
ABSTRACTS (PH D THESIS)

Study on miniaturization of plasma wave measurement system

(Graduate School of Engineering, Laboratory of Space Electromagnetic Environment
Exploration, RISH, Kyoto University)

Takahiro Zushi

Interplanetary space is filled with plasma, mostly generated by the solar wind. In the near-Earth region, the Earth's magnetosphere is formed by the interaction of the geomagnetic field and the solar wind. The magnetosphere is divided into several regions depending on the characteristics of the plasma and the various phenomena occurring in each of these regions. In addition, the magnetosphere experiences the phenomenon of magnetic storms, in which disturbances are caused by the Sun throughout these regions. Magnetic storms have various influences on the whole magnetosphere. Although these characteristics and various phenomena in the Earth's magnetosphere are well understood, there are many unexplained phenomena. For this reason, observations of the space electromagnetic environment are still being made by satellites.

Since the kinetic energy of the collisionless space plasma is exchanged through plasma waves, observations of plasma waves are important for understanding the behavior of space plasma. Hence, plasma wave instruments are essential for exploring the space electromagnetic environment and magnetospheric exploration satellites carry plasma wave instruments. Plasma wave instruments necessarily include large electric circuits because they require wide frequency range, high gain, and low noise analog circuits and digital signal processors for onboard calculations. The present thesis focuses on the miniaturization of plasma wave instruments. Science missions are restricted by limitations on resources in spacecraft. Thus, miniaturization allows plasma wave instruments to be included on new scientific missions and can be expected to lead to new discoveries.

For miniaturization of plasma wave receivers, application-specific integrated circuits (ASICs) are used in this study. An ASIC is an integrated circuit specialized for a particular use. A full custom design is used for developing analog ASICs and a standard cell design is used for digital ASICs.

In the present study, an ASIC for a waveform capture (WFC) receiver is developed, which improves on three points that are unsatisfactory in conventional ASICs: a high offset voltage in the main amplifier, high harmonic distortion in the switched capacitor (SC) filter, and narrow input/output range over the circuit. The main amplifier often has a high offset voltage for a gain setting of 20 dB or 40 dB. To address this problem, an offset adjustment circuit is added. An SC filter is used as an anti-aliasing filter in a WFC receiver. SC filters exhibit high harmonic distortion due to charge injection effects. The harmonic distortion of the SC filter is reduced by the following three improvements: increasing the capacitance, changing the switching sequence, and changing the transfer function. To narrow the dynamic range of the ASIC, a rail-to-rail opamp. is designed. Finally, rail-to-rail of the whole WFC receiver is realized by replacing the Gm-C filters.

The application of an ASIC for a WFC receiver, plasma wave instruments on board a sounding rocket, and a small sensor probe for multiple point observations are developed. SS-520-3 is a sounding rocket experiment for clarifying the ion outflow phenomenon in the polar cusp region. In order to measure wave-particle interactions, which are considered the primary mechanism of the ion acceleration, a plasma wave instrument called the low frequency analyzer system (LFAS) is installed in the rocket. The LFAS has two receivers for electric sensors, and pre-amplifiers. In addition, LFAS has a circuit for software-type wave-particle interaction analyzer calculations that allows the measurement of waveforms and plasma particles synchronously with high time resolution.

Since conventional one-point observations of plasma phenomena in space cannot distinguish between time and spatial variations, missions based on multiple-point observations have become the trend. A new system for multiple-point observations, referred to as the monitor system for space electromagnetic environments (MSEE), is proposed. The MSEE consists of small sensor probes that can measure

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electromagnetic waves and transfer received data to a central station through wireless communication. A prototype model of the MSEE sensor probe is developed. The sensor probe includes a plasma wave receiver, microcontroller, wireless communication module, and battery in a 75-mm cubic housing. In addition, loop antennas, dipole antennas, and actuators to expand the dipole antennas are attached on the housing. The total mass of the sensor probe is 692 g and the total power consumption is 462 mW. In the function test, it was found that the analog components had sufficient characteristics to measure electric fields, and the A/D conversion and wireless transmission worked correctly. For the whole performance in an electric field, the sensor probe had an equivalent noise level of -135 dBV/m/sqrt(Hz).

Recent scientific satellites have carried fast Fourier transform (FFT)-based spectrum receivers. However, such receivers have a disadvantage in that they use a wideband analogue component. A new receiver which overcomes this disadvantage of previous receivers is proposed. The new receiver includes band-limiting in the first stage of the analogue component, and it covers the entire observation frequency range of each band by switching its cutoff frequency. To miniaturize the circuit size, the new receiver uses an ASIC and a field-programmable gate array (FPGA). The ASIC chip includes the analogue component of the receiver and the analogue-to-digital converter, and the FPGA includes an FFT module and the controller of the receiver. The proposed spectrum receiver was successfully implemented with a size of 55 mm x 80 mm x 35 mm and a total power consumption of 948.3 mW. The time resolution of the receiver was 112 ms, and the frequency resolutions for frequency bands 10 Hz to 1 kHz, 1 kHz to 10 kHz, and 10 kHz to 100 kHz were 13 Hz, 130 Hz, and 1.3 kHz, respectively.

In conclusion for the present thesis, the miniaturization of the plasma wave observation systems was achieved successfully.

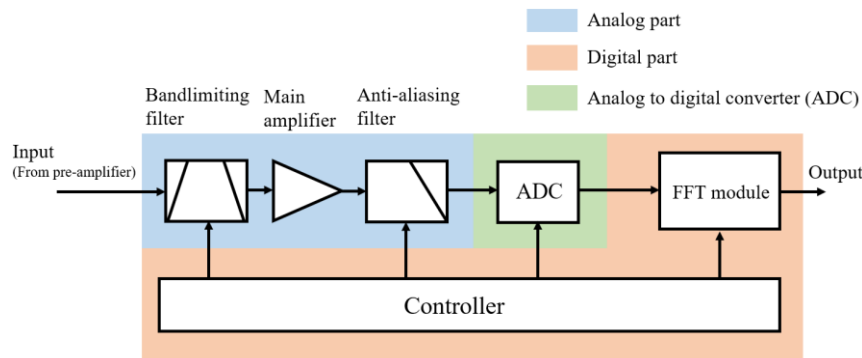


Figure 1. Block diagram of the new type of the spectrum receiver.

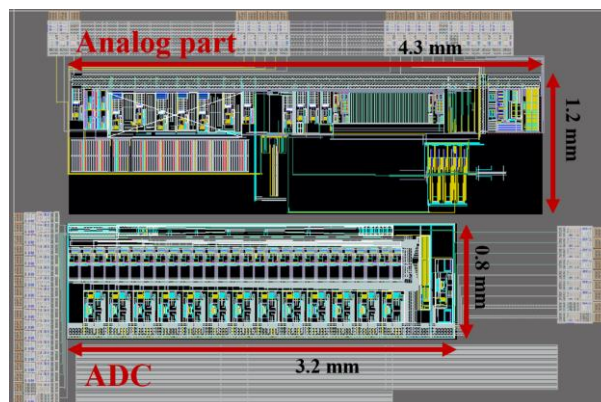


Figure 2. Chip layout of the new type of the spectrum receiver.