Automatic Tuning of SMART, KOSMA's 490/810 GHz Array Receiver

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1 ABSTRACT

We describe the control system of SMART (Submillimeter Array–Receiver for Two–Frequencies), KOSMA's 490/810 GHz array receiver. All major electronic functions of the instrument such as mixer bias, magnetic field, PLL, and IF processing can be controlled either by computer or manually. The computer also monitors important status information.

Based on the hardware control system a procedure to automatically tune the array receiver has been developed. The automatic tuning is necessary to increase the duty cycle of the receiver and to avoid mistakes from manual operation of the complex tuning procedure.

To tune the 16 SIS (Superconductor-Insulator-Superconductor) receiver channels, many parameters have to be optimized. Especially the magnetic field, which is applied to the junctions to suppress excess mixer noise caused by the Josephson effect, is very important and can not be set from look-up tables. An algorithm was developed to measure the relation between the strength of the Josephson effect and the applied magnetic field for each junction. Based on these data, the algorithm automatically finds and sets the optimum field strength and mixer bias.

2 INTRODUCTION

SMART, KOSMA's 490/810 GHz array receiver[1] currently consists of 8 SIS receiver channels. It has been installed in September 2001 on the KOSMA telescope[2] and has been operational since then. It will be upgraded to 16 channels in 2002, resulting in a 2×4 beam pattern on the sky, which is covered simultaneously in two frequencies. Besides the automatic mixer tuning its design includes innovative features like Fourier-gratings[3] for the local oscillator supply, integrated optics[4], and compact bias- and IF-electronics[5].

Although SMART is an array receiver, each of the channels has to be tuned individually, only the local oscillator tuning is done for each frequency channel (i.e. for 4 to 8 mixers) at a time. In addition to the tuning algorithm and software, the automatic tuning requires specially designed hardware.

3 HARDWARE

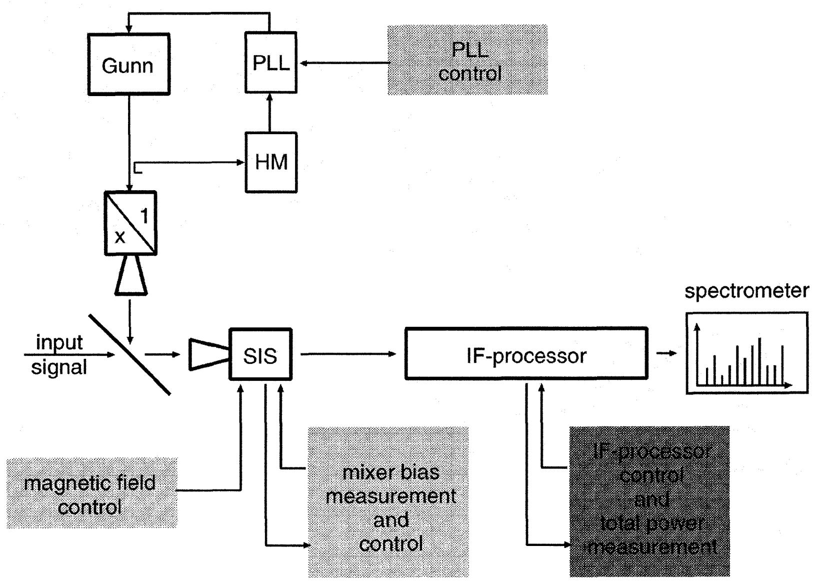


Figure 1: *Schematic drawing of the receiver electronics. Shaded boxes are computer controlled.*

Figure 1 shows the main elements of the electronics: the magnetic field control, the mixer bias measurement and control system and the IF-processor, in which the IF total power measurement is integrated.

The magnetic field control generates the current to establish a magnetic field which is applied to the junction to suppress the Josephson current (Figure 2) with its associated noise.

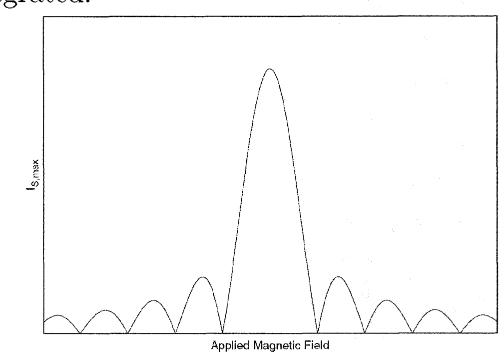


Figure 2: *Josephson current versus magnetic field (theoretical curve).*

The mixer bias control unit is the primary power supply for the junctions. Additionally, their IV characteristics can be measured with this device.

The IF-processor amplifies and converts the IF signal of the junction. With this system we can also measure a total power IF signal for laboratory and astronomical operation. In addition a 5 bit attenuator is integrated for each channel. A zero switch and a comb generator can be used for dark current measurements and frequency calibration of the acousto-optical spectrometer backends (AOS) [6].

An address bus connecting all units including the PC makes sure that all measurements and all modifications always refer to the same channel to avoid confusion.

3.1 RECEIVER RACK

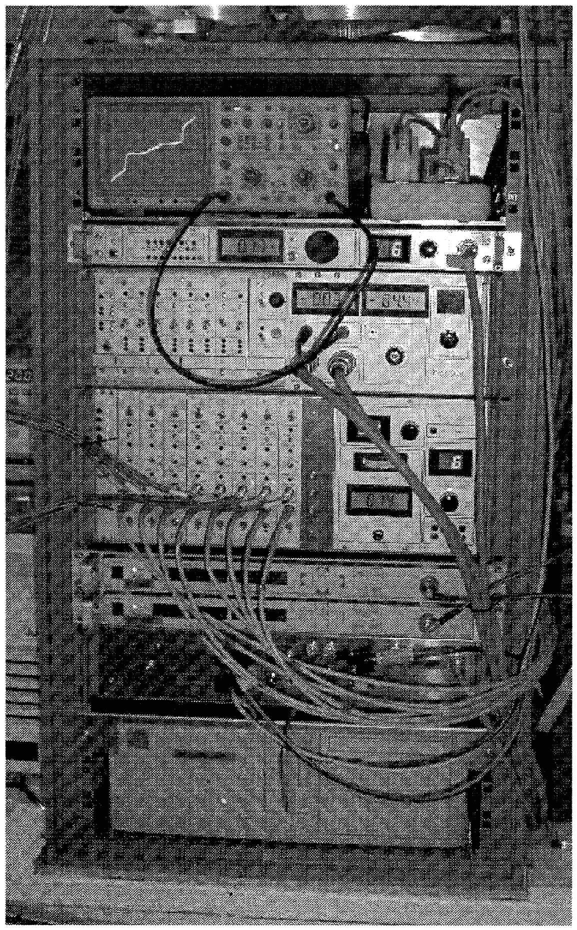


Figure 3: *Photograph of the SMART electronics rack containing magnet supply (beneath the oscilloscope), bias box, IF processor, two synthesizers, computer interface box and the control computer on the bottom.*

The receiver rack contains all the major electronics subsystems of KOSMA's array receiver. To automatically tune the receiver, a control PC has been set up, which is connected to all other subsystems through the PC interface. Using this interface the PC can read out all analog values of all channels directly. A 64 channel Analog-Digital-Converter card in the PC converts these values. The PC can also change all parameters in the subsystems to tune the junctions. All signals needed for this process have to pass the PC interface, where a manual/remote switch controls whether the PC is connected to the subsystems or not. Using this switch the PC can be put "offline", so the receiver can be tuned manually or pretuned values can be finetuned by the user. After this operation the computer can be turned "online" again.

The control PC runs under LINUX, which ensures reliable operation. All functions can be remote controlled through an Ethernet link. Additionally, changes of parameters and IV-curves as well as conversion curves are logged as housekeeping data.

3.2 ADDRESS BUS

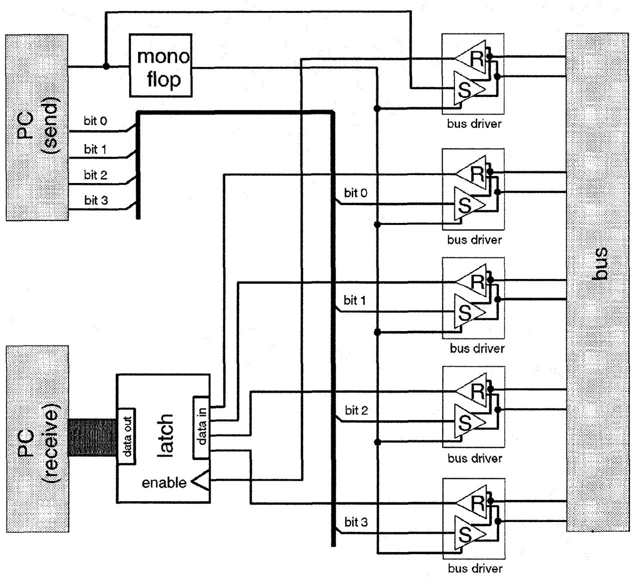


Figure 4: *Schematics of the address bus.*

An important part of the electronics system is the 5 bit address bus, which is connected to all subsystems including the PC interface. Each receiver channel is addressed by a unique number. Only the parameters of the channel selected in this way will be displayed and changed. This address can be set either by the PC or manually through any one of the control boxes. To avoid noise pickup from other telescope systems, a bus driver for each bit has been set up. Also the system avoids inconsistencies in case two or more subsystems attempt to set a channel, because all setting devices will read back the selected channel address.

3.3 DIGITAL POTENTIOMETER

One of the major requirements of the electronics was to give the operator the chance to correct or retune all parameters manually. This is useful for debugging and was needed to develop the algorithm for the automatic tuning. To ensure that both the operator and the computer can manipulate the same values, the digital potentiometer has been developed. A digital counter stores the value for each channel. It is connected to a DAC, which produces the desired voltage. Besides the advantage that the value can be manipulated either manually or under computer control, the voltage is independent of analog signals out of the computer so they are more immune against noise contamination from the computer hardware.

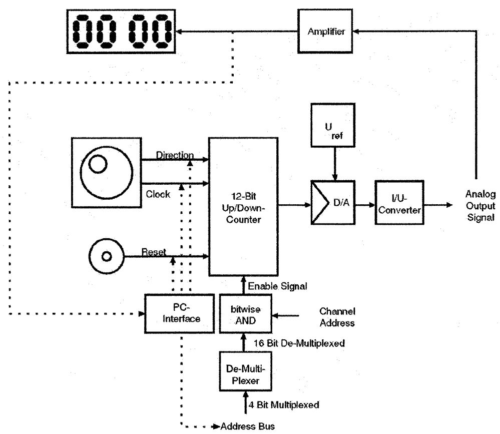


Figure 5: *The digital potentiometer.*

4 TUNING ALGORITHM

The tuning parameters are the local oscillator frequencies and pump levels, the mixer bias and the current for the magnetic field, which suppresses the Josephson current. LO tuning is done manually since it requires moving backshorts and it only needs to be done once per frequency.

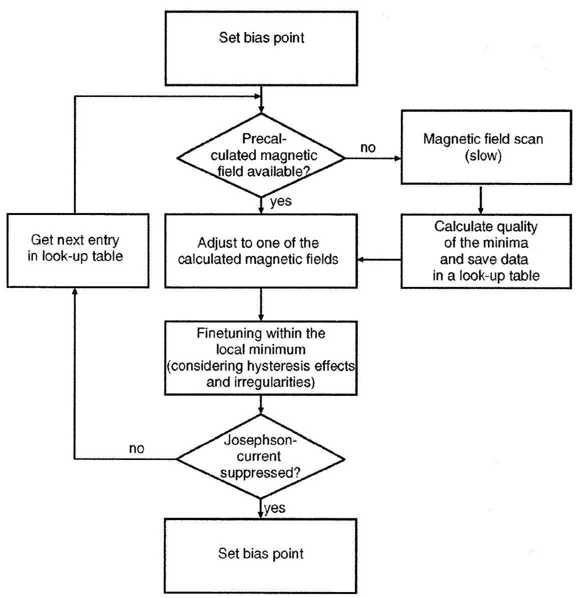
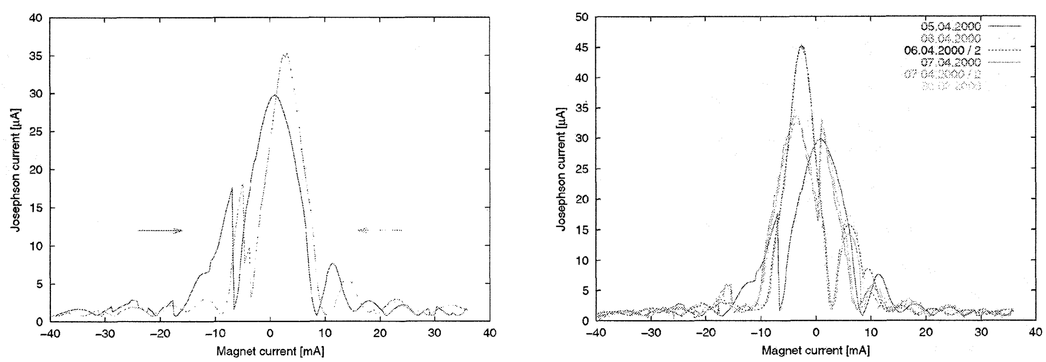


Figure 6: *Flow diagram of the tuning algorithm to tune bias voltage and magnetic field current.*

Figure 6 shows a flow diagram of the algorithm to tune the bias voltage and magnetic field for one receiver channel. In order to minimize the receiver temperature the noise caused by the Josephson current has to be measured. This is done by scanning the conversion curve near the Shapiro step. So, initially, the bias point has to be set to that special voltage.

After that the optimum magnetic field strength to suppress the Josephson current has to be found. In general, a look-up table will provide a few rough estimates of suitable magnetic field coil currents. In this case a finetuning algorithm will optimize the current locally. If no table is available, or the values in the table are not good enough, a complete magnetic field scan is taken.

For tuning reasons the bias point was set near to the Shapiro step, where the conversion reacts very sensitively to a mistuned magnetic field. The optimum bias point for astronomical measurements is more robust and can be chosen from tabulated values.



(a) Two magnetic field scans in different directions. A shift is visible which occurs due to the hysteresis of the field coil's iron core.

(b) Magnetic field scans measured on different days. There are remarkable changes so a tuning algorithm based on lookup tables can not be used.

Figure 7: *Hysteresis and statistical effects of the magnetic field scans.*

4.1 SETTING THE MAGNETIC FIELD

The main problem when tuning the receiver, is the setting of the magnetic field, which suppresses the Josephson noise, since the field required is not always reproducible due to external and statistical effects. Therefore magnetic fields can not be tuned by using a look up table. The correct magnetic field strength has to be calculated by measuring the IV-curve or the conversion curve.

As can be seen in figure 7 there are several kinds of disturbances (e.g. frozen flux, hysteresis) which have to be managed to find the optimum magnetic field current. First of all, hysteresis of the magnetic field leads to a shift between scans in different directions (Figure 7a). Changes in the magnetic environment may change the required field in a non-predictable way (Figure 7b).

To set the magnetic field to its optimum value the noise contribution by the Josephson current has to be estimated very precisely. This can be performed either by measuring the Josephson current on the IV-curve or the excess noise on the conversion curve. Using the conversion curve gives more precise information so this method is used for tuning.

The measured magnetic field scans are evaluated automatically in order to get the optimum magnetic fields for the junction. This is done by an algorithm which searches for minima and maxima separately (see Figure 8) and classifies the minima according to their expected usefulness in order to establish a new look-up table as input for the finetune algorithm.

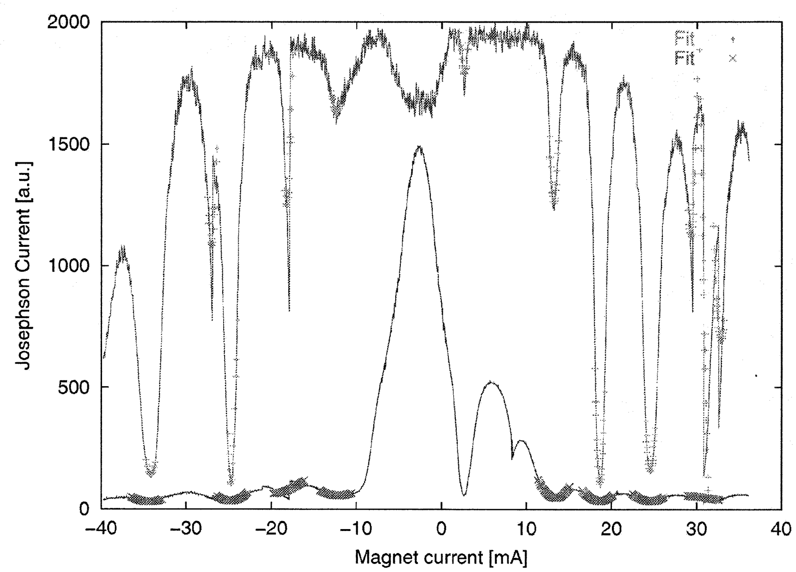


Figure 8: *Magnetic field scans. Outlined are the fitted minima. The Josephson noise was measured via the Josephson current in the IV-curve (blue line) or the excess noise on the conversion curve (red line). The algorithm finds minima in both cases.*

4.2 CALIBRATION OF THE BIAS VOLTAGE SCALE

To compute the proper bias point, first the IV-curve with maximum magnetic field is recorded. The gap voltage is derived to provide a preliminary scaling of the IV-curve. Now the shapiro step on the IV-curve without any applied magnetic field is determined. This yields a very accurate calibration of the voltage scale, which is required to set accurate bias points.

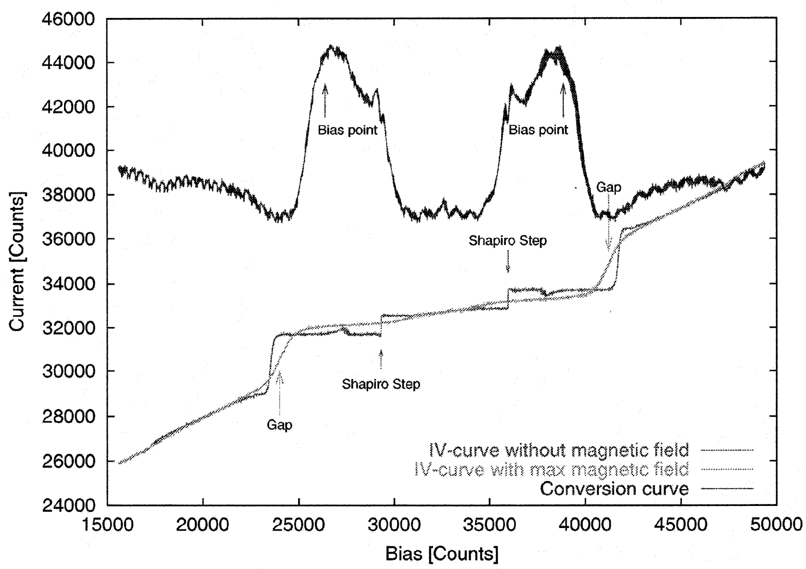


Figure 9: *Gap voltage and bias point derived from IV-curve with high magnetic field and without. The conversion curve is shown to demonstrate the bias point.*

5 PERFORMANCE

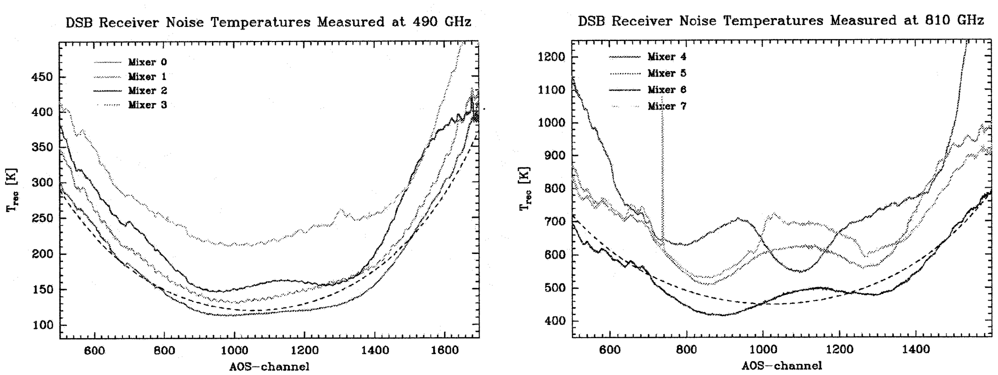
The noise temperature measurements shown in figure 10 where made at the KOSMA telescope with two 4 channel array acusto-optical spectrometers. Since we have no sideband filter in the array all temperatures are double sideband temperatures. The central part of the IF-band reaches DSB noise temperatures of 150 K to 250 K for the 490 GHz and 500 K to 700 K for the 810 GHz frequency band.

6 FUTURE PROJECTS

The immediate project is to expand the electronics and successively the software to tune and operate 16 instead of 8 receiver channels. This is no basic problem because, except for the local oscillator setting, all individual channels are treated as single SIS receivers.

Another step is to adapt the software to control future receivers such as STAR (SOFIA Terahertz Array Receiver) on SOFIA and possibly upcoming space missions, where manual tuning is impossible.

Implementation of an automated diplexer and LO-tuning will be part of a future project as well. Then LO pump levels can be tuned by the control PC.



(a) 490GHz **(b)** 810GHz

Figure 10: *Measurement of the receiver noise temperature of the 490 GHz and the 810 GHz channels. The IF center frequency in both measurements is 1.5 GHz (AOS channel 1100) with 1 GHz nominal bandwidth (approx. 1000 AOS channels). The dashed line indicates the noise temperature function caused by the sinusoidal diplexer transmission assuming a 120 K (490 GHz) / 450 K (810 GHz) receiver.*

7 CONCLUSION

We developed the control electronics and algorithms to automatically tune an SIS receiver array. We also performed the first laboratory and astronomical measurements[7] which show high performance in terms of sensitivity and usability.

ACKNOWLEDGMENTS

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References

[1] U. U. Graf, S. Heyminck, E. A. Michael, S. Stanko, C. E. Honingh, K. Jacobs, J. Stutzki SMART: The KOSMA Sub-Millimeter Array Receiver for Two Frequencies.. in Proceedings of the 13th International Symposium on Space Terahertz Technology, Cambridge, Massachusetts, 2002.

[2] C. G. Degiacomi, R. Schieder, J. Stutzki, and G. Winnewisser. The KOSMA 3m submm telescope. in Optical Engineering 34(9), 1995.

[3] U. U. Graf, and S. Heyminck. Fourier Gratings as Submillimeter Beam Splitters. in IEEE Transactions on Antenna and Propagation, Vol. 49, No. 4, April 2001.

[4] D. Rabanus, et. al.. Techniques for Heterodyne Array Receivers. in USRA/NASA Det. Tech. Workshop, Monterey, Apr. 2002, in print.

[5] U. U. Graf, S. Heyminck, E. A. Michael, and S. Stanko. KOSMA's 490/810 GHz Array Receiver. in Proceedings of the 12th International Symposium on Space Terahertz Technology, San Diego, California, 2001.

[6] R. Schieder et al. The Cologne Acousto Optical Spectrometers. Experimental Astronomy Vol I, 1989.

[7] B. Mookerjea, C. Kramer, and J. Stutzki. Multiline study of star forming regions. Galactic Star Formation Across the Stellar Mass Spectrum Workshop, LaSerena, 2002.