FMCW Radar:
CW Radar with Frequency Modulation

Lecture 22-23
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Introduction

• CW Radar limitations
  • Cannot measure distance
  • Most developers realized that modulating the frequency will allow distance to be calculated.
FMCW Radar is a low cost technique, often used in shorter range applications.

Applications include,

- altimetry for aircraft landing,
- speed guns,
- laboratory test instruments,
- education, runway debris monitoring,
- avalanche detection,
- volcano eruption onset and many more

The technology is simple to fabricate but requires care to obtain high accuracy.

The technique has the same conceptual basis as pulse compression and high resolution.
• Frequency Modulated Continuous Wave (FMCW)
• Chirp pulse compression ...
• FMCW-Radar with classic sawtooth or triangle shaped frequency shift (Chirp-radar);
• FSK-FMCW (frequency shift keying FMCW);
• SFMCW (Stepped FMCW) for interferometric measurements;
• FMiCW (Interrupted FMCW) for better isolation between transmitter and receiver PMCW (phase modulated CW) with pseudorandom codes.
Up-chirp

\[ f' = \frac{f_1 - f_0}{T_{\text{mod}}} = \frac{T_{\text{mod}}}{T_s} = \frac{\text{sweepBW}}{\text{sweeptime}} \]

Down-chirp
A radar transmitting a continuous carrier modulated by a periodic function such as a **sinusoid or saw tooth wave** to provide range data (IEEE Std. 686-2008).
FMCW Radar: Principle

Stationary Target

\[ \text{two-way propagation delay} \quad \tau = \frac{2r}{c} \]

\[ \text{Beat Frequency} = \Delta f' = \frac{2r}{c} f' \]
Radar

Range $R$

Time $T_s$

Frequency excursion, sweep bandwidth $B_{\text{sweep}}$

Diagram showing the relationship between radar range, sweep time, and frequency.
Beat Frequency and Range

Radar

-range $R$

- frequency

- frequency excursion, sweep bandwidth $B_{\text{sweep}}$

- sweep time $T_s$

- beat frequency $f_b$

- receiver output

- Fourier transformation

- modulus of the spectrum

- range $R$

- $t_d = \frac{2R}{c}$

- $\frac{t_d}{T_s} = \frac{f_b}{B_{\text{sweep}}}$

- $R = \frac{cT_s f_b}{2B_{\text{sweep}}}$
A moving target induces a Doppler frequency shift

\[ f_D = \frac{2v_r}{\lambda} \]

with the radar wavelength \( \lambda \).

The beat frequency is not only related to the range of the target, but also to its relative radial velocity with respect to the radar.
Moving single target

Beat frequency components due to range and Doppler frequency shift:

\[ f_b = \frac{B_{sweep}}{T_s} \cdot \frac{2R}{c} \]

\[ f_D = \frac{2v_r}{\lambda} \]

that are superimposed as

\[ f_{bu} = f_b - f_d \]

\[ f_{bd} = f_b + f_d \]

so range and radial velocity can be obtained as

\[ R = \frac{cT_s}{4B_{sweep}} (f_{bd} + f_{bu}) \]

\[ v_r = \frac{\lambda}{4} (f_{bd} - f_{bu}) \]
Цикл повторения модуляции $1/f_m$

Переданная волна

Полученная волна

Центрачная частота $f_0$

Время задержки

Доплеровский сдвиг

Частота

Beat-частота $f_B$

Время

Амплитуда

Beat-сигнал
Transmitted and received triangular LFM signals and beat frequency for stationary target
Transmitted and received LFM signals and beat frequency, for a moving target.
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
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre frequency</td>
<td>94 GHz</td>
</tr>
<tr>
<td>Radar wavelength</td>
<td>3.2 mm</td>
</tr>
<tr>
<td>Sweep bandwidth</td>
<td>3 GHz</td>
</tr>
<tr>
<td>Sweep duration</td>
<td>1.6 or 0.4 ms</td>
</tr>
<tr>
<td>Pulse Repetition Frequency</td>
<td>625 or 2500 Hz</td>
</tr>
<tr>
<td>Transmit power</td>
<td>10 mW</td>
</tr>
<tr>
<td>Antenna size</td>
<td>7 mm × 5 mm</td>
</tr>
<tr>
<td>Antenna beamwidth</td>
<td>32° E- &amp; H-plane</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>15 dBi</td>
</tr>
<tr>
<td>Resolution</td>
<td>ΔR: 5 cm, Δx:1 cm</td>
</tr>
<tr>
<td>SNR at 3 m range</td>
<td>22.5 dB</td>
</tr>
</tbody>
</table>
A
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94 GHz VCO
3 GHz bandwidth

10 dBm

non-linearity compensation

voltage

stop

start

position sensors

sawtooth generator

frequency
time

6 dB coupler

transmitting antenna

receiving antenna

4 dBm

mixer

8 dB conversion loss

8 MHz, 1st order

20 kHz, 3rd order

low noise amplifier, gain - 60 dB

transistor stage + op-amp

400 kHz, 3rd order

anti-aliasing

sync

10 MHz CLK

A/D board

1 MHz sample rate,
12 bit resolution

10 MHz CLK

1 MHz sample rate,
12 bit resolution
Radar Transmitter

- Power level monitor
- Triggered sawtooth sweep
- Pulse generator
- PA
- BPF
- VCO
- PLL
- OCXO
- Mixer
Radar Receiver

- Microwave Preamp #1
- Microwave Preamp #2
- Mixer
- BPF
- Audio Amp
Summary and Conclusion

The advantages of FM-CW Radar are:

- (1) low cost
- (2) good sensitivity
- (3) high spatial resolution
- (4) high reliability
- (5) portability
- (6) simplicity
- (7) safety

FM-CW radar is capable of producing range-resolved velocities.

FM-CW radar has limited range.