Design Team 6 Technical Lecture
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Frequency Modulated Continuous Wave (FMCW) Radar

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Outline

- History of Radar
- How FMCW Works
- Signal Processing
- Applications of FMCW

Birth of Radar

- Heinrich Hertz (1887)
  - Discovery of radio waves
- Christian Huelsmeyer (1904)
  - Telemobiloscope
  - No range or speed
- Guglielmo Marconi (1922)
  - Wireless Radio advocate
- Sir Robert Watson-Watt (1935)
  - Daventry Experiment
  - Full-scale development begins

Continuous Wave Radar

- First Radars were Pulse-Wave
  - Fast decay; High EM interference
- New technology
  - Slow decay
  - Continuous sinusoid
- CW Radar
  - Uses Doppler effect
  - Measures Speed

FMCW

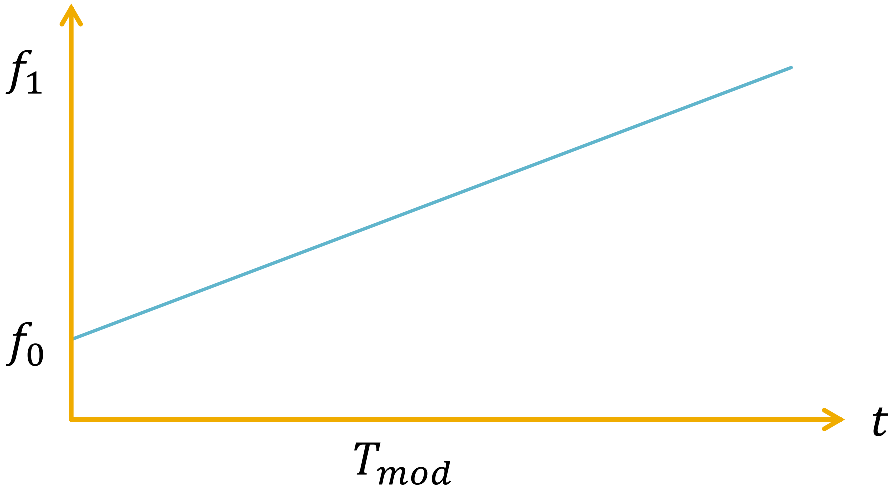
- No single inventor
  - Many different corporations and government bodies discovered it.
- CW Radar limitations
  - Cannot measure distance
  - Most developers realized that modulating the frequency will allow distance to be calculated

System Overview

- Frequency modulated transmitter
- Transmit signal also used as local oscillator (LO)
- Received signal amplified and mixed with LO to create beat
- Beat frequency proportional to distance

Linear Modulation

- Simplifies transmitter design
- Allows for easy signal processing
- Both allow for a low cost system
- Signal is represented as a "chirp" in time domain and a linear ramp in the frequency domain



$$f' = \frac{f_1 - f_0}{T_{mod}}$$

Transmitted Signal

- Signal is represented by a frequency-modulated sine wave

$$T_x = \sin\left[2\pi t\left(f_0 + \int_0^t f' d\tau\right)\right] = \sin\left[2\pi t\left(f_0 + \frac{f't}{2}\right)\right] \qquad f' = \frac{f_1 - f_0}{T_{mod}}$$

- Signal travels a distance and is reflected back
- Time signal takes to travel back is

$$t_d = \frac{2d}{c}$$

- d = distance to object
- c = speed of light in medium

Received signal and mixing

- Received signal is identical to transmitted signal, but delayed in time

$$R_x = \sin\left[2\pi(t - t_d)\left(f_0 + \int_0^{t-t_d} f' d\tau\right)\right] = \sin\left[2\pi(t - t_d)\left(f_0 + \frac{f'(t-t_d)}{2}\right)\right]$$

- R_x is mixed with T_x and passed through a low-pass filter, resulting in a signal proportional in frequency to target distance

$$f_{out} = f' * t_d = \frac{f_1 - f_0}{T_{mod}} * \frac{2d}{c}$$

Example Target

- $f_0 = 2.26GHz$
- $f_1 = 2.59GHz$
- $T_{mod} = 20ms$
- $d = 10m$
- $f_r = \frac{f_1 - f_0}{T_{mod}} * \frac{2d}{c} = 1.1kHz$

Additional Parameters

- FMCW has a range resolution that varies with the range of frequencies used

$$\Delta R = \frac{c}{2 * (f_1 - f_0)}$$

- Power received from reflection modeled by radar equation

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R^4}$$

Signal Processing

1. Fast Fourier Transform (FFT)
   - Transform a time signal into the frequency domain. $x(t) \Rightarrow X(k)$
2. Filtering
3. Detection Rules
4. Multiple Object Detection

Fast Fourier Transform

- Discrete Fourier Transform: Transform a time domain signal into the frequency domain

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i 2\pi k \frac{n}{N}} \qquad k = 0, \dots, N-1$$

- Evaluating the DFT directly requires $O(N^2)$ operations. FFT algorithms require $O(N \log N)$ operations which results in significantly faster speed
  - Example: A signal estimated by 1024 samples : N=1024

    $O(N^2)$ = 1,048,576 computations for DFT

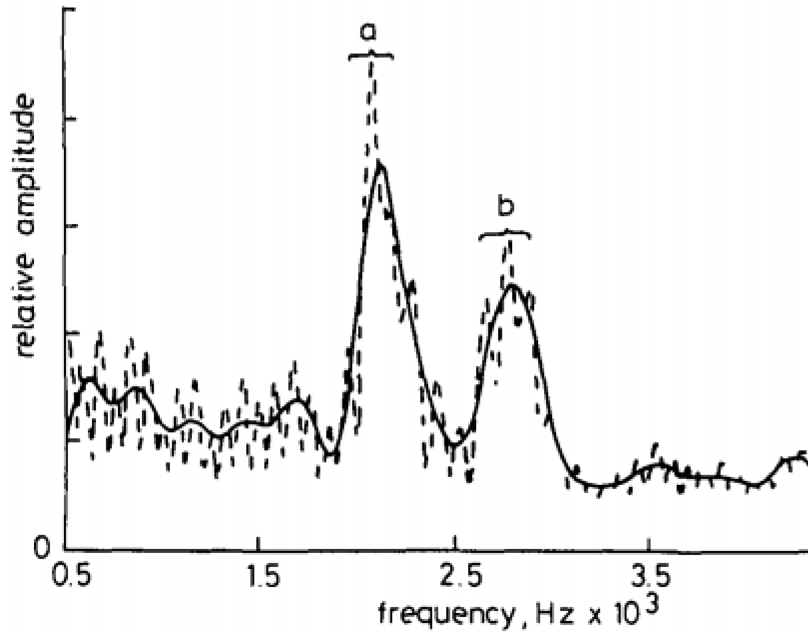
    $O(N \log N)$ = 10,240 computations for FFT

Filtering

- The result of the FFT contains noise as well as the signal. In some cases the noise may be stronger than the signal itself.
- Target signal is typically low frequency
- Noise is broadband and high frequency
- Use a Low Pass Filter to get rid of the noise and keep the target signal this will increase the Signal to Noise Ratio

Detection Rules

- Data set is now a filtered set of amplitudes some low frequency noise remains



- We must now set a minimum amplitude for object detection to occur.
- If an amplitude at a given frequency does not reach the threshold it should be reset to zero.

Object Differentiation

- Objects are identified by spectra that have non-zero amplitude.
- A number of consecutive zero spectra is required to differentiate between objects.
  - This number is set arbitrarily and fine-tuned through testing.

Through Wall Sensing

- Could be between 0 and 3-Dimensional
  - 0D: Presence detection
  - 1D: Detects movement and velocity
  - 2D & 3D: Imaging, able to detect velocity and angle
- Operates between 0.5 GHz and 8.0 GHz and split up into 3 sub-bands depending on material and thickness of wall
  - 0.5-2.0 GHz
  - 1.0-4.0 GHz
  - 2.0-8.0 GHz
- Attenuation of signal is increased as frequency increases

Why FMCW for Through Wall?

- Simple and Cheap to implement
- Fast switching synthesizers, specific DSPs, and fast ADCs are expensive
- Low power consumption
  - Consumption is increased by its pulse integration
  - Consumption decreased by its low duty cycle
- Based on FFT so processing is fast and efficient

Automotive Applications

- Anti-Collision – Measures velocity to avoid accidents
- Parking Sensor – Measures distance to avoid collision
- Traffic Sensor – Detects flow or speed of traffic

Applications: Tracking Transit

Why FMCW for Tracking Transit?

- Ability to detect stationary and moving objects
- Only need ONE radar
- Environmental factors won’t affect the accuracy of the radar
- Detects speed and direction

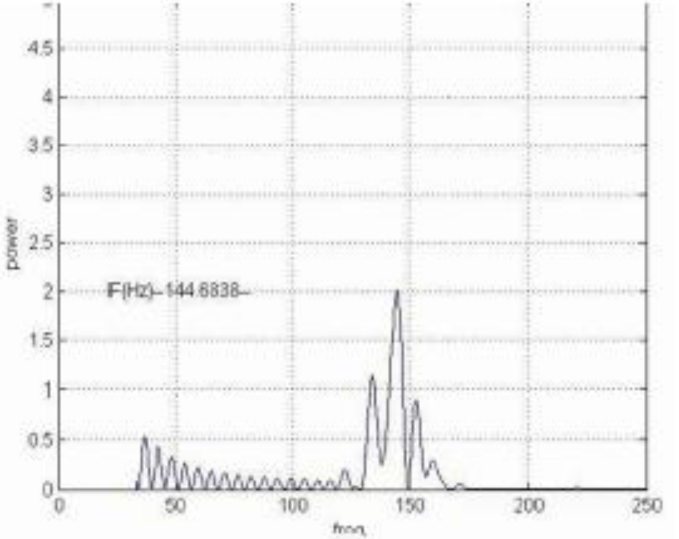
Applications: Tank Level Gauging

Why FMCW for Tank Level Gauging?

- Radar waves are unaffected by the atmosphere above the product
- Only antenna is inside the tank
- High reliability
- High accuracy
- Resistance to dust and dirt

Applications: Concealed Weapon Detection

- Finding hidden objects
  - Found in:
    - Furniture
    - Covered cloth
    - Thick clothing



Why FMCW for Concealed Weapon Detection?

- 94 GHz radar
- reasonable penetration for certain materials (thickness)
- High accuracy
- Resistance for outdoor and indoor use
- Could be used for imaging or non-imaging
- Low emitted power – no health concern
- Can be remotely deployed

Questions

References

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