

Conference paper

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### Time-resolved measurement of resistance

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**Abstract.** This article discusses and implements a method for measuring sharp jumps in sample resistance with time resolution of 100 ns at a temperature of 4.2 K using the ATF-55143 transistor as an example. The operating principle of the circuit, calibration, and accounting for parasitic capacitance are described.

**Keywords:** time-resolved measurements, radio frequency measurements, resistance change

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Конференционная статья

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### Измерение сопротивления образцов с разрешением по времени

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**Аннотация.** В статье рассматривается и реализуется метод измерения резких скачков сопротивления образцов с разрешением по времени в 100 нс при температуре 4.2 К на примере транзистора ATF-55143. Описывается принцип работы схемы, калибровка и учёт паразитной ёмкости.

**Ключевые слова:** время-разрешенные измерения, радиочастотные измерения, изменение сопротивления

**Ссылка при цитировании:** Васильев С.Я., Храпай В.С., Тихонов Е.С. Измерение сопротивления образцов с разрешением по времени // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2026. Т. 19. № 1.1. С. 141–145. DOI: <https://doi.org/10.18721/JPM.191.123>

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## Introduction

Accurate measurements of sample resistance with high time resolution are a highly demanded task in the field of solid-state physics. A well-established, high-speed resistance measurement method can be used to study samples that change their resistance during the experiment. This method can be used to monitor fast processes in solid-state physics, which occur in microseconds or less. For example, such a method could be used to read the state of a charge sensor on a semiconductor platform for fast quantum calculations [1]. The motivation for this work comes from a paper [2] on the suppression of superconductivity in superconducting islands in Al-InAs nanowires by transport current. The results of this study suggest that the destruction of superconductivity in such islands occurs abruptly at certain bias voltages with a characteristic relaxation time of the order of  $\mu\text{s}$ . The ultimate goal of the present work is to create an electrical circuit capable of operating at low temperatures, rapidly changing the voltage on the sample and maintaining it constant for several microseconds, while also ensuring current measurement with time resolution of at least 100 ns. Circuit tuning in this study was performed using a commercial Agilent ATF-55143 low noise enhancement mode pseudomorphic high electron mobility transistor. Abrupt changes of resistance in response to fast gate modulation in this study mimic the resistance switches in nanowires caused by superconducting transition.

## Materials and Methods

To use the transistor in the experiment and adjust its resistance, the resistance dependence on gate voltage must be measured. A four-terminal circuit was used to measure the sample resistance and eliminate the wiring contribution and high-impedance load [3]. The resistance  $R$  of the transistor for different voltage  $U_g$  applied to its gate was extracted from the current–voltage characteristics shown in Fig. 1, *a*. To minimize the experimental uncertainty, 15 measurements were performed for each gate voltage value, and the average value was taken. The obtained dependence of  $R$  on  $U_g$  is given in Fig. 1, *b*. This dependence is later used for tuning the time-resolved resistance measurement method.

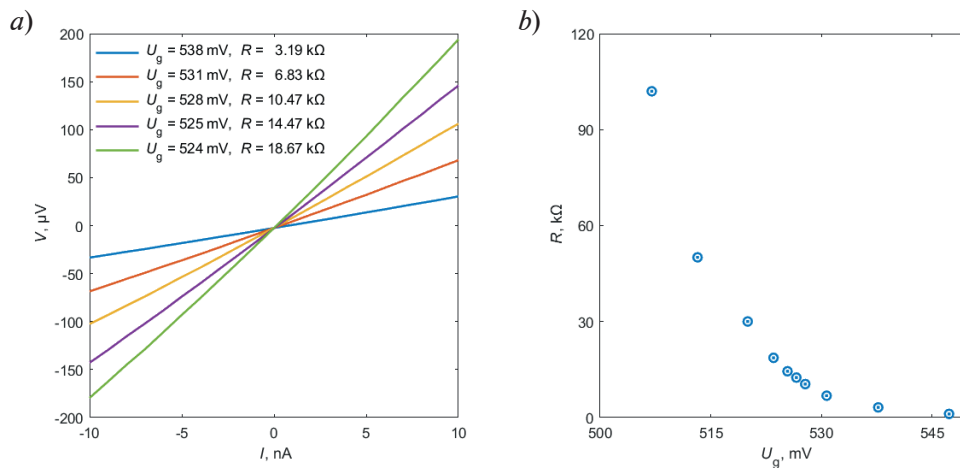


Fig. 1. Transistor  $I$ – $V$  characteristics for various gate voltages (*a*); transistor resistance dependence on the applied gate voltage (*b*)

The detailed electrical circuit of the experiment is shown in Fig. 2. In addition to the four-terminal circuit, the circuit also includes components required in time-resolved measurements: resistors ( $R_0$ ) for impedance-matching of the coaxial cable to prevent signal reflection [4]; capacitors ( $C_1$ ) in the AC path for decoupling the DC and AC currents; resistors ( $R_1$ ) as a high-impedance load; grounded capacitors ( $C_2$ ) in the DC circuit for filtering interference; resistor ( $R_2$ ) to create a current source. The inevitable stray capacitance ( $C_s$ ) is also shown in the scheme and will be considered later.

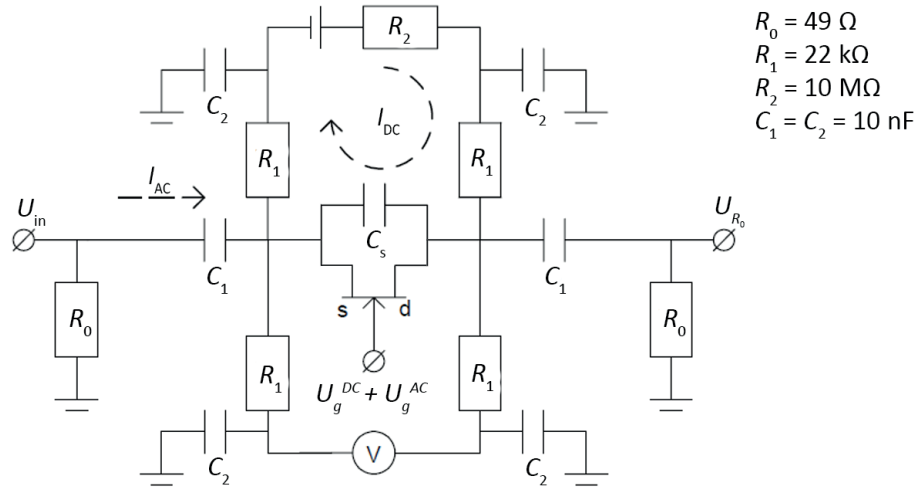


Fig. 2. Electrical diagram with the sample, radio-frequency components and four-terminal DC measurement layout

The radio-frequency (RF) measurement scheme is presented in Fig. 3. The measurement is performed by sending a square-wave signal from the AFG 3021B RF arbitrary function generator to the input and reading the signal from the circuit's output using Keysight DSOX1204G oscilloscope. Three stages of high-frequency amplifiers were used to bring the signal to the oscilloscope. The response time of the amplifiers was increased to a few microseconds with the help of extra capacitors between the stages (200 nF – 2 μF). Additional low-pass (15 MHz) filter was also used in the output circuit to reduce noise in the output signal. The sample and the first amplifier are placed in the cryostat at a temperature of 4.2 K.

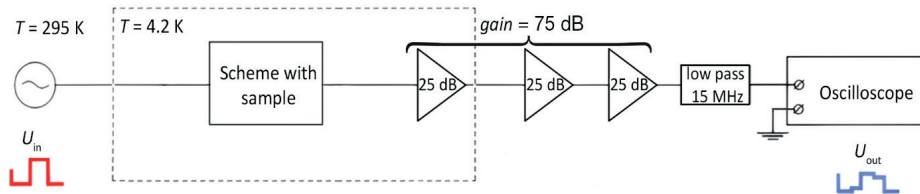


Fig. 3. Electrical diagram of the time-resolved resistance measurement

The signal is received relative to  $R_0 = 49 \Omega$  resistance. Therefore, the sample resistance  $R$  and  $R_0$  create a voltage divider, which can be seen in Fig. 2. Thus, the dependence of the ratio of the input voltage  $U_{in}$  and output voltage  $U_{out}$  on  $R$  can be written using the formula for a voltage divider. Considering gain from amplifiers:

$$\frac{U_{out}}{U_{in}} = gain \cdot \frac{U_{R_0}}{U_{in}} = gain \cdot \frac{R_0}{R + R_0}. \quad (1)$$

Note that Eq. (1) is valid on time scales much shorter than the charging time of the capacitors in Fig. 2, which depends both on the sample resistance and the load resistances  $R_1$ . In our experiment the charging time falls in the microsecond range for  $R > 1 \text{ k}\Omega$ . Under this condition, Eq. (1) can be simplified in this way:

$$u = r \cdot gain, \quad (2)$$

where  $u = U_{out}/U_{in}$ ,  $r = |R_0 / (Z_{||} + R_0)|$  and gain is the total voltage gain of the amplifiers. Note that here we have taken into account the stray capacitance, which is connected in parallel to the sample. The effective impedance of the sample is thus  $Z_{||} = R \parallel Z_s$ , where the stray impedance  $Z_s$  is the imaginary impedance of the stray capacitance.

### Results and Discussion

As the transistor resistance can be controlled, Eq. (2) can be tested for a set of  $R$  values. The 100 kHz square-wave with 158  $\mu\text{V}$  (peak-to-peak) input signal  $U_{\text{in}}$  is sent to the sample. The output signal does not decay noticeably during half-period for  $R > 10 \text{ k}\Omega$ , so its  $U_{\text{out}}$  values can be correctly determined. For smaller  $R$  the capacitors charge faster and the time decay of the signal becomes visible, as seen in Fig. 4. For simplicity, the value of  $U_{\text{out}}$  for such signals is taken as the signals' maximum value.

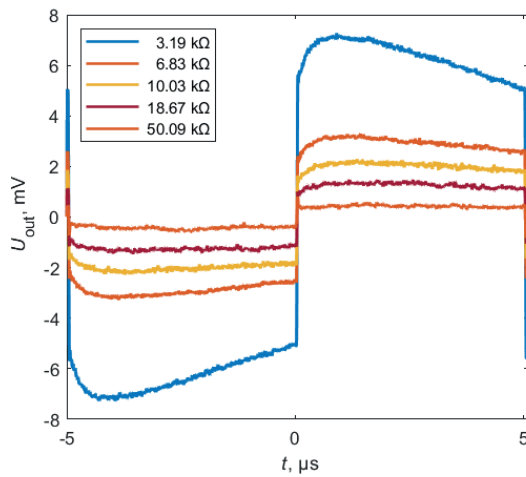


Fig 4. Measured output signal amplitude  $U_{\text{out}}$  as a function of  $t$ . Different colors correspond to different sample resistances  $R$  displayed in the legend. Input AC amplitude  $U_{\text{in}} = 158 \mu\text{V}$  (peak-to-peak)

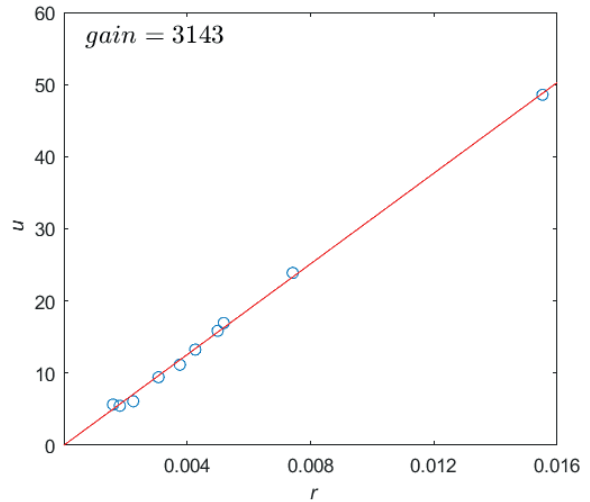


Fig. 5. Dependence of  $u$  on  $r$  for  $U_{\text{in}} = 158 \mu\text{V}$  (peak-to-peak). The data is obtained from a calibration shown in Fig. 4. The slope of the fitted line corresponds to the *gain*

Fig. 5 shows the obtained dependence  $u(r)$  according to Eq. (2). The dependence is linearized taking the stray impedance  $|Z_{\text{S}}| = 32.91 \text{ k}\Omega$ . This data allows obtaining a total gain of the setup, which equals  $\text{gain} = 3143$ . This value corresponds to approximately 70 dB and is smaller than the total gain 75 dB of the amplifiers calibrated independently. Most likely, the discrepancy comes from cable losses.

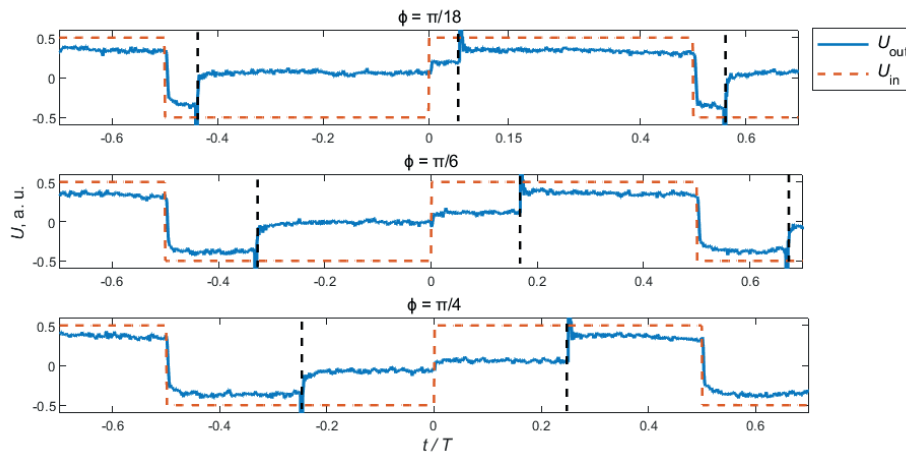


Fig. 6. Output signal amplitude  $U_{\text{out}}$  changing in time for different phase shifts between the square-wave signals applied to the input terminal and to the transistor.  $U_{\text{in}} = 158 \mu\text{V}$  (peak-to-peak).  $U_{\text{g}}^{\text{AC}} = 30 \text{ mV}$  (peak-to-peak). The time axis is shown relative to the input signal period  $T = 10 \mu\text{s}$ . Black dashed lines mark the time instances of the resistance switches mediated by the signal at the transistor gate

Finally, we have used the setup for the time-resolved resistance measurement. Applied input voltage  $U_{in}$  remains the same. The constant voltage  $U^{DC} = 270$  mV is applied to the gate of the transistor (see Fig. 2) to make its resistance on the order of  $10$  k $\Omega$ . Note that the gate voltage characteristics changed in this experiment as compared to Fig. 1 owing to uncontrollable switching of the transistor state at low temperature. In addition, a square wave signal  $U^{AC} = 30$  mV (peak-to-peak) at the frequency of input signal  $U_{in}$  with a phase delay  $\phi$  relative to it was sent to the transistor gate. This leads to abrupt changes in the transistor resistance, which is then detected as sudden switches in the output voltage. An example of the experiment is shown in Fig. 6. The time axis on the graphs is shown relative to the input signal period  $T = 10$   $\mu$ s, to compare it with the phase delay  $\phi$  of the gate-voltage signal (vertical dashed lines). As expected, the time delay of switches mediated by the gate-voltage follows the value of  $\phi$ .

### Conclusion

As a result of this work, a setup for detecting abrupt resistance switches in the sample was assembled and configured. The achieved time resolution of the method is limited by the 15 MHz low-pass filter (Fig. 3) and, according to the datasheet, does not exceed 100 ns. Such a resolution is enough for the purpose of measurement of the superconducting switching time in floating superconducting islands in Al-InAs nanowires, which is expected to be in the microsecond range.

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