A Miniaturized Impedance Probe for Ionospheric Sensing

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Space Weather & The Ionosphere

The term **space weather** describes the variation of conditions on the Sun, in interplanetary space, and in the Earth's upper atmosphere (including the ionosphere) that have the potential to harm health or affect technological systems [*NSWP*, 1995].

The **ionosphere** is an ionised region of the upper atmosphere, ranging in altitude from approximately 90 km up to 1500 km. In this region, **solar radiation** breaks down some of the atoms and molecules into electrons and ions, creating a **plasma** [*Davies*, 1990].

Measurements of the **ionospheric electron density** can be used to improve ionospheric models. These are used to aid us to develop systems to **mitigate** the impact of space weather on our radio systems.

Measurements are often made of the **bottom-side** of the ionosphere (i.e. below the altitude of peak electron density) using **ground-based radar systems**. **Integrated measurements** of the ionosphere can be made using **GPS satellites**. However, **top-side** ionospheric measurements generally require **satellite-based instrumentation**.

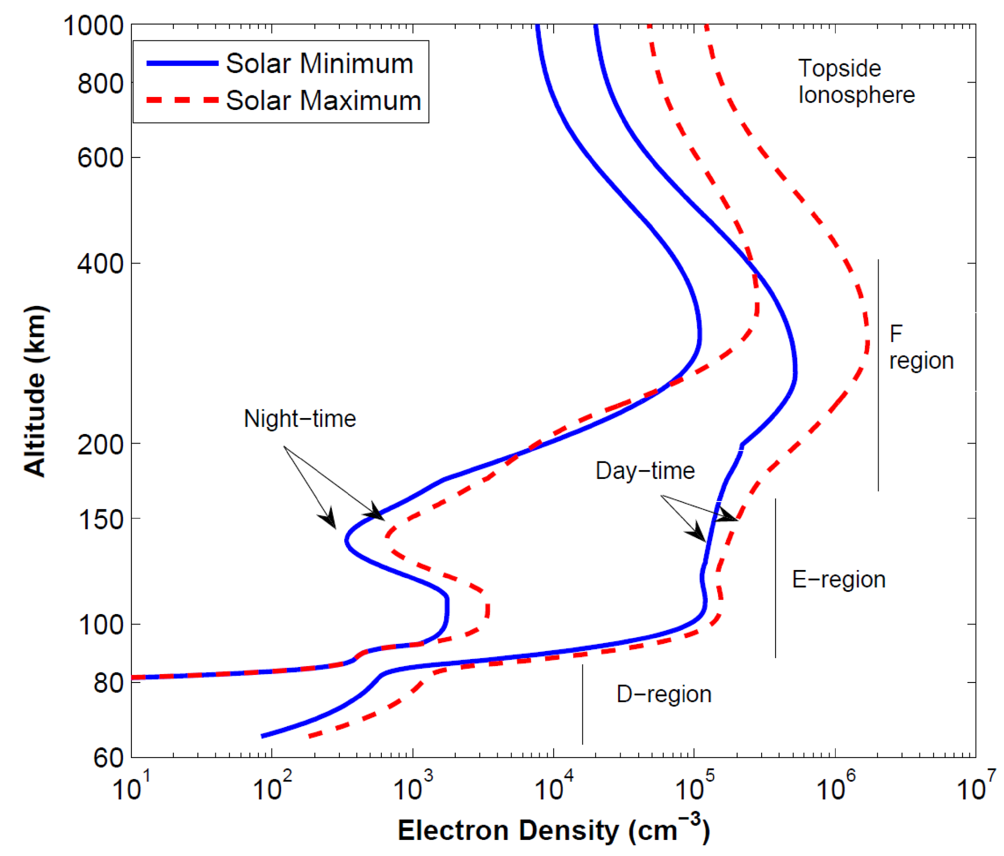

Figure 1 – Day-time and night-time ionospheric electron densities, at both solar max and min, against altitude.

Impedance Probe Concept

The ionospheric **Impedance Probe (ImP)** is being developed to provide measurements of the top-side electron density.

Measurements will be obtained by sweeping a radio frequency signal from 100 kHz to 10 MHz, exciting the ionospheric plasma, to determine the **Upper Hybrid Resonant** (UHR) frequency. Using this measurement, and knowledge of the Earth's magnetic field, we can mathematically determine the **electron density**.

Impedance probes, such as ImP, have two main advantages over other electron density measurement devices; these being **antenna geometry independence** [*Balmain*, 1964] and **spacecraft charging independence** [*Baryatja*, 2007].

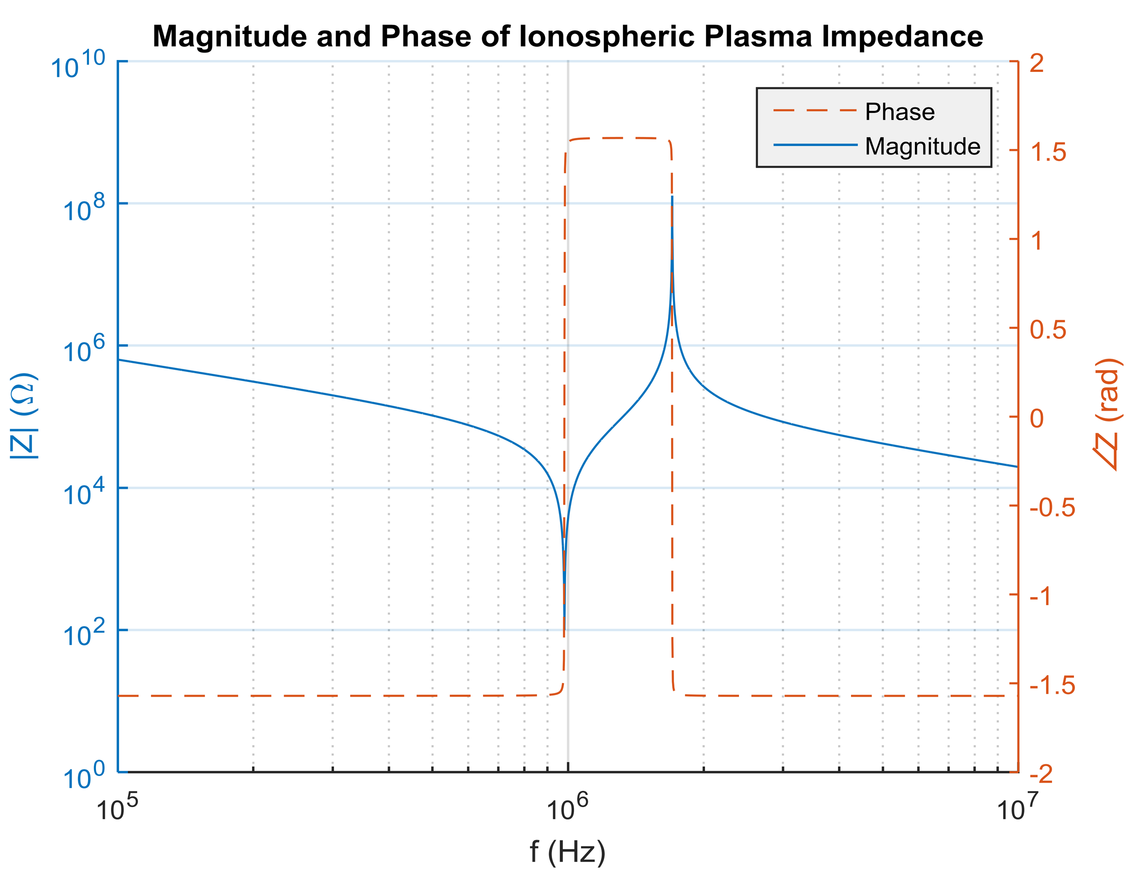

Figure 2 – The magnitude (blue) and phase (orange) of the electrical impedance of an short antenna embedded in ionospheric plasma. Two resonant points can be seen. The one on the right is the Upper Hybrid Resonant frequency and this can be used to determine the electron density of the ionospheric plasma.

ImP Sensor Architecture

ImP is being designed to be a miniaturized sensor, following on the PQ60 standard. A SWAP estimate was taken, with the results shown in Table 1.

The ImP sensor architecture will be split into three distinct parts. An **Analogue Front End (AFE)** to properly condition the current entering from the antenna probe and convert it into a voltage using a series of operation and instrumentation amplifiers; a **Signal Generation Block (SGB)** to generate the required frequency sweeping signal to excite the ionospheric plasma; and a **Digital Back End (DBE)** to control the signal generation block, sample the data from the analogue front end, and to relay all the data back to the spacecraft on-board computer.

Size	*Weight*	*Power*
42×42×10 mm	20 g	50 mW

Table 1 – SWAP estimate and targets for ImP

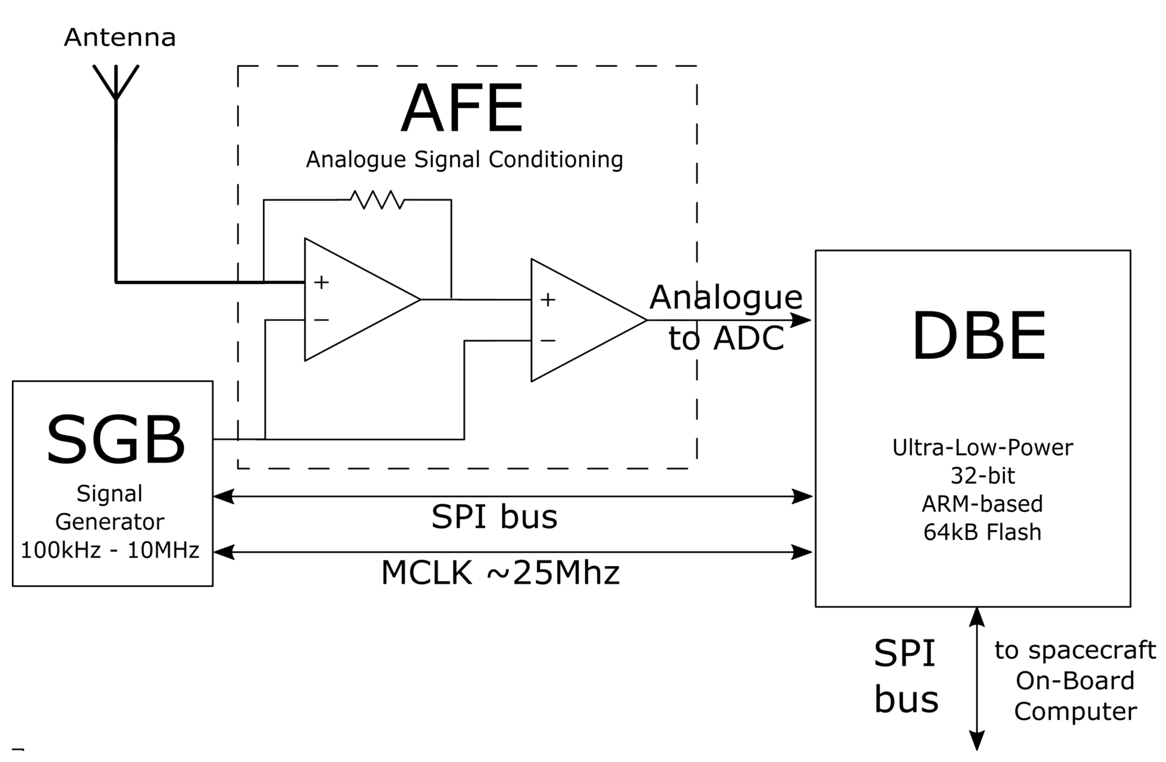

Figure 3 – ImP sensor architecture. Currently the first ImP prototype is being built, with the Analogue Front End undergoing initial testing.

Spacecraft Architecture

A **PocketQube (PQ)** platform, of dimensions **5×5×5 cm** is being developed by the Astrionics research group at the University of Malta.

The platform design is being developed to meet the requirements for hosting ImP, mainly having a **magnetically clean design** as electron density readings are susceptible to local magnetic fields. ImP also requires **orbital positioning**, **attitude determination** and **magnetic field data** which will be provided by the platform.

The PQ constraints include a total mass of **250 g** and an estimated average orbital power of **300 mW**. Thus the main challenges are **miniaturization** and keeping within the available power budget without sacrificing redundancy. Figure 4 show the top level architecture being proposed.

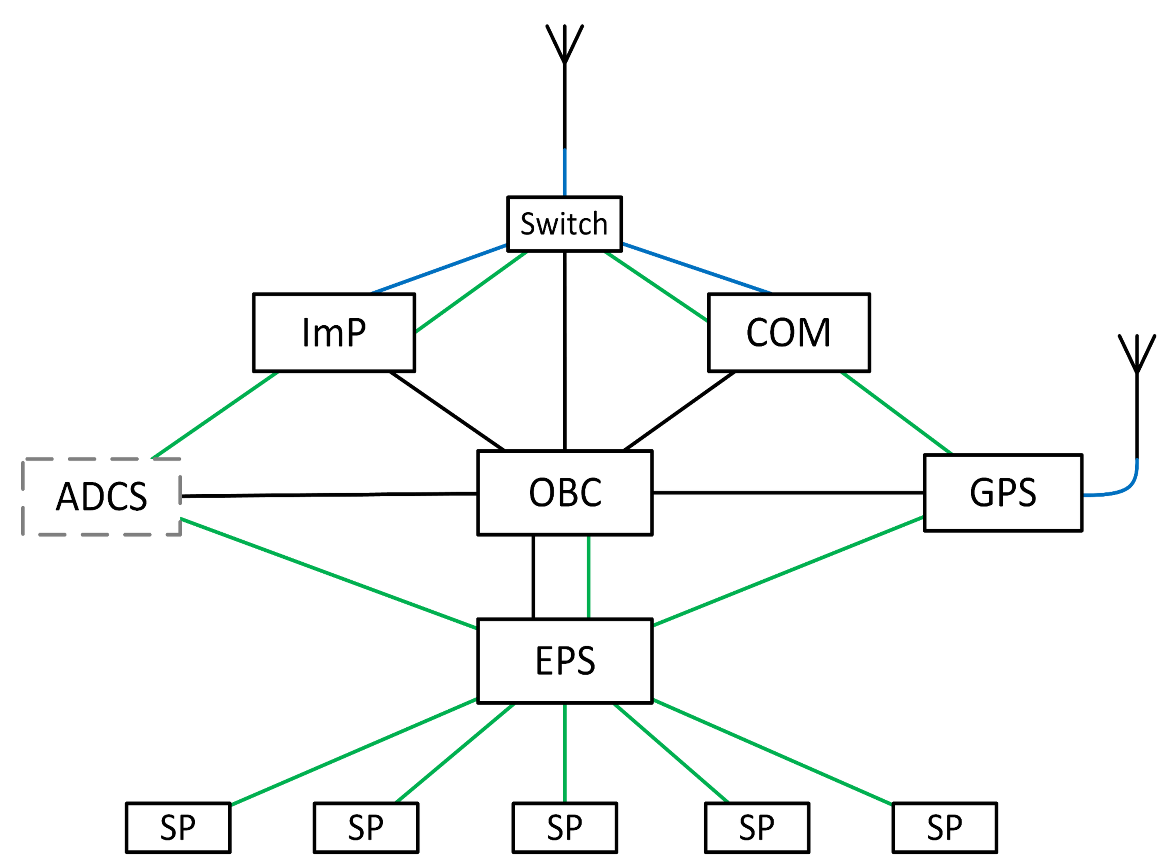

Figure 4 – Proposed spacecraft architecture, showing the major subsystems and inter-connections; radio frequency (blue), power (green) and SPI bus (black).

Future Work

The first prototype of ImP is currently under development. Also, the **Tiny Ionospheric Test Chamber (TITCh)** is being developed at the University of Birmingham. TITCh will provide an artificial ionosphere inside a thermal vacuum chamber that will be used to test ImP, and eventually the whole spacecraft.

The PQ platform top level design together with all requirements have been identified and subsystems are currently being developed.

We hope to launch ImP into orbit in 2018 as part of a collaboration between the University of Birmingham and the University of Malta. Other flight opportunities are also being considered.

References

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