Matrix Readout Scheme for Superconducting Tunnel Junction Arrays

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Abstract

We report on the design and testing of a new readout scheme for Superconducting Tunnel Junction (STJ) arrays. By grouping the electrodes in rows and columns, this method drastically reduces the number of connections and electronic circuits required for reading out a large format array of pixelated detectors. Using charge sensitive amplifiers with junction field-effect transistors (JFETs) we verify that the energy resolution degrades primarily due to capacitance increase at the amplifier's input node. However, since each detector is read-out by two independent circuits, these two outputs can be combined to increase the signal-to-noise level. For a $N \times N$ array, we show that the equivalent noise charge at the input worsens by a factor much less than N as compared to single device read-out. We also report on a proof-of-principle experiment carried out on a two-by-two array of STJs using optical photon excitation. These measurements show that stable biasing of STJs is possible in this configuration and that the line resolutions are consistent with our theoretical predictions.

1 Introduction

During the last few years, non-dispersive detectors based on superconducting materials such as Superconducting Tunnel Junctions (STJs) or Transition Edge Sensors (TESs) have been developed extensively and have now demonstrated rather high energy resolutions. Reported values range from 0.12-0.3eV full width at half maximum (FWHM) in the optical wavelengths using STJs [1,2] to 4.7eV (FWHM) at 6keV X-ray energies using a TES [3]. The next step in the development of these detectors is to group them into arrays so as to obtain an imaging capability. Already a small prototype instrument based on a 6x6 array of STJs has been developed and installed on the William Herschel Telescope at La Palma [4]. Similarly, a 2x18 array of bolometers will be used in one of the X-ray cameras onboard the Japanese satellite ASTRO-E [5].

These cryogenic detectors have all been read out using individual acquisition chains for each pixel. This severely limits the number of pixels for three main reasons:

- i. All these detectors require very low operating temperatures (0.1-0.3K) and thus the most serious problem is related to heat load onto the cryogenic cooler through the wiring between the room-temperature electronics and the detector. Current amplifier designs based on junction field-effect transistors (JFETs) cannot operate at the required detector temperature. Some reports [6] show a reduced number of wires for addressing TES detectors using superconducting quantum interference devices (SQUIDs). These methods are based on multiplexing schemes and are severely limited in speed, both in terms of photon flux and in pulse sampling [7].
- ii. The second concern relates to the specific case of the application to space instruments, where power consumption and weight are to be minimised. Indeed, each pixel requires an individual readout chain comprising a biasing circuit and a preamplifier, shaping filter, low-level threshold detector, sample-and-hold and analog-to-digital converter circuits.
- iii. In the specific case of front illumination by soft X-rays, the amount of wiring crossing the detectors effectively suppresses the low energy response.

We describe here a potential new method for reading out large format arrays of pixel detectors which drastically reduces the number of wires on chip as well as between the detector and the acquisition electronics and reduces by the same amount the number of electronic channels. With this new method, an array of $N \times N$ pixels can be read-out by $2 \times N$ amplifier chains instead of the normally required N^2 .

In this paper we shall describe the pixel array interconnection principle, which we shall refer to as matrix read-out, and evaluate its advantages and disadvantages. The discussions and illustrations will be based on STJ arrays but we believe the concept is more generic, being applicable to a wider range of detectors (e.g. TES arrays). We demonstrate the approach through the use of a two-by-two array of STJs. We will report on the results obtained with Tantalum devices illuminated by optical photons.

2 The Pixel Array Interconnection Principle

2.1 Description

The principle is based on interconnecting the pixels in rows and columns as shown in figure 1. In this specific case of an STJ array, the base electrodes are interconnected in rows and the top electrodes in columns. Each row and each column is connected to a separate bias and amplification circuit. This means only $2 \times N$ wires and circuits are needed to read out a $N \times N$ array, instead of the traditional N^2 . When a pixel has been hit by a photon, the excess tunnel current will produce a signal proportional to the photon's energy simultaneously in its corresponding row and column. A coincidence measurement between rows and columns can therefore determine which pixel recorded the photon event. The photon's energy can be derived in the usual way by filtering the integrated charge output from the charge sensitive preamplifier using a pulse shaper followed by a peak detector. Figure 2 shows a possible implementation using conventional JFET charge sensitive amplifiers. Voltage biasing of the detectors is achieved by creating a virtual ground on all columns and a virtual bias voltage on each row. This can be implemented using a high open loop gain amplifier with negative feedback and a very low offset voltage operational amplifier controlling the amplifier's input JFET DC operating point. Another type of readout implementation which uses SQUIDs as a first stage amplification is shown in figure 3. This has the advantage of greatly simplifying the biasing circuit. It also reduces pick-up noise since the SQUIDs are placed close to the detectors (e.g. on an intermediate cooling stage at 4K) and present a low output impedance. Unfortunately, currently available SQUIDs cannot be efficiently coupled to STJs and therefore cannot, yet, reach the noise levels obtained with JFETs [8]. As we shall see later, SQUIDs could offer additional advantages in the matrix readout scheme because their series noise is negligible. They are however the element of choice for reading out Transition Edge Bolometers.

2.2 On the Advantages of the Readout Approach

Obviously, with the proposed readout approach, the number of wires and circuits for reading out a large format array can be reduced drastically. A conventional approach would currently limit the number of pixels to about 100 and with major development (particularly related to the cryogenic cabling) possibly to 10^3 due to excessive heat load on the cryogenic system. We can now however envisage arrays of 10^4 to 10^6 pixels. Such large format arrays open up the possibility to develop large format, large field-of-view imaging spectrometers for UV-optical astronomy and high-energy X-ray astrophysics.

Since the number of connections to the detector chip has decreased and because the contacts are intrinsically available at the border of the array (see figure 1), no complex routing is necessary to connect the array pixels to the reduced number of contact pads. Bonding can be achieved by traditional wire bonding, i.e. no bump-bonding is necessary.

This scheme does not require additional processing steps in the fabrication of the array chips. In reality, it can actually reduce the processing complexity. Indeed, in the case of STJs, the detectors are usually covered with SiO_2 and vias patterned so as to create contacts onto the top electrodes. This is not necessary for our proposed scheme since there are no tracks that need electrical isolation from the top electrodes. In addition, the traditional pixel addressing method requires a separate top electrode contact for each detector and therefore the number of tracks required increases rapidly

with the array size. At some point, one would have to move to multiple layers of routing metal, increasing the processing complexity for the traditional readout even further.

The tracks covering the top electrodes also mask the detector in the case of illumination from the top. This is a major problem when used for X-ray detection. For optical or UV photons, the illumination can be through the transparent sapphire or Magnesium Fluoride substrate. Figure 4 shows a microscope image of a 6x6 STJ array as installed on the WHT at La Palma while figure 5 is a snapshot of an 18x50 STJ array currently under development where the track density problem can be clearly recognised. The new addressing scheme alleviates this problem by first and foremost avoiding having tracks across the top electrodes. This can be seen in Figure 6 which is a microscope picture of a new Vanadium 12x8 STJ array designed according to the matrix scheme. Now only 20 connections are required compared to the 37 of figure 4 while increasing the field coverage by almost a factor of 3.

2.3 Possible Drawbacks with the Readout Approach

2.3.1 Noise considerations

For electrical modelling purposes, an STJ can be represented by a capacitor in parallel with a dynamic resistance. The dynamic resistance can be estimated from I-V curves and in practice is always larger than the leakage current at the bias point divided by the bias voltage. The capacitance is estimated as that of a parallel plate capacitor of identical size using a relative electrical permittivity ϵ_r of 10.5. The detector's corner frequency above which it can be modelled by a pure capacitor is given by:

$$f_c = \frac{1}{2\pi} \frac{J_b \cdot l^2}{V_b} \frac{d}{\epsilon_0 \cdot \epsilon_r \cdot l^2} \quad (1)$$

In Ta based devices, we currently achieve leakage currents densities (J_b) better than $50\text{fA}/\mu\text{m}^2$ at a temperature of 0.3K and a bias voltage (V_b) of $100\mu\text{V}$; the oxide thickness (d) is of order 1nm which yields a corner frequency, f_c , of 860Hz. For pulse height analysis, traditional semi-Gaussian pulse shaping is used with time constants of order $10\mu\text{s}$ [8], this is an order of magnitude shorter than the detector's RC time given by (1). For a wide range of detector sizes ($l \times l$), the STJ can therefore be represented electrically by a capacitor.

Let's consider now a single STJ connected to a JFET charge-sensitive pre-amplifier. The major noise sources are represented in Figure 7 [8,9]. The JFET's series noise (e_n), physically generated in its channel, consists of white Gaussian noise and '1/f' noise and is referred to the input node provided the transistor's input capacitance (gate-to-source, C_{gs} and gate-to-drain, C_{gd}) is added to the input node capacitance (C_{stray}) [10,11]. The input referred current noise from the transistor can be shown to be negligible [11]. The parallel noise (i_n) consists of the detector bias current which is responsible for shot noise ($i_{n,sh}$) and Johnson noise from the feedback resistor ($i_{n,Rf}$). The shot noise can usually be neglected since we routinely manufacture extremely high quality barriers with consistently very low leakage currents. The noise contribution from the feedback network can also be made small by choosing an appropriate high resistor value.

Equation (2) shows the total noise power spectrum density at the output of a charge sensitive amplifier where C_d , C_w , C_f and C_{gs} and C_{gd} are the detector, wiring, feedback and input transistor's capacitances respectively.

$$|v_o|^2 = \left| \frac{C_d + C_w + C_f + C_{gs} + C_{gd}}{C_f} \right|^2 e_n^2 + \left| \frac{1}{j\omega C_f} \right|^2 (i_{n,sh}^2 + i_{n,Rf}^2) \quad (2)$$

In the new read-out scheme, each amplifier senses a parallel combination of N detectors as sketched in Figure 8, for a $N \times N$ array. The parallel noise power density due to the detectors' leakage currents will increase by a factor N compared to the single detector case, but should remain negligible with high quality barriers. The new read-out scheme does not influence the value to be chosen for the feedback resistor and therefore its noise contribution remains unchanged.

The proposed read-out scheme affects in two ways the output noise related to the JFET's input referred (series) voltage noise. Firstly, this component is directly influenced by the input node capacitance as is seen in equation (2). The detector's capacitance C_d has now increased to $N \times C_d$ as perceived at the output of a $N \times N$ detector array. Secondly, each row (column) is connected to each column (row) amplifier through the detectors (Figure 9). The series noise related to the column (row) amplifiers are therefore also coupled in through the detectors' capacitance. One can easily show that these noise voltage sources add quadratically (since they are uncorrelated) so that the total noise power spectrum density at the output of the charge sensitive amplifier is now given by:

$$|v_o|^2 = \left[\left| \frac{N \cdot C_d + C_w + C_f + C_{gs} + C_{gd}}{C_f} \right|^2 + N \cdot \left| \frac{C_d}{C_f} \right|^2 \right] e_n^2 + \left| \frac{1}{j\omega C_f} \right|^2 (N \cdot i_{n,sh}^2 + i_{n,Rf}^2) \quad (3)$$

If the noise is dominated by the series component and assuming we use the same preamplifier (i.e. having the same e_n), the equivalent noise charge will increase for this new matrix readout method over the traditional case by a factor ξ given by:

$$\xi = \left[\frac{(N \cdot C_d + C_w + C_f + C_{gs} + C_{gd})^2 + N \cdot C_d^2}{(C_d + C_w + C_f + C_{gs} + C_{gd})^2} \right]^{1/2} \quad (4)$$

Consider a practical example where we assume that the parallel noise is negligible; $C_d=60\text{pF}$ ($25 \times 25 \mu\text{m}^2$ detector); $C_w=90\text{pF}$; $C_{gs}=30\text{pF}$; $C_f=1\text{pF}$. The equivalent noise charge will increase by a factor ~ 4 for a 10×10 array of detectors when using the matrix read-out. If we consider an array of 10^4 STJs each of size $10 \times 10 \mu\text{m}^2$, C_d is lowered to 9.6pF , $N=100$, ξ becomes 8.3.

The degradation in noise performance can be compensated slightly by realising that each detector is read-out using an independent row and column amplifier. Since their series noise components are to a large extent uncorrelated, their signals can be combined thereby lowering the series noise component by a factor $\sim \sqrt{2}$. In the above examples, ξ can be lowered to 3 and 6 respectively.

2.3.2 FET optimisation

In the previous section, we compared the noise performances using the same amplifier. Since the noise increase is mainly due to increased input node capacitance, the pre-amplifier's input FET can be optimised. Since CMOS technology is more readily available for custom integrated circuit (ASIC) design we will consider a MOS input transistor, the analysis for a JFET being similar. Assuming operation in saturation, the transistor's transconductance (g_m) and related white series noise voltage (e_n) are given by:

$$g_m = \sqrt{2 \cdot \mu \cdot C_{ox} \cdot \frac{W}{L} \cdot I_D} \quad (5)$$

$$e_n = \sqrt{4 \cdot k \cdot T \cdot \frac{2}{3 \cdot g_m}} \quad (6)$$

where μ , C_{ox} , W , L , I_D , k and T are the carrier mobility, gate oxide capacitance, effective channel width, length, drain bias current, Boltzmann's constant and temperature respectively. The transistor's gate capacitance is given by $2/3 C_{ox} W L$. If I_D and L are kept constant because of power and processing technology considerations, the optimum gate widths, which minimise the series noise power density, are:

$$W_{opt} = \frac{C_d + C_w + C_f}{2 \cdot C_{ox} \cdot L} \quad (7)$$

$$W_{opt} = \frac{N \cdot C_d + C_w + C_f}{2 \cdot C_{ox} \cdot L} \left[\sqrt{4 + \frac{3 \cdot N \cdot C_d^2}{(N \cdot C_d + C_w + C_f)^2}} \right] \quad (8)$$

In the cases of standard and matrix readout respectively. The previously defined parameter ξ becomes:

$$\xi_{opt} = \left\{ \frac{N \cdot C_d^2 + [N \cdot C_d + C_w + C_f]^2 \cdot \left[1 + \frac{1}{3} \left[\sqrt{4 + \frac{3 \cdot N \cdot C_d^2}{(N \cdot C_d + C_w + C_f)^2}} - 1 \right] \right]^2}{\sqrt{N \cdot C_d + C_w + C_f} \cdot \sqrt{4 + \frac{3 \cdot N \cdot C_d^2}{(N \cdot C_d + C_w + C_f)^2}} - 1} \cdot \frac{9}{16 \cdot [C_d + C_w + C_f]^{3/2}} \right\}^{1/2} \quad (9)$$

If $N C_d^2 \ll (N C_d + C_w + C_f)^2$, (9) can be simplified to:

$$\xi_{opt} = \left[\frac{N \cdot C_d + C_w + C_f}{C_d + C_w + C_f} \right]^{3/4} \quad (10)$$

Further applying the $\sqrt{2}$ improvement by signal combination, the noise worsening factors for the 2 examples given in the previous section are 2.3 and 4.1 respectively. This optimisation did not take '1/f' noise into account. A '1/f' noise optimisation would require a 3 times larger input transistor compared to the 'white' noise optimisation [9]. An analytical solution including both 'white' and '1/f' series noise is not possible to derive since it depends on device parameters. Any real values for ξ will therefore likely be somewhat higher than those reported here. This analysis only shows what the maximum gain in signal-to-noise ratio can be by optimising the input transistor's size.

2.3.3 Biasing issues

A more serious problem is related to the biasing of STJs. Figure 10 shows a current versus voltage (I-V) curve of a typical single $25 \times 25 \mu\text{m}^2$ Tantalum device at 0.3K. Due to electronic offsets, the I-V curve is not perfectly centred. One can clearly see the Josephson current at zero bias voltage and the Fiske resonances. These features are normally suppressed with a magnetic field of about 100 Gauss so as to ensure stable biasing. The suppression is very effective for single devices but is not perfect for each device in an array. This is thought to be related to small geometrical differences between each junction and small magnetic field non-uniformities. When

biasing an array, a sub-optimum magnetic field (for individual devices) has to be chosen and some residual Josephson current will persist. In order to bias the junctions this Josephson current has to be surpassed, i.e. the biasing network has to be able to provide sufficient current during the bias settling time and every time the junction is disturbed from its equilibrium bias point. Since our connection scheme involves a single bias circuit for each row (and column), it has to provide sufficient current to overcome the sum of all Josephson currents in a row (and column). As can be seen in Figure 2, this current has to be provided by the feedback resistor in the charge sensitive amplifier. A difficulty arises from the fact that a high value is needed for low parallel noise and a low value is required for providing sufficient bias current. Using an active feedback element as proposed for leaky semi-conductor detectors [12,13] could probably solve this problem.

2.3.4 Count rate issue

A photon absorbed in a particular junction has to be localised by a simultaneous detection in the corresponding row and column. If another photon is absorbed in another junction within the electronic response time, position ambiguity and possible pile-up can result. The position ambiguity can be resolved by using a fast threshold detection circuit. In principle, sub-microsecond response times are possible since a slow shaping time (optimised for best signal-to-noise ratio) is not required for detection purposes [14]. Therefore >1MHz rates are theoretically feasible. Pile-up will occur if two events are absorbed either in the same junction or in the same row or column. Pile-up within the same junction is, of course, identical to the individual read-out case.

If two or more photons are absorbed within the same row but not in the same junction, they can be detected and analysed separately since there will be no pile-up in the columns. In this case however, the row signal cannot be used for improving the signal-to-noise ratio since it will contain pile-up.

Another problem related to pile-up is the issue of infrared (IR) flux. Any heat source in the field of view of the detector will produce IR events in the detectors. These will see a base-line current increase together with a variance due to the statistical arrival of the photons. This variance can significantly reduce the resolution [15]. Each electronic chain will record the total IR flux received on its line as additional noise, which is N times higher than for the traditional read-out under the same illumination circumstances. Extreme care has to be taken in the design of baffling and filters for an instrument using these extremely sensitive detectors.

2.3.5 Diagnostics and yield

STJs are normally diagnosed by tracing their current versus voltage (IV) characteristic. Due to the fact that all junctions are interconnected in the matrix scheme, it becomes impossible to diagnose individual detectors. However, an IV curve is still a good analysis tool in that it will provide upper limits to the Josephson and sub-gap currents of the devices.

Note however that if a junction has a short, cannot be biased or is too noisy, it will spoil the complete row and column. This could pose a serious yield problem for large arrays.

3 Test Results

The chip used for this test was a Tantalum based 6x6 array produced by Oxford Instruments [16]. On these chips, fabricated for the conventional readout (see Figure 4), the base films are interconnected in rows and available on two pads. The

top films are all individually available. The base film lead of the first row (junctions 11...16 [17]) was laser-cut and wire-bonded to a separate pad. At the time of the tests, only a 4-channel electronics system was available which limited us to a 2x2 array. The selected junctions were connected to the 4 individual electronic channels as shown in Figure 11.

The measurements reported here were performed in an Oxford Instrument's Heliox system at a base temperature of 0.31K and with a magnetic field of 214 Gauss. For the spectral measurements, the junctions were biased at 140 μ V (on Ch1 and 3 while Ch2 and 4 were kept at Ground potential).

3.1 The I-V Curve

All 36 devices forming this array were measured individually prior to the editing and tests reported here. A selection was made on the basis of minimum residual Josephson current at identical magnetic field and similar optimum bias voltages. The four selected junctions all show a sub-gap current below 50pA. When all 4 devices are connected in parallel, a residual Josephson current of 43nA was measured at a magnetic field of 214 Gauss. Once the devices were wired using the new read-out scheme, IV curves were re-measured. As was mentioned in chapter 2.3.5, individual STJs cannot be diagnosed but the curves can show upper limits on the sub-gap currents and residual Josephson currents. They will also show that no detector is damaged or has trapped flux. An example is provided in Figure 12 where Channel 4 was set to Ground potential and Channel 1 swept between -500 and +500 μ V.

3.2 Response to Photons

In order to detect photons, each pre-amplifier channel is followed by a slow [18] and a fast [19] shaping filter. The fast filter is used for triggering and time stamping the events while the slow filter is optimised for accurate pulse amplitude measurements. Data files contain an event list of the fast and slow samples of all 4 channels and a time stamp for each trigger. A Xenon lamp with a programmable double monochromator was used as a light source and coupled to the detector array via an optical fibre. Illumination was through the sapphire substrate. Measurements were performed at 250, 300 and 500nm wavelength.

3.2.1 Channel Correlation

Figures 13 and 14 show grey-scaled 2-D histograms of one (slow-PHA-) channel against another when the detector was illuminated with 300nm photons. Clear correlation can be seen between channels sharing a common STJ (Figure 13). Channels which do not share a detector only have a few points off the axes. In the case of channel 1 versus channel 3 (Figure 14), these correspond to pile-up events and represent only ~0.08% of the total amount of recorded events in these channels, in agreement with the expectation for a photon flux of ~100Hz and the acquisition electronics' characteristics.

3.2.2 Spectra

For each junction, events were retained by selecting those which had a non-zero signal in both its corresponding channels. For instance for junction J₁₁, valid events were those for which channels 1 and 2 were simultaneously triggered within the coincidence window of 5 μ s [20]. Figure 15 shows the spectra obtained from J₁₁ with 500nm-photon excitation for both its channels (CH1 and CH2). The spectra

include curve fits to determine the full width at half maximum (FWHM) energy resolutions.

A summary of line resolutions obtained at the different wavelengths is given in tables I to III. Each table contains the average charge output from the slow channel (in electronic ADC units) as well as the corresponding line width and electronic pulser resolution (both calibrated in nm and eV, FWHM) for each STJ, using only CH1 or CH3. Table IV represents results at 300nm from the same junctions using the traditional individual device connection method (i.e. individual electronics channels for each detector) with the same set of electronics. The electronic pulser noise is a factor 1.4, and the line resolution about 1.17 larger in Table II as compared to Table IV, in agreement with equation (3).

For the results summarised in tables VI to IX, the pulses from both channels of each junction have been added together. As was discussed in section 2.3.1, this results in lower noise. The energy resolution is now comparable to the results listed in Table IV. We can also compare these results to Table VIII, which is a summary of (300nm) measurements taken individually on each junction using a slightly better single channel electronics set and optimum biasing conditions. Since in this case each individual junction could be biased to its own specific optimum bias voltage and magnetic field, a further improvement of 9% was possible.

4 Conclusions

We have presented a novel connection scheme for arrays of pixelated detectors. This scheme drastically reduces the number of wires and circuitry necessary for reading out large array detectors. We have presented results obtained on a 2x2 array of STJs using optical photon excitation. While we have shown that these devices can be properly biased, the energy resolutions obtained are on average only 17% worse when compared to the traditional individual multi-channel readout. When compared to the most optimum single channel measurements (at 300nm), the degradation is 24%. We have also shown that the signals from rows and columns can be combined to improve the signal-to-noise ratio. In this case, our results are comparable to the traditional multi-channel read-out and show a worsening of only ~9% on average compared to the best measurements. We attribute this to sub-optimal magnetic field and bias voltage settings in the multiple channel read-out (matrix and conventional).

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11 (CH1)	433.3	20.4	0.405	17.5	0.347
13 (CH3)	475.5	22.4	0.445	17.7	0.351
22 (CH1)	419.2	21.9	0.434	18.1	0.359
23 (CH3)	479.4	22.0	0.437	17.5	0.348

Table I: line resolution and noise measured at a photon wavelength of 250nm, using the matrix readout scheme.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11 (CH1)	364.0	26.1	0.360	26.9	0.371
13 (CH3)	398.4	30.3	0.417	27.2	0.375
22 (CH1)	358.9	30.0	0.413	27.4	0.377
23 (CH3)	400.0	33.4	0.460	27.1	0.374

Table II: line resolution obtained at 300nm, using the matrix readout scheme.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11 (CH1)	207.7	70.6	0.350	73.2	0.363
13 (CH3)	227.5	85.5	0.424	83.1	0.412
22 (CH1)	200.0	78.0	0.387	76.0	0.377
23 (CH3)	232.8	80.0	0.397	77.4	0.384

Table III: line resolution obtained at 500nm, using the matrix readout scheme.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11	400.9	25.9	0.357	20.0	0.276
22	427.8	25.1	0.346	19.7	0.272

Table IV: line resolution obtained at 300nm using a conventional 4-channel read-out.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11	-	17.6	0.349	-	-
13	-	18.1	0.360	-	-
22	-	19.0	0.376	-	-
23	-	18.3	0.364	-	-

Table V: Improved resolution for the matrix read-out at 250nm photon wavelength, by combining the row and column data.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11 (CH1)	-	23.4	0.323	-	-
13 (CH3)	-	26.7	0.368	-	-
22 (CH1)	-	25.3	0.348	-	-
23 (CH3)	-	28.8	0.397	-	-

Table VI: Improved resolution for the matrix read-out at 300nm by combining the row and column data.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11	-	59.1	0.293	-	-
13	-	63.5	0.315	-	-
22	-	62.5	0.310	-	-
23	-	62.9	0.312	-	-

Table VII: Improved resolution for the matrix read-out at 500nm by combining the row and column data.

Pixel	Q [adc #]	FWHM		Pulser noise	
		[nm]	[eV]	[nm]	[eV]
11	5968	24.1	0.332	20.0	0.275
13	5997	24.1	0.332	20.0	0.275
22	6081	24.4	0.336	19.0	0.262
23	6215	22.9	0.315	17.7	0.244

Table VIII: resolution obtained at 300nm using the best configuration single channel measurements.

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17. Indices refer to a junction's row and column respectively.
18. Filter centre frequency = 15.9kHz
19. Filter centre frequency = 79kHz
20. Limited by the current electronics set.

Figure captions

1. Layout of the matrix read-out scheme as applied to a 6x6 STJ array. The 2 side columns are the contact pads. The 36 detectors are interconnected in rows and columns by their top and base electrodes respectively.
2. Schematic representation of a traditional semiconductor amplifier chain connected to the detector matrix. The high open loop gain amplifiers ensure the row and column biasing voltages through the feedback network.
3. Possible implementation of a matrix read-out based on SQUID preamplifiers. Here we have represented a series arrays of DC-SQUIDs which avoid the need for flux modulation and an output transformer and can be matched directly to room temperature low-noise electronics.
4. Optical micrograph of the 6x6 array of Tantalum detectors used in the SCAM camera. Note how the tracks cover the top electrodes.
5. Layout for a prototype 18x50 array of STJs. The detectors are in the middle of the picture and surrounded by the leads to the contact pads on the top and bottom of the image. The inset is a zoom on the corner of the detector array and shows the track density required by the traditional read-out scheme.
6. New Vanadium based 12x8 STJ array designed according to the matrix connection scheme.
7. Major noise sources for a (J)FET preamplifier system connected to an STJ. $I_{n,Rf}$ is the feedback resistor's thermal noise; $I_{n,sh}$ is the detector's shot noise; e_n is the first transistor's input referred channel noise. C_{stray} represents all the stray capacitances to ground on the input node ($=C_w+C_{gs}+C_{gd}$). The amplifier's feedback network consists of C_f and R_f .
8. Schematic of the noise sources resulting from the parallel connection of STJs in rows and columns.
9. Schematic representation of the influence on the row's amplifier by the column's amplifier noise.
10. Typical IV curve for a $50 \times 50 \mu m^2$ STJ detector cooled at 0.3K. Note the Josephson current at zero bias voltage and the Fiske resonances at ± 300 and $\pm 410 \mu V$. The graph is not perfectly centred due to offsets in the electronics.
11. Test set-up - STJ and Amplifier connection schematic.
12. Detail of an IV curve obtained with the 2x2 matrix connection of $25 \times 25 \mu m^2$ STJs. The subgap current is less than 100pA at $100 \mu V$. For measuring the curve, the voltage is swept back and forth which explains the double trace.
13. 2-D Histogram of channel 1 versus channel 2. The lines on the axes are events seen on either of the channels but not the other. The correlated events correspond to junction J_{11} .
14. 2-D Histogram of channel 1 versus channel 3. Only a few points due to pile-up are visible in the middle of the plot.
15. Charge spectra obtained with J_{11} at 500nm illumination and derived from channels 1 (left) and 2 (right). Over-imposed are the results of a curve fit (the vertical lines determine the limits taken for the fitting procedure) to determine the energy resolution. The units on the horizontal axes are in ADC channels.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

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Figure 14

Figure 15