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Analysis and Features of the Element Base of Modern Satellite Transponders

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***Abstract*: This article analyzes the element base of modern satellite transponders, identifies their characteristics, and determines promising development directions. The study provides an overview of the components used (amplifiers, processors, filters), a comparison of their characteristics (power, mass, radiation resistance), and an assessment of the impact of technological solutions on overall system performance. Both traditional silicon-based technologies and innovative developments, including nanotechnology and adaptive systems, are considered.**

***Keywords*: satellite, transponder, amplifier, microprocessor, filter, antenna, artificial intelligence, efficiency, radiation resistance.**

1. Introduction

Satellite transponders are an integral part of modern communication systems, providing data transmission for telecommunications, television, navigation, and scientific research [1]. Their role is especially significant in regions where terrestrial infrastructure is limited or absent, such as remote areas or outer space. The efficiency and reliability of such systems directly depend on the element base—microelectronic components, power amplifiers, filters, and antenna systems that must function under extreme conditions [2].

Over the past decades, microelectronics technologies have made significant advances, improving key parameters of transponders: reducing power consumption, decreasing mass, and increasing longevity [3]. The transition from silicon (Si) technologies to new materials such as gallium nitride (GaN) and gallium arsenide (GaAs), along with the development of digital signal processing, has changed satellite system design approaches [4]. However, space operation—radiation exposure, temperature fluctuations, and vacuum—imposes unique requirements on components, making their analysis a crucial task for both science and industry [5].

2. Results

Today, satellite transponders have evolved from simple analog devices to complex digital platforms capable of processing large volumes of data in real time [6]. This has been made possible by integrating high-performance microprocessors, high-efficiency amplifiers, and compact antenna systems [7]. Nevertheless, despite progress, challenges remain: the need for further miniaturization, increased reliability, and cost reduction, especially amid growing competition in the space technology market [8].

The analysis of the element base of modern satellite transponders has revealed significant changes in the characteristics of key components over recent years. The primary focus has been on power amplifiers, microprocessors, signal filters, and antenna systems, as they determine the system's performance and reliability.

A. Power Amplifiers

The most common types of amplifiers remain Traveling Wave Tube Amplifiers (TWTA) and Solid-State Power Amplifiers (SSPA). A comparison of their characteristics is presented in Table 1 [9], [13], [16].

Table 1
Comparison of power amplifier characteristics

Amplifier Type	Mass, kg	Power, W	Efficiency, %	Radiation resistance, rad
TWTA	2,5	250	65	10^5
SSPA (Si)	1,8	150	50	10^4
SSPA (GaN)	1,5	200	70	10^5

GaN-based SSPA outperform TWTA in efficiency (70%), making them promising for small satellites such as CubeSat [16]. For example, the GaN SSPA model QPA2210D (manufactured by Qorvo) provides 7 W of power [17] (Fig. 1). The evolution of specific power is shown in Fig. 2.

B. Microprocessors

Microprocessors for signal processing are transitioning from Si to GaAs. However, GaAs processors are primarily used for specialized tasks, while modern processors increasingly incorporate Silicon-on-Insulator (SoI) and Silicon-Germanium

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(SiGe) technologies. A comparison of Si and GaAs processors is presented in Table 2 [6], [12].

Table 2
Comparison of microprocessors for satellite transponders

Material	Frequency, GHz	Energy consumption, W	Radiation resistance, rad
Si	2,5	15	10^3
GaAs	3,0	12	10^5

GaAs processors, such as RAD5545 (manufactured by BAE Systems), provide up to 5.6 billion operations per second and offer radiation resistance up to 10^5 rad, making them ideal for digital satellite transponders [6] (Fig. 3).

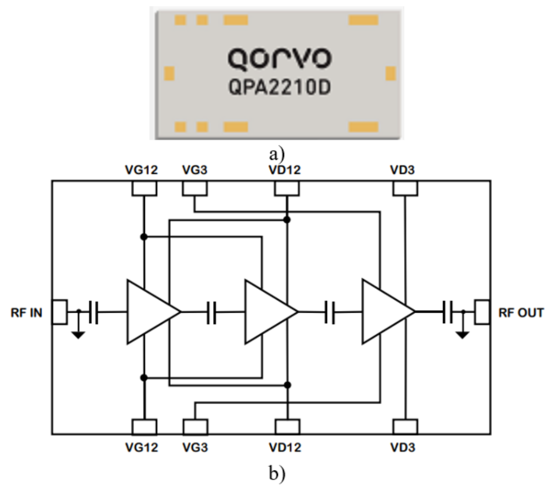

Fig. 1. Solid-State amplifier QPA2210D: a) External view, b) Block diagram

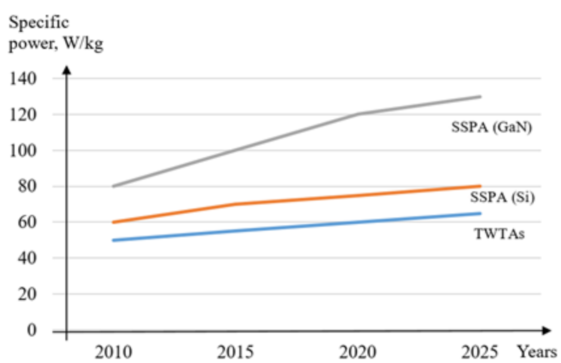

Fig. 2. Increase in Specific Power of Amplifiers (W/kg) [5], [14]

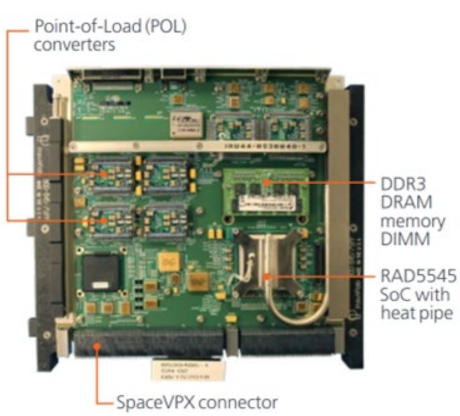

Fig. 3. GaAs processor RAD5545 [6]

C. *Signal Filters*

SAW (Surface Acoustic Wave) filters and ceramic filters remain standard. Their mass has been reduced from 200 g to 120 g, and thanks to new materials, the operating frequency range has expanded to 20 GHz [11].

For example, modern filters provide radiation resistance of 10^4 rad while maintaining compact dimensions. Additionally, Bulk Acoustic Wave (BAW) filters are beginning to be used in satellite systems, enabling operation at even higher frequency ranges (up to 30-40 GHz) [18].

D. *Antenna Systems*

The transition to Phased Array Antennas (PAA) has reduced antenna mass and, compared to mechanical antennas and conventional deployable arrays, improved pointing accuracy by 10% [19]. A notable example is the Phased Array Antenna of the Iridium NEXT satellite (Fig. 4) [14].

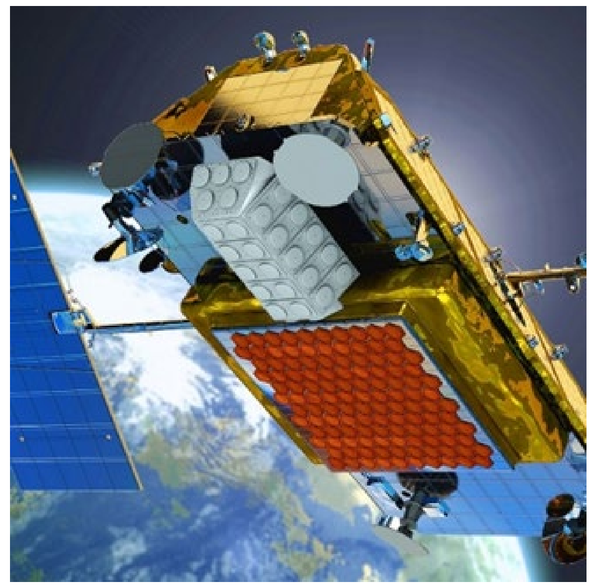

Fig. 4. View of the phased array antenna of the iridium NEXT satellite

The dynamics of the mass of key satellite transponder components (amplifiers, filters, antennas) is shown in Fig.5.

Observing the general trends in the element base of satellite transponders [5], [14], [16]:

- over the past 10 years, the mass of components has decreased by 20–30%;
- amplifier efficiency has increased from 50% to 70%;
- GaN radiation resistance has reached 10^6 rad.

The analysis results confirm the evolution of the element base of satellite transponders towards improved performance and reliability. GaN SSPA, with an efficiency of 70% and radiation resistance of 10^6 rad, outperforms TWTAs in terms of compactness and energy efficiency, which is particularly important for small satellites [16].

For example, GaN amplifiers reduce power consumption by 20% compared to Si SSPA, thereby lowering the load on solar panels [17]. GaAs processors, such as RAD5545, provide high frequency and stability, which is crucial for real-time signal processing [6].

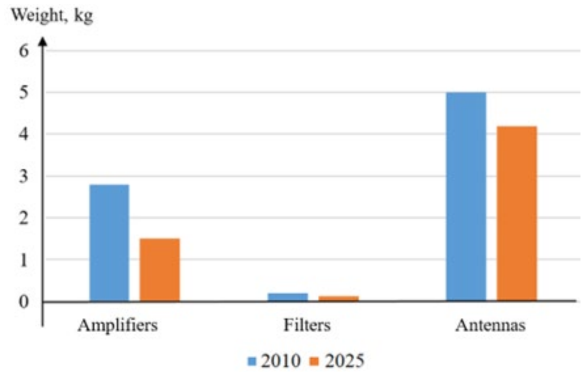

Fig. 5. Dynamics of the mass of key components [11], [14], [19]

A comparison with transponders from the late 20th century shows that system mass has decreased from 50 kg to 20–30 kg, while service life has increased from 10 to 15 years [14]. This was made possible by new materials and the transition to phased array antennas (PAA), which replaced bulky mechanical antennas [19]. However, the high cost of GaN components (several times higher than Si) and the complexity of their integration remain challenges [20]. SAW filters, despite their reduced mass, are limited in frequency range, necessitating the development of alternative solutions [11].

3. Future Prospects

The key development areas include miniaturization, the implementation of artificial intelligence (AI) for adaptive control (e.g., optimizing amplifiers based on load conditions), and quantum technologies for data processing [7], [10].

For example, AI implementation can increase system efficiency by 10–15%, while quantum processors can reduce signal processing time by several orders of magnitude [20]. These directions require further research and funding.

4. Conclusion

The analysis of the element base of modern satellite transponders has demonstrated that the transition to GaN and GaAs, along with improvements in antenna systems, has led to significant progress. GaN SSPA, with 70% efficiency and 10^6 rad radiation resistance, surpasses TWTAs in terms of mass and efficiency, while GaAs processors provide high frequencies with low power consumption.

The mass of transponders has been reduced by 20–30%, while longevity has increased to 15 years. These advancements reflect the overall trend of enhancing performance while reducing energy costs.

For further development, it is recommended to focus on integrating nanotechnology, AI-based adaptive systems, and overcoming the cost barriers of new materials.

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