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EVOLUTIONARY DESIGN OF SEVEN-TIER LM-MODE FILTERS OPTIMIZED WITH ORIGINAL KNOWLEDGE-BASED CAD SYSTEM

The evolutionary strategy of multi-tier WDR - filters with LM-modes, optimized with original knowledge-based CAD system designing is proposed and tested. Main point of the strategy is to solve the problem of synthesis and optimization of the seven - (or more) tiered filter through the gradual complication of the simplest - one-tiered design, which corresponds to the evolutionary principle of gradual cost function complication. The efficiency of the strategy is confirmed by the designing of three to five and seven-tier millimeter filters, which are intended for the next generation of millimeter waveband wireless systems and conform to the latest standards like ECMA- 387, WirelessHD, IEEE 802.15.3c and IEEE 802.11ad.

Keywords: Evolutionary strategies, Knowledge-based CAD system, LM-mode filters**,** WirelessHD, IEEE 802.15.3c, IEEE 802.11ad.

Introduction. The creative nature of biological evolution is demonstrated not only by the fact that it creates a surprising variety of organisms that can impress us with its phenotypic originality [1], but the fact of homological creativity of nature and the individual [2,3]. Biological evolution in the mathematical sense is the result of a phenotypes optimization period that took more than 4 billion years in the space of our planet by means of mutation genotypes. A fundamental feature of the process of evolution is compatible co-evolutionary organisms in ecosystems, because each of them other representatives of the biosphere play the role of the so-called "Cost function", which itself is subject to change due to mutation genome plasticity. Consideration of organisms as effective "solvers" problems of survival [4], led to the formation of a new direction in artificial intelligence – the so-called "Computing" is based on the model of some aspects of evolutionary mechanisms [5,6].

The observed tendency for increase in density of information channels is objective and will continue to intensify in the future as far as it ensures synchronization and optimization of industrial and technological processes in development of societies. The societies themselves possess obvious features of a super-organisms in which each active individual using his/her PC strives to integrate into Internet and telecommunications networks like in a «nervous web» of developing «global mind» [7, 8]. The evident homology of all known creative processes leads to concept of Geo-Solaris, i.e. a view of the Earth embraced with evolving living matter as an intuitively thinking brain bringing about the bio-technological mind of Noosphere [8]. A characteristic feature of this noogenesis [9] is in replication of personal intellectual potential on the level of the mankind: the world population is approaching the number of the nerve cells in an individual brain while the World-Wide Web is acquiring the structure of a neural network [10]. Actually, we observe the rapid growth of wireless networks based on dozens of different standards regulating frequency resources ranging from hundreds of megahertz to hundreds of gigahertz. Recently produced standardization of ranges 3-5 millimeter waves allows to expect dynamic growth of high – quality radio- telecommunication networks of information relaying [11-13]. Currently industrial usage of millimeter waves (predicted back in the 60s) is widespread because (1) it allows obtaining «sharply directed emission, which is important not only for radar systems but for wireless systems as well, particularly for radio relay lines»; (2) in this wave- band, «atmospheric and many types of industrial noise become insignificant; (3) with higher frequencies the density of stations in the air becomes less significant so more stations can work without interference;(4) the lover density allows using noise-resistant wideband modulation systems; (5) greater transmission speed requires greater frequency...» [14]. Such features of this waveband make it «extremely attractive for high-speed ultra-wideband transmission, including transmission of video streams from multiple video cameras, transmission of high definition video and traffic management in cellular networks. Besides, wide band allows a variety of scrambling schemes and error correction codes, provides greater choice of optimal methods for modulation and multiple access in data transfer, which allows data transmission at the specified speed with very low signal-to-noise ratio» [15]. Two most important economic factors should be briefly noted as well: there are no licenses required for usage of this waveband and the equipment necessary is quite small in size. All these circumstances caused a new «innovation wave» here resulting in its turn in great demand for high-quality hardware components [15, 16]. According to this there is a necessity in development of the proper high-quality millimeter wave components base. It is clear that the electromagnetic situation on the air requires constant improvement of receiver protection against electromagnetic interference as well as more strict requirements to transmitters, which are the sources of the interference. Traditionally these problems are solved using passive band filters mounted on receiver inputs and transmitter outputs. Among the known micro – and millimeter wave filters, the designs based on leukosapphire and quartz partially filled waveguide-dielectric resonators (WDR) pleased into cut-off waveguides are distinguished due to their general quality parameters, such as high unloaded Q's, sparse spectrum of parasitic eigen- modes and usable level of transmitted power [17, 18]. It should be noted that in the review article listed links of filter designs are incorrectly placed [19], though general bibliography contains its references. Note that the technical implementation of the WDR filters confirmed experimentally up to 100 GHz[20]. Moreover, long-term experience of their application for the defense industry of the USSR led to the development of technology supporting both microwave and microwave [21, 22] – optical of primary – dielectric substrates and of secondary – of the bars and resonators themselves [23-25]. High values of resonators Q allows to design multi-tier filters that have improved selectivity properties with maintaining of low level of insertion losses in the band-pass of 0.5-0.7 dB. In this regard, problem of the synthesis of design and its optimization according to the priority criteria, such as the shape factor or the required level of extra band attenuation at certain frequencies becomes relevant. This article proposes and confirms the efficiency of the evolutionary strategy to the synthesis of seven-tier WDR filters design with LM-modes optimized by original knowledge-based CAD system, which was used previously for the filters in a smaller number of tiers [26 - 29]. Thus, it is proposed to solve the problem of synthesis and optimization of the seven- tier (or more tier) filter through the gradual complication of simplest one-tier design that corresponds the evolutionary strategy of gradual complication of the cost function.

The disadvantages of filters designing traditional methods. The traditional methods of filter synthesis are based on various prototypes from the circuit theory with concentrated or distributed parameters. Their basic disadvantage is that they don't account for higher wave types induced on filter discontinuities. Currently, there are different CAD systems for designing active and passive microwave components. They use wide range of numerical and analytical methods and provide greater opportunities for component design but come short when it concerns computation error estimation or design optimization. The common drawbacks of direct and combined numerical optimization methods are insolvability of the problem of finding the global extremum of the objective function and exponential growth of calculation time with the increase in the number of resonators or the accuracy of calculations. Such systems usually do the optimization using gradient and probabilistic methods whose low efficiency can be explained by the fact that most alterations in the task (design) parameters done during the algorithm steps are unjustified from the physical point of view. Therefore, the development of knowledge-based optimization methods is a prospective and actual task. From a mathematical point of view, this approach is an alternative to well-known optimization methods and is also very promising for solving the problem of finding a global extremum of an objective function. For many applications, it is necessary to deal with multi-tier filters, filters based on WDR seem to be very promising. However, only three-tier и five-tier structures have been comprehensively studied so far [26 - 29]. From the fact that it was possible to develop system of the synthesis of three-tier и five- tier structure, the establishing of the systems of seven - and a multi-tier structures does not automatically follow. The problem lies in the adjustment of productions (rules) in such a way as not only to eliminate possible «ringing» of the system, but also regularize them in the correct logical order, ensuring the implementation of rule of inference, i.e. completion of designing stage at all. The number of the productions, by the increasing of the number of filter tiers by two, increases in the half or two times, in case five- tier structure it is about – from twenty five to fifty, due to significant increases in the number of possible states of the system to be optimized.

In case of seven-tier the number of productions can range from thirty five to eighty. It should be noted that the formalization of the productions requires a deep electrodynamic understanding of the physics of the process of frequency response of the multi-tier resonance structure forming, that forms a feed through filter.

The design of seven-tier WDR filter with Quasi-Modes and the method of its electrodynamicmodeling. Figure 1 presents basic design of seven-tier WDR filter with H-plane dielectric plates with quasi-LM_{101}-modes [30]. Cross-shapes of the cut-off waveguide cross-sections enable to fix there E and H-plane resonance size dielectric inserts by means of projections [30, 31]. Quartz and leucosapphire-monocrystals are used as dielectric materials in designing band-pass filters for millimeter wave band, thus ensuring that the dimensions of inserts are suitable for manufacturing process and unloaded Q of the working type electromagnetic modes is induced in the inserts. Comparative characteristics of WDR and microstrip filters, including superconducting, show the advantage of the first on the electrical parameters and justify the possibility of adapting their designs to the planar technologies [27].

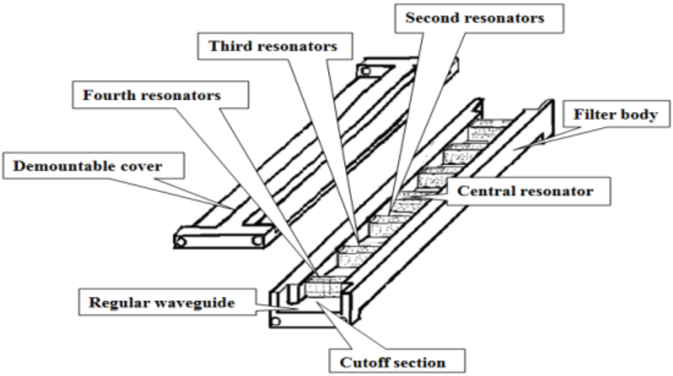

Figure 1 – Seven-tier WDR LM_{101}-mode filters geometry

In this structure, the problem of scattering H_{10} waves is solved with mode matching method described in [7, 9, 18] where electrodynamics model parameters are discussed in detail and the model validity is illustrated through comparison of calculated values with experimental results.

Knowledge-based CAD System for Seven-Tier LM-Mode Filter – Evolutionary Approach. To design such filters, we modified the knowledge-based CAD (KB CAD) system developed previously for *three*- and five-tier microwave filters [26-29]. Whereas a detailed description of this system is published in an open access journal, we provide here only its brief description focusing on the developments done to process seven-tier filters. Thus, basing on formalized physical knowledge about the behavior of coupled resonators, the KB CAD system analyses electromagnetic signal passing through a filter structure and makes decisions gradually approaching the optimal filter design through a series of changes in its geometry. The efficiency of the KB CAD system depends only on the accuracy of the solution for the analysis problem and on the accuracy with which the conditions of the rules applied match the actual data. Therefore the efficiency is rather high: the errors don't exceed 2 %. The optimization of a filter design is done in four evolutionary stages, as shown on Figure 2 and Figure 3.

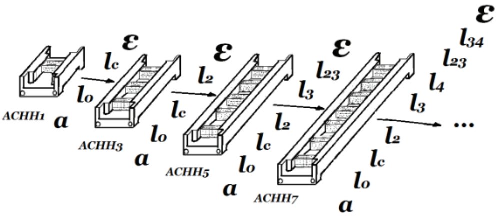

Figure 2 – The sequence of evolutionary multi-tier filters design

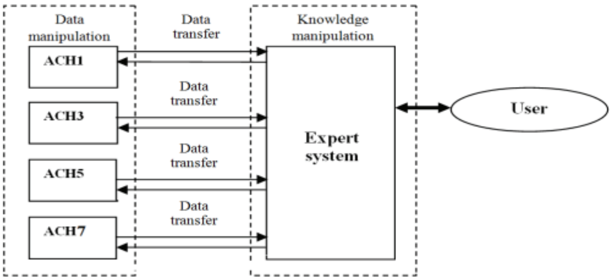

Figure3 – Logical structure of seven-tier LM-modefilter optimized with KB CAD system

First, the intellectual system calculates the length of the central resonator and searches for the optimal value of dielectric permittivity εkeeping the length of the resonator within 1 – 0.3 mm limits (depending on frequency), which is a compromise between its unloaded Q factor and manufacturability. At the second stage, the optimized parameters of one-tier filter are input to the block of three-tier filter design. On calculation of three-tier filter frequency response, the system optimizes the filter design for specified bandwidth reducing its overall length. The first two steps are repeated for different cut-off waveguide widths, thus forming a set of filter designs with their electrical properties. At the third stage, the optimized parameters of three-tier filters are input to the block of five-tier filter design. First, this block performs symmetrization and elimination of marginal and middle pulsations using logical rules like the following: IF there is poor frequency response to the left of the central frequency THEN reduce the length of the outermost resonators; IF there is poor frequency response to the right THEN increase the length of the outermost resonators.

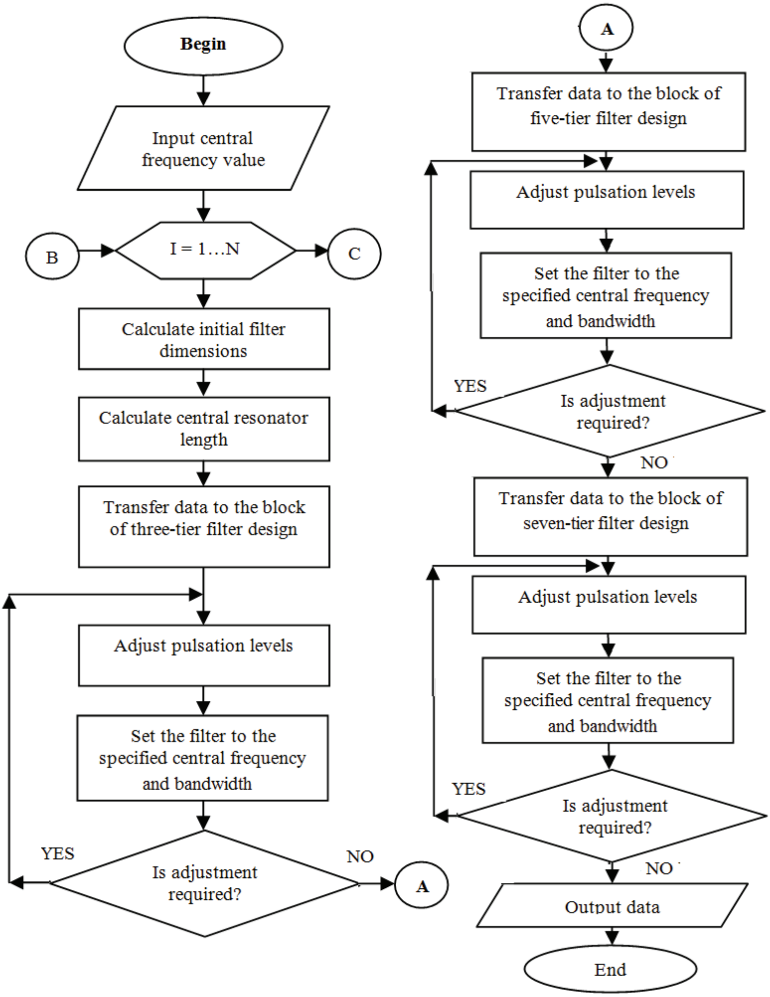

Figure 4 – The KB CAD system algorithm for seven-tier WDR filters

IF there are poor frequency responses in the middle THEN reduce the distance between central and middle resonators. Then, the filter is adjusted for central frequency with the following rules: IF central frequency is above the specified value THEN enlarge all resonators; IF central frequency is below the specified value THEN shrink all resonators; etc. At the final stage parameters of the five-tier filter are passed as the initial for the seven-tier designing, where the modified products are used similarly to the listed. A feature of this stage of the designing is a foreground formation of bandwidth with a given level of irregularity and the subsequent adjustment of the design by proportional scaling of geometric dimensions. Figure 4 shows a diagram of the above algorithm, and Fig. 5 – Fig.6 demonstrate initial and final stages of filter designing under working frequency of 83.5 GHz with 6% bandwidth.

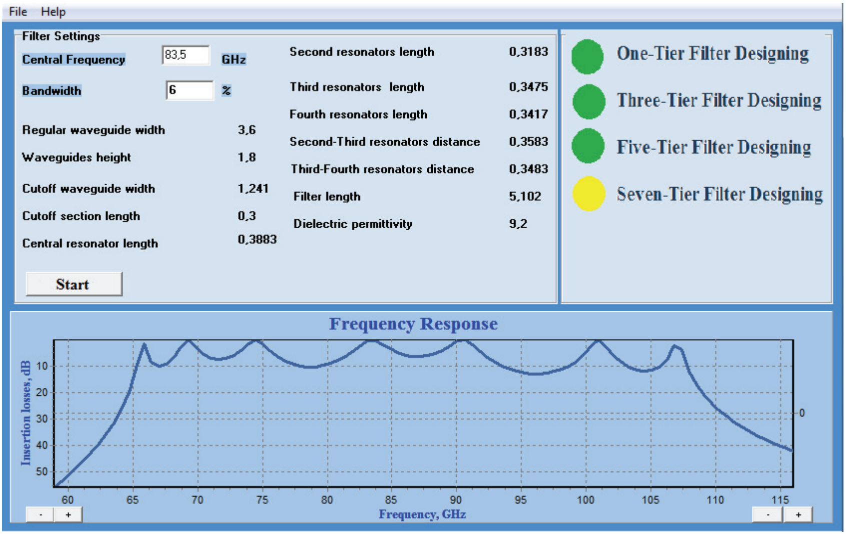

Figure 5 – KB CAD seven-tier filter optimization initial state

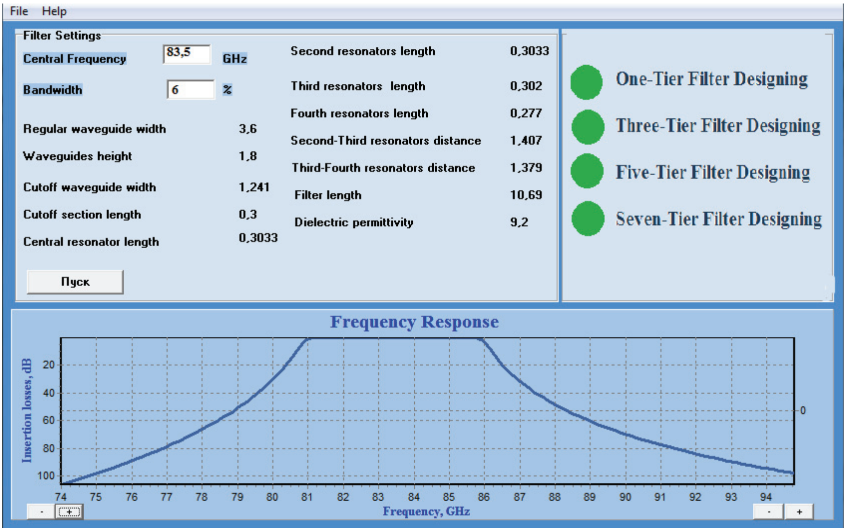

Figure 6 – KB CAD system has finished seven-tier filter optimization

The results of the evolutionary designing of seven-tier filters of E-band range. The efficiency of KB CAD system was tested in the evolutionary designing of band pass filters that can be applied as preselectors or form the basis of the new millimeter generation of radio - telecommunication systems duplexers. The frequency response of the filters shown in Fig. 7 - Fig. 11 and their structural dimensions in the Appendix.

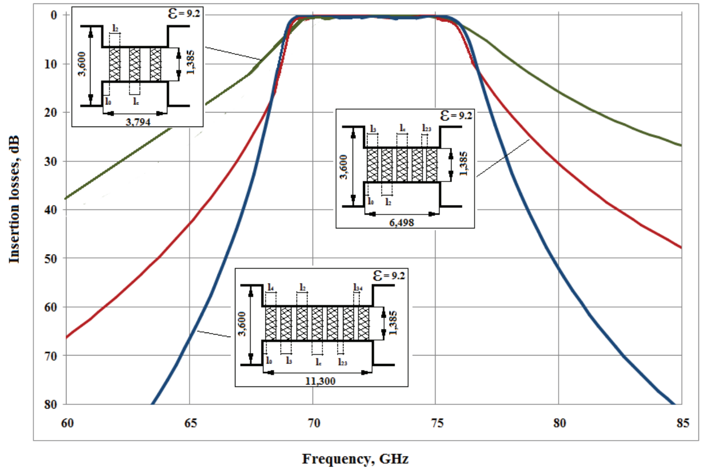

Figure 7 – Frequency responses of the filters (f = *73.5 GHz,* δf = 6.8 %) designed with the KB CAD system in three- and five- and seven tier variants: band passes

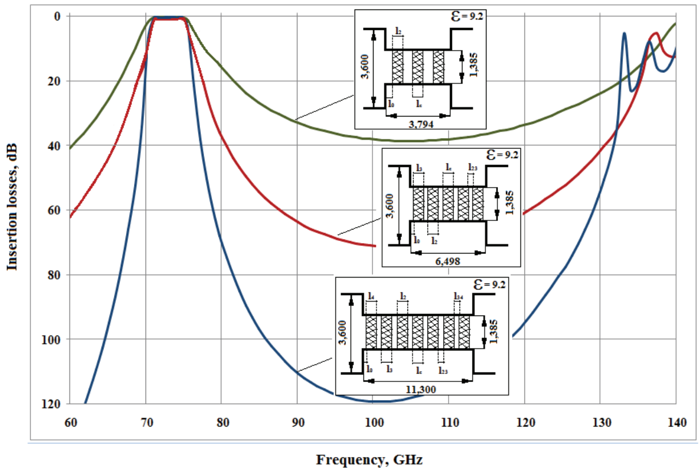

Figure 8 – Frequency responses of the filters (f = *73.5 GHz,* δf = 6.8 %) designed with the KB CAD system in three- and five- and seven tier variants: extra-band attenuations

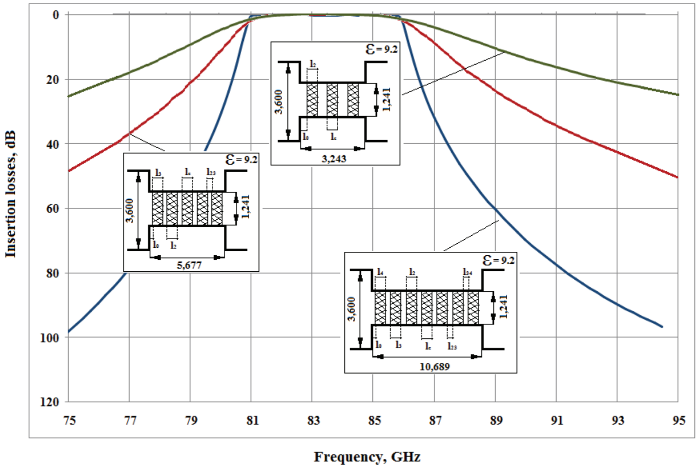

Figure 9 – Frequency responses of the filters (*f = 83.5 GHz, δf* = 6 %) designed with the KB CAD system in three- and five- and seven tier variants : band passes

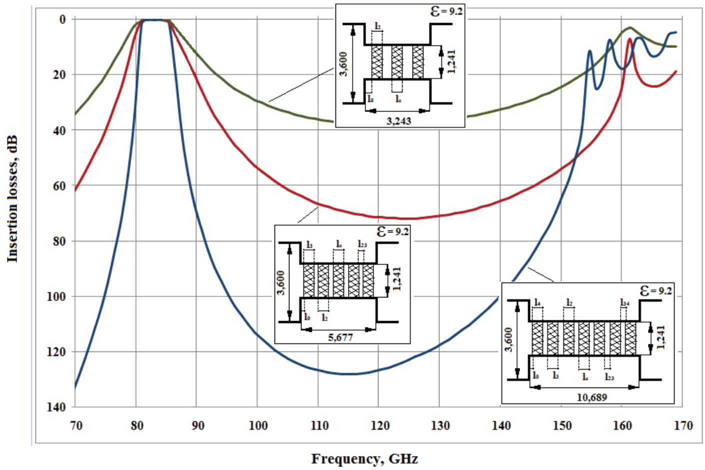

Figure 10 – Frequency responses of the filters (*f = 83.5 GHz, δf*= 6 %) designed with the KB CAD system in three- and five- and seven- tier variants: extra-band attenuations

The comparison of the calculated characteristics of three, five and seven-tier designs allows to evaluate their electrical , weight and size parameters, indirectly, the cost parameters . As we see an increase of tiers dramatically increases the steepness of the slopes of the response and respectively, the level of extra band attenuations. By increasing the number of tiers a slight approximation of the parasitic bandwidth happens due to its expansion, since at higher frequencies resonators are more connected than at lower where the attenuation of waves in the cutoff waveguide is higher. Comparison of seven-tier duplex filters demonstrates their prospect for EMC of transmitter and receiver, which are using the same antenna system , in this case will it is required some engineering redesign in order to combine them into a single waveguide tract.

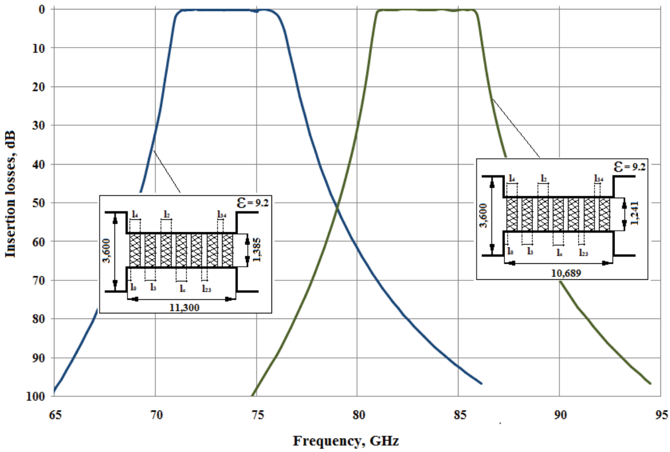

Figure 11 – Evaluation of designed filters duplex using

Conclusions. Thus, we have proved and confirmed by numerical experiments the efficiency of the evolutionary strategy to step by step designing of seven-tier WDR filters using the original KB CAD system. Corresponding to the strategy the designing of highest level filters based on the results of lower layer designs optimization, which contain the lower number of tiers and , therefore, essentially easier to optimize. The efficiency of the proposed strategy shows the results of the optimization of telecommunication filters that correspond to the latest standards like ECMA- 387, WirelessHD, IEEE 802.15.3c and IEEE 802.11ad. A comparative analysis of three-five and seven -tier filter properties and described designs of the letter, which have been provided. It seems that through the optimization with the system, we can obtain high-quality filter designs, which are fairly manufacturable as well. As a whole the successful solution of the task of developing of the knowledge based CAD system for optimization of the seven -tiers filters makes the pillar for developing of the optimization system of the nine-tier structure. Since KB CAD system is based on a deep understanding of the dynamics of the frequency of coupled resonators, which in many ways is similar to the resonators of different classes with the evanescent modes, we can expect the possibility of its modification for the multi-tier filters of other designs.

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Appendix

Table 1 – Structural dimensions of the filters optimized by KB CAD system – 73.5 GHz

Filter Settings	Three-tier Filter	Five-tier Filter	Seven-tier Filter
Central frequency, GHz	73.5	73.5	73.5
Bandwidth, %	6.8	6.8	6.8
Regular waveguide width, mm	3.6	3.6	3.6
Cutoff waveguide width, mm	1.385	1.385	1.385
Waveguides height, mm	1.8	1.8	1.8
l_0, mm	0.17	0.01	0.27
l_c, mm	0.3263	0.3813	0.3863
l_2, mm	0.3863	0.3863	0.3863
l_3, mm	-	0.3812	0.387
l_4, mm	-	-	0.345
l_{23}, mm	-	1.318	1.446
l_{34}, mm	-	-	1.419
Filter length, mm	3.794	6.498	11.300
ε, leucosapphire	9.2	9.2	9.2

Table 2 – Structural dimensions of the filters optimized by KB CAD system – 83.5 GHz

Filter Settings	Three-tier Filter	Five-tier Filter	Seven-tier Filter
Central frequency, GHz	83.5	83.5	83.5
Bandwidth, %	6.0	6.0	6.0
Regular waveguide width, mm	3.6	3.6	3.6
Cutoff waveguide width, mm	1.241	1.241	1.241
Waveguides height, mm	1.8	1.8	1.8
l_0, мм	0.12	0.01	0.3
l_c, mm	0.2383	0.3033	0.3033
l_2, mm	0.2983	0.3033	0.3033
l_3, mm	-	0.212	0.302
l_4, mm	-	-	0.277
l_{23}, mm	-	1.225	1.407
l_{34}, mm	-	-	1.379
Filter length, mm	3.243	5.677	10.689
ε, leucosapphire	9.2	9.2	9.2

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