mmWave Radar – ADAS Applications

Chethan Kumar Y.B  Abdulraheem Kiledar
Embedded Processing → Radar, Analytics & Processors
Chethan Kumar Y. B  
Hardware Applications Manager (SMTS) & Radar & Analytics Processors

• **Career**
  – Masters degree in Electronics Design and Technology from Indian Institute of Science
  – Joined TI as NCG and that was in the year 2000.

• **Expertise**
  – Started career as an Analog Design Engineer and held various positions with multiple groups within High Performance/High Volume Analog, Wireless and Embedded Processing organizations.
  – Rich experience on Analog and Mixed Signal Products in silicon, systems and applications functions.
  – Published multiple papers including best papers awards in various internal and external conferences.
  – Has two granted patents and is pursuing a few more
  – Currently leads the Hardware applications team for the Auto Radar Product line

Likes adventure sports and is an avid badminton player
Abdulraheem Killedar
Hardware Applications Engineer- Radar and Analytics Processors

• Career
  – Masters Degree in Digital Electronics
  – Over a decade of experience in Semiconductor industry across TI, Marvel and ST Micro. Joined TI in 2011. Prior to joining the Radar team, managed Application, Verification & Validation teams in Processor BU for SoCs like AM335x/437x and TDA2/3

• Expertise
  – Comprehensive knowledge of “SoC Design cycle” spanning across IP/SoC-RTL Design, Design Verification, Emulation and Prototyping
  – Pre/Post Silicon AV&V of Digital, Mixed Signal SoCs and Applications Engineering
  – Proudly ramping (finding my way) on mmWave Sensing Applications

Likes Travelling to far away corners and spending time with his adorable daughter
Outline

- **What is RADAR??**
  - Introduction
  - Automotive RADAR applications and Challenges
  - Why mmWave?
  - Brief introduction to Frequency Modulated Continuous Wave RADAR (FMCW)
  - System Block diagram

- **TI’s mmWave RADAR solutions**
  - TI mmWave Journey
  - Device Portfolio
  - Device Architecture
  - Sensor configuration with TI mmWave solutions
  - Applications

- **How to get started**
  - Introduction to EVMs
  - 3rd Party Sensor modules
What is RADAR??
Yah we remember… seeing this in School 😊

**Observables**
- Range,
- Angle (Azimuth, Elevation)
- Velocity
- Size

**Types**

**Applications**: Military, Industrial, **Automotive-ADAS** ……many more!!
Automotive Radar Applications

Core Applications:
- Adaptive Cruise Control
- Automatic Emergency Brake
- Lane Change Assist
- Blind spot detect

Emerging Applications:
- Parking and Proximity warning
- Surround sense
- Urban Driving

Increased Demand for Accuracy and Miniaturization
Types of Radar Sensing-mmWave Radars

- **Long-Range Radar (LRR)**
  - 76-78 GHz
  - 1 m – 250 m

- **MRR & IR**
  - 26 GHz
  - 77-81 GHz
  - 0.2 m – 160 m

- **Video**
  - 0 m – 80 m

- **Short-Range Radar (SRR)**
  - 24-26 GHz and 77-81GHz
  - 0.2 m – 80 m

- **Ultrasonic (US)**
  - 48 kHz
  - 0.2 m – 3 m
### Why mm-wave?

<table>
<thead>
<tr>
<th>Property</th>
<th>Microwave</th>
<th>mm-Wave</th>
<th>IR/Visible Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td>Electronic</td>
<td>Electronic</td>
<td>Optics</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>~cm – m</td>
<td>~mm – cm</td>
<td>um</td>
</tr>
<tr>
<td>Coupling (antenna) size</td>
<td>PCB</td>
<td>Package</td>
<td>Package</td>
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<tr>
<td>Propagation Through Walls, Boxes, etc.</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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</table>

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM 10^3</td>
</tr>
<tr>
<td>FM 10^6</td>
</tr>
<tr>
<td>mm-Wave 30-300GHz</td>
</tr>
<tr>
<td>THz 10^12</td>
</tr>
<tr>
<td>IR 10^15</td>
</tr>
<tr>
<td>X-rays</td>
</tr>
</tbody>
</table>
Frequency Modulated Continuous Wave FMCW Radar

FMCW – Freq vs. Time

\[ f_{Tx}(t) \]

\[ f_{Rx}(t) \]

\[ f_{IF} \text{ (few MHz)} \]

\[ t_d = \frac{2R}{c} \]

\[ B \text{ (in 100’s of MHz or few GHz)} \]

\[ T_{chirp} \]

**Key Features**

- Ability to sweep wide RF bandwidth (GHz) while keeping IF bandwidth small (MHz)
  - Better range resolution. RF sweep bandwidth of 2 GHz can achieve 7.5cm range resolution, while IF bandwidth can still be <15MHz
- Lower peak power requirement

**Performance**

- Range precision \( \propto \) RF (sweep) Bandwidth
- Velocity precision \( \propto \) Dwell (frame) time
- Angle precision \( \propto \) Number of Tx,Rx

\[ \frac{\text{Range}}{\text{m}} \]
System Block Diagram

How does it work?

- LO is ramped linearly to produce L-FMCW transmit signal
- Received signal (from object reflections) is mixed with the same ramping LO
- Baseband ADC output is post processed in DSP
- Beat frequency (fb) - Range
- Phase shift between successive chirps - Doppler (relative velocity)
- Angle of arrival is obtained using beamforming (multiple Tx, Rx)

Beat freq = Round-trip delay * Slope

$ f_b = \frac{2RB}{cT_{chirp}}$
Journey & the Offering !!
The last 7 years: TI mmWave Journey

- **2010**: Kilby Radar
  - 160 GHz
  - Module level circuits
  - Single chip embedded antenna

- **2011**: Test Chip 1
  - 77 GHz
  - Module level circuits

- **2012**: Test Chip 2
  - 76-81 GHz
  - Single chip
  - Package variant 1
  - Package variant 2
  - Embedded Antenna
  - Field Trials

- **2013**: Test Chip 3
  - 76-81 GHz
  - Module level circuits
  - Final tune
  - Model matching

- **2014**: AWR1243
  - 76-81 GHz
  - Single Chip Transceiver
  - Production intent
  - Sampling Now
  - PPAP Q1 2018

- **2015**: AWR1642
  - 76-81 GHz
  - Single Chip Radar
  - Production intent
  - Sampling Now
  - PPAP Q4 2017
Smart, accurate radar sensors enable autonomous driving

- 5cm resolution
- 1° angular accuracy
- Ability to distinguish two closely placed objects
- 300km/h max relative velocity detection
- Jammer avoidance from other radars
- Intelligent self monitoring

CMOS
mm-wave
76 – 81 GHz

Ultra high resolution
Multi-mode
Global coverage
Robust
Scalable
Single chip
76 – 81 GHz mmWave SoCs (Sampling)

**Radar Sensor**
- **Use Cases**
  - Imaging Radar Sensor
    - 2x AR12 + External DSP
    - 4x AR12 + External DSP

**Radar Sensor + HW Accelerator**
- **Use Cases**
  - Entry-level Single-chip Radar
    - Proximity warning, Blind spot

**Single Chip Radar**
- **Use Cases**
  - USRR Single Chip Radar
    - 160 Degree, 40m
  - SRR Single chip Radar
    - 120m Cross traffic Alert
Scaling from front-end only to full radar integration

- Received Signal
- Pre-conditioning
- Range, Doppler, angle estimation
- Object detection
- Object Classification, Tracking

**RF**
- Antenna
- LNA

**Analog + DFE**
- Mixer
- HP/LPF
- AGC/DC
- ADC
- Re-sampling

**DSP**
- Range FFT
- Doppler FFT
- Angle Estimation
- Object detection

**Cortex R4F**
- Kalman Filtering
- Object Classification
- Car network communication

AWR12x

AWR14x

AWR16x
Architecture: AWR1243 Single Chip FMCW Transceiver

Overview
- Highly integrated 76-81GHz front-end
- 3 TX, 4 RX channels
- LVDS/CSI2 interface for ADC data output
- Multi-chip cascading support
- Built-in Radio (BIST) processor for RF calibration and safety monitoring
- Closed loop PLL for precise and linear chirp synthesis
- Complex baseband architecture for improved noise figure and interference tolerance
- Flexible Ramp Generator and Digital front-end supporting multiple chirp profiles
- Wide IF bandwidth (15MHz) and reconfigurable output sampling rates
Overview

- Single chip proximity Sensor
- IF bandwidth – 5MHz
- Highly integrated 76-81GHz radar frontend
- 3 TX, 4RX channels
- Multiple automotive interfaces
- Built-in Radio (BIST) processor for RF calibration and monitoring
- Programmable lock step R4F MCU
- Integrated hardware accelerators
Architecture: AWR1642 Single Chip RADAR Sensor

**Overview**

- Highly integrated 76-81 GHz radar frontend
- 2 TX, 4RX channels
- Multiple automotive interfaces
- Built-in Radio (BIST) processor for RF calibration and monitoring
- Programmable lock step R4F MCU
- High performance C67 DSP
- ASIL B capable
Software Offering - High Performance RADAR Front end

AWR1243

Firmware is Embedded

Control Interface (SPI and GPIOs)

Data Interface LVDS or CSI2

External Processor

Platform Software (SDK)

• Control is via messages over SPI
• mmWaveLink: TI offers driver with APIs that abstract these messages

Software Offering

mmWave Device Firmware Package (DFP)
Software Offering - Single Chip RADAR Sensor

Software Offering

Platform Software
- RTOS
- Device Drivers
- APIs and Processing Libraries
- Sample Applications
- Tools (Image Creation, Flashing etc.)

mmWave Software Development Kit
Sensor configuration with TI mmWave solutions
Applications

- 150 m +
  - RCS: 10 – 50sqm
  - Adaptive Cruise Control
  - Automated Highway Driving

- 100 m – 150 m
  - RCS: 1 – 10sqm
  - Automated Emergency Braking
  - Automated Urban Driving

- 20 m – 100 m
  - RCS: 0.1 – 1sqm
  - Pedestrian Detection
  - Bicyclist Detection
  - BSD, RCA, LCA

- 5 m – 20 m
  - RCS: 0.1sqm
  - Proximity warning
  - Parking
  - Stop and Go Traffic

- 2 cm – 5 m
  - RCS: micro sqm
  - Proximity warning
  - Chassis sensors
  - Gesture detection
  - Driver monitoring
  - Occupant detection
Trend in Radar sensors

- 77 GHZ LRR Micro + MMIC
- 77 GHZ MRR Micro + MMIC
- 24 GHz SRR Micro + MMIC

Today

+ Highly Automated Driving
+ NCAP, Surround Radar, Park Assist

2021

Cascaded 77 GHz (8+)RX (6+)TX Signal Processor
Single Chip 76-81 GHz 4RX 3TX
Delivering mmWave sensing solutions

mmWaveStudio
mmWaveSDK
mmWaveSoft

TI DESIGNS
TOOLS & KITS

ECOSYSTEM PARTNERS

SILICON
mmWave SOC

TI E2E™ Community

TRAINING

SUPPORT

MACHINE VISION

AUTOMOTIVE

ANALYTICS

INDUSTRIAL
Delivering the most precise sensors in CMOS
Enabling Level 2 and above

Ultra high resolution
Wide RF BW, Chirp linearity

Intelligent
Built-in Self monitoring & calibration Complex baseband

Higher range and velocity
Wide IF BW

Multi mode
Long-/Mid-/Short-/Ultra-short-range

Auto-friendly package
Reliability, mass production

Small
Single chip, cost optimized BOM, lower power

• < 5cm range resolution
• 0.01% chirp linearity

-< 1° angular resolution
• 300km/hr max relative velocity
Competing Technologies!
## Competing Technologies

Adapted from Kunert, MOSARIM W23 at EuMW 2012

<table>
<thead>
<tr>
<th></th>
<th>24GHz NB Radar</th>
<th>24GHz UWB Radar</th>
<th>76-81GHz Radar</th>
<th>Mono Video</th>
<th>Stereo Video</th>
<th>Far/Nea IR</th>
<th>Sensor</th>
<th>Laser Scanner</th>
<th>Ultrasound</th>
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<tbody>
<tr>
<td>Range &lt; 2m</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Range &gt; 100m</td>
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<tr>
<td>Angular resolution</td>
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<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Object separation/discrimination</td>
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<td></td>
<td>X</td>
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<td></td>
<td>X</td>
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<tr>
<td>Object classification</td>
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<td></td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Direct velocity measurement</td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Operation in dust/fog/snow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Dazzling sunlight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Day and night</td>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<td>Sensor blockage due to dirt</td>
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<td>X</td>
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<tr>
<td>Mounting/surface cover constraints</td>
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<td></td>
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<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Regulatory constraints</td>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Effect on vehicle aesthetics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sensor data fusion capability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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</tr>
</tbody>
</table>

### Stereo Camera
- Object Classification
- Better Angular resolution
- High Processing bandwidth

### Lidar
- Best in class angular resolution
- Slower scan ~20Hz
- Expensive

### Ultrasonic
- Cost Effective
- Large sensors,
- Can’t be placed under bumper
Technology comparison

<table>
<thead>
<tr>
<th></th>
<th>CMOS</th>
<th>SiGe BiCMOS</th>
<th>III-V (GaAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed</strong></td>
<td>Fast</td>
<td>Fast</td>
<td>Very Fast</td>
</tr>
<tr>
<td><strong>Breakdown</strong></td>
<td>Low</td>
<td>Med</td>
<td>High</td>
</tr>
<tr>
<td><strong>Power Gain</strong></td>
<td>Med</td>
<td>Good</td>
<td>Very Good</td>
</tr>
<tr>
<td><strong>Temp. Behavior</strong></td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Logic Density</strong></td>
<td>Very High</td>
<td>High</td>
<td>Very Low</td>
</tr>
<tr>
<td><strong>Wafer Cost</strong></td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
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</table>
# Basic Transistor Comparison

<table>
<thead>
<tr>
<th></th>
<th>CMOS</th>
<th>SiGe</th>
<th>GaAs/III-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max operating frequency</td>
<td>&gt;100GHz</td>
<td>&gt;100GHz</td>
<td>&gt;100GHz</td>
</tr>
<tr>
<td>Logic integration</td>
<td>Very High (&gt;10X SiGe)</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>A2D integration</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Wafer cost</td>
<td>Lowest</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>RF Power output</td>
<td>Medium/Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Power dissipation – RF circuitry</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Power – data converters</td>
<td>Very Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Power - logic</td>
<td>Very Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>
Let's get started & WIN....
## Hardware Platforms

<table>
<thead>
<tr>
<th>Platform</th>
<th>Description</th>
</tr>
</thead>
</table>
| **AWR1443/AWR1642 EVM** | • Enables evaluation of single chip radar  
• Proximity sensor demo on AWR1443 EVM  
• SRR demo on AWR1642 EVM |
| **AWR1243 + TSW1400** | • Enables RF performance evaluation  
• Raw ADC capture into PC and then post process  
• mmWave Studio to visualize object range/velocity/angle |
| **AWR1243 + TDA3x** | • Enables radar algorithm and MRR/LRR application development on TDA3x  
• Enables vehicle validation/demonstration |
| **AWR1443/AWR1642 Sensor module** | • Enables radar algorithm and proximity/SRR application development on AWR1443/AWR1642  
• Enables vehicle validation/demonstration |
EVMs-AWR1243/AWR1443/AWR1642

Key Features

- The Booster Pack
- Rogers RO4835 material
- Antenna on board
- XDS110 based JTAG emulation
- On board QSPI flash for application code storage.
- UART through USB to PC for debug logging.
- On-board CAN transceiver for AWR1443 & CAN/CANFD for AWR1642.
- Provision for ADC raw data transfer over LVDS/CSI.
- leverages the Launchpad ecosystem
- 5V power jack to power the board
Antenna element on RO4835- 3-element series-fed inset

<table>
<thead>
<tr>
<th>Substrate</th>
<th>RO4835, 4mil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna length</td>
<td>6.5mm</td>
</tr>
<tr>
<td>BW (RL&gt;10dB)</td>
<td>76-85GHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>76</th>
<th>78.5</th>
<th>81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Angle (EL,AZ) (deg)</td>
<td>2.5,0</td>
<td>9,0</td>
<td>17.5,0</td>
</tr>
<tr>
<td>Peak Directivity (dBi)</td>
<td>12.8</td>
<td>12.1</td>
<td>11.6</td>
</tr>
<tr>
<td>Peak Gain (dBi)</td>
<td>11.7</td>
<td>11.1</td>
<td>10.5</td>
</tr>
<tr>
<td>Radiation Efficiency (%)</td>
<td>78</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Side lobe Level (dB)</td>
<td>13.5</td>
<td>9.2</td>
<td>5.3</td>
</tr>
<tr>
<td>H-plane Beamwidth (deg)</td>
<td>66</td>
<td>65</td>
<td>61</td>
</tr>
<tr>
<td>E-plane Beamwidth (deg)</td>
<td>24.4</td>
<td>27.1</td>
<td>23.1</td>
</tr>
</tbody>
</table>
Debug Devpack

Key Features

- Micro USB Powered.
- PC interface through on board FTDI for SPI, GPIO controls & UART loggers
- 120pin connector to interface with TDA3 EVM (via DIB and VAB boards) and the TSW1400
- 20 pin LaunchPad connectors for Control signals to/from the AWR1443 EVM
- 60 pin high density (HD) connector to get the high speed ADC data over CSI or LVDS interface from the Booster-Pack..
- 60pin MIPI connector for JTAG trace (for AWR1642 ONLY)
- Header for DMM interface (for AWR16XX device ONLY)
- Second CAN connector (for AWR1642 device ONLY).
ADC data capture solution: TSW1400

Key Features

- Altera Stratix IV based FPGA generic ADC data capture board.
- Supports 900MBPS Serial LVDS capture on 7 Pairs of LVDS pins.
- 512MB of on board storage space
- Supports capture and post processing in RT3 directly.
- Supports single-tone, multi-tone signal performance analysis
- Supports up to 16 converter channels simultaneously
- Capability to feed CMOS parallel data using DAC interface.
System Block Diagram – Proximity Sensor

**TI Products in this System**

- Device #1 AWR1443
- Device #2 LP87524B-Q1
- Device #3 TPS7A8801
- Device #4 TPS7A8101

**Associated Reference Designs**

- Ref Des #1 TBD
System Block Diagram – Short Range Sensor

Associated Reference Designs

Ref Des #1 TIDEP0092

TI Products in this System

Device #1 AWR1642
Device #2 LP87524B-Q1
Device #3 TPS7A8801
Device #4 TPS7A8101
mmWave Sensing Ecosystem

Hardware solutions

Software and Tools

Turnkey solutions
3rd Party Module – AWR1243+TDA3x : High level Architecture

Signals between TDA3X and AWR1243
3rd Party Modules ALPS: Sensor Module

**Key Features**

- Supports Radar system development on TDA3X + AWR1243 Platform
- Supports Multiple antenna configuration: 2 Flavors of RF Boards
- RJ45 Connector based Ethernet support
- 60 pin MIPI connector with Trace debug capability
- Single Power supply Module with Aluminum casing acting as heatsink
Design kit availability

Silicon

- TI(Ecosystem partner) built reference HW

EVM
- TI(Ecosystem partner) built reference HW

RF tool
- Signal Path analysis, Radiative measurements

HDK
- Reference Schematic/Layout, BOM, RF Model, Thermal Model

SDK
- Firmware, Device drivers, Operating system, Development environment

<table>
<thead>
<tr>
<th>Silicon</th>
<th>EVM</th>
<th>RF tool</th>
<th>HDK</th>
<th>SDK</th>
</tr>
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<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
</tbody>
</table>

AWR1443 (PPAP) June 2018
AWR1443 (PPAP) June 2018
AWR1642 (PPAP) Jan 2018
Thank you
Back up