A data acquisition system for test and control of superconducting integrated receivers

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***Abstract*— A data acquisition system for the Integrated Receiver Test and Control ("IRTECON") was developed and tested with the single-chip quasioptical receiver containing a planar double-dipole antenna SIS mixer and FFO as a local oscillator. The basic system includes a controlling computer with two acquisition cards, an analogue bias supply and GPIB linked peripheries. The system collects and analyzes I-V data of the FFO and SIS mixer, tunes their regimes over the receiver frequency range. The possibility to optimize automatically the receiver noise temperature is realized. This system can be adopted to control a wide range of SIS-based receiving system such as an imaging receiver on remote location.**

***Index Terms*— data acquisition, flux-flow oscillator, Josephson junctions, SIS receiver, SIS mixer, superconducting devices**

I. INTRODUCTION

New family of light-weight and compact ultra sensitive submm-wave superconducting integrated receivers (SIR) with low power consumption are developed for both radio-astronomical research and remote monitoring of the Earth atmosphere [1], [2]. SIR is a chip 4 mm x 4 mm with superconducting tunnel junction used in quasi-particle mode (SIS mixer) incorporated in a double-dipole antenna, a Flux Flow Oscillator (FFO) based on unidirectional flow of magnetic vortices in a long Josephson tunnel junction [3] and matching circuits. The manual test and control of such a sophisticated device are difficult, because at least four sources have to be tuned and monitored simultaneously. To obtain main parameters of SIR, large amount of experimental data has to be collected. Since IV-curve of FFO has hysteresis, a recovering procedure is needed for maintaining an optimum regime in presence of pulse interference or in the case of occasional shutdown of the receiving system.

To make all these operations possible a new data acquisition (DAQ) system and program "IRTECON" (Integrated Receiver Test and Control) has been developed. Details of design and possible applications for a variety of superconducting receivers are reported here.

II. CONCEPT OF DATA AQUISITION SYSTEM

A. Experimental setup

Photo of the experimental setup [4] is presented in Fig.1. The hardware includes a *dc* unit, which contains four bias supplies (central part of the photo) and can be controlled from computer cards. The bias current up to 200 mA is used for a FFO, which has a typical resistance 0.02 Ohm. The bias with voltage stabilization control up to 10 mV is used for SIS-mixer. Two current sources up to 100 mA and 150 mA to operate magnetic field for the FFO's frequency control and for suppression of the critical current of the SIS-mixer respectively are used. Two computer cards from "National Instruments" 16 bits resolution (PCI-MIO-16XE-10) and 12 bits resolution (Lab-PC+) are used to operate FFO and SIS-mixer respectively. Note that FFO voltage has to be monitored with an accuracy of about 1 μV to provide the required FFO frequency control. Four DACs and 10 ADCs are used in the DAQ system. GPIB interface card (NI AT-GPIB/TNT) controls the power meter (HP436) and lock-in Amplifier (SR510) needed for noise temperature measurements.

The program "IRTECON" is written under LabWindows/CVI ver. 4.01 on C language. The main ideas of the program can be formulated as following: measuring a number of channels at the same time, interactive and semi-automatic measuring modes, multi-window presentation of multi-dimensional graphs, adaptability for different experimental setups, that includes an updateable library for both hardware and measuring procedures. Virtual channels, simultaneous multiple graphic windows (panels) and measurement modes are basic concepts in "IRTECON" system.

B. Virtual channel

A virtual channel correspond to either a measured physical port (like DAQ card and measuring device with GPIB, USB or RS-232 interface) or a result of computation. A driver library with interface panels like real front panels of measuring device was created. Each virtual channel has a number of edited properties: name, type (set/get), physical

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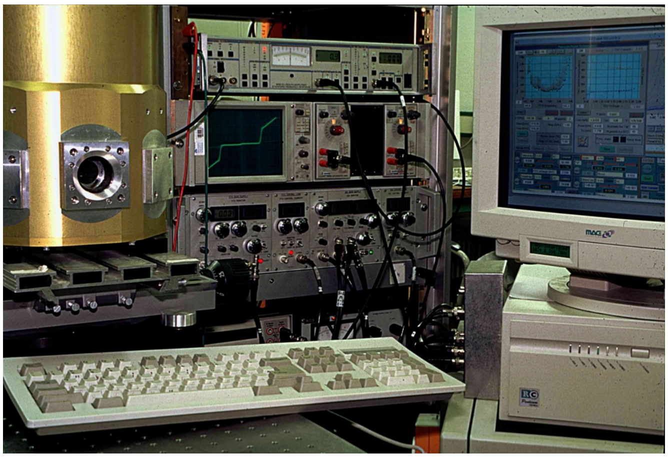


Fig.1 Photo of the experimental set-up controlled with IRTECON program: quasi-optical cryostat at the left, bias supply unit in the center and data display at the right.

unit (voltage, current, frequency, temperature, etc.), dependency on the source data, limits, calibration table, filters and so on. A virtual channel can be "connected" to a special in-house-made device with its own settings.

C. *Data presentation*

The data presentation is based on multi-window approach. Each window contains a multi-dimention graph with its own settings. The number of graphic windows is limited by the computer memory only. A new graphic window can be created and edited for presentation of particular experimental data. The virtual channels and corresponding data files are defined during opening of a new window. Each graphic window can be in "active" or "background" state. The measurement cycle is organized to provide data to all active windows at the same time.

D. *Measuring modes*

All measurement procedures performed by the DAQ system can be classified as follows: i) offset measurement, ii) calibration of a channel, iii) nested loops, iv) automatic monitoring with user pre-defined triggered measurement, v) manually triggered measurement, vi) monitoring of current status of the system (displaying current data), vii) noise tracking, viii) recovering of the optimal regime. Nested loop is the main mode. In this mode a parametric channel (outside loop) and its boundary values are selected along with the number of points to be measured. The typical example of the parametric channel is the current of the FFO's magnetic field control line. During each step of the parametric channel a one-dimensional scan is performed (inner loop), that is recorded as a separate curve (e.g. IV-curve of the FFO). Several start/stop-conditions can be defined for the measured channel (e.g. to stop the scan just after the voltage jump of the hysteresis IV-curve). All the measurement modes can be performed in interactive or batch modes. The frequency analysis procedure and noise minimization for each channel are developed. The data pick-up delays can be optimized by special procedure for each channel. In the following section we describe the application of such system.

III. A TEST OF SUPERCONDUCTING INTEGRATED RECEIVER.

The test of the chip receiver consist of the following typical procedures: i) measurement of IV-curves of SIS-mixer and FFO, ii) determination of the range of FFO parameters, in which sufficient coupling between mixer and LO occurs, iii) measurement of the receiver noise temperature (T_{RX}) and optimization of T_{RX} within certain frequency range. All the experimental data are stored and can be used later to control the particular chip of the integrated receiver.

At the beginning the IV-curve of SIS mixer is recorded at magnetic field, which completely suppress its critical current I_C. There is an option to measure the dependence of I_C on the control line current, I_{SISCL}. Then DAQ system computes the main electrophysical parameters of the SIS junction automatically. To determine main parameters of a SIS-junction, a new stable and reliable algorithm was developed for IV-curve influenced by EMI (e.g. 50 Hz noise). Definitions of the main parameters are present in Fig. 2. Here R_n is the resistance in normal state; R_j - leakage resistance; R_v – line for definition of the gap voltage V_g; I_g - current rise at the gap voltage; I_k - current, characterizing the knee structure just above the gap; dV_g - gap smearing using $R_n/2$ criterion; DV_g - gap smearing using $R_j/2$ criterion.

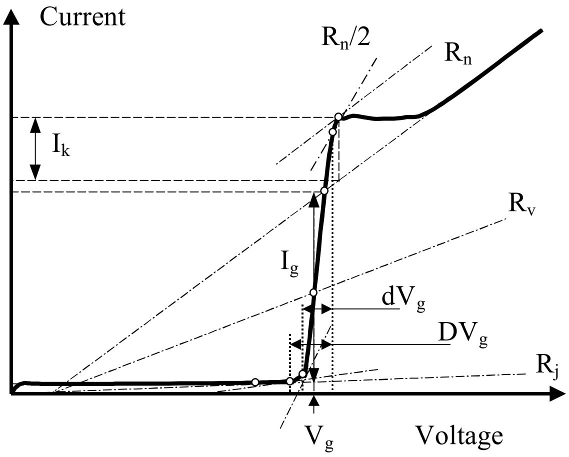


Fig. 2 Definition of the main parameters for the model SIS IV-curve.

The LO part of the receiver is tested via recording the family of IV-curves of the FFO at different control line currents. During this test the mixer bias is fixed (usually at about 2 mV), that corresponds to the optimal regime of the mixer. The LO induced current is measured, and these data are presented on the IV-curves of the FFO by color. The typical result of this test is presented in Fig. 3. The maximum level of the mixer pump can be chosen using this color pattern. Note that LO frequency corresponds to the FFO voltage via the Josephson relationship $f_{LO}=2eV_{FFO}/h$ (where e is the electron charge and h is the Plank's constant). After the particular point of the "hot spot" from Fig. 3 is chosen, the pumped IV-curve of the SIS mixer is measured. The complete test of both SIS-mixer and FFO can be done by the DAQ system within 10 min, while it takes about 2-3 hours manually.

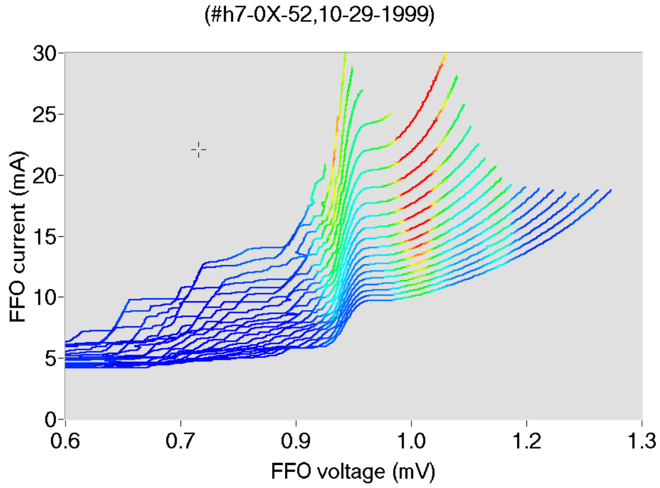
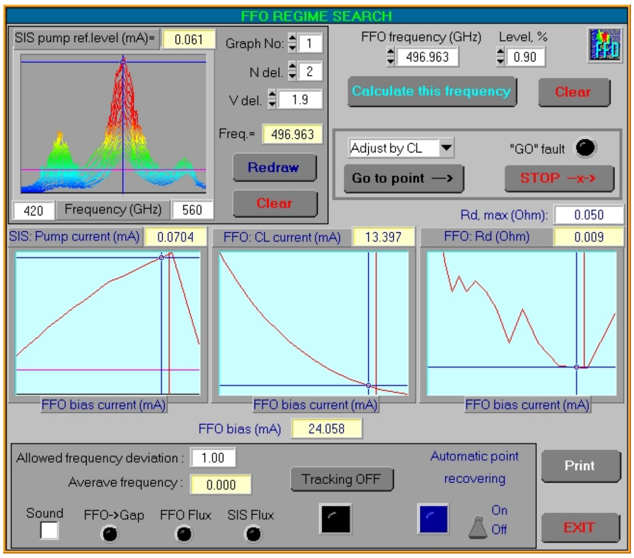


Fig. 3. IV-curves of FFO at different magnetic fields. A gray scale indicates the regions in which photon-induced current of SIS-mixer is sufficient for receiver operation (the brighter color means the larger value of the induced current).

To define an operational range of chip receiver, a special procedure was developed (see Fig. 4). Since the effective heterodyne operation requires optimal level of LO power, the frequency range of the chip is defined via analysis of the SIS-mixer pump, that is computed using data from Fig. 3. This data are presented at the top-left corner of the panel from Fig. 4. To adjust the FFO regime accurately, several dependencies are computed for the given frequency: i) pump current of the SIS mixer vs. FFO bias current, ii) dynamic resistance of the FFO vs. bias current of the FFO, iii) current of the FFO control line vs. bias current of the FFO. Since FFO is quite sensitive to EMI, the emergency diagnostics and automatic recovering of the optimal regime of the operation have been developed.

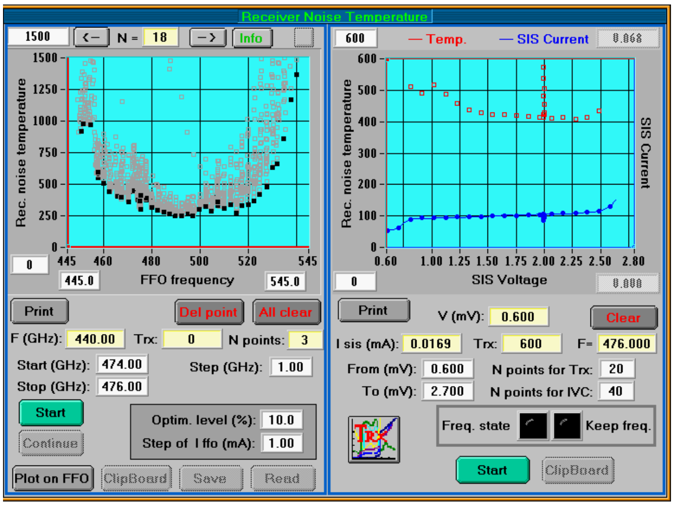


SIS pump ref.level (mA)= 0.061
Graph No: 1
N del. 2
V del. 1.9
Freq.= 496.963
420 Frequency (GHz) 560
FFO frequency (GHz) 496.963
Level, % 0.90
Adjust by CL
Rd, max (Ohm): 0.050
SIS: Pump current (mA) 0.0704
FFO: CL current (mA) 13.397
FFO: Rd (Ohm) 0.009
FFO bias (mA) 24.058
Allowed frequency deviation : 1.00
Averave frequency : 0.000

Fig. 4. Panel for FFO regime search and control. For selected frequency (494.503 GHz) three tuned dependencies with safety parameter's ranges are computed (lower graphs). These dependencies are used for setting available FFO's regimes in tracking and automatic recovering procedures (lower part of panel).

IV. A NOISE TEMPERATURE MEASUREMENTS.

Measurement of T_{RX} starts with calibration of the output of the lock-in amplifier by the slow but accurate power meter HP436. For doing this, the standard Y-factor, used in calculation of T_{RX}, is measured twice at IF $\approx$ 1.5 GHz: first with slow "hot/cold" shutter, and then with running "hot/cold" chopper, fast rf-detector, logarithmic amplifier and lock-in amplifier, which supplies the calibrated Y-factor data in dB/mV for the computer. The computer tunes the FFO at a frequency within a particular range via selection of two parameters: bias current and control line current of the FFO. Since the power delivered by FFO is about proportional to the bias current (see Fig. 4), the optimum pump of the SIS mixer can be found at the given frequency via real-time analysis of T_{RX} data. The best bias point for the SIS mixer is found via scanning its IV-curve, obtained for the best Y-factor. The Trx data presented in Fig. 5 are measured by the automatic procedure, where black boxes are minimum T_{RX} and light boxes are intermediate measurements of T_{RX}.



1500
N = 18
0
445.0
545.0
F (GHz): 440.00
Trx: 0
N points: 3
Start (GHz): 474.00
Step (GHz): 1.00
Stop (GHz): 476.00
Optim. level (%): 10.0
Step of I ffo (mA): 1.00
600
0
V (mV): 0.600
I sis (mA): 0.0169
Trx: 600
F= 476.000
From (mV): 0.600
N points for Trx: 20
To (mV): 2.700
N points for IVC: 40

Fig. 5. Panel for receiver noise temperatures (T_{RX}) optimization. Left graph collects all measured noise temperatures. Black boxes – optimal noise temperature for the current frequency, gray boxes – the intermediate noise temperature. Noise temperature measurements for the current frequency (476 GHz) are presented on the right graph.

V. SUPERFINE RESONANT STRUCTURE ON FFO IVC.

FFO IVC can have the tiny resonances [5], [6], which are so closely spaced (~20 nV) that they cannot be recorded by usual methods. According to Josephson relation the FFO IVC can be reconstructed in detail by measuring a current-frequency dependence of FFO. An accuracy of frequency reading is determined by spectrum analyzer resolution. By using new manual triggered experimental mode the frequency from spectrum analyzer, FFO bias and control line current were recorded simultaneously. From these data the exact shape of the FFO IVC has been reconstructed [7].

VI. A MEASUREMENTS OF CHERENKOV FLUX-FLOW OSCILLATORS

The *dc* measurement of Cherenkov Flux Flow Oscillator (CRFFO) is another example of efficient use of the program. The detailed design of CRFFO is discussed in [8], [9]. The CRFFO chip includes a long Josephson junction (LJJ) embedded in slow wave system and two SIS detector junctions connected to the LJJ and slow wave system respectively. CRFFO is controlled by magnetic field and bias current, so for the complete characterization a nested loop measurement with magnetic field value as a parameter is required. The Cherenkov synchronism takes place only in the narrow range of bias current and magnetic field settings. It is difficult to analyze this effect without automatic system of measurement and presentation. The concept of virtual channel allows measurement of two detectors simultaneously that correspond to direst and backward radiation of the CRFFO. The detected *rf* power can be readily shown by color (or gray shade) at CRFFO I-V curves outlining the region of Cherenkov resonance.

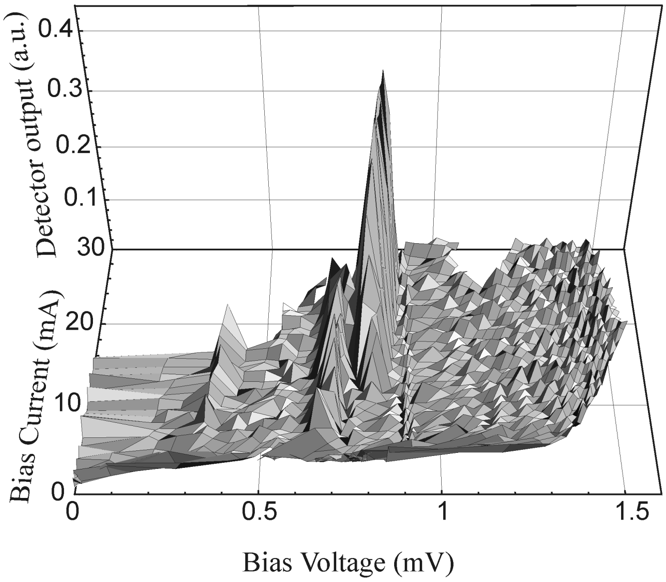


Fig. 6. Set of I-V characteristics measured at different magnetic fields. The vertical scale indicates the detector

The open data output format allows to save the measured data and read it in different software packages (like Mathcad™ and Mathematica™) for further analysis. One example of this data analysis in Fig. 6 shows Cherenkov backward wave resonance.

VII. CONCLUSIONS

Data acquisition system "IRTECON" was developed for automated measurement and control of Superconducting Integrated Receiver. The design of the system makes this program an effective tool, which can be used in study of various superconducting structures.

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