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Impedance Probe

The AEROS-B Electron Density Experiment

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Abstract. The Impedance Probe, one of five active experiments on the satellite AEROS-B is described briefly in theory and experimental lay out. The well established RF method for *in situ*-measurement of electron densities by means of determining the self impedance of a cylindrical sensor is used. The phase shift between the signal of the RF generator and the signal coupled to the plasma condensor is taken as criterion for selecting discrete frequencies to be telemetered.

Key words: Electron Density — RF Impedance Probe.

1. Scientific Aim

The scientific purpose of the experiment Impedance Probe (IP) in the satellite AEROS-B is to determine the local ionospheric electron density. In addition it is expected to provide electron or total ion density calibration for other on board experiments.

The resolution of about 8 kilometers in measuring electron densities together with its accuracy of better than 10% will allow for mapping the global structure in density as well as for observations of small scale phenomena. For an integrated analysis of AEROS-B experimental results the electron density value is a basic parameter for aeronomic studies.

2. Principle of the Method

The swept frequency RF impedance probe makes use of the fact that the frequency depending impedance Z of a plasma filled condensor shows resonances, mainly a series and a parallel one. These resonances are particulary suited for plasma diagnostic purposes, especially the parallel resonance, which always occurs above the series resonance. This parallel resonance frequency can be transformed to the plasma frequency (formula 1), which in turns is related in a simple way to the electron density (formula 2). Therefore the parallel resonance frequency is determined by the instrument.

Probably caused by a mechanical malfunction in the sensorsystem the IP experiment on AEROS-A unfortunately failed. Therefore as an illustration in Fig. 1 curves of phase and magnitude of the plasma impedance for

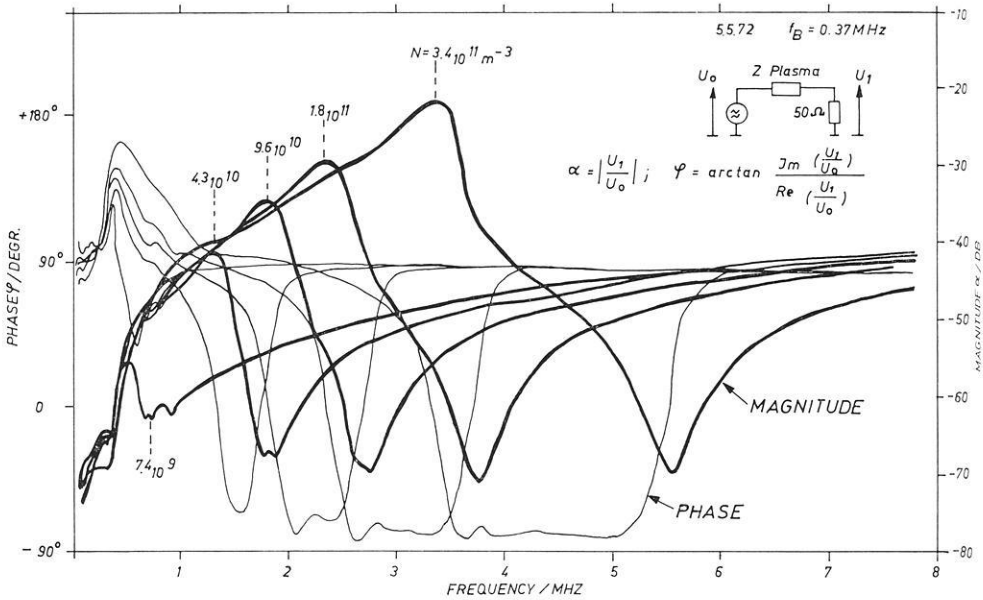

Fig. 1. Phase (thin line) and magnitude of the plasma impedance Z measured in a plasma tank

various electron densities N are shown, which have been measured in a plasma tank (Kist and Neske, 1973). According to the measuring principle indicated in the picture the parallel resonance is given by a minimum and the series resonance by a maximum as well as by zero crossings of the phase. Below about 1 MHz the curves are modified by the influence of the tank walls. The comparison between these density values and those taken from simultaneous measurements of decontaminated Langmuir probes showed an agreement within 20%.

The impedance Z consists of two components Z_S and Z_N, where Z_S is known and given by shunt capacitance and by shunt resistance, whilst Z_N is the plasma impedance. Applying Balmains formula (Balmain, 1969), which describes the impedance of a cylindrical dipole in a magnetoplasma, to the configuration of the AEROS satellite, Z_N is expressed in the following form:

$$\boxed{Z_N = -j\,\frac{F(A)}{8\,\pi f\,C_0 \sqrt{K_1\,T}}} \quad \text{with} \tag{1}$$

$$F(A) = \ln \frac{(1+\sqrt{1+A^2})^2}{A(2+\sqrt{4+A^2})} + \tfrac{1}{2}\,(3\,A + \sqrt{4+A^2} - 4\sqrt{1-A^2})$$

$$A = \frac{R+S}{2L}\sqrt{\frac{K_0}{T}}\left(1+\sqrt{\frac{K_1}{T}}\right); \quad K_0 = 1 - X; \quad K_1 = 1 - \frac{X}{1-Y^2}$$

$$T = K_0 \sin^2\theta + K_1 \cos^2\theta; \quad X = \frac{f_N^2}{f^2}; \quad Y = \frac{f_B}{f}$$

R: sensor radius; L: sensor length; S: ion sheath thickness; θ: angle between magnetic field and sensor; C_0: free space capacity between sensor and satellite; f: measured resonance frequency; f_N: plasma frequency; f_B: gyrofrequency. The values of R, L and C_0 are fixed and known, whilst the values of f_B and θ will be given by spacecrafts magnetometer and attitude control.

For $\theta = 0$ the parallel resonance frequency, meaning $Z_N \rightarrow \infty$, converts to the wellknown Upper-Hybrid-Frequency $f^2 = f_N^2 + f_B^2$.

The influence of the ion sheath around the sensor, a region of high gradients of potential and plasma density, is included in the impedance formula (1). The corresponding parameter is the ion sheath thickness S. By using a positive DC bias of the sensor with respect to the spacecraft a small frequency shift of the parallel resonance will occur as function of the applied voltage. Therefrom first the ion sheath capacitance around the sensor and then the parameter S will be calculated. The ion sheath around the spacecraft itself will be neglected, because in the serial connection of ion sheath capacity around the sensor, free space capacity and ion sheath capacity around the spacecraft, the two former are the smaller ones and therefore dominant.

In order to deduce electron density N_e from the measured frequency f the only remaining free parameter f_N in formula 1 is varied such that the relation for the real and imaginary part of Z meets the additionally given phase condition (see sec. 3.2). From the plasma frequency thus determined the density is calculated according to:

$$\boxed{N_e = \frac{4\pi^2 \varepsilon_0}{e^2} m_e f_N^2} \qquad (2)$$

m_e: electron mass; e: electron charge; ε_0: free space dielectric constant.

The electron densities which have to be expected along the AEROS orbit can be covered by choosing a measuring frequency range for the impedance probe limited by 0.64 and 10.24 MHz.

3. The Instrument

The experiment consists of two main parts, the plasma condensor and the electronic device. The location and the configuration of the experiment Impedance Probe in the satellite is shown in (see footnote page 596).

3.1. Plasma Condensor

The plasma condensor is realized by the satellite surface as the one and by a cylindrical sensor as the other electrode[1]. The wrapped sensor is mounted within the adapter section of the spacecraft and will be deployed by a self deploying mechanism in orbit, forming a cylinder of 1.8 m length and 2.4 cm diameter. The sensor axis is oriented along the spin axis of the satellite. The sensor material consists of gold plated copper berylium and cobalt alloy filaments, which are woven to a mesh structure of about 76% transparency. The transparent mesh sensor of the above dimensions represents a mechanically feasible compromise between the demand for a small sensor surface on the one hand and a large free space capacity with electric field lines covering a large measuring volume on the other hand.

A resonant circuit housed in the deployment mechanism and connected to the enrolled sensor allows for simulation of the plasma condensor during test phase. A microswitch provides information about the beginning of the sensor deployment in orbit.

At the base of the sensor a guardring, fed with a RF-signal derived from the RF-signal actually applied at the sensor, is to exclude the inhomogeneous plasma distribution from the measuring volume, by preventing the electric field lines between sensor and spacecraft to pass through this region.

3.2. Electronic Device

The electronic device has to measure the highest frequency for different sensor biasing conditions in the adapted range from 0.64 to 10.24 MHz, at which the ratio of imaginary to real part of the plasma impedance has a given value (see below).

Fig. 2 shows the principle of the impedance measurement: A RF-signal produced by the generator part splits into measuring and reference path. The measuring path signal is fed through a coupling resistor Rc to the plasma condensor. The impedance of the plasma condensor causes a phase shift of the measuring signal with respect to the reference path signal, which is analyzed by a phase detector.

The electronic system is shown in the more detailed blockdiagram of Fig. 3. The wide measuring frequency band is produced in the generator part by mixing technique. The phase difference of the swept frequency bands of the measuring and the reference path is detected by means of a fast phase detector. A frequency counter as well as the sensor potential

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[1] See Fig. 1 of the paper by K. Spenner and A. Dumbs: The Retarding Potential Analyzer on AEROS-B. J. Geophys. *40*, 585—592, 1974.

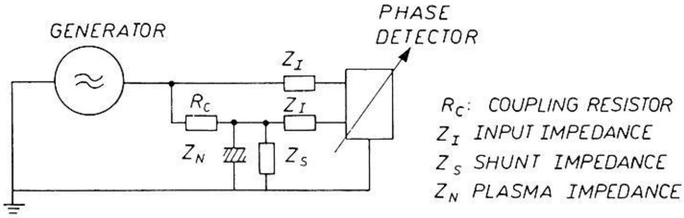

Fig. 2. Principle of measurement

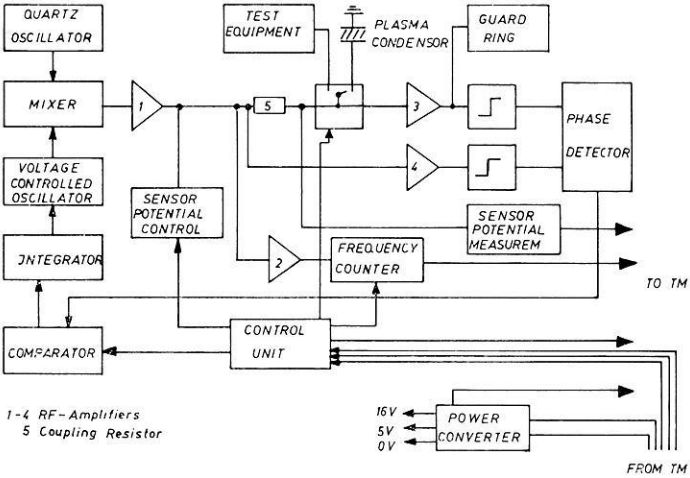

Fig. 3. Blockdiagram IP – AEROS-B

measurement are activated by a control unit in a sequence which is schematically shown for one impedance probe scan in Fig. 4: The positive slope of the frame pulse resets and starts the experiment. A search programm drives the frequency from about 12 MHz through the measuring range down to about 0.1 MHz. If a certain phase value is found in this range, the sweep is stopped and the frequency actually applied to the plasma condensor is counted and stored for telemetry readout. After frequency counting the DC potential of the sensor is measured. Within the remaining time intervall of the scan the sensor potential control (SPC) may be switched on or off according to signals correlated to the measuring time of the experiments Mass-Spectrometer and Retarding Potential Analyzer. The negative slope of the frame pulse triggers the readout of the stored frequency value by telemetry thus accomplishing the one second scan.

During the 6 seconds scan shown in Fig. 5 four phase levels, namely $\varnothing = 0°$, $-22.5°$, $-45°$ and $-67.5°$ are consecutively given as "search" and "stop sweeping" condition. The case $\varnothing = 0$ denotes the proper res-

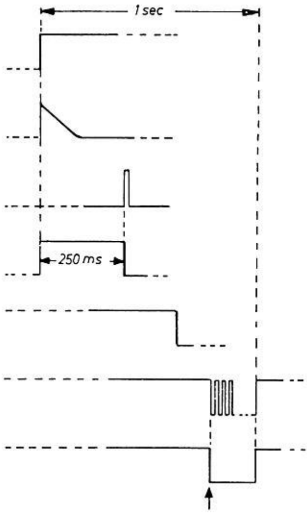

Fig. 4. 1 sec sequence of IP scan

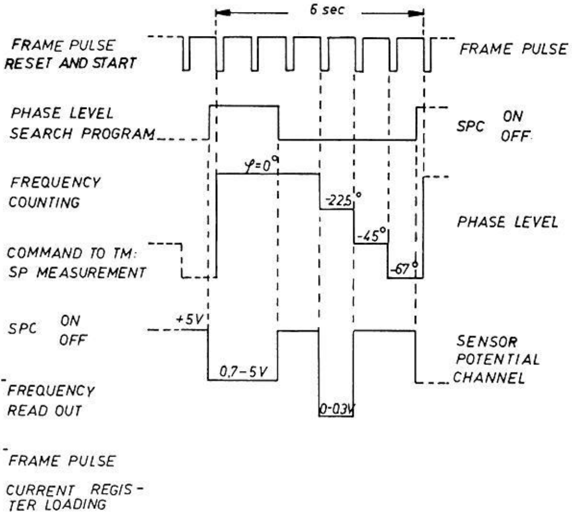

Fig. 5. 6 sec IP sequence

onance frequency (and its variations caused by change of the DC sensor potential), but in all other cases, too, the measured frequency together with the actual phase condition provide sufficient input for determining the electron density. For proper sequence identification at ground the $\varnothing = -22.5°$ state condition of the experiment is accompanied by a zero volt signal applied to the SP channel during "SPC off".

Depending on the measured resonance frequency i. e. the actual electron density a certain electron current (see Table 1) is drawn from the plasma by means of the SPC thus leading to a DC bias of the sensor. The current register loading occurs always at the end of the scan (Fig. 4) and the value of the DC sensor potential is measured at parallel resonance frequency in the following scan. The currents have been selected such that on the one hand the sensor potential approaches plasma potential within a few hundred millivolts and that on the other hand the satellite potential is not changed more than 10% with respect to its equilibrium value. A small effective sensor surface (transparent mesh) is to meet both requirements.

4. *Interface Parameters*

The electronic box is of cylindrical shape with 94.5 mm height and 200 mm diameter. Its weight is 2.4 kg. The deployment mechanism with the wrapped sensor has an overall size of 115 × 75 × 120 mm. Its weight is 300 g. The experiment power at 28 V is 2.6 W in operating mode.

Two telemetry channels with 9 and 7 bits/s provide the resonance frequency and the sensor potential measurements. Three housekeeping chan-

Table 1. Selected frequency range versus sensor DC-current

Frequency range/MHz	Current/uA
< 1.91	10
1.92 — 2.55	40
2.56 — 3.82	110
3.84 — 5.10	210
> 5.12	350

nels inform about power converter voltages, temperature and status of the in-flight-test equipment.

5. Calibration

Calibration of the IP experiment comprises capacity measurements and inflight test of phase levels.

For the conversion of the measured resonance frequency into plasma frequency the values of the free space capacity C_0 and the shunt capacity C_p must be known. The free space capacity is defined as the capacity between sensor and satellite which will be filled by the ionospheric plasma, whereas the shunt capacity consists in that part of the capacity between sensor and satellite which will not be influenced by the plasma.

The measurements have been performed using a satellite model having flight configuration. To avoid disturbing influences from walls or ground, the satellite has been lifted by means of a crane to a height of about 15 meters.

The automatic inflight test equipment consists in a passive network with defined resonant frequency, to which the RF signal is switched over from the sensor every 12 minutes. In this way the function of the whole electronic is controlled, especially any long time change of phase levels can be detected. The identification of the inflight test mode is given by a triple zero output of the SP channel.

6. Data Interpretation

The measured data from the experiment are given by the combination of frequencies, phase levels and sensor potentials presented in Table 2. The switching to different combinations works automatically in the satellite's normal program. It is interrupted every 12 min by the testmode which in turn covers a time period of 6 seconds.

In addition to the usual data from the spacecraft the magnetic field magnitude and the angle between magnetic field and sensor axis are required.

Table 2. Relations between the measured data

Frequency	Phase level	Sensor potential
f_1 MHz	0°	U (10 μA) V
f_2	0	U (f_1)
f_3	0	0
f_4	— 22.5	0
f_5	— 45	0
f_6	— 67.5	0

Starting with this set of data the impedance Z which consists of $Z_N = Z_N$ $(f, f_N, f_B, \theta, C_S)$ combined with the shunt impedance and a loss term is calculated in such a way, that the relation (3) is fullfilled:

$$\boxed{\varnothing = \text{arc tan} \frac{F R_c}{E R_c + E^2 + F^2}} \quad \text{with } Z = E + iF \qquad (3)$$

This iterative process will provide in a first order approximation the plasma frequency and the damping resistance, taking various combinations of measured frequencies and phase levels.

The accuracy in electron density achieved by this method is expected to be better than 10%.

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