Spectrometers for (sub)mm radiometer applications

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***Abstract*— The autocorrelation spectrometer is one of 5 types of spectrometers being considered for space based (sub)millimetre heterodyne systems. The advantages of the digital autocorrelation spectrometer compared to Chirp Transform, Acousto Optical and Filterbank spectrometers are; stability, compactness, high reliability and variability in bandwidth and resolution. FFT spectrometers based on the latest generation of FPGA devices now promise a cost effective alternative for low to medium bandwidth applications with high resolution requirements.**

Omnisys has designed and implemented several generations of autocorrelation chip sets and spectrometers. This range from the ODIN satellite spectrometers now in LEO to our current 8 GHz single chip spectrometer under development.

The ODIN chip set was a breakthrough at the time (1998). The power consumption was lowered by a factor of 50 compared to state of the art. Since then we have further improved the power consumption with a factor of 40, and we are now reaching 8 GHz of bandwidth for a single spectrometer chip.

***Index Terms*—Spectrometer, Radiometer, Correlator, FFT.**

I. Introduction

THE autocorrelation spectrometer is one of 5 types of spectrometers being considered for space based (sub)millimetre heterodyne systems. The advantages of the digital autocorrelation spectrometer compared to Chirp Transform, Acousto Optical and Filterbank spectrometers are; stability, compactness, high reliability and variability in bandwidth and resolution. FFT spectrometers based on the latest generation of FPGA devices now promise a cost effective alternative for low to medium bandwidth applications with high resolution requirements.

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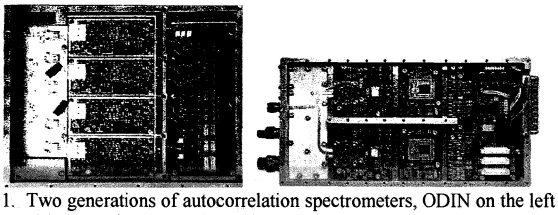

Fig. 1. Two generations of autocorrelation spectrometers, ODIN on the left and IntRad on the right.

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Omnisys has now a preliminary design of a single chip spectrometer with 8 GHz bandwidth and 1024 channel resolution, backed by simulation based on extracted parasitics. Tape-out for spectrometer chip is planned for June 2006 with devices available for commercial use 6-9 months later. This spectrometer can be configured for operation with 64, 128, 256, 512 and 1024 channels. The maximum power consumption with 1024 channels at 8 GHz is estimated to be 2.8 W and with 64 channels, we will have a power consumption of about 0.5 W.

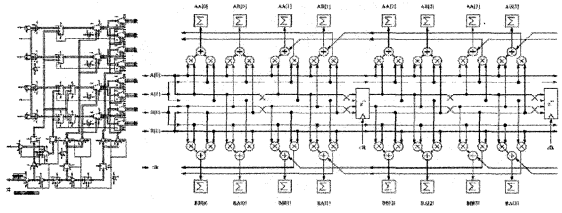

Fig. 1. Schematics of the single chip spectrometer. On the left is the bipolar digitiser and on the right, the CMOS correlator part.

Omnisys has also developed an FFT spectrometer for ground based applications. It follows the single Eurocard standard size and provides up to 2 GHz bandwidth and 1-4 inputs. With four inputs, the maximum processed bandwidth is 500 MHz. Two spectrometer boards will be delivered to customers during Q1 and Q2 of 2006, one for aeronomy and one for radio astronomy. The price starts at 20 000 Euro per board.

II. Autocorrelation Spectrometers

Omnisys development of autocorrelation spectrometers since 1992 has focused on minimising power consumption and mass to make them compatible with satellite operation. For ODIN, the power consumption was reduced with a factor of 49 compared to state of the art another factor of 100 is expected for the current generation. The processed bandwidth has increased from 20 MHz up to 8000 MHz in the same period.

A. ODIN

The ODIN spectrometers were developed and produced during 1996-1999 and being operated successfully on ODIN

since 2001. The main specifications are; 100-800 MHz bandwid th, 896 channels, 18 W, 1 kg.

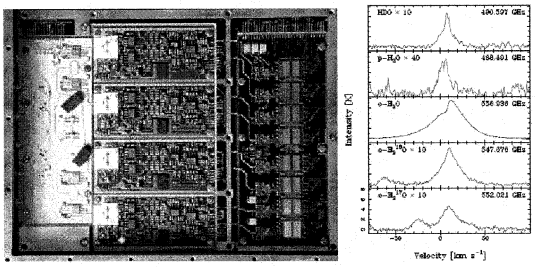

Fig. 3. The ODIN autocorrelator spectrometer and spectra obtained from space.

B. TELIS

The TELIS generation of spectrometers were developed and produced during 2000-2002 and will be operated on the TELIS balloon platform. The chip set was developed as demonstrators under an ESA contract, motivated by missions such as HIFI/HERSCHEL and MASTER.

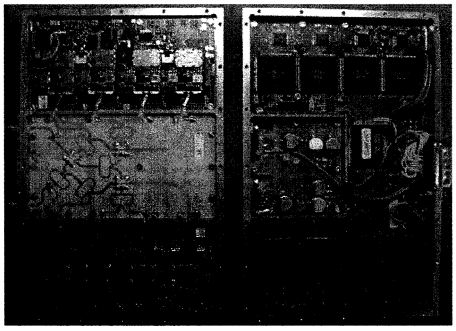

Fig. 4. The TELIS generation of spectrometers.

The main specifications are;

- 2x2 GHz bandwidth
- 2x1024 channels
- 2-4 GHz Input
- 22 W
- 1.1 kg
- 100 k Euro

C. INTRAD

The INTRAD generation of spectrometers were developed and produced during 2001-2003 and was demonstrated in a 300-380 GHz integrated 1 kg / 10 W radiometer in 2003. The chip set was developed as demonstrators under an ESA contract, motivated by missions such as Mambo. The main specifications are;

- 1x4 GHz bandwidth
- 1x4096 channels
- 4-8 GHz Input
- 10 W
- 493 grams

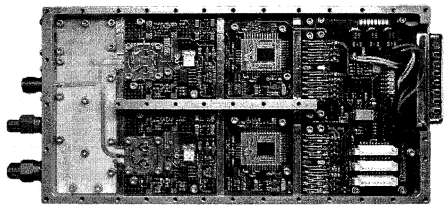

Fig. 5. IntRad spectrometer.

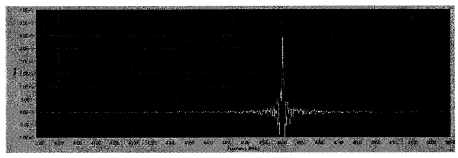

Fig. 6. Spectrum at 320 GHz input CW signal.

III. SINGLE CHIP AUTOCORRELATION SPECTROMETER

Based on the demonstration chip sets and production based single chip spectrometer is under realization. Tape out is planned for june-2006. The single chip spectrometer will be implemented in IBM 7WL 0.18 um BiCMOS process.

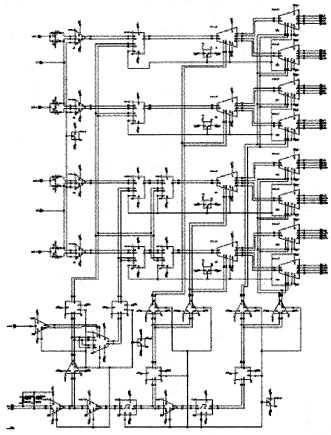

Fig. 7. Bipolar digitiser schematics.

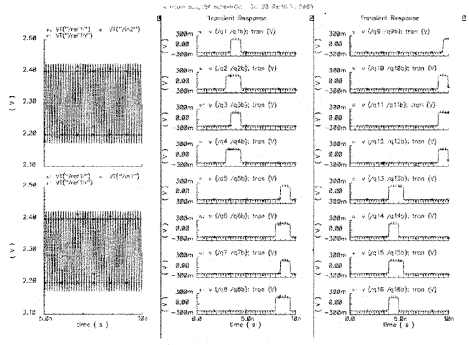

Fig. 8. Simulation at 7.9 GHz CW input signal.

The digitiser/ADC is a 100% bipolar design as this is required to make the analog part compatible with autocorrelation spectrometer requirements, in respect to sampling jitter, gain and bandwidth, analog comparator accuracy etc.

The correlation signal processing is implemented in CMOS, the technology of choice for fast, high density digital circuits today. The current design is scalable to 20 GHz bandwidth and beyond within a few years time.

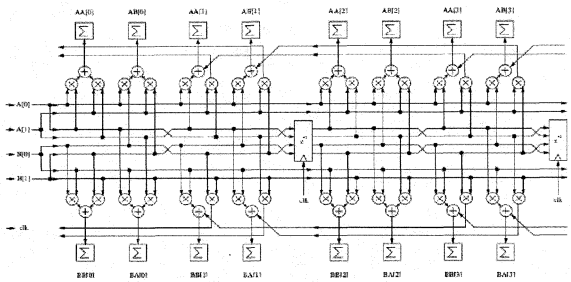

Fig. 9. Correlator block diagram.

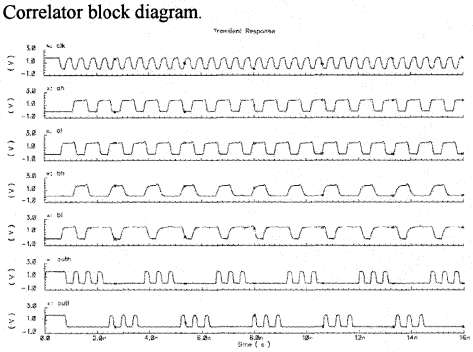

Fig.10. Simulation at 17.2 GHz effective sampling rate.

The chip will be directly compatible with the requirements for instruments and missions such as STEAM, CIWSIR and MASTER/MARSCHAL. In addition, it also suits interplanetary radiometers such as Mambo, making complete radiometers realistic with mass and power budgets compatible with such missions, i.e. < 1 kg, < 10 W.

- 0.1-8 GHz bandwidth
- 64-1024 channels
- 0.5-2.8 W
- 30 kRAD

IV. FFT SPECTROMETER

Not all radiometer spectrometers operate in the space environment with very hard restrictions in power consumption and mass in combination with radiation tolerance etc.

Omnisys has developed an FFT type of spectrometer compatible with ground based operation with emphasis on flexibility and cost effective design solutions. One spectrometer has been delivered in February 2006 and tested with the instrument and the second one will be shipped in May 2006. The board support up to 2x1000 & 4x500 MHz operation, Stokes parameter processing, and more that 32 k channels of resolution. Price will start at 20kEuro.

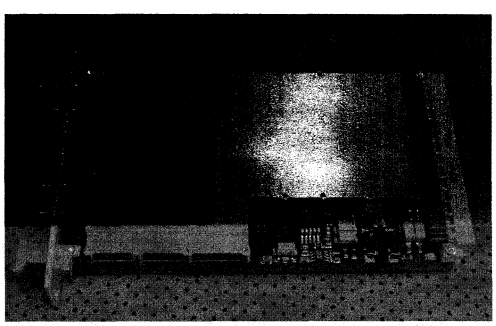

Fig. 11. FFT spectrometer board. 100x160 mm with 96-pin Euroconnector.

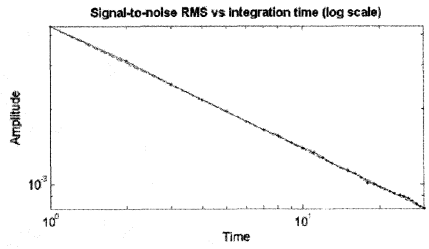

Fig. 12. SNR as a function of integration time.

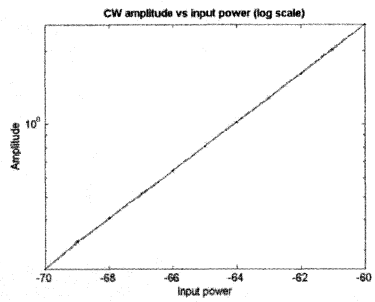

Fig. 13. Linearity over 10 dB.

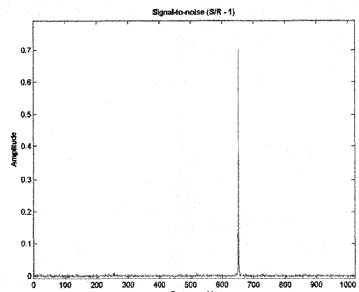

Fig. 14. Signal minus reference with noise + CW signal. (BW:500 MHz).

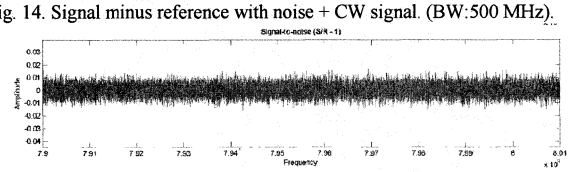

Fig. 15. Signal minus reference with noise.

V. CONCLUSION

Omnisys has developed several generations of autocorrelation spectrometers. The ODIN spectrometers have now started the 6th year of successful operation in orbit, while the generation that is scheduled for tape out in June 2006 promise to deliver up to 8 GHz of processed bandwidth with 1024 channels. The power budget is between 0.8-2.8 W depending on clock speed and configuration.

Omnisys has also developed an FFT spectrometer platform that can be used to realise highly flexible solutions providing up to 2 GHz bandwidth and more that 32k channels. Variable resolution, polarisation processing etc will be supported and it is available for shipping in Q3 2006.

ACKNOWLEDGMENT

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