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Physics Procedia 81 (2016) 141 – 144

Physics Procedia

28th International Symposium on Superconductivity, ISS 2015, November 16-18, 2015, Tokyo, Japan

Experimental demonstration and performance estimation of a new relaxation oscillator using a superconducting Schmitt trigger inverter

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Abstract

An experimental demonstration and performance estimation of a superconducting relaxation oscillator using the Schmitt trigger inverter are reported. The superconducting Schmitt trigger inverter is composed of a threshold gate that uses coupled superconducting quantum interference devices. The oscillator is based on the general concept of using the Schmitt trigger inverter and a delayed feedback loop. The oscillation frequency is characterized by the circuit parameters of the delayed feedback loop and the hysteresis structure of the Schmitt trigger. The circuit parameter dependence of the oscillation frequency is estimated by numerical simulations. In order to confirm the circuit operation, the proposed relaxation oscillator is fabricated by a Nb/AlOx/Nb standard process and tested. The operation of the oscillator is demonstrated successfully.

Peer-review under responsibility of the ISS 2015 Program Committee

Keywords: superconductivity; superconducting quantum interference device (SQUID); relaxation oscillator; Schmitt trigger

1. Introduction

Recently, we have proposed a new superconducting relaxation oscillator based on the Schmitt trigger inverter using superconducting quantum interference device (SQUID) gates [1]. The Schmitt trigger inverter consists of a threshold gate with hysteretic characteristics using two coupled SQUIDs (c-SQUIDs) gates with a cascade connection [2]. Although, several other superconducting relaxation oscillators have already been proposed, these are

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Peer-review under responsibility of the ISS 2015 Program Committee
doi:10.1016/j.phpro.2016.04.030

based on the hysteresis properties of the switching characteristics of one or two Josephson junctions shunted by a series of inductance and resistance [3]-[6]. On the other hand, it is expected that our new relaxation oscillator has high current drivability because it does not use the hysteretic structure on the *I–V* curve of the Josephson junction. Such an oscillator has valuable use as a clock generator in superconducting logic circuits or sensor devices operating in the low temperature environment. In this paper, an experimental demonstration and a performance estimation of the new oscillator are reported. The oscillation frequency is characterized by the circuit parameters of the delayed feedback loop and the hysteresis structure of the Schmitt trigger. The circuit parameter dependence of the oscillation frequency is estimated by numerical simulations. The proposed relaxation oscillator is fabricated by the AIST standard process (STP2) [7] and further tested. The operation of the fabricated relaxation oscillator is experimentally demonstrated.

2. Relaxation oscillator using superconducting Schmitt Trigger Inverter

2.1. Schmitt Trigger Inverter Using Coupled SQUIDs Gates with Flat Output Characteristics

Figure 1(a) shows the circuit diagram of the Schmitt trigger inverter that is composed of cascaded two-stage c-SQUIDs gates. The double-junction SQUID (DC-SQUID) reads out the quantum state of the single-junction SQUID. Because the transition of the quantum state of the single-junction SQUID follows a step-like function, the output voltage of the DC-SQUID is characterized by a sharp rise in the voltage. The second stage C-SQUIDs gate operates as the output buffer gate for generating step-like output characteristics [2].

To obtain the characteristics with a Schmitt trigger shape, the input gate must have hysteretic characteristics. Such characteristics can be obtained by solely increasing LI_c product of the single-junction SQUID. In addition, a negative offset bias current I_{off1} is supplied to the first stage c-SQUID gate in order to achieve an inverting configuration [1]. Figure 1(b) shows the static input vs. output characteristics of the Schmitt trigger inverter. The output V_{out2} shows characteristics identical to the Schmitt trigger inverter.

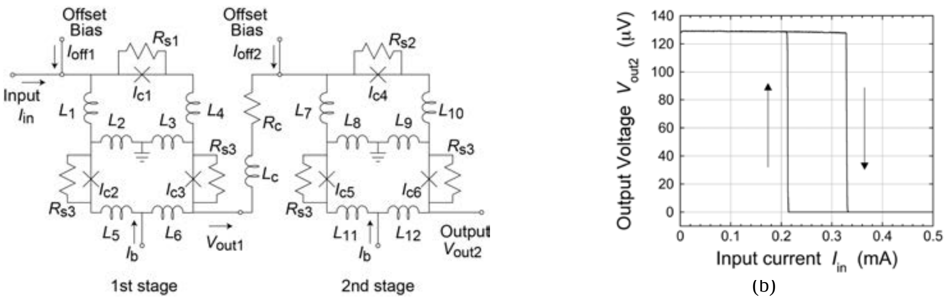

Fig. 1. (a) Threshold gate composed of cascaded two-stage c-SQUIDs gates. The device parameters used in the design are I_{c1} = 0.205 mA, I_{c2} = I_{c3} = I_{c5} = I_{c6} = 0.750 mA, I_{c4} = 0.193 mA, L_1 = 1.32 pH, L_2 = L_3 = L_8 = L_9 = 1.13 pH, L_4 = L_{10} = 0.40 pH, L_5 = L_6 = L_{11} = L_{12} = 0.34 pH, L_7 = 1.20 pH, L_c = 5.0 pH, R_c = 0.10 Ω, I_b = 1.45 mA, R_{s1} = 1.9 Ω, R_{s2} = 2.0 Ω, and R_{s3} = 0.52 Ω. (b) Simulated static input vs. output characteristics of the Schmitt trigger inverter. (I_{off1} = -0.80 mA, I_{off2} = 0.35 mA, and output load R_{load} = 0.5 Ω)

2.2. Relaxation Oscillator Using Schmitt Trigger Inverter

It is well known that a circuit composed of the Schmitt trigger and some negative feedback element operates as a simple relaxation oscillator. Using the semiconductor circuits, this is achieved by connecting a single RC integrating circuit between the output and the input of an inverting Schmitt trigger. On the other hand, a typical delay element in the superconducting electronics is usually obtained by certain combinations of a resistance and an inductance. Figure 2(a) shows a relaxation oscillator using the superconducting Schmitt trigger inverter and a delay element using a series of the resistance R_{fb} and the inductance L_{fb}.

Figure 2(b) shows a simulated output waveform of the relaxation oscillator using the superconducting Schmitt trigger inverter. This output voltage is monitored by using an additional *RC* filter, with R = 1 kΩ and C = 0.1 pF, in order to remove the high frequency spectrum due to Josephson oscillation. This low pass filter does not affect the