Microwave generator based on the Josephson Junction

R. Tyumenev[1], D.S. Kalashnikov[1,2], A.G. Shishkin[1,2], V.S. Stolyarov[1,2]

[1]Moscow Institute of Physics and Technology; [2]Dukhov Research Institute of Automatics (VNIIA)

Introduction

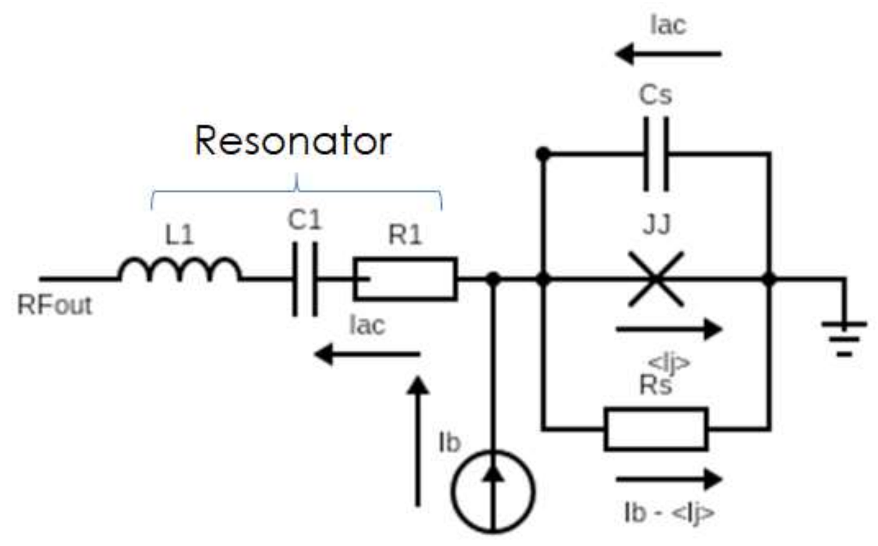

fig 1. An equivalent generator circuit proposed in [1]. The generator consists of a Josephson junction, a microwave resonator, a shunt capacitance and a resistance

Physical systems used for quantum computing operating in the microwave range require advanced control electronics, and the use of integrated components operating at the temperature of quantum devices is potentially beneficial. In [1], a generator operating at a temperature of 20 mK at a frequency corresponding to the control of qubits was demonstrated. However, the manufacturing technology of this device is quite time-consuming.

In this paper, we consider a generator consisting of a Josephson junction, a microwave resonator, a shunt capacitance and a resistance. The aim of the work is to determine the range of generator parameters in which stable generation is possible by numerical solution of the system dynamics equations, the manufacture of individual generator elements, as well as the search for its optimal parameters using modeling taking into account the obtained generator elements.

Results

System modeling:

- The calculated system:

$$\beta\frac{\ddot{\varphi}}{{\omega_c}^2}+\frac{\dot{\varphi}}{\omega_c}+\sin\varphi=\frac{I_{dc}+I_{ac}\sin(W\tau)}{I_c}$$

$$\beta=\frac{2e}{\hbar}I_cCR^2 \quad W=\frac{\omega}{\omega_c}, \tau=\omega_c t \quad \omega_c=\frac{2eI_cR_s}{\hbar}$$

- The criterion for the appearance of AC generation[2]:

$$Re\left(z_J(\omega)\right)=Re\left(\left(\frac{iW^2}{2\pi i_{ac}}\right)\int_0^{2\pi/W}\varphi e^{iwt}dt\right)\right)<0$$

- The resulting generation power is spent on dissipation and payload. This requirement makes the condition above more stringent:

$$Re(Z_J)=-R1$$

- A small capacity in the system ensures the appearance of generation. (**fig. 2**). Generation is observed when: $\beta > 0.1, W > 0.2$

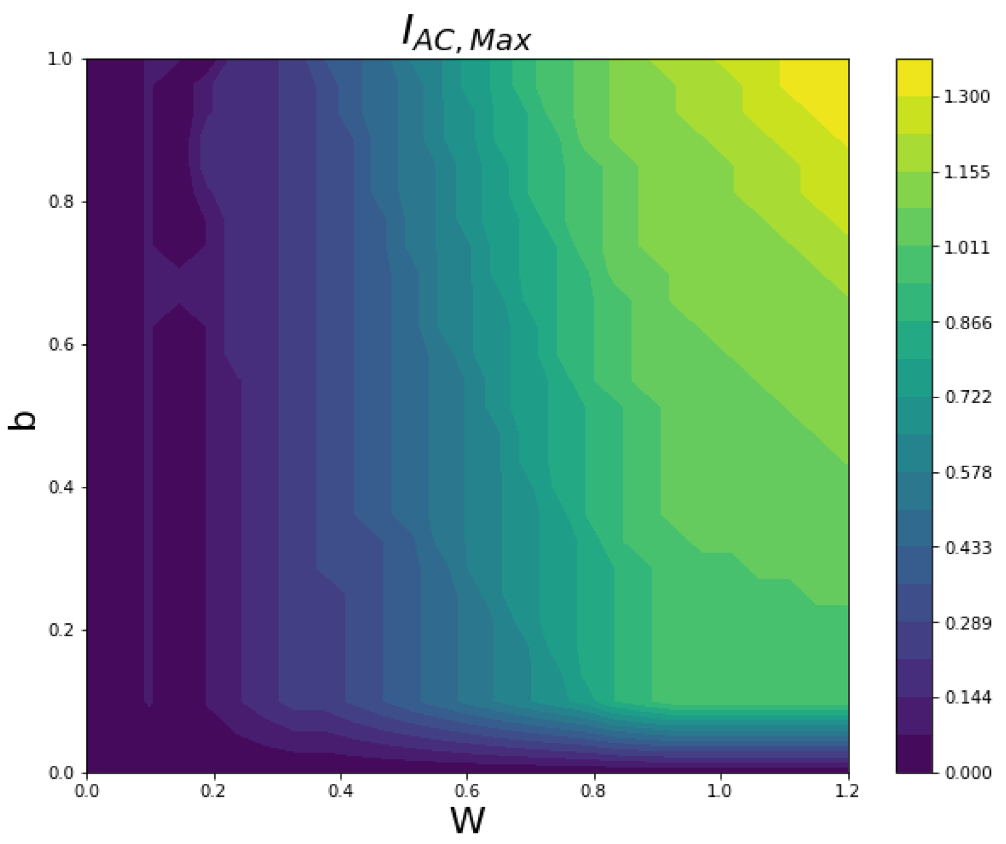

Fig 2. Dependence of the maximum normalized generated AC amplitude (indicated by color) on small system parameters

Manufacturing of individual generator elements::

- The Josephson junction is a planar SNS. The shunt resistor is a strip of copper according to planar technology. (**fig. 3**).
- The shunt capacitor is a planar capacitor. **(fig. 4)**. The resulting capacitance: $C = 40\,pF$.
- A coplanar resonator is used as a resonator : $Q_l \approx 25000$
- The dependence of the critical current on the temperature $I_c(T)$ allows to find the operating point for the generator. (**fig. 5**).

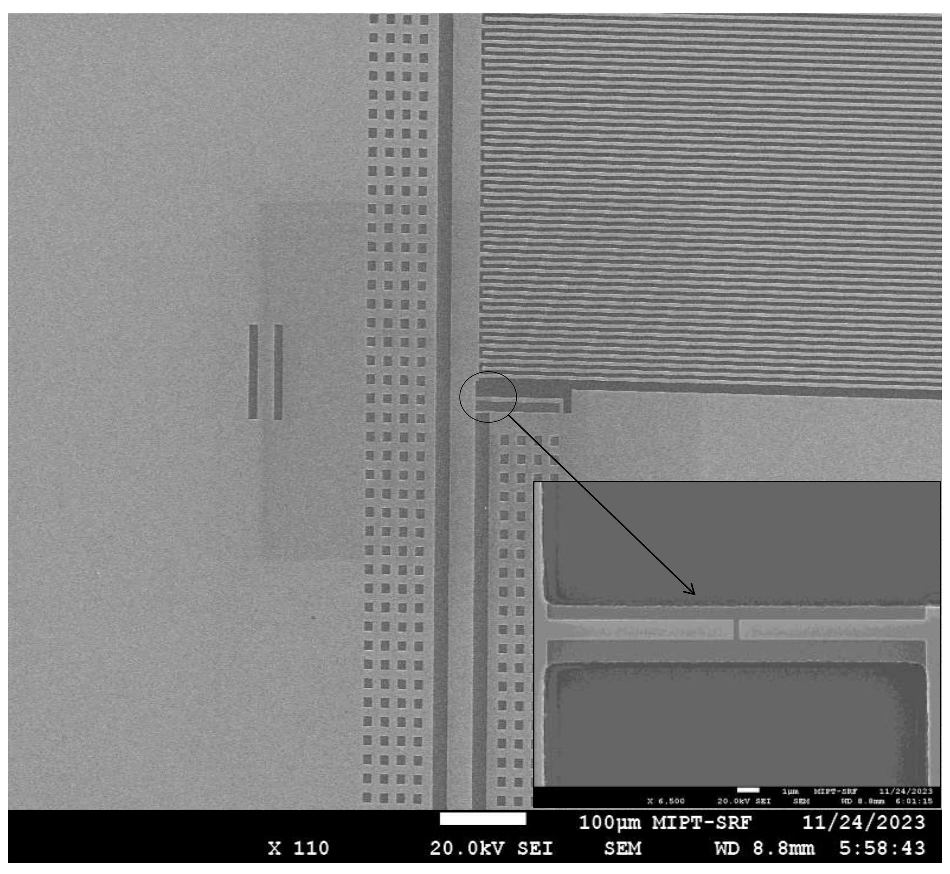

Fig 3. A photo of the sample taken on SEM. Enlarged image of the planar SNS

	f (GHz)	C (pF)	Q_l	I_c (μA)	R_t (Ohm)	P_{out} (pW)	β	W
Result	8	40	20000	25	2	15	11.1	0.35
Article [1]	5.3	200	6000	10	1	25	5.83	1.08

Table 1. Comparison of the obtained generator characteristics with the results [1]

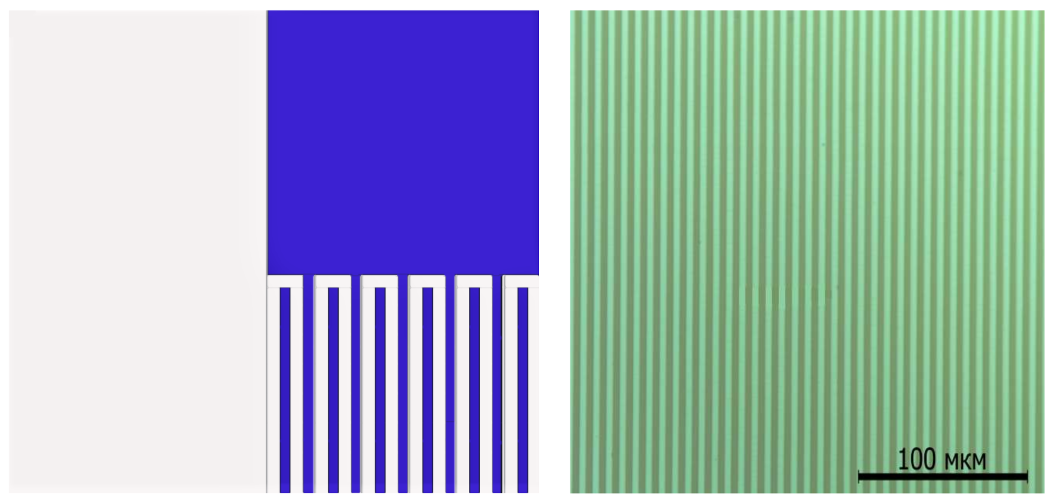

Fig 4. Left: design of a planar capacitor; right: photo of the resulting sample

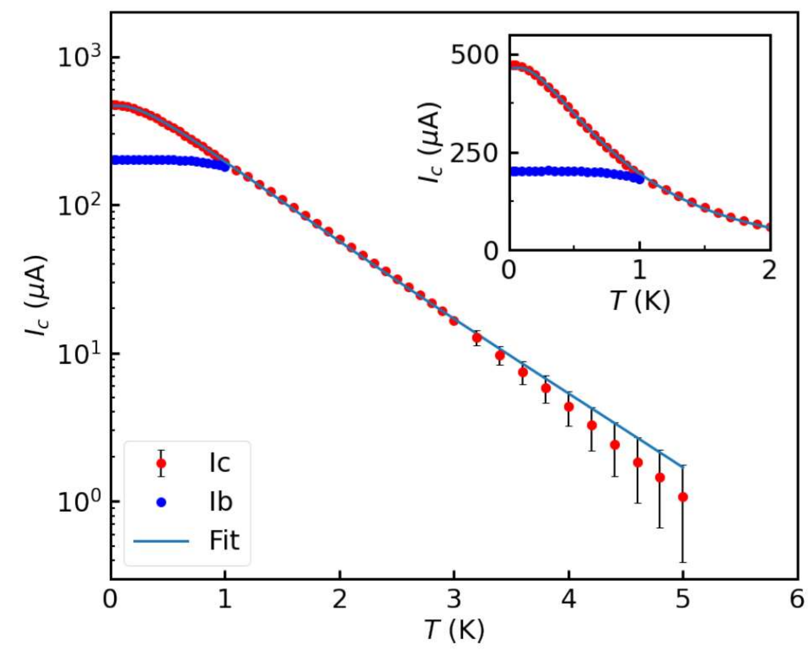

Fig 5. Dependence of the critical current planar SNS on temperature [4]

Modeling + manufactured elements :

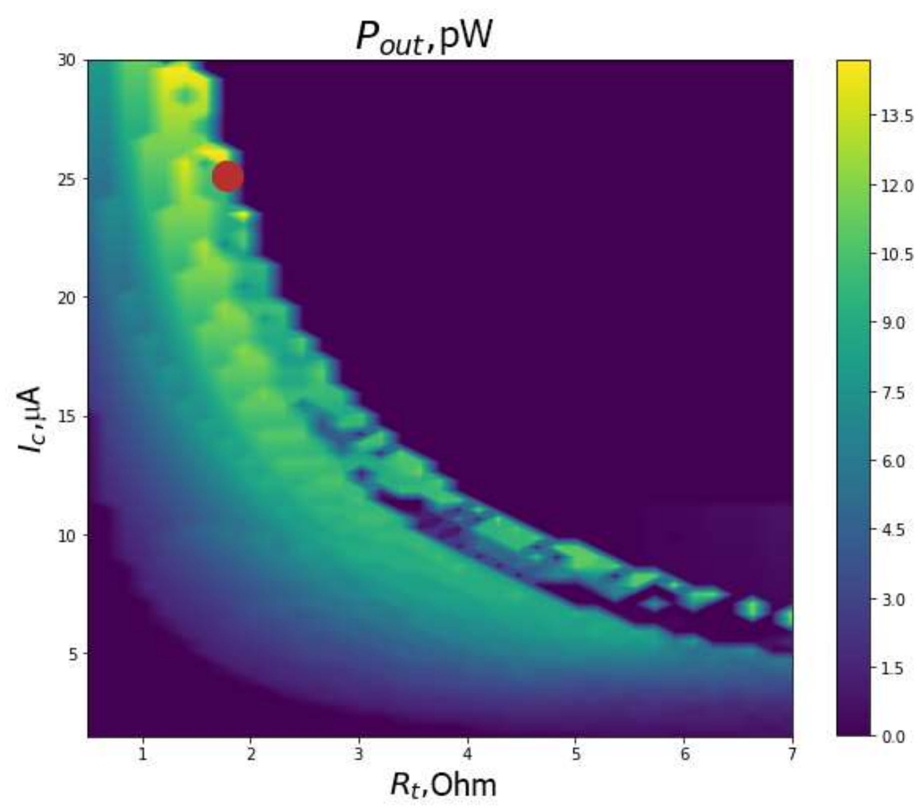

Fig 6. The dependence of the AC generation power (indicated by color) on the actual parameters of the system. The maximum possible power is highlighted with a red dot

Conclusion

This work is devoted to the development of a new design and technology of the Josephson microwave generator.

- Numerical simulation of the dynamics of the Josephson generator was carried out and a program for calculating the generation power was written.
- Generator elements were manufactured and measured: planar capacitors, Josephson SNS junctions and normal resistance.
- The experimentally obtained characteristics of the elements formed the basis for the search for optimal parameters for the generator. (**fig. 6**).

A significant and new result of this work is the fact that these values can be obtained using *planar technology*, which will simplify the manufacture of the generator compared to the use of *multilayer structures*.

References

1.C. Yan, J. Hassel, V. Vesterinen, Jinli Zhang, et. al // Nature Electronics volume 4, pages885–892, (2021)

2. Z. Zhai, Patanjali V. Et. al. // Phys. Rev. B 59, 9573 – Published 1 April 1999

3. Hassel J., Grönberg L., Helistö P. // Appl. Phys. Lett. 2006.

4. D.S. Kalashnikov, master's thesis, Skoltech (2022)

Financing

The work was supported by Grant from the ministry of science and higher education of the Russian Federation No. 075-15-2024-632