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Development of Microwave Monolithic Integrated Circuits of 5 mm Wavelength Range for Application in Promising Space Systems

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Abstract. A set of monolithic integrated circuits (MIC) to be applied in the transmitter receiver modules (TRM) with rigid restrictions for the mass-dimensional characteristics and power consumption, and increased requirements to the resistance to the external and special factors, and operating in the frequency range of 57–64 GHz was developed based on nitride heterostructures at IUHFSE RAS. Technical and operational characteristics of the stated products are presented. The developed MIC can be used in severe service conditions and, owning to their functionalities, they can be applied in the communication and control systems of spacecraft.

Keywords: electronic component base, super high frequency, monolithic integrated circuit, nitride heterostructure

Introduction

Creation of the functionally complete range of products of the electronic component base (ECB) meeting to the full extent the requirements of the rocket and space technology for functional parameters, reliability and resistance to radiation is one of the priority problems solved by the entities of a radio electronic complex and the relevant organizations of the Russian Academy of Sciences.

This problem has become very urgent because of the wide use of the import ECB in new samples of space technology (up to 43% of all the range for some satellite systems) and a tough policy of sanctions promoted by the western countries.

The components of the microwave technology belong to the ECB products, which, on the one hand, determine tactical, technical and operational characteristics of modern space systems, and on the other one, are almost unavailable for domestic manufacturers in the international market, since there are considerable restrictions on their export and severe prohibitive measures on distribution of the appropriate technologies.

The list of the main objectives for import substitution of the microwave ECB includes the following:

- creating a scientific and technical base in the field of the microwave devices in providing promising samples of the ground and onboard space systems;
- ensuring technological independence of domestic manufactures and producers of the radio electronic equipment on foreign suppliers of the ECB, special materials, manufacturing process equipment and control and measuring equipment.

The main course of research and development in the field of the microwave technology are [1]:

- producing the optimized heterostructures on the basis of gallium nitride (GaN) and other broadband materials for powerful microwave devices in ultra high, super high and extremely high frequency bands;
- development and introduction of manufacturing techniques of the microwave transistors and monolithic integrated circuits (MIC) on the basis of broadband semiconductor materials (GaN, SiC, InP, polydiamond and graphene), including extremely high frequency (EHF) band (60 … 200 GHz);
- development and introduction of manufacturing techniques of the multipurpose single-crystal microwave MIC ("system on a chip" type), including analog, switching and digital schemes.

Application of the high-integrated multipurpose ECB products is a basis for producing potential low weight dimensional spacecraft (no more than 120–150 kg.) as crucial elements of the space segment for the domestic industry. It is connected with the main tendency of space engineering development at the present stage, which is based on essential expenditures reduction on development, deployment and operation of space based systems through microminiaturization, integration of nanotechnologies and nanoelectronics. Creation of such spacecraft allows one to deploy orbital groups by means of rather inexpensive lightweight carrier rockets that can lead to expenditure reduction on launch services for 10–15%.

Therefore, increase in operating frequencies and level of integration in case of simultaneous support of high resistance to the external and special influencing factors becomes a defining trend in developing the ECB of a very high frequency.

The development results of promising microwave MIC on GaN heterostructures

Federal State Budgetary Scientific Establishment Institute of Super High-Frequency Semiconductor Electronics of the Russian Academy of Sciences (IUHFSE RAS) has developed a frameless MIC set of the 5 mm wavelength range (Fig. 1).

The developed MIC set of 5411 series (the characteristics of the crystals are given below) has a low-noise amplifier (LNA) with a built-in antenna on an input (5411UV01AN) and without antenna (5411UV01N), power amplifier (PA) with a built-in antenna on an output (5411UV02AN) and without antenna (5411UV02N) and signal converter 5411HC01H (SC). It is to be applied as a part of the TRM with rigid restrictions on weight dimension characteristics and power consumption, increased requirements on resistance to external and special factors operating in the frequency range of 57–64 GHz.

Fig. 2 illustrates the microwave parameters of LNA; Fig. 3 shows the microwave parameters of the intermediate frequency amplifier (i-f amplifier).

The specified frequency range of 57–64 GHz has the following advantages:

- makes it possible to work in broadband of frequencies and provides data transmission rate up to 5 Gbit/s and more;

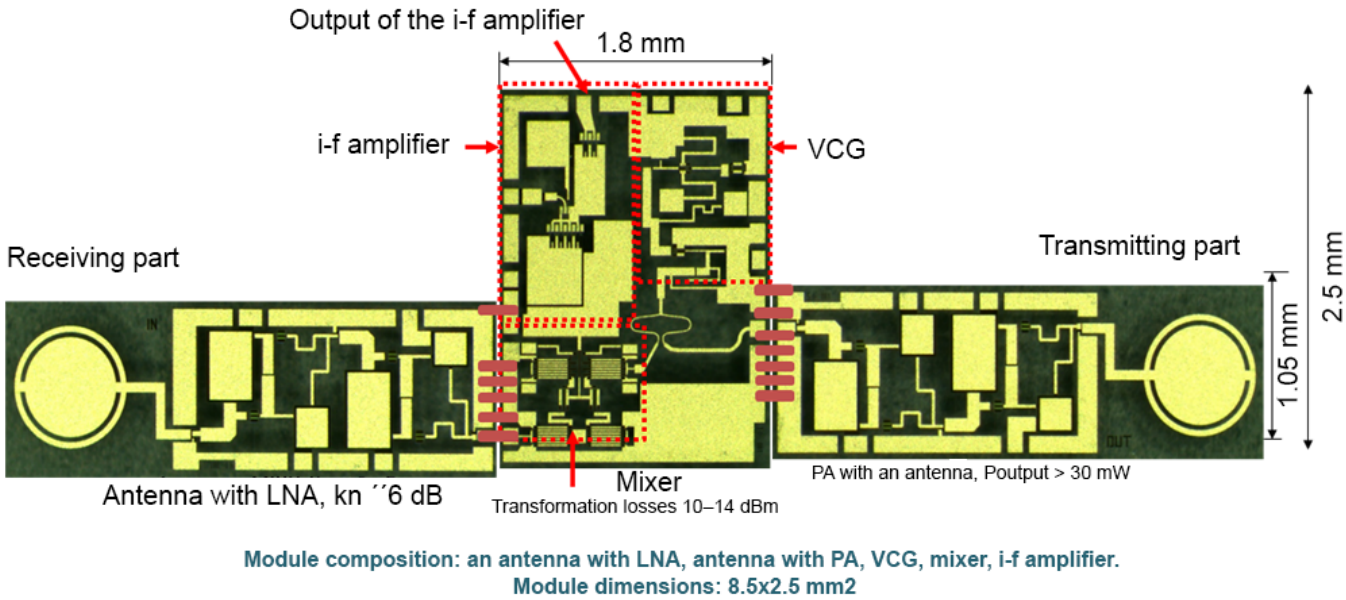

Fig. 1. A TRM for frequency ranges of 57–64 GHz on the heterostructure AlGaN/GaN/Sapphire

- it is characterized by a high degree of absorptivity in the atmosphere that enables one to create the isolated communication channels;

- a small wavelength integrates antennas and whole antenna grids on one crystal.

In the range of 57–64 GHz, it is possible to create transmiter receiver devices of broadband jam-resistance communication providing a high speed and hidden data transfer between electronic subscribers and also to transfer to creation of mobile broadband communication networks 5G [2].

MIC are built on NEMT-transistors formed on nitride heterostructures of AlGaN/GaN with a sapphire substrate of 340 microns thick with technological regulations of 110 nm. It should be noted that using GaN heterostructures provides potential benefits of the developed MIC in comparison with traditional products on gallium arsenide (GaAs) owning to the bigger width of the forbidden GaN zone (3.4 eV), including providing higher electric durability, power, resistance to impact of external and special factors, and integration of elements on a crystal.

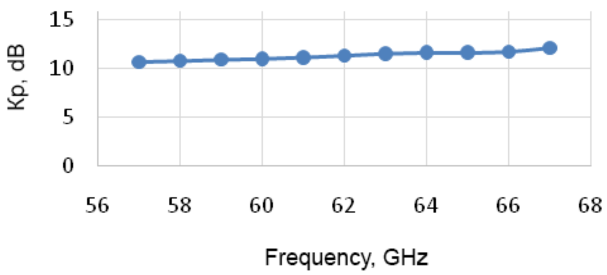

Fig. 2. The microwave parameters of LNA

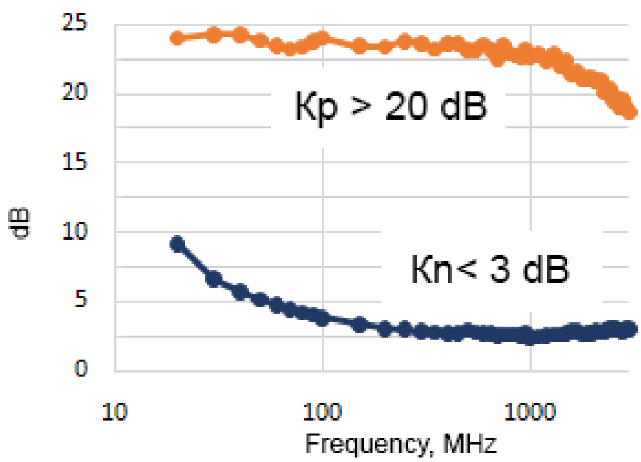

Fig. 3. The microwave parameters of the i-f amplifier

It is no coincidence that leading European organizations of aerospace industry chose GaN heterostructures as the main technological direction for creating radar equipment of the next generation and its components, including high power amplifiers and TRM.

The main technical characteristics of the developed MIC are presented in Table 1.

Table 1. Technical characteristics of the GaN MIC set

Parameter name, unit of measurement	**Parameter symbol**	**Parameter value**	
		Not less than	**Not more than**
Operating frequency range of the input signal, GHz Lower frequency value Upper frequency value	f_{input}	 64	 57
Low-noise amplifier (LNA)			
Noise factor, dB	k_n		6.5
Transmission factor, dB	k_{trans}	16	
VSWR of input and output	SWR_{Un}		2
Current consumption, mA	I_{cons1}		100
Dimensions of MIC of LNA, mm x mm	S_{LNA}		1.15 x 2.26 ±0.1
Dimensions of MIC of LNA with the antenna, mm x mm*	S_{LNA2}		1.15 x 3.4 ± 0.1
Power amplifier (PA)			
Amplification factor by power, dB	K_p	20	
Output power of PA, mW	P_{output}	100	
VSWR of input and output	SWR_{Un}		2
Current consumption, mA	I_{cons2}		200
Dimensions of MIC of PA, mm x mm*	S_{PA}		1.15 x 2.26 ± 0.1
Dimensions of MIC of PA with the antenna, mm x mm*	S_{PA2}		1.15 x 3.4 ± 0.1
Signal converter (SC)			
Operating frequency range of the output signal of i. f, GHz Lower frequency value Upper frequency value	$f_{i.f}$	 2	 0
Conversion coefficient, dB	K_{conv}	0	15
VSWR of input and output	SWR_{Un}		2
Current consumption, mA	I_{cons3}		100
Dimensions of MIC of SC, mm x mm*	S_{SC}		1.9 x 2.26 ± 0.1
* MIC dimensions are given with allowance for tolerance on the cut line			

The parameters of the products resistance to the influence of climatic and mechanical factors are given in Table 2.

It should be noted that the developed MIC perform their function and have the parameters value within the limits of the set norms during and after the influence of the special factors 7.И with the characteristics values $7.И_1$-$7.И_7$, $7.И_{10}$, and $7.И_{11}$ according to GOST РВ 20.39.414.2 for the performance group $3У_c$.

A TRM based on the developed MIC set has two antennas operating to transmit and receive signals.

Figs. 4 and 5 show calculated and measured diagrams of antenna radiation pattern.

Under such conditions, both transmitted and received signals are sent to the balance mixer involved in the SC, where subtraction of one signal from another takes place, and their difference is sent to the i-f amplifier. This diagram is common for the devices that determine the distance to the target and the object movement velocity. Antennas integration on one crystal with amplifiers deceases the losses in the path that, in its turn, decreases noise factor in the receiving path and increases the transmitted power of the transmission path. An antenna radiation area is above the crystal. Radiation maximum is perpendicular to the crystal plane. A voltage-controlled generator (VCG) retunes the signal in the range of 2 GHz

Table 2. The parameters of the MIC resistance to the influence of climatic and mechanical factors

Name of the external influencing factor	Name of the factor characteristic, unit of measure	Characteristic value of the influencing factor
Mechanical factors		
Mechanical shocks of single action	Peak impact acceleration, m/s^2 (g)	15 000 (1500)*
	Action durability of shock acceleration, msec	0.1–2
Climatic factors		
Increased ambient temperature	Maximum value during operation, °C	minus 85
Decreased ambient temperature	Minimum value during operation, °C	minus 60
	Minimum value during transportation and storage, °C	minus 60
* Resistance requirement to the influencing factor is imposed only for strength		

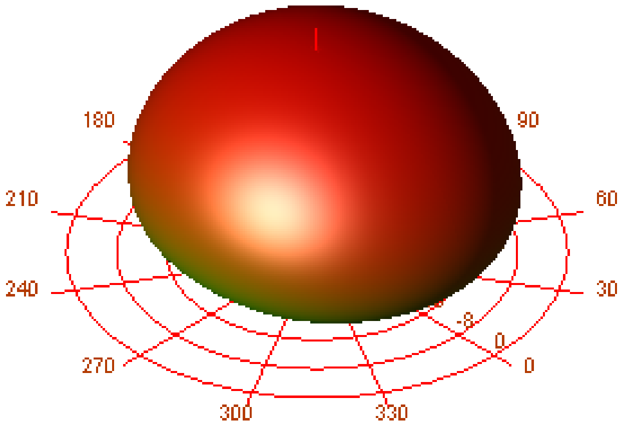

Fig. 4. Radiation pattern (calculation)

owning to the control voltage (initial value of the VCG frequency therewith lies in the range of 57–64 GHz) and power from 10 to 20 mW. The high frequency signal range received from the receiving antenna to the mixer is 57–64 GHz. In such a way, VCG fine-tune makes it possible to receive an output signal of the intermediate frequency in the range from 0 to 2 GHz.

The dependence of the VCG generation frequency on the control voltage and microwave parameters of the PA are shown in Figs. 6 and 7.

The analysis of the present state of the similar developments of the microwave MIC abroad has shown that in this range, the MIC built according to CMOS or SiGe technologies on the silicon substrate are employed [3, 4]. Only separate components (amplifiers, mixers, etc.) are built on AlGaN/GaN/Al_2O_3 heterostructures.

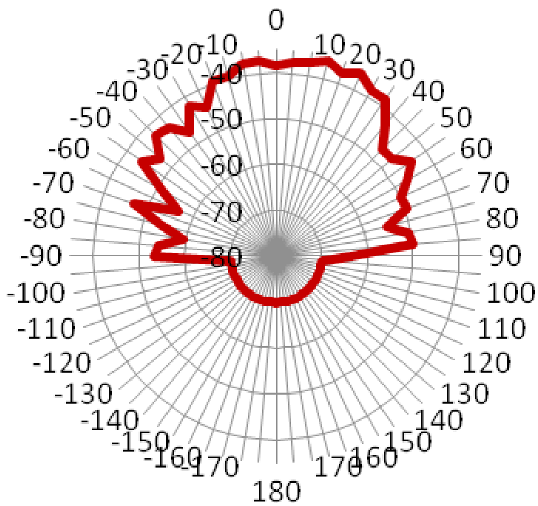

Fig. 5. Radiation pattern (measurement)

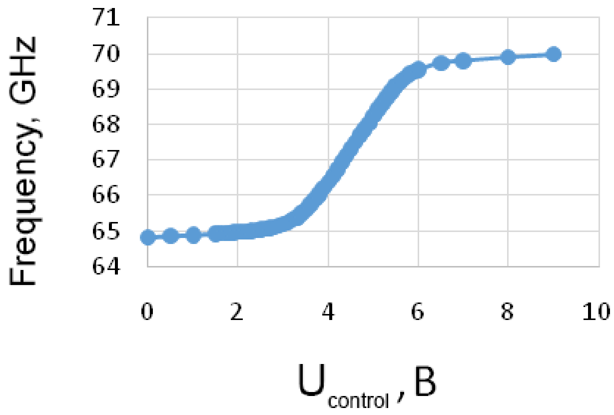

Fig. 6. Dependence of the VCG oscillation frequency

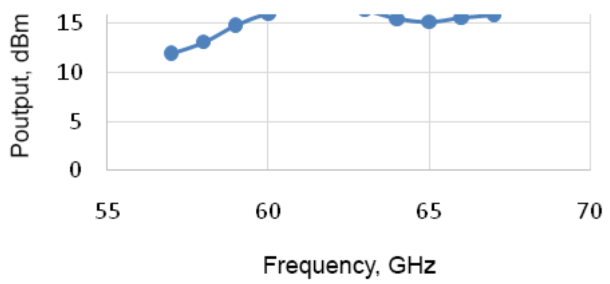

Fig. 7. Microvawe parameters of PA

Conclusion

The technology developed in IUHFSE RAS allows one to create MIC amplifiers of increased power and low noise factor, as well as to integrate on one crystal all components of the transmitter receiver devices: VCG, mixer, amplifiers and antennas.

In future, in the terms of mass production of microwave MIC, it will be possible to transfer to silicon substrates to reduce products cost. IUHFSE RAS is actively carrying out research to solve the problem of production of GaN heterostructures on silicon.

The created basic technology and design solutions have become the basis to fulfil future efforts on building promising microwave ECB in the interests of space technology [5].

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