WIDE FREQUENCY BAND SAMPLING SYSTEM TO TEST RSFQ LOGIC

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The new design of the Josephson junction based sampler has been proposed. Such a device seems to be useful for the investigating of the Single Flux Quantum (RSFQ) Logic circuits because they are based on the same junctions. The aim of this paper is to measure experimentally the time resolution of this sampler and to improve its parameters. As a delay line an array of shunted Josephson junctions have been used. The sampler is a high frequency system fed by single junction generator. The trilayer Nb–AlO_x–Nb technique has been employed to fabricate tunnel junctions with critical current density 1000A/cm^2. The Josephson oscillations on the junction under investigation have been measured directly at frequencies from 2 GHz to 50GHz. The proposed sampler can be used for the experimentally measurement of the RSFQ upper frequency limit.

INTRODUCTION

The basic principle of the recently suggested Rapid Single Flux Quantum Logic (RSFQL) [1] is the controlling of the single flux quanta with the shunted $\beta_c \approx 1$ Josephson junctions. Extremely high operation frequency about 100GHz of the RSFQ elements had been obtained [2,3]. There are two kinds of measurements of RSFQL available. The first one is made at relatively low frequencies a few KHz [2,3] and these measurements shows the correct digital operation of the circuits. The other kind of experiment is the measuring of DC characteristics which determines the maximum voltage or the frequency (about 100GHz) of operation due to the Josephson relation. Apart from the high speed operation of a single element one needs to have a very stable repetition rate of single pulses expanded in two Josephson lines to provide time synchronization between the clock and signal pulses [1]. This is the main requirement of the RSFQ logic and seems to be the main reason of the frequency limitation of the logic devices. In real experiments the parameters of Josephson junctions and the superconductor micro strips which connects them imply the frequencies of circuit resonance modes greater than 10 GHz. To measure experimentally the high frequency limit of RSFQ logic devices we have used the simple circuits which is appeared the RSFQ Josephson sampler [4]. The basic principle of this sampler is the measuring of the critical current of the gate junction as a function of time delay between the two pulses coming simultaneously to the gate. We report at this paper the first experimental data which show that the processes in a simple uniformly shunted Josephson transmission line are more complicated than one expected. We suggest to employ this simple completely DC powered circuit to solve the single flux quantum propagation problem experimentally. We hope this technique makes it possible to reach the highest frequency of operation of the RSFQ devices as is possible.

CIRCUIT DESIGN

Fig.1 a shows the Josephson transmission line which involves identical elements and presents a sequence of overdamped ($\beta_c \leq 1$) and underbiased junctions. The inductance is small enough to prevent the trapping of quantum by interferometers ($J_t L_t < \Phi_0$). The total bias current I_t is applied to all junctions via the resistances R_t. The changing of the bias current permits variations in the flux quantum propagation time. Fig.1b shows the equivalent circuit of the test sample. Junction J_{in} generates repetitive pulses which are directed to two transmission lines JTL_2 and JTL_3. The generator produces SFQ pulses of a frequency f which is related to the voltage V by the Josephson relation $f=V/\Phi_0$. The pulses are branched into two transmission lines. One of them leads to the strobe pulse generator J_{p3} and the other one to the junction J_{s3} which generates a test pulse. The difference of bias currents $I_s - I_p$ produces a change in the time required for pulses to pass through the lines, so that it is possible to provide the time delay between the signal and strobe pulses. Two pulses, one from the pulse generator J_{p3} and another from the signal junction J_{s3}, are added to the current I_G and the result is applied to the sampling gate J_G. The measuring of gate critical current as function of time delay, or really as a function of $I_s - I_p$, permits reproduction of the shape of the investigated pulse because of the signal junction is more shunted than the pulser. If the repetition rate of the signal pulse is stable enough for the RSFQL devices one should observe the periodic dependence of sampler response vs the time delay. Finally the JTL_1 transmission line serves to prevent influence on the generator voltage by the changing of the bias currents I_s, I_p. To eliminate the large influence of its own resonance modes, we employ the distributed shunting of the transmission line junctions. This kind of shunts increases the time delay produced by transmission line also, so that smaller changing of bias currents are required. The standard trilayer Nb–AlO_x–Nb technology with external shunt Mo resistances has been used for the sample fabrication.

EXPERIMENTAL RESULTS

All measurements were done at 4.2K. Fig 2. shows the input voltage Vin vs. the bias current of the input junction Jin. Fig. 3a and 3b shows the signal pulse reproduction by sampler at different input voltages. The period of oscillations follows the input voltage up to the value of 14 μV. The increasing of the input voltage doesn't change the measured repetition rate of pulses. Furthermore the complicated picture of amplitude and frequency modulations of the pulses are apparent. This might be caused by the effect of nonuniform distribution of magnetic field in transmission lines [5]. This effect leads the transmission line being divided into a number of magnetic domains. The differences between domains is the number of flux quantum per one transmission line interferometer. As computer simulation shows each domains contain its own generator junction and the resulting JTL time delay depends on the nonlinearity of the JTL bias current. The domain effect is responsible for the steps on IV curve on Fig.2 also. The nonuniform distribution of a magnetic field is caused by the input current Iin flowing through all inductances of JTL. The special construction of Josephson generator, with additional buffer junctions which prevents this flowing, might suppresses this effect.

CONCLUSION

We experimentally investigated the sampling system based on shunted Josephson Junctions. One can see the rather complicated behavior of the two Josephson lines connected via the gate junction. There are four problems should be solved before the design complicated RSFQL devices. The first one is the building of a high frequency SFQ pulse generator which doesn't produce nonuniform magnetic field in transmission line. It means that curve on Fig.2 should be without any steps. The second problem is a preventing of mutual phase locking between the clock and signal transmission lines. Experimentally the simplest way to do that is the investigation of RSFQ comparator which gives on its output the difference of line voltages. The third problem is the using of the sampler to measure the upper frequency limit of RSFQL devices,and, finally, the last one is the matching of junction with the superconductor microstrip to prevent the internal resonance modes which can be excited because of the wavelength is comparable with the circuit size.

In addition Fig.4 shows the sampler based magnetic flux sensor functionally resembles a SQUID. The sampler which is merged in the gap of the receiving SQUID loop, as Fig.4 shows, is very sensitive to the changing of the circular current I_H. The current I_B is the bias one for the transmission lines and the current I_H, induced by input coil, produces the time delay. The I_G provides a voltage on gate junction and this voltage depends periodically on the time delay. The estimation shows the sensitivity more than 20 $\mu V/\Phi_0$, Φ_0 being the flux quantum, but the noise problem of the suggested device is still open.

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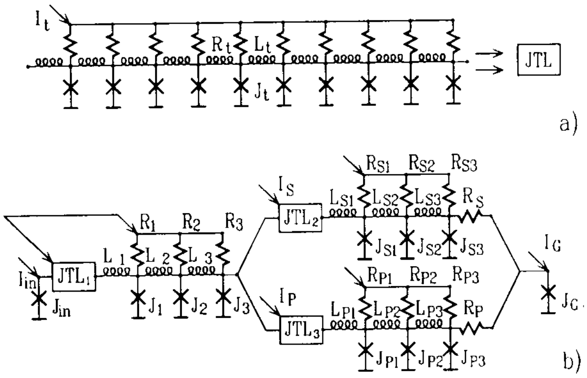

Figure 1 a) Equivalent circuit of Josephson Transmission Line (JTL) J_t = (I_c = 80μA, R = 0.4Ω, C = 0.75pF), L_t = 7.2pH, R_t= 20Ω. b) Equivalent circuit of the Josephson sampler. The McCumber parameter of all junctions were βc=0.8 except the Js3 for which the βc=0.2. In amplification lines (J1–J3, Js1–Js3, Jp1–Jp3) the critical current of the following junction is 1.5 larger than of the previous one. R_s=3Ω, R_p=0.33Ω.

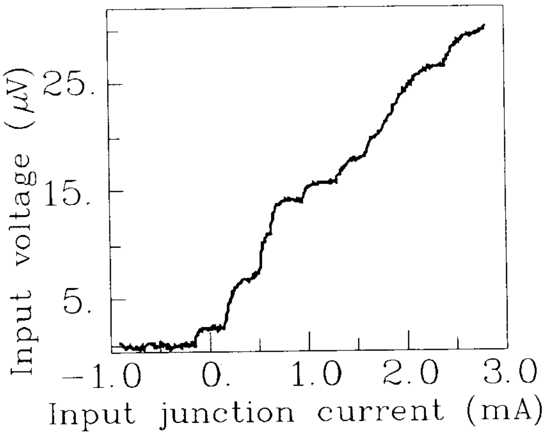

Figure 2 Input voltage vs. the bias input junction current Jin.

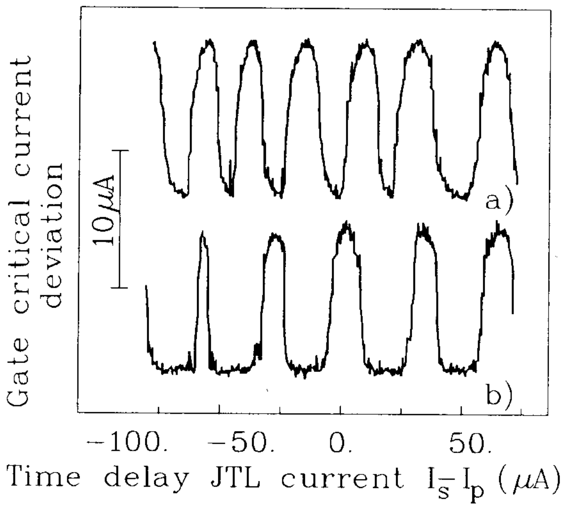

Figure 3 The investigated pulse reproduction by sampler at a) Vin = 6.3μV; b) Vin=10.3μV.

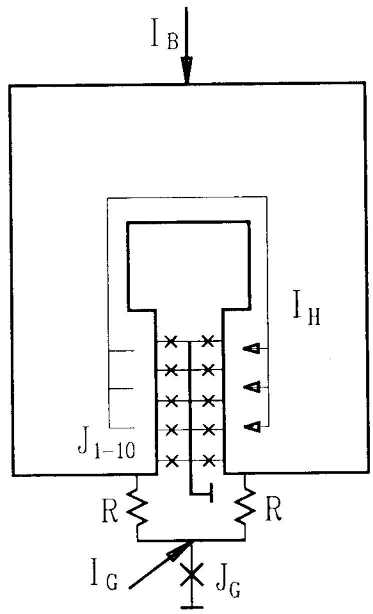

Figure 4 The proposed sampler based magnetic flux sensor.