FFT-based Automatic Frequency Control for Direct RF Sampling Architecture Applied to VHF Avionics

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Track 2:
Communications, Navigation, and Surveillance
Session D:
SDR and Spectrum
Outline

1. Introduction

2. FFT based Automatic Frequency Control
   a. Overview
   b. Implementation

3. Result analysis

4. Conclusion and Future work
1. Introduction
1. Introduction

Today’s Avionic Systems

- Multiple dedicated antenna
- Multiple rack mount avionics
- Kilometers of cables and connectors
1. Introduction

Proposed Avionic Systems

Advantages:
- Less equipment and cables
- Hardware to software redundancy
- Software function reallocation
- Easier maintenance
- Lower cost
1. Introduction

Context of the AVIO-505 Project

• 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)
1. Introduction

**AVIO-505: Direct RF Sampling**

- **Direct RF Sampling (DRFS) Architecture**

![Diagram showing Conventional and DRFS architectures](image)

<table>
<thead>
<tr>
<th><strong>ADC</strong></th>
<th><strong>ADS62P49</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sampling Rate</strong></td>
<td>140 MHz</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>14 bits</td>
</tr>
</tbody>
</table>
1. Introduction
Direct RF Sampling basics

- Sampling GHz signal with MHz sampling rate
- Sampling and processing multiple Signal of Interests with one ADC (VOR, ILS, VHF Radio…)

![Diagram showing the sampling process and frequency zones]

**1st Nyquist zone**

Low pass filter

Shift by \( f_3 \)

Shift by \( f_2 \)

General Purpose Processor

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1. Introduction

Direct Digital Synthesizer in DRFS

![Diagram of Direct Digital Synthesizer in DRFS]
1. Introduction
Challenges and Objectives of the Work

- Offset 1: Round up and Quantization (VOR signal at 108.0 MHz)

- Offset 2: Frequency Offset of the Real Station

<table>
<thead>
<tr>
<th>System</th>
<th>VOR</th>
<th>LOC</th>
<th>GS</th>
<th>VHF Radio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station TX Offset</td>
<td>± 1.2 kHz</td>
<td>± 9 kHz</td>
<td>± 17 kHz</td>
<td>± 4 kHz</td>
</tr>
</tbody>
</table>

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1. Introduction
Challenges and Objectives of the Work

- Frequency Offset of VOR Station YJN-St.Jean (Québec, Canada)

- Frequency Offset of LOC station CYHU-St.Hubert (Québec, Canada)
2. Implementation
2. FFT based Automatic Frequency Control (AFC)

Overview

- AFC run independently to the main DDC system
- DDC filters bandwidth 40 kHz
- Sample rate 200 ksp, 32768 points FFT
- Final resolution: ~3 Hz

FFT based AFC modules

Main DDC system
2. FFT based Automatic Frequency Control Implementation

### FFT based AFC module

- **Tuning Word Controller Module**
- **Digital Down Converter**
- **FFT Calculation**
- **Max hold System**
- **Tuning word correction**
- **Corrected word**

### Bit Control

<table>
<thead>
<tr>
<th>Bit</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Select the entered tuning word for the AFC. (GS, LOC, VOR1, VOR2)</td>
</tr>
<tr>
<td>2-5</td>
<td>Save the corrected tuning word (1 bit for each system).</td>
</tr>
<tr>
<td>6-9</td>
<td>Apply the corrected tuning word (1 bit for each system). When 0 return the default entered tuning word</td>
</tr>
</tbody>
</table>
2. FFT based Automatic Frequency Control Implementation

FFT based AFC module

- Tuning Word Controller Module
- Digital Down Converter
- FFT Calculation
- FFT amp
- Max hold System
- FFT Index
- Tuning word correction
- Corrected word
2. FFT based Automatic Frequency Control Implementation

FFT based AFC module

- Tuning Word Controller Module
- Digital Down Converter
- FFT Calculation
- Max hold System
- Tuning word correction
- Corrected word

Diagram:

FFT based AFC module flowchart with components and connections.

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3. Result analysis
3. Results analysis
Sensitivity

• Before Correction

• After Correction
3. Results analysis

Sensitivity

VOR Bearing results before and after correction
(−80 dBm, 210 degrees)

Before Correction  After Correction

VOR Bearing

Reference

Time (second)
3. Results analysis

Audio Signal Output

- VHF Radio

<table>
<thead>
<tr>
<th>Tuning Type</th>
<th>SNR (dB)</th>
<th>THD (dB)</th>
<th>SINAD (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Tuning</td>
<td>0.54</td>
<td>-21.77</td>
<td>0.51</td>
</tr>
<tr>
<td>Manual Tuning</td>
<td>8.72</td>
<td>-40.61</td>
<td>8.72</td>
</tr>
<tr>
<td>AFC Correction</td>
<td>9.06</td>
<td>-42.55</td>
<td>9.05</td>
</tr>
</tbody>
</table>

**SNR:** Signal to Noise Ratio  
**THD:** Total Harmonic Distortion  
**SINAD:** Signal to Noise And Distortion
3. Results analysis

Summary

<table>
<thead>
<tr>
<th>System</th>
<th>Standard (dBm)</th>
<th>No Tuning</th>
<th>Manual Tuning</th>
<th>With AFC</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOR</td>
<td>−93</td>
<td>−70</td>
<td>−87</td>
<td>−90</td>
<td>↑ 20 dB</td>
</tr>
<tr>
<td>GS</td>
<td>−77</td>
<td>−70</td>
<td>−76</td>
<td>−82</td>
<td>↑ 12 dB</td>
</tr>
<tr>
<td>LOC</td>
<td>−87</td>
<td>−51</td>
<td>−72</td>
<td>−78</td>
<td>↑ 27 dB</td>
</tr>
</tbody>
</table>
4. Conclusion and Future work
4. Conclusion and Future work

- The AFC increased the general performance of the DRFS architecture, particularly the sensitivity.
  - A gain of 20 dB for VOR
  - A gain of >10 dB for Glide Slope
  - A gain of >20 dB for Localizer
  - Increase the audio quality of VHF Radio

- By using the control bits, the integration of the proposed AFC is light weight, can be expanded easily without the need of more resource.
4. Conclusion and Future work

• For the Automatic Frequency Tracking System:
  – Reduce latency
  – New algorithms compatible with other modulations

• For DRFS
  – Integrate other avionics
  – Flight Test with commercial airplane
  – New ADC/DAC to increase the capacity of the architecture
Questions?

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Thank you