Investigations on Digitizing Front-Ends for Wide-Span, Low-Magnitude Current-Output Sensor Probes in Space Plasma Diagnostics

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by

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Abstract

Enhanced digitizer schemes for current-output sensors (COS) in space applications are described in this report. These schemes were designed to interface sensors with a wide output range spanning sub-microampere current magnitudes. The design and development of these schemes were carried out with a special focus on Retarding Potential Analyzers (RPA) and Langmuir Probes (LP), used to study the space plasma. The schemes feature a wide measurement range with minimal and controlled effects of error, faster conversion times, offset error correction and cost-effectiveness. The primary motive of this study was to minimize the effects of analog-to-digital converter (ADC) quantization noise (q_E), a source of error predominant in wide-range current measurement circuits. This report discusses four proposed schemes to address various problems in the conventional current measurement techniques for use in spacecraft-mounted plasma diagnostic probes. A brief idea of the four schemes is provided below.

The first scheme, the digitizer for low-current measurement (D-LCM) technique, provides a digital output proportional to the sensed current, with reduced effects of q_E. In addition, the proposed D-LCM technique ensures the following features: simple and cost-effective architecture for COS, bidirectional current sensing over a large span using a unipolar ADC and reduced effects of various error sources such as q_E and offset errors due to circuit non-linearities. The novel D-LCM design, comprising a transimpedance amplifier and a multi-regime integrator, helps to realize the above features. The gain of analog circuit is intelligently controlled by a simple digital unit such that the input span is split and operated in multiple regimes. This splitting is done using the geometric mean of the upper and lower limits of the input range. The entire methodology and its circuit realization are mathematically derived, and its capability to reduce the effects of q_E is discussed. Detailed evaluation of other error sources and necessary compensation/design guidelines are also elaborated.

The second scheme describes a low-cost integrator-based programmable-gain digitizer for current output sensors. The circuit features a transimpedance amplifier as the front-end followed by a programmable gain integrator. The scheme uses the multi-regiming technique, where the gain of the integrator is intelligently set by adjusting the integration time. This enables modification of gain and range through software. The scheme's design for a current

range of ± (100 pA, 100 nA) is explained with analysis using error and noise models. The effectiveness of the proposed scheme has been proven to work for RPA sensors using a current-profile test on the designed hardware. Recommendations for optimizing RPA operation, in conjunction with the proposed digitizing scheme, are also discussed.

The third scheme is a single-stage current digitizer. This circuit features a transimpedance amplifier with a programmable-gain attenuator in its feedback. The attenuator helps in realizing high-valued resistances using conventional resistance values. The proposed scheme offers fast response with reduced effects of q_E and it is immune to switch resistances present in the feedback circuit. A mathematical model of the scheme with error and noise analysis is presented. The performance of the digitizing interface has been established using a hardware prototype for a current range of 500 pA to 5 μA.

A unified scheme for interfacing plasma diagnostic probes, such as RPA and Langmuir Probe, is described as the fourth scheme. With a transimpedance amplifier as the front-end and a switchable gain voltage amplifier, this scheme features faster and constant response time, irrespective of input current magnitude. The switchable gain amplifier, designed based on the multi-regiming technique, ensures minimal effects of the ON resistance of switches used in gain stages. The effectiveness of the proposed scheme with LP and RPA was also tested using respective current profiles. Test results show that the proposed scheme can be a universal platform for plasma diagnostic probes.

Finally, the report explains the details of two prototypes of Retarding Potential Analyzer designed for the study of Earth's ionosphere under the Advanced RPA for Ionospheric Studies (ARIS) project. Featuring the D-LCM scheme as the analog front-end, ARIS prototypes were developed at the Indian Institute of Space Science and Technology (IIST) with the help of the Indian Space Research Organization (ISRO). These payloads were successfully tested on the Earth's ionosphere by utilizing the stage 4 experimental platforms of Polar Satellite Launch Vehicle (PSLV) C-45 and C-55.