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Non-Dissipative Addressing for Time Division SQUID Multiplexing

D. Prêle, F. Voisin, J. Martino, M. Piat, E. Bréelle

Abstract—Recent and future astronomical instruments are based on a focal plane mapped by a large array of superconducting bolometers [1][2]. Cryogenic analog multiplexing readout techniques, based on Superconducting QUantum Interference Devices (SQUID), are currently developed to achieve the readout of large arrays of this kind of low noise background-limited detectors [3]. To effectively reduce the number of cryogenic wires (particularly, the SQUID biasing), line/column addressing is currently used in time division multiplexing, *i.e.* the same biasing is applied to a few SQUIDs (on a line) of different columns. This technique should increase dramatically the power consumption if parallel biasing is applied *via* resistors to isolate each column; the power budget is particularly limited on this kind of front-end cryogenic readout. A design with one transformer per SQUID is also used to read out SQUID biased in series with no excess of consumption and cross talk.

We propose here a new biasing technique using simple surface mounted capacitors which is easier to implement. Those capacitors are used to parallel bias SQUIDs without additional Joule effect while minimizing cross talk. However, capacitors does not allow DC biasing and need a current mean value equal to zero to avoid biasing sources saturation. We have then tested square current biasing through capacitor on commercial SQUID. This measurement shows that capacitors are able to proper bias SQUID and then to perform a non-dissipative addressing for time division SQUID multiplexing.

Index Terms—SQUIDs, Time division multiplexing, Superconducting bolometer, Crosstalk

I. INTRODUCTION

SQUID arranged in time division, frequency division or coded division multiplexing [4][5] are techniques developed to perform superconducting bolometers multiplexing. Time division SQUID multiplexing is used to sequentially current readout (boxcar modulation [4][6]) superconducting bolometers by using SQUIDs biased one by one (Fig. 1). In a two-dimensional (2D) line/column configuration, SQUID biasing is applied in line at the same time to different SQUIDs from different columns (Fig. 2).

In this paper, we review techniques for biasing 2D time division SQUID multiplexing: firstly, using bias resistors which adds power dissipation and cross talk; then, using transformers which solves power and cross talk consideration even if the gain is slightly degraded. After this short review, we propose a new biasing method based on the use of capacitors instead of resistors like in the first technique. This method does not add dissipation and allows to minimize cross talk. Moreover, capacitors will be easier to implement than transformers even

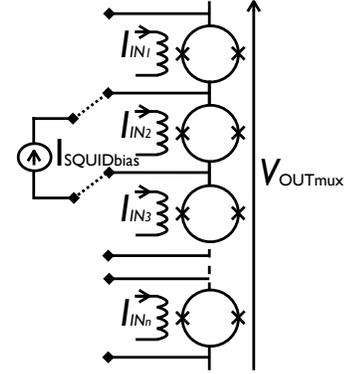


Fig. 1. Column of SQUIDs in time division multiplexing topology.

if capacitive biasing needs to have an alternating positive and negative current bias. Finally, we experimentally demonstrate the feasibility of this alternating biasing *via* capacitors on commercial SQUID.

II. LINE BIASING OF TIME DIVISION SQUID MULTIPLEXING

A. 2D time division SQUID multiplexer biased via resistors (R_{mux})

To avoid cross talk between SQUIDs biased at the same time (by the same addressing line), resistors were used (*bias resistors* on Fig. 2) [7]. Indeed, SQUID output voltage is the transduction of a current ($I_{IN,LC}$) coming from one bolometer; then, the voltage readout across a column of SQUIDs is the superposition of the biased SQUID voltage of this column and $m - 1$ other SQUID output voltages from the same line attenuated by the resistor voltage divider (form by the *bias resistors* and the SQUID : Eq. 1). R_{bias} are then chosen larger than the SQUID impedance Z_{SQUID} because of cross talk (Eq. 2).

$$V_{OUT_{mux}} = V_{SQUID} + \sum_{m-1} \frac{V_{SQUID} \times Z_{SQUID}}{Z_{SQUID} + 2 \times R_{bias}} \quad (1)$$

$$\begin{aligned} crosstalk_{R_{mux}} &\propto \frac{Z_{SQUID}}{R_{bias}} \\ &with \quad (R_{bias} > Z_{SQUID}) \end{aligned} \quad (2)$$

However, the SQUID current bias through these large resistors (typically, few hundred ohms) induces an important power dissipation by Joule effect. As a result, the power dissipation of this kind of time division SQUID multiplexer is essentially

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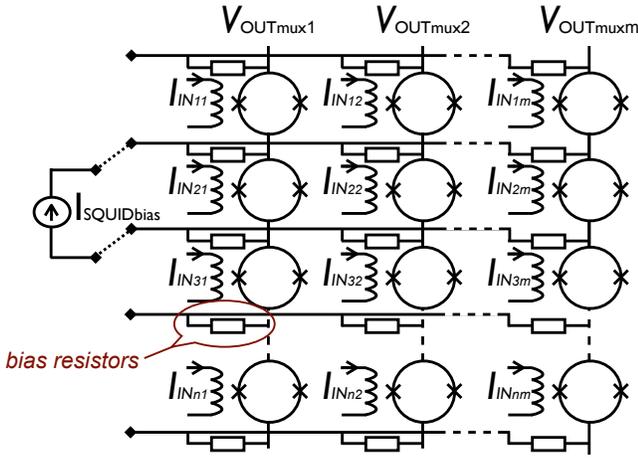


Fig. 2. 2D time division SQUID multiplexing with resistors for line biasing and voltage readout on column (Rmux).

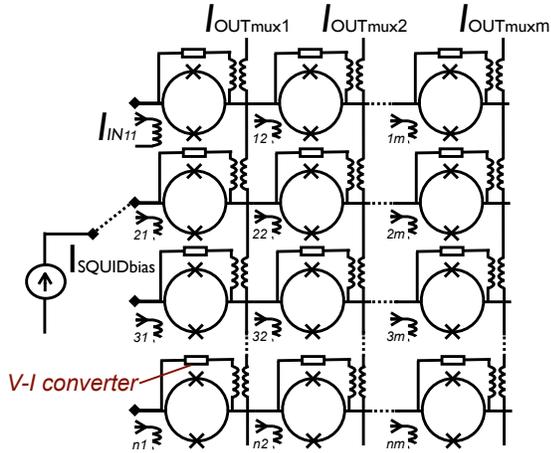


Fig. 3. 2D time division SQUID multiplexer biases in serie on a line and current read out via transformers for summing on column SQUID outputs (Tmux).

due to bias resistor dissipation. The front-end readout power consumption is given by Eq. 3.

$$P_{Rmux} = \sum_m (Z_{SQUID} + 2 \times R_{bias}) \times I_{SQUIDbias}^2 \quad (3)$$

In order to minimize cross talk of the order of 1 %, bias resistors have to be at least 100 times larger than the SQUID impedance. For this reason, 99 % of the multiplexer power consumption is not dissipated by the SQUIDs, but by the bias resistors !

B. 2D time division SQUID multiplexer current readout with transformers (Tmux)

Another time division SQUID multiplexing topology is to bias in line a 2D array without resistors [8]. SQUIDs are arranged in series on a line. Columns are read out by summing, in transformers, voltage SQUID outputs converted in current (Fig. 3).

This technique improves at the same time the cross talk¹ (Eq. 4) and the readout power consumption² (Eq. 5). Nevertheless, to sum the signal from a SQUID column in a transformer, a resistor (*V-I converter* on Fig. 3) is used to convert the SQUID output voltage in current $I_{OUTmuxC}$. This current is finally read out by a second SQUID stage (not shown in Fig. 3). The resistance value R_{V-I} of the *V-I converter* is a tradeoff between the power consumption (Eq. 5) and the gain of the readout (Eq. 6). SQUID output impedance and SQUID gain typical values are of the order of 1 Ω and 100 [V/A] respectively. The *V-I converter* resistance should then be larger to 1 Ω in order not to increase the power consumption but its value counteracts the SQUID gain; so a value of 100 Ω totally annihilates the SQUID gain.

$$crosstalk_{Tmux} \propto \frac{Z_{SQUID}}{Z_{ISQUIDbias}} \quad (4)$$

$$P_{Tmux} = \sum_m \frac{Z_{SQUID} \times R_{V-I}}{Z_{SQUID} + R_{V-I}} \times I_{SQUIDbias}^2 \quad (5)$$

$$\lim_{R_{V-I} \rightarrow \infty} P_{Tmux} = \sum_m Z_{SQUID} \times I_{SQUIDbias}^2$$

$$G_{Tmux} [A/A] = \frac{I_{OUTmuxC}}{I_{INLC}} = \frac{SQUID \text{ gain } [V/A]}{R_{V-I}} \quad (6)$$

Moreover, this technique needs a lot of transformers to sum the output signal. This is then only compatible with a development of the overall SQUIDs readout on the same wafer. In this case, transformers and SQUIDs are realized with the same planar technology.

C. 2D time division SQUID multiplexer biased via capacitors (Cmux)

We propose in figure 4 a new technique based on the first scheme (Fig. 2) but where resistors are replaced by capacitors [9]. The main idea is to use non-dissipative impedance to apply the biasing current with optimal power consumption (Eq. 7). Capacitors C_{bias} are chosen to have a larger impedance than the SQUID one to reduce the cross talk (Eq. 8).

$$P_{Cmux} = \sum_m Z_{SQUID} \times \int I_{square}^2 = \sum_m Z_{SQUID} \times I_{SQUIDbias}^2 \quad (7)$$

$$crosstalk_{Cmux} \propto \frac{Z_{SQUID}}{Z_{Cbias}} \quad (8)$$

Square current I_{square} with zero mean value ($\pm I_{SQUIDbias}$) is applied instead of DC biasing. Indeed, a static current leads to a voltage drift across capacitors and finally a current sources saturation. Moreover, the SQUID bias current source is not able to supply more than about 1 V

¹current sources have generally a very large output impedance ($Z_{ISQUIDbias} \gg R_{bias}$)

²only if the *V-I converter* resistance R_{V-I} is large enough ($R_{V-I} \gg Z_{SQUID}$)

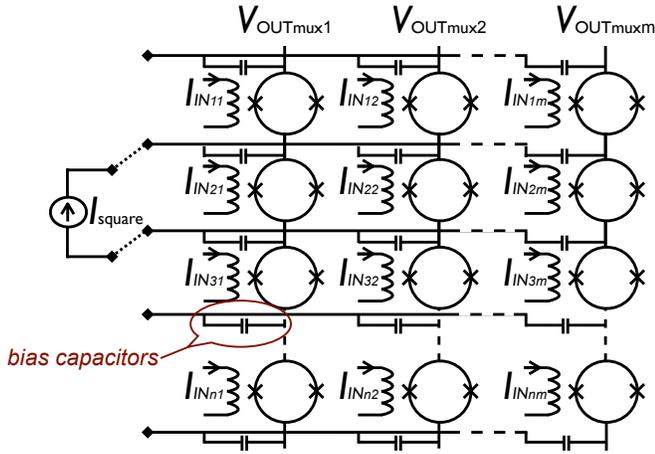


Fig. 4. 2D time division SQUID multiplexer with capacitors for line biasing (C_{mux}).

across the two capacitors and the SQUID (Eq. 9). So, this voltage swing is inversely proportional to the capacitance and the multiplexing frequency³ f_{mux} (Eq. 10).

$$V_{pp\ SQUIDbias} = Z_{SQUID} \times I_{pp\ square} + 2 \times V_{pp\ C_{bias}} \quad (9)$$

$$V_{pp\ C_{bias}} = \frac{1}{C_{bias}} \int_{T_{mux}} I_{square} dt = \frac{I_{SQUIDbias}}{C_{bias} \times f_{mux}} \quad (10)$$

The capacitance value C_{bias} is then a tradeoff between the cross-talk and the bias sources voltage swing. But a wide range of capacitance values satisfy both. For example: $I_{SQUIDbias} = 30\ \mu A$, $C_{bias} = 10\ nF$ and $f_{mux} = 10\ kHz$ lead to a reasonable voltage swing $V_{pp\ SQUIDbias} \simeq 0.6\ V$ and a very small cross talk $\ll 10^{-3}$. For instance, a C_{bias} of $10\ nF$ is large enough to neglect parasitic capacitors which could be associated to the current sources and the wiring. Furthermore, the successively positive and negative bias current (zero mean value) is used to read out two adjacent columns (Fig. 5). The TES signal (I_{IN}) is amplified during a half period ($=T_{mux}$) by the first column. The negative bias is used by the next column during the next T_{mux} . Each column amplifies successively TES signals around a positive and negative operating point. This is particularly suitable for our readout development [7] which uses a second multiplexing stage realized in SiGe technology. This circuit voltage reads out successively each column.

III. SQUID BIASED *via* CAPACITORS

We have tested square biasing of SQUID *via* capacitors. For this measurement, a Star Cryoelectronics SQ680 commercial SQUID has been biased by a $1.2\ kHz$ square current through $1\ \mu F$ capacitors. A sawtooth of $1\ V$ at the same frequency has been applied to the input coil of the SQUID through

³ $f_{mux} = \frac{1}{T_{mux}}$ with T_{mux} a sample duration of the multiplexing

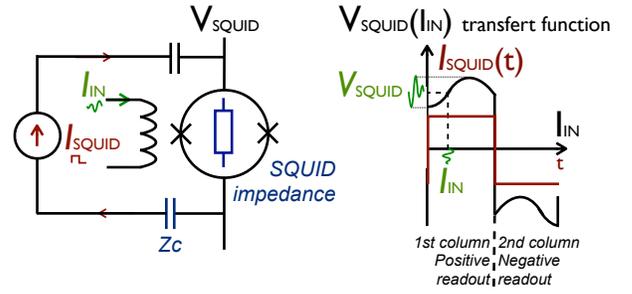


Fig. 5. Square SQUID biasing through capacitors for successive (time domain) readout of different columns.

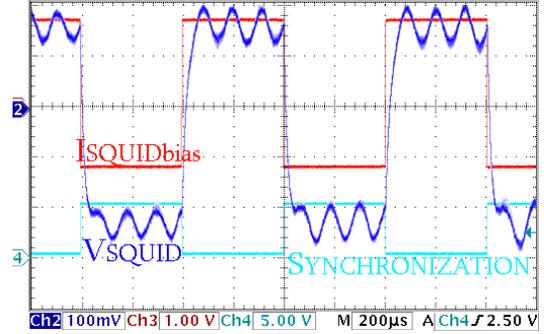


Fig. 6. Measured $V_{SQUID}(I_{IN})$ characteristic (Ch2) of a Star Cryoelectronics SQ680 SQUID biased by a square current (Ch3) through capacitors.

two $10\ k\Omega$ resistors instead of the bolometer signal. Figure 6 shows the measured $V_{SQUID}(I_{IN})$ characteristic of the SQUID described by the sawtooth. This common characteristic is obtained around a positive and negative operating point as expected as regard to the square biasing.

IV. CONCLUSION

We have described advantages and disadvantages of known techniques for bias 2D time division SQUID multiplexing and finally proposed a new one. AC bias SQUID *via* capacitor is a promising way to develop low power dissipation cryogenic multiplexer with negligible cross talk. This method may be easier to implement than the one with transformers. Square biasing SQUID through capacitors has been successfully tested, showing the possible operation of a non-dissipative addressing for time division SQUID multiplexing. This development is done in preparation for the new generation of cameras for ground-based telescopes in the millimeter wavelength range, and for the cosmic microwave background B-mode detection instrument QUBIC [2].

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