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Radar System Design Considerations -- System Modeling Findings
(MOS-AK Conference Hangzhou 2017)
Outline

1 Introduction to Short Distance Radar Applications
2 FMCW Radar Basics (Frequency Modulated Continuous Wave Radar)
3 FMCW Radar System Model
4 Signal Leakage Causes & Modeling
5 Signal Leakage Effects & Compensation
6 Improved System Model
7 Results & FMCW Radar Demo
8 Silicon Radar at a Glance
Short Distance Radar Applications

**Gesture Recognition**
HMI for small displays

**Drones (UAVs)**
Sense & avoid, Landing assist,

**Industrial Sensors**
IoT; Industry 4.0 Factory automation

**Robotics**
Object detection, Collision avoidance, Collaboration

**Automotive**
Parking assist, Blind spot detection, Driver alertness, Autonomous driving
Application Requirements

• Miniaturized electronic components
• Low weight
• Low power consumption
• Low cost
• Mixed analog and digital signal designs

=> High performance, especially industrial applications
# Radar vs Other Sensor Technologies

<table>
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<tr>
<th>Application Flexibility</th>
<th>122 GHz Radar</th>
<th>24 GHz Radar</th>
<th>Infrared Triangulation</th>
<th>Ultrasonic</th>
<th>Laser</th>
<th>Magnetostriction</th>
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<td>Miniaturization</td>
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<td>Resistance to moisture, dirt, wind, darkness</td>
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<td>Accuracy Sensitivity and Resolution</td>
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<td>Detection of special materials (glass, water, down)</td>
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<td>Cost</td>
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FCMW Radar Technology

- **Short range distance measurement**
  Measurement accuracy <1mm (<1µm in phase mode!)
  Range up to 40 meters with 120 GHz

- **Velocity measurement**
  Detection of moving targets by characteristic radar signature

- **Presence Detection**
  Presence detection in dead band through phase evaluation
FMCW Radar Basics

Sawtooth signal (ramp) tunes a VCO

Also: sine, triangle ...

B ... Bandwidth

\( t_r \) ... ramp time

\( t_d \) ... time diff. TX-RX

\( d \) ... distance to object

\[ \frac{t_d}{t_r} = \frac{f_b}{B} \]

\[ t_d = 2 \times \frac{d}{c} \]

\[ f_2 - f_1 = B \]

Modulated signal

\[ d = c \times \frac{f_b}{2 \times B} \]

Output spectrum

FMCW sawtooth ramp signal which tunes a VCO
Transceiver
+ Baseband
  • PLL
  • Clock
  • Filters
  • Amplifiers
  • ...

Analog 120 GHz radar transceiver chip
Microprocessor based FMCW radar system

1. 5m, -35dB
2. 12m, -59dB
3. 21m, -63dB
4. ...

Expected spectrum output

F

d (f)
Results: Signal Leakage

Small SNR
- < 40 dB max

Huge DC part
- > 40 dB
- Hides near targets

Frequency spectrum and CFAR output after FFT
Signal Leakage Causes

- TX to RX over substrate
- Packaging
- Power over f (VCO) / ramp

Leaked signal may be orders of magnitudes higher than the output signal
Chip Signal Leakage Modeling

- Hard to measure signal leakage
- Correction methods lacking
- Simulate part of the leakage (max 50%)

TX signal leakage through:
- Antenna
- Internal circuitry
Chip Signal Leakage Modeling

No Leakage

Strong Leakage

Conversion Gain

IF I/Q Differential Output Voltages (at -24dBm RF, 0dBm LO)

IF Outputs (at -24dBm RF, 0dBm LO)

IF Outputs (at -24dBm RF, 0dBm LO), AC coupled
Signal Leakage Effects

Ramp (red) and ramp enable signal (yellow)
Signal Leakage Effects

![Graphs showing signal leakage effects](image)

- **f**: Frequency
- **t**: Time
- **ADC value, I channel**: ADC values for the I channel over different points.
- **target detector**: Graph showing the detector response.

The graphs illustrate the comparison between an ideal signal and a signal with leakage effects, highlighting the differences in frequency response and ADC values.
Signal Leakage Cancellation

• Compensation in the chip is expensive and complicated
  --> Better use external correction methods

• Calibration with a known input signal that is substracked from the output spectrum is simple but very expensive, drift effects not covered (aging, temperature dependency)
  --> Better use dynamic corrections methods

• Combination of Filters (simple), DC-coupled diff. amplifiers or dynamic ramp compensation and software DC cancellation
  --> Best SNR / effort ratio
Signal Leakage Cancellation

- AC-Coupling: HPF or DC-coupled diff. amp
- But: ramp still contained in AC part of the signal
- Too much filtering increases the min distance
- Ramp compensation vs. target detection

Dynamic ramp compensation

- Further filtering & software DC Cancellation

![Signal Leakage Cancellation Diagram](image-url)
Microprocessor based FMCW radar system

1. 5m, -35dB
2. 12m, -59dB
3. 21m, -63dB
4. ...

Improved System Model
Results: Reduced Signal Leakage

Good SNR

• > 80dB

Reduced DC part

• by > 40 dB
FMCW Radar Demo
Summary: Design Considerations

Transceiver package and antenna size
• Low weight, low power, miniaturized

Low noise PLL
• Signal quality, range, accuracy

Pay attention to signal leakage
• Increase dynamic range

Transceiver frequency and bandwidth
• FMCW Radar: accuracy increases with bandwidth
• Pay attention to local regulations
Ultra Compact Radar Sensors

**Miniaturized Radar-Chips**
130nm SiGe BiCMOS
1.2 x 1.0 mm

**Ultra Compact Radar-Frontends**
With 2 ext. antennas within molded QFN package
8 x 8 mm QFN, 56 Leads, RoHS & REACH;
with 2 integrated antennas in 5 x 5 mm QFN

**Evaluation Radar-Sensor**
Implementing embedded baseband signal processing
Radar algorithms and target tracking

**Mass production**
Since 2015

**Assembly Process**

**Evaluation board**

**120 GHz Radar ICs / Frontends**
24 GHz Radar ICs
Receiver RX, Transceiver TRX, TRX2, LNA
Upcoming:
9.6 GHz, 10 GHz, 14 GHz, 24 GHz,
36 GHz, 60 GHz, 120 GHz
High-Prec. Sense/Avoid (120GHz ISM)

**Miniaturized**
8x8mm 56 Lead QFN with Antennas in Package

**License free**
Worldwide free of use ISM band with at least 1 GHz bandwidth

**Low Power**
370mW 112 mA at 3.3 V in full FMCW Mode

**Accuracy**
Distance measurement with accuracy of 700um within 20m

**Reliable**
100% secure detection of glass, water, absorbing materials

**Low Cost**
True low cost solution based on silicon process & plastic package

**120GHz ISM**

8x8mm <1g

120 GHz Radar Frontend

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Thank You for Your Attention

Please do not hesitate to contact us in any case of question.

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