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Optimization parameters of broadband tripler diodes of 75...110 GHz frequency

We optimized the parameters of the broadband tripler diodes of 75...110 GHz frequency according to the proposed method of calculation and design in order to increase the conversion efficiency.

Keywords: frequency tripler, microwave device, capacitance-voltage curve, power output.

Introduction

Broadband diode frequency multipliers are widely used as output wave-shaping stages in SHF and EHF signal sources. Most modern domestic and foreign-made solid state measuring generators and synthesizers operating in the frequency band over 20 GHz are based on the principle of frequency amplification.

The study objective is to improve the efficiency of the 75...110 GHz frequency tripler, because this parameter defines the output power level of a signal source if there is no output amplifier.

One of the problems in design of SHF and EHF devices based on non-linear elements is the lack of efficient automated calculation methods based on a computer-aided design (CAD) system, combining electrodynamic methods of waveguide structure analysis with results of calculation of non-linear semiconductor element characteristics.

Despite a variety of methods (analytical and numerical) of analysis of SHF devices (mixers, frequency multipliers, etc.), the design problem is rather difficult and usually requires an iterative solution, including very important experimental studies and further development of the implemented circuit.

The performance of SHF and EHF frequency band multipliers depends on optimally selected circuit-structural elements of the device, and, to a great extent, on parameters of non-linear elements (diodes) being used. First and foremost, it depends on stray parameters, non-identity degree, non-linearity of volt-ampere (VAC) and capacitance-voltage (CVC) characteristics, overall dimensions, etc.

The diode frequency tripler calculation and design procedure proposed in [1] allows to determine requirements for basic parameters of frequency multiplication diodes with an accuracy sufficient for applications in practice in order to ensure the required characteristics of the device.

Design features of frequency tripler

The frequency tripler with optimized parameters of diodes is designed as two series-connected waveguides of different cross-sections: input WR-28 and output WR-10 [2]. 0.2 mm thick metal plates forming an H-shaped waveguide are inserted into the cut in the center of wide walls of waveguides (Fig. 1).

In the input segment, the cross-section of the output waveguide is narrowed to 2.14×1.27 mm in order to make it evanescent for the output signal second harmonic frequency range. Diodes with self-bias circuits are symmetrically installed on different sides of the plate, near the area where waveguides of different cross-sections are interconnected. On the input side, at distance $\lambda_{out\ avg}/4$, there is a polyimide plate (1×0.5×0.05 mm with one-side bonding) acting as a matching and short-circuiting element for the third harmonic. Immediately after the diodes there is a plate (0.5×0.25×0.05 mm) installed for output matching (Fig. 1). Fig. 2 shows the frequency tripler.

The top-priority technical characteristics of broadband frequency multipliers are as follows: conversion efficiency (loss), maximum available output power, output power ripple in the frequency range and the level of spurious components in the output signal spectrum.

According to experimental data, the best performance characteristics of a 75...110 GHz

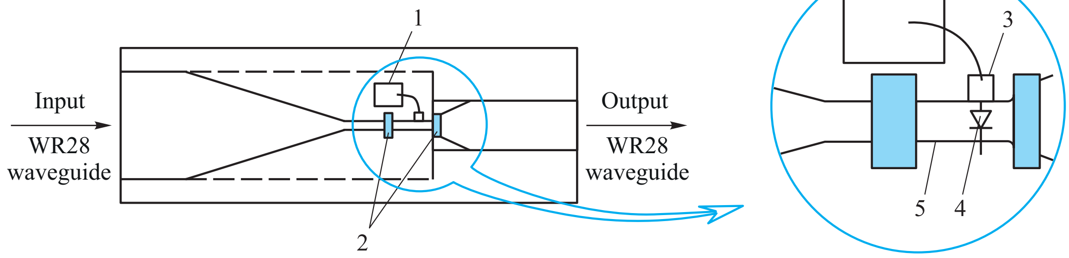

Fig. 1. Sketch of 75...110 GHz frequency tripler:
1 – resistor; 2 – polyimide plate; 3 – capacitor; 4 – diode; 5 – regular section

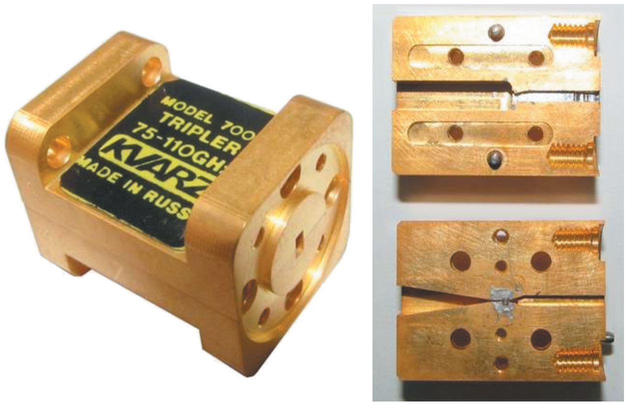

Fig. 2. 75...110 GHz frequency tripler

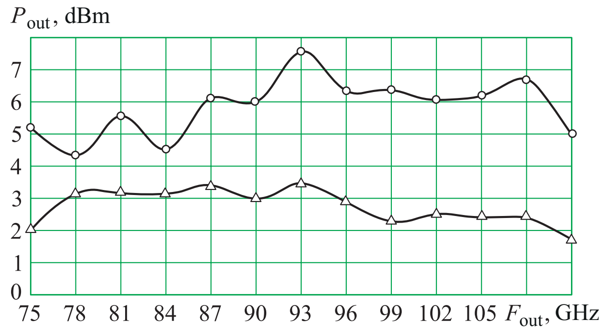

Fig. 3. Frequency tripler output power level at P_{in} = 100 mW:
—○— – calculation; —△— – experiment

broadband tripler (minimum conversion loss, maximum output power of ~2...3 mW) can be achieved by using frequency multiplication chip Schottky diodes with beam leads, type A92220-2 (manufactured by NPO “Salyut”, Nizhny Novgorod) [3, 4].

Typical characteristics of diodes are as follows: zero bias capacitance C_0 = 0.07 pF; loss resistance R_s = 5 Ω.

Diodes can be selected with the non-identity of VAC and CVC characteristics of around 10 %.

Calculation results

With the help of the broadband tripler calculation and design procedure [1], the tripler design was optimized using the A92220-2 diodes with identical characteristics.

The obtained results are shown in Fig. 3.

The difference between the experimental characteristic averaged by 10 tripler specimens and the calculated characteristic is not more than 1…4 dB.

Let us analyse the dependence of the tripler’s output power level on the variation of main diode parameters.

Fig. 4 shows calculated characteristics of the output power level for different values of diode C_0 at fixed R_s = 5 Ω; Fig. 5 shows these characteristics for different R_s at C_0 = 0.07 pF.

It is obvious that simultaneous reduction of C_0 and R_s to increase the efficiency of tripler conversion is not possible without a decrease in the available diode dissipation power; therefore, optimal values of C_0 and R_s for a given frequency range of the tripler and optimal values of the maximum output power level of 100 mW

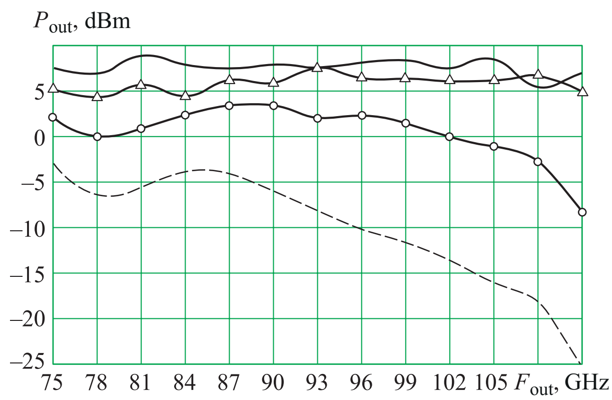

Fig. 4. Output power level at P_{in} = 100 mW, R_s = 5 Ω and different C_0, pF:
—— – 0.01; —△— – 0.07; —○— – 0.15; – – – – 0.25

are to be selected based on the following compromise: $C_0 = 0.07$ pF and $R_s = 5\ \Omega$.

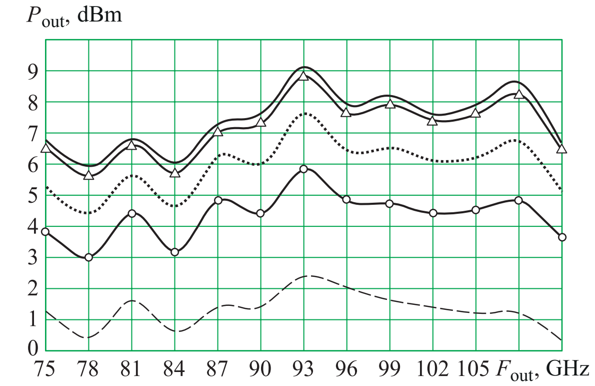

Fig. 5. Output power level at P_{in} = 100 mW, C_0 = 0.07 pF and different R_s, Ω: —— – 0.1; —△— – 1.0; ········ – 5.0; —○— – 10; – – – – 20

A detailed analysis of the requirements for non-identity of diode parameters in terms of C_0 and R_s, which causes spurious components in the tripler's output signal spectrum, is given in [1]. It is shown that at the minimum practically available identity of C_0 and R_s equal to 10 %, the second harmonic is suppressed by 25 dB relative to the third one, while the fourth harmonic is suppressed by 35 dB. The level of the second harmonic is more sensitive to the non-identity of diodes by R_s , while the level of the fourth one is more sensitive to the non-identity of diodes by C_0. We should mention that the 75...110 GHz broadband frequency tripler cannot filter the second and fourth harmonics, because they are within, or in close proximity to, the operating frequency range. That is why, the requirements for the non-identity of diode parameters are very tough.

The conversion efficiency largely depends on the behaviour of the variable CVC slope of frequency multiplication diodes. We analysed three different CVCs: nominal characteristic corresponding to real A92220-2 diodes, flat and steep characteristics (Fig. 6).

Fig. 7 shows output power level characteristics depending on the CVC slope.

Comparison of the results shows that a steeper CVC allows to increase the conversion efficiency by about 2 dB.

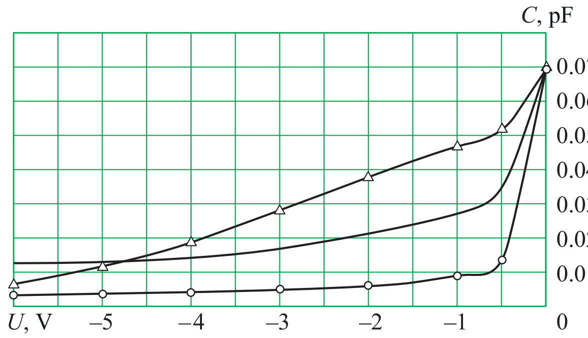

Fig. 6. Diode CVC family: —— – nominal; —△— – flat; —○— – steep

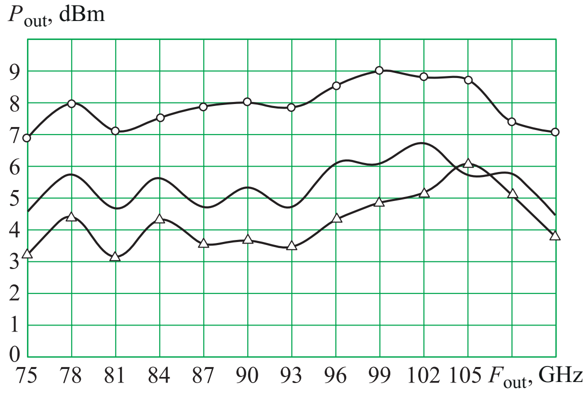

Fig. 7. Output power level depending on CVC slope: —○— – steep; —— – nominal; —△— – flat

Conclusion

According to completed calculations, parameters of diodes and the degree of diode CVC non-linearity have a considerable effect on the frequency tripler's output power level. Optimal selection of diode parameters allows to design a 75...110 GHz frequency tripler with output power of at least 5 mW at P_{in} = 100 mW (conversion loss of no more than 13 dB with non-uniformity of ±1 dB) and with the level of spurious component suppression in the output signal spectrum of at least 25 dBc.

Comparing the obtained results with the parameters of the equivalent WR10X3 frequency tripler model developed by Virginia Diodes, Inc., one of the leading foreign manufacturers, we should mention that this model has the conversion loss of 12…15 dB in the frequency range of 75...110 GHz.

Taking into account a good agreement of calculation and experimental results regarding all the basic characteristics of the frequency tripler, we may conclude that the proposed procedure allows for a priori determination of appropriate characteristics of a non-linear device without expensive and labour-consuming experimental studies.

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Оптимизация параметров диодов широкополосного утроителя частоты 75...110 ГГц

Проведена оптимизация параметров диодов широкополосного утроителя частоты 75...110 ГГц на основе предложенной методики расчета и проектирования с целью повышения эффективности преобразования.

Ключевые слова: утроитель частоты, СВЧ-устройство, вольт-фарадная характеристика, выходная мощность.

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Область научных интересов: преобразование частоты в приемо-передающей и радиоизмерительной аппаратуре СВЧ- и КВЧ-диапазонов.