THE COMPUTER-CONTROLLED SOLAR RADIO SPECTROMETER „IKARUS“

(Report from a Solar Institute)

M.R. PERRENOUD
Institute of Astronomy, ETH Zurich, Switzerland

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Abstract

The radiospectrometer IKARUS is a fully computer-controlled instrument covering the frequency band 0.11 to 1 GHz in steps of 1 MHz. It can automatically detect solar radio bursts and then write, on magnetic tape, 2000 measurements per second of intensity and circular polarization. The frequencies to be measured can be readily programmed in the band, compromising between frequency and time resolution. Reference noise sources are switched in automatically by the computer to calibrate the receiver at each frequency. The dynamic range is about 50 dB, recorded logarithmically with 8 bit resolution.

The novelty of the instrument is its ability to measure broadband calibrated spectra (flux and degree of polarization) in the very interesting region of the lower corona.

1 Introduction

The Radio Astronomy Group[1] of the Institute of Astronomy[2] at the Federal Institute of Technology in Zurich, Switzerland has been involved in radio astronomy for more than 10 years. Since 1972, an analog recording spectrograph, „DAEDALUS“[3], has been in use and, in 1974, the first version of the computer-controlled radiospectrometer „IKARUS“ came into operation. The first observation site was in Zurich, the second was at Dürnten, about 30 km east of Zurich. In 1979, the instruments found their final site at Bleien, about 50 km west of Zurich, a location chosen for its low level of manmade interference (Figure 1). In the meantime, „IKARUS“ has been developed to become a powerful

[1] http://mimas.ethz.ch
[2] http://mimas.ethz.ch/astronomy.html
[3] http://mimas.ethz.ch/papers/others/DAEDALUS/daedalus.html

instrument because of its flexibility, wide frequency coverage, and its ability to give calibrated spectra. The purpose of this paper is to present a description of the instrument and its capabilities.

2 The Antenna and Its Steering

The system is fed from a parabolic reflector of diameter 7 m and focal ratio 0.34. It is azimuthally mounted and its position is measured with 11 bit absolute anglecoders (LSB = 0.18 deg.). Antenna steering is in positional steps of one minute of time generated by the computer. These steps are small (0.25 deg.) compared to the beam width at 1 GHz (3.6 deg.). The slewing of the antenna is about 20 deg. per minute.

3 Feed and Front-end

A crossed log-periodic feed is mounted at the primary focus, covering 0.11 to 1.0 GHz with a gain of about 7 dB. This, as we shall see later, is not critical as the calibration procedure corrects for gain variation from one frequency to another. A temperature controlled package is mounted close to the feed and contains a 90°-hybrid to produce a left- and right-circularly polarized signal. A PIN-diode switch selects between the polarizations and three reference noise sources for calibration. A high-pass filter, with a cutoff frequency of 110 MHz, and a preamplifier, with a noise figure of about 5 dB, complete the focus package.

4 The Receiver

Through a low-loss cable, the signal is sent to the receiver located 35 m from the antenna. Figure 2 shows a schematic drawing of the signal path through the focus package and the receiver. A PIN-diode switch selects between the preamplified signal and frequency calibration signals, at the input to the receiver. A second broadband preamplifier follows. The signal is then up-converted to X-band. Frequency selection is performed by tuning the local oscillator, a YIG-oscillator, over a range of 1 GHz. A narrow bandpass filter eliminates the second sideband. The signal is then down-converted to the final IF of 70 MHz. After further amplification and a 1 MHz passband filter, the signal is detected by a logarithmic IF-amplifier.

5 Integration and Digitization

One measurement at a given frequency lasts 500 μs and so 2000 such measurements can be taken per second. The first 100 μs are used to stabilize the

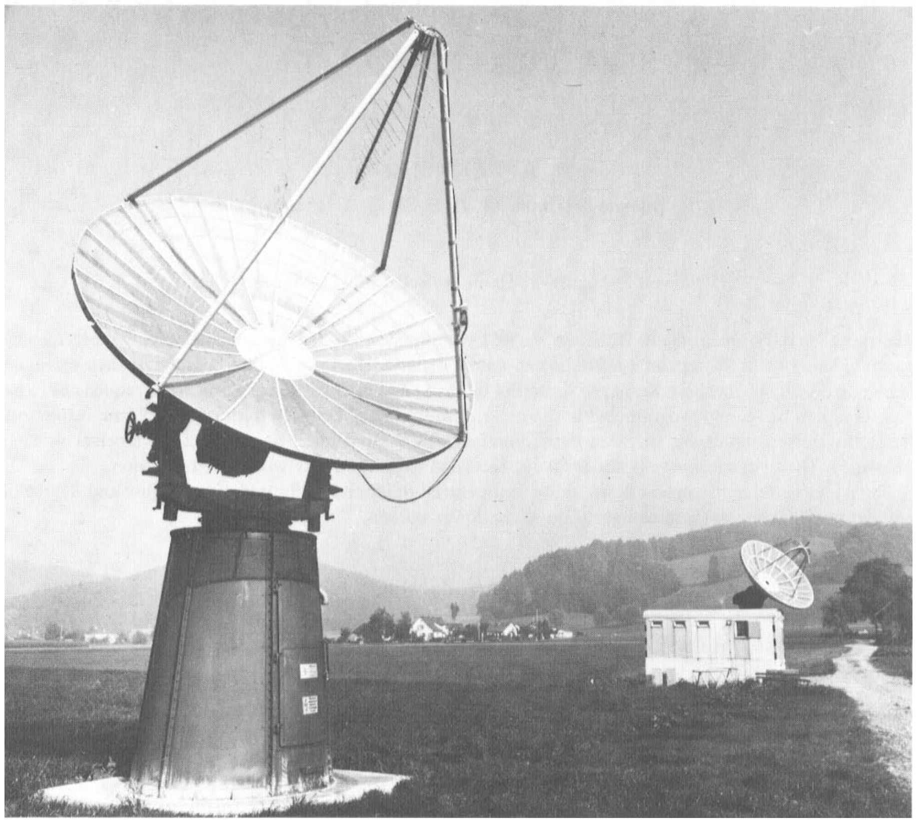

Figure 1: The radio observatory at Bleien. The 5 m „DAEDALUS“ dish is shown in the foreground. The 7 m „IKARUS“ dish is located behind the trailer with the computer and the receivers.

YIG-oscillator at each new frequency. The remaining 400 μs are divided into two equal parts for the measurement at two positions of the PIN-diode switch in the focus package. Two analog integrators sample the sum and the difference of these two signals. In this way, several different measurements can be obtained, as follows:

- switching between the two circularly polarized signals gives measurements of intensity and of degree of polarization;

- switching between an antenna port and a noise source gives a Dicke-type measurement.

Digitization of the signals into two 8-bit-words takes place during the first 50 μs of the next measurement cycle.

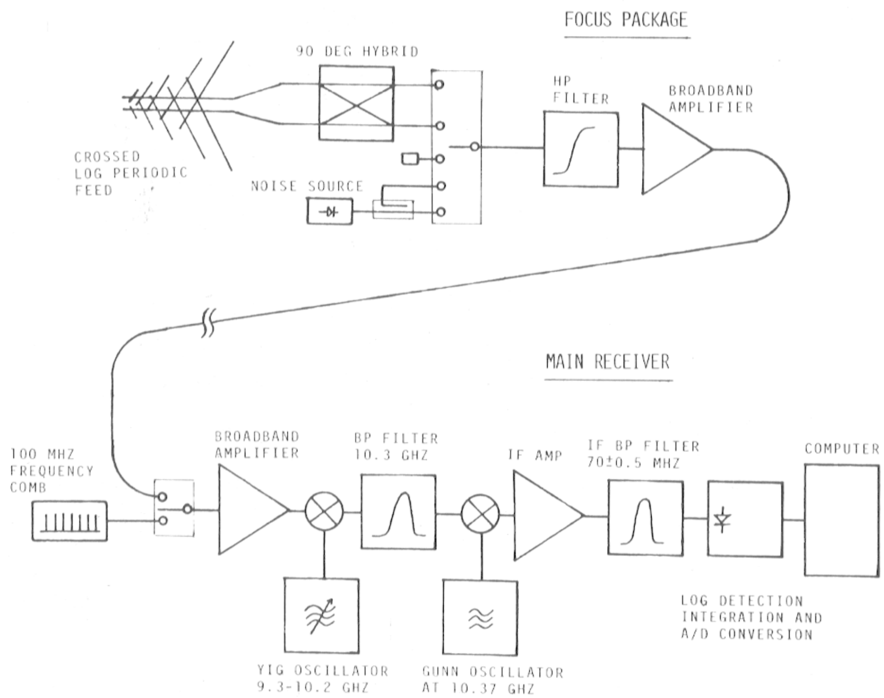

Figure 2: Schematic of the IKARUS system.

6 The Computer and Its Software

The whole system is under the control of an HP-2100 computer. All software has been written in assembler to keep up with the high data rate. The system is fully automatic with powerfail restart and preprogrammed observations to last for several weeks. A change of the program of observation can be made at any time either directly, at a console, or by telephone and modem. Each 10 min interval of a day can be programmed independently regarding antenna position, sequence of frequencies to be measured and mode of recording on magnetic tape.

The above mentioned sequence of frequencies is actually a list of up to 500 frequencies, independently selectable within the receiver band of 0.11 to 1 GHz, also containing a code for the sequence of the two switch positions for each frequency. Up to 4 such lists are stored in the computer.

Before the data are stored on magnetic tape, they are differently treated, depending on the programmed mode. The main modes are digital integration, mostly used with Dicke-type measurements, and burst recognition mode. Here the data is only recorded if the computer detects typical signs of solar burst. The tested features are:

- bandwidth;
- growth of intensity with time;
- duration of the event.

The criteria for the detection of a burst are included in the list of frequencies, because the type of burst and the observed frequencies are, of course, closely related.

7 Calibration of the System

For calibration we have to distinguish between slower and faster changing components. In our system we have three typical calibration modes with typical times:

- The antenna and the 90 deg. hybrid are assumed to change their properties very slowly because they are passive components. They are calibrated only once or twice per year.
- The chain of amplifiers is much more variable and so the receiver noise temperature, gain and logarithmic compression are measured every few hours for all frequencies by switching to the reference noise sources. The measurements are then integrated digitally and stored on magnetic tape for later processing.
- The most sensitive device is the detector. Small temperature changes can cause quite large errors. This is checked, therefore, several times per second by measuring one frequency in every frequency list at a reference noise source. This results in a slow switching Dicke-like measurement for the normal observations of intensity and polarization.

The antenna calibration is the largest source of inaccuracy. Our antennas are not large enough to give good results on Cassiopeia-A. So the quiet Sun is used as a reference source. We assume this to be unpolarized and average and interpolate between all available data of fixed frequency solar radiotelescopes. We take integrated Dicke measurements at all frequencies for the Sun and for a reference spot in the sky several times per year; from these the best and the „quietest“ measurements are selected for the antenna calibration.

Figure 3 gives an idealized impression of the accuracy of the calibration. Curve 1 shows the variations of the different single frequency observations used to determine the flux of the quiet Sun. Curve 2 gives the differences between several antenna calibration measurements at different times and days. Curve 3 shows the fluctuations of the same data, if they are calibrated with noise source reference measurements taken at different times and days. All curves are peak-to-peak.

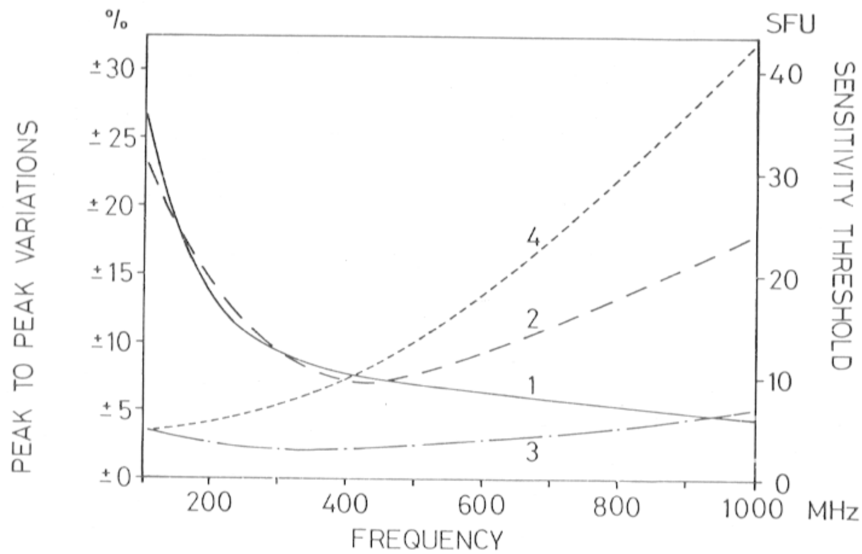

Figure 3: Schematic representation of the accuracy of calibration. Curve 1: Variation between published results from different stations measuring the quiet Sun. Curve 2: Differences between measurements of the quiet Sun at different times and days with IKARUS. Curve 3: Variations of calibrated values, if the same measurement is calibrated with noise source reference measurements at different times and different days. Curve 4: Sensitivity threshold (3σ) above the quiet Sun for digital non-integrated data.

To clarify this let us consider the feasibility of using Cass-A as a reference source. In this case curve 1 would be displaced upwards because the antenna beam-width ranges from 3.6 to 36 degrees (HPBW). Even at 1 GHz the beam-width of 3.6 degrees would not allow us to separate the intensity contributions of Cass-A and the galactic background to 5%. Similarly curve 2 would be displaced upwards because the signal (due to Cass-A) would be much weaker.

Curve 4 indicates the 3σ sensitivity threshold above the quiet Sun for digital non-integrated data, were σ is the standard deviation.

Polarisation measurements are very noisy as they are based upon the difference of two measurements, each of 200 μs duration. Therefore, they must always be integrated over several frequencies or sweeps.

Comparison of our observations with single frequency measurements made at 240 MHz in Trieste (Italy) indicate intensities within $\pm5\%$ of one another and polarisation within $\pm10\%$.

Besides the intensity calibration, we also need a frequency calibration because a YIG-oscillator is not very stable. In each run through the frequency list, therefore, the computer switches the receiver for a few measurements to the frequency comb and checks the measured position of the comb. The computer then adjusts the receiver if necessary.

8 Data Analysis

The data reduction takes place at the computer center of the Federal Institute of Technology in Zurich (a CDC-System with a Cyber, a 6500 and a 6400 CPU). Standard programs, such as calibration of the data into Solar Flux Units, frequency and time profile plots have been developed, as well as more specialized programs, for example, Fourier transformation or analysis of typical burst features, such as drift, spectrum of the burst maximum and energy spectrum. For further details see (Perrenoud, 1981).

Several papers, based upon observational data taken with this system have already been published, for example: Bernold (1980), Trottet *et al.* (1981), Benz and Treumann *et al.* (1982b), Benz and Zlobec *et al.* (1982a). A typical record of several type III bursts is shown in Figure 4.

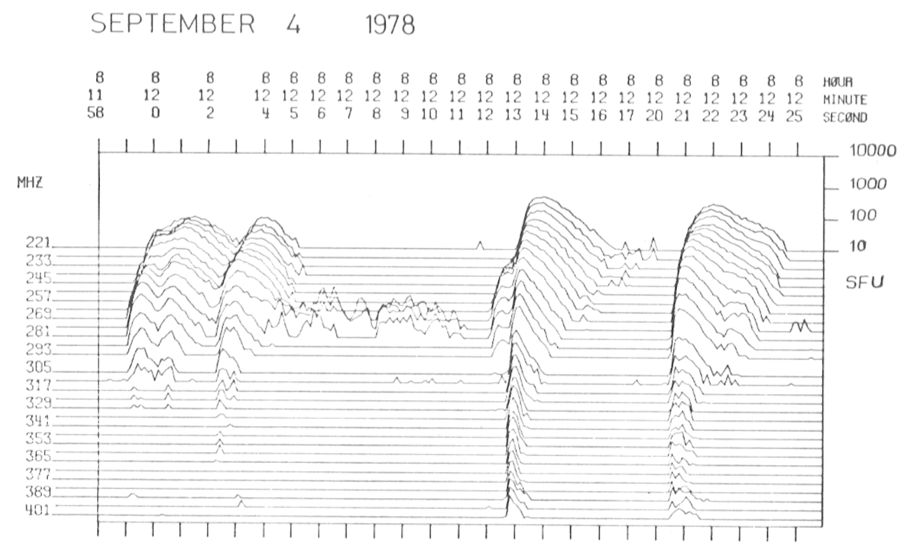

Figure 4: A typical record of several type III bursts.

9 Future Developments

By 1983, the frequency range of the receiver will be expanded from 1 to 3 GHz. At the same time, the YIG-oscillator will be replaced by a newly developed X-band synthesizer, covering 1 GHz in steps of 1 MHz with a switching time of a few microseconds. The expansion to 3 GHz will be achieved by using 3 IF-frequencies in X-band. The final IF-bandwidth will be selectable between 1, 3, and 10 MHz, programmable for each frequency.

Also, the data reduction possibilities will be greatly enhanced in the future. In 1981, our institute has received a VAX computer system and a De Anza 8500 color-image processing system has been ordered. This will enable us to handle the enormous dataflow from our instruments very efficiently.

10 Other Instruments at the Site

The oldest instrument is an analog recording spectrograph known as Daedalus which has been in operation since 1972. The receiver is very similar to the previously described Ikarus receiver, but it is not computer-controlled (except for the antenna steering of its own 5 m dish, which is controlled together with the 7 m dish). The whole band, of 0.1 to 1 GHz, is swept four times per second and the measured intensity recorded continuously on film. This allows solar activity to be monitored and also indicates interesting events which can be studied in greater detail with the more sophisticated Ikarus system (Tarnstrom, 1973, cf also).

An acousto-optic spectrograph is under construction and this should come into operation in about 1983. It will cover 150 MHz with a resolution of 150 KHz. The center frequency can be chosen anywhere between 0.1 and 2 GHz. The dynamic range is expected to be around 30 dB, logarithmically compressed and digitized to 8 bits. The data rate will be 5×10^6 per second, but a programmable data reduction processor will reduce it to about 2×10^5 bytes s^{-1} before recording on magnetic tape. This system will be used to study all types of fine structures, fast drifts in solar bursts as well as for non-solar observations.

Acknowledgements

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References

Benz, A. O., Treumann, R., Vilmer, N., Mangeney, A., Pick, M., and Raoult, A., 1982a, *A&A* **108**, 161

Benz, A. O., Zlobec, P., and Jaeggi, M., 1982b, *A&A* **109**, 305

Bernold, T., 1980, *A&A* **42**, 43

Perrenoud, M., 1981, *Ph.D. thesis*, Swiss Federal Institute of Technology, Zurich, In German

Tarnstrom, G. L., 1973, *Astr. Mitteil. der Eidg. Sternw. Zürich* **317**, 1, http://mimas.ethz.ch/papers/others/daedalus/daedalus.html

Trottet, G., Kerdraon, A., Benz, A. O., and Treumann, R., 1981, *A&A* **93**, 129