Doppler Radar Simulator and Spoofing Device
Why Doppler Radar?
Project Breakdown

- **Doppler Radar Simulator**
  - Radar Unit
  - Computer Interface

- **Spoofing Device**
  - Spoofing Device
  - Test Vehicle
Doppler Radar Simulator Criteria

- Accurately measure speed of moving object
- Operate within police radar band
- Display numerical and graphical results
- Minimum Range of 10 ft
How does Doppler Radar Work?
How does Doppler Radar Work?
Calculations

Transmitted Frequency: $f_t$

Returning Frequency: $f_r$

Doppler Frequency: $f_d$

$f_r = f_t + f_d$

$f_d = f_r - f_t$
Calculations

\[ f_d = \frac{2V_r}{\lambda} \]

where \( \lambda = \frac{c}{f} \)

\[ = \frac{2V_r}{c/f} = \frac{2V_r f}{c} \]

while factoring target angle

\[ 2V_r f \cos \theta \]

\[ = \frac{2V_r f}{c} \]

\[ = 19.49 \text{ V} \quad \text{Km/hr} \]

\[ = 31.36 \text{ V} \quad \text{mph} \]

\[ c = 3 \times 10^8 \text{ m/s} \]

\[ f = 10.525 \text{ GHz} \]

\[ \theta = 0 \]
HB100

Microwave Motion Sensor
## Specs

<table>
<thead>
<tr>
<th>Spec</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$10</td>
<td>Per unit + shipping</td>
</tr>
<tr>
<td>Frequency</td>
<td>10.525</td>
<td>GHz</td>
</tr>
<tr>
<td>Radiated Power</td>
<td>15</td>
<td>dBm</td>
</tr>
<tr>
<td>Received Signal Strength</td>
<td>200</td>
<td>μVp-p</td>
</tr>
<tr>
<td>Weight</td>
<td>9</td>
<td>gm</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-15° - 55°</td>
<td>°C</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>5</td>
<td>$V_{DC}$</td>
</tr>
<tr>
<td>Current Consumption</td>
<td>30</td>
<td>mA</td>
</tr>
</tbody>
</table>
Amplifier

Low Frequency, High Gain
Approximately 40dB gain
Computer Integration
Integration

DOPPLER RADAR

RADAR SIMULATOR

SIGNAL AMPLIFIER

A/D

SOFTWARE INTERFACE
Software Choice

- Matlab
  - Many built in functions (Oscilloscope, Data Acquisition, Fourier Transform)
  - Easy to program, great graphical output
  - Most experienced in Matlab
  - Tech Support
Matlab Algorithm

CREATE ANALOG INPUT OBJECT

DEFINE SAMPLING FREQUENCY

DEFINE DURATION

COLLECT DATA

COMPUTE FOURIER TRANSFORM

DETERMINE AND PLOT FREQUENCY

COMPUTE AND DISPLAY SPEED

COLLECT DATA
% Create an analog input object to communicate with the data acquisition device.
ai = analoginput('winsound');
addchannel(ai, 1);
% Configure the object to acquire 'duration' seconds of data at 'Fs' Hz (max 44000Hz).
fs = 44000;  % sampling frequency
duration = 1;  % how long to read the signal
set(ai, 'SampleRate', fs);  
set(ai, 'SamplesPerTrigger', duration*fs);
% Start the acquisition and retrieve the data.
start(ai);
signal = getdata(ai);

% Finding Fourier Transforms of current signals
SFT=fft(signal,size(signal,1));  % Message Signal

% Converting data into Frequency (Hz) x-axis
freq = (0:size(signal,1)-1)*fs/size(signal,1);  % calculate Hertz values

% Converting data into Magnitude (dB) y-axis
mag = 20*log10(abs(SFT));  % convert magnitude into dB
mag = mag(1:floorsize(abs(SFT)/2));  % this line will convert 2 dim matrix to a single

% Convert data into Time (s) x-axis
time=(0:1:size(signal,1)-1)/fs;

% Calculating Frequency
[ymax,maxindex]= max(mag);
maxfreq = freq(maxindex);
printf('Frequency is %f Hz, maxfreq %f', maxfreq);

% Calculating Velocity
c = 3e8;
Ft = 10.525e9;  % HZ
lambda=c/Ft;
speedms = (maxfreq*lambda/2);  % Value in meter per second
speedkmh = (speedms*3600)*(1/1000);
speedmph = speedms*0.00062137119273600;
printf('The speed of the target is: %f km/h rounded to %f mi/h, speedkmh, speedmph);
Graph of Input Signal (Time Domain)

Input Signal

Graph of Fourier Signal (Frequency Domain)

Fourier Transform Plot
- Generate an executable file
- Can be run from any windows OS
Radar Spoofer
Different Methods of Spoofing

**Active Noise Jamming**
- Continuously transmits noise
- Detectable implementation
- Illegal broadcasting

**Active Deception Jamming**
- Triggered transmission of specific frequency
- Illegal broadcasting

**Passive Deception Jamming (Spoofing)**
- Modulates incoming radar signal and reradiates modified signal
- Legal
How do we Spoof Doppler Radar?
Radar Spoofer Criteria

- Spoof doppler radar signal
- Operate on police radar band
- Operate autonomously once activated
- Battery powered
- Maximum dimensions 6” X 4”
- Capable of in class testing
System Diagram

WAVEGUIDE

OSCILLATOR

MIXER

DC OFFSET
Options for Signal Alteration

- **AM**
  - Radio transmission
  - Variation of amplitude while frequency is constant
  - Ease of implementation

- **FM**
  - Radio transmission
  - Variation of frequency while amplitude is constant
  - More sophisticated
AM: Basic Operation

\[ f_{\text{out}} = f_{\text{in}} \pm f_{m} \]

- Input signal: \( f_{\text{in}} \)
- Modulation frequency: \( f_{m} \)
- Output signal: \( f_{\text{out}} \)

Sinewave Oscillator

Fourier Transform of Modulated Signal
AM: Frequency Behavior

- Frequency can not be negative
- Once frequency becomes 0, frequency increases in positive direction
Realistically, all radars have a passband filter with the cutoff point set at a certain frequency.

Purpose is to filter out noise and unwanted frequency components.
### Calculation

![Diagram](image)

The relationship between the real speed and the spoof speed can be expressed as:

\[ f_d = 2 \frac{V}{\lambda} \quad \rightarrow \quad V = f_d \frac{\lambda}{2} \]

<table>
<thead>
<tr>
<th>Real speed</th>
<th>Spoof speed</th>
<th>Real</th>
<th>Spoof</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vr(mph)</td>
<td>Vr(m/s)</td>
<td>Vr(mph)</td>
<td>Vr(m/s)</td>
</tr>
<tr>
<td>100.00</td>
<td>44.69</td>
<td>70.00</td>
<td>31.29</td>
</tr>
<tr>
<td>100.00</td>
<td>44.69</td>
<td>50.00</td>
<td>22.35</td>
</tr>
<tr>
<td>10.00</td>
<td>4.47</td>
<td>7.00</td>
<td>3.13</td>
</tr>
<tr>
<td>10.00</td>
<td>4.47</td>
<td>5.00</td>
<td>2.23</td>
</tr>
<tr>
<td>10.00</td>
<td>4.47</td>
<td>7.00</td>
<td>3.13</td>
</tr>
<tr>
<td>10.00</td>
<td>4.47</td>
<td>5.00</td>
<td>2.23</td>
</tr>
</tbody>
</table>

### Units

- **f_d (Hz)**: Frequency of the spoof signal.
- **V (mph)**: Real speed in miles per hour.
- **f_m (Hz)**: Frequency of the modulated signal.
- **Vr (m/s)**: Real speed in meters per second.
Oscillator

LM555CN

- 5-16V supply voltage
- Easy to obtain a square wave with 50% duty cycle
- Adjustable frequency by varying the value of 1 resistor
- Output sources up to 200mA
- Inexpensive
Properties of Square Wave

- Pass the square wave to a LPF to get sinewave

\[ v_{\text{square}} = \frac{4}{\pi} V_m \left( \sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \frac{1}{7} \sin 7\omega t + \cdots + \frac{1}{n} \sin n\omega t \right) \]
Lowpass Filter

MAX7480

- 5V supply voltage
- 8th order Butterworth LPF
- Low noise distortion
- Clock tunable $f_{cutoff}$
- Low output offset
- Low power consumption
Voltage Regulator

- 3.5 → 16.5V input
- Max adjustable voltage 15V with preset at 5V
- Max output current 250 mA
- Low battery detector
PCB of Spoofing Circuit

PCB Design in Orcad

Fabricated PCB
Waveguide

Characteristics:
- Hollowed inside for wave propagation
- RF diode mounted inside
- Can operate as signal detector or mixer
- Allows for larger radar cross-section
Detector Mount Requirements

- Operate within police band
- Preferably tunable
- Weight restrictions
- Size restrictions
Waveguide

Part: X485B
Mfr: HP/Agilent

- X-band (8.2-12.4 GHz)
- Tunable
- BNC
- Diode crystal: 1N23
- Cost: $95 + S/H
- Weighs < 1 lb
- Appx. 5.5×1.5 inches
Horn Antenna

- **Characteristics:**
  - Purpose is to be mounted at opening of waveguide
  - Flares out from base
  - Increases the gain for applications requiring higher signal strength
  - Expensive if purchased on market
Horn Antenna

Solution:

- Elected to build our own
- Foam mold with aluminum foil along interior
- Appx 5” long attachment to end of waveguide
- Opening appx 3” x 2”
- Negligible weight
Mixer Diode

Requirements:
- Needs to be square law, relationship of $V=I^2$
- 1N23 crystal
- VSWR should be close to 1

Solution:
- Samples from Micrometrics
- 1N23 crystal with removable base
- VSWR = 1.3
IV Characteristics

- First section square law, then linear relationship
- Must propagate within square law section to maintain mixing characteristics
Test Procedure 2

Proving the Spoofing Device works

Trial run # 1 : Spoofer OFF
  Determine actual speed of a target

Trial run # 2 : Spoofer ON
  Same test variables, observe spoofed speed
## Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Waveguide</td>
<td>$101.50</td>
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<tr>
<td>Microwave Diodes</td>
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<tr>
<td>Microwave Motion Sensor (8)</td>
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<tr>
<td>Amplifier</td>
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<tr>
<td>555 Timers</td>
<td>Donated</td>
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<tr>
<td>Low-Pass Filter</td>
<td>Donated</td>
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<tr>
<td>Voltage Regulator</td>
<td>Donated</td>
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<tr>
<td>Circuit Materials</td>
<td>Donated</td>
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<td>Test Vehicle Materials</td>
<td>$17.50</td>
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<tr>
<td>Test Track Materials</td>
<td>$8.00</td>
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<tr>
<td>Other Components</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$314.00</strong></td>
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Test Procedure 1

Proving the Radar Works

Compare speed measured by Radar to speed determined through timed trial
## Work Distribution

<table>
<thead>
<tr>
<th></th>
<th>Justin</th>
<th>Johnny</th>
<th>Sam</th>
<th>Vlad</th>
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<tbody>
<tr>
<td>Radar Spoofer</td>
<td></td>
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<tr>
<td>Test Car &amp; Track</td>
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<tr>
<td>Waveguide &amp; Detector</td>
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<td>Oscillator &amp; Current Amplification</td>
<td>Radar Transmitter &amp; Amplification</td>
<td>Computer Integration</td>
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<tr>
<td></td>
<td>Testing</td>
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Questions?

RADAR SPOOFER

HORN ANTENNA

DOPPLER RADAR

LOW PASS FILTER

DIODE DETECTOR (MIXER)

OSCILLATOR

WAVEGUIDE

SIGNAL AMPLIFIER

SOFTWARE INTERFACE

A/D

RADAR SIMULATOR