Passive Aircraft Radar

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1 Introduction

1.1 Objective

The major markets for passive radar technologies are military, commercial airports, and flight tracking services. Military and commercial applications are sophisticated, but expensive. Commercial applications do exist, and range from personal projects to subscription based services. Most of these applications rely on decoding ADS-B/Mode-S transponder data to identify aircraft and determine altitude. This method, while effective, is vulnerable to spoofing for air-to-ground communication [1].

We propose to create an affordable, accessible solution that doesn't depend on transponder data to get accurate aircraft positioning. The solution shall consist of individual receivers that together form a radar network. Instead of using ADS-B signals like other solutions [2], the network will strictly use multilateration (MLat) to determine an aircraft's position. The receivers shall be 'plug-and-play', requiring only a Power of Ethernet (POE) connection to be used in our network.

1.2 Background

Radar technology has existed since the beginning of World War II. Traditional radar systems use a transmitter to send an electromagnetic (EM) wave, and read the received reflected wave in order to compute the position of an object. In recent years, research of passive radar technology has increased. A passive radar does not transmit, and only uses existing EM waves of the target in order to locate an object [3].

The military is researching passive radar solutions to detect stealth aircraft, but these solutions require a heavy amount of signal processing, and can be costly to implement [4]. There are many hobbyist solutions which use a passive receiver in order to detect aircraft, but these implementations often use external websites in order to interpret the received data, and designs which are inexpensive aren't very accurate [5].

1.3 High-Level Requirements

1. This project shall have a cost below $100 per receiver, excluding the costs of the server and POE injector.
2. This project shall have an accuracy of at least 50 m.
3. The receiver network shall sustain timing accuracy and run independently without user interactions for at least 1 week.

2 Design

Figure 1 shows a block diagram of a single receiver connected to a central server. Each individual receiver will consist of an RF front end that receives the aircraft transponder signal, a GPS unit which captures GPS data, including the pulse per second (PPS) signal, a control unit which will verify the transponder signal, and a power unit which will power the individual components in the receiver. As shown in figure 2, our design will consist of a network of 4 receivers connected to a central server through ethernet, and will be deployed in different parts of the community, pictured in figure 2.

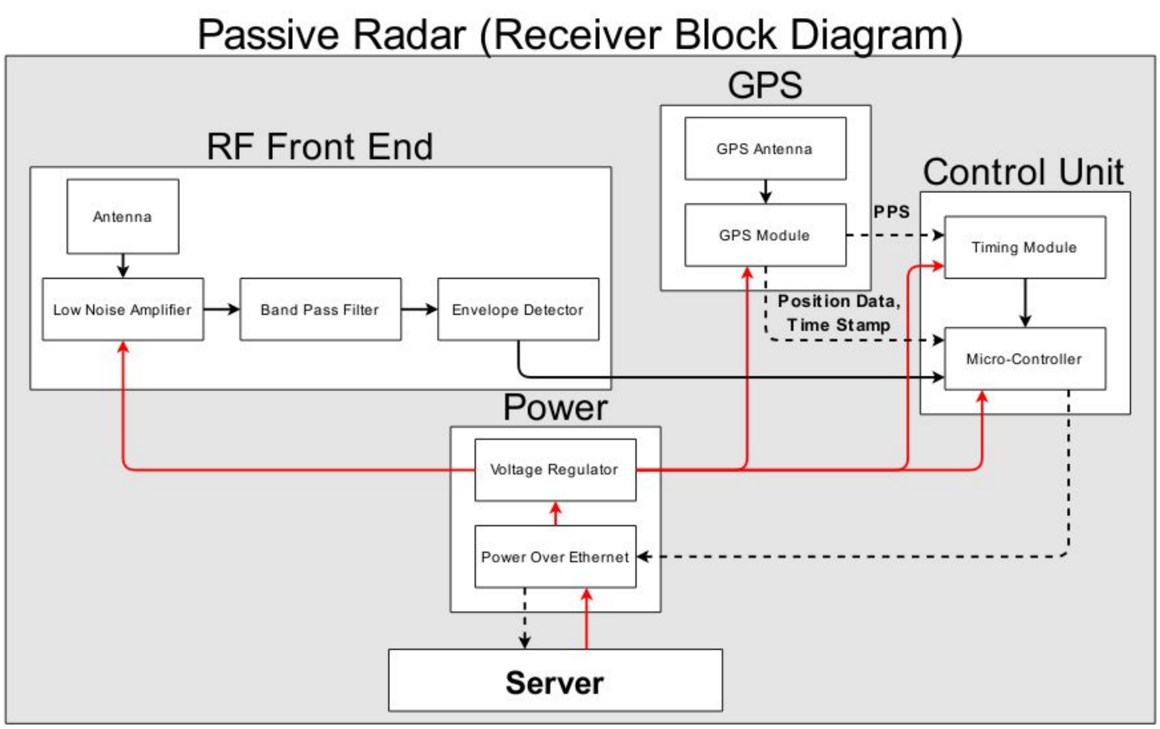

Figure 1: Design Block Diagram

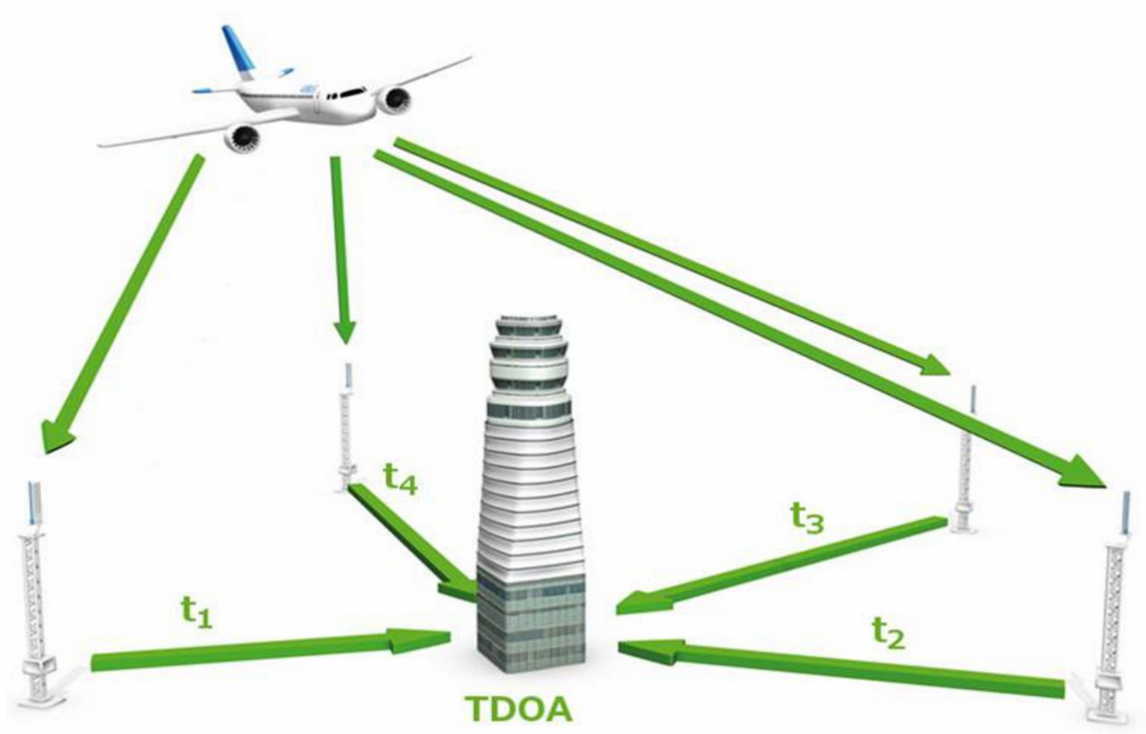

Figure 2: Physical Diagram (Provided by Professor Levchenko)

2.1 RF Front End

The RF front end will capture the aircraft transponder signal (which is transmitted at 1090 MHz), amplify it with a low noise amplifier (LNA), and filter out unwanted frequencies using a band pass filter (BPF).

2.1.1 Antenna

The antenna will capture the signal and will be implemented as a half wave dipole (subject to change). The antenna should be non-directional so it can receive signals from any orientation. Directivity isn’t a factor when determining position using multilateration.

Requirement: *Total Loss < 7 dB*

2.1.2 Low Noise Amplifier (LNA)

The LNA will amplify the signal without changing the signal to noise ratio (SNR) by a significant amount.

Requirement 1: *Noise Figure < 1dB*
Requirement 2: *Gain > 10 dB*

2.1.3 Band Pass Filter (BPF)

The BPF will filter out any unwanted frequencies (other than 1090 MHz).

Requirement 1: *Total Loss < 3 dB*
Requirement 2: *3dB BW < 30 MHz*

2.1.4 Envelope Detector

The envelope detector will demodule the transponder signal, and will give the message signal as an output (on-off keyed signal in the mode-s format).

Requirement: *BW > 1100 MHz*

2.2 GPS

The GPS unit will be used for gathering the location of the receivers, as well as time stamping the received signals of each receiver.

Requirement: The GPS Module should be able to generate a reference signal (PPS signal). It should also be able to provide position data to the microcontroller.

2.2.1 GPS Antenna

The GPS Antenna will receive the GPS signal.

2.2.2 GPS Module

The GPS Module will decode the GPS signal for position and time syncing. This serial data will go to the Control Unit. The timing module requires the PPS output from this module.

2.3 Control Unit

2.3.1 Timing Module

The timing module will be used to create an accurate timestamp of when the aircraft transponder signal was received

Requirement: Time stamp accuracy of 200 ns

2.3.2 Micro-Controller

The microcontroller is responsible for tracking time/timestamps, interpreting transponder signal, posting data to server/website, and general management (acquire IP, find server, reset/test control).

Requirement: Clock Speed 20+ MHz, functioning temperature shall remain under 70°C.

2.3.3 Status LEDs

The status LEDs provide basic operational visuals for the receiver. The main states for a user-friendly module include normal functionality, connection issues to server, and device failure.

2.3.4 Control Buttons

One button will provide the ability to manually reset the receiver to force a reconfiguration to the server and clear data. Another button will be implemented to trigger a false received transponder signal to verify server functionality and connectivity.

2.4 Power

The power unit will power the receiver through POE.

2.4.1 Power Over Ethernet (POE)

The POE module will provide power to the receiver, and will be used to transfer data to a central server.

2.4.2 Voltage Regulator

The voltage regulator will provide a constant voltage to individual components in the receiver.

Requirement: Must be able to hold a voltage of 5V and 3.3V with an accuracy of 10%

2.5 Server

The central server will receive the time stamps of the received transponder signals, and will use multilateration in order to compute the position of the aircraft based on the time delay between receivers [6].

2.6 Risk Analysis

The block which poses the greatest risk to the completion of the project is the RF front end. It needs to have a large enough range in order to capture the aircraft transponder signal. MLat receivers are typically deployed on towers to minimize interference and increase the chances of receiving transponder signals. Since we plan to deploy this design commercially (for example, in households), we will need to employ methods to improve sensitivity and filter out interference. The RF front end has the largest risk factor in our design because we cannot locate the aircraft if all four receivers do not receive the transponder signal.

3 Safety and Ethics

The proposed project incurs several possible ethical and safety concerns that require attention when proceeding in the design, implementation, and deployment phases. These ethical concerns will reference both IEEE and Association of Computing Machinery (ACM) Code of Ethics.

From the Association of Computing Machinery's Code of Ethics, "An essential aim of computing professionals is to minimize negative consequences of computing, including threats to health, safety, personal security, and privacy. [7]". This is similar to the #1 IEEE Code of Ethics [8]. A particular concern arises as the data acquired by the proposed receiver solutions includes GPS positional data and this information is needed on the server, sent over the ethernet. In order to protect the locational privacy of our users, we shall encrypt both the data before sending and the database of collected timestamps and locations on the server back-end.

Although the transponder signals are be collected by each receiver unit, these devices are inherently designed to be passive and shall not interfere with any FCC regulations.

Special thanks to Professor Levchenko for this project pitch

References

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