State diagnostics of RTD based on nanoscale multilayered AlGaAs heterostructures

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Abstract. In the present work the problems of technical diagnostics of RTD based on nanoscale multilayered AlGaAs heterostructures are being solved. The technique and the algorithms of RTD functionality region developing are being considered.

1. Introduction
One of the most promising elements of SHF and EHF radioelectronics is a resonant tunneling diode (RTD). RTDs can be regarded as nanoobjects due to the physical phenomenon of electron resonant tunneling occurring in resonant tunneling structure, which consists of the layers with the thicknesses from one to dozens nanometers [1-6].

The prospects of RTD applications for modern radioelectronics are caused by the following aspects:
- RTD operates in a temperature range and under other external effects required for technical applications;
- technologies and facilities for RTD production are validated in the framework of micro and nanoelectronics technologies;
- limiting operating frequency of RTD reaches up to THz units;
- changing the heterostructure layers parameters (thickness, chemical composition), one can manage the IV-curve shape and create diode with optimal IV-curve for the exact type of nonlinear transformation.

In [1-6] it is shown, in particular, that the possibility of IV-curve optimization as well as declining section presence in it allow creating a number of nonlinear SHF radiosignal transformers with improved characteristics based on RTD. A set of possible nonlinear transformations with RTD usage is very wide: radiosignals generation, frequency modulation, mixing of radiosignals, amplitude detection, rectification, frequency tags grid generation etc.

The task of assignment parameters improvement by usage of a new domestic hardware components is particularly true for space radioelectronic systems, for which an emergence of qualitatively new functions, increased requirements to accuracy and effectiveness of a task performance, intensification of operational modes are characteristic. Especially rigid demands are made to the reliability of space radioelectronic systems. On the one hand, they are dictated by hard exploitation conditions, on the other hand - by stepped-up active shelf periods of space objects. Maximum consistent and complete reliability parameters of radioelectronic systems are usually obtained as a result of exploitation. However, obtaining of such information takes time. In many cases, traditional test methods do not allow confirmation of radioelectronic systems reliability target due to hidden defects presence as well.
One of the most promising direction in the development of reliability and quality estimation methods of space-related application radioelectronic systems is prediction of their further condition.

The problem of the technical system reliability increase with reliability prediction development on specified exploitation period in specified conditions is solved by technical diagnostics (TD), the scientific base of which are outlined particularly in [7].

2. Results
Technical diagnostics solves many different problems, which are intersected with the problems of other scientific disciplines. One of the main problems of TD is the identification of the object state under conditions of limited information. Object state identification is based on identification algorithms, which are usually considered as classification problems.

Identification algorithms in technical diagnostics are based on the diagnostic models, which establish relation between object state and its representation in the diagnostic signals dimension. An important part of identification problem is the rules of decision making (decision rules). Enumerated elements of the TD structure need to be developed regarding to the specific object of diagnostics. In this work, the major elements of TD structure regarding to RTD as a part of SHF radio signal mixer are considered. Herewith, two hypotheses are accepted:
- Reliability of RTD and radio signal mixer are based on gradual failure model.
- Degradation of radio signal mixer parameters is determined by degradation of RTD. Degradation of RTD leads to the changes of its IV-curve shape, resulting in mixer parameters changes. The failure of mixer and RTD occurs, when at least one of the mixer assignment parameters falls outside of set limits range (region of functionality).

2.1. Decision making rules
The rules of decision-making are meant for decision making of RTD IV-curve location in the region of functionality $F$. Figure 1 shows in a simplified manner IV-curves of RTD used in mixers and conditionally marked regions of functionality $F$, correct operation $CO$, catastrophic failure $CF$.

![Figure 1. IV-curves range of RTD used in mixers.](image)

RTD IV-curves rating depends on radio signal mixer characteristics based on it. Mixer functionality is determined by the following main parameters [8] conversion loss, noise factor, service band, SWR of input and output, suppression of signal on image channel, suppression of intermodulation components, signal-heterodyne channels isolation, dynamic range, and required power of heterodyne.
In this paper, conversion loss $L_s$, dynamic range $P_{IP3}$, input signal reflection factor $K_{ref}$ are considered as the appointment parameters of a mixer. Consider that the region of mixer functionality is determined by following conditions:

\[
L_s \leq L_{s \text{tol}}, \quad (1) \\
P_{IP3} \geq P_{IP3 \text{tol}}, \quad (2) \\
K_{ref} \leq K_{ref \text{tol}}. \quad (3)
\]

Decision making algorithm of relating RTD IV-curve to a certain category is shown in figure 2.

**Figure 2.** Decision making algorithm.

Special feature of decision making of the RTD IV-curve classification involves region of functionality $F$ transformation from mixer parameters dimension into RTD IV-curves plan, so that one point in mixer parameter dimension $\{L_{s i}, P_{IP3 i}, K_{ref i}\}$ corresponds to one RTD IV-curve $I_i(U_i)$.

On the first stage, a RTD IV-curve is measured, which is used in the program module, where mixer characteristics are calculated. Particularly, MWO system, widely used among the developers of SHF hardware, could be used for this particular task [9].

The electrical parameters (1-3) are the mixer modelling results.
In the following algorithm module calculated mixer characteristics are compared with the limitations (1-3). If the parameters (1-3) are fallen within corresponding limitations, it is concluded that the mixer parameters and RTD IV-curves are laid in functionality region $P$; if any of mixer parameters is out of the limitations framework, it is concluded that mixer parametric failure is detected and RTD IV-curve is related to $CO$ or $CF$ region.

In general, the program module of a mixer characteristics modelling can be replaced by measuring module, however such a replacement deals with necessity of a mixer mocking-up and RTD integration in it.

2.2. Detection algorithm

The algorithm is designed to forming RTD functionality region. Above mentioned decision making rules are the integral part of detection algorithm shown in figure 3.

![Detection algorithm diagram](image)

**Figure 3.** Detection algorithm.

The algorithm assumes carrying of RTD accelerated testing, during which the destabilizing impacts and accelerating degradation processes are applied to RTD. While choosing the type, intensity and impact duration only the characteristic of normal exploitation conditions which may cause mechanism failure of the device are considered [10]. Practically, it is high temperature tests that are frequently used for degradation process of semiconductor devices acceleration. The number of the impact cycles is chosen to be no less than 4-5 in order to estimate the RTD IV-curve kinetics. Minimal intensity and impact duration are set to such a value, so that the variation of IV-curve induced by the impact is no
less than the measuring instrument error rate; maximum intensity and impact duration are limited by
the risk of IV-curve overranging of F region for one impact cycle. Thus, at the input of the «decisive
rules» unit goes RTD IV-curve after one cycle of destabilizing impacts, at the output of the unit–classification of RTD as failed or working component.
Termination of the cycle «destabilizing impact – decision making rule» is implemented as soon as
at the time moment $t_i$ the failure of mixer and RTD is detected. IV-curve, corresponding to the time
moment $t_i$ is a boundary of RTD functionality region.

3. Conclusions
Consideration of the proposed technique and the algorithms in relation to mixer RTD does not limit
their generality. Considered technique and algorithms may be used in developing RTD’s region of
functionality as a part of any nonlinear device, which characteristics depend on the shape of RTD IV-
curve.

The considered technique and algorithms may be used in manufacturing process while planning of
control technological operations for hardware components.

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