Imminent Collision Intervention Systems

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Imminent Collision Intervention Systems

Automotive Radar for Collision Avoidance

Background

- 75% of traffic fatalities in the United States involve rear-end collisions and lane departures
- It is estimated that almost 50% of these accidents could have been avoided with some form of advanced driver assistance system
- As a direct result, automotive manufacturers have begun incorporating active collision prevention systems into their flagship product lines
- What about current passenger vehicle owners?

Project Goals

- The goal of this project is to develop a microwave radar-based automotive collision mitigation system
- The system will monitor the distance to and relative velocity of a preceding vehicle
- Should the rate of change of distance between the two vehicles increases such that immediate deceleration is required, the system will warn the driver of an imminent collision
- Universal vehicle application (i.e. retrofit to existing passenger vehicles)

Theory of Operation

- Conventional pulsed radar requires high power, large bandwidth, and exhibits range ambiguities at short distances
- <u>F</u>requency <u>M</u>odulated <u>C</u>ontinuous <u>W</u>ave
- Analogous to standard FM transmission
- Transmitter frequency swept linearly between two predetermined frequencies
- The transmitted and reflected signals are mixed to produce a differential frequency that represents the illuminated target's range

Theory of Operation

- In other words, target distance is determined by measuring the frequency output of the mixer
- Using an 80 MHz bandwidth and a 100 Hz sweep rate, the frequency / distance relationship is as follows:

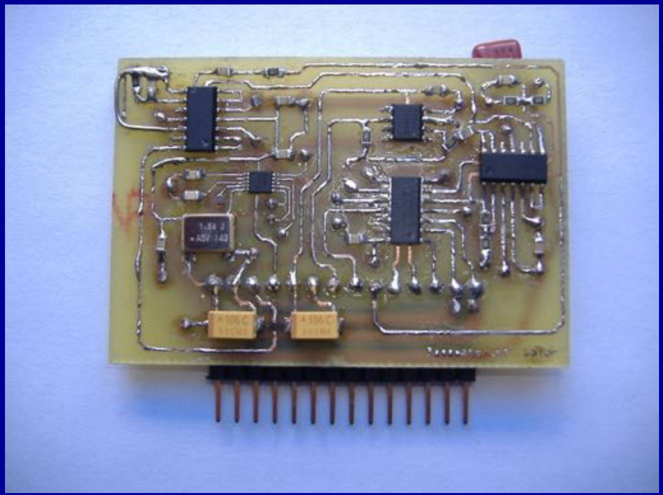
$$\Delta f = \frac{r \cdot 4 \cdot BW}{T_m \cdot c} = 106.7 \, \frac{\text{Hz}}{\text{m}}$$

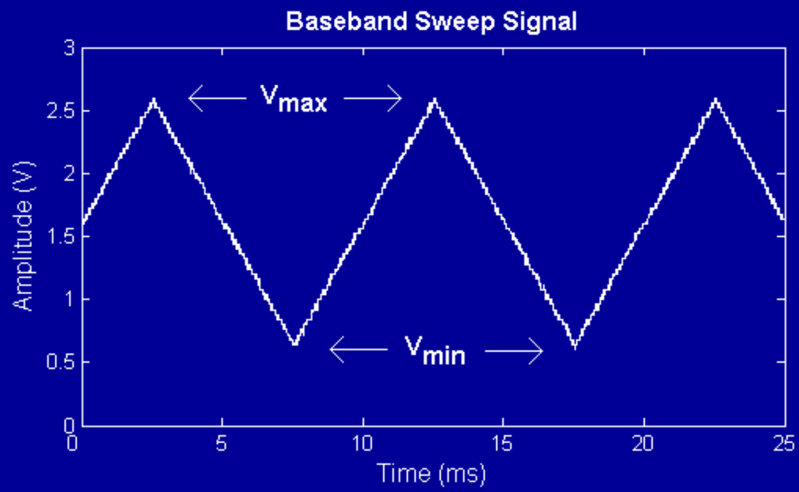
- For example, a target 10 m in front of the antenna will result in a differential frequency of 1066.7 Hz

Microwave Radar Transceiver

- 24.05 – 24.25 GHz transmitter and receiver
- Internal homodyne mixer and low-pass filter
- 18 dBm output power

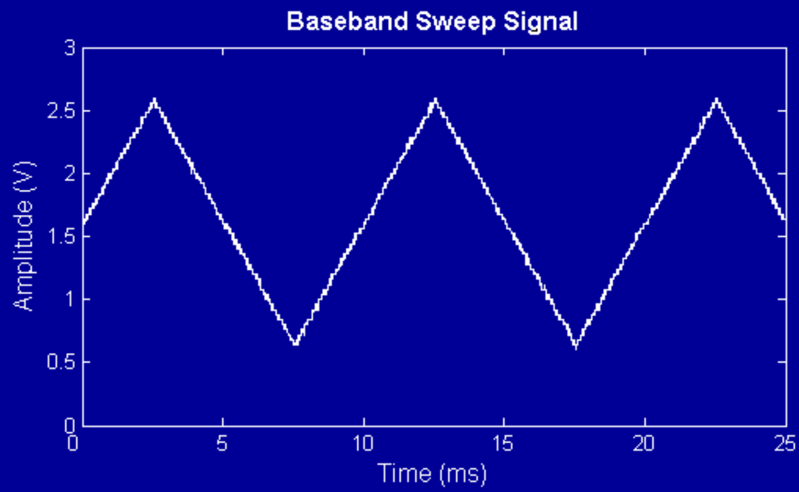
Baseband Oscillator

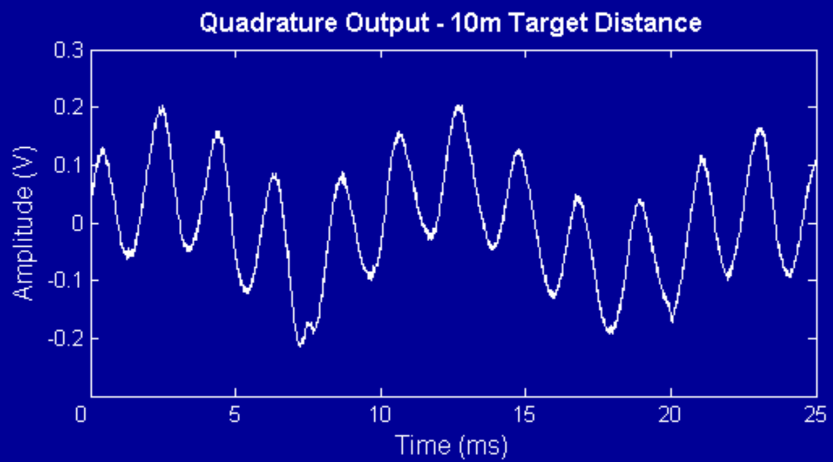




- The baseband sweep signal is generated by a direct digital synthesizer (DDS)
- V_{min} and V_{max} determine transmitter bandwidth
- The signal's frequency, phase, amplitude and offset are controlled by the digital signal processor

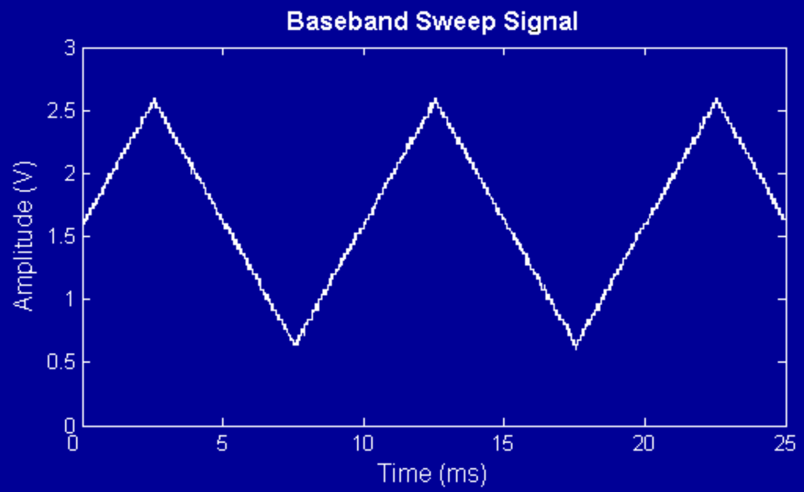
Radar Transceiver Output Signal

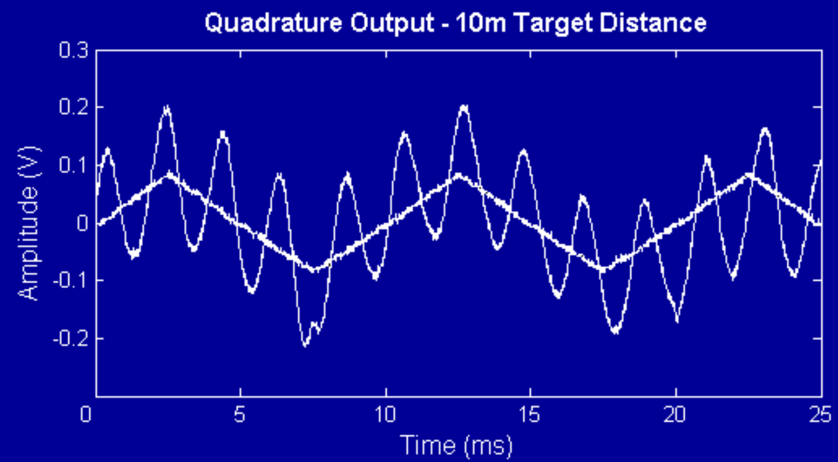




- The ≈ 1 kHz sinusoidal signal is the resulting differential frequency for a target at 10 m

Radar Transceiver Output Signal



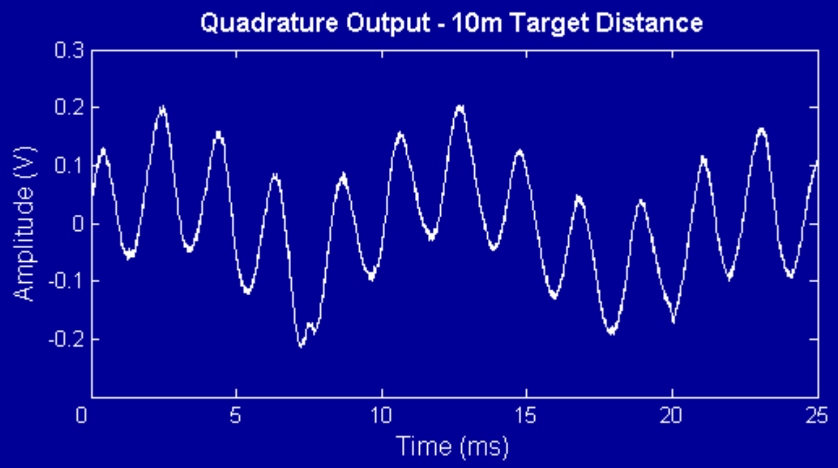


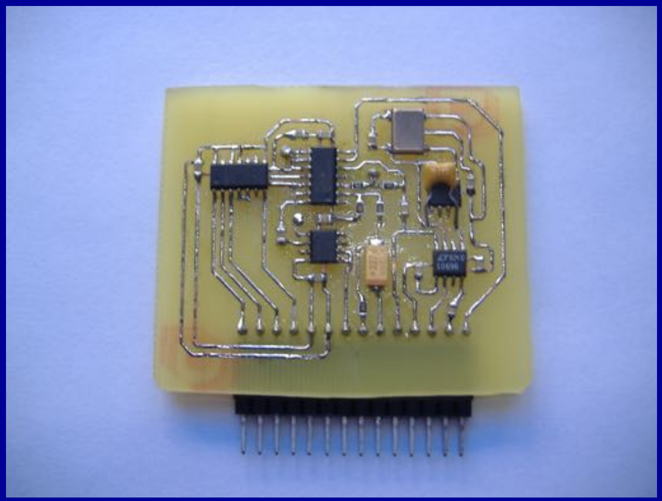
- However, there is also a triangular waveform present in the radar output signal
- This triangular waveform is called crosstalk, or *carrier feed-through* (CFT)

Carrier Feed-Through

- Carrier feed-through is caused by finite isolation between the transmitter and receiver signal paths
- The CFT signal amplitude remains constant regardless of target distance, ultimately dominating the radar output signal for long range targets
- The unwanted CFT signal's harmonic content falls into the same frequency band (500 Hz to 16 kHz) as the wanted signal generated by a target reflection, making conventional filtering difficult

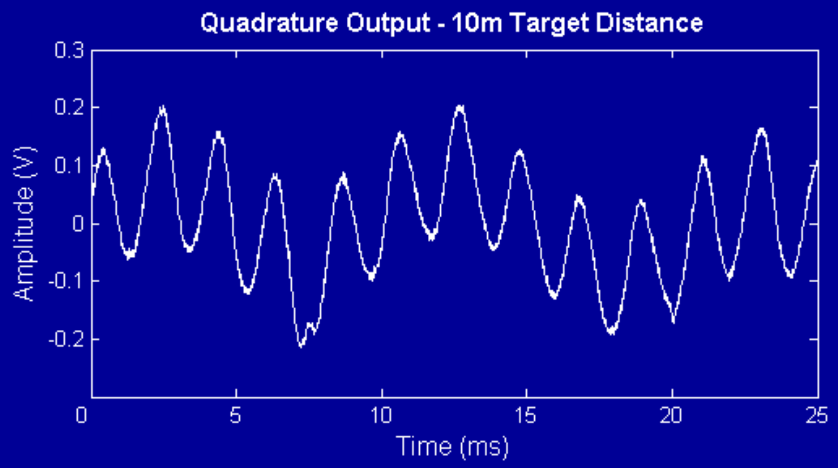
IF Preprocessor

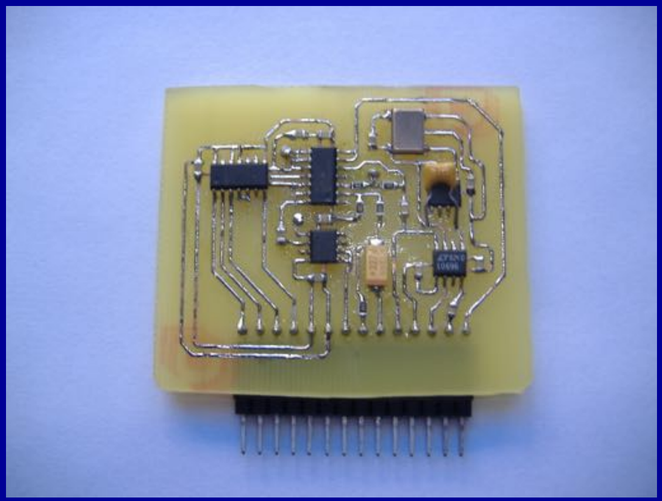




- The IF preprocessor contains the IF amplifier, differential amplifier, and anti-aliasing filter
- The unwanted triangular waveform (CFT) is removed by exploiting two of its properties:

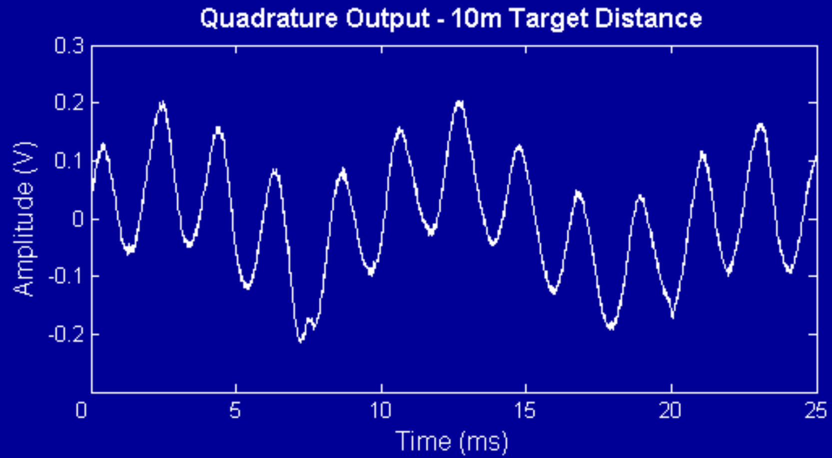
IF Preprocessor

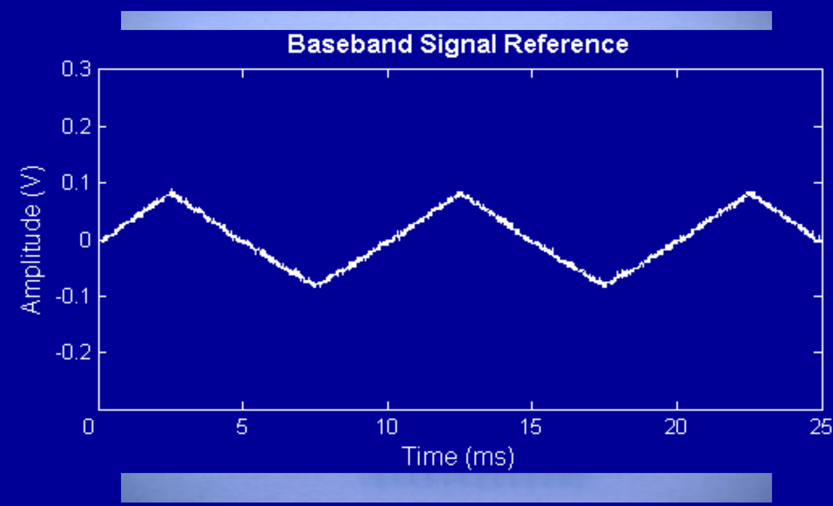




1. The amplitude remains constant regardless of target distance
2. It is in-phase with respect to the baseband signal

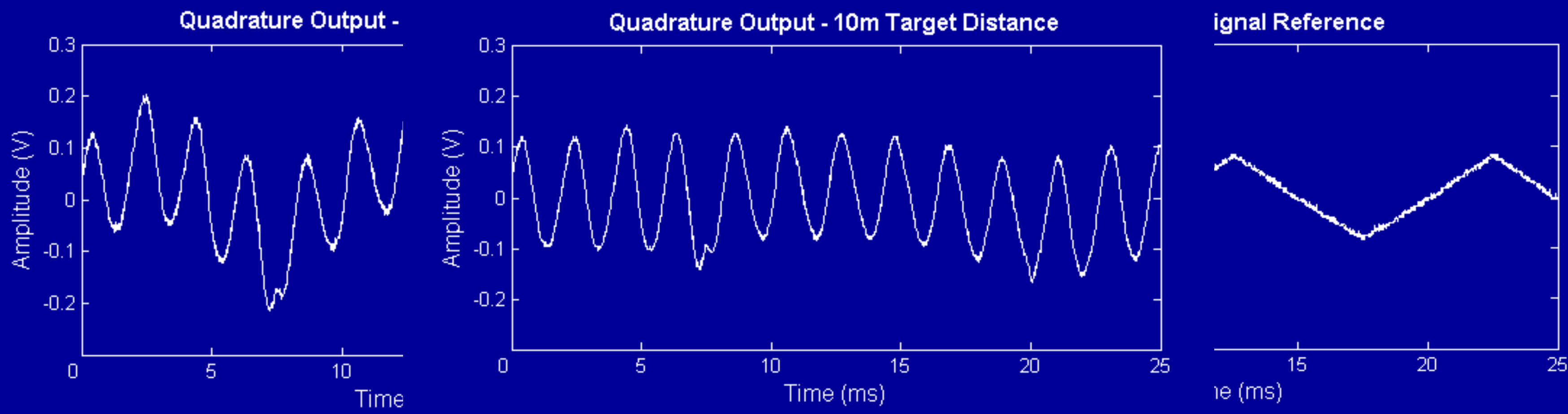
IF Preprocessor





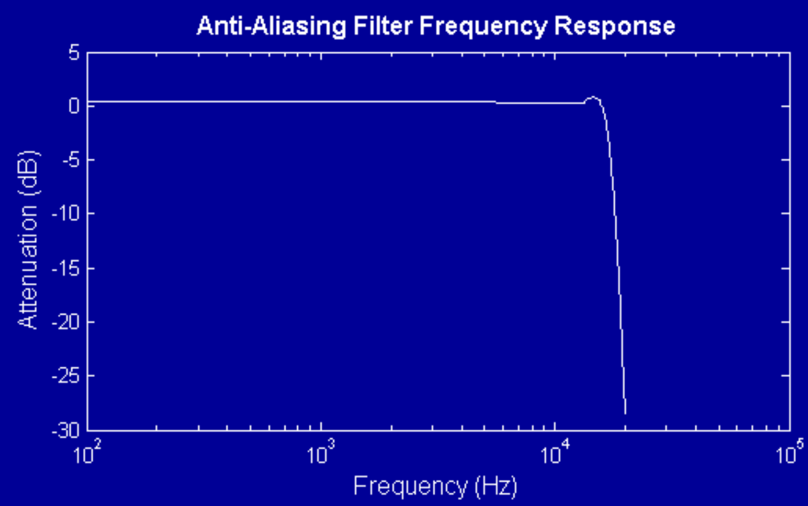
- The baseband signal is simultaneously fed into the IF preprocessor, and its amplitude is digitally adjusted to match that of the unwanted triangular waveform

IF Preprocessor



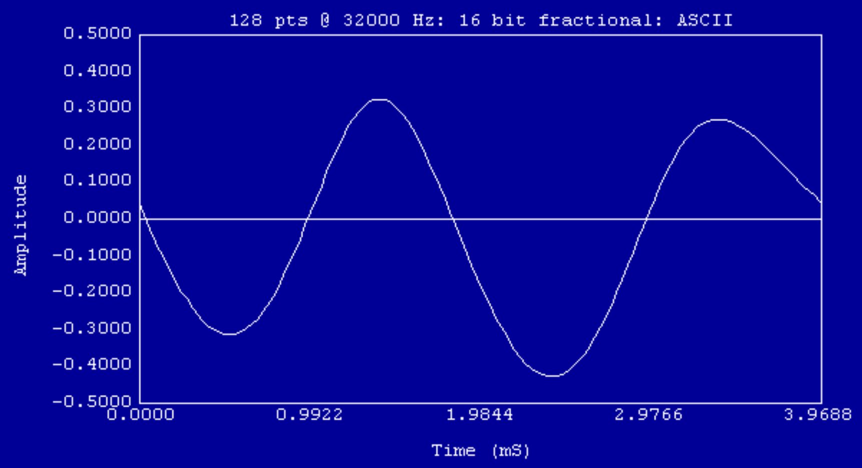
- Both waveforms are fed into a differential amplifier, which outputs the difference between the two input signals
- This effectively removes the unwanted triangular waveform from the radar output signal

Anti-Aliasing Filter



- The anti-aliasing filter band limits the signal to 16 kHz (equivalent to 150 m target distance)
- 8th order switched capacitor Euler (Elliptic) filter
- Filter bandwidth is an integer fraction of the master clock
- 1.6 MHz ÷ 2 ÷ 50 = 16 kHz cut-off frequency

Digital Signal Processor



- A Digital Signal Processor (DSP) converts the analog radar signal into digital samples
- 128 samples @ 32 kHz
- A 1024 point fast Fourier transform (FFT) is used to determine signal frequency

Digital Signal Processor

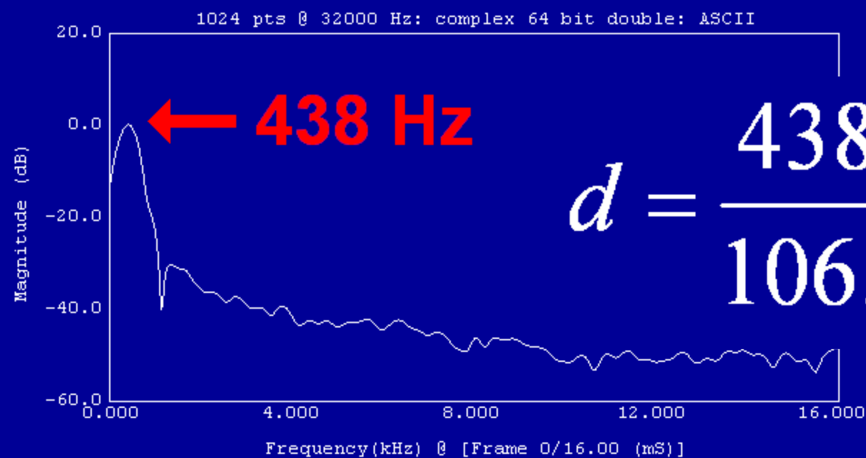
- The FFT frequency bin spacing is determined as follows:

$$\frac{\text{Sampling Rate}}{\text{FFT Points}} = \frac{32\ \text{kHz}}{1024} = 31.25\ \text{Hz}$$

- This, in turn, results in the minimum resolvable target range of the system:

$$\frac{31.25\ \text{Hz}}{106.7\ \frac{\text{Hz}}{\text{m}}} = 0.29\ \text{m}$$

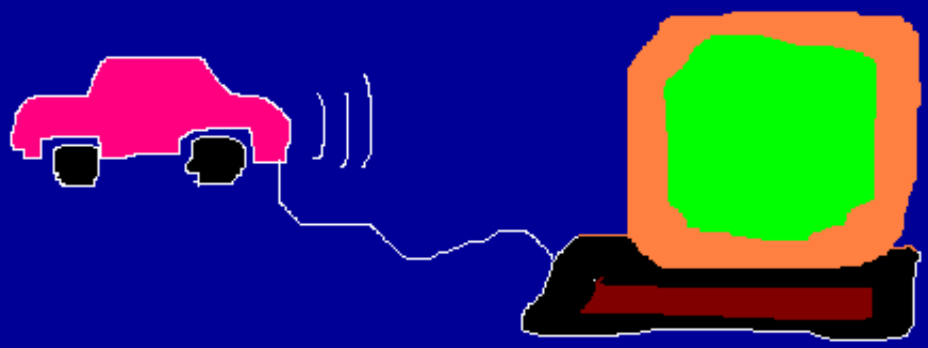
Digital Signal Processor



$$d = \frac{438\ \text{Hz}}{106.7\ \frac{\text{Hz}}{\text{m}}} = 4.1\ \text{m}$$

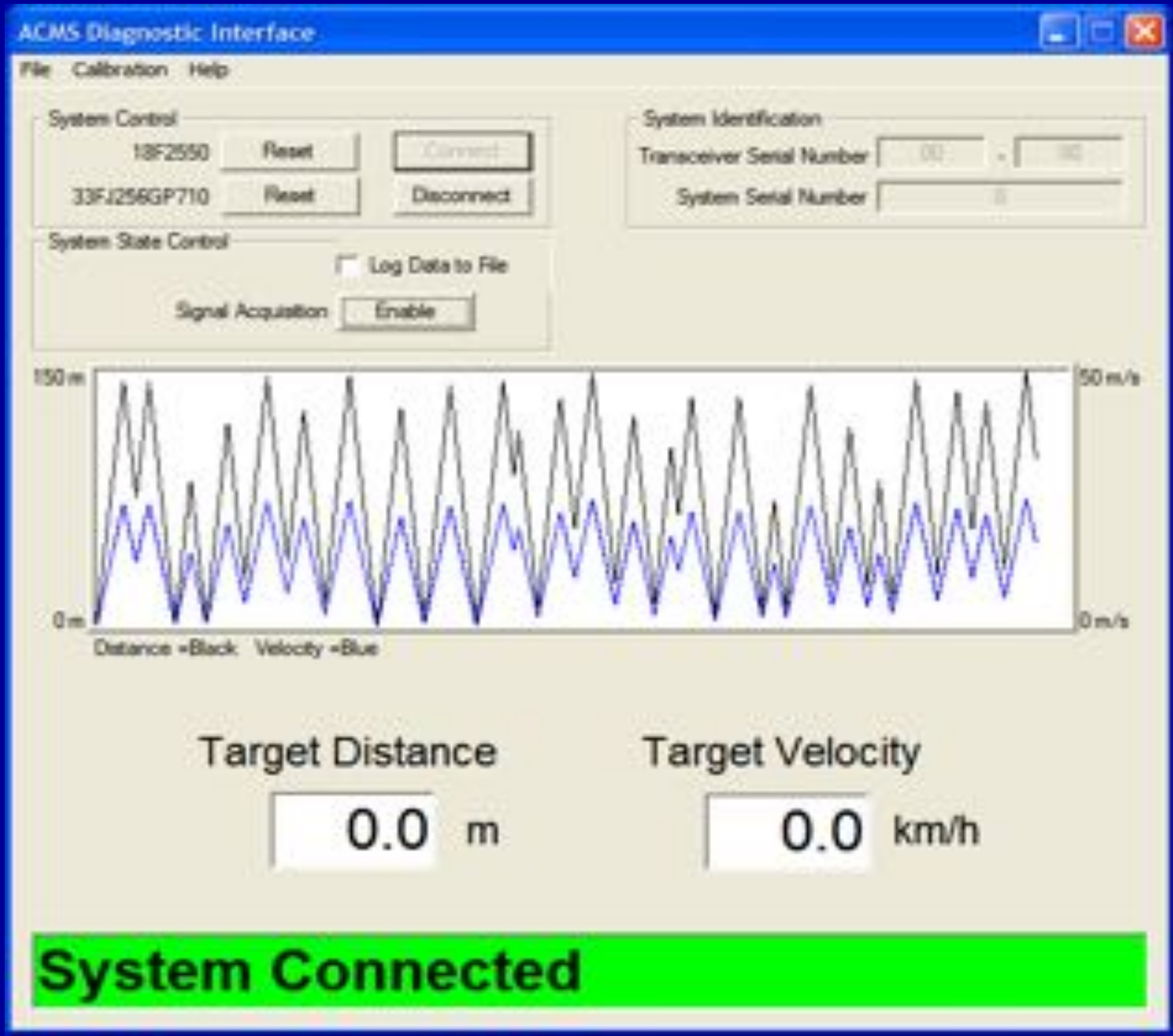
- The FFT is applied to the radar signal vector
- The frequency bin with the largest spectral component is located…
- …and target distance is then easily calculated

Diagnostic Interface

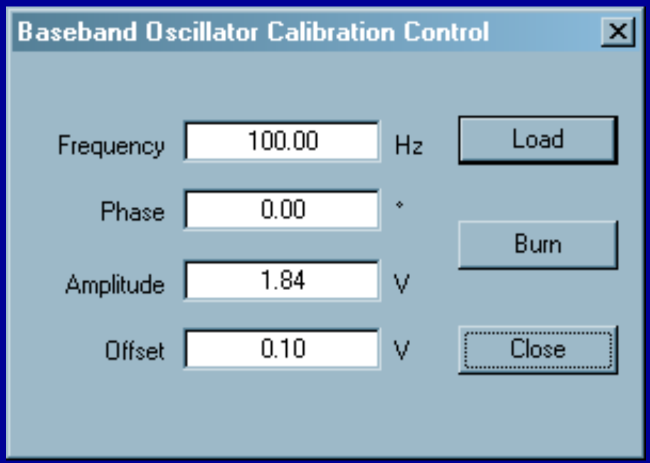


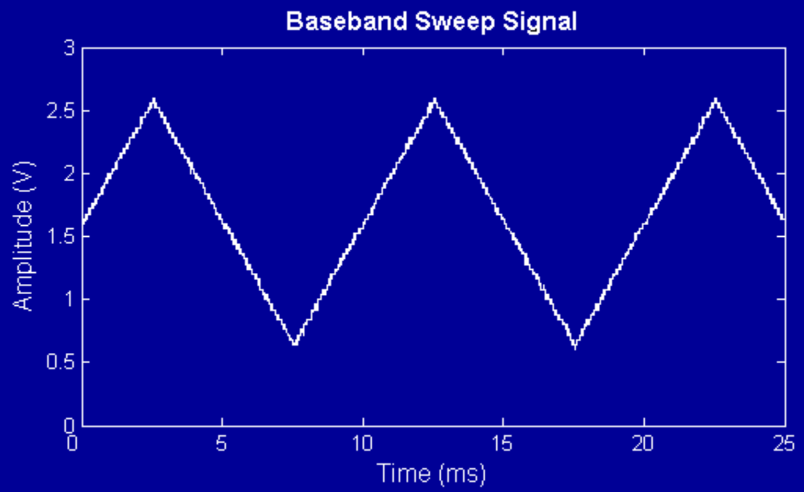
- Windows-based software application that will communicate with the collision warning system
- The software is targeted towards both the manufacturing and installation processes
- Allows a technician to perform system calibration, diagnosis, and firmware updates

Diagnostic Interface



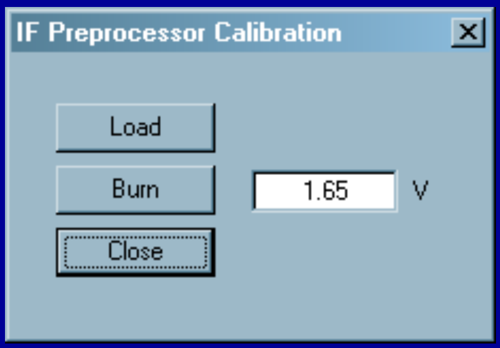
Baseband Control Dialog

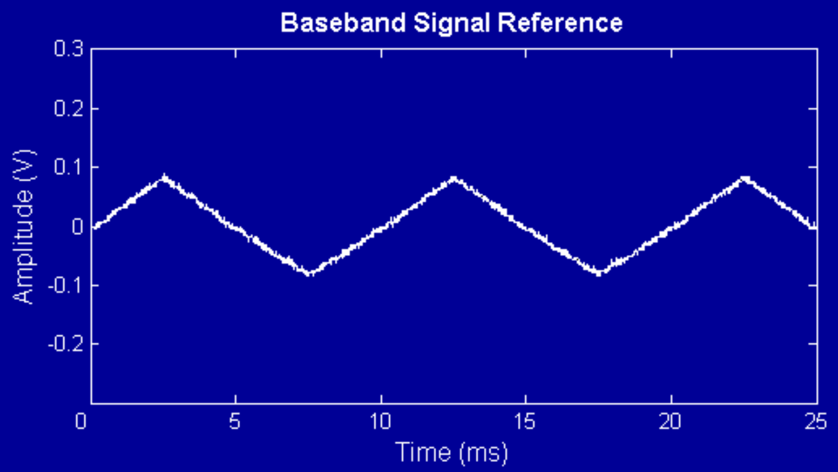




- The baseband dialog controls the transmitter sweep signal parameters
- The **LOAD** control transfers the new settings to the DSP, which in turn updates the DDS and amplitude controllers
- The **BURN** control writes the new settings to the external EEPROM

IF Preprocessor Dialog





- The IF Preprocessor dialog controls the amplitude of the baseband reference signal
- The **LOAD** and **BURN** controls are functionally equivalent to those of the Baseband dialog

USB Microcontroller

- A USB microcontroller serves as an intermediary communication link between the calibration software and DSP
- Microcontroller and DSP transfer data using UART @ 500 kbps
- Microcontroller and calibration software transfer data using HID class USB
- USB VID and PID sub-licensed from Microchip Technology
- Microcontroller firmware passed Chapter 9 and HID class compliance tests

Preliminary Road Test

Actual Target Vehicle Distance = **30.25 m**

Measured Vehicle Distance = **30.1 m**

March and April 2009

Hardware

- Incorporate automatic gain control (AGC)
- Construct the aural and visual alerting system
- Complete the printed circuit board layouts

Software and Firmware

- Incorporate target velocity calculations
- Design and incorporate the target threat assessment algorithm (when do we warn the driver?)
- Create a dialog and supporting code to calibrate the threat assessment algorithm

Questions?