Exploring Radar Detection

Designing A Millimeter Wave Sensor

Objective

Could I design a device to detect when radar is in operation nearby?

More specifically, could I detect energy in the Ka band?

A lot of police scanner manufacturers say stuff like “Ka band radar has a frequency between 26.5 and 40 GHz, but police radar has to be between 33.0 and 36.0 GHz. However, Ka band radar can be hard to detect since police can use 3 different frequencies: 33.8 GHz, 34.7 GHz, and 35.5 GHz.“

Certain commercial devices are available that aim to analyze the intensity and direction of Ghz range RF emissions produced by police speed sensors. These are fascinating, but also expensive. They operate on the X, K, and Ka bands, which are way more complex to design and test due to the dark arts and witchcraft involved in HF-UWB-RF design. Perhaps they use multiple antennas? I am too broke to tear one open.

Initial googling & looking into existing research papers shows a few main challenges.

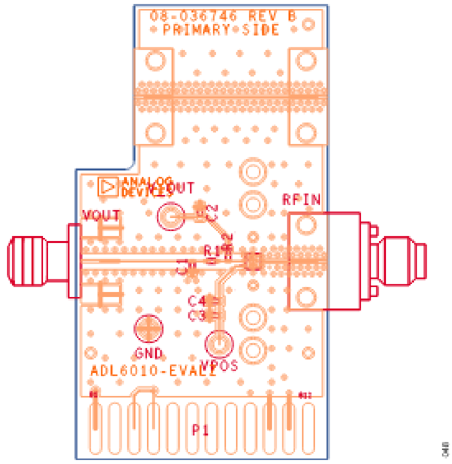
- Low signal intensity + integrity
  - Low power at high frequency → noise constraints
- High precision components, geometries, and materials
- Expensive equipment for analyzing hardware
- Specific Ka band sections used

Initial Approach

The idea is as follows…

ANT → Bandpass → LNA → Envelope detector → Amplifier → ADC

First, we look into the *LNA → Envelope detector* stages. Analog Devices offers several [LNA configurations] that have pretty high bandwidth. They also publish some example PCB drawings that are super valuable for me because I have no experience designing around RF constraints, so there is much to absorb from.



[ADL6010-EVALZ](#) Drawing

All their devices are pretty much impedance matched to 50 Ω too. This makes it useful to use an LNA from the aforementioned list in conjunction with this ADL6010 zero biased Schottky envelope detector. It seems like 50 Ohms is the standard impedance for this stuff anyways.

What about the antenna itself? In my research I discovered Horn antennas, dish antennas, and single place patch antennas. For this project, my solution is to attempt a [Vivaldi antenna](#). I found [this paper](#) that gives some background on the physics of the whole situation too.

“Advantages of Vivaldi antennas are their broadband characteristics, their easy manufacturing process using common methods for PCB production, and their easy impedance matching to the feeding line using [microstrip line](#) modeling methods” – **Wikipedia**

In order to effectively design one of these, I will need to learn and make use of software that models the physics interactions with these geometries. OpenEMS is a notable one that saves a lot of time if you aren't seeking intimacy with Maxwell's equations.

This paper - "A Compact Active Ka-Band Filtenna for CubeSats" - goes more into depth on the concepts of a “Filtenna” or filtering antenna, which could entirely eliminate the need to implement a hyper complex filtering circuit. The work discussed there is more geared towards communication on the target frequencies, but still valuable proofs of concept. Most likely, a functional design for a single plane filter will involve tuning the antenna for resonances and using a stub filter.

Simplified Approach

In order to decrease complexity, and make it easier to actually make, let's remove the LNA from our diagram and seek a microstrip integrated filter solution. This must be at least a highpass filter, which simplifies the design a little more. The ADL6010 also may not require an output amplifier, depending on the intensity of the output signal (which is proportional to the intensity of the HF radiation). It is also useful to design a few different versions and connect them to the same MCU, each adjusted to different frequencies or situations.

ANT → HPF → ADL6010 → Amplifier (?) → ADC → MCU

This paper called “Engineering Planar Antenna[...]” has enough background for me to be able to design an effective patch antenna, given the math and analysis provided. It uses a filter-antenna Vivaldi configuration.

For a Vivaldi antenna, the design is somewhat simplified. The main aspects that constrain the design of any planar antenna are the dielectric constant of the material, the loss tangent, and the substrate thickness. The exponential curve geometry of the Vivaldi introduces less variables as well (tuning 2 variables to shape it).

Antenna Design

In order to achieve our desired performance, the antenna will need to be tuned for resonance (S11 performance of < -10dB) at the target wavelengths, as well as employing a bandpass filter like a stub filter or coupled line filter to minimize interference at the target frequency. If possible, a multi-band or more selective antenna would allow for super efficient radar detection. In this case we are targeting a center frequency of 34.5 Ghz with a bandwidth of 5Ghz to encompass radar signals in the Ka band.

Running a RF performance simulation involves Matlab/Octave and OpenEMS. The substrate, connectors, simulation mesh, conductors, and more must be laid out programmatically to simulate our antenna.

In order to design something that can actually be manufactured, I looked at JLCPCB and determined that consistent low leakage materials like Rogers were available in 0.51 mm and 0.76 mm thicknesses, with 35um copper trace thickness. The manufacturer also provided this datasheet which summarizes the Rogers R4003C material. This will be used to create a substrate and metal in the simulation that will be most accurate.

```
%% Rogers R4003C
w = 2 * pi * 34.5e9;
dissipation_factor = 0.0027;
substrate.epsR   = 3.55;
substrate.kappa  = dissipation_factor * w * EPS0 * substrate.epsR;
substrate.width  = 10;
substrate.length = 10;
substrate.thickness = 0.508;
substrate.cells = 8;
```

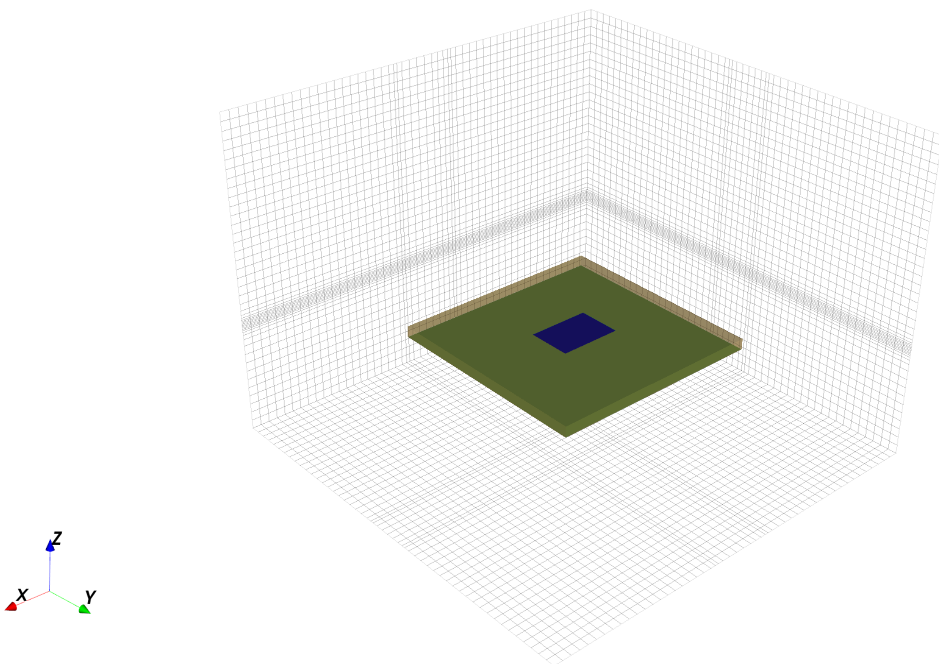
For an initial test I designed a patch antenna using these equations I found from an online calculator.

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}}; \quad \varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

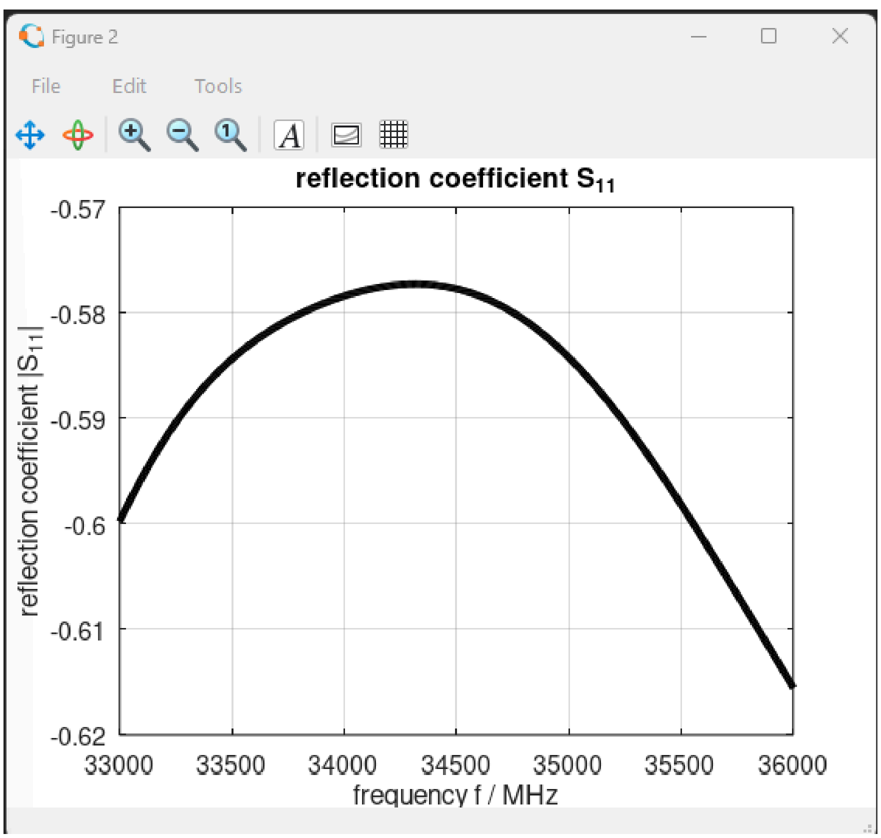
$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

Width (mm)	2.881
Length (mm)	2.048

With the physical design implemented:



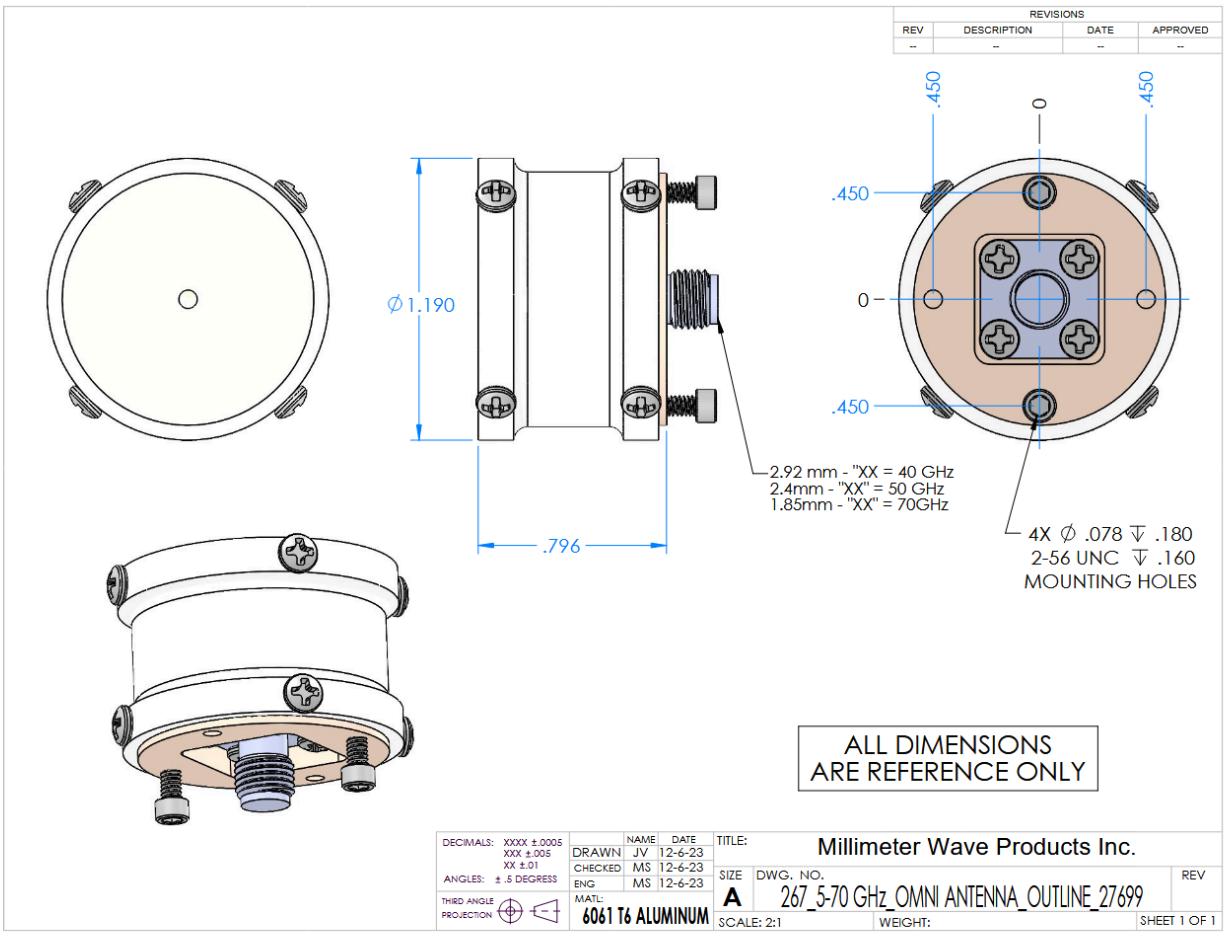
Which resulted in this terrible reflection data…



This just doesn't make a lot of sense to me. In a similar setup researchers were able to effectively absorb a very specific frequency band around 26 GHz with practically identical geometries, materials, and dimensions ([A 2x2 Millimeter-Wave Microstrip Antenna Array]). The FDTD simulation method is also difficult, as calculating the E field and H field for an entire 3D mesh is not a fun way to iterate on a design.

Drawing Board

Rogers is too expensive for prototyping anyway at this stage. With no VNA to work with, it would take extensive simulation to land on a good configuration. In addition to that, the dielectric property of the material would be way too slightly off in real world conditions not to mention the technical challenges of dimensioning the patch I specified earlier. I imagine there exists an antenna that does what I want with an SMA connector?



Do these work? Omnidirectional wideband millimeter wave antennae? Definitely breaks the bank…

Part 2 coming soon, I have to play around with RF modeling more.