Design of Integrated Mode S Transponder, ADS-B and Distance Measuring Equipment Transceivers

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1. Introduction

Benefits of SDR for Aviation

• Minimization of SWaP-C requirements
  – GHG emissions reduction
  – Design, development and installation time and cost
  – Maintenance, repair and modernization time and cost

• Reprogrammability & reconfigurability
  – Seamless transition to new standards

• Scalability

• Reduced number of parts
  – Increased reliability
1. Introduction

Context of the Work

**AVIO-505 project**

- “Software defined radios for highly integrated system architecture”
- **Objectives:**
  - Integration of navigation, communication and surveillance systems under a single universal reconfigurable platform
  - Demonstrate the capabilities and performance of SDR in aerospace
  - Address new regulatory initiatives (NextGen)
- **Partners:**
  - Academic: ETS Montreal, Ecole Polytechnique Montreal, UQAM
  - Industrial: Bombardier, MDA, Marinvent Corporation
2. Receiver Design

SDR: ADC next to the Antenna

- **Required dynamic range**
  - 100 dB (3 dBm to -97 dBm)
- **Minimum sampling frequency**
  - DRFS: 607.5 MHz
  - I/Q sampling: 255 MHz
2. Receiver Design

ADC State-of-the-Art

![Graph](image)

- **Spurious/Noise Level, dBm**
  - **Sampling rate, MHz**
  - **Target Level**
  - **DRFS**
  - **IQS**
  - **Noise Level**
  - **Thermal Noise (F=0dB)**
  - **Ref. [4]**
  - **Ref. [5]**
  - **Ref. [6]**
  - **Ref. [7]**

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2. Receiver Design

Architecture

Dynamic Range Compression

960-1215 MHz

1090 MHz

Level equalizer

960-1215 MHz

I/Q Sampling

290 MHz

1250 MHz

90°

290 MHz

Signal conditioning

290 MHz

ADC → To DSP

290 MHz

ADC → To DSP
2. Receiver Design
Down Conversion

\[ f_{OL} = 1250 \text{ MHz} \]

\[ f_s = 250 \text{ MHz} \]
3. Transmitter Design

Architecture

- Spurious emission level
  - 60 dBc
- TDMA technique
  - Only one subsystem at a time
### 3. Transmitter Design

#### TDMA Feasibility

“First-come, first-served”

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Successful Transmission Rate</th>
<th>PRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode S</td>
<td>100.0 %</td>
<td>50-75 Hz</td>
</tr>
<tr>
<td>ATCRBS</td>
<td>99.5 %</td>
<td>1000-1200 Hz</td>
</tr>
<tr>
<td>ADS-B</td>
<td>99.4 %</td>
<td>5-10 Hz</td>
</tr>
<tr>
<td>DME</td>
<td>92.3 %</td>
<td>125-150 Hz</td>
</tr>
</tbody>
</table>
4. Antenna/Duplexer Design
Requirements / TDD

- Tx/Rx signals cannot be separated in the frequency domain
- Required Isolation
  - 61 dB
  - Antenna separation: 88 m
  - *(Promising experimental works based on Tx signal cancellation [1]-[3])*

- Time-Domain Division (TDD)
  - Antenna switches to **Tx mode IF in Rx mode AND:**
    - After successfully receiving an ATCRBS / Mode S interrogation
    - A DME interrogation begins
    - An ADS-B message (Mode S ES) begins
  - **Otherwise** transmission is aborted
  - Antenna switches to **Rx mode:**
    - At the end of current transmission
4. Antenna/Duplexer Design

TDD Feasibility

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode S</td>
<td>99.1</td>
<td>99.4</td>
<td>98.9</td>
<td>98.9</td>
<td>91.6</td>
</tr>
<tr>
<td>ATCRBS</td>
<td>99.1</td>
<td>99.1</td>
<td>99.2</td>
<td>99.1</td>
<td>97.7</td>
</tr>
<tr>
<td>ADS-B Out</td>
<td>99.5</td>
<td>99.4</td>
<td>99.3</td>
<td>99.5</td>
<td>99.3</td>
</tr>
<tr>
<td>ADS-B In</td>
<td>97.6</td>
<td>97.3</td>
<td>95.0</td>
<td>90.8</td>
<td>90.0</td>
</tr>
<tr>
<td>DME</td>
<td>99.5</td>
<td>99.5</td>
<td>95.4</td>
<td>92.2</td>
<td>99.5</td>
</tr>
</tbody>
</table>

A. Only interference between DME and other subsystem considered (Results referred to most common installation)

B. A + interference between ADS-B In and other subsystem (Results referred to isolated ADS-B In installation)

C. B + Non-rotating Mode-S SSR antenna (Peak interrogation)

D. C + Non-rotating ATCRBS SSR antenna (Peak interrogation)

E. B + interference between any subsystem with each other (raw successful rate)
Conclusion

- **Software Defined Radio benefits to aviation**
  - Reduced operation costs
  - Open the door to multi-standard scenario for CNS modernization

- **Current ADC technology**
  - Cannot implement DRFS
  - Dynamic Range compression in the analog domain

- **Current DAC technology enables DRFS**

- **TDMA techniques allows for HPA sharing**

- **Antenna sharing feasible through TDD**
Future work

• Implementation of the analog front-end with COTS parts

• Integration with fast prototyping SDR platforms

• Lab Tests

• Flight Tests
References


5. Analog Devices, “**AD9652 16-Bit, 310 MSPS, 3.3 V/1.8 V Dual Analog-to-Digital Converter (ADC)**,” *Data Sheet*. 2013.


Questions?

Thank you

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