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DATA COMPRESSION FOR THE CASSINI RADIO AND PLASMA WAVE INSTRUMENT

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Abstract. The Cassini Radio and Plasma Wave Science experiment will employ data compression to make effective use of the available data telemetry bandwidth. Some compression will be achieved by use of a lossless data compression chip and some by software in a dedicated 80C85 processor. A description of the instrument and data compression system are included in this report. Also, the selection of data compression systems and acceptability of data degradation is addressed.

1. Introduction

The Radio and Plasma Wave Science (RPWS) experiment is being built by an international team led by the University of Iowa for the Cassini spacecraft. This experiment will study a wide range of plasma and radio wave phenomena in the magnetosphere of Saturn and will also make scientifically important measurements during the cruise phase and at other encounters. A particular feature of the data from wave receivers is that they have a potentially vastly greater volume than the spacecraft telemetry link and onboard data handling systems are able to handle and transmit to Earth. Thus event selection, data selection and onboard data compression techniques are important for such instruments. Historically data selection has been based on hardware signal processing but recently the use of onboard software has been considered important[1,2]. The RPWS instrument has one processor dedicated to data compression tasks. In this paper we briefly outline the scientific data requirements for RPWS, the RPWS instrument hardware including the data compression processor (DCP) and potential DCP software structure. We then present some results of data compression tests and finally discuss the present planning for the implementation of data compression in the RPWS instrument. We note, in particular, that the complexity in the number of RPWS modes will impact on data compression yet the priority for compression will be directed at the producers of the largest data volumes.

2. The Scientific Requirements

Figure 1 shows the typical signal levels for the various noises which can be expected around Saturn[3]. A simple calculation would show that to measure all of these fully one would need - (3 antennae) x (2 x 10^8 samples) x 16 bps or approximately 10 Gbps for the electric components (assuming 100 MHz bandpass), and (3 antennae) x (2 x 10^5 samples) x 16 bps or approximately 10 Mbps for the magnetic components (assuming 100 kHz bandpass) of the wave-field. This calculation assumes that the dynamic range can be adequately quantized using a 16 bit word length. This naive and simplistic calculation does not include the telemetry allowance for a Langmuir probe or a sounder both of which are in the RPWS instrument. Typical data rates available for RPWS are a few kbps, i.e. a factor of some 10^6 lower than could be used. Thus the need for data compression.

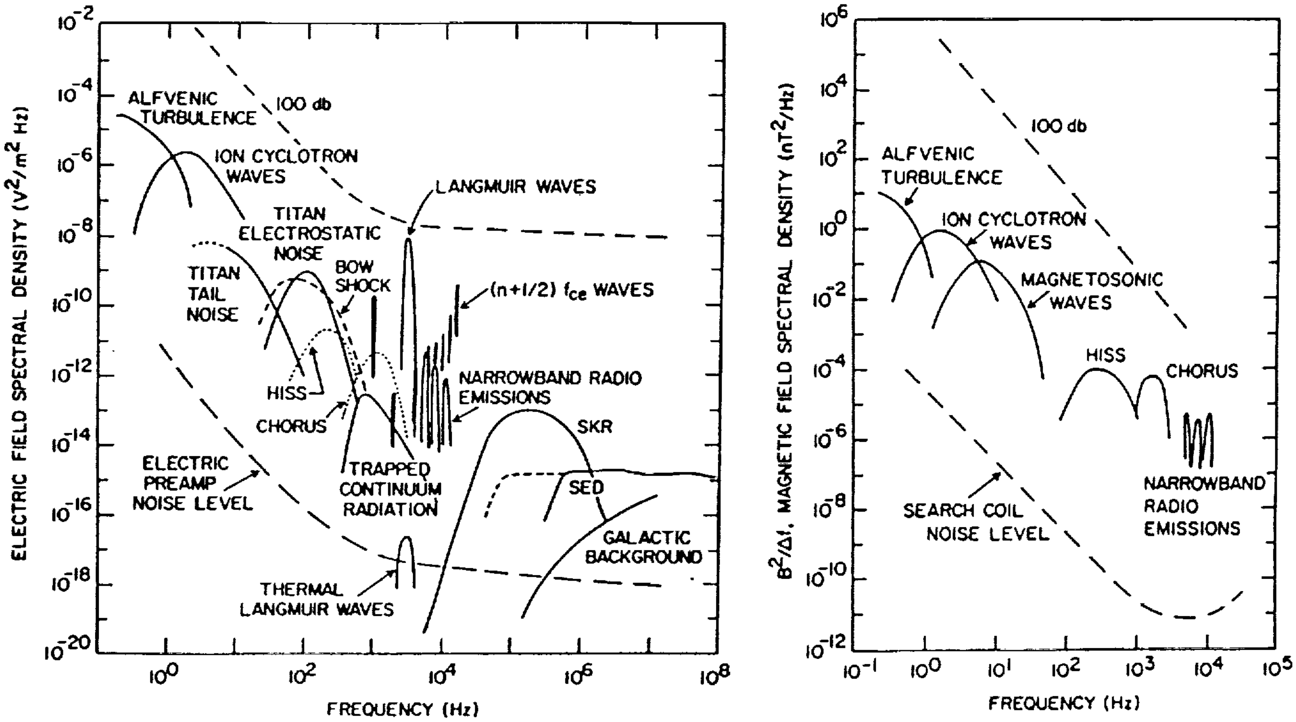

Figure 1 — The spectral characteristics of the various emissions expected to be detected during the Cassini mission to Saturn. Without any compression or selection, nearly 10^8 bps are required to return this information, which is a much larger value than the telemetry allows.

Clearly the RPWS team would be unwise (and unlikely to get support to try) to build sensors with such a capacity to over-produce data. In the next section we describe the RPWS instrument block diagram.

3. The RPWS Instrument and Data Compression Processor

Figure 2 is a simplified block diagram showing the current RPWS configuration. Three electric field antennas (configured as either a dipole plus a monopole or three monopoles), three orthogonal magnetic search coils and a Langmuir probe are the sensors. Two electric antennas can be connected to an active plasma sounder. The main signal processing blocks are the high frequency receiver (HFR), the medium frequency receiver (MFR), the five channel waveform receiver (5CWF), a digital wideband receiver (WB) and a Langmuir probe (LP). Both the HFR and MFR contain internal averaging and intensity compression circuitry, thereby reducing the onboard data handling requirement. In contrast, the 5CWF and WB receivers sample very fast, each near their respective Nyquist frequencies. Considering the WB receiver, as many as 160k samples per second are obtained in some modes. The data rates available for the RPWS investigation is around 2kbps in normal operation, but can be increased to greater than 100 kbs at predetermined times.

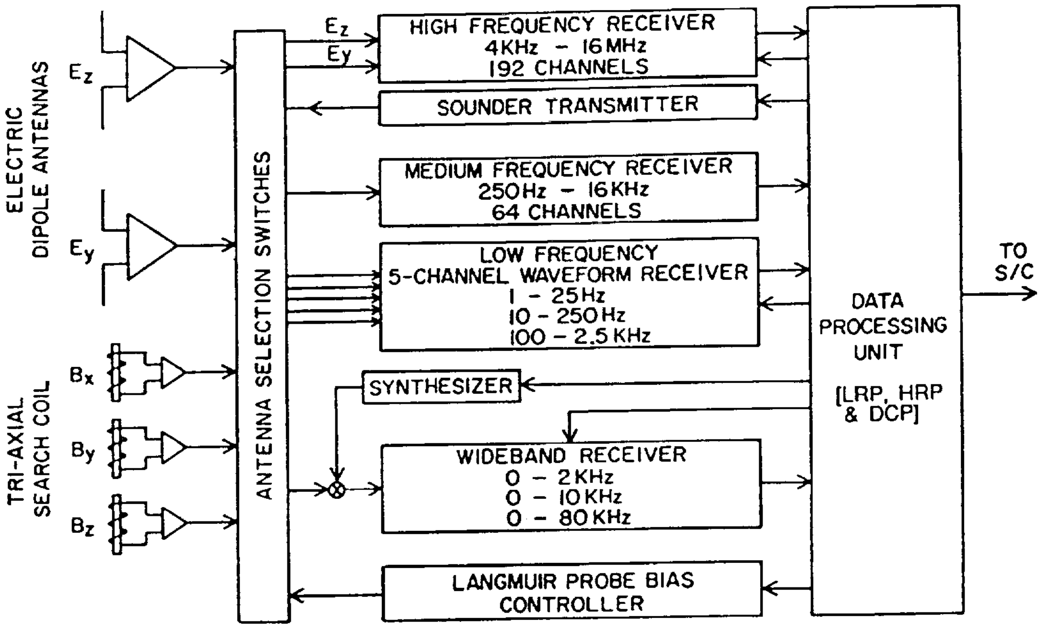

Figure 2 — A block diagram of the Cassini Radio and Plasma Wave (RPWS) experiment. Note that the Data Processing Unit (DPU) accepts signals from five different receivers. Due to the very different types of data, compression systems cannot be generic, but must be specifically tailored for each receiver.

Outputs from the signal processing blocks are taken to either the high rate data processing unit (HRP) or the low rate data processing unit (LRP). These processors are part of the instrument block labeled as the "Data Processing Unit" in Figure 2. A more detailed diagram of the DPU layout is shown in Figure 3. The HFR and MFR data will be processed by the low rate processor. In contrast, the faster-sampling 5CWF, LP, and WB data will be processed by the high rate processor. The high rate data processing unit contains a dedicated compression chip (produced by JPL using Rice's split-sample scheme) which can compress the data by a factor of approximately 2. This chip will be primarily for data from the digital wideband receiver. Other forms of data compression and data selection can be performed in the data compression processor (DCP). The DCP is connected by a single bus to both the high and low rate data processing units. This bus can only handle communications between two of the three processors at any particular time. The DCP is an 80C85 processor with 2k bytes of PROM and 64k bytes of RAM. It also includes a 16 x 16 multiply and accumulator device (Marconi MAR 7010). The DCP will perform data compression on the outputs from the various receivers, in scenarios that will be described below. Compressed data from the DCP is sent to the low rate processor where it is packetized and returned. Ultimately the spacecraft data interface is with BIU (bus interface unit) which is connected to the low rate processor.

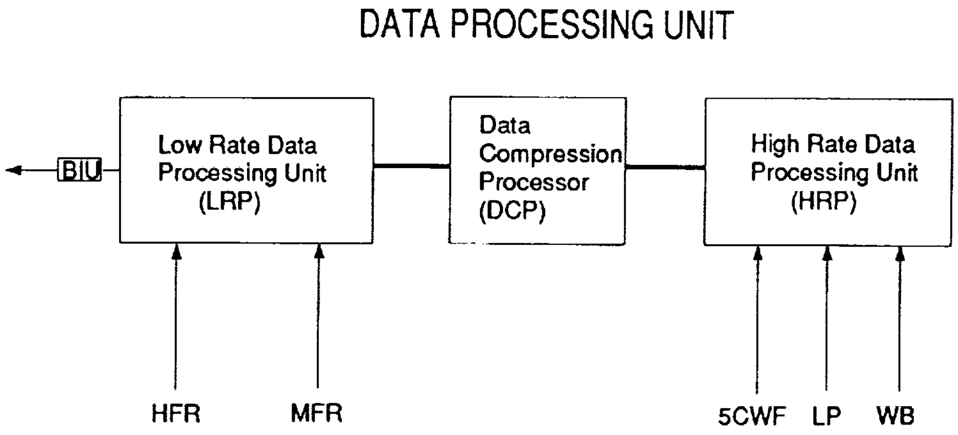

Figure 3 — A specific block diagram of the DPU. Note that internal to the HRP is a lossless compression chip. Besides this capability, there is a dedicated data compressor (DCP) that performs both selection and compression tasks.

4. Algorithm Tests on Possible Compressors

In this section we present the results of some simulations and tests of data compression on various sources of data. These include tests of compression upon data obtained from a ground-based lightning sferic radio detection system, along with simulations of compression using Voyager radio wave data.

For the detection of VLF signals associated with lightning discharges, a ground-based waveform capture system was recently developed at GSFC. The system examined waveforms obtained in the frequency range between 1–30 kHz, capturing the most active interval via a "smart" selection process. Figure 4 shows a captured VLF waveform generated by a cloud-to-ground return stroke occurring on 28 August 1992. During this particular day, storms associated with the remanent of Hurricane Andrew passed near the observation site (i.e., about 50 km). The "smart" selection process identified this particular interval of time as "active" and saved the corresponding receiver output in memory. The information is further compressed using an adaptive quantization algorithm, the results of which are shown in the middle panel. In this compression scheme, the original 16–bit words are requantized to 4–bit words using 16 quantization steps equally-spaced between the minimum and maximum waveform values. This algorithm is very quick, yielding moderate, synchronous compression. Although the compression, by nature, is lossy, there is little loss of essential information concerning the lightning-generated waveform. The bottom panel of the figure displays a simple model of a typical VLF waveform from cloud-to-ground return strokes[4] for comparison.

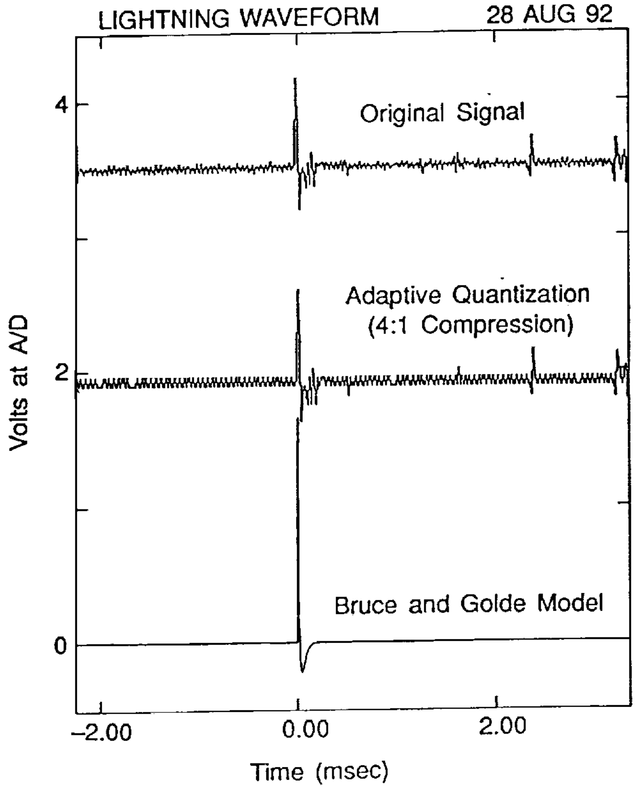

Figure 4 — A captured VLF waveform from a groundbased receiver that features a data compression system. Shown is the emission generated by a cloud-to-ground return stroke occurring on 28 August 1992, observed between 1–30 kHz. A compressed version of the waveform using adaptive quantization is also shown. Both waveforms compare well with modeled results.

There are other methods besides selection and adaptive quantization for the compression of data in the form of time series. We now present a couple examples of these methods using the data from the Voyager 2 encounter with the planet Neptune. Specifically, the data presented is from the planetary radio astronomy (PRA) experiment onboard the spacecraft. This experiment consists of a sweep frequency receiver operating between 1.2 kHz and 40 MHz[5]. The data from the closest approach period on 25 August 1989 is used in the study.

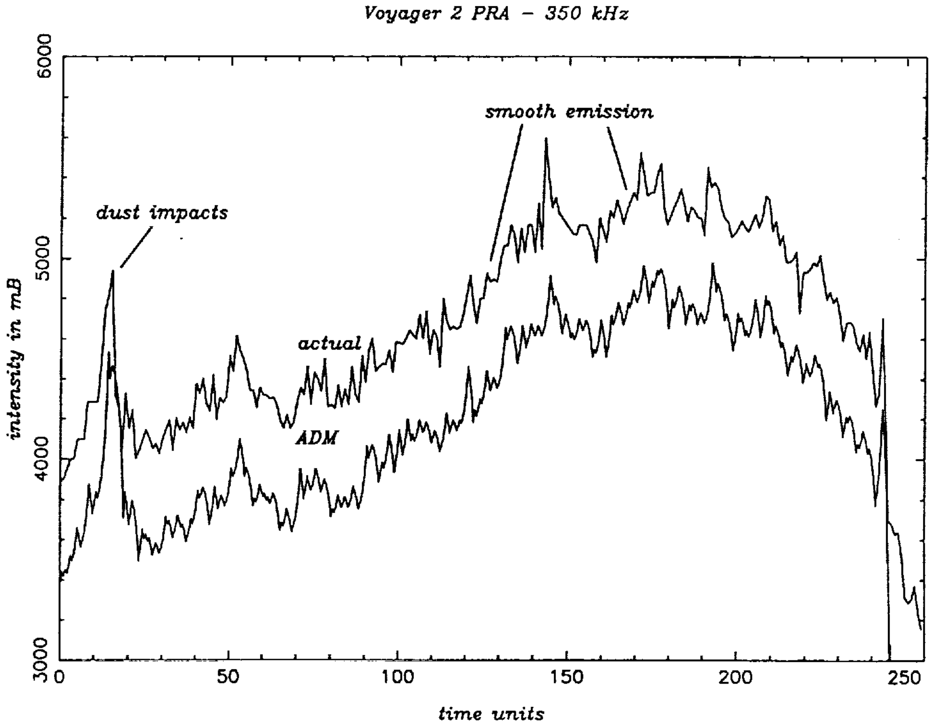

Figure 5 — A time series from the Voyager planetary radio astronomy (PRA) experiment (top curve) and its reconstruction following its compression using a 2–bit per sample adaptive delta modulation system (bottom curve).

Figure 5 shows the PRA measurements obtained during a 25 minute period just prior to closest approach to the planet. During this period, a time-averaged signal associated with dust impacts was detected by the receiver, along with a smooth emission that persisted for many hours. In the figure, the original data is presented in the top curve. The bottom curve is the same time series reconstructed following the application of an adaptive delta modulation (ADM) system commonly used in speech compression[6]. The ADM technique is relatively fast and yields a synchronous, 2–bit per sample output. Note that there is a reasonably good correspondence between the actual and ADM time series. Specifically, all the signals of scientific relevance, such as the dust impacts and smooth emission, are captured by this system.

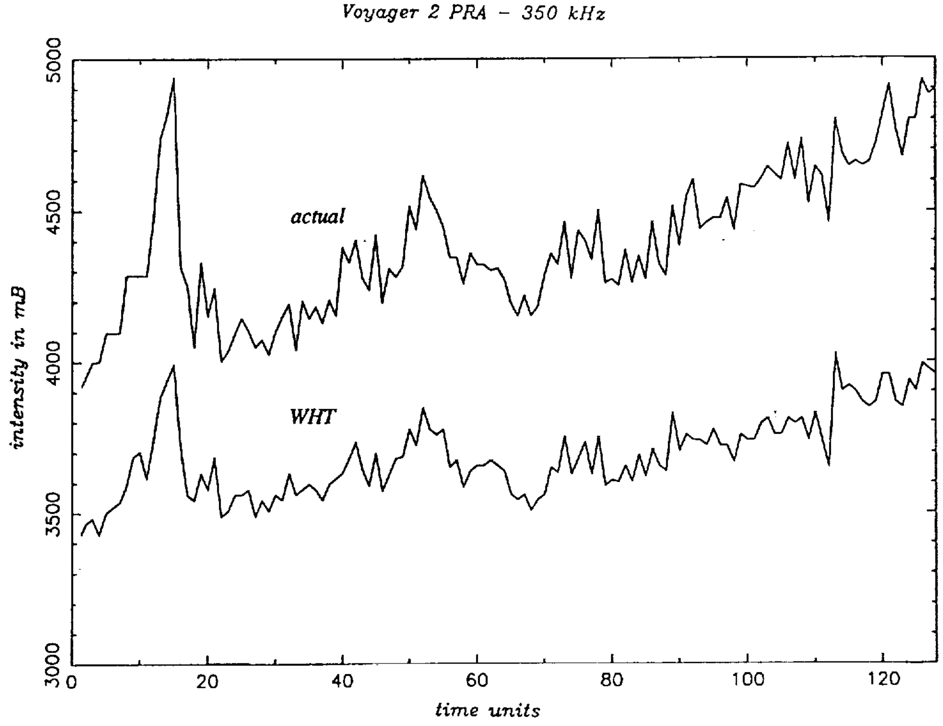

Figure 6 — A time series from the Voyager planetary radio astronomy (PRA) experiment (top curve) and its reconstruction following its compression using a Walsh-Hadamard transform/coefficient selection process (bottom curve).

In the event that there are very low data rates and available CPU time, then transform coding may be a possible means of compressing the data. Figure 6 shows a time series from the Voyager PRA experiment (top curve) along with reconstructed signal using the Walsh-Hadamard transform (WHT). The transform, itself, does not compress the data. However, once in transform space, selection of the most intense coefficients is performed. After selection, the coefficients are requantized to three bits and returned using run length encoding techniques for efficient packing in the telemetry stream. The reconstructed time series following these processes is shown in the bottom curve of Figure 6. This transform system results in compression down to about 2 bits per samples. As evident in the figure, there are some minor distortions in the WHT time series that result from the requantization process. However, the relevant scientific information is returned.

5. Compression Plans for RPWS

The implementation of data compression in RPWS is not yet fully decided. It is clear that the DCP will not have sufficient capacity in either processing power or memory for a extended suite of compression algorithms. Neither do we consider that it is possible to employ a single algorithm for all formats of input data, our experience suggests that algorithms need to be selected according to the nature of the data being considered. Thus, testing on the ground prior to flight will have to be performed to find the proper algorithms suitable for the different data types.

An initial approach to the Cassini RPWS compression is to compress the data from the source which produces the greatest volume of data. For example, compression and selection of events associated with the fast-sampling WB system is of primary importance due to the large data volume created by this instrument. When high rate telemetry modes (> 100 kbs) are available, the data can be returned directly or undergo fast lossless compression. The dedicated compression chip produced by JPL should accomplish the latter task. However, when data rates are low (< 10 kbs), data selection and lossy compression are required. One possible scenario is a selection and simple requantization process similar to that associated with Figure 4.

The DCP will also process the 5CWF and LP data. Like the WB experiment, these data sets consists of waveform measurements, but with much lower temporal resolution. Since the information rate is lower for these two receivers, the use of CPU-intensive compression systems may be possible. For example, it is desirable to transform the output from the 5CWF receiver in order to obtain spectral information. Compression in transform space may then be possible.

The HFR and MFR return spectral information averaged over a predefined time interval (usually averaged values in 10's of milliseconds). The data points are correlated in both frequency and time, thus a number of compression systems are possible. However, the compression applied is dependent upon the data sets usage. If radio spectrograms of limited resolution are created as the final output, lossy compression with large compression ratios may be used. Adaptive delta modulation is one possible system. Since the operation times of these receivers are relatively slow, transform coding and coefficient selection may also be possible within the constraints of the processor. However, if measurements are going to be crosscorrelatated, exact values are needed, and these can only be realized using lossless compression. As described below, the final usage of the data product on the ground is another driver in the selection of the compression system.

6. Discussion

The discussion of the use of data compression for scientific data raises the question of what, if any, degradation in the quality of the data is acceptable. For wave data where the data in question are a time series of field amplitude measurements it may be appropriate to guarantee that the additional uncertainty, or noise, in the data is below the noise level of the receiver, typically by around 3dB or so lower. For frequency spectra the scientifically important information are usually plotted on a grey-scale or colour scaled plot with a restricted quantization of the number of levels. For these data, then, a data compression to a word length somewhat longer than that needed to code the number of colour levels will usually be entirely adequate. When, for example, polarization and directions of the incoming wave are being measured then it is important not to have any data degradation. In general, the data compression tests by simulations should show that no scientific result is changed or be an artefact of the compression strategy which was selected.

It is evident that the choice of data compression system depends upon the receiver and its associated data product, DCP processing time, and the final data usage on the ground. Choosing the correct compression systems for each receiver will be difficult, but might be performed with the use of logic diagrams, like that shown in Figure 7. Illustrated is the possible compression scenario for the MFR data product. Note that very different compression systems could be applied, depending upon the data's final usage. In situation where there are multiple paths to the same final visualization product, one path will be selected based upon the compressability and speed of the system. For example, to create frequency versus time spectrograms, adaptive delta modulation, transform coding, or adaptive quantizing are just a few of the possible scenarios, given an infinite amount of processing strength. In reality, the RPWS system uses an 8085 processor, thus only the most simple compression is possible. Thus, adaptive quantizing or delta modulation might may be selected in lieu of a transform coding system.

COMPRESSION SCENARIO: MFR

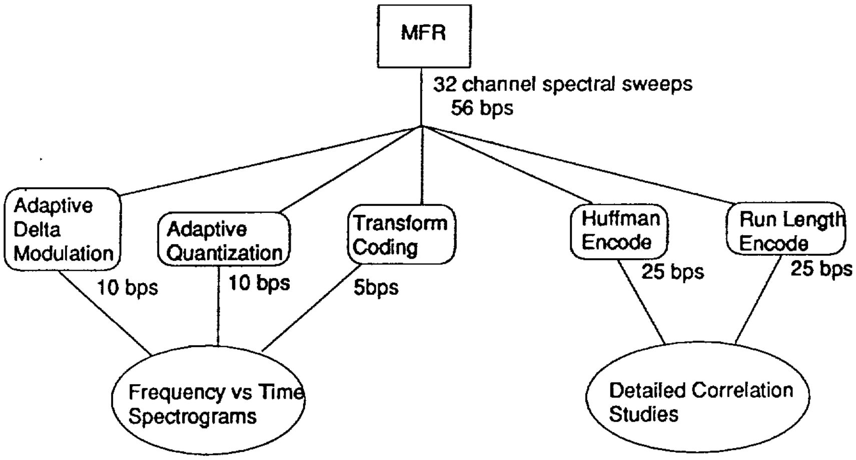

Figure 7 — An illustration of the logic that will be implemented to select the data compression systems for the DCP.

Conclusions

This brief report gives an overview of the Cassini RPWS data processing system. At this time, the hardware portion is well defined and is selected based upon weight, power, and development costs considerations. The corresponding software portion is more complicated, with many different scenarios possible depending upon the application of the data on the ground. Future work includes algorithm selection, testing, and development for the DCP.

References

[1] Gough M.P. and L.J.C. Woolliscroft, Microprocessors in Space Instrumentation, *Space Technology, 9*, 305 - 313, 1989.

[2] Woolliscroft, L.J.C., et al., Cassini radio and plasma wave investigation: Data compression and scientific applications, submitted, *J. Brit. Interplanetary Soc.*, 1992.

[3] Gurnett, D. A., *A plasma and radio wave science investigation for the Cassini orbiter*, Proposal to NASA, 1990.

[4] Bruce, C. E. R., and R. H. Golde, The lightning discharge, *J. Inst. Elec. Eng., 88*, 487–505, 1941.

[5] Warwick, J. W. et al., Planetary radio astronomy experiment for Voyager missions, *Space Sci. Rev., 21*, 309–327, 1977.

[6] Song, C.-L. et al., A variable-step robust delta modulator, *IEEE Trans. Comm. Tech., COM-19*, 1033–1044, 1971.