Dynamics of Bloch oscillating transistor near divergence and its applicability for common mode signal rejection

Jayanta Sarkar[1], Antti Puska[1], Juha Hassel[2] and Pertti J.Hakonen[1]

[1]Low Temperature Laboratory, O.V.Lounasamaa Laboratory, Aalto University, P.O. Box 13500, FI-00076 AALTO, Finland
[2]VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland
jay@boojum.hut.fi

Abstract: Bloch oscillating transistor is a combination of a Josephson junction or a squid connected with a large resistor and a NIS junction (c.f. Fig. 1). BOT was demonstrated as a current amplifier which has a very low input equivalent noise of ~ 1fA/√Hz[1]. The tendency of BOT to bifurcate has been theoretically predicted and followed by experimental verification[2]. We have studied the dynamics of BOT near the bifurcation threshold[3]. This is an important feature for an amplifier as this can be utilized to improve the performance characteristics of it. In this present work we have investigated it in more detail followed by a separate experiment with a differential pair BOT to determine the common mode rejection capability of this amplifier for the first time.

Near the bifurcation point BOT behavior is fully governed by switching dynamics with the rates imposed by the biasing conditions. Near the bifurcation point the base current is a combination of a working point current not inducing inter-band transition, and a part that leads to transitions. The ratio of these two is given by $\langle N_e \rangle$, which is the average number of tunneling events before a downward transition triggered by injected base current.

We have measured the *I*-*V* characteristics of the BOT with different base currents (I_B) over a wide range of Josephson coupling energy (E_J). A typical *I*-*V* with different I_B is shown in Fig. 2. The current gain (β) is found to be increasing with increasing I_B and eventually it diverges. We have found a record large $\beta \sim 50$ in our experiment. The base current, I_{B-H} required for the onset of hysteresis with different E_J has been determined from the $\beta - I_B$ plots.

We have modeled our experimental data with analytical model as well as simulation. From the simulation we found a change of factor of 15 in $\langle N_e \rangle$ over the measured E_J range but unfortunately we have not been able to determine it from the experiment. The numerical analysis has also generated the similar phase diagram as was found in experiment. The analytical estimate of crossover curve also too fits well with measured I_{B-H} - E_J curve (see Fig. 3)[3].

In order to determine the common mode rejection ratio (CMRR) of a differential pair BOT we followed the scheme shown in Fig. 4. The common mode port is connected to the bases of the two BOTs and fed with varying voltages; simultaneously emitter currents of the two BOTs are recorded. We found that in order to achieve a CMRR, the matching of transconductances (g_m) of two BOTs is sufficient. In our experiment we found a 20dB of CMRR even though g_m of the two BOTs were not exactly equal (Fig. 5). We measured the input equivalent noise in β -mode and in g_m – mode (c.f. Fig. 6) and estimated the Z_{opt} to be 5 -10MΩ which matches with $Z_{in} \sim 6$MΩ within a factor of 2 for the measured BOT devices. In short, BOT pair has the potential to use as a transconductance amplifier in cryogenic applications.

References:

[1] J. Delahaye, J. Hassel, R. Lindell, M. Sillanpää, M. Paalanen, H. Seppä and P. Hakonen, Science 299 (2003),1045

[2] J. Hassel and H. Seppä, J. Appl. Phys. 97 (2005), 023904.

[3] J. Sarkar, A. Puska, J. Hassel and P. J. Hakonen, arXiv: 1301.5546, (2013)

[4] J. Sarkar, A. Puska, J. Hassel and P. J. Hakonen, arXiv: 1301.6053, (2013)

Figures:

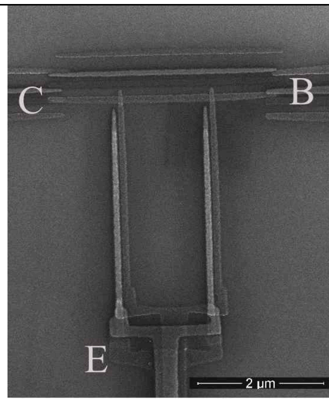

Figure 1: Scanning electron micrograph of a BOT. Collector, base and emitter are designated by C, B and E.

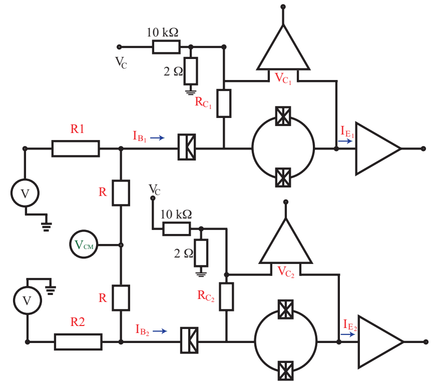

Figure 4: Measurement scheme used for measured of CMRR.

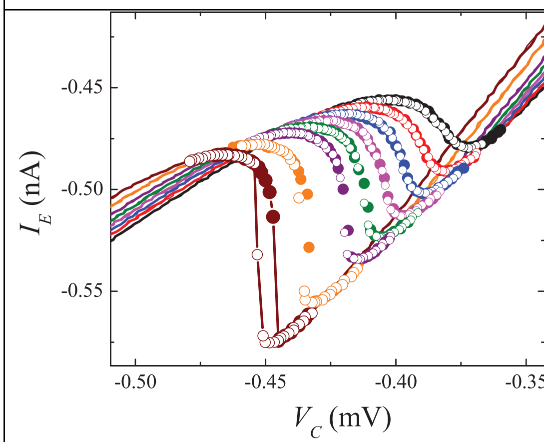

Figure 2: The effect of I_B on the *I-V* characteristics of BOT. With increasing I_B, it clearly shows the approach towards bifurcation (right to left).

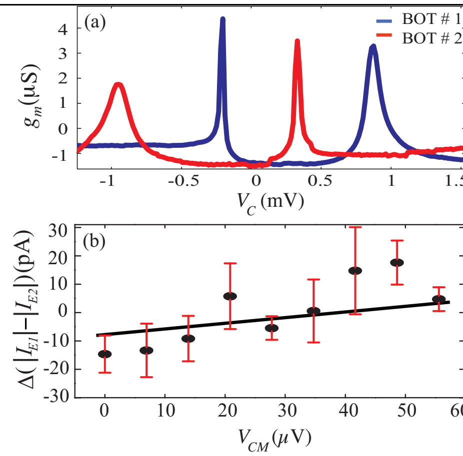

Figure 5: (a) g_m of the BOTs vs. collector bias V_C. (b) Difference of absolute output currents of the BOTs plotted vs. voltage applied to the CM port. Straight line yields a CMRR of 20dB.

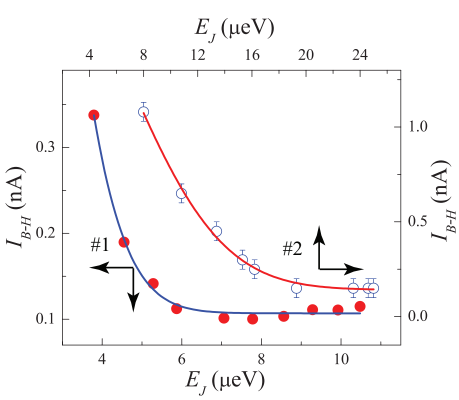

Figure 3: Bifurcation threshold over the $I_{B\text{-}H}$ - E_J plane. #1 and #2 correspond to two samples measured in our experiment. Arrows denote the axis.

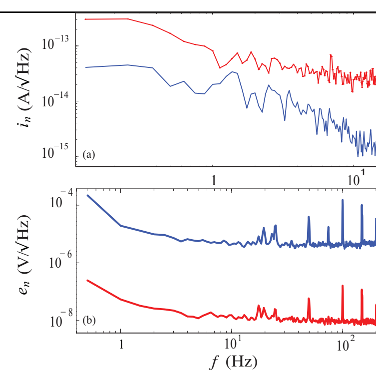

Figure 6: Input referred current noise (i_n) in the current gain mode: red trace displays in with $\beta_E = 1$. The blue curve depicts i_n measured at $\beta_E = 35$. b) Input referred voltage noise (e_n) in the transconductance mode: the blue curve is obtained at g_m = 10 nS while the red trace was measured at g_m = 10 µS.