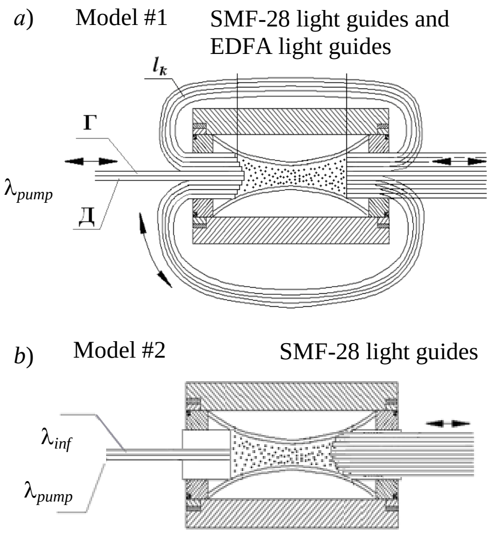


Fig. 1. The OSCD models schemes: a) – the model provides splitting function 1x44, recommended for AA use; the number of output light guides can be increased if necessary; λ_{inf} – informational signal emission wavelength and λ_{pump} – pump emission wavelength (necessary for EDFA light guides, equal to 980 nm); b) - the model provides splitting function 1x44, recommended for AA fixed lobe positioning

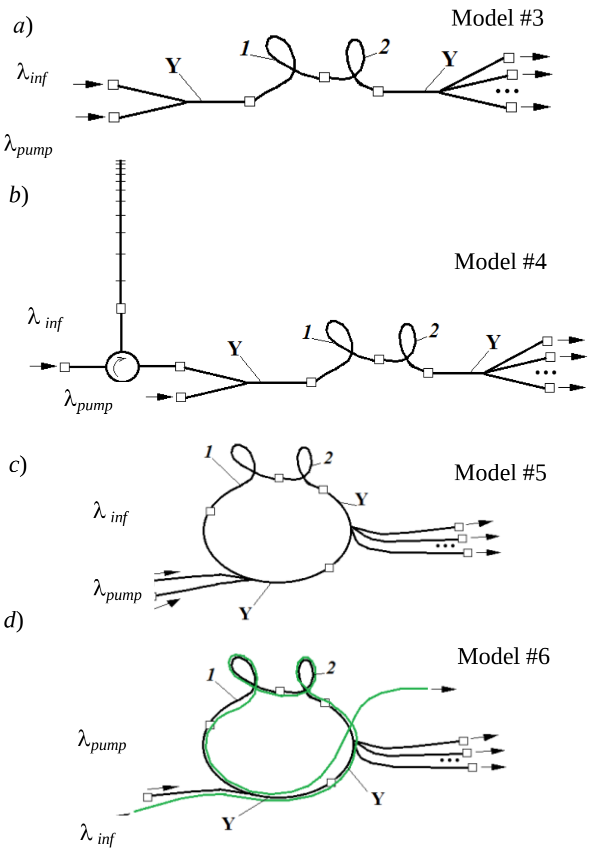


Fig. 2. The OSCD models schemes: a) and b) – linear topologies; c) and d) – ring topologies different in the way of informational signal feed (for the *d* case) light guides are stripped off their outer opaque coat thus radiation into the ring topology is inducted by means of light striking [5]: 1 – EDFA, 2 – DSF and/or light guide with high non-linearity (NL); Y – Y-shape splitter which can have structures of 1x2, 1x3, 1xN; □ - connectors or places of fusion splice. Wavelength values are $\lambda_{inf} \approx 1550$ nm; $\lambda_{pump} \approx 980$ nm

Both these types of the OSCD implementation successfully meet the initial objectives. However, resonator of the type OSCD, firstly, is more diminutive than the long-haul OSCD, and secondly, which is more important, it allows not only splitting input optical signal power components but also splitting spectral parameter components – on wavelength including optical impulse chirp functions (type of frequency modulation function). To produce the OSCD, models the mixers the ITHP method in which optical parameters symmetric to the central axis. We consider symmetry in relation to coating, drilling orifices to connect input and output light guides, etc. The interferential OSCD models were assembled practically in all design options that are of any practical interest RoF segment applicability viewpoint (number of output light guides). The long-haul OSCD models were constructed without an optical mixer. They assume EDFA light guides and specific light guide close to triangular refraction index profile (DSF) presence, or fiber with high nonlinear coefficient of the Kerr type [6, 7]. Figure1 legend shows double arrows ("towards-backwards") for passing radiation, which means principle functionality of the device that provides light trespass either in direct or inverse direction. This feature is important from duplex RoF channel construction viewpoint and complex-splitting PON-RoF segments use.

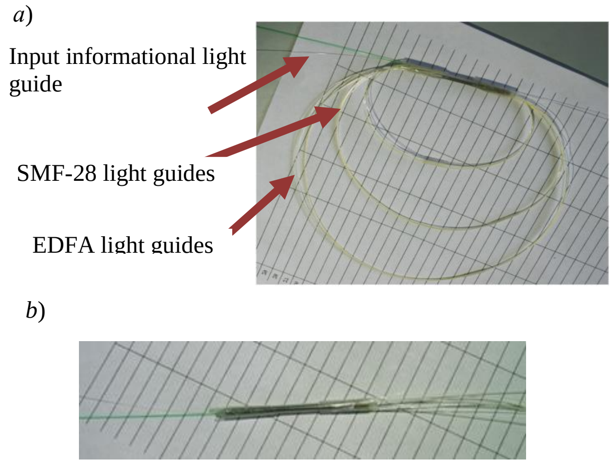


Fig. 3. Pictures of the interferential type OSCD: a) – OSCD model #1; b) – OSCD model #2; c) – OSCD model #7; d) – OSCD model #6. Pictures of models #3 and #4 are not given due to outer identity to models #1 and #2. Model shell is made on the basis of metallic steel interlock.

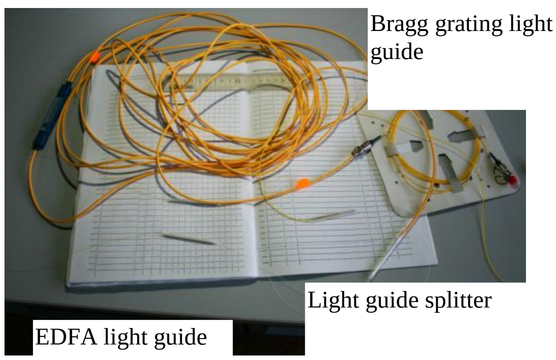


Fig. 4. Long-haul OSCD model scheme #4 (models #3, #5 and #6 externally look similar)

Long-haul OSCD model schemes suggest chain connection of EDFA and specific (DSF or NL) light guides. Besides, all these models are equipped with fiber optic splitters or switchers. From the technical characteristic point of view it is possible to consider emission losses and transmission coefficients (on intensity) that are defined with the same characteristics for the OSCD splitters/switchers, and also for fusion connection quality. Consider losses in light guides segments (EDFA and specific fiber) are small and not taken into consideration due to their short distance (EDFA – no longer than 15 m [5, 6], and specific fiber if any – no longer than 10 m). The value of induced positive chirp (the one that defines negative chirp compensation gained due to chromatic dispersion) depends on the structure of such OSCD (the type of light guides, the way the fiber topology is assembled – linear or ring topology) and the value of pump intense for EDFA. The latter directly shows the EDFA amplification coefficient.

Presented Fig.4, the model #4 is designated for optical signal amplification, induction of a positive chirp via self-phase modulation (SFM) [8], appearing in EDFA and further in NL, and also for splitting of optical signal intensity/power for feeding series of emitters. To estimate the amplification level we use the ratio from [5]:

$$G(\omega) = \hat{G}_0 \cdot \exp\left[\frac{g_0\left(\delta\omega, P_{\text{pump}}\right)\cdot \ell}{1+\delta\omega^2 \cdot T_{д}^{2} + P_{\text{inf}}/P_{\text{нас}}}\right] \qquad (1)$$

where $g_0\left(\delta\omega, P_{\text{pump}}\right)$ – normalized in length value of amplification coefficient (on low input signal) that depends on pump power P_{pump};

$\delta\omega$ – the difference central frequencies of an input optical signal and the electron quantum transition which is responsible for the amplification process;

T_d – active medium substance dipole triggering time determined by the time of dipole transition from stable balanced condition to metastable balanced condition (it has an order of 0.01-0.03 ns for erbium-ytterbium medium [6, 7]);

P_{inf} – input optical signal power for OSCD;

P_{sat} – active medium saturation power, approximately equals to 32 mW for this case [6];

ℓ – EDFA light guide length (m);

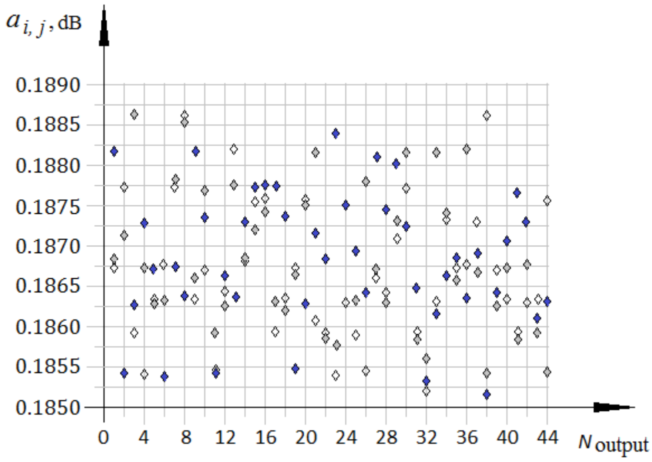
$\hat{G}_0$ – medium amplification coefficient on the length of 1 m.

Consequently, for recommended pump power of P_{pump} = 70 mW and lowest tune-out value of $\delta\omega$ = 103 rad/s we obtain $g_0\left(\delta\omega, P_{\text{pump}}\right)$ = 0,134 1/m, and further – for available EDFA waveguide average length of ℓ = 10 m and P_{inf} = 1 mW, also taking $\hat{G}_0 \cong$ 20.5 [6], we can reach up to 46 mW in power for the input signal of 1 mW right after EDFA output which is suffice to its splitting and further transmission via fiber optic line.

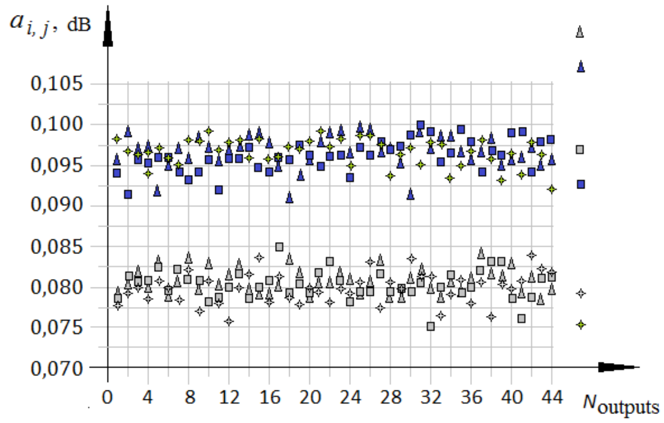
To increase target effects efficiency (the values of amplification and positive chirping) the chirping Braggs grating was used. It provides chirp induction into the signal not only due to the self-phase modulation as mentioned above but also due to selective multiple wave interference. Models #5 and #6 are also modified options of the model #4 – they have increased EDFA length on account of ring topology. It also advances amplification and inducted positive chirp. It should be noted that model #5 meets the requirements of the RoF network related to the described parameters. Nevertheless, model #6 represents great practical interest due to less pump power consumption within the ring topology, which is vital nowadays. Besides, as estimation shows, there is no necessity to use specific light guides – DSF or NL – connected after the EDFA in the ring topology, which also reduces cost of such OSCDs, or if applicable increases the device efficiency indices.

3. OSCD MODELS EXPERIMENTAL APPROVAL

After all the above-mentioned OSCD models were assembled, experimental laboratory approval on their working capacity of the RoF segment test bench took place. The latter includes emitting sources on 1550 nm and 980 nm wavelength and a long-haul (30 km) fiber optic communication line (FOCL-RoF). Spectral analyzer is used as an optical signal receiver. The measurements were taken with the help of a frame-controller that contains two laser emitters on 1550 nm and 980 nm wavelengths, and optic power meter. As a result, loss coefficient (with splitting) $a_{i,}$ and transmission coefficient (with splitting) $b_{i,j}$ where i and j – the number of OSCD informational inputs and outputs, respectively, were defined. Loss coefficient shows power level reduction (in dB) in output channel due to production inaccuracy and splitting and partition occurrence. Loss coefficient was measured under powered down 980 nm radiating unit on frame-controller. Transmission coefficient was measured under powered 980 nm radiating unit on frame-controller assuring EDFA amplification, and thus required output power level. Figure 5 represents the loss coefficient measurement results; Figure 6 yields the transmission coefficient results for models #1, #2 and #4. Figure 7 illustrates the assembled RoF test bench. Similar results of the mentioned coefficients for the rest of the models were obtained.

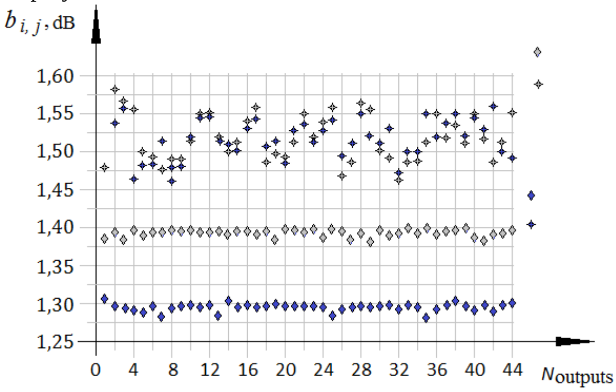


◇- Model #1 -Model #2 - Model #3

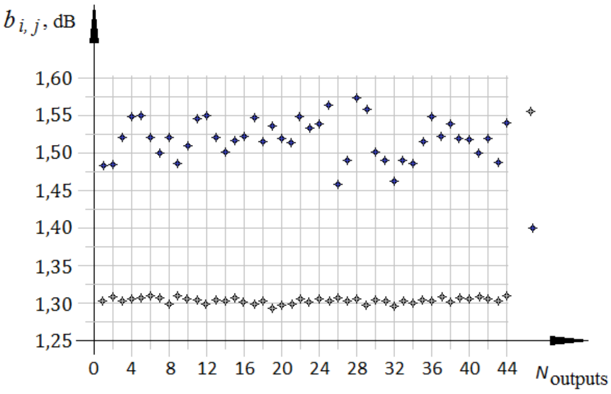


- Model #1 with FOCL-RoF test bench
- Model #1 without FOCL-RoF test bench
- Model #2 with FOCL-RoF test bench
- Model #2 without FOCL-RoF test bench
- Model #4 with FOCL-RoF test bench
- Model #4 without FOCL-RoF test bench

Fig. 5. Loss coefficient determination (with splitting) results for the OSCD models #1, #2 and #4: a) – with frame-controller employment; b) – with test bench emitter employment



- Model #1 on equipment
- Model #1 on test bench
- Model #2 on equipment
- Model #2 on test bench



- Model #4 on equipment
- Model #4 on test bench

Fig. 6. Transmission coefficient determination (with splitting) results for the OSCD models #1, #2 and #4 with test bench employment: a) – for OSCD models #1 and #2; b) – for OSCD model #4

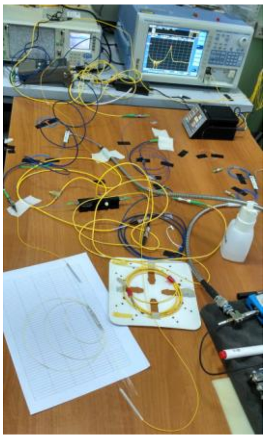


Fig. 7. Loss and transmission coefficients measurement process for the OSCD models #1 within test bench equipment

4. CONCLUSION

The results of loss and transmission coefficients measurements for designed and assembled OSCD models produced on frame-controller equipment and within the RoF test bench suggest that:

1) values of the mentioned coefficients are negligibly (no greater than 6…7%) depending on OSCD output number, which stands for sufficient homogeneity of the model assembly and, thus, acceptable technological quality of the model production;

2) these mentioned coefficients values on frame-controller equipment and the RoF test bench are also close (the difference is no greater than 15%) with and without FOCL-RoF losses. The latter assures the given results and acceptability of the mentioned models, while research and development correlate to the OSCD;

3) the above-mentioned coefficients are close (also no greater than 15%) for the OSCD models of both interferential and long-haul types, the design of the models essentially differs, though. This suggests compatibility of the OSCD designs in different tasks of the RoF segment construction.

Thus, this article presents developed schemes of optical functional devices designated for RoF antenna radio lobe management. The enumerated devices can be produced either on the basis of multiple resonant interferometer or long-haul ring topology FOCL. These options of the OSCD production were prototyped and then underwent experimental laboratory approval. As a result of approval an acceptable work capacity of the assembled models was affirmed..

3. DETAILS

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