4.12 STATE-OF-THE-ART RADIOSONDE TELEMETRY

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1. INTRODUCTION

This paper introduces a new Vaisala ground equipment radio receiver, the ”Software Radio”. Used together with the Vaisala digital radiosonde RS92-AGP, this technology answers the increasing demand for telemetry link performance and bandwidth efficiency.

The fully digital telemetry link between the RS92-AGP radiosonde and the ground equipment using the Software Radio enables the use of modern digital modulation methods, error correction algorithms and telemetry diagnostics. The technology used in the Software Radio is similar to that used in cellular phones and their base stations.

The telemetry link performance of the new sounding system is based on the properties of GMSK (Gaussian Minimum Shift Keying) modulation, Reed-Solomon error correcting coding and the Software Radio receiver. The advantages achieved with the new system are reliable, low-power narrowband radiosonde transmission and increased temporal data resolution of two levels per second.

2. SOFTWARE RADIO

The Vaisala Software Radio is a modular, multifunctional, reconfigurable software receiver with a broad dynamic range and network connection. It will replace the current Vaisala URR20/UPP201 radiosonde receiver in the DigiCORA **III** generation of sounding ground equipment. The intention is that it will receive all existing and future Vaisala transmitter types used in the RS80 and RS9x generations of radiosondes.

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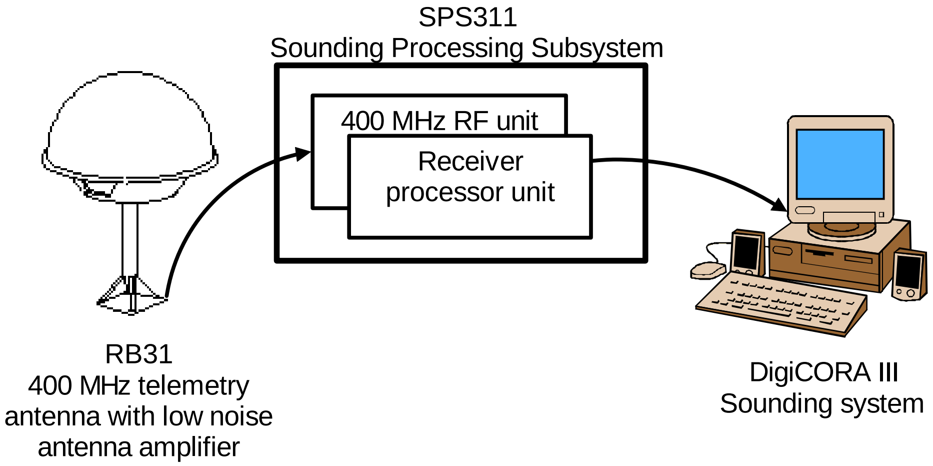


Figure 1. The Software Radio hardware.

The Software Radio hardware consists of a low-noise antenna amplifier which resides in the antenna, a 400MHz RF receiver unit and a receiver processor unit.

In the 400MHz RF unit the entire 400...406 MHz meteorological frequency band is first translated to an indermediate frequency (IF) band of 16...22 MHz. The IF signal is then sampled by a high-performance, 14-bit analog-to-digital converter using a sampling rate of 64 Msamples/second. Filtering and down conversion of the digital signal to the baseband is done with a digital down converter (DDC) in the receiver processor unit. Multiple digital down converters are used to enable multichannel reception.

Further processing of the signal – demodulation, error detection/correction and telemetry analysis – is done in a powerful 32-bit floating point digital signal processor (DSP).

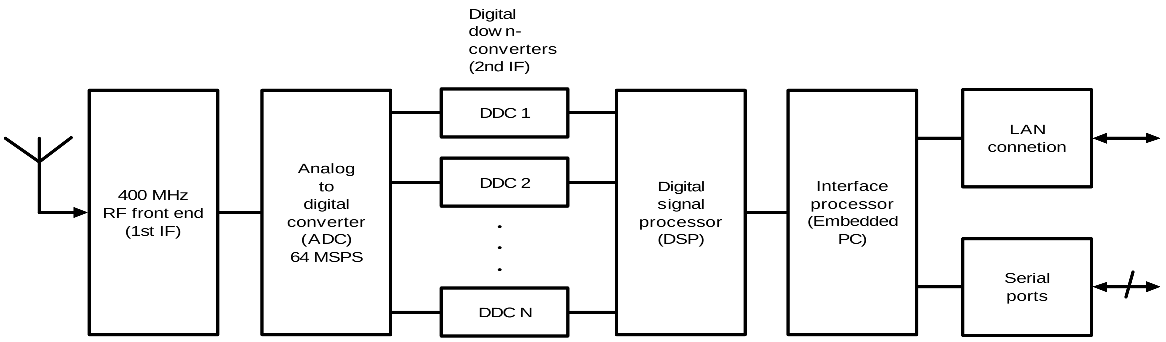
The signal processor sends the data to a front processor server process that takes care of the data delivery to the sounding software client processes according to the data subscriptions. The server process also communicates with the GPS unit of the sounding processing subsystem and delivers the local GPS data for windfinding.

The main emphasis in the design of the radio receiver has been to improve the spurious free dynamic range and sensitivity over its predecessors. Some specifications of the 400 MHz RF unit can be seen in the table below.

Table 1. 400 MHz RF unit specifications.

Frequency Range	400 … 406 MHz
Noise Figure	8 dB
Intermediate Frequency	16 … 22 MHz
Image Rejection	45 dB
Spurious Free Dynamic Range	80 dB
Third Order Intercept Point (IIP3)	+16 dBm
Maximum Input Power Level	-9 dBm full scale

Figure 2. The Software Radio receiver.



3. TELEMETRY

3.1. Digital telemetry

Figure 3. below describes the general principle of the digital telemetry link. Digital systems use digital modulation that modulates the carrier directly.

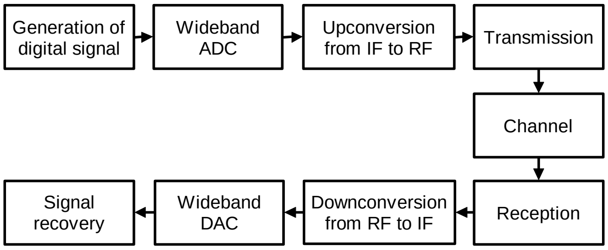


Figure 3. Digital telemetry link.

In the digital transmitter, the waveforms are generated as sampled digital signals, converted from digital to analog via a wideband digital-to-analog converter (DAC) and then possibly upconverted from the intermediate frequency (IF) to the radio frequency (RF).

The digital receiver, similarly, employs a wideband analog-to-digital converter (ADC) that captures the entire frequency band. The receiver then extracts, downconverts and demodulates the channel waveform using software loaded in a general-purpose digital signal processor, Mitola (1996).

3.2 Implementation of the telemetry

The RS92-AGP transmits a GMSK (Gaussian Minimum Shift Keying) modulated signal which carries 2400-bit data frames at a data rate of 4800 bps. The radiosonde frame is divided into several sub-blocks. Each sub-block is followed by a CRC-16 checksum to ensure that the data is valid. In addition, each data frame is protected with Reed-Solomon check-bytes that are used in error correction. A maximum of 12 corrupted 8-bit-long bytes can be corrected within each 255-byte-long data frame. Data is also scrambled to get a uniform distribution of ones and zeros and to avoid long sequences of the same value.

In the receiver end, the demodulated baseband data is descrambled and the Reed-Solomon error correcting algorithm is applied. The data is then validated by using the checksums.

Figure 4. shows the different phases of the signal processing in the transmitter and in the Software Radio receiver.

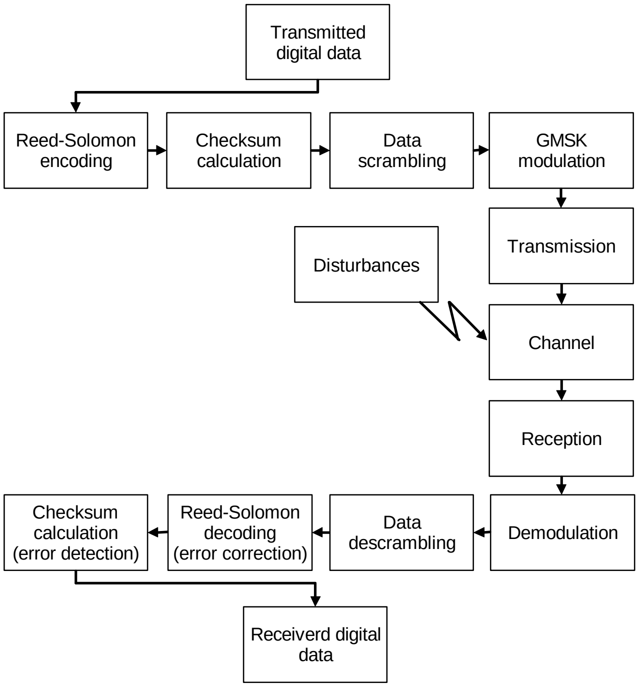


Figure 4. Digital signal prosessing in the transmitter and the receiver.

3.2.1 GMSK modulation

The transmitter modulates the carrier wave using GMSK (Gaussian Minimum Shift Keying) modulation. GMSK modulation offers a compromise between high spectrum efficiency and an acceptable level of demodulation complexity. It enables a narrow spectral width and thus makes it possible to use several channels in the allowed frequency band. GMSK modulation also makes it possible to achieve a low level of adjacent channel interference.

A GMSK-modulated signal has a constant envelope which makes it possible to amplify the signal with simple nonlinear amplifiers. This reduces the receiver's power consumption, an important advantage in battery-powered devices, A. Linz, A. Hendrickson (1996).

3.2.2 Reed-Solomon error correction

Reed-Solomon error correction coding is a widely used error correction method in wireless communications. It is suitable for applications in which data is naturally structured in blocks. The Reed-Solomon encoder adds redundant bits to the blocks of digital data and the encoder attempts to recover the original data distorted by the transmission channel. However, the redundancy level is not high and thus Reed-Solomon is suitable for applications in which channel capacity is relatively low.

By nature, Reed-Solomon coding is especially effective in correcting burst errors, that is, data that is not handled by bits but by m-bit-long symbols. An (n, k) Reed-Solomon code has $n = 2^m - 1$ code symbols and k message symbols. The number of parity check symbols is $n - k = 2t$. Such a code is capable of correcting t erroneous symbols in the code.

The code used in the radiosonde is $RS(255,231)$, $m = 8$. Thus 12 erroneous symbols per each block of 255 symbols can be recovered. This means that 4.7% of the symbols can be erroneous without the system losing any data.

Reed-Solomon coding enables transmission error correction at the receiver. The signal-to-noise ratio can be reduced without losing any information. It is also possible to calculate the coding gain for a given code. With the Reed-Solomon coding described above, the coding gain is approximately 4 dB. In other words, with Reed-Solomon coding, the transmitter signal power can be greatly reduced in comparison to a similar system that does not use Reed-Solomon coding, F. Carden (1995), A. Houghton (1997)

3.2.3 CRC-16 checksum

The Reed-Solomon decoder does not reliably detect more errors than it can itself correct. Therefore, a special checksum must be used in addition to the Reed-Solomon coding in order to reliably detect frames which have more errors than can be corrected by the Reed-Solomon decoder. Sub-blocks with a valid checksum can be used even if the rest of the frame is corrupted.

4 SOUNDING TESTS

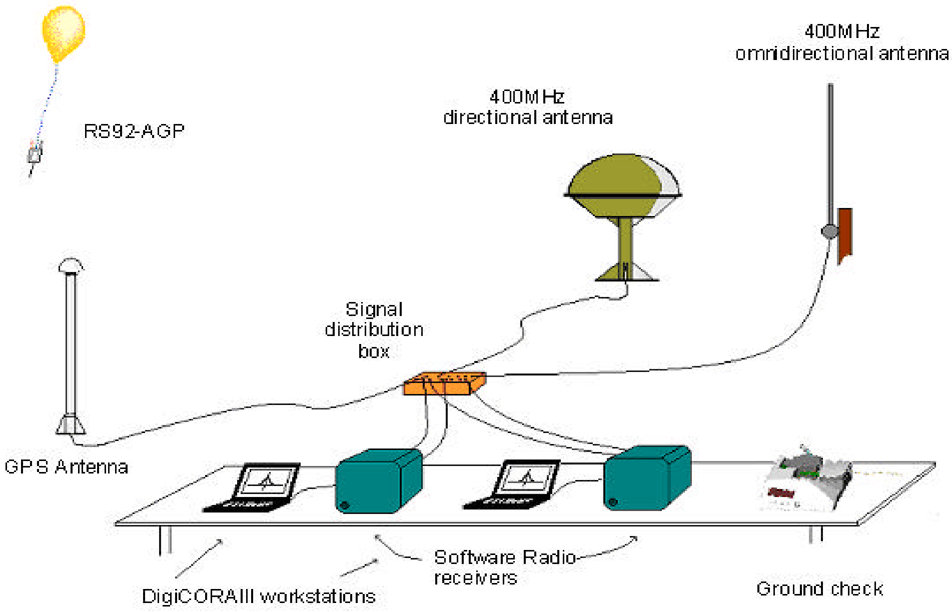
In this paper performance of the telemetry with different types of antennas and the effect of the Reed-Solomon algorithm are investigated.

The results have been collected from three test sounding sets using RS92-AGP radiosonde and the Software Radio receiver. The soundings were conducted in the premices of the Jokioinen Observatory of Finnish Meteorologigal Institute during the year 2003.

4.1 Test setup

The measurement setup in Jokioinen is presented in Figure 5. There were two different setups, one using a directional antenna and the other using an omnidirectional antenna. The GPS antenna signal was shared for the two systems.

Figure 5. Test setup.



4.2 Test results

4.2.1 Antenna performance

The transmitted signal is affected in several ways during the transmission. It is bent, scattered and reflected in the atmosphere. At 400 MHz and within the distances in the radiosonde soundings these phenomena are not very significant. The most important propagation mechanisms of the radiosonde signal are the line-of-sight propagation and multipath propagation. The latter is problematic, because it can cause fading that degrades the performance of the telemetry link. Buildings, hills, forest and other obstacles can cause diffraction and therefore fading through multipath propagation. This makes the performance of the telemetry link dependent also of the sounding environment, the kind of an antenna that is used and the location of the antenna, Pousi (2003).

To compare the performance with the directional and omnidirectional antennas single RS92-AGP radiosondes were received with both setups presented in Figure 5.

Signal to noise ratios (SNR) and occurred frame errors for both antennas in an exceptionally long sounding are printed in the Figure 6. With the omnidirectional antenna the error count starts to increase after 160 km and the signal is too weak for reception at about 270 km. The directional antenna performed well up to 320 km.

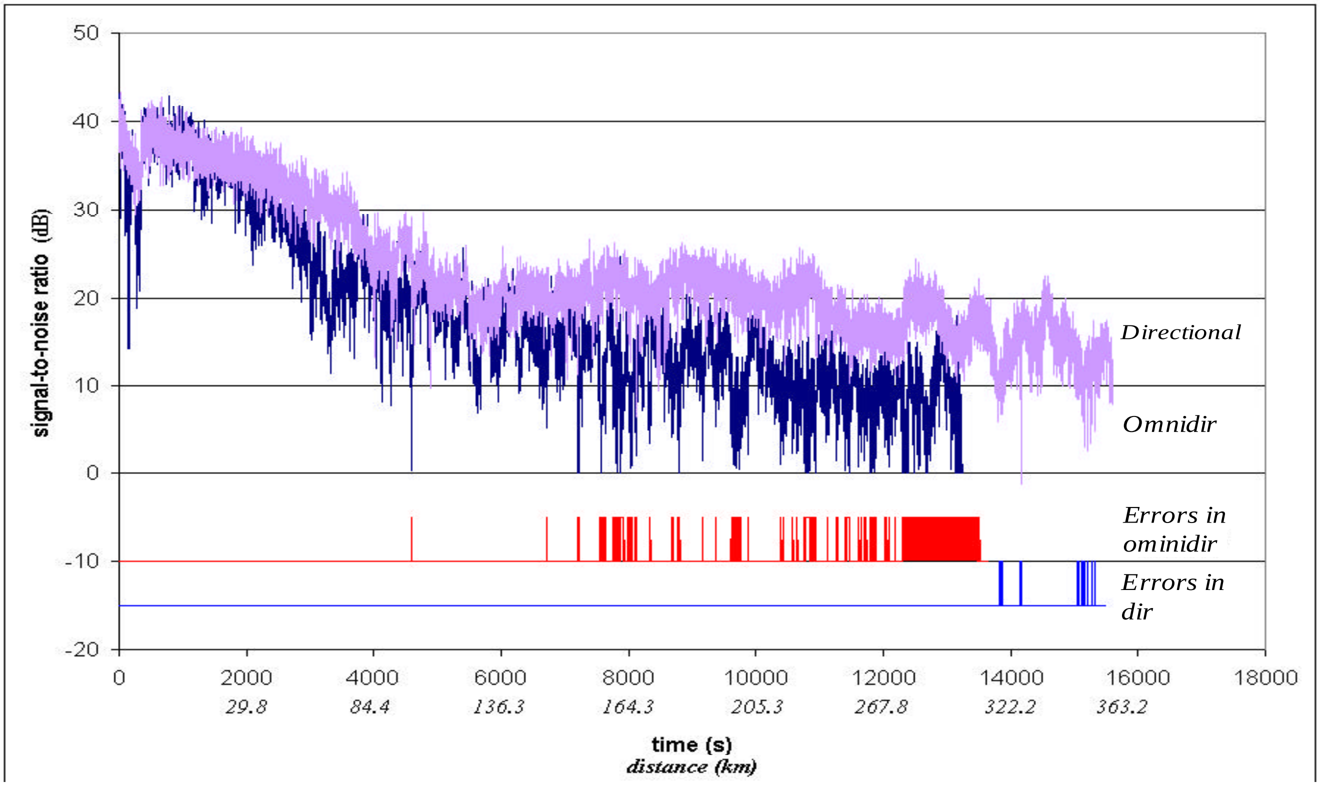
As can be expected, there are rather large variations in the SNR with the both antennas. It can also be seen that there are more rapid changes with the omnidirectional antenna. The omnidirectional antenna is more sensitive to multipath fading which is the most important reason for the signal level variations. It is also probable that the narrower radiation pattern of the omnidirectional antenna is more sensitive to the movements of the radiosonde during the ascent, Pousi (2003).

4.2.2 Effect of Reed-Solomon algorithm

The effect of the Reed-Solomon algorithm was studied only with omnidirectional antenna. This is because the radiosonde search algorithm selecting the directional antenna element may cause additional errors that are corrected by the Reed-Solomon algorithm, but make the interpetation of the results somewhat more complicated.

The results of the test soundings can be seen in Table 2. In the table *FER with EEC* stands for frame error ratio with error correction and thus *FER no EEC* is frame error ratio with no error correction.

Figure 6. Test sounding with two antennas.



As can be seen from the Table 2. the Reed-Solomon algorithm has a dramatic effect on FER. The selected Reed-Solomon code *RS(255,231)* seems to be cabable of correcting most errors within the sounding range in most cases. In practise this also means that the burst errors are less than 12 bytes long.

5. SUMMARY

The fully digital telemetry link between the RS92-AGP radiosonde and the ground equipment using the Software Radio enables the use of modern digital modulation methods, error correction algorithms and telemetry diagnostics. The advantages achieved with the new system are reliable, low-power narrowband radiosonde transmission and increased temporal data resolution of two levels per second.

6. REFERENCES

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Mitola 1996: What is a software radio?, www. ourworld.compuserve.com/ homepages/ jmitola, Copyright Mitola's Statisfaction, all rights reserved, used by permission for educational purposes

Pousi 2003: Digital Meteorologigal Radiosonde Telemetry, Master's thesis

Table 2. Results of the test soundings.

SNo	Range [km]	Height [km]	FER with EEC [%]	FER no EEC [%]
Y3627235	78	26	0.120	6.740
Y3627738	52	18	0.140	7.690
Y3627219	51	20	0.034	6.660
Y3627201	53	26	1.930	10.850
Y3627212	54	21	0.014	6.700
Y3627203	54	24	0.012	2.390
Y3627210	50	27	0.048	5.110
Y3627211	47	24	0.013	5.220
Y3627204	48	25	0.012	4.990
Y3627198	71	27	0.150	7.160
Y3627196	70	30	0.390	6.890
Y3627205	72	30	0.390	6.500
Y3627206	80	28	0.010	5.560
Y0617110	161	28	3.680	9.840
Y0647077	146	30	1.940	6.620
Y0647086	173	26	0.190	4.320
Y0617071	100	28	0.510	7.270
Y0647084	100	29	0.360	6.990
Y0647078	76	34	0.017	7.490
Y0647098	50	13	0.036	3.800
Y0617005	108	34	0.016	0.240
Y0537028	161	27	0.097	2.460