A Minimal Radio and Plasma Wave Investigation for a Mercury Orbiter Mission

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1. Introduction

The primary thrust of the effort at The University of Iowa for the definition of an orbiter mission to Mercury is a minimum viable radio and plasma wave investigation. While it is simple to add sensors and capability to any payload, the challenge is to do reasonable science within limited resources; and viable missions to Mercury are especially limited in payload mass. For a wave investigation, this is a serious concern, as the sensor mass often makes up a significant fraction of the instrumentation mass.

2. Science and Measurement Objectives

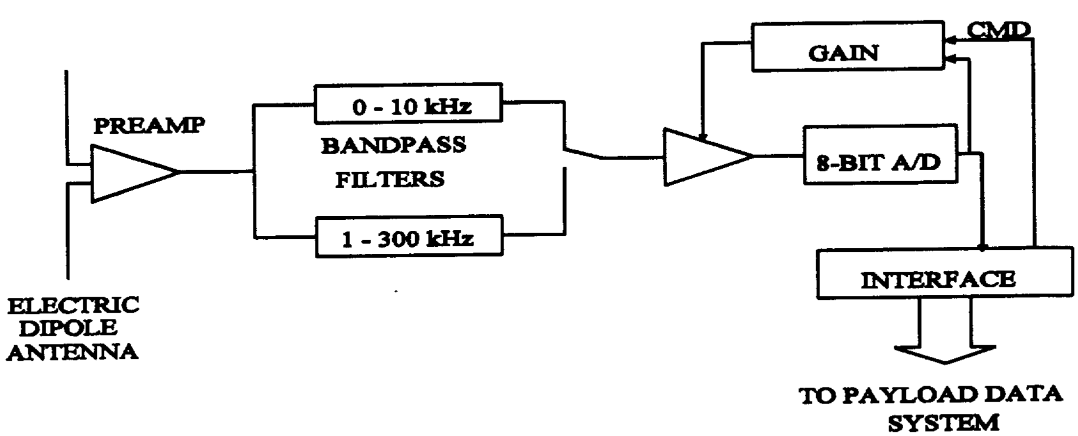
The primary science objective to which a plasma wave investigation would contribute is the investigation of Mercury's magnetosphere and its interaction with the surface and the solar wind. Specifically, there have been no plasma wave measurements in the Hermean magnetosphere at all, so the primary measurement objective is to survey the radio and plasma wave spectrum. Based on observations in other planetary magnetospheres, including Earth, the outer planets, and even Ganymede, it is reasonable to expect to observe whistler-mode emissions, electron cyclotron harmonic emissions, electrostatic solitary waves, ion acoustic waves, ion cyclotron waves, and auroral hiss. These waves likely play important roles in the acceleration, heating, and even loss of plasma and energetic particles in the Hermean magnetosphere. The waves are likely important intermediaries in the conversion of various forms of free energy in the plasmas to others. We would also expect to observe non-thermal continuum radiation (a form of which is observed in every other planetary magnetosphere), and possibly emissions generated by the cyclotron maser instability usually associated with auroras. The wave investigation would also contribute magnetospheric diagnostics information. The most important example is a good measurement of the plasma density which is unaffected by spacecraft charging effects. This can be accomplished by measuring wave resonances and cutoffs, or if the electric antennas are suitably long ($L >$ Debye length), by the analysis of quasi-thermal plasma noise.

Secondary objectives of any plasma wave investigation traveling to within 0.3 AU would have to include an extension of Helios plasma wave observations of solar wind plasma wave phenomena. The Helios results show that most common solar wind wave phenomena increase in intensity with decreasing heliocentric radial distance. This is true for Langmuir waves, whistler-mode emissions, and ion-acoustic waves. A survey of such waves during the long cruise from 1 AU to Mercury's orbit plus the station-keeping at Mercury would greatly enhance our knowledge of these emissions and the roles they play in the evolution of the solar wind.

3. Instrumentation

A minimum radio and plasma wave investigation is determined primarily by the sensors which can be afforded under strict resource limitations. We suggest that the minimum sensor complement for such an instrument is a single-axis electric dipole antenna. There are several reasons for this. Primarily, an electric antenna, given sufficient length and receiver sensitivity, can detect all electromagnetic wave modes; a magnetic sensor would not detect the several electrostatic modes such as Langmuir waves. Furthermore, for radio emissions at higher frequencies, an electric antenna is more efficient in terms of sensitivity per unit mass than a magnetic antenna. The lack of a magnetic antenna in the minimum configuration leaves open the possibility of confusion between electromagnetic and electrostatic modes, primarily in the frequency range below the electron cyclotron frequency. However, the Voyager plasma wave investigation managed to provide fairly reliable identification of basic wave modes based on the frequency of emissions relative to the various characteristic frequencies of the plasma and also by comparison of frequency-time phenomenology with well-known modes from terrestrial measurements. Certainly, the addition of a magnetic search coil to cover the frequency range up to about 15 kHz would be a welcome addition to the minimum payload, provided resources are available.

The receiver should be able to analyze the spectrum from a few Hz to ~ 300 kHz which is well above the solar wind plasma frequency at 0.3 AU. The lower frequency limit is set by the capability of the DC magnetometer which typically has good response up to several Hz. The primary issues are spectral and temporal resolution; both of which drive the telecommunication requirements for the instrument. We propose a solution which can provide relatively low-resolution measurements both in frequency and time for continual "survey" observations of the Mercury magnetosphere and the local solar wind, yet provide the opportunity to obtain brief periods of very high temporal and spectral resolution measurements targeted for special magnetospheric regions or campaigns when addition data volume is available.



MERCURY ORBITER RADIO AND PLASMA WAVE RECEIVER

Figure 1

This instrument uses two analysis bands (0 - 10 kHz and 1 - 300 kHz), a fast A/D converter and onboard processing of digital waveforms to accomplish the measurement objectives. The A/D sampling rate is nominally 2.5 times the upper end of the analysis band (or 25 kHz and 750 kHz, respectively). See the block diagram in Figure 1. Continuous waveforms of at least 1024 8-bit samples are collected periodically, as often as once per 50 msec. The waveforms themselves provide the maximum spectral and temporal resolution outputs of the instrument, and it would be important to reserve some fraction of the mission data volume to telemeter some of these raw waveforms for specific regions or times. However, the normal operations would apply a fast Fourier transform to each waveform series and average the resulting spectra for a time interval appropriate to the phenomenon being studied and consistent with the data rate available. For example, the spectral averages could typically range from 1 second to as long as 30 seconds or more. The averaged spectra will have 512 frequency components (assuming a 1024-point waveform) which would require large telemetry capabilities to transmit to the ground. Instead, an additional onboard data processing step could involve binning the Fourier components in such a way as to generate a quasi-logarithmic spectrum with 10 to 20 channels per frequency decade. For 5 decades of frequency with 15 channels/decade and 10-second temporal resolution, this results in 60 bps assuming 8-bit measurements utilizing logarithmic compression. Further data compression could be accomplished by treating the amplitude as a function of frequency and time data set as an image and using an integer cosine transform as is currently being used on Galileo. This technique can provide a factor of 5:1 compression quite comfortably. The instrument characteristics are summarized in Table 1.

Table 1: Radio and Plasma Wave Instrument Characteristics

Frequency Range	~10 Hz - 300 kHz
Noise threshold	10^{-17} $V^2m^{-2}Hz^{-1}$
Sample Rate: 10 kHz band 300 kHz band	25,000 s^{-1} 750,000 s^{-1}
Spectral Resolution*: 10 kHz band 300 kHz band	24 Hz 732 Hz
Temporal Resolution	50 ms/spectrum maximum 10 s/spectrum typical
Data rate	60 bps (survey) up to 165 kbps (burst rate)
Power: Standby Data Acquisition mode	0.4 W 0.8 W
Mass: Electronics Antenna Total	500 g 500 g 1.0 kg

* Achievable via fast Fourier transform; may be degraded to reduce data volume

4. Antenna Considerations

A significant fraction of the effort at the University of Iowa went into electric antenna concepts. There are a fairly large number of existing designs from which to choose, however, most of them are quite massive, sometimes a few kg per unit (a dipole configuration would normally require two monopole units). An additional challenge is to ensure that the antenna element would survive the thermal environment in an elliptical orbit about Mercury. The University released a small purchase order to TRW Astro Aerospace Corporation to study one possible solution. This solution is based on their A-204 STEM TDM Antenna. However, the design can be modified to work within the Mercury thermal environment and to reduce the mass to 250g/unit for element lengths of 5 m/unit; this would provide a 10 m tip-to-tip length, a short but acceptable length for this mission. The TRW Astro effort also verified by analysis that the modified design would work in the Mercury environment and determined that the 250 g/unit goal is achievable. Other concepts have also been considered, including folding carbon-carbon rods, however, there has been no significant design effort for these other concepts.