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The Design of the LNA based on the Domestic ECB Using CAD AWR

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Abstract. The purpose of this work was to design a low noise amplifier (LNA) based on the domestic electronic component base (ECB). The LNA is in the form of microassembly. This microassembly was designed on the base of the transistor of 3П398 type (manufactured in Veliky Novgorod). The results of this research showed that the microassembly based on the domestic ECB meets the requirements of the receiver. The paper presents the design solutions used in the creation of the X-band LNA. Moreover, the results of calculations characteristics of amplification, noise temperature, matching from input and output and assessment of stability are presented. The design work was made by means of CAD (computer-aided design) "MWO AWR". As a result of this study, this LNA was compared to foreign analogues and it turned out that this product is at the same level as foreign analogues used in space technology. In addition, a method of increasing the lifetime of circuit operation of transistors is demonstrated.

Keywords: LNA, VSWR, transistor, HEMT, ECB, radiation, lifetime

Introduction. State of a problem

As operational requirements to the low noise amplifiers (LNA), manufactured according to the technology of hybrid integrated circuit (HIC) grow, the attention to the accuracy of calculation of electric characteristics and both the design of the amplifier in general and each of its elements in the frequency range from a direct current to the boundary frequency of the used transistors (f_b) considerably increases. Moreover, at rather small working bandwidths due to increase in accuracy of calculations there is a possibility of fuller use of properties of transistors and the LNA scheme to meet contradictory requirements for k_n (noise factor), k_a (amplification factor), VSWR (voltage standing wave ratio), and work stability.

Nowadays the following main requirements to the LNA parameters for the majority of communication systems of centimeter range are present:

k_a = 20–30 dB,

k_n = 0.8–1.2 dB,

VSWR = 1.2–1.4.

In general, monolithic microcircuits (MMC) and modules of many foreign firms meet these requirements. The examples of their characteristics are given in Table 1 and in Fig. 1.

Table 1. Low noise VHF-microcircuits of foreign production

Name	Characteristics			
	Gain, dB	k_n, dB	VSWR	R1, dBm
HMC753LP4E Hittite	14	2	2.7	15
HMC903 Hittite	19	1.6	2.3	16
CHA3666-QAG UMS	21	1.8	2	16
CGY2120XUH/ C1 Ommic	13.2	0.5	3	12
AMF-5F-04000800-07-10P Miteq	50	0.7	2	10

The unification purposes are performed in monolithic devices owing to simplification of the structure of the matching circuits in the wide range of frequencies. The parameters of the given products of UMS and Miteq companies are unique in their own way; however, their working frequency range is slightly lower than necessary for the device under development.

Apart from political (imposing of sanctions) and the financial (high price) reasons influencing a possibility to use foreign MMC, there are also purely technical reasons according to which their application is not considered to be an optimal solution.

Certain technological aspects of installation of the microcircuits without output UMS and Hittite, in particular, soldering control and counteraction to diffusion processes in low capacitance gaps of operation in the conditions of space production are considered to be for a long time to be technical reasons. Big dispersion power (about 3 W) for very small sizes of the case in case of using MMC Miteq and micron thickness of the transmission line inside MMC are a problem, because it bears potential unreliability in the long term. The requirement for providing the acceptable loadings out of the required working system bandwidth, but inside the band pass of a chip, is also critical.

With collapse of the USSR, the production of the Russian electronic component base (ECB) has been almost turned down.

During the last 20 years, the ECB (from 80 to 90%) used onboard was delivered from abroad. Often the components of the Industrial type, after carrying out the corresponding tests, were used for cost reduction. In especially responsible cases, the components of the Space type, acquired at very high price, were applied. Due to the last geopolitical risks, such approach becomes less justified.

A calculation method of the LNA using domestic ECB

In this work one of the key elements of a satellite communication system – the unit of the X-band LNA built entirely on the domestic modern ECB and meeting the parameters of the world requirements – is considered.

As a rule, the range of the used frequencies in space communication lines does not exceed 10% of the transistor working bandwidth. Thereof, potential properties of the transistor can be implemented in preferable way. This can be observed in the form of the tendency of the nowadays in foreign developments when LNA designing for the solution of priority tasks.

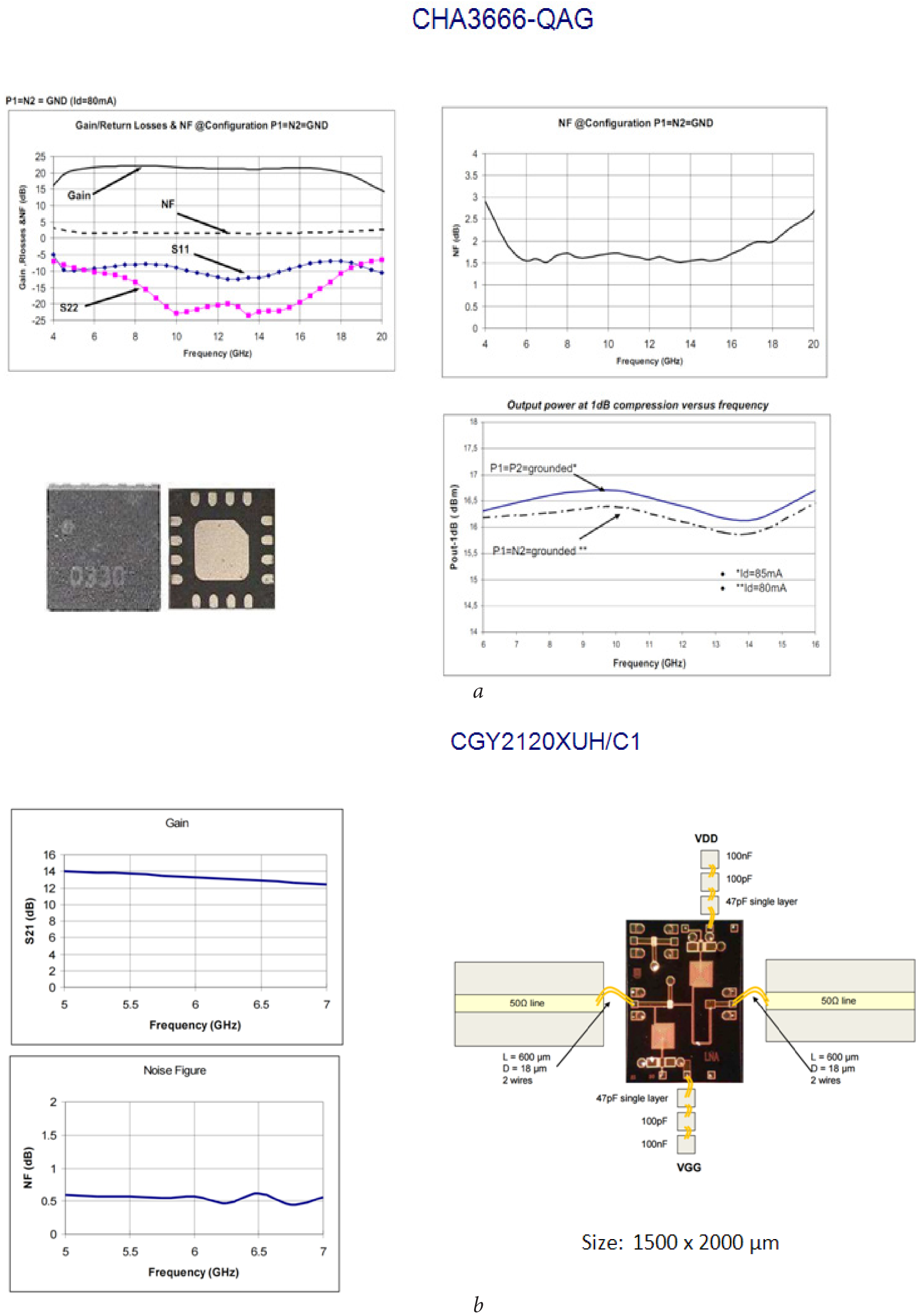
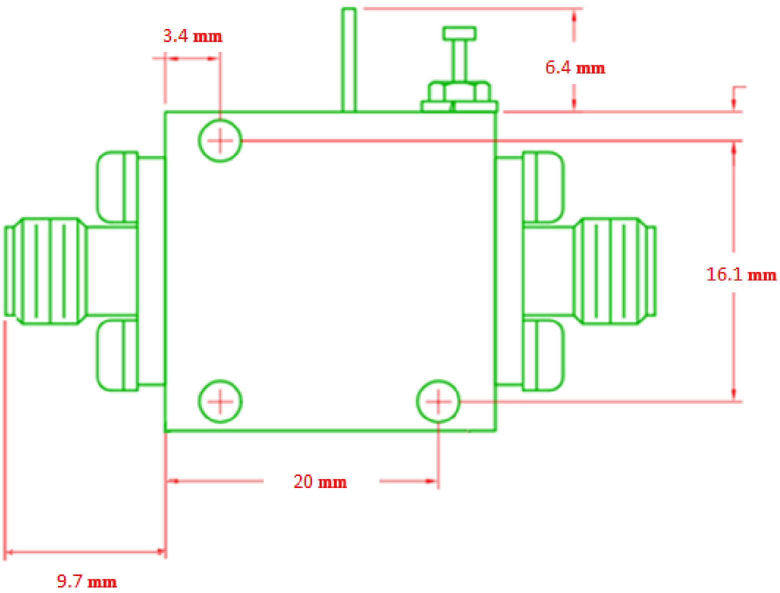


Fig 1. Parameters detailing of low noise MMC of foreign production: *(a)* copulate amplifier of UMS company, *(b)* amplifier made in crystal of Ommic company.

AMF-5F-04000800-07-10P

Description:	Amplifier
Specifications at	23 °C:
Frequency:	4 to 8 GHz
Gain:	50 dB min.
Gain Flatness:	1.5 dB+/- max.
Noise Figure:	0.7 dB max.
Noise Temperature:	50.7 K max.
VSWR In:	2:1 max.
VSWR Out:	2:1 max.
P1dB Out:	10 dBm min.
Voltage:	15 V nom.
Current:	200 mA nom.
Outline Drawing:	131581-5
Operating Temp:	-40 to 75 °C



c

Fig 1. *(c)* amplifier in assembly of Miteq company.

The choice of the transistor for implementation of the long-term project does not give a wide field for activity.

This work describes the possibility of the HIC LNA development using HEMT transistors of domestic production (Planet Argall, Veliky Novgorod) and application of the dialogue mode with CAD MWO AWR. Types and the main parameters of transistors are given in Table 2 [1].

The following provisions are offered to achieve the acceptable result:

1. In the ranges of frequencies that are 2-3 times smaller than the boundary frequency of the used transistors in HIC on VHF there are difficulties with autoshift at frequencies smaller than f_b due to parasitic resonances of a parallel type in blocking capacitors. This leads to instability of the amplifier and unacceptable unevenness of K_n and K_a characteristics, if the resonance is near to a working band. For example, the K10-71 capacitor with capacity C = 5.1 pF, dimensions 1.5 x 1.5 x 0.2 mm has the reactance presented in Fig. 2.

Using such capacitor in an autoshift chain in the two-stage LNA of the X-band leads to emergence of instability and sharp increase in K_n (see Figs. 3a, b).

Therefore, an autoshift is applied, as a rule, only in LNA working at those frequencies where it is possible to choose the capacitor for grounding the source of the transistor with the first consecutive resonance getting to a working frequency band, and the parallel resonance has to be outside f_b.

2. The transistor case considerably transforms its small-signal parameters and leads to decrease in achievable characteristics. If measurement of

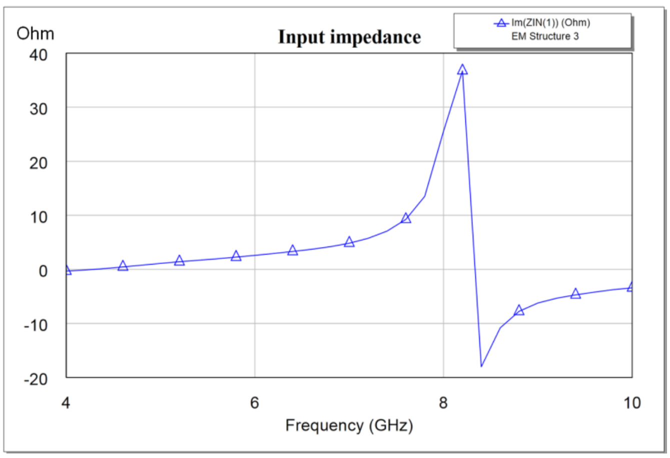
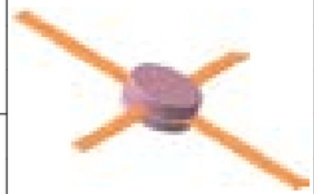
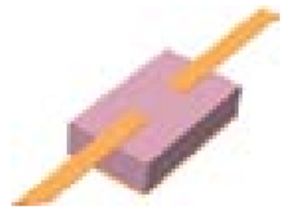


Fig. 2. An example of the spurious resonance of the parallel type in the blocking capacitor

Table 2. Low noise VHF transistors of dual application

Name of the item	Δf_p, GHz	f_{meas}, GHz	Electrical parameters values ($T = 25 \pm 10$ °C)					Case
			$K_{Ш\ min}$, dB (max)	Kap_{opt}, dB (min)	S, mA/B (min)	P_{output}, mW (min)	P (dispersion), мВт	
3П 398А-2	4–18	8	0.4 (type)	K_{yPmax} 12.9	60	–	50	023 
3П 398Б-2	4–18	12	0.45 (type)	K_{yPmax} 12.9	30	–	50	
3П 373А-2	1–8	4	0.4	11.5	30	–	100	
3П 373Б-2			0.5	11				
3П 373В-2			0.6	10				
3П 374А-2	4–18	12	0.85	9	15	–	35	
3П 374Б-2			1	10				
3П 374В-2			1.2	8.5				
3П 397А-2	0.1–6	0.1–6	0.3	16	30	30	200	022 
3П 398В-2	12–25	18	0.95 (type)	K_{yPmax} 11.3	24		50	
3П 385А-2	12–25	18	0.8	9.5	15	–	35	
3П 385Б-2			1	10				
3П 385В-2			1.2	8.5				
3П 618А-2	0.5–4	0.5–1	0.3	18	60	500	1000	
3П 618Б-2		2	0.5	15		250	500	
3П 386А-2	18–30	25	1.05	8	10	5	30	010 
3П 386Б-2			1.25	7.5				
3П 386В-2			1.5	7				
3П 398Г-2	25–35	30	0.8 (type)	K_{yPmax} 9.3	20	–	30	
3П 618В-2	1–10	4	0.7	12	60	150	300	
		8	1.5	6		100		
3П 389А-2	25–40	37	2.5	6	5	–	20	
3П 389А-5			2	6.5				

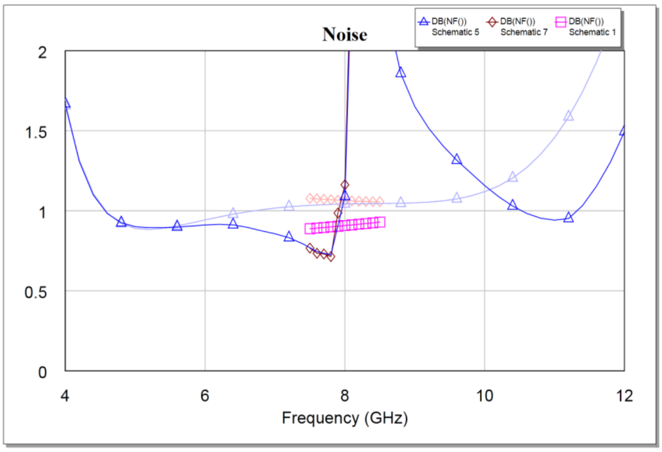


Fig. 3a. Noise growth of the amplifier due to reactance of the blocking capacitor

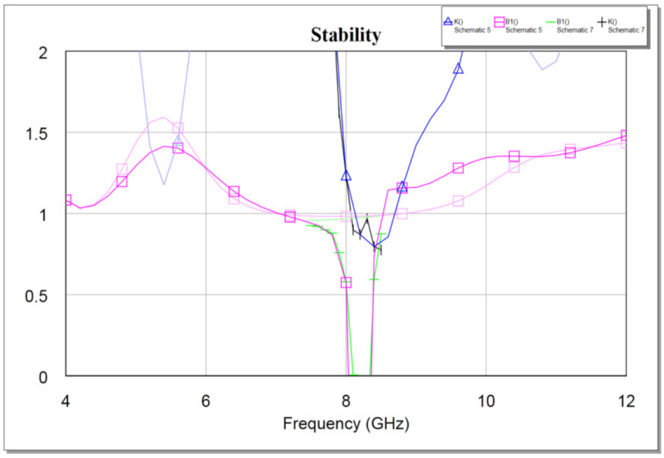


Fig. 3b. Emerging an amplifier instability due to reactance of the blocking capacitor

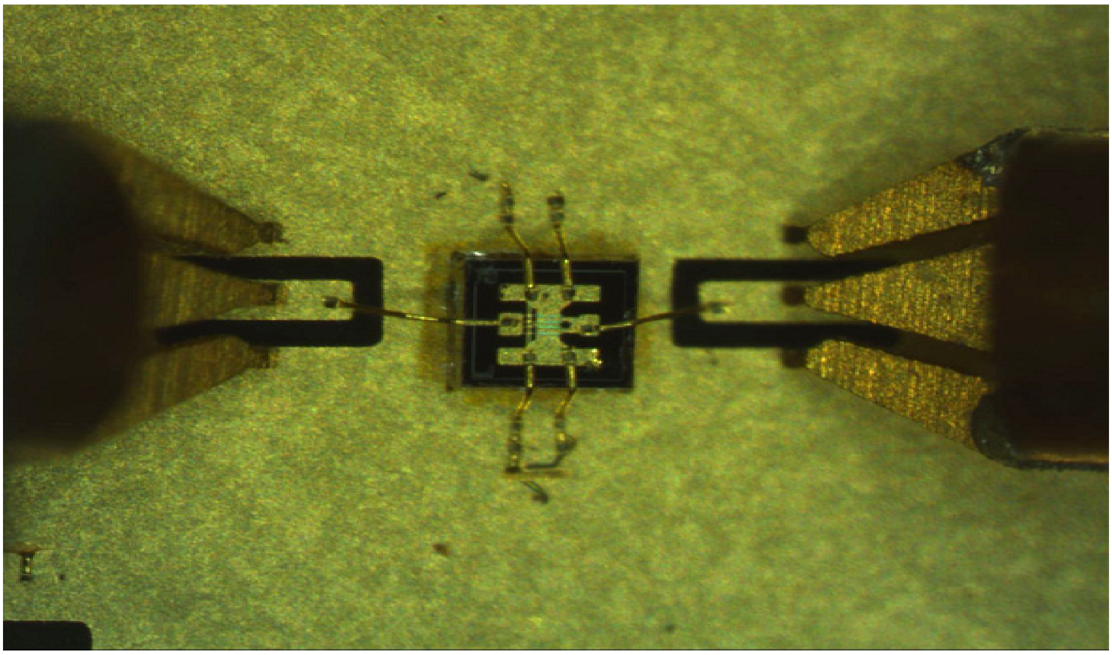


Fig. 4. 3П398Б-5 crystal parameters change by the probe

S-parameters of a crystal is made at a very high modern level (by means of probe stations, see Figs. 4 and [2]), so the measurement of the case parameters is carried out by the simplified technique that can lead to calculation errors at high frequencies.

Fig. 5 shows the characteristics of the two-stage LNA based on cased and uncased 3П398Б-2 and 3П398Б-5 transistors

In the uncased variant gain is 3 dB more; K_n is 0.2 dB less; VSWR is considerably lower. Difference, that is even more essential, is in the three-stage LNA. The decision to use uncased transistors is based on these reasons.

3. Their noise matrixes for analytical calculation of K_n are not given in reference data on parameters of domestic transistors. As a rule, the size of $k_{n\ min}$ measured in the coordination mode at one frequency is given. Therefore, to calculate the characteristics of the LNA it is expedient to use a small-signal HEMT model presented in CAD as FETN. Initial values of the FETN parameters are very close to parameters of real HEMT of C-, X-, and Ku-bands. Use of the installed programs of optimization allows one to provide coincidence of these parameters with the set accuracy. At the same time, it is necessary to exclude precisely known, for example, Lg, Ld, Ls, etc. from the varied FETN parameters. In Fig. 6, the measured

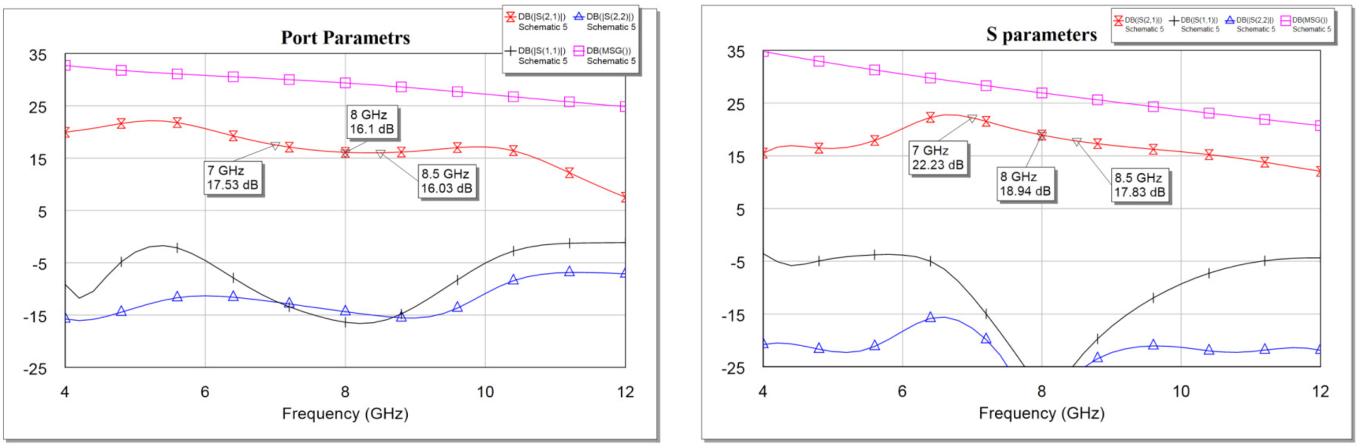


Fig. 5. Comparison of the optimal parameters of two-stage amplifiers based on cased transistors *(a)* and on crystals *(b)*

S-parameters of the transistor 3P398A-5 and the optimized FETN S-parameters are presented. Extraction of the T_d and T_g noise parameters was made in a 50-Ohm path manually in the FETN mode coordination.

4. Input and output chains of each transistor were calculated on transistor impedances in one-stage version of the amplifier at the initial stage of design.

As the working frequency band of the three-stage LNA did not exceed 20%, so quarter-wave stubs were used for power isolation that provided possibility of installation behind the stubs of the resistors, providing a necessary stock of stability at extra band frequencies due to introduction of dissipative losses at suppression of their noise inside the band.

In the course of calculations it has become clear that a very essential role for complex optimization of the amplifier is played by the inductance size in a source of transistors (that is hard to achieve when using cased transistors parameters). In the first and second stage consecutive feedback on current in the form of a piece of a high-resistance transmission line in a source is applied. In the first stage the size of feedback was chosen proceeding from realization of necessary stability and coordination in noise parameters. In the second stage the feedback size, electric distance between the 1 and 2 stage and chains of coordination were chosen based on the realization of K_u stability and maximization. In the third stage parameters selection of coordination chains, decoupling and attenuation provided stability and correction of unevenness of the characteristic, as well as the size of K_u.

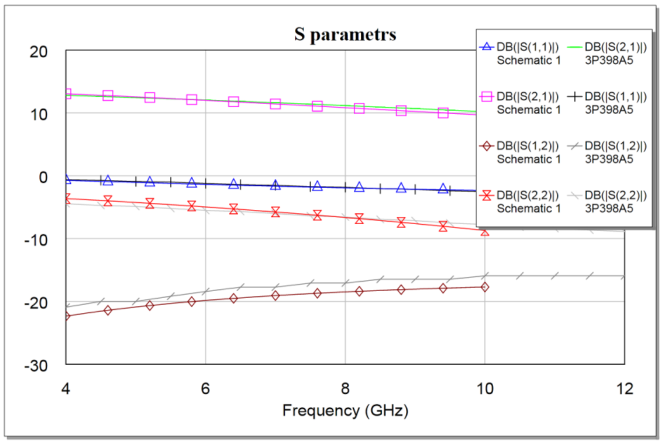


Fig. 6. The measured and optimized parameters ratio of the 3П398Б-5 transistor

On the basis of the above mentioned, a three-stage LNA with the central frequency of 8 GHz and a frequency band more than 15%, K_u = 28 dB, K_n = 1.1 dB, VSWR less than 1.3 has been developed. The scheme and layout of the LNA are given in Figs. 7 and 8.

In Fig. 9, calculation frequency characteristics of k_a, VSWR, k_n, and stability factors on amplitude K and on the phase B_f are shown.

The experience of the previous calculations of similar amplifiers on foreign transistors and their realization show the high extent of coincidence of calculations with the results obtained.

Based on the received data, the LNA device (Fig. 10) is functionally completed including two identical microassemblies of the amplifier, microstrip filter and two stripline isolators serving as input loading for amplification microassemblies. A waveguide isolator

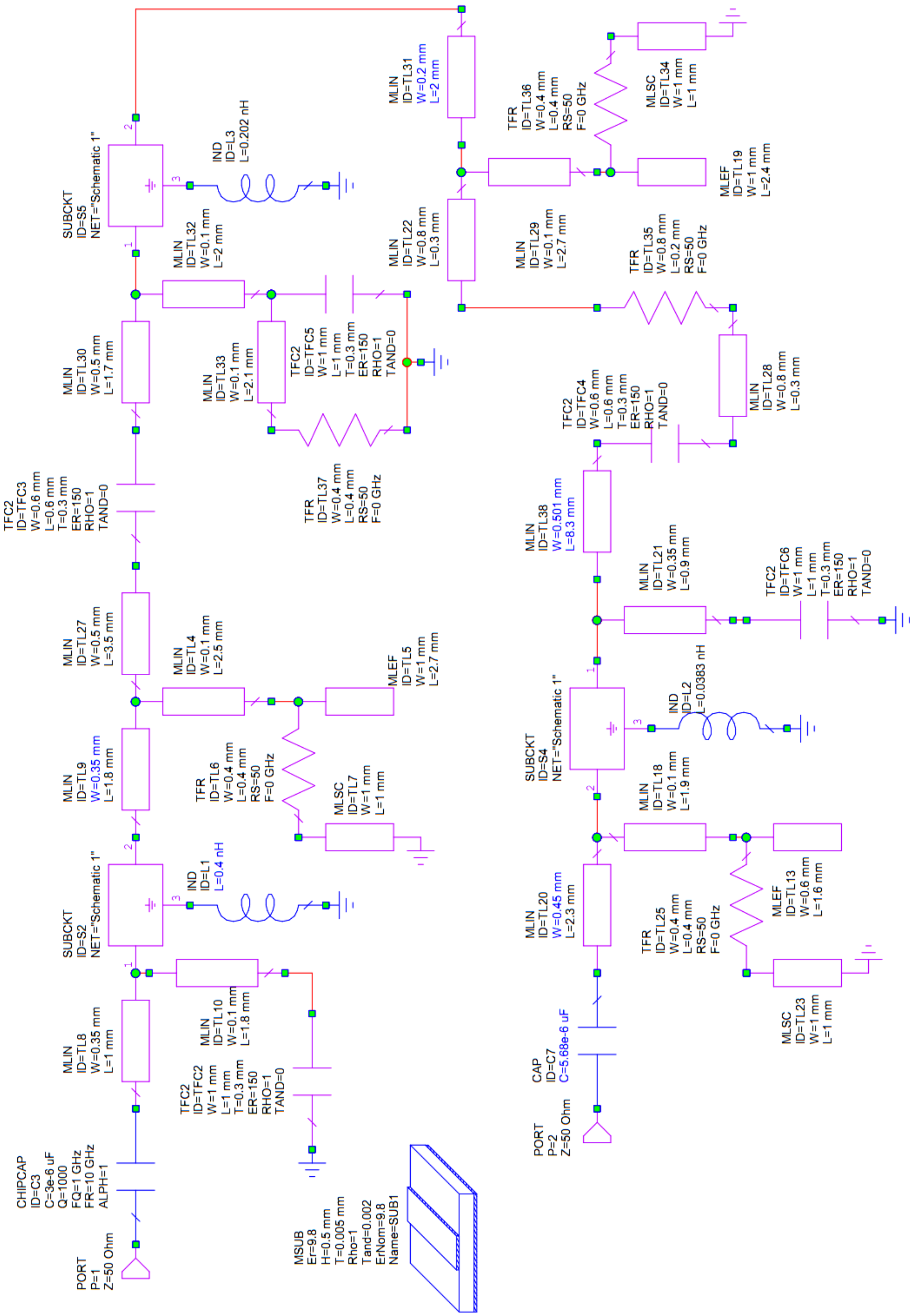


Fig. 7. Presentation of calculating elements of the LNA layout in AWR

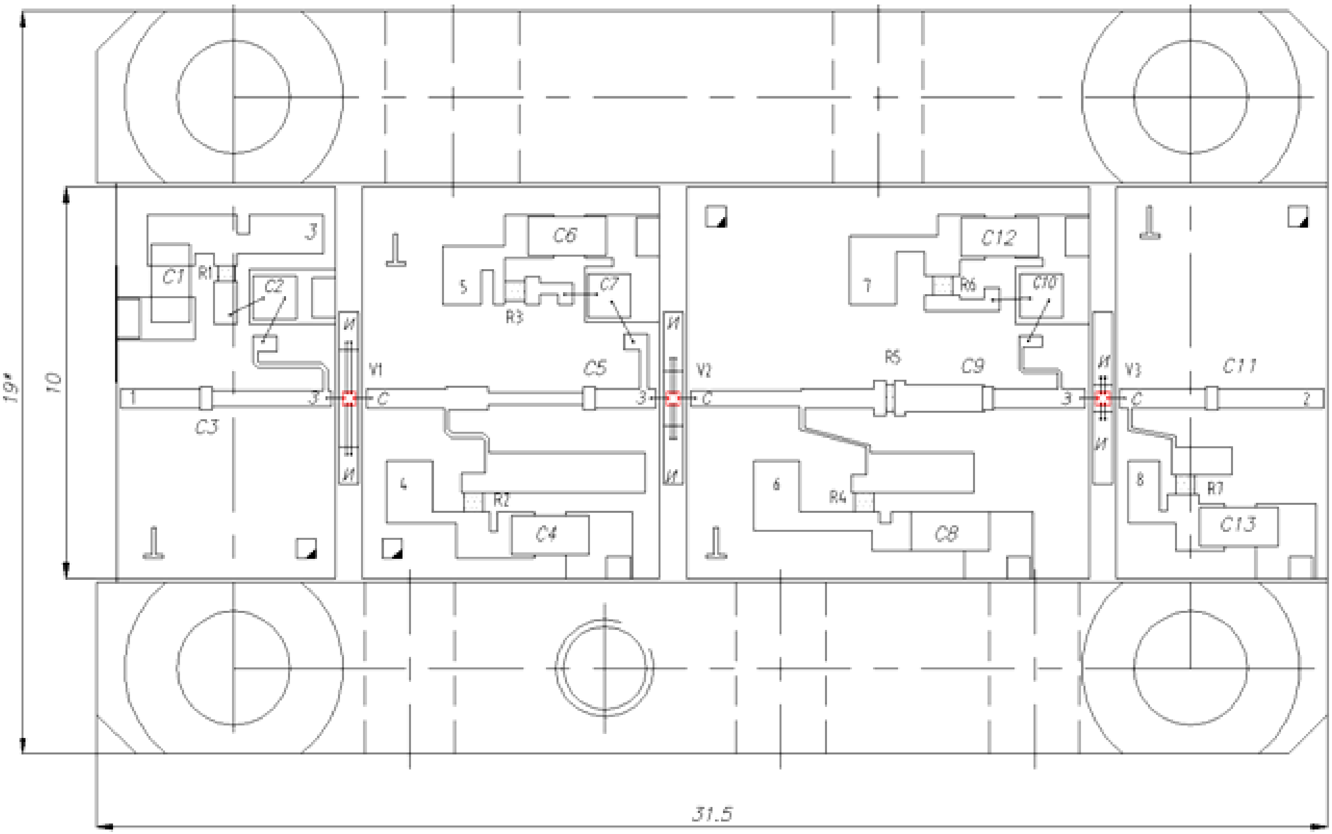


Fig. 8. The LNA layout implementation in the microassembly type

bringing a minimum of losses in the general highway provides output loading. Full autonomy to the device is provided by the source of secondary power supply with dimensions 60×40×8 mm established on the opposite side from a radiopath.

The LNA characteristics received during modulation are given in Fig. 11

The following measures are proposed to increase the operation reliability of the device:

1. There is no need of introduction of exotic technologies in the superhigh frequency band. Only strict implementation control of already available is necessary.

2. Time of no-failure operation of the transistor 3P398B-5 stated in the specifications is 50 000 hours under hard operation conditions. When solving the creation problem of satellites with the 15-year service life, the specified resource has to be 140 000 hours. In this regard, it is offered to apply triple redundancy of input blocks. That will require either purchase or own development of the three-position electromechanical switch operated by voltage pulses.

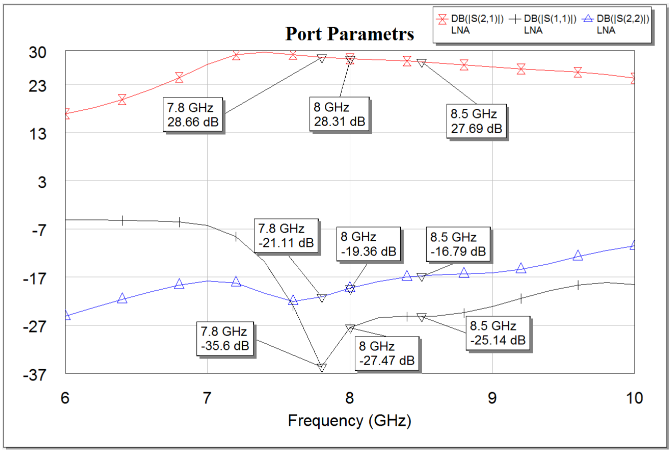
3. Moreover, increase in both transistors and a LNA unit service life is possible when the established threshold level of current consumption is achieved using the timely start of relaxation process of a working half-set.

A method to increase the operation recourse of the VHF transistors for special applications

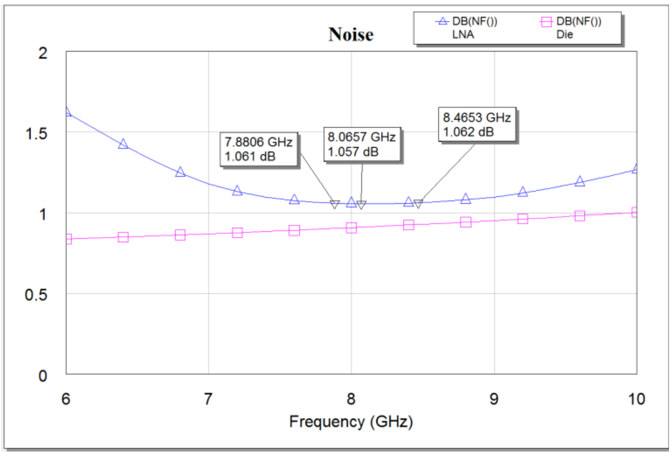
Ensuring the required radiation resistance of the onboard electronic equipment to the space ionizing radiation is one of the most important solvable problems of spacecraft creation with long terms of service life (10–15 years).

Duration of spacecraft lifetime directly depends on resistance of the electronic component base (ECB) being used to special factors of the space (S).

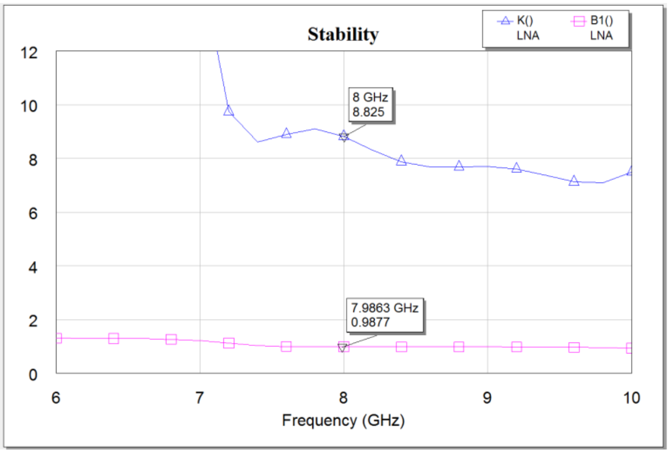
In technical requirements for the transistor being used, the time of no-failure operation is 50 000 hours at the ambient temperature up to +85 °C. According to the specification on the system, the maximum working temperature is +50 °C. This circumstance objectively promotes increasing mean-time-between-failures; however, it requires additional tests and coordination with the producer of the element base.



a)



b)



c)

Fig. 9. Design characteristics of the LNA microassembly: S-parameters *(a),* noise characteristics *(b)* and stability *(c)*

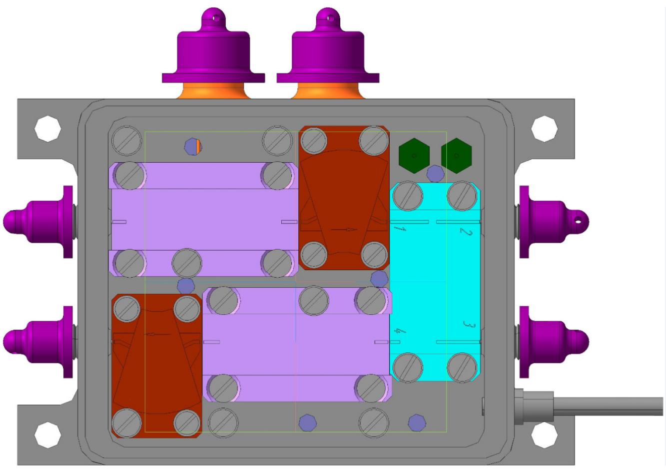


Fig. 10. An external appearance of the LNA

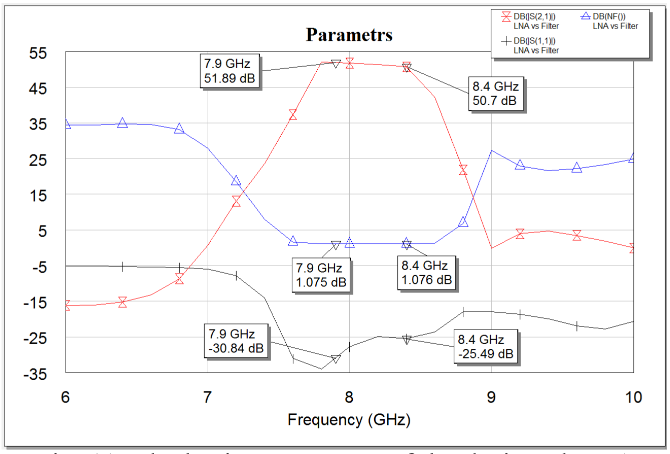


Fig. 11. The basic parameters of the designed LNA

The interests in ensuring reliability of onboard devices require reservation at the level of devices. For unconditional implementation of the customer requirements, it is offered to use triplicating for the operating time for the LNA unit.

In turn, this decision assumes using a three-position electromechanical switch operated by voltage pulses.

The research data of special space factors impact on the operation physics of semiconductor devices indicate a gradual increase in current consumption by electronic

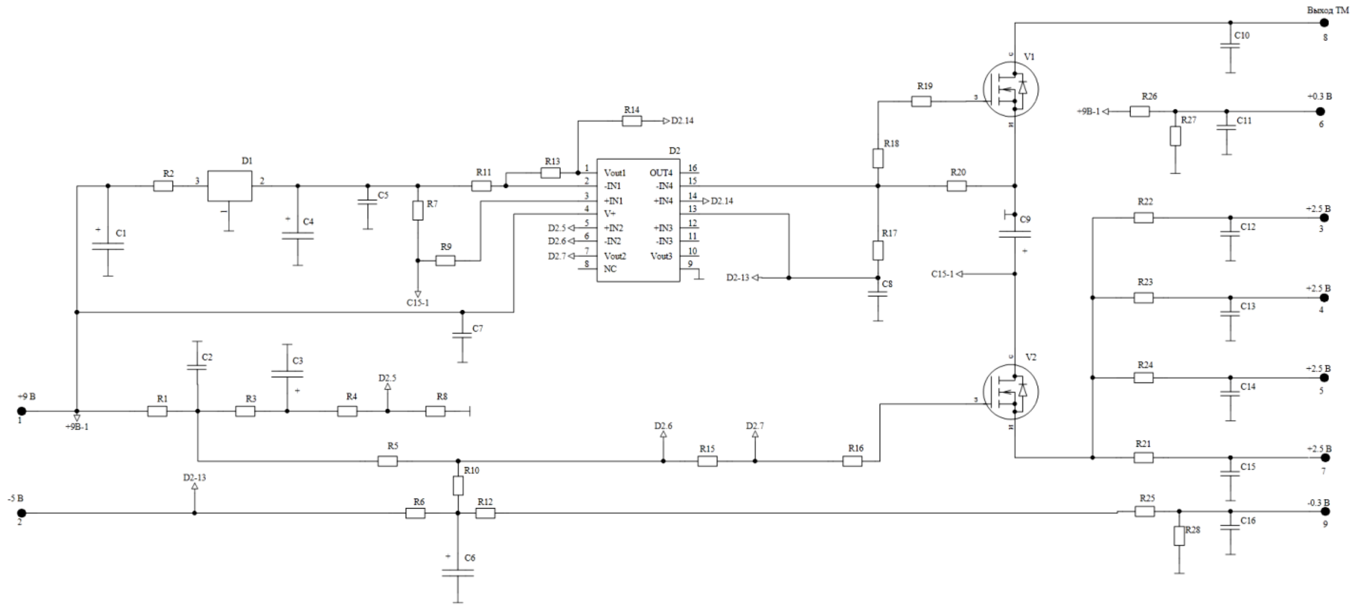


Fig. 12. A fragment of power supply scheme to the LNA with the protection function on the accumulated dose. Scheme active elements: D1 — a linear voltage regulator 1325ЕР1У; D2 — a microcircuit of operation control of the electronic equipment 1114СК1У; V1, V2 — MOSFET- transistors 2П525А-9

devices in course of time. As the statistics shows, failures in the space conditions are caused largely by excess of the maximum values of the absorbed dose of the ionizing radiation specified in element technical requirements. The heavy charged particles (HCP) influence on operation reliability of arsenide-gallium transistors is negligible. The radioelement parameters drift involves the ionizing space radiation influence on the semiconductor structure and, in fact, involves a critical dose excess indicator in relation to the ECB element. At the same time, the element degradation extent under the influence of the ionizing radiation is defined by a ratio between accumulation processes and relaxation processes (annealing). Annealing partially allows products to be brought to a working condition, that is to neutralize a taken positive charge by the radiation-induced electrons from a conductivity region. The element restoration speed is defined by temperature optimum values duration of annealing.

This article offers the design solution that enables failures to be prevented in the equipment via tracking the moment of consumption current excess by active elements under the influence of special factors and giving the relevant telemetric information to the decisive device. The LNA scheme entirely developed on the domestic ECB meets the requirements of the priority (according to time) feed of negative bias on locks of microwave transistors and also identifies failures due to potential jumpers break. The similar circuit decision can be employed in the majority of the reserved radio frequency blocks of a retransmitter. A fragment of the scheme is presented in Fig. 12.

The R1 resistor is connected in series into the feed bar of the LNA. Depending on the current consumption, voltage drop to R1 (about 60 mV) is amplified by the first two stages of the operational DC amplifier D1. As current consumption by amplifiers grows up to 25% (at the corresponding excess of a threshold at the input of the second operational amplifier (OpAmp) stage up to 5 mV), the positive output voltage of the operational amplifier (+ 5 V) is transformed into negative (-5 V) one. Thus, the V1 transistor, being used for telemetry of the LNA block operability, will pass from an open state into the closed mode. It will serve as a fault signal, according to which the system will carry out the following switching: an input signal and voltage supply into a reserve half-set of the LNA, and the working half-set into the relaxation mode. Removal of potential from the switched half-set allows its working capacity to be restored eventually either completely or substantially, depending on time of the subsequent relaxation.

Conclusions

1. By means of the CAD system based on serially released low-noise transistors of a domestic production, the layout of the three-stage amplifier (with parameters at the level of the international standards), which has stability, internal coordination, amplification factor, and noise temperature, is calculated.

2. The production technology of amplifiers of a similar class in the superhigh frequency band (which was optimized during decades) enables one to realize in practice the offered scheme of the LNA without special improvements. Costs of production can be significantly reduced at the order of the lot of the average sizes products.

3. The proposed design concept making it possible to prolong a service life of devices in the conditions of influence of space factors can be used when developing the equipment for spacecraft with the long term of active existence.

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