11

Features of the external harmonic effect on the nonlinear oscillatory microwave circuit

© N.A. Maksimov, E.A. Myasin

Fryazino Branch, Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Fryazino, Moscow oblast, Russia
E-mail: maksna49@mail.ru

Received January 9, 2025
Revised January 30, 2025
Accepted January 30, 2025

It is shown that as a result of external influence on a nonlinear microwave circuit, resonances are formed in the system at frequencies determined by the magnitude of the inductance, the constant component of the nonlinear capacitance of the $p-n$ junction, at zero offset on it, and the higher harmonics of the nonlinear capacitance. The presence of such resonances forms the amplitude-frequency response of the circuit and allows you to control the spectral response of the oscillations excited in the system. This study was conducted on the basis of circuit modeling using the ADS software package.

Keywords: nonlinear circuit, Si$-$Ge transistor, $p-n$ junction, spectra, resonant characteristics.

DOI: 10.61011/0000000000

Let us consider a nonlinear microwave circuit (Fig. 1, a). The circuit includes a linear inductance and a nonlinear capacitance, which is represented by one of the $p-n$-junctions of a BFP 620F Si$-$Ge- with a cutoff frequency of ~ 65 GHz.

The circuit capacitance is specified by the nonlinear capacitance of one of the $p-n$- junctions of the BFP 620F transistor (in the present case, the collector junction). Fundamental resonance frequency $f_{m1} = 8.6$ GHz of the circuit is set by the value of this capacitance at zero DC bias at the junction and inductance L, which assumes a value of 1 nH (Fig. 1).

Let us consider the resonant characteristics of the circuit within this frequency range and the reasons for the emergence of resonances within the entire operating range of the transistor.

Owing to the nonlinearity of barrier capacitance $C_b(t)$, current $i_c(t) = C_b(t)\,\frac{dU}{dt}$ through it should have, in addition to the fundamental frequency, a series of harmonics [1].

At $L = 1$ nH (Figs. 1, b, 2, c), the capacitances underlying these resonances have the following values: $C_{m1} = 0.345$ pF, $C_{m2} = 0.06$ pF, $C_{m3} = 0.017$ pF, and $C_{m4} = 0.006$ pF. These values are close in magnitude to the capacitances calculated using the formulae for higher harmonics in [1]. Four resonances were observed: the first was located at the fundamental frequency of the circuit, while the last (fourth) was positioned at a frequency of 65 GHz (i.e., in the vicinity of the cutoff frequency of the transistor). The intensity (amplitude) of resonances and their position on the frequency axis depend on the circuit inductance. Specifically, the resonances at harmonics may be neglected at $L \geq 5$ nH (in the present case), since the fundamental resonance is tens of decibels stronger.

As L decreases, the resonances at harmonics become more significant, and the intensity in the region of the fundamental resonance decreases considerably at $L < 1$ nH, while the amplitude of resonances at harmonics increases (Figs. 2, a, c, e). At $L = 0.1$ nH, the most intense resonances are the ones at ~ 47 and 69 GHz. It is known that complex oscillations (including those with a continuous spectrum) are excited in a microwave circuit with a sufficient amplitude of the external influence and its frequency falling within the range of $0 < f_{ext} \leq 2f_{m1}$, where f_{ext} is the frequency of the external force and f_{m1} is the frequency of the fundamental resonance [2]. Varying the value of L, one may shift the intensity of a continuous spectrum from low frequencies (Figs. 2, a, b) to the cutoff frequency of the transistor (Figs. 2, e, f) or align the generation of oscillations with the continuous spectrum within the entire operating frequency range of the transistor (Figs. 2, c, d). In each case, the external signal is applied at the $m1$ fundamental resonance frequencies.

It should be noted that the values of the first resonance (and, accordingly, the harmonics) capacitance corresponding to 18 different inductances $L = 0.1-50$ nH considered in the present study vary from 0.49 pF at $L = 0.1$ nH to 0.16 pF at $L = 50$ nH. The average value of the first resonance capacitance was ~ 0.2 pF. The same collector–base junction capacitance is given in the datasheet of the BFP 620F transistor. Intriguingly, when scanning the external signal by frequency, the system with a given inductance does itself select the unperturbed capacitance of the fundamental resonance from the above $0.16-0.49$ pF interval.

Thus, the results of examination of the circuit model suggest that the overall resonant characteristic of a nonlinear oscillatory circuit with the capacitance of the $p-n$- junction

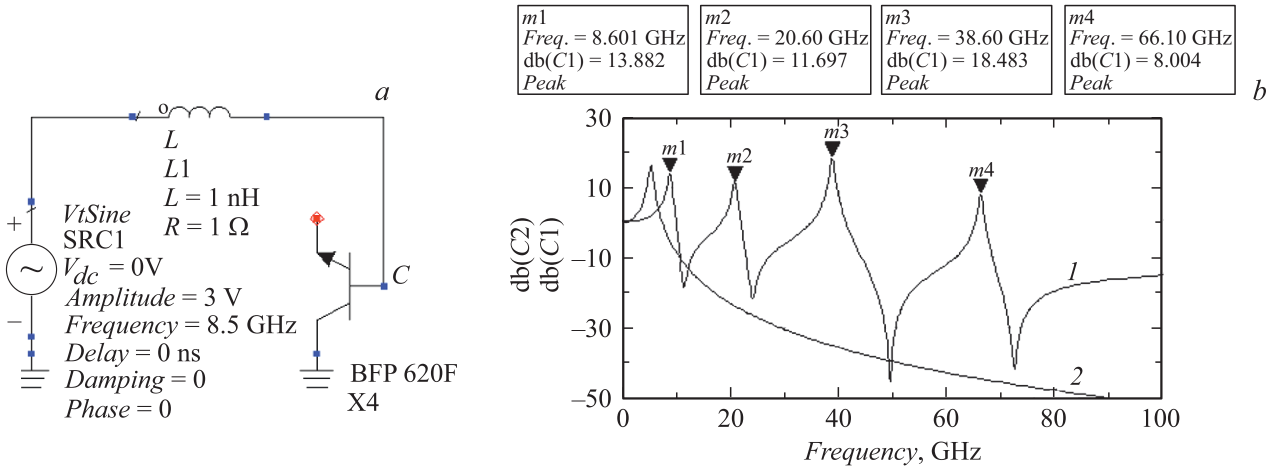

Figure 1. a — Nonlinear circuit based on the $p-n$- junction of a BFP 620F transistor and inductance $L = 1$ nH under external harmonic influence. b — Comparison of resonant characteristics of the nonlinear circuit (*1*) and a linear circuit with $C = 1$ pF and $L = 1$ nH (*2*).

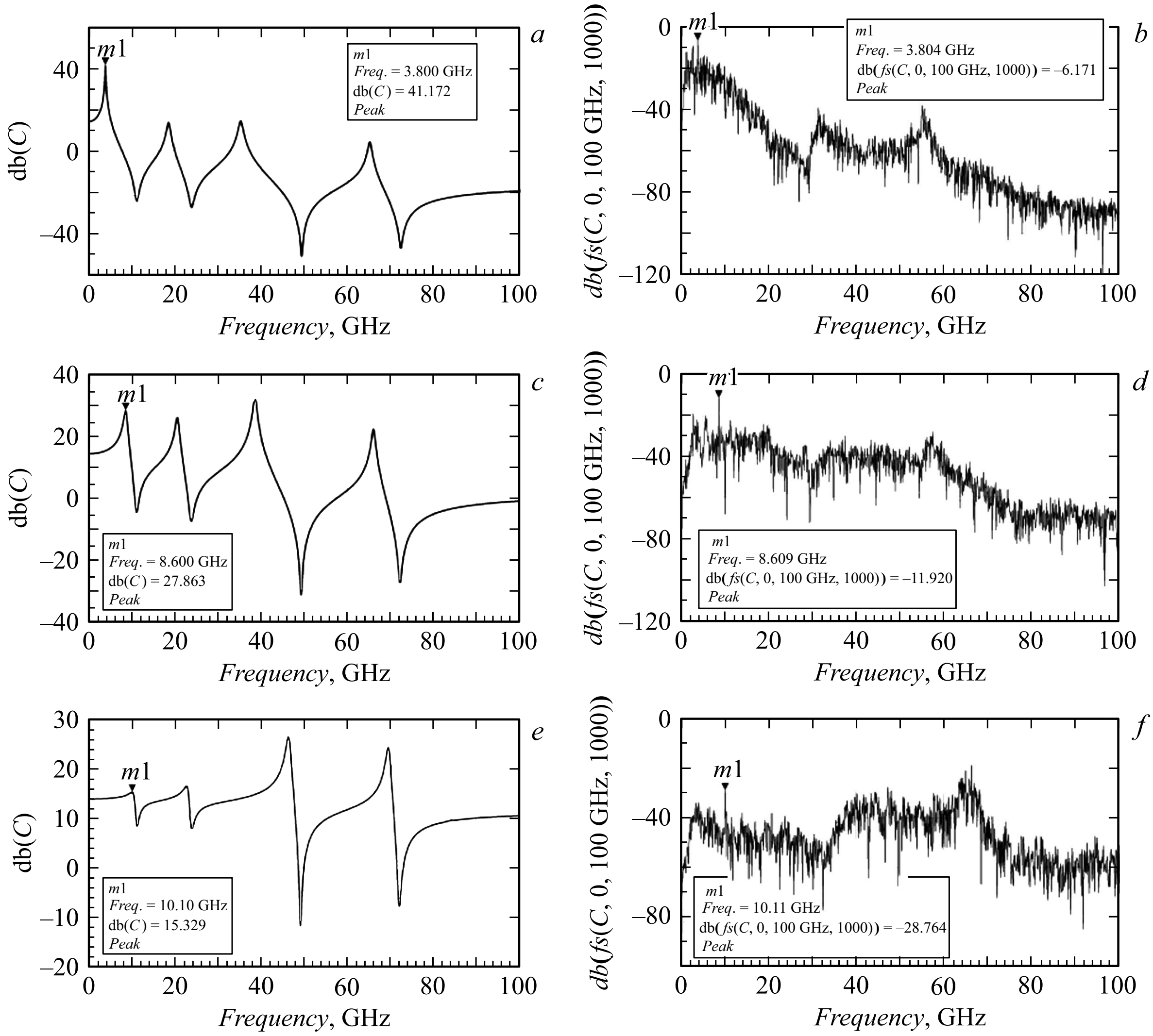

Figure 2. Dynamics of variation of resonant characteristics of the circuit with inductance L (a, c, e) and the corresponding change in spectral characteristics of continuous oscillations in the circuit (b, d, f). $L = 10$ (a, b), 1 (c, d), and 0.1 nH (e, f).

of a microwave BFP 620F heterotransistor used as a nonlinear element is shaped both by the resonance at the fundamental frequency of the circuit and by resonances at higher harmonics. The type of this resonant characteristic depends on the circuit inductance, which allows one to adjust the spectral characteristic of oscillations excited in the circuit within the entire operating range of the transistor (through to its cutoff frequency of ~ 65 GHz). This feature must be taken into account in the design of microwave generators of various purpose.

Funding

This study was carried out as part of the target plan.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] L.S. Berman, *Vvedenie v fiziku varikapov* (Nauka, L., 1968) (in Russian).
[2] A.S. Dmitriev, E.V. Efremova, N.A. Maksimov, A.I. Panas, *Generatsiya khaosa* (Tekhnosfera, M., 2012) (in Russian).

Translated by D.Safin