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A Digital Radio Receiver for Ionospheric Research

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ABSTRACT

Compared with the experience of the past few decades, ionospheric research in the near future will depend less on new science-dedicated orbital platforms and more on networks of ground facilities. An important role of scientific spacecraft in this context will be to provide space perspectives, as part of space-ground coordinated studies. The enhanced Polar Outflow Probe (ePOP) instrument suite will be launched on the Canadian CASSIOPE spacecraft in early 2008 for space-ground coordinated research. This low-earth-orbit payload will include three instruments for radio-scientific investigation of the ionosphere. One of the radio instruments is a four-channel digital Radio Receiver Instrument (RRI). RRI will be fed by four 3-metre monopoles, arranged in a crossed configuration, each connected to a high-input impedance preamplifier. The RRI bandwidth will extend from 10 Hz to 18 MHz.

RRI will measure the electric fields of either spontaneous waves or waves created by ground transmitters, such as ionosondes, high-frequency radars and ionospheric heaters. A review of the design features of the RRI reflects the observational requirements. Accurate measurements of the intensity, frequency, direction of propagation, and signal delay of such fields over the broad frequency range will be accomplished using modern digital receiver techniques. The amplified signals from the monopoles will be digitized at a rate of 40 megasamples per second, and from there, the signal will be down-converted, filtered, time-stamped, and communicated purely in digital form.

The major features of the RRI are described in the light of the measurement goals that inspired them. Results of recent end-to-end tests of the RRI protoflight model are followed by an outline of the operating modes of the instrument.

1. INTRODUCTION

The Radio Receiver Instrument (RRI) is being built for the Enhanced Polar Outflow Probe (ePOP) space-science payload. ePOP is one of two payloads on the upcoming Cascade SmallSat and Ionospheric Polar Explorer (CASSIOPE) satellite planned for launch in 2008 [1]. In an 80°-inclined elliptical orbit between 325 and 1500 km altitude, the RRI is designed to exploit recent advances in digital broadband radio techniques for research topics in space radio science. The science objectives are described in the present section, which is followed in Section 2 by a description of the major functional components of the RRI. Section 3 provides some results of characterization work on the engineering model. Section 4 concludes with indications of the flexibility in operating modes that can be attained in this software-controlled radio, serving as an invitation for

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space radio scientists who might like to propose some measurement routines with it and other ePOP instruments.

The ePOP payload development is the responsibility of the University of Calgary under a Contributions Agreement contract awarded by the Canadian Space Agency. The present paper follows an earlier article on RRI written around the time of its conceptual design [2]. The scientific objectives of ePOP/RRI have not changed significantly. Hence this paper emphasizes the details of the engineering design approach taken to meet the scientific requirements laid out in 2002.

1.1 Experimental objectives

The RRI is a four-channel digital ULF-HF receiver. It will be fed by four 3-m monopoles with preamplifiers. From below 100 Hz to about 3 MHz, the RRI will measure the electric fields of spontaneous waves. Between about 10 kHz and 18 MHz, the receiver will measure the electric fields of waves created by ground transmitters, such as ionosondes, HF radars, and ionospheric heaters. The scientific objectives of the RRI program will be to improve understanding in the following areas:

1.1.1 The morphology and dynamics of density structure in the ionosphere. The formation of density structures of a variety of sizes in the auroral regions is one of the important manifestations of the injection into the earth's atmosphere of energy and momentum originating at the sun. Fluid processes around the peak of the ionospheric F region, such as the gradient-drift instability, give rise to density irregularities. Joule heating may produce travelling ionospheric disturbances. Polar-cap patches are formed near the ionospheric cleft as a result of magnetospheric flux transfer. This part of the RRI agenda encompasses the detailed explanation of the physical origins of such structure and its subsequent motion through the ionosphere.

It is planned to observe waves from HF transmitters on the ground using the RRI on ePOP when it makes an orbital pass through the nearby topside ionosphere. The objective will be to measure 4 basic quantities of the waves: the electric field **E**, the Doppler frequency shift, the direction of arrival (DOA), and the signal-delay time. These four quantities can all be applied to the "imaging" of ionospheric structures that produce the backscattered or reflected signals observed at ground facilities. Such measurements will be coordinated with simultaneous recordings at the ground facilities.

1.1.2 The generation of spontaneous radio emissions created by auroral processes. The 325-to-1500-km altitude range of the CASSIOPE spacecraft will bring ePOP into the observation region of various wave-particle interactions (WPI) that give rise to freely propagating electromagnetic waves. The microphysical explanation of the exchange of energy between charged particles and electromagnetic (EM) waves can be addressed with the emphasis on processes involving energies that the ePOP Suprathermal Electron Instrument (SEI) and the Imaging Rapid Mass Spectrometer (IRM) can observe, that is, from thermal to about 100 eV. The WPIs that lead to upflowing ion conics and transversely accelerated ions will be investigated with the RRI set to detect waves in the Ultra Low Frequency to Very Low Frequency range. Broadband ion cyclotron waves and lower-hybrid resonance waves are in this category. An explanation will be sought for the trapping of intense lower-hybrid waves in density depletion cavities of 100–m extent.

1.1.3 The nonlinear plasma physics of the HF-modified ionosphere. In ionospheric modification experiments, HF waves are used to perturb the ionosphere. In the E region, the active change of plasma bulk properties through heating permits a controlled study of auroral electrojet-related processes. In the F region, stimulation of parametric instabilities provides insight into the role of nonlinearities in limiting microphysical plasma processes that influence bulk plasma characteristics. In previous experiments with the heater at

Arecibo, Puerto Rico, wave fields with fine scale structures, both directly from the heater and excited nonlinearly in-situ, were observed. The coordinated use of RRI with ionospheric heaters will elucidate the complex interplay between various electromagnetic (EM) and electrostatic wave modes and field-aligned density structures.

1.1.4 The physics and metrology of radiowave scattering, diffraction and refraction. The high-latitude ionosphere can have a dramatic effect on EM waves passing through it. Waves can be refracted, scattered, amplified, damped, or nonlinearly decomposed, depending on the local state of the medium. The results from the OEDIPUS-C mission illustrate the importance and efficiency of field-aligned ionospheric density structure in trapping and guiding HF EM waves. This structure may be the same as irregularities that coherently backscatter HF waves or those that cause spread-F in ionograms. Transionospheric propagation in ePOP will continue to exploit the attractions of two-point radio propagation experiments for better comprehension of the roles of scattering, diffraction and refraction.

These investigations of large-scale density structure, mentioned in Section 1.1.1, would be coordinated with searches for (oblique) backscatter from the small-scale irregularities.

1.2 Parameters to be measured

The RRI will measure and record various parameters associated with RF wave electric fields **E** incident upon the spacecraft. The magnitudes of **E** in the case of discrete modulated CW signals emitted by artificial sources on the ground below will need to be accompanied by information about the wave polarization or DOA of the incident waves. As explained in [3], the DOA should be determinable in the case of identifiable HF ground transmitters detected in upper branch O and X modes of cold-plasma propagation [4]. DOA will be determined by using the magnitude and relative phase of voltages induced on the RRI monopoles combined as orthogonal dipoles.

Detection of the Doppler Shift of artificial signal carrier frequencies will constitute an independent tool for checking the direction of propagation of waves. The application of time stamps on the received data stream will be made to the required accuracy of ±8 μs by connection to the spacecraft clock, which will be controlled by 1-pps ticks from the Global Positioning System (GPS) receivers in the GPS-based Attitude and Position (GAP) instrument in the ePOP payload. Absolute time will thereby allow determination of the absolute signal delay time of waves from the ground. A fourth wave parameter will thus be obtained that will aid the evaluation of imaging techniques.

In the case of observation of spectra of spontaneously emitted EM waves arising from wave-particle interactions, the **E** field spectrum E(f) will be an important representation of observed data. Spectra will be observed in particular characteristic frequency ranges, typically defined with respect to the electron plasma frequency and the electron gyrofrequency.

2. INSTRUMENT DESCRIPTION

2.1 Overview

The RRI design, to be described in this section, targets a dynamic range of 120 dB above an input threshold of 0.3 μV. This total range is achieved by dividing it into three overlapping preamplifier gain settings, each of 72 dB. Bandwidths up to a maximum of 30 kHz are available in each of the four receiver channels. Both the amplitude and relative phase of an incoming electric field can be measured. After suitable amplification, the signals are digitized and then processed by a digital down converter (DDC) and decimating low-pass filter. The resultant digital data are time-tagged to an accuracy better than ±8 μs.

Figure 1 shows the functional blocks comprising the RRI system. The system has four identical signal processing channels, of which two are shown. Each channel is tied to a single monopole antenna. Additionally, there is a power supply function providing the necessary voltage, current, and electromagnetic interference filtering for the electronic components, and a digital clock function required by the synchronous digital electronics. The following description treats the RRI as a system composed of three physically separate units: the antennas, the preamplifiers and a digital radio receiver module. These three separate functional units are identified with three background colours, which provide a link to the corresponding programmable parameters of Table 3, to be discussed in Section 4 below.

2.2 Monopole antennas

Monopole antennas detect the electric field intensity of electromagnetic waves at the CASSIOPE spacecraft. Each antenna is not intended to extract electromagnetic energy in the manner of a classic radio receiver; rather the antenna acts as a high-impedance voltage probe of the wave environment. In this passive antenna mode, the voltage appearing at the antenna terminals can be related directly to the amplitude of the wave field in the surrounding medium that induced it.

The monopoles are storable extendible members of BeCu forming a tubular structure 1.2 cm in diameter and 3 m long when released. Before launch these antennas are coiled up inside Delrin® insulating containers which are part of the antenna assembly. When an electrical signal is received from the spacecraft Data Handling Unit, a retaining door is released and the antenna's stored mechanical energy deploys the BeCu elements to their full length. The tubular antennas are 3-m “STEM Jib” monopoles manufactured by Astro Aerospace, and have considerable flight heritage.

2.3 Preamplifiers

The voltage induced by the electrical field of a wave on the antenna can lie within a wide dynamic range (at least 120 dB), in the low end requiring amplification and at the high end requiring attenuation. Amplification or attenuation is performed by the preamplifier (PA). The PA must also present a high input impedance to the monopole antenna to assure that the input voltage to the preamplifier is the open-circuit value.

The high dynamic range expected of input voltages also requires that there be some means of adjusting the gain of the PA to match the expected signal amplitude, so that the output signal stays within the linear dynamic range of the following digitizer block. Hence, the PA is shown accepting a gain control input command. Since the ePOP RRI experiments are planned in advance using the Instrument Modes in Section 4, the expected maximum signal amplitudes will also be known and the gain setting programmed. Therefore, an automatic gain control function is not used. The gain will be preset by ground control along with the other RRI programmable parameters listed in Section 4.

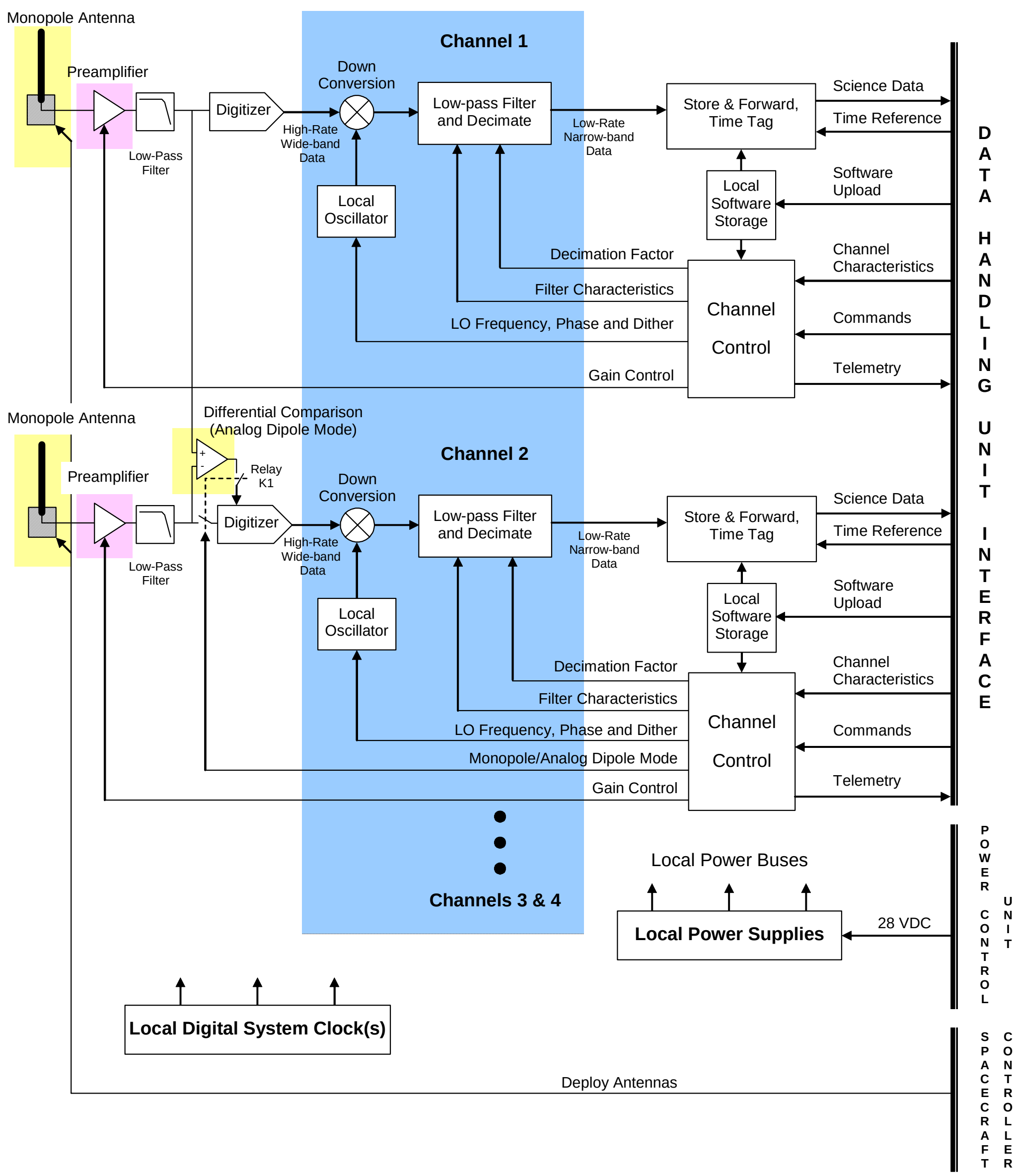

Figure 1: Top level functional block diagram of two of the four RRI channels.

2.4 Digital Radio Receiver Module

This section covers all the remaining functions in Figure 1, that is, the functions to the right of the pink-coloured PAs.

Digital radio techniques have been applied to the design of the RRI. The output of the PA is presented to a digitizer to convert the analog signal into a digital data stream. In preparation for this operation, an anti-aliasing low-pass filter is needed in advance of the digitizer to bandlimit the signal to, ideally, half the digitizer rate. The specified signal bandwidth is 18 MHz, therefore the digitizer must operate at a minimum sample rate of 36 MHz requiring an anti-aliasing filter with an 18-MHz bandwidth. A somewhat higher sampling rate, 40 MHz, has been chosen, to permit the filter to have a feasible high frequency roll-off. The analog-to-digital converter (ADC) selected for this function is the Analog Devices AD9238.

An alternate path of the filtered data is through the indicated differential comparison block. This block is switched in when opposing monopoles are combined in a dipole mode of operation. When switched in, a differential amplifier accepts the signals from two monopoles to produce an analog differential output signal which is presented to a digitizer instead of a monopole signal. A relay "K1" is shown toggling between the monopole and dipole connections. A differencing of digital monopole values can also be performed later during ground data processing, if required. Performing the operation in this way does not lose the individual monopole signal data, which may also be of interest. The output of the differential blocks is shown feeding into channel 2 only as a matter of convenience to simplify the diagram. Similar differencing blocks are positioned between channels 3 and 4.

The digitized signal is then mixed, or multiplied, with that of a stable, well-controlled local oscillator (LO), to move the signal band of interest down to the baseband region centred on DC. The frequency of the LO is programmable and changed according to the programmed plan for the current experiment. It is also possible to precisely program and synchronize the LO phase across the four channels. The LO mixer is, also, a complex-number device mixing the signal with two sine waves having a 90° phase difference producing an in-phase (I) and quadrature (Q) signal output. These two I and Q signal trains are processed in parallel throughout the rest of the system.

The mixed signal is then filtered by the low-pass decimating filter block. The low pass filter aspect simply rejects the out-of-band high-frequency signal components. Since a finite impulse response (FIR) filter is employed in this filter block, it is also readily capable of other, more sophisticated operations such as matched filtering. The decimating aspect modifies the output sample rate to better match the reduced signal bandwidth. For instance, if the analog signal is sampled at a 40-MHz rate and then filtered to a working bandwidth of 30 kHz, the filtered output signal is adequately represented by a 60-kHz sample rate. The decimating filter removes the unnecessary samples so that the subsequent processing stages in the system are presented with a more manageable, and meaningful, data rate. All of the functions in the blue area of Figure 1 are carried out by an Analog Devices AD6624 four-channel DDC.

The low-rate filtered data are then fed to the final processing block where they are given a time tag associated with an absolute GPS time reference. These time-tagged data are briefly stored and then transmitted in a message block to the spacecraft control and Data Handling Unit (DHU). A GPS time reference is received from the DHU every second. Between GPS updates the local clock providing the time stamp must be accurate to ±8 μsec.

The preamplifier gain, the LO characteristics, the filter characteristics, and the decimation factor are all set by the Channel Control block. These settings are uploaded and changed on command from the spacecraft DHU. The Channel Control block also monitors the RRI internal status and Built-In Test (BIT) results, reporting this information to the DHU as telemetry.

The “Store and Forward", "Time Tag”, and “Channel Control” blocks are implemented in an Analog Devices ADSP-2191M Digital Signal Processor (DSP) under software control. This software will be loaded on startup from the Local Software Storage block, an EEPROM. This software can be modified or upgraded by the spacecraft DHU. Hence, a software upload data path is shown. Also, the channel control block can check the integrity of the Software Storage and report integrity back to the DHU within the telemetry stream.

Finally, two support functions are shown at the bottom: the "Local Power Supplies" block, and the "Local Digital System Clock(s)". The Power Supplies block converts and regulates the voltages and provides the current flow required by the RRI electrical devices from the Spacecraft 28 VDC unregulated power source. It also provides the required electromagnetic interference filtering. The Digital Clock(s) provides the local clock signals (plural since more than one frequency and/or phase is needed), sourced from a stable crystal oscillator, required by the synchronous digital electronics.

2.5 Monopole antenna supports and PA enclosure

Figure 2 shows the major features of the BeCu tubular monopoles in relation to their Delrin® deployer housings, the support brackets, and the PA enclosure. Such a design realizes the objective of bringing the inboard ends of the tubes as close as possible to the points where they electrically connect to their respective PA inputs inside the PA enclosure.

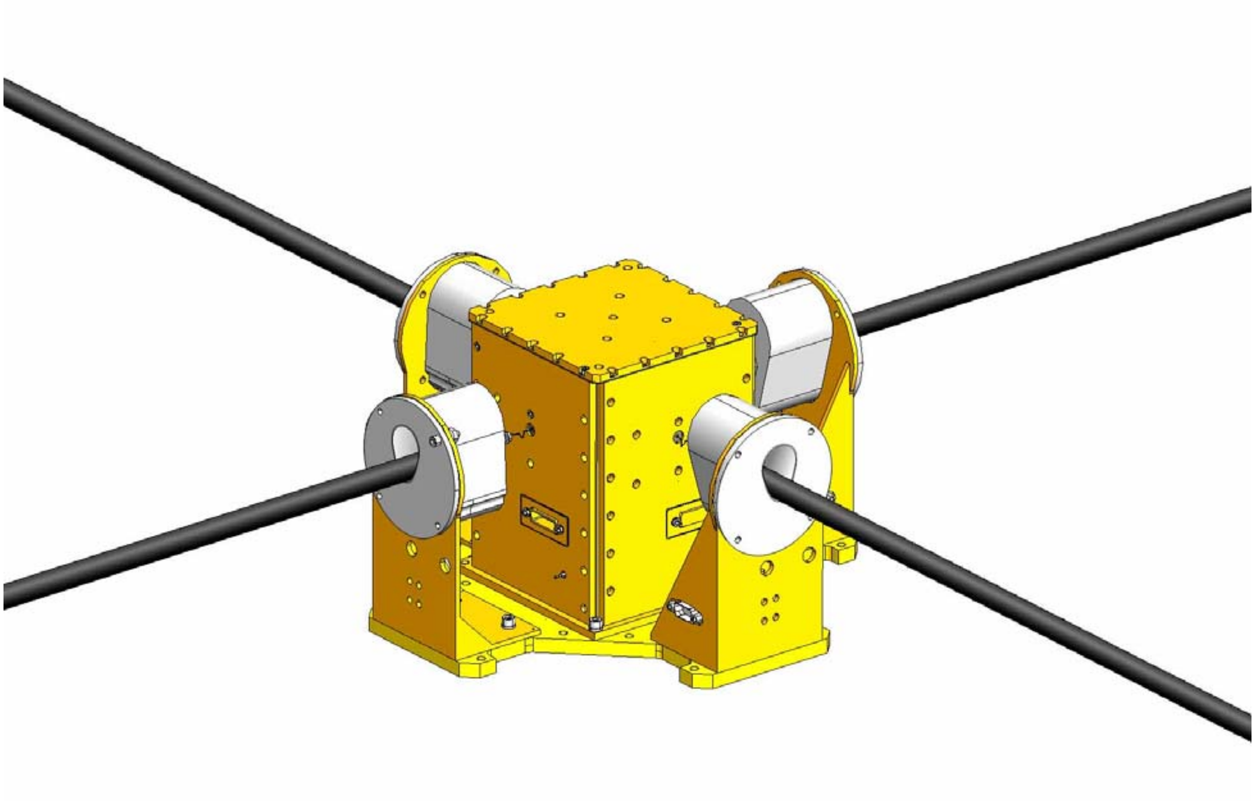

Figure 2: Preamplifier enclosure and supports for monopole deployers, in white.

The antennas deploy under the energy of storage imparted to them when they are placed in the Delrin® deployers. A non-pyrotechnic actuator releases spring-loaded doors on the front face of the deployers. In turn, the BeCu elements deploy under their storage energy.

The RRI monopoles will lie in a plane parallel to, and slightly above, the $+x$ face of the CASSIOPE spacecraft. A full view of the spacecraft with the RRI monopoles and all other instrument probes deployed is in Figure 3. The CASSIOPE spacecraft has an attitude control system that permits the spacecraft to take one of several different orientations, including one which slews fast enough to keep a spacecraft-centred direction fixed on an earth target. In the spacecraft orientation most frequently used, the +*x* axis will lie parallel to the spacecraft velocity direction, and the +*z* axis, parallel to the Coherent Electromagnetic Radio Tomography (CERTO) and Magnetic Field (MGF) instrument booms, will be the nadir direction.

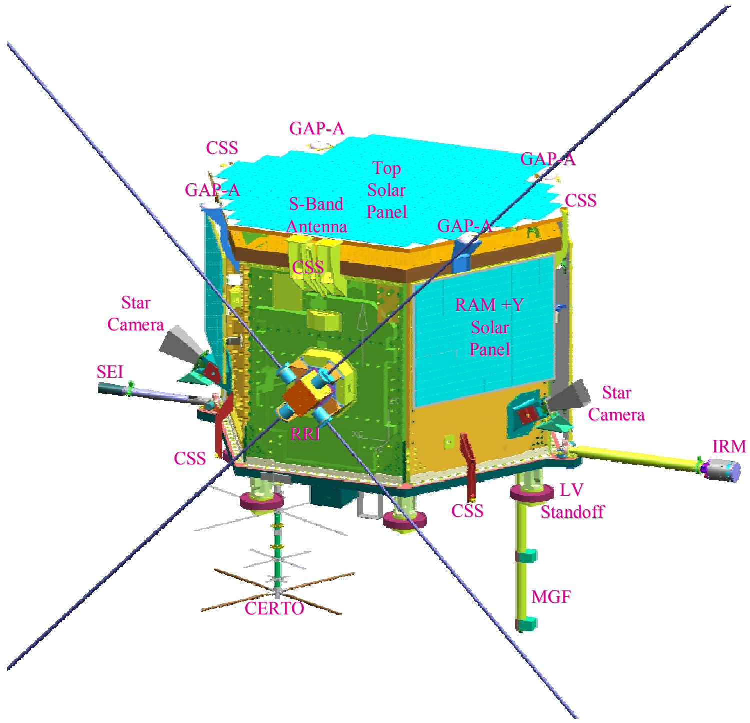

Figure 3: Four 3-m RRI monopoles deployed on the +*x* face of the CASSIOPE spacecraft, and other instruments of the ePOP payload [1].

2.6 Tabular summaries of RRI design

Table 1 is a list of the main parameter ranges achieved for RRI operations. Table 2 summarizes the resource requirements of the RRI on CASSIOPE.

Table 1: Parameter ranges.

Parameter	Value
Preamplifier	
Input impedance	$> (\omega 10\ \text{pF})^{-1}$
Low level signal range	0.32-1260 μV
Mid level signal range	0.010-39.8 mV
High level signal range	0.32-1260 mV
Digital radio receiver	
Frequency range	10 Hz-18 MHz
Baseband sampling rate	$\leq$ 60,000 s^{-1}
Full scale sample range	2^{12}
Bandwidths	1, 5, 30 kHz
Settling time	$\leq$ 100 μs
Time stamp accuracy	$\pm$ 8 μs
Output streams	Four (I , Q)
Total data rate	3.84 Mbits s^{-1}
Environment	
Survival temperatures	-20 to 60 C
Operating temperatures	-10 to 40 C
Tolerable radiation dose	15 krad

Table 2: Resource requirements of the RRI.

Component	Mass, kg	Volume, cm^3	Dimension, cm	Power, W
Preamplifier				
Monopole antenna (ea.)	0.23	-	7.9 x 8.3 (dia.)	-
Monopole bracket (ea.)	0.16	720	13 x 8.3 x 6.7	-
Circuit Card Assembly (ea.)	0.05	-	7.9 x 7.9	0.55
Enclosure and hardware	3.16	2900	13 x 13 x 17	-
Total	4.92	5800	30 x 30 x 18	2.2
Digital Radio Receiver Module				
Enclosure and hardware	1.52	1600	20 x 16 x 5	-
Digital radio receiver circuit	0.25	-	5.4 x 3.1	3.3
Power supply circuit	0.22	-	5.1 x 2.4	2.0
Total	1.99	1600	20 x 16 x 5	5.3
Cable Harness				
Connector and backshell (ea.)	0.08			
Cable (2 m @170 g m^{-1})	0.34			
Total	1.68			
Instrument total	8.68	7400	-	7.5

3. RESULTS OF ENGINEERING MODEL BENCH TESTS

Engineering models have been constructed of all the RRI electronic circuit cards. These have proven valuable for validating the design performance of the instrument and identifying areas for improvement. A number of the engineering model test results are provided in this section.

The preamplifier gain control was designed not only to be always within the dynamic range of the digital radio receiver, but also to have a linear response (in dB) to the control voltage setting. The measured gain values presented in Figure 4 show that this objective was achieved.

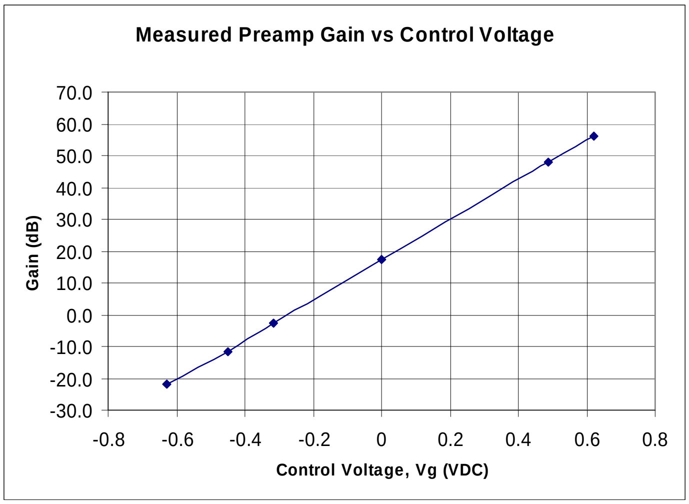

Figure 4: Preamplfier gain linearity.

Another RRI design challenge was a flat frequency response over the 10 Hz to 18 MHz bandwidth of the instrument for all gain settings. Figure 5 shows the frequency response over the full gain range of the instrument. The four gains shown were chosen only for purposes of illustration, but are not specifically used by the instrument. As is seen, the objective of wideband flat gain performance has been achieved, though the high frequency roll-off begins at 16 MHz.

The end-to-end frequency response of the radio, within the preamplifier bandwidth, is determined by the filter characteristics programmed into the DDC. As such, there are an almost unlimited number of filter response illustrations possible. Since RRI is principally concerned with fixed bandwiths at or below 30 kHz, we illustrate in Figure 6 the results of a 10-kHz test filter centred at approximately 1.2 MHz. The stop band curves have been clipped in order to expand the display of the passband. The shape of the passband is consistent with that predicted by the SoftCell filter design software used.

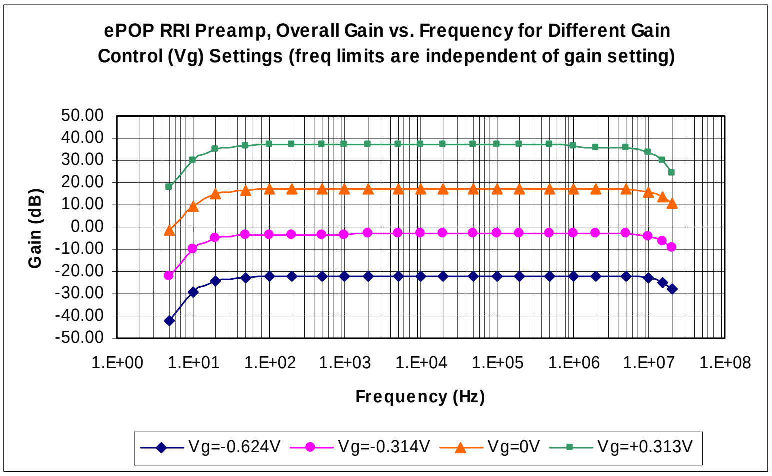

Figure 5: Preamplifier Bandwidth.

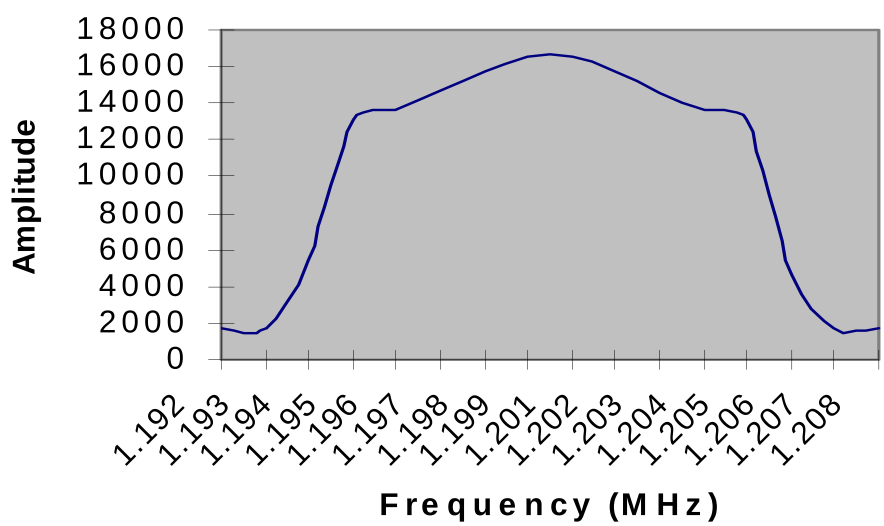

Figure 6: RRI 10 kHz bandwidth filter response.

4. RRI INSTRUMENT MODES

RRI has been designed as a scientific instrument with digital control and considerable flexibility in operating parameters. The processing of signal values undertaken by the RRI Digital Signal Processor aboard CASSIOPE is minimal compared with what has been required in other spaceborne scientific radio receivers. The large telemetry bandwidths available on CASSIOPE allow the sampled baseband signal data from the digital downconverter to be telemetered directly to ground for processing there. After data analysis, subsequent measurements will be undertaken usually with some change in instrument configuration, to zero in on a particular wave phenomenon during subsequent CASSIOPE passes. This rationale has the option of post-launch reprogramming of the RRI for new instrument modes not anticipated before launch.

The purpose of this section is to give potential users of RRI data an idea of the operating mode choices that will be available. At payload level, each ePOP payload Operating Mode is conceived to address a scientific objective. Each ePOP mode calls up particular modes of some of the instruments in the payload suite. To date, 12 RRI instrument modes have been identified to respond to the range of perceived uses of the instrument. They are tabulated in Table 3. The parameters shown in each box are default values, any of which can be changed for a particular spacecraft data-recording session. The spacecraft telecommand timeline will call up RRI and other instrument modes in the order that they are required. The RRI command structure will indicate which of the parameters are to be changed from the default values in Table 3.

The instrument parameters have been grouped into major sectors corresponding to major functional areas in Figure 1, where the colour coding identifies the relevant part of Table 3. The yellow colour highlights the selection of monopole antennas to be used. The most frequently used combination is the differential mode. Here the K1 switches are positioned to subtract signals from opposite monopoles, thus producing a dipole analog signal which is subsequently digitized and processed. Only RRI11 and RRI12 record monopoles separately. These two modes anticipate investigation of the electromagnetic performance of separate monopoles.

In Figure 1, the preamplifiers are pink coloured. Their only variable parameter is gain, which is set at "low" level, meaning high gain, for low-level signals, and so on. The low-level, mid-level and high-level settings that lead to linear processing of signals are shown in Table 1. The row "FF/SF" indicates whether the frequency is fixed (FF) or swept (SF). "DF" sets the frequency step in a sweep mode. "Lin" called for a linear sweep, and "Log1" calls for a sweep in which the centre frequencies are stepped in a particular logarithmic fashion.

The entries in Table 3 can be related to the scientific investigations in Section 1 which prompted them. The imaging of ionospheric structure in 1.1.1 using transmissions from a SuperDARN (SD) transmitter on the ground will call upon mode RRI01. Here the receiver bandwidth BW of 30 kHz has a default central fixed frequency (FF) of F0 = 10 MHz, the SD carrier frequency. Assuming that the **E** field strength at the spacecraft of waves from a SD transmitter with an effective radiated power of 1 MW is of the order of 1 mV m^{-1}, and that the dipoles formed from monopole pairs have effective lengths of half their physical lengths, an open-circuit voltage of 3 mV results at the PA input. This level is closest to the logarithmic centre of mid-level gain setting. The I and Q components of the baseband signal are both telemetered, to allow |**E**|, DOA, Doppler frequency and signal delay to be found at ground processing.

The two-step sweeps in RRI02 and RRI04 have similar objectives, for work with Canadian Advanced Digital Ionosondes (CADIs) on the ground. The distinction is that the CADIs have two intervals of fixed frequency operation interspersed with their conventional 1-20 MHz sweep in their duty cycle. The RRI receiver mode alternates between the two known fixed frequencies F1 and F2, and does not attempt to synchronize with the CADI sweep.

Table 3: RRI Instrument Mode with parameter default settings

Instr. mode →	RRI01	RRI02	RRI03	RRI04	RRI05	RRI06	RRI07	RRI08	RRI09	RRI10	RRI11	RRI12
Parameter↓												
PA level												
Mono. 1	Mid	Mid	Low	Mid	Mid	Low	Low	Low	Mid	Low	Mid	Mid
Mono. 2	Mid	Mid	Low	Mid	Low	High	Low		Mid		Mid	Mid
Mono. 3	Mid	Mid	Low	Mid	Mid	Low	Low	Low	Mid	Low	Mid	Mid
Mono. 4	Mid	Mid	Low	Mid	Low	High	Low		Mid		Mid	Mid
Switch K1	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.	Diff.	Mono.	Mono.
DDC INA												
Monopoles	1, 3	1, 3	1, 3	1, 3	1, 3	1, 3	1, 3	1, 3	1, 3	1, 3	1	1, 3
FF/SF	FF	SF	FF	SF	FF	FF	FF	SF	FF	FF	FF	FF
BW kHz	30	30	30	30	30	30	30	5	30	30	30	30
F0 MHz	10		0.015		0.015	0.015	1.00, 1.03		0.015	0.015	15	15
Sweep		Lin.		Lin.				Lin.				
F1 MHz		3		3				1				
F2 MHz		5		5				5				
DF MHz		2		2				0.025				
Dwell s		1		1				0.001				
Components	I,Q	I,Q	I	I	I	I	I,I	I	I	I	I,Q	I,I
DDC INB												
Monopoles	2, 4	2, 4	2, 4	2, 4	2, 4	2, 4	1, 3		2, 4	1, 3	3	2, 4
FF/SF	FF	SF	FF	SF	FF	FF	FF			FF	FF	FF
BW kHz	30	30	30	30	30	30	30			30	30	30
F0 MHz	10		0.015		2	3	1.06,1.09			3	15	15
Sweep		Lin.		Lin.					Log1			
F1 MHz		3		3					1			
F2 MHz		5		5					5			
DF MHz		2		2					x1.1			
Dwell s		1		1					0.001			
Components	I,Q	I,Q	I	I	I	I	I,I		I	I	I,Q	I,I

Section 1.1.2 is concerned with spontaneous radio noise generated by energetic particles in the auroral zone. Where the objective is to examine continuously emissions in some fixed band, on one dipole, while logarithmically sweeping the frequencies near the plasma frequency on the other dipole to understand the plasma context, RRI09 will be applied. Histories of the variation of noise characteristics can be tracked in a fixed-frequency band using RR01, RR03 or RR08, with PA probably set to "Low". RRI08 will be used when the RRI supports other ePOP instrument objectives through the recording of the noise intensity spectrum. The linear-with-time ("Lin") sweep limits of 1 and 5 MHz will need to be changed depending on the anticipated plasma conditions in the ionospheric neighbourhood being studied. RRI07 exploits the software radio concept by sampling noise in one I signal across 4 adjacent bandwidths, stretching over a bandwidth of 120 kHz extending from 985 to 1105 kHz in the default case.

The investigation of the nonlinear ionospheric responses to intense HF waves in Section 1.1.3 can be supported by RRI. Mode RRI05 will be used in the search for VLF radiation from auroral-electrojet modulation operations. RRI06 has the particular role of measuring both intense primary heater waves near the pump frequency in the DDC's input bus B (INB) channel and simultaneously the much weaker nonlinear wave products at ULF-VLF frequencies, in DDC input bus A (INA). RRI10 may be alternated with RRI06 when it is desirable to know the importance of antenna orientation, hence of wave polarization, in these nonlinear plasma processes.

Section 1.1.4 above is concerned with wave metrology in space. The character of scattered waves can be investigated with RRI01 or RRI02 with a level of "Low" presumably needed. RRI11 is used to acquire the I and Q signals from opposite monopoles when recording a well characterized ground source. When run alternately with RR01, RRI11 can be used to confirm our understanding of the forming of a dipole signal through the subtraction of two monopole signals. RRI12 will be used to research the symmetry of the four monopoles on the spacecraft forming two orthogonal dipoles. Closely commanded RR01, RR11 and RR12 could provide a more complete understanding of the RRI antennas.

5. CONCLUDING REMARKS

The RRI project in ePOP assumes that there will continue to be a need to understand the microscale physics of processes occurring in localized regions of the ionosphere. Investigations on regional or even global scales of the ionosphere will only succeed if there is adequate attention to the microscale descriptions that are the theoretical foundations of the larger-scale models. Also, technologies developed heretofore for measuring space plasmas do not have sufficient resolution to address small-scale structures being discovered in the ionosphere. The ePOP/RRI instrumentation will answer this call for improved observations. Special applications of the RRI to in-situ active experiments will show clearly the pertinence of this approach to space radio science. Electromagnetic wave observations and analysis remain an integral part of research on the physics of unbounded space plasmas, in particular the low density plasmas of the ionosphere-magnetosphere system.

It is hoped that, through the acquisition in Canada of a space-borne digital receiver, RRI will enhance other national opportunities to exercise and expand our expertise in high-latitude space plasmas. RRI will exploit niche opportunities in Canada, and elsewhere, for multipoint investigations with ground and other space facilities. RRI will thereby help to maintain the traditional Canadian expertise in space-borne radio equipment.

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References

[1] Yau, A.W., H.G. James, and W. Liu, The Canadian Enhanced Polar Outflow Probe (e-POP) Mission in ILWS, Advances in Space Research, in press, 2005.

[2] James, H.G., C.L. Siefring, and E.P. King, "The Radio Receiver Instrument on the e-POP small satellite", Conf. Proc., 12th Conf. on Astronautics Astro2002, CASI, Ottawa, Canada, 12-14 Nov. 2002.

[3] James, H.G., High-frequency direction finding in the ionosphere, Rev. Sci. Instrum., 74(7), 3478-3486, 2003.

[4] Budden, K.G., The Propagation of Radio Waves - The Theory of Radio Waves of Low Power in the Ionosphere and Magnetosphere, Cambridge University Press, Cambridge, 1985.