A Software Defined Radio AIS for the ZA-002 Satellite

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Introduction

- Design and implementation of a SDR AIS receiver
- GMSK demodulator, symbol synchronizer
- Experimentation with actual AIS signals
- Monitor marine traffic
- Scientific experiment in SDR
- Possibility of reconfiguring radio on satellite, through software updates
- SDR space applications, changing satellite mission, reconfiguring radio
- Capability not possible with hardware radios
• Second satellite developed in SA
• LEO Satellite with MSMI for high resolution pictures
• Launched into sun-synchronous orbit, altitude 500 km
• Launch scheduled: Dec 2006
• Two ground stations (ESL and SAC)
AIS Functional Overview

- AIS broadcasts ship's ID and navigational messages
- Two VHF receivers and one transmitter
- TDMA assigns multiple users to a single frequency
- Frequencies 161.975 & 162.025 MHz, Tx power = 12.5W
- Uses FM-GMSK and NRZI for data encoding
- Data transmission begins, preamble, start, data, FCS and stop flag
System-Level Design

- Proposed system: Ship with AIS, Satellite with AIS receiver, Groundstation.
- OBC for satellite control is SunSpace design
- RF amp, mixer, BPF, DAC/ADC
Satellite subsystems

- Existing technology
- DSP&T development
- ESL / Sunspace

Diagram showing various components and their connections:
- **SH4**
- **SDR software**
- **daughtersboard FPGA**
- **DAC ADC LPF**
- **Mixing**
- **RF amp**

Other primary and experimental payloads:
- CAN BUS

Layout & power management
SU SDR Functionality

- SDR: Radio functionality (e.g. modulation, demodulation, filtering) performed in software
- Analog radios (drift with time) vs Digital radios (consistent)
- SU developing software architecture for SDR development
- Goal: library of reusable building blocks portable to various platforms
- SDR components have read, process and write methods
GMSK Modulation

- GMSK: Minimum shift keying with premodulation Gaussian filter
- Smooth phase transition, bandwidth reduced
- Gaussian pulse lasts longer, ISI introduced
- ISI depends on BT product
- Baseband GMSK pulse train is frequency-modulated using DDS
Gaussian impulse response
Software Design of the GMSK Demodulator

- GMSK demodulator uses blocks of components
- Message in instantaneous frequency of modulated signal
- FM discriminator component
- Differentiator: implemented by backward difference
- Rectifier: implemented by absolute value
- LPF, DC offset removal, Early-Late synchronizer, decoder
Early-Late gate synchronizer

- Receiver must have knowledge of beginning and end of a symbol
- Integration not at beginning of symbol results in errors
- Three integrations are performed
- Timing error is determined by the differences

Diagram of an Early-Late gate
Physical layer simulation and results

Differentiated signal

Rectified signal
Recovered baseband signal after symbol synchronization
Experimental setup

- Actual AIS signals transmitted
- Marine Data systems AIS station used
- Demodulated using HP RF Comm test set, squelsh set high
- Recorded using 14-bit, 4-CH, 2MS/s DAQ
- Demodulated signal passed to Early-Late gate synchronizer, check for training sequence, decoder, remove start flag, stop flag, bit destuff and flip bytes.
- FCS CCIT16 used for error detection, changed to characters and then translated
Experimental setup
Experimental results (Actual AIS signal after demodulation and symbol synchronizer)
## Experimental results

### AIS Message 1

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSG ID</td>
<td>1</td>
</tr>
<tr>
<td>Repeat indicator</td>
<td>0</td>
</tr>
<tr>
<td>MMSI number</td>
<td>3390030</td>
</tr>
<tr>
<td>Navigational status</td>
<td>0</td>
</tr>
<tr>
<td>Rate of turn</td>
<td>0</td>
</tr>
<tr>
<td>SOG</td>
<td>0.1 knots</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>0</td>
</tr>
<tr>
<td>Longitude</td>
<td>18 Degrees : 52.0 minutes East</td>
</tr>
<tr>
<td>Latitude</td>
<td>33 Degrees : 55.7 minutes South</td>
</tr>
<tr>
<td>COG</td>
<td>257.5 degrees true</td>
</tr>
<tr>
<td>True heading</td>
<td>511 degrees true</td>
</tr>
<tr>
<td>Time stamp</td>
<td>3 seconds past the minute</td>
</tr>
<tr>
<td>Regional application</td>
<td>0</td>
</tr>
<tr>
<td>Spare</td>
<td>0</td>
</tr>
<tr>
<td>RAIM</td>
<td>0</td>
</tr>
<tr>
<td>Communication State</td>
<td>22740</td>
</tr>
<tr>
<td>Syncrornization State</td>
<td>0</td>
</tr>
<tr>
<td>SlotTimeout</td>
<td>1</td>
</tr>
<tr>
<td>UTC</td>
<td>12 HOURS : 53 minutes</td>
</tr>
</tbody>
</table>
### Experimental results

<table>
<thead>
<tr>
<th>AIS Message 5</th>
<th>Static and voyage related data</th>
</tr>
</thead>
<tbody>
<tr>
<td>!AIVDM,1,1,,B,503&gt;rCP0kfTq=@DhiD1=@Dhj1DpUJ1@E=@00000000004000?</td>
<td>gggggggggggggggggg</td>
</tr>
<tr>
<td>MSG ID</td>
<td>5</td>
</tr>
<tr>
<td>Repeat_indicator</td>
<td>0</td>
</tr>
<tr>
<td>MMSI Number</td>
<td>3390030</td>
</tr>
<tr>
<td>AIS version number is</td>
<td>0</td>
</tr>
<tr>
<td>IMO number is</td>
<td>3390030</td>
</tr>
<tr>
<td>Call sign is</td>
<td>CD5&lt;&lt;E0</td>
</tr>
<tr>
<td>Ship name is</td>
<td>CD5&lt;&lt;PE&gt;9FPD5CD00000</td>
</tr>
<tr>
<td>Type of ship and cargo is</td>
<td>0</td>
</tr>
<tr>
<td>Dimension/Reference is</td>
<td>0</td>
</tr>
<tr>
<td>EPFD is</td>
<td>1 GPS</td>
</tr>
<tr>
<td>ETA is</td>
<td>0</td>
</tr>
<tr>
<td>Maximum static draught is</td>
<td>0</td>
</tr>
<tr>
<td>Destination is</td>
<td>vvvvvvvvvvvvvv</td>
</tr>
<tr>
<td>Data terminal ready is</td>
<td>1</td>
</tr>
<tr>
<td>SPARE is</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusions

- GMSK demodulator implemented as SDR
- Much of functionality tested in software (e.g. differentiator)
- Early-Late gate symbol synchronized within preamble
- Actual AIS signals demodulated, synchronized correctly
- AIS messages 1 and 5 demodulated and translated
- Advantages: Modulation scheme updated as new software techniques available
- Possibility of reconfiguring radio to new applications
- Concept of changing satellite mission while in orbit
- Disadvantage: limitation of ADC's sampling frequency