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ANALYSIS OF RELIABILITY AND ADAPTABILITY OF MICROWAVE ATTENUATOR

The paper considers the analysis of reliability and adaptability of a microwave attenuator as exemplified by commercially available attenuators used in modern powerful wattmeters of absorbed type.

Keywords: *microwave attenuator, wattmeter, reliability, failure-free operation, durability, maintainability, adaptability, labor intensity, material consumption, energy consumption, technological cost.*

1. Introduction

At present it turns out that in Russia high-power matched resistor microwave attenuators that are still in operation have became outdated, do not meet the requirements of the consumer market and customer representatives for dual-use products, and mass production of new samples are not very cheap, or not available at all. It is worth noting that the equipment of foreign production has a cost that cannot be afforded by the majority of domestic consumers. In this context, the most urgent task is to create a fundamentally new device that does not have in its composition costly microwave components but has a sufficiently broad range of functional features suitable for solving a large range of engineering problems. And, what is very important, the engineered device should be automated and have the smallest inaccuracy of measurements [1-4].

Design and technological implementation of fundamentals proposed in the paper is needed to create a broad scaled base for scientific justification of a number of technical innovations for a radical renovation and modernization of radio metering equipment of the microwave range powerful wattmeters of absorbed power of the M3-106 type, in accordance with the norms and standards adopted in international practice and theory of modern metrology (ISO 9001, ISO 9001, GOST RV 15.002), as well as in accordance with increasing demand of more powerful, reliable, modern radio devices and microwave devices in the global market [1-4].

Powerful wattmeters of absorbed type such as M3-106 were developed in 1982, and indeed, in the days of the former Soviet Union presented a promising Microwave Radio measuring Equipment of dual purpose. At present, these devices are obsolete models that do not meet modern requirements of metrological science in the field of microwave measurement technique, and represent samples that require emergency retrofit and immediate modernization in the direction of improving their essential technical and performance characteristics [1-4].

In commercially available wattmeters M3-106 and M3-108, the key elements of absorbing incoming power are microwave attenuators [1-4] characterized by sufficiently high performance.

Let us consider the basic technical criteria for selecting the model of projected matched resistor microwave attenuator with high power dissipation using the example of the structure designed for the measuring instrument of absorbed power M3-106 and M3-108:

1) Load Resistance – $\mathbf{R_l}$ = 50 [Ом] ($R_{in} \approx R_{out} \approx$ 50 [Ом]);

2) Maximum microwave power dissipation (absorption) – $\mathbf{P_{мax\ microwave}}$ = 1,5 [kW] for a wattmeter such as **M3-106** and $\mathbf{P_{мax\ microwave}}$ = 2 [kW] for a wattmeter such as M3-108;

3) The nominal value of attenuation – $\boldsymbol{\alpha_{eff}}$ = 40 [dB];

4) Unevenness of amplitude-frequency characteristic in the frequency range of 50 [Hz] ... 1.2 [GHz] – $\mathbf{A_{max}}$ = ± 1,2 [dB] for a wattmeter such as **M3-106** and 50 [Hz] ... 2.0 [GHz] – $\mathbf{A_{max}}$ = ± 0,5 [dB] for a wattmeter such as **M3-108;**

5) The value of $\mathbf{КСВ_{U\ in}}$ ≤ 1,15 for a wattmeter such as **M3-106** and $\mathbf{КСВ_{U\ in}}$ ≤ 1,05 for a wattmeter such as **M3-108.**

Among the above mentioned optimal criteria, the maximal complication to implement them is represented by the values of maximum power dissipation and unevenness of amplitude-frequency characteristic over a wide frequency range – from 50 [Hz] and to 1.2 ... 2.0 [GHz].

In the development of microwave attenuators of increased power it is necessary to satisfy a set of mutually conflicting requirements. In the analyzed structure, the requirement to provide a high power limit is reduced to the increase of the dimensions of the attenuator at the expense of the increase of the amount of the absorbing resistor elements operated in the standard dielectric substrates. The accompanying increase of solder joints using copper (Cu) foil not only leads to difficulty in obtaining acceptable values of $\mathbf{КСВ_U}$ and unevenness of amplitude-frequency characteristic in a predetermined frequency range but also to reduction of reliability. [5]

In terms of power and thermal characteristics of microwave attenuation [1-5], its construction can be divided into two parts:

1. The input thin film resistor structures made in the form of packets and connected sequentially have total resistance $\mathbf{R_\Sigma} \approx$ 43,91 [ohm]. In case of the input and output impedance of attenuator $R_{in} \approx R_{out} \approx$ 50 [ohm], for the given resistive structures the most part of the power supplied to the input (approximately 80%) will dissipate.

The released thermal energy in these structures, in the form of Joule losses is drawn aside mainly at the expense of the mechanism of thermal conductivity and heat transfer through the side faces of packets to the base frame, which has diametric through holes for forced air cooling using a pair of high-powered fans. The design of microwave attenuator is provided by minimal thermal resistance between the side faces of the resistor boards and the walls of the wave guide.

It is interesting to note that the body itself is aligned with the heat-removing radiator implemented out of aluminum alloy **B – 95,** in the form of through holes on each side (in a microwave attenuator wattmeter of the type **M3-106** as a standard profile). Packets with resistive thin-film structures connected in series circuit represent the central vein of energy, in the form of a strip line of suspended type fastened in the middle, inside a rectangular waveguide whose walls and radiator frame are mounted on "common wire – earth".

It must be recognized that here microwave power dissipation in the form of feebly marked, multiple re-radiation of heat waves of infrared range (no more than 5%) presents in a much less degree.

2. The output resistive structure (structure of a voltage divider), which dissipates up to 19% of the power supplied, is realized on the individual (aluminum – 98% Al_2O_3) substrates soldered to the base of attenuator radiator frame. The mounting plane is oriented at the right angle to the microwaves spread, thereby introducing minimal additional mismatch on the end part of the attenuator. At the same time, the mounting area of substrates is somewhat held away from the base area cooled by fan, causing their temperature regime to be more energy consumed and strained.

In order to ensure the specified maximum power of attenuator, the end portion is realized in the form of two symmetrically shaped resistive structures connected in parallel.

2. Reliability analysis of a microwave attenuator design

The analysis of the considered microwave attenuator for **M3-106** wattmeter showed that its design **is not the best one** as to the reliability criteria given below in Table 1 compared with the proposed structure of microwave attenuator for **M3-108** wattmeter**,** according to the studies [1-9].

Requirements for the reliability of a microwave attenuator design are the following:

1. Simplifying the design and reducing the number of resistive circuit boards to minimum without worsening output characteristics through the use of rational circuit design.

2. Verification of design by the analysis of reliability at all stages of CAD.

3. The most possible extension of the tolerance for the parameters of microwave resistors.

4. The maximum possible facilitation of operation modes of microwave-film resistors at the expense of lowering operating parameters compared to the nominally calculated ones.

5. Reducing $\mathbf{T_w}$ [°C] of resistive boards in a microwave attenuator providing heat-removal and the corresponding layout and good forced air-cooling (the possibility of forced liquid or oil cooling is not excluded).

6. Elimination of vibration with the help of good damping.

7. Protection against impacts, moisture, corrosion, external radiation and electromagnetic fields.

8. Setting reliability requirements for resistor boards' components.

9. Specification of test conditions and methods of running-in of produced microwave attenuators.

Table 1. Initial data for calculation of the basic criteria and reliability indices of the attenuator design for wattmeter such as M3-106 and M3-108

Order number of ranked sequence $i=\overline{1,s}$	Particular (relative) index	Type of wattmeter	Index notation, Design formula	Measurement unit		Weighting factor (function, normalizing index weighting significance) $\phi_i = \frac{i}{2^{i-1}}$
				Hour	%	
1	**Reliability** Mean (basic) time to failure of devices	**M3-106**	$\overline{N}_б$	≥ 15000	100	1,0
			$\overline{N}_{\mathrm{Re}al}$	≥ 12000	80	
		M3-108	$\overline{N}_б$	≥ 20000	100	
			$\overline{N}_{\mathrm{Re}al}$	≥ 18000	90	
	Reliability mean factor of devices makes up:	$0 < \overline{k}_N = \frac{\overline{N}}{\overline{N}_б} \leq 1,0$			100	
		M3-106	$\overline{k}_N \geq 0,8$		80	
		M3-108	$\overline{k}_N \geq 0,9$		90	
	Base probability of absence of devices' latent defects during calibration interval equal to 24 months with average use factor 0,1 is defined	$P_{T_{пов.б}}\Big\vert_{\langle k_{использования}\rangle=0,1} \geq 0,95$			95	
		M3-106	$P_{T_{пов}} \geq 0,80$	24 months = 2 years	80	
		M3-108	$P_{T_{пов}} \geq 0,92$		92	
2	**Durability** (Base γ-percentile life of devices)	**M3-106**	$\Gamma_{ресурс.б}\Big\vert_{\gamma=95\%}$	≥ 10000	100	1,0
			$\Gamma^{\mathrm{Re}al}_{ресурс.}\Big\vert_{\gamma=95\%}$	≥ 8000	80	
		M3-108	$\Gamma_{ресурс.б}\Big\vert_{\gamma=95\%}$	≥ 12000	100	
			$\Gamma^{\mathrm{Re}al}_{ресурс.}\Big\vert_{\gamma=95\%}$	≥ 11000	90	
	Confidence probability	$\gamma = 0,95$			95	

2	Averaged factor of γ-percentile life of devices makes up:	$0<\bar{k}_{Г_{ресурс}}=\frac{Г_{ресурс}\big\vert_{\gamma=95\%}}{Г_{ресурс.б}\big\vert_{\gamma=95\%}}\le 1,0$			100	1,0
		M3-106	$\bar{k}_{Г_{ресурс}}\ge 0,8$		80	
		M3-108	$\bar{k}_{Г_{ресурс}}\ge 0,9$		90	
	Base g-percentile lifetime of devices. Averaged factor of g-percentile lifetime of devices makes up:	$0<Г_{служб.б}\big\vert_{\gamma=95\%}\le 25$, $\bar{k}_{Г_{служб}}=\frac{Г_{служб}\big\vert_{\gamma=95\%}}{Г_{служб.б}\big\vert_{\gamma=95\%}}$		25 years	100	
		M3-106	$\bar{k}_{Г_{служб}}\ge 0,48$	12 years	48	
		M3-108	$\bar{k}_{Г_{служб}}\ge 0,80$	20 years	80	
2	C-percentile storageability time of devices	Norm according to requirements specification	$Г_{сохр.отап.б}\big\vert_{\gamma=95\%}$	≥10 years	100	1,0
			$Г_{сохр.неотап.б}\big\vert_{\gamma=95\%}$	≥5 years	100	
		M3-106	$Г_{сохр.отап.}\big\vert_{\gamma=95\%}$	≥8 years	80	
			$Г_{сохр.неотап.б}\big\vert_{\gamma=95\%}$	≥3 years	60	
		M3-108	$Г_{сохр.отап.}\big\vert_{\gamma=95\%}$	≥9 years	100	
			$Г_{сохр.неотап.б}\big\vert_{\gamma=95\%}$	≥4 years	90	
	Averaged factor of storageability time of devices for not heated storehouses	$0<\bar{k}_{Г_{сохр.неотап}}=\frac{Г_{сохр.неотап}\big\vert_{\gamma=95\%}}{Г_{сохр.неотап.б}\big\vert_{\gamma=95\%}}\le 1$			100	
		M3-106	$\bar{k}_{Г_{сохр.неотап}}\ge 0,6$		60	
		M3-108	$\bar{k}_{Г_{сохр.неотап}}\ge 0,8$		80	

2	Averaged factor of storageability time of devices for heated storehouses makes up:	$0<\bar{k}_{\Gamma_{сохр.отап}}=\frac{\Gamma_{сохр.отап}\big\vert_{\gamma=95\%}}{\Gamma_{сохр.отап.б}\big\vert_{\gamma=95\%}}\le 1,0$			100	1,0
		M3-106	$\bar{k}_{\Gamma_{сохр.отап}}\ge 0,8$		80	
		M3-108	$\bar{k}_{\Gamma_{сохр.отап}}\ge 0,9$		90	
	Base g-percentile life-time of devices.	$0<\Gamma_{служб.б}\big\vert_{\gamma=95\%}\le 25$, $\bar{k}_{\Gamma_{служб}}=\frac{\Gamma_{служб}\big\vert_{\gamma=95\%}}{\Gamma_{служб.б}\big\vert_{\gamma=95\%}}$		25 years	100	
	Averaged factor of g-percentile lifetime of devices makes up:	**M3-106**	$\bar{k}_{\Gamma_{служб}}\ge 0,48$	12 years	48	
		M3-108	$\bar{k}_{\Gamma_{служб}}\ge 0,80$	20 years	80	
	Base mean time to repair of devices	$\bar{T}_{восс.б}$		≤120 min	100	
		M3-106	$\bar{T}_{восс}$	$\le\begin{pmatrix}150\\ ...180\end{pmatrix}$ $[\min]=$ $\begin{pmatrix}2,5...\\ 3,0\end{pmatrix}$ $[hours]$	125… 150	
		M3-108	$\bar{T}_{восс}$	$\le\begin{pmatrix}90\\ ...120\end{pmatrix}$ $[\min]=$ $\begin{pmatrix}1,5...\\ 2,0\end{pmatrix}$ $[hours]$	75… 100	
	Averaged factor of mean time to repair of devices makes up:	$0<\bar{k}_{\bar{T}_{восс}}=\frac{\bar{T}_{восс}}{\bar{T}_{восс.б}}\le 1,0$			100	
		M3-106	$\bar{k}_{\bar{T}_{восс}}\le(1,25...1,50)$		125… 150	
		M3-108	$\bar{k}_{\bar{T}_{восс}}\le(0,75...1,00)$		75… 100	

3	**Maintainability** (Base interchange factor by standard items or unified assemblies of devices)	**M3-106**	$K_{\text{взам.б}}\Big\vert_{\gamma_{\text{qualities\&guarantee}}=95\%} = 0,80...0,85$	80…85	1,0
			$K^{\text{Re}\,al}_{\text{взам}}\Big\vert_{\gamma_{\text{qualities\&guarantee}}=95\%} = 0,30...0,40$	30…40	
		M3-108	$K_{\text{взам.б}}\Big\vert_{\gamma_{\text{qualities\&guarantee}}=95\%} = 0,90...0,95$	90…95	
			$K^{\text{Re}\,al}_{\text{взам}}\Big\vert_{\gamma_{\text{qualities\&guarantee}}=95\%} = 0,80...0,85$	80…85	
	Beforehand known quality level and guarantees of items and units	$\gamma_{\text{qualities\&guarantee}} = 0,95$		95	
	Averaged factor of interchange by standard items or unified assemblies of devices	$0 < \langle k \rangle_{K_{\text{взам}}} = \dfrac{K_{\text{взам}}\Big\vert_{\gamma_{\text{qualities\&guarantee}}=95\%}}{K_{\text{взам.б}}\Big\vert_{\gamma_{\text{qualities\&guarantee}}=95\%}} \le 1,0$		100	
		M3-106	$\langle k \rangle_{K_{\text{взам}}} \approx 0,375...0,471$	37,5… 47,1	
		M3-108	$\langle k \rangle_{K_{\text{взам}}} \approx 0,889...0,895$	88,9… 89,5	

The number of component resistor boards based on the heat-removing dielectric substrates is understood as the adaptability of microwave attenuator where there is a possibility of process technology with the most rapid and cost-effective introduction of microwave attenuator in series production, when the launch of the finished product comes with the minimum cost, high reliability and efficiency. In this case, while evaluating the degree of design adaptability in terms of its reliability, it is necessary to proceed from the level of production technology, the degree of modernization and required accuracy class of manufacturing according to inaccuracy given in the requirements specifications for the product, and machining equipment, according to the international **(ISO 9001),** or to the Russian type of quality and standards **(RD.4110.02 OST4.0018-93-95).** It is also necessary to take into account the level of total automation and mechanization of the most time-consuming operations during mass production of component resistor circuit boards package and sections in the design of a microwave attenuator heavily used, for example, in measuring instruments of high power dissipation **M3-106** and **M3-108.**

The main task of working out the design for adaptability consists in increasing labor productivity at optimum cost savings of labor, equipment, materials and time to design, pre-production, production, maintenance and repair, while insuring other quality indicators of the product under accepted conditions of its production and operation [5-9].

3. The analysis of the adaptability of a microwave attenuator

The analysis of the considered microwave attenuator for the **M3-106** wattmeter, in view of its design features at the production, maintenance and repair, showed that its design is not the best one as to the criteria of adaptability given below in Tables 2 ... 4, compared with the design of proposed microwave attenuator for the **M3-108** wattmeter, according to the studies [1-9].

In case of quantitative assessment of adaptability indices of the design of 1 item of microwave attenuator (**IDA**), the relative indices are the most common and useful for comparative evaluation. In this case the values of relative particular indices are taken within the limits $0 < k_i \leq 1$, and increase of the value of the index $\mathbf{k_i}$ corresponds to the higher degree of **IDA.**

It should be noted that the particular indices define only one attribute (criterion) of adaptability. Unlike particular indices, complex indices define not the individual signs of adaptability, but a certain group of characteristics (criteria) of **IDA.**

Table 2. Analysis of a microwave attenuator design according to the criteria of adaptability

o/n	Adaptability criteria of devices, items, units, etc	Microwave attenuator, %	
		M3-106	**M3-108**
1	**Labor intensity** – the amount of labor spent on one piece of item	100	70…75
2	**Material consumption –** the amount of material resources needed to create and use 1 item		74…80
3	**Energy consumption –** the amount of fuel and energy resources needed for 1 item		82…85
4	**Technological cost** – the cost of resource expressions for 1 item		80…85

The method for defining the complex index of ADI of microwave attenuator as a weighted average (arithmetic mean) value of particular indices with the introduction of weighting factors is the most simple, obvious, easy to mechanization and computerization of computational work, therefore it is widespread in the electronic industry in serial manufacturing of measuring instruments of increased absorbed power of **M3-106** and **M3-108**. In this case, the limits of the complex index, as well as for particular indices, which it generalizes, are the same $\left(0 < K_{ADI} \leq 1\right)$. The ADI level is defined as the ratio of the achieved adaptability index $\mathbf{K_{ADI}}$ to the value of base or normative index $\mathbf{K_б}$ given in preliminary specifications (**PS**), and it must satisfy the following condition (1):

$$K_y = \frac{K_{ТКИ}}{K_б} \geq 1,02. \quad (1)$$

The procedure for determining the level of adaptability $\mathbf{K_y}$ of the item design (microwave attenuator) is clearly considered in Tables 3 and 4, at setting rigid conditions.

Table 3. Source data for calculation of adaptability indices of microwave attenuator design

Order number	Parameter designation	Parameter symbol	Parameter value for wattmeter	
			M3-106	M3-108
1	The number of microcircuits and micro assemblies in the item	$Н_{мс}$	0	0
2	The number of radio components, including modules and micro modules	$Н_{ЭРЭ}$	282	190
3	The number of mounting operations that can be performed by mechanized or automated process	$Н_{м.монт}$	1	6
4	The number of operations of a certain type	$Н_0$	3	7
5	The number of individually attached components, preparation of which for mounting can be carried out by power-operated or automated means, including the elements that do not require preparation (relays, connectors, sockets, etc.)	$Н_{м.подг}$	15	164
6	The number of dimension types of printed circuit boards	$Н_{т.п.п}$	2	2
7	The number of dimension types of radio component s	$Н_{т.ЭРЭ}$	11	4
8	The total number of printed circuit boards in the item	$Н_{п.п}$	109	59
9	The number of operations control and tuning, which can be carried out by mechanized or automated means	$Н_{м.к.н}$	2	57
10	The number of standard processes		5	46
11	The total number of processes	$Q_п$	60	50

The values of the basic complex indices of maintenance workability of microwave attenuator design are determined from the following conditions:

Table 4. Composition of additional indices of attenuator design adaptability for wattmeter such as M3-106 and M3-108

Order number of ranked sequence $i=\overline{1,s}$	Particular (relative) index	Index designation, design formula and the value for wattmeter		Weighting factor (function normalizing index weighting significance $\phi_i = \frac{i}{2^{i-1}}$
		M3-106	**M3-108**	
1	Use factor of microcircuits and micro assemblies	$k_{исп.мс} = \frac{H_{мс}}{H_{мс} - H_{ЭРЭ}}$		
		0	0	

<table>
<tr><td rowspan="2">2</td><td rowspan="2">Coefficient of automation and mechanization of mounting</td><td colspan="2">$k_{м.монт} = \frac{H_{м.монт}}{H_0}$</td><td rowspan="2">1,0</td></tr>
<tr><td>1/3</td><td>6/7</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Coefficient of mechanization and automation of preparation of individually attached components and mounting</td><td colspan="2">$k_{м.подг} = \frac{H_{м.подг}}{H_{ЭРЭ}}$</td><td rowspan="2">0,75</td></tr>
<tr><td>15/282</td><td>164/190</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Coefficient of automation and mechanization of control and adjustment</td><td colspan="2">$k_{м.к.н} = \frac{H_{м.к.н}}{H_0}$</td><td rowspan="2">0,5</td></tr>
<tr><td>2/3</td><td>57/7</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Coefficient of repeatability of microcircuit and micro assemblies</td><td colspan="2">$k_{повт.ЭРЭ} = 1 - \frac{H_{т.ЭРЭ}}{H_{ЭРЭ}}$</td><td rowspan="2">0,3125</td></tr>
<tr><td>271/282</td><td>186/190</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Coefficient of repeatability of printed circuit boards</td><td colspan="2">$k_{повт.п.п} = 1 - \frac{H_{т.п.п}}{H_{п.п}}$</td><td rowspan="2">0,1875</td></tr>
<tr><td>107/109</td><td>57/59</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Application factor of standard processes</td><td colspan="2">$k_{т.п} = \frac{Q_{т.п}}{Q_п}$</td><td rowspan="2">0,109375</td></tr>
<tr><td>5/60</td><td>46/50</td></tr>
<tr><td colspan="2" rowspan="2">Complex index of item design (microwave attenuator) adaptability</td><td colspan="3">$K_{ТКИ} = \frac{\sum_{i=1}^{s=7}(\phi_i \cdot k_i)}{\sum_{i=1}^{s=7}\phi_i}$</td></tr>
<tr><td>$\approx \frac{1,200}{3,810} \approx 0,315$</td><td colspan="2">$\approx \frac{6,164}{3,810} \approx 1,618$</td></tr>
<tr><td colspan="2" rowspan="2">The adaptability level of item design (microwave attenuator)</td><td colspan="3">$K_у = \frac{K_{ТКИ}}{K_б}$</td></tr>
<tr><td>$\approx \frac{0,315}{0,7} \approx 0,450 < 1,020$</td><td colspan="2">$\approx \frac{1,618}{0,7} \approx 2,311 \geq 2,0 \geq 1,020$</td></tr>
</table>

1. $K_б = 0,6...0,7$ – for the stage of development of design documentation for the implementation level, in the form of technical project;

2. $K_б = 0,7...0,8$ – for the stage of development of design documentation for the level of development as a work paper.

The level of adaptability $\mathbf{K_y}$ of microwave attenuator can be determined by one or more particular and complex indices taken as evaluation criteria **ADI** in **PS** (specifications) for the development and manufacture of a microwave attenuator. The acceptable limits of $\mathbf{K_y}$ values for microwave attenuator correspond to the set base indices $\mathbf{K_б}$, according to the studies [7-9].

The level of adaptability $\mathbf{K_y}$ of microwave attenuator defines the capability of production capacities of radio electronic companies and firms to the preparation and industrial production of equipment:

1. If $K_y \geq 2,0$, there is a high level of attenuator design adaptability;
2. If $1,02 \leq K_y < 2,0$, the low level of attenuator design adaptability is detected;
3. If $0 < K_y < 1,02$, the attenuator design is not practically feasible.

The composition of the basic indices of design adaptability, their optimal values and limit deviations are defined for the same types of items – microwave attenuators approved by industrial standards (**OST**). In this case, the optimal values of basic indices **ADI** – $\mathbf{K_{б\ optim}}$ are specified in **PS** for the development and mass commercial implementation of an item – microwave attenuator.

With the coefficients $k_{м.монт} \approx 0,333... < 1,0$ and $k_{м.подг} \approx 0,053... < 1,0$ there is a production need for microwave attenuators' application in a single and small-scale production, with high proportion of manufacturing operations, using manual labor (preparation, tool set, assemblage, mounting, repair, adjustment, etc.), sometimes reaching up to 95 ... 97% in some operations. It is worth noting that there is an extremely low value of recurrence of similar and primitive manual operations in the general process at manufacture of needed measuring instruments of high power dissipation, where microwave attenuators of absorbed type $0 < k_{повт.р.о} = 0,5\,(50\,\%) < 1$ are widely used. The following regularity has been experimentally detected – the higher the accuracy class of microwave attenuators (less inaccuracy in the results) is, the more increasing is the degree of labor-intensive and low-end manual processes for the industrial production of devices [7-9].

Since $K_y \approx 0,450 < 1,020$, then the relation (1) is not fulfilled, therefore, the pilot design of microwave attenuator [6] does not meet the requirements of adaptability in series production of **M3-106** wattmeters. The design of the investigated sample of attenuator is not practically feasible!

On the contrary, since $K_y \approx 2,311 \geq 2,0 \geq 1,020$, then the known relation (1) is already fulfilled, and therefore, the pilot design of microwave attenuator [5-9] fully meets all the requirements of adaptability during series production of **M3-108** wattmeters at factories of the radio industry in Russia. In this case, the high level of adaptability of desired attenuator design is revealed.

The requirements for the design adaptability of microwave attenuator include the following extending range of activities to reduce the labor content and cost of manufacturing and installation on the manufacturing entity [8]:

1. Increasing series of microwave attenuator and its components in the manufacture (processing, assemblage, testing) by standardization, unification and ensuring design similarity (currently there is only a single or small-scale production).
2. Restricting the range of constituents of structural elements and materials used in the microwave attenuator.
3. The introduction of high-performance and low-waste technology solutions based on typing of processes and other advanced forms of their organization.
4. Application of high-performance standard technological equipment to ensure the best level of mechanization and automation.

5. Application in developed design of microwave attenuator introduced in the production of design solutions that meet modern requirements.

6. The use of design and technological solutions allowing to reduce the cost of providing access to constituents and transport microwave attenuator in assembled form or in the form of finished constituents that do not require during the installation at the site disassembling or adjustment operations (fitting operations of microwave attenuator units with follow-up its test in the structure of the microwave path of measuring instruments of high power dissipation, to avoid completely at present is not possible).

When solving the main task of evaluating **ADI** (microwave attenuator), it is necessary to take into account that any product is to be regarded as objects of design, production and operation [8].

When considering the microwave attenuator as a design object, it is necessary to be involved in the development of the design at all stages of development, to be clearly aware of the specific character of each stage of the design.

If the microwave attenuator is regarded as an object of production, it is necessary to take into account: types and methods of obtaining work pieces, types and methods of processing, types and methods of assemblage, control and testing, the possibilities of automation and mechanization, conditions of material security of production [8].

When assessing the adaptability of microwave attenuator, which is the object of field application, the following is analyzed: the convenience of microwave attenuator for control and check up of operability, reduction of labor intensity of preventive maintenance, convenience and reduction of repair, insuring of safety requirements, transportability [8].

Based on the above facts, it follows that the design of microwave attenuator has significant shortcomings, which apparently can be avoided even at available objective difficulties of developing harmonized microwave attenuators of increased power dissipation.

The design of calculated microwave attenuator has revealed a number of shortcomings [1-4]:

1. Presence of shielding foil along the entire length of microwave path and under the boards.
2. A large number of specific surface resistivity of resistors.
3. Setting the nominal values of resistors in packs A1 ... A6 with two decimal places [ohm].
4. Tight-tolerance fit for permissible spread of resistors (± 1 ... 3%).
5. A significant thermal loading of resistors R7 ... R10 on the boards.

The listed shortcomings result in increase of labor intensity, cost of manufacturing and reduction the reliability of a microwave attenuator.

Furthermore, the presence of numerous soldered joints and with bridges and solder alloys with different melting points, the use of a double sided coated foil **tin – bismuth (Sn – Bi)** does not exclude the possibility of carrying out the individual connections with an increased contact thermal resistance. In this case, high levels of electrical and thermal load typical for the attenuator, the **Sn – Bi** coating peeling is possible, and further deterioration of electromechanical contacts, resulting in further heating of the heat dissipating element. First of all, it concerns the end portion of the attenuator (resistors R_7 ... R_{10}), boards A_7 ... A_{10} which are soldered to the base through a pad of foil, which acts as a shield layer.

In the calculated construction, there is no need to install a layer of shielding foil directly under the boards A7 ... A_{10}, it is enough to solder it to the base nearby of these boards. Experimental verification of the simulated version of the design, **M3-108**, in which the boards A7 ...A_{10} directly soldered to the base, showed good performance of the attenuator for levels $\mathbf{P_{Нч}}$ = 2,0 [kW] and for short-time (t ≤ 30 [min.]) at $\mathbf{P_{Нч}}$ = 2,5 [kW] and in microwave mode. In the latter case the deterioration of frequency characteristics and $\mathbf{КСВ}_U$ was not observed.

4. Conclusions

1. 9 points of reliability requirements are offered for the construction of the projected microwave attenuator at the stage of design and technological development.

2. The analysis and calculation of the main reliability indices of for the newly designed structure of microwave attenuator (Table 1) is proposed according to the following evaluation criteria of reliability: reliability, durability and maintainability.

3. The analysis and calculation of microwave attenuator design adaptability (Table 2) is proposed according to the following evaluation criteria: labor content, material consumption, energy content and technological cost.

4. A method for determining the complex index of **ADI** is investigated, with respect to the compared designs of basic outdated sample and re-designed the newest type of microwave attenuator.

5. The paper considered a comparative analysis of the reliability and microwave attenuator design adaptability on example of commercially available attenuators used in wattmeters of outdated type **M3-106** and the newest type of **M3-106**.

6. During the comparative analysis of the basic characteristics of microwave attenuators it became obvious that in the frequency range up to **2 [GHz]** at rated dissipation power of radio signal up to **2 [kW],** the most optimal model, in terms of conformance as to input and output when $R_{вх} \approx R_{вых} \approx 50$ **[Ohm],** is assumed to be the designed microwave attenuator **M3-106**, which on the average has $КСВ_U = 1{,}05 \ldots 1{,}07$ and **unevenness of amplitude-frequency characteristic spans ± 0,5 [dB].**

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