PM AND AM NOISE ANALYSIS IN MICROWAVE BJT OSCILLATOR BASED ON POLYHARMONIC APPROACH

V.N. Kuleshov ®, A.A. Perfilyev

Moscow Power Engineering Institute (Technical University),
14 Krasnokasarmennaya, Moscow 111250, Russia, e-mail: kuleshov@srv-vmss.mpei.ac.ru

ABSTRACT

Polyharmonic approach to analysis of steady-state oscillations, their stability, and PM and AM noise in microwave BJT oscillator was developed. A computer program providing calculation of complete power spectral density of oscillation at any Fourier frequency. The program provides also calculations of PM and AM noise power spectral densities. Both wideband and 1/f noise sources in BJT are taken into consideration.

Results of the oscillator parameters optimizing providing minimum of wideband PM noise power spectral density with given BJT and oscillator output power are presented.

1. INTRODUCTION

Most of the approaches to PM and AM noise calculation in oscillators are based on the assumption that input voltage of the oscillator active device is almost harmonic function of time. In means that phase and amplitude of this voltage supposed to be slowly varying functions of time and an influence of higher harmonic components of the voltage is not taken into consideration. The algorithms based on these assumptions do not provide good accuracy of calculation of power spectral density (PSD) of the oscillations at frequency offsets from carrier that are large by comparison to the bandwidth of the resonator used in the oscillator. In some cases of practice it is necessary to know a PSD of the oscillator output voltage at any frequency offset. To solve this problem a polyharmonic approach to PM and AM noise calculation in oscillator was developed (-Ref.1). In this paper a polyharmonic approach is applied to noise calculation in microwave bipolar junction transistor (BJT) oscillator. The program for oscillations PSD calculation based on this approach provides an opportunity to find both PSD of the oscillator noise at any offset from the carrier, and PSD of PM and AM noise of the oscillator. It provides also THE oscillations stability analysis taking into consideration all possible causes of the oscillations instabilities (for example, due to influence of chokes or BJT nonlinear capacitances).

2. CIRCUIT DIAGRAM AND CIRCUIT MODEL OF THE BJT OSCILLATOR

The circuit diagram of the oscillator under consideration is shown in Fig.1. In this circuit diagram C_1, C_2, C_3, L_3, and r_3 – elements of Clapp oscillator positive feedback resonator, L_1 and L_2 – chokes, R_e and R_b – self-biasing resistances, r_e – emitter current feedback resistance, E_b, E_c – biasing voltages, u_L – output voltage of the oscillator. Such circuit diagram describes low power BJT oscillator that can be used up to frequencies 2÷4 GHz.

To describe BJT operation in active, cut-off and saturation regions a charge control model is used -Ref. 2. It is shown in Fig. 2. In this model $u_{b'e'}$ and $u_{b'c'}$ – voltages, applied to emitter and collector junctions, $i_f = I_s(\exp(q_e u_{b'e'}/k_b T)-1)$ and $i_i = I_s(\exp(q_e u_{b'c'}/k_b T)-1)$ – forward and inverse component of emitter current, I_s – saturation current, q_e – electron charge, k_b – Boltzman constant, T– absolute temperature, β_f and β_i – large signal common emitter forward injection and inverse injection Short circuit current gains, τ_f and τ_i – forward injection and inverse injection charge control parameters, $C_e(u_{b'e'})$ – emitter junction capacitance, C_{ca}, C_{cp} – collector junction capacitances, r_b' – base resistance, $p = d/dt$, L_b, L_c, L_e – base, collector and emitter lead inductances, r_c', r_e' –collector and emitter lead resistances, C_{ce} – capacitance between points c' and e' in BJT structure.

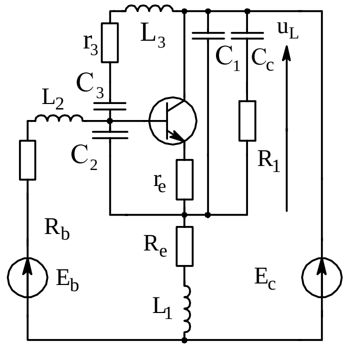

Fig.1. Circuit diagram of the BJT oscillator.

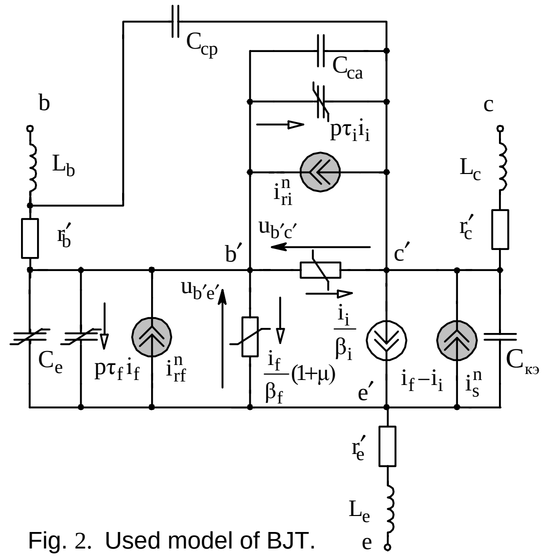

Fig. 2. Used model of BJT.

The current sources of recombination noise i^n_{rf}, i^n_{ri} and shot noise i^n_s are shown in Fig. 2. In addition to them an influence of all sources of thermal noise both in Fig. 1 and in Fig.2 was taken into consideration to calculate an influence of wideband noise sources on PSD of output oscillations and PM and AM noise PSD.

To take into consideration 1/f noise influence relative fluctuations $\mu(t)$ of recombination current (i_f/β_f) were introduced in the model Fig. 2. Power spectral density $S_\mu(\omega)$ of $\mu(t)$ has to be found from collector current PSD measurements.

3. BASIC FEATURES OF POLYHARMONIC APPROACH TO OSCILLATOR NOISE ANALYSIS AND OPPORTUNITIES OF DEVELOPED SOFTWARE

Basic features of polyharmonic approach to noise analysis in nonlinear nonautonomous systems were offered by P. Penfild (-Ref. 3). Development of this approach giving an opportunity to use it for autonomous systems (oscillators) was given in Ref. 1.

It is based on polyharmonic solution of the oscillator model equation, and derivation of equations for small perturbations of oscillations frequency, and amplitudes and phases of the oscillations harmonic components due to noise sources influence.

To be sure that the perturbations are really small one has to check stability of the oscillations. In our approach stability is checked using mapping theorem.

Solution of perturbation equations leads to calculation of the oscillation PSD and to calculation of PM and AM noise PSD. The oscillations PSD is calculated for any Fourier frequency from zero to the value that is necessary to solve the problem. PSD of PM and AM noise is calculated for Fourier frequency changing from 0 to ($\omega_o/2$), where ω_o – oscillations frequency.

Basing on this approach the special software is developed. It presents wide facilities not only in analysis, but also in parameters optimization of BJT oscillator. For example one can minimize PM noise in oscillator with given carrier frequency, output power, resonator unloaded Q-factor, efficiency, power supply voltage, etc. All results, presented below, are obtained using this software.

4. AN EXAMPLE OF THE BJT OSCILLATOR NOISE CALCULATION

Some results of noise calculations for 2 GHz low power oscillator with BJT 2T3115A are presented below. The BJT model parameters are: $I_s = 10^{-13}$ A, β_f=50, β_i=0.6, τ_f=0.023 ns, τ_i=0.5 ns, C_{ca}=0.2 pF, C_{cp}=0.4 pF, C_{ce}=0.1 pF, C_{e0}=0.5 pF, L_b=0.75 nH, L_e=0.2 nH, L_c=0.3 nH, $r_b' = 10$ Ohm, $r_c' = 2.5$ Ohm, $r_e' = 1$ Ohm. The circuit Fig. 1 parameters are: C_1=1 pF, C_2=14 pF, C_3=10 pF, L_3=4.2 nH, r_3=1 Ohm, $r_e = 0$, R_1=1 kOhm, R_e=430 Ohm, R_b=500 Ohm, C_c=10 pF, L_1=0.75 μH, L_2=0.25 μH. They were obtained using algorithm, proposed in -Ref. 4.

Harmonic balance calculation gives: carrier frequency f_0=1.986 GHz, output power P_{out}=2.361 mWt, efficiency η=14.2 %, (number of harmonics taken into account N=20). Loaded Q of the feedback resonator is equal to 15.1. Collector biasing voltage was found from demand of transistor operating at the boundary of saturation region. In our case E_c=4.5 V.

The PSD of output voltage is shown in Fig. 3. In this figure log-scale was used for offsets from frequencies nf_o up to $nf_o \pm 0.5f_o$. The values of PSD at the points nf_o correspond to offset values $10^{-3} f_0$. The error of these calculations is less then 0.005 dB. In this figure and further curve 1 is corresponding to total PSD, curve 2 – due to thermal noise, curve 3 – due to forward recombination noise, curve 4 – due to shot noise. The PSD of

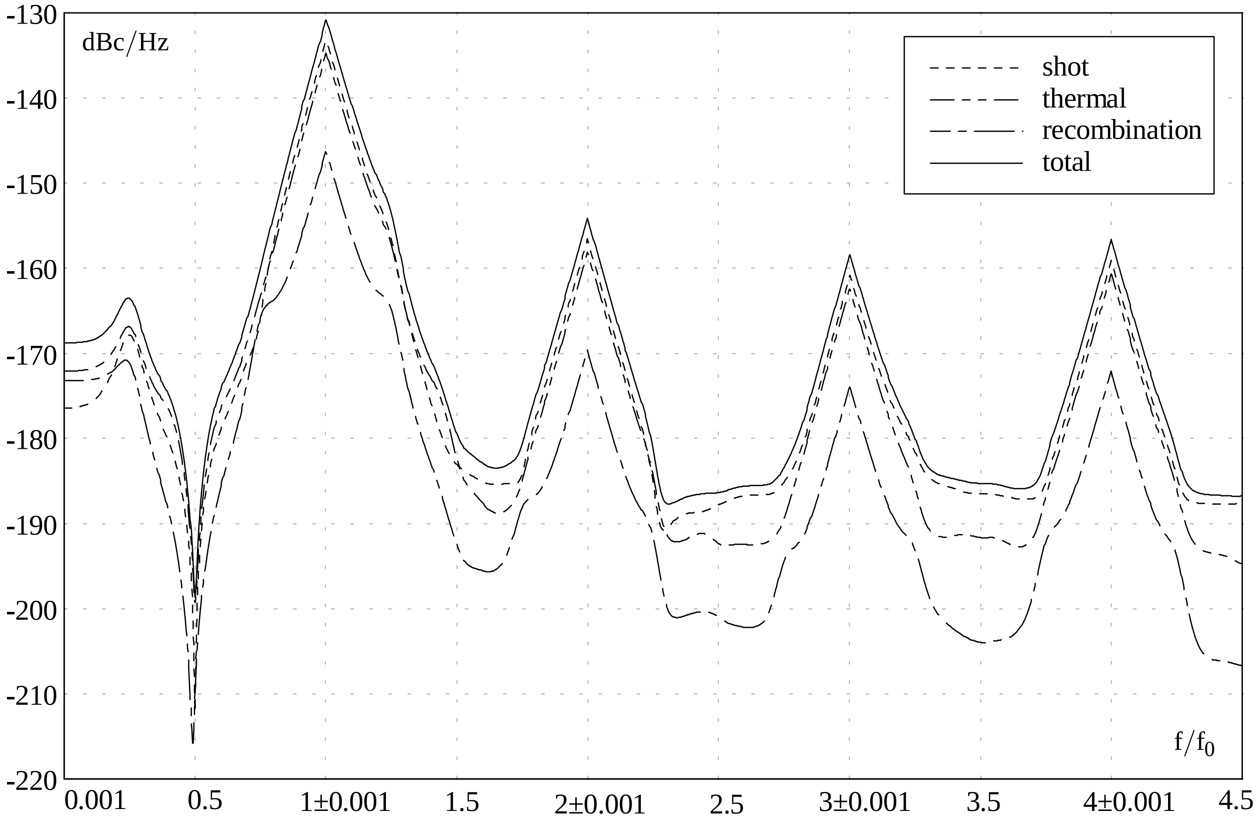

Fig. 3. Power spectral densities of noise at the output of an example of 2 GHz BJT oscillator and its components caused by different sources of wideband noises.

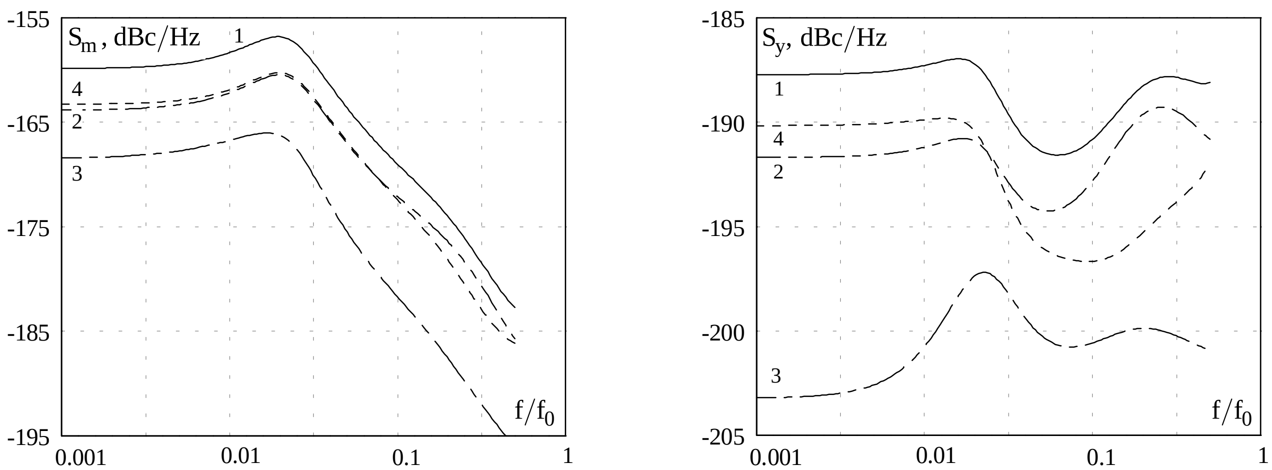

Fig. 4. AM and FM noise PSD's.

AM noise m(t) and relative FM noise $y(t)=(d\varphi/dt)/\omega_o$ in interval of Fourier frequencies ($0.001f_0 \div 0.5f_0$) are shown in Fig 4,a,b.

5. OPTIMIZING OF THE OSCILLATOR PARAMETERS

When one develops BJT oscillators with autonomous power supply it is important to reach the lowest PSD of PM noise at rather low Fourier frequencies ($f<0.01f_0$) in the oscillator with given f_0, P_{out}, efficiency η and unloaded Q-factor $Q_0=\omega_0 L_3/r_3$. It is clear that if one obtains minimum of FM noise due to wideband noise sources $S_y(0)=(f/f_0)^2 S_\varphi(f)\big|_{f\to 0}$ than minimum of $S_\varphi(f)$ for each $f \ll f_0$ will be found. But if furred out that formal minimizing of $S_{y0}=S_y(0)$ leads to increasing of $S_m(0)$ and one can obtain minimum of $S_y(0)$ for each given value of $S_{m0}=S_m(0)$. That is why the optimizing problem statement looks as follows. It is necessary to find

$$S_{y0}^{min}=\min S_{y0}(C_1,C_2,C_3,r_e,R_b \mid f_0,P_{out},\eta,Q_0,S_{m0}), \quad (1)$$

where minimum has to be looked for in the space of variables C_1, C_2, C_3, r_e, R_b.

If one takes into consideration only thermal noise of the resonator a simple formula for PSD $S_{y0,th}^{min}$ and $S_{m0,th}^{min}$ caused by this noise can be obtained

$$S_{y0,th}^{min}=\frac{k_b T}{2}\frac{\eta}{(1-\eta)^2}\frac{1}{P_{out}Q_0^2}, \quad (2)$$

$$S_{m0,th}^{min}=2k_b T\eta/P_{out}. \quad (3)$$

It is convenient to discuss results of the oscillator optimizing if we consider the ratio

$$\tilde{S}_{y0}^{min}=S_{y0}^{min}/S_{y0,th}^{min} \quad (4)$$

as a function of f_0. This function is shown in Fig. 5. Contributions of different wideband noise sources are also shown in this Figure. The curves shown on Fig. 5 were calculated for the next fixed parameters: $P_{out}/((2/r_b')(k_b T/q_e)^2)=16$ dB, $S_{m0}/S_{m0,th}^{min}=25$ dB $\eta=0.2$, $Q_0=50$. The ratio $\tilde{S}_{y0}^{min}$ (4) can be considered as a minimum frequency noise factor of the oscillator.

It is found that the function (1) has several local minima at some intervals of f_0. But the values of S_{y0}^{min} at these minima don't differ significantly. At low oscillations frequencies $f_0<0.17f_T$ (where $f_T=1/(2\pi\tau_f)$) one obtain $\tilde{S}_{y0}^{min}$ when $r_e>0$. At higher frequencies $\tilde{S}_{y0}^{min}$ is obtained when $r_e=0$. For each value of f_0 an optimum value of $C_3 \neq \infty$ exists. For optimized oscillator the main contribution in the total FM noise at low f_0 is provided by BJT thermal noise, and at high f_0 – by shot noise. One can notice that in the interval $0.06f_T<f_0<0.3f_T$ the value of $\tilde{S}_{y0}^{min}$ grows almost proportionally to f_0. A value of $\tilde{S}_{y0}^{min}$ doesn't depend very significantly on P_{out}, η, Q_0 and S_{m0} in rather wide area of their variation. That is why an influence of P_{out}, η and Q_0 on S_{y0}^{min} can be estimated using formula (2).

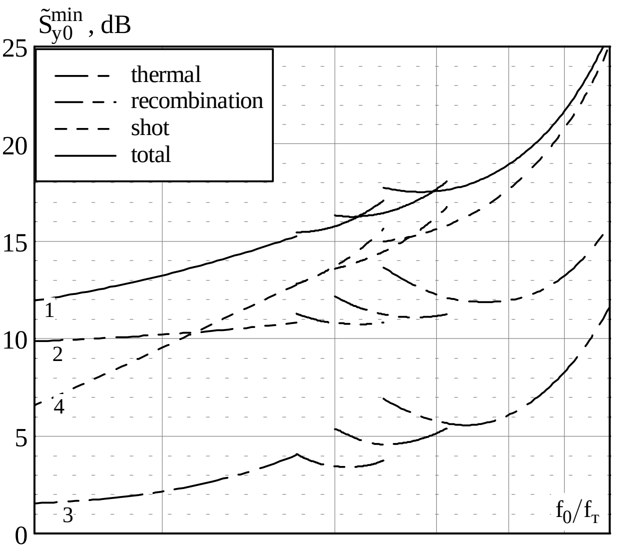

Fig. 5. Dependence of minimum frequency noise factor upon normalized oscillations frequency f_0/f_T.

Results of PM and AM noise calculation in the optimized oscillator with f_0=2 GHz ($f_0/f_T=0.286$) taking into consideration 1/f noise source influence are shown in Fig. 6. The data for $S_\mu(f)$ for the BJT 2T3115A were taken from the -Ref. 5: $S_\mu(f)=S_\mu^H(I_{cH}/I_{c0})(f_H/f)$, where S_μ^H=-138 dB/Hz, I_{cH}=10 mA, f_H=1kHz. One can see that corner frequencies for $S_\varphi(f)$ and $S_m(f)$ are 330 Hz and 1,25 kHz.

6. AN INFLUECE OF COLLECTOR BIASING VOLTAGE

Results of analyzing of collector biasing voltage influence on $S_y(0)$ and $S_m(0)$ are shown in Fig.7. One can

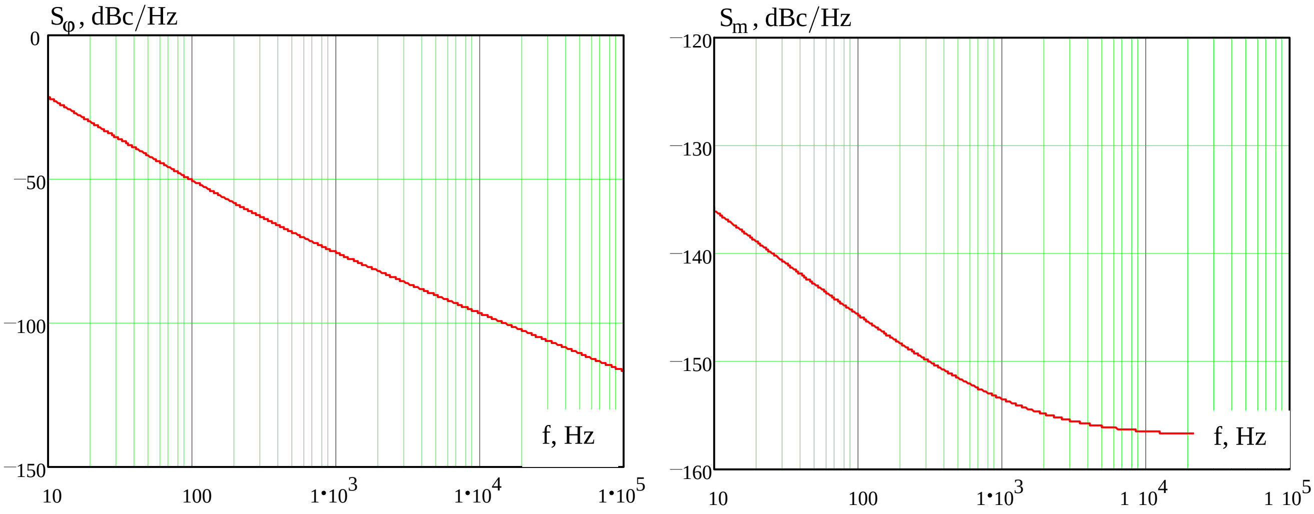

Fig. 6. PM and AM noise PSDs for 2 GHz oscillator.

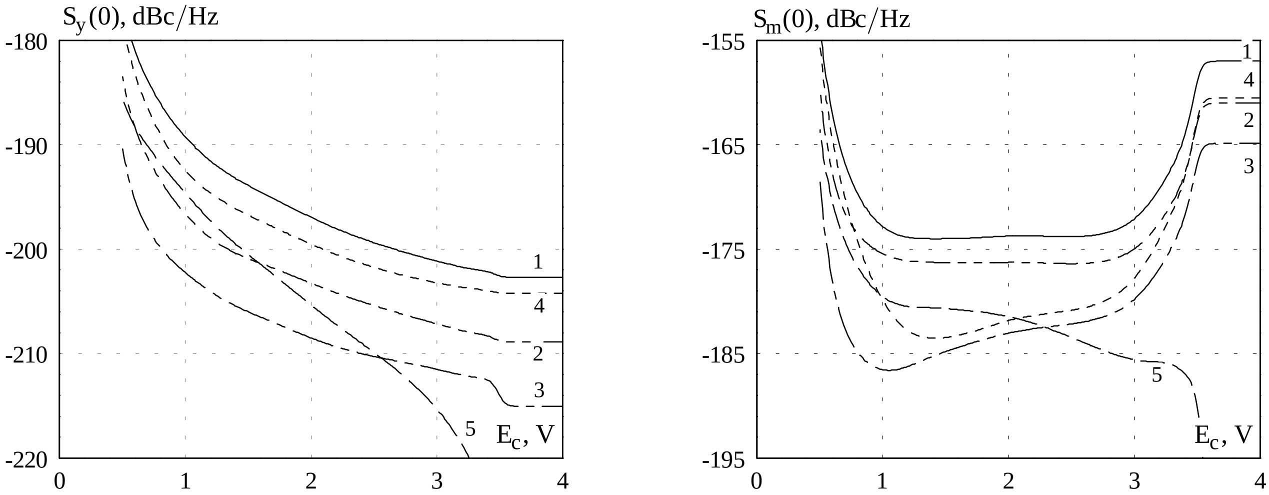

Fig. 7. Collector biasing voltage influence on FM and AM noise in BJT oscillator.

see that if BJT works partly in the saturation region than $S_m(0)$ can be decreased rather significantly with small increasing of $S_y(0)$. A contribution of inverse recombination noise current (curve 5 in Fig. 7) is not significant.

7. CONCLUSIONS

Example of the BJT oscillator noise analysis and optimizing of the oscillator parameters shows opportunities of polyharmonic approach. It seams reasonable to combine polyharmonic approach with simple methods of the oscillator noise estimation using it to get complete information about noise of the oscillator under consideration.

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