RF Interference Avoidance Algorithms for Cognitive Radios

Jiamin Xie, Long Huang, Christopher Fitzhugh, Harpreet Dhillon
Virginia Polytechnic Institute and State University, 302 Whittemore Hall, Blacksburg, VA 24061, USA
United Technology Corporation Aerospace Systems, 2730 W Tyvola Road, Charlotte, NC 28217, USA
xjm1013@vt.edu longh93@vt.edu

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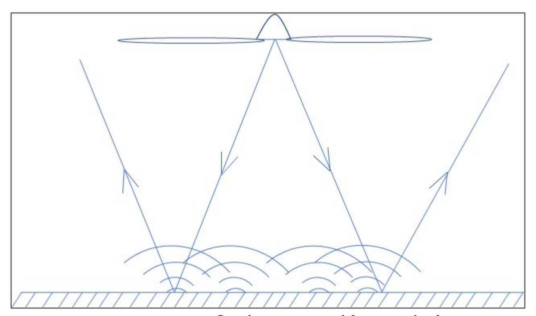
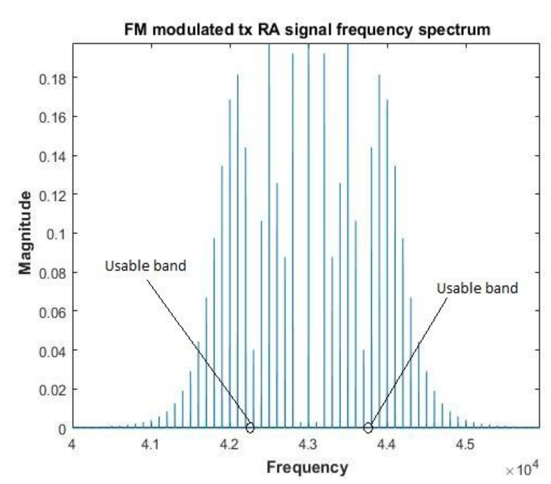
Background & Goals

- **Making modern airplanes lighter**
  Wireless sensors can eliminate tons of wires on an airplane, and facilitate ease of maintenance. Thus, the need of wireless sensors onboard are growing everyday.
- **Cross-Talk between devices**
  The sensors are planned to operate on 4.2 and 4.4 GHz band. However, the existing radio altimeters used for airplane navigation are currently working on the same band. This would pose an inference problem to the sensors.



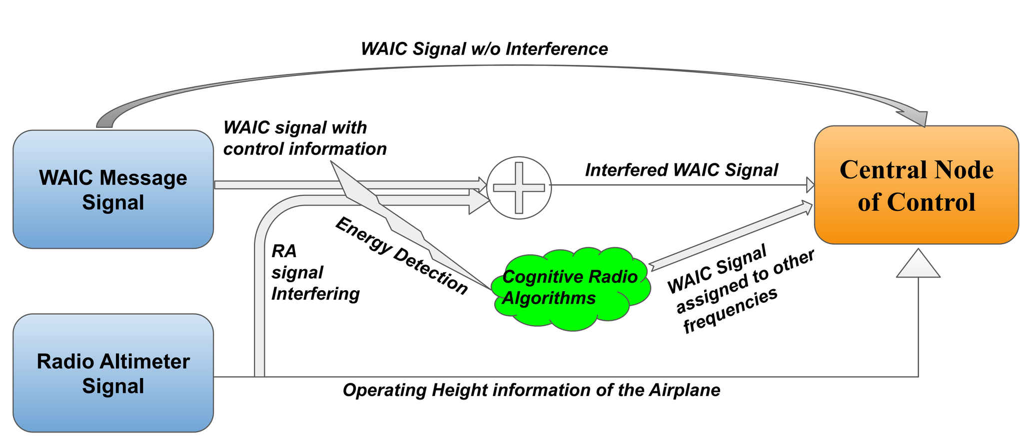
- **Our goal** is to detect presence of the radio altimeter signal in a small time interval, and find & assign an empty band for sensors communication between 4.2 - 4.4 GHz, where the radio altimeter is not present.

- The figure shows the RA received frequency spectrum.
- The empty spaces between spectral lines can be used to transmit WAIC signals without interference with RA.
- The ratio of the parameters in this FM modulation is kept to be a match with the 4.3GHz case.



Elements of Design

- **Signals Flow Diagram**



- **The Wireless Avionics Intra-Communication (WAIC)**
  - WAIC is a sensor network that contains critical information of the airplane status in forms of the data collected from various sensors.
- **The Radio Altimeter (RA)**
  - RA is a frequency sweeping device that calculates the operating altitude of the airplane by using EM waves.

- ***The interference*** occurs when RA sweeps to the frequency band of operation in WAIC.
- ***The Energy Detection method (EDM)*** identifies the interference in air by setting an optimum energy threshold of decision.
- ***A cognitive radio algorithm*** - Frequency Hopping switches the victim signal from the interfering channel to another less severed one.

Approach

- **Use MATLAB to simulate the algorithm.** A simplified 43 kHz center frequency is used to make the processing fast.
- Solutions can be divided into 3 steps, **Energy Detection**, **Frequency tracking**, and **Frequency Hopping**.
- The **Energy Detection** is based on a calculation of the RF power in presence,
  - Equation used: $P = \frac{\sum_1^N x_i^2}{N}$
  - Choose the **optimum length of time** to sample the environment and set the **optimum energy threshold**.
- The **RA signals** and **WAIC signals** are modeled in MATLAB for analysis.
  - **Radar equation** is used to model the received signals.
- **Frequency tracking** is done by finding the maximum frequency tone in the spectrum.
- **Frequency Hopping** of the WAIC device will be based on the tracking knowledge and proactively assign WAIC to another empty channel.

Solution Descriptions

- **Simulation of the Radio Altimeter Transmitted Signal**
  - Math representation: $S_{tx}(t) = A_{tx} * \cos\left(w_c t + 2\pi * k_f * \int_0^t m(\tau)d\tau\right)$
  - Antenna equation: $Pr = \frac{Pt * G^2 \sigma \lambda^2}{(4\pi)^3 R^4}$

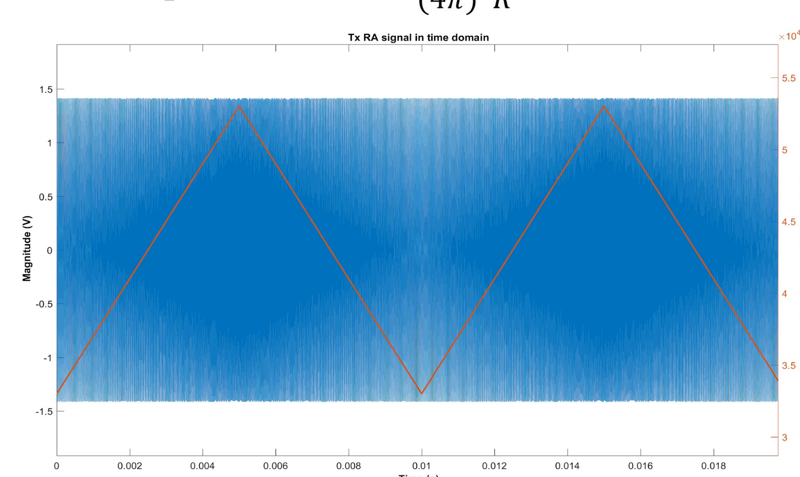


Figure 1. Transmitted RA signal (FM modulation) & Instantaneous Frequency

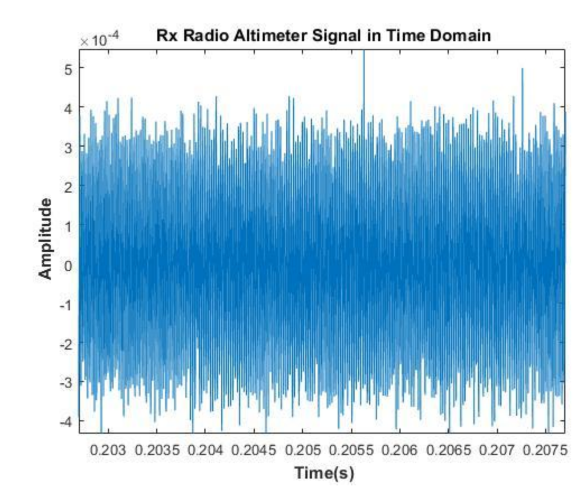


Figure 2. Received RA signal (FM modulation) with noise added

- **Simulation of the WAIC Transmitted Signal**
  - WAIC signal is essentially QPSK modulated
  - Example below that transmits data: 00111001

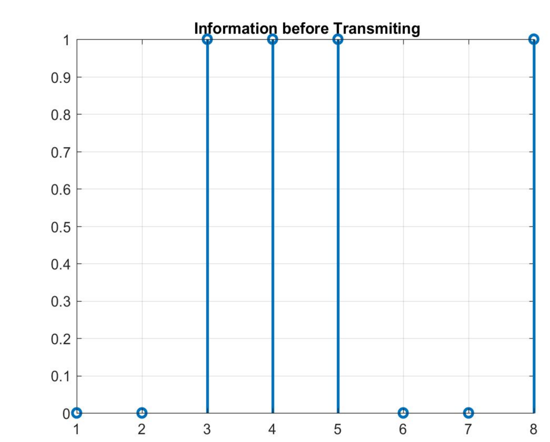


Figure 3. Information before Transmitting (00111001)

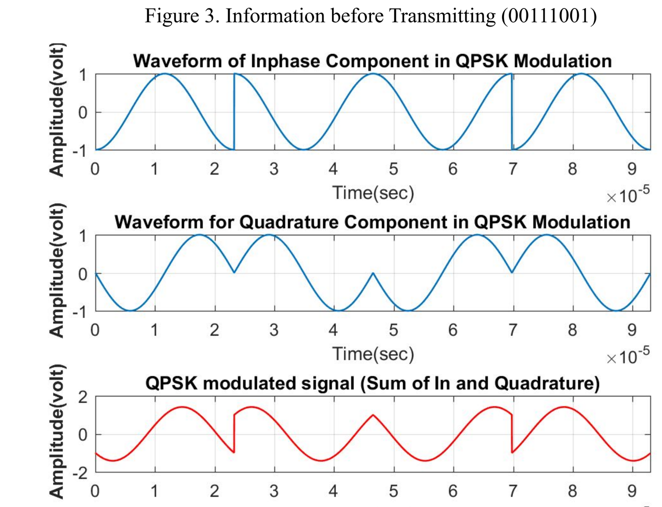


Figure 4. QPSK Transmitted Signal (In phase, Quadrature, Composite Signal from the top)

- **Energy Detection Method**
  - This EDM plot shows the RA's power fluctuating due to additive white gaussian noise(AWGN).

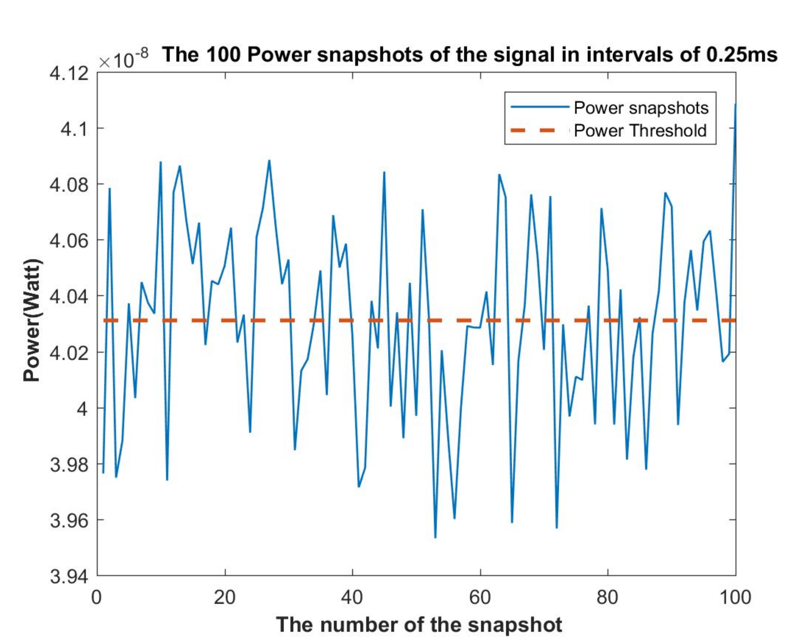


Figure 4. The Energy detection method to determine RA presence

- **Frequency tracking of the RA signal**
  - The program scans the channel in frequency domain within 100 cycles of a 4.3 GHz oscillation at one instance (23 ns).
  - It detects the highest peak tone, where the instantaneous RA locates.
  - This allow us to predict future interference.

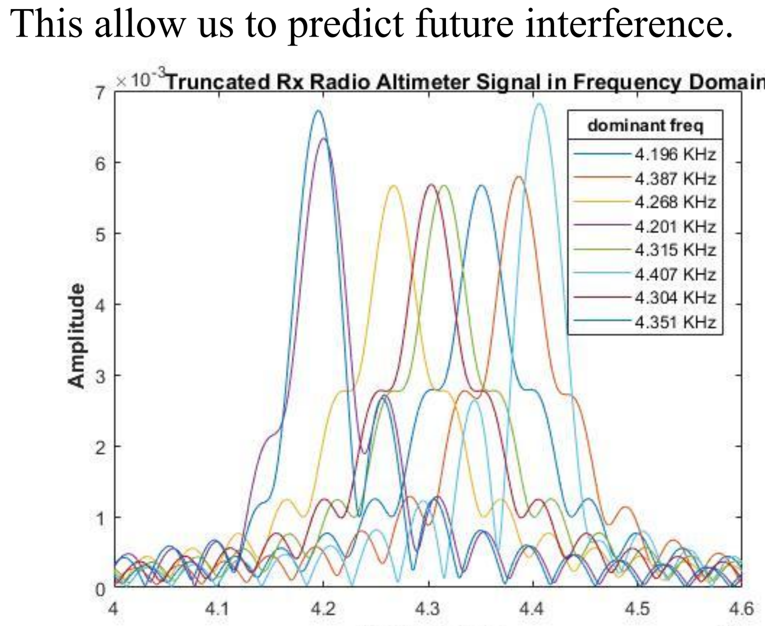


Figure 5. Radio Altimeter spectrum for different time windows at which it is observed

Results

- **Power of the received Radio Altimeter Signal:**
  - -53.96 dBm (~0.04µW)
- **Power of the received WAIC signal[1]:**
  - -6 dBm
- **Required detection time:** 10ns - 100ns
  - **Achieved detection time:** 23ns
  - 23ns detection time was sufficient to determine the power and spectrum of the received RA signal.
- **Packet error rate:** 0.1% - 0.01%
  - Expected error rate of 0.08%

1. Assume line of sight, true value can differ. See reference: Report ITU-R M.2197

Future work

We see future works can be done to the project:

- **Real field test data** can be added to increase the fidelity of our simulation
- Consider **Offset-QPSK** for WAIC modulation to approximate real cases
- Model condition with **multiple sets** of the RA and WAIC pair.
- Take in account of other communication **fading channel**, i.e Rayleigh
- Focus on severe interference environment, such as **landing gears**
- **Environmental loss factor** should be considered. Clear air attenuates high frequency.
- **Doppler shift** is also a factor when the airplane ascends and descends
- **Optimal Pulse shaping** can be added to increase bandwidth efficiency
- The simulation was performed around 43 kHz signals. However, the work performed here can be perform on 4.3 GHz. **Lower received power is expected for 4.3 GHz.**

Conclusion

- In the simulation, we found the frequency hopping algorithm an adequate approach to the mitigation of the interference.
- Energy Detection Method provides a backup plan to ensure the additional reliability.
- Detection time of the interference is limited to within 23ns by tracking the frequency of received RA signal effectively.
- The RA and WAIC signal characteristics was found to be a correct simulation of the data demonstrated in ITU documents.

Reference

[1] ITU-R. Operation and technical characteristics and protection criteria of radio altimeters utilizing the band 4 200 - 4 400 MHz | *M-Series, 2059-0, Feb, 2014.*
[2] ITU-R. Technical characteristics and operational objectives for wireless avionics intra-communications (WAIC) | *M-Series, 2197, Nov, 2010.*
[3] T. Meyerhoff, H. Faerber and U. Schwark, "Interference Impact of Wireless Avionics Intra-Communication Systems onto Aeronautical Radio Altimeters," *10th International ITG Conference on Systems*, Hamburg, Germany, 2015, pp. 1-6.