# Introduction

Crash-Sat is in need of a way to detect AGL altitude without pre-flight ground calibration or communication with a ground station. Altitude needs to be accurate within +/- 5 meters and operate without GPS. A radar altimeter design will be investigated as a potential means of altitude sensing. The trade study for this is kept elsewhere, but is summarized with the following options and rationale.

* Barometric altitude – Requires premature calibration with ground pressure, and liftoff site may drastically vary in altitude from landing site. The time of flight can be long enough that ground pressure changes, resulting in poor accuracy and user convenience.
* GPS altitude – Requirements deny GPS measurements for any purpose that directly involves mission success. Relative altitude is accurate, but uncalibrated AGL altitude is based on geode accuracy, which is low.
* LIDAR – Ultimate range must be at least 1 km, and no such lidar altimeter exists with acceptable volume and price
* Sonar – Same problems as LIDAR
* Ground station triangulation – Transmitting any data except mission abort data is not allowed under crash sat requirements.
* Camera and sensor fusion with another option – Could be a possible alternative to explore, but visible light cameras require there to be no clouds and exceptional image processing and analysis.

Through methods of sensor fusion including velocity sensors, accelerometers, relative distance measurements, and more, the altitude can be determined with very high accuracy. A very reliable and direct AGL measurement is needed at minimum for this method to work. With the added sensors for sensor fusion we can relax the necessary sample rate needed for a radar altimeter. As such, no minimum sample rate is yet known. Possibly only 1 accurate measurement would be needed at any height for this method to work.

This document stands to track major updates and definitions of how a Continuous Wave Frequency Modulated (CWFM) and Pulse Wave (PW) altitude radar might work in a package size and price small enough for a UAV. This document will ONLY be dedicated to a radar altimeter measurement, and any design of sensor fusion algorithms will be limited to hypothetical and conceptual.

# Design

Two types of radar measurements for distance detection are common in the industry. These are continuous wave and pulse wave. A continuous wave radar is able to use a constantly emitted signal to measure time phase shift and/or doppler effect due to distance and velocity, respectively. Continuous wave radar is usually frequency modulated, thus the name, Continuous Wave Frequency Modulated (CWFM). Pulse wave radar instead sends a single pulse, or “ping” to the target for distance measurement, and the signal eventually returns back to the sender. The time difference from sent versus received is related to the speed of light and thus a distance measurement can be made.

CWFM is very popular for short range measurements as short as a few feet, but is functional for many kilometers as well. Pulse wave radar is more popular for long distance measurements. It is for this reason that attention will be given to the CWFM radar first.

Diagram

Description automatically generated

**Figure 1: Basic frequency domain simulation and design of CWFM radar.**

The basic premise for my radar will use a square wave frequency instead of a chirp frequency signal. Chirp frequency variation allows for both distance and speed measurements, but I can acquire speed with other methods. Distance is determined by phase shift so I can use a dual set of frequencies and avoid the complication of accurately controlling frequency. Figure 1 shows a frequency domain simulation of the current concept design. This frequency domain simulation does not take transient effects, noise figures, S parameters, and many other practical engineering effects into account which will be analyzed later. The carrier waveform is expected to be 2.4 GHz or 5 GHz in the respective ISM band, and attention will be given to FCC class rating and compatibility.

The carrier wave will vary by (at least) 10 kHz. A voltage-controlled oscillator is used to generate the transmitted frequency which will be released by some currently undetermined antenna. The transmitted frequency will bounce off the ground and travel back with some shifted frequency due to the doppler effect. For the expected maximum speed of Crash-Sat (100 m/s) the doppler shift will be at most 800 Hz. This is why the high and low frequency differ by (at least) 10 kHz. Because a good bandpass filter can be designed to filter out hundreds of Hz from thousands of Hz. After the transmitted frequency scatters off the ground and returns to the sensor, the RX antenna will see a very attenuated and possibly noisy signal. The simulation assumes the returned signal is clean and amplified. Sufficient circuitry must be used to clean and amplify the received signal without causing further time delay or by creating a consistent delay which can be calibrated for.

The above equation is very important. It is the physical relationship of multiplying (or “mixing”) two signals together. Signal 1 has frequency f1 while signal 2 has frequency f2. If you multiply the two waveforms together you get a Fourier series composed of 2 new waveforms. These two new waveforms will have frequencies equal to f1+f2 and |f1-f2|. i.e. the new signal will be composed of the sum and difference of both input signals. Important to our case is that if The sum of the frequencies are far greater than the difference (f1+f2 >> |f1-f2|) then a high pass, low pass, or band pass filter of relatively low order can be implemented to remove one of the two produced frequencies. If our carrier wave is 2.4 GHz and our bandwidth is 10 kHz, then the sum of frequencies is 4,800,000 kHz, whereas our difference is 10 kHz. This is sufficiently different in magnitude that a basic analog filter can remove either of the two produced frequencies when mixed together. Mixing frequencies is typically nonlinear and can result in 2nd order and 3rd order frequency mixtures that will need to be filtered out.

In the simulation we assume that the phase angle difference between the TX and RX signals are unchanged after amplifying and filtering the signals. The mixing occurs and a filter removes all signals except the 1st order difference of frequencies, and this is represented in the simulation as a difference block, and no sum block. At any given instance depending on how long it takes the TX signal to emit and return, the difference of the signals will either be near 0 or near 10 kHz. A frequency to voltage device can be selected such that 0 Hz is equivalent to 0 volts and 10 kHz is equivalent to VCC volts. Then the resulting voltage waveform will be a PWM signal with pulse width dependent on how far from the ground the altimeter is.

Any number of methods can be used to interpret the signal at that point, ranging from a low pass filter and analog circuitry to high speed software interpretation. In truth, a good ADC could be implemented anywhere in the analog circuitry to perform the rest of the calculations in software instead of analog hardware, and given the presence of high power EMI from the RX and TX antennae this will probably be a major design consideration.

Various tests need to be run before a prototype can be planned. It is important to have a strong understanding of the integral components to avoid becoming a harmful radiator of EMI when assembling a prototype. The next teir of analysis is to use advanced MATLAB tools to heighten the accuracy of our simulation in preparation for parts selection and as a further proof of concept. MATLAB’s RF toolbox/blockset and antenna tools offer a professional-grade simulation space for this kind of project. The learning curve is very steep due to a lack of documentation, but the current state is shown below in Figure 2:

Diagram, schematic

Description automatically generated

**Figure 2: RF blockset current Simulink model**

The first series of testing will involve using a pair of signal generators to emulate sent and received signals to test mixers and analog voltage. This should, theoretically, be the “easy part” as we are assuming in these tests that the waveforms have been captured perfectly and clean from the environment, that no EMI is interfering with our analog circuitry, and that after amplifying and filtering our signals we have perfect phase based on distance. If this testing does not produce positive results then the fundamental design has to change.