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DESIGN OF POWER LIMITER FOR ANTENNA-FEEDER SYSTEM FOR DIRECTION FINDING PROTECTION ON GaAs pHEMT

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Abstract. This paper presents the development results of a power limiter for the 30–6500 MHz frequency range, implemented as a microwave monolithic integrated circuit (MMIC) based on a domestic GaAs pHEMT technology. Implementing the power limiter as a monolithic integrated circuit reduces the weight and size of the final device compared to a hybrid implementation. The power limiter consists of three cascaded stages connected in parallel, comprising Schottky diodes interconnected by microstrip transmission lines that compensate for the parasitic capacitances of the diodes. The developed power limiter exhibits an insertion loss of less than 0.7 dB, an input and output VSWR of less than 1.2, an input 1 dB compression point of at least 22.8 dBm, and a maximum input power of at least 40.7 W. The MMIC die dimensions are 1400 × 1300 μm. The developed power limiter can be used in the input stage of receiving devices, such as antenna feeder systems for direction finding.

Keywords: microwave, monolithic integrated circuit, power limiter, antenna-feeder system, GaAs pHEMT, Schottky diode

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РАЗРАБОТКА ОГРАНИЧИТЕЛЯ МОЩНОСТИ ДЛЯ ЗАЩИТЫ АНТЕННО-ФИДЕРНЫХ СИСТЕМ ПЕЛЕНГОВАНИЯ НА ОСНОВЕ GaAs pHEMT-ТЕХНОЛОГИИ

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Аннотация. В данной статье представлены результаты разработки ограничителя мощности диапазона частот 30–6500 МГц, реализованного в виде СВЧ монолитной интегральной схемы на основе отечественной GaAs pHEMT-технологии. Реализация ограничителя мощности в виде монолитной интегральной схемы позволяет уменьшить массогабаритные параметры конечного изделия по сравнению с гибридным вариантом реализации. Ограничитель мощности состоит из трех каскадов, включенных параллельно, диодов Шоттки, соединенных микрополосковыми линиями передач, компенсирующими влияние паразитных емкостей диодов. Разработанный ограничитель мощности обладает вносимыми потерями менее 0,7 дБ, КСВН входа и выхода составляет менее 1,2, величина входной мощности точки компрессии по уровню 1 дБ составляет не менее 22,8 дБм, максимальная входная мощность не менее 40,7 Вт. Размеры кристалла монолитной интегральной схемы составили 1400 х 1300 мкм. Разработанный ограничитель мощности может быть использован во входном тракте приемных устройств, таких как антенно-фидерные системы пеленгования.

Ключевые слова: СВЧ, монолитная интегральная схема, ограничитель мощности, антенно-фидерная система, GaAs pHEMT, диод Шоттки

Финансирование: Производство интегральной микросхемы было выполнено за счет средств Министерства науки и высшего образования Российской Федерации в рамках федерального проекта «Подготовка кадров и научного фундамента для электронной промышленности» по государственному заданию «Разработка методики прототипирования электронной компонентной базы на отечественных микроэлектронных производствах на основе сервиса MPW» (FSMR-2023-0008).

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Introduction

In modern antenna-feeder bearing systems (AFS) for direction finding, the power limiter (PL) is one of the key components of the input stage [1]. The primary threat to AFS is a strong signal that falls within the system's operating frequency band. This could be either random interference from a nearby transmitter or a deliberate attempt to "blind" the bearing system through a targeted attack. Such a powerful signal can overload the receiving stage elements (for example, a low-noise amplifier in a preselector) or cause irreversible damage to the device (Fig. 1). Consequently, the PL's role is to safeguard highly sensitive components against signals whose power surpasses a safe threshold [1, 2].

One of the major trends in the evolution of radio electronic equipment is the adoption of microwave monolithic integrated circuits (MMICs) [3, 4]. Specifically, PLs implemented using MMICs

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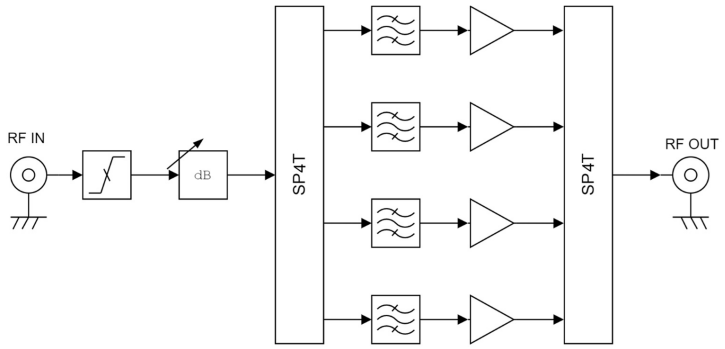


Fig. 1. Preselector block diagram

are characterized by compact dimensions, high performance, and the absence of the need for external matching [5, 6].

Due to difficulties in accessing high-tech foreign-produced equipment and the limited availability of specialized microcircuit solutions, there is a particular focus on expanding the range of MMICs manufactured using domestic technological processes (for example, at Svetlana-Rost JSC) [7–10].

This work explores the specifics of designing a power limiter for the frequency range from 30 to 6500 MHz based on domestic GaAs pHEMT technology, utilizing process design kits for solid-state microwave devices (PDK_pHEMT05D) [11].

The design of a broadband MMIC PL based on domestic GaAs pHEMT technology presents several challenges. The primary scientific and technical problem lies in the contradiction between the need for high input power handling (tens of watts) and the low breakdown voltage of Schottky diodes compared to PIN-diodes. Furthermore, ensuring minimal insertion loss (< 1 dB) and voltage standing wave ratio (VSWR) < 1.5 across a wide frequency range (30–6500 MHz) is non-trivial due to the parasitic capacitance of the diodes.

The purpose of this work is to develop a compact MMIC PL for antenna-feeder bearing systems using domestic GaAs pHEMT technology, providing protection against high-power input signals while maintaining linearity in the low-signal mode.

To achieve this goal, the following research tasks were formulated:

1. To select and justify the choice of the domestic technological process (pHEMT05 vs pHEMT025) based on the analysis of the current-voltage characteristics of Schottky diodes.

2. To determine the optimal number of limiting stages and the periphery of the diodes to ensure the required compression point (P1dB ≥ 20 dBm) and maximum input power (≥ 10 W).

3. To develop a distributed structure of the limiter where the parasitic capacitance of the diodes is absorbed by the microstrip transmission lines to achieve broadband matching.

4. To evaluate the key electrical parameters (insertion loss, VSWR, P1dB) through electromagnetic simulation and compare them with existing commercial and domestic analogs.

Operating principle

The PL MMIC is a device composed of several stages implemented as segments of a transmission line with nonlinear elements – diodes – that alter their electrical characteristics when the incident microwave power exceeds a certain threshold level [1, 3, 5, 7]. In the high-power mode, when the input microwave power equals or surpasses the threshold level, the PL reduces it to a level safe for the receiver's input circuits. Due to its relatively low value, this power is referred to as the leakage power. In the low-power mode, the input microwave power is significantly lower than the threshold level, and the device allows the input signal to pass through with minimal attenuation [1, 13].

For PL MMIC, PIN-diodes or Schottky diodes are utilized [5, 6]. Schottky diodes have a lower breakdown voltage and are less resistant to overheating compared to PIN-diodes [12]. However, they are technologically compatible with low-noise transistors, unlike PIN-diodes, enabling the creation of core-chips [4, 6] and reducing the cost of the final product.

PL design

At present, Svetlana-Rost JSC offers two GaAs technological processes with diodes for the commercial launch of MMICs: pHEMT05 (0.5 μm gate length) and pHEMT025 (0.25 μm gate length).

Analysis of the diode IV-curves (Fig. 2) revealed that the breakdown voltage for the first process is approximately -11.2 V, whereas for the second process it is around -5.7 V. Consequently, pHEMT05 is a more preferable choice, as diodes produced using this process feature significantly higher breakdown voltage and can thus handle greater input microwave power.

In addition to the breakdown voltage, the performance of the PL is influenced by the number of diodes in the stage and the periphery of the diodes used [6, 13]. A larger diode periphery enables higher microwave power handling. However, the higher parasitic capacitance of such diodes restricts the operating frequency range. To address this issue, a distributed structure was employed, where the parasitic capacitance of the diodes is absorbed by a distributed transmission line [14, 15].

The methodology for determining the number of stages and the total diode periphery was based on the required input 1 dB compression point (P1dB) and the withstand input power. A single-stage limiter using Schottky diodes with a total periphery of 640 μm (4 x 160 μm) provides a P1dB of approximately 26–26.5 dBm but fails to limit power above 30 dBm due to the risk of breakdown. To achieve withstand input power no less than 10 W, a three-stage distributed topology was adopted (Fig. 4). This allows for sequential activation of the diode cells: diodes VD11–VD26 are turned on first and handles moderate over loads, while diodes VD1–VD10 provide limiting at high power levels, preventing voltage swings from exceeding the reverse breakdown voltage of 11.2 V (as verified in Fig. 9).

Microstrip transmission lines composed of two metallization layers are used as inductances L1 and L2. The characteristic impedance and electrical length of each transmission line section were synthesized to absorb the parasitic capacitance Cj into a distributed LC network, forming a low-pass filter structure. The optimization goal was to achieve insertion loss < 1 dB and VSWR < 1.5 over the 30–6500 MHz band. The two-layer metal lines were chosen not only for high current density but also to reduce the series inductance per unit length, which improves the cutoff frequency of the limiter.

The layout of the designed PL is presented in Fig. 4. The MMIC dimensions are 1.4 x 1.3 mm.

All electromagnetic simulations of the passive structures and harmonic balance simulations of the nonlinear circuit (Schottky diodes) were performed using AWR Design Environment. The performance of the PL in the small-signal mode is demonstrated in Figs. 5–6. Insertion loss is no more than

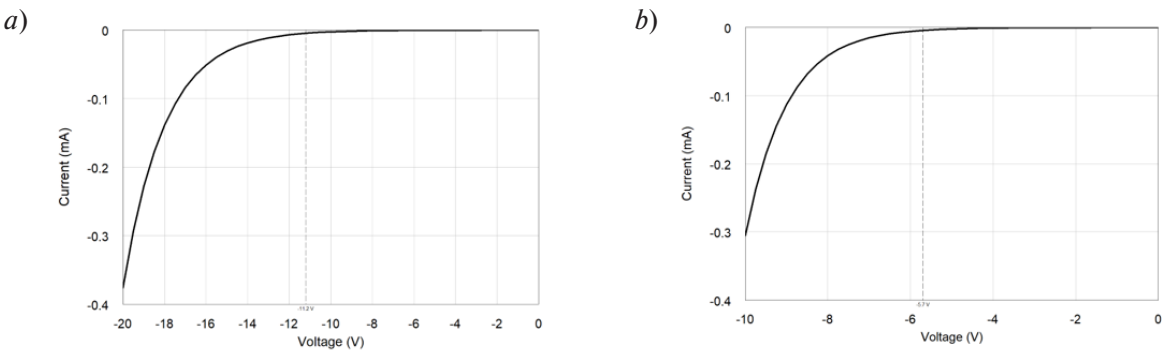


Fig. 2. IV-Curve of the 4 x 40 μm reverse biased diode: pHEMT05 (*a*); pHEMT025 (*b*)

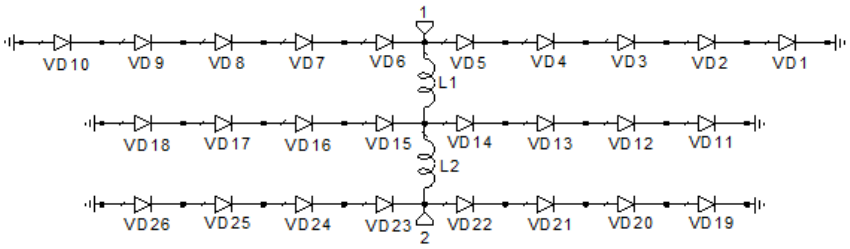


Fig. 3. PL schematic

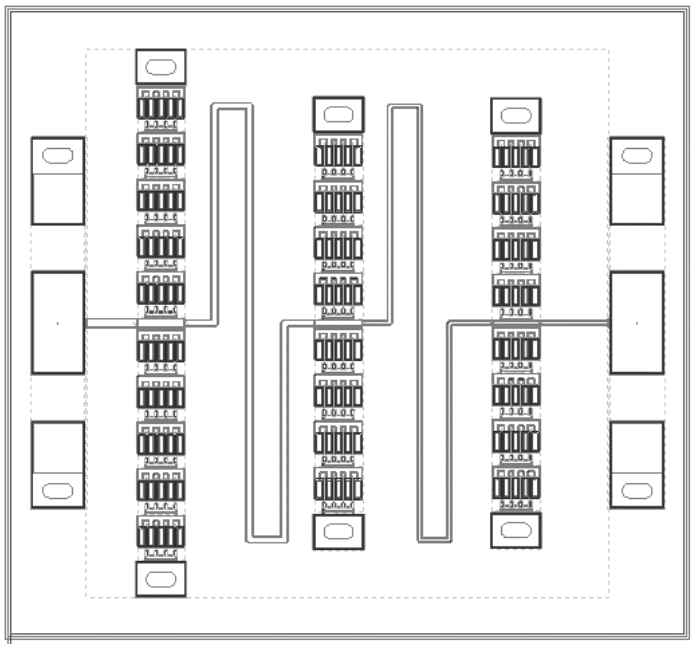


Fig. 4. PL layout

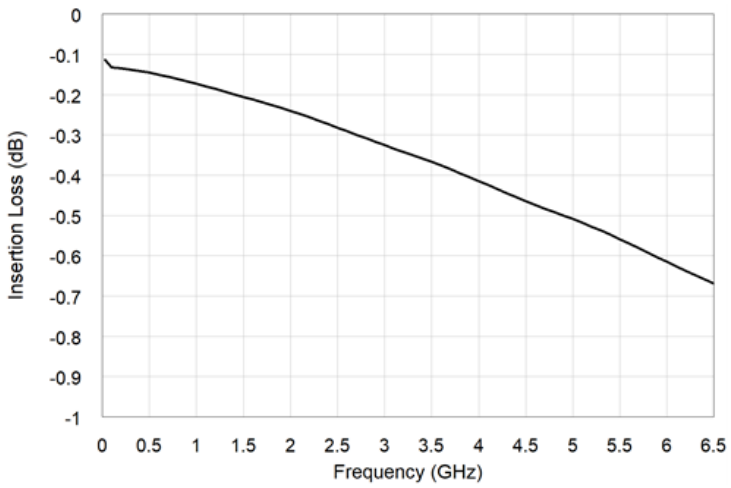


Fig. 5. PL insertion loss

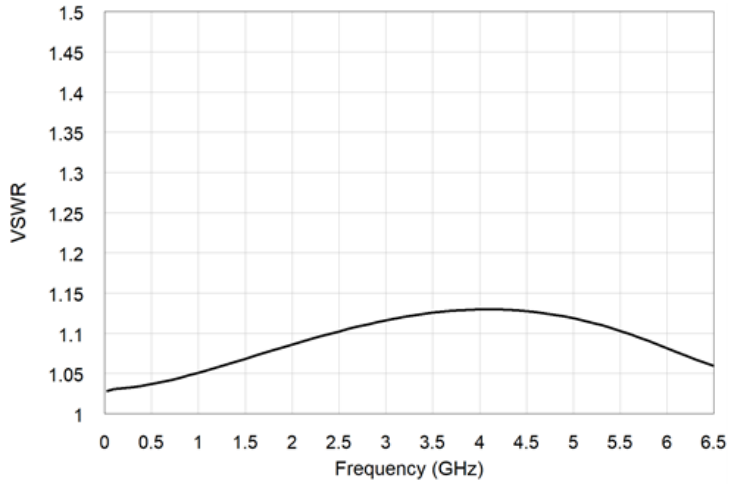


Fig. 6. PL VSWR

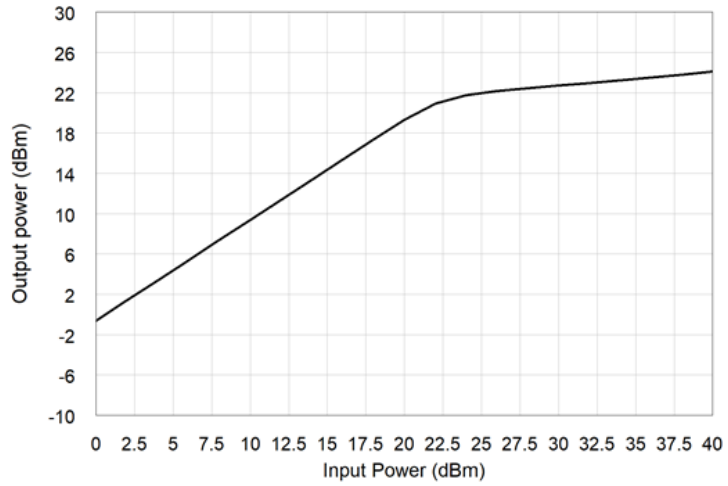


Fig. 7. Output power vs input power at 6 GHz

0.7 dB, and VSWR does not exceed 1.2 units. These parameters consider the parasitic impact of wire bonding using 35 μm diameter gold wire.

The results of the analysis of the PL in the high-signal mode are shown in Figs. 7–8.

Fig. 9 shows the simulated voltage swings across the VD5 and VD6 diodes when the input power is 10 W (40 dBm) at 6 GHz. As you can see from the graph, the peak voltage is almost 8 V, which is lower than the breakdown voltage of 11.2 V. The predicted power of this limiter is 40.7 W (46.1 dBm).

A comparison of the results shows that the main characteristics of the PL designed on the basis of domestic technology are comparable to foreign and domestic analogues, and in some cases even surpasses them. For example, the Qorvo TGL2210-SM[1] GaAs PL is also based on three cascades. With a similar operating frequency range (0.05–6.0 GHz) and comparable insertion loss (less than 0.7 dB), this PL provides a higher maximum input power (49.3 dBm) due to the use of PIN-diodes. However, Qorvo's chip has significantly larger dimensions (4.0 x 4.0 mm), and the linearity level (input 1 dB compression point is less than 20 dBm) does not allow it to be used in AFS due to possible input signal distortions.

[1] TGL2210-SM, Available: https://www.qorvo.com/products/p/TGL2210-SM (Accessed 17.02.2026)

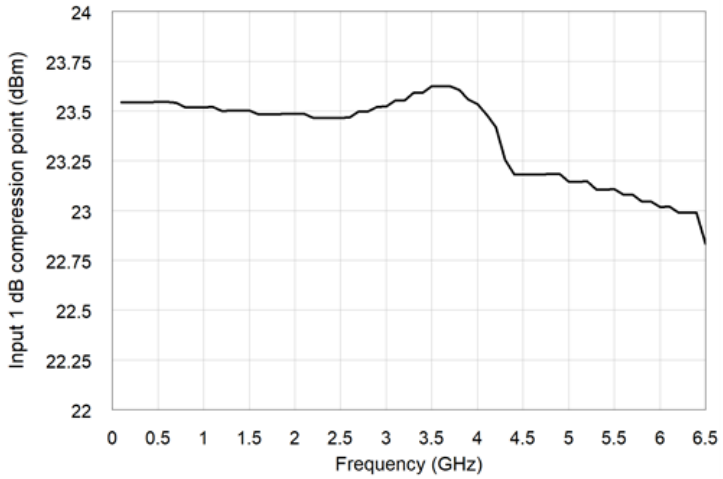


Fig. 8. Input 1 dB compression point vs frequency

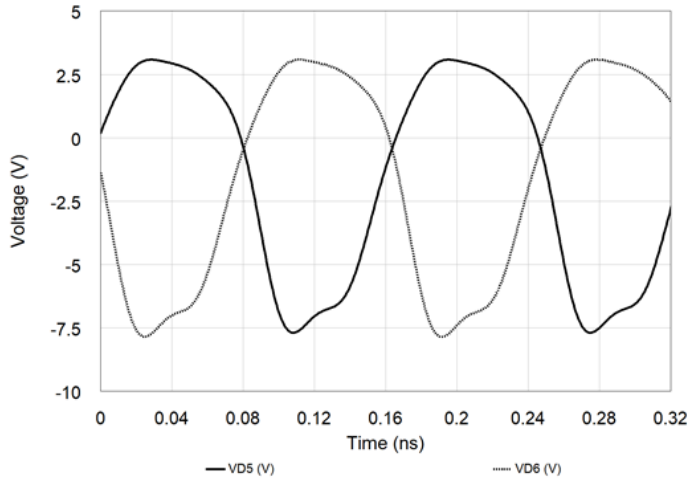


Fig. 9. Voltage swings on VD5 and VD6 diodes at 40 dBm input power

The domestic analog, the M54404 PL from Planet Argal[2], is also comparable in the operating frequency range (0.1–6.0 GHz), but in other characteristics it is completely inferior to the developed PL: insertion loss reaches 1.5 dB, input 1 dB compression point is less than 20 dBm, maximum input power is not more than 40 dBm, and the dimensions of the MMIC are 3.4 x 2.3 mm.

Conclusion

As a result of this research, the PL MMIC was designed on the basis of domestic GaAs pHEMT-technology using process design kit pHEMT025D. The PL consists of three stages of Schottky diodes connected in parallel by microstrip transmission lines. The values of the parameters of the components have been found that provide insertion losses of less than 0.7 dB in the frequency range 30–6500 MHz, VSWR of no more than 1.2, input 1 dB compression point is no less than 22.8 dBm, maximum input power of at least 40.7 W. The size of the MMIC is 1400 x 1300 microns.

[2] SVCh zashchitnoe ustroistvo M54404 [Microwave protective device M54404], Available: https://argall.nov.ru/wp-content/uploads/2021/08/M54404.pdf (Accessed 17.02.2026)

The designed PL is comparable in basic parameters to its analogs, but is significantly smaller in size and has a higher level of linearity. This PL is planned to be used in the AFS preselector of domestic production.

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