TI Designs: TIDEP-0091
Power Optimization for IWR1443 77-GHz Level Transmitter Reference Design

Description
The TIDEP-0091 highlights strategies for power optimization of a IWR1443 76- to 81-GHz mmWave sensor in tank level-probing applications, displacement sensors, 4- to 20-mA sensors, and other low-power applications for detecting range with high accuracy in minimal power envelope. In these applications, the system often operates on a low-voltage data line that provides power much smaller than the operational power consumption. Duty cycling is critical to reduce the average power to meet the power input restrictions. Power optimization is achieved through MSP432™ external duty cycling the IWR1443 device for periodic sensing. Additionally, the TIDEP-0091 provides a sample configuration for single-dimensional range detection.

Features
- Includes Software Source, Schematics, Bill of Materials (BOM), and Design Files
- Provides an Optimized Chirp for Single Dimension Range Detection
- Applicable to Any Application Requiring Low-Power Duty Cycling
- Offers Test Results of Power Optimization

Applications
- Tank Level-Probing
- Displacement Transmitters
- Safety Guards
- Motion Detectors

Resources
TIDEP-0091 Design Folder
IWR1443 Product Folder
IWR1443BOOST Tool Folder

An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.
System Description

1 System Description

In the TIDEP-0091 the MSP432 LaunchPad™ is the master controller and is physically connected to the IWR1443 EVM through the standard LaunchPad, 20-pin headers. All communication between the boards is accomplished using these headers. A standard, 3-pin serial peripheral interface (SPI) is used as communications protocol, and general purpose IOs (GPIOs) are used for control and measurement flagging. User communication is provided through a micro-USB cable, which carries standard UART serial data to a host (PC) terminal window.

The MSP432 is directed through UART commands to power up the IWR1443 as necessary, to obtain range measurements through SPI from the IWR1443, and to power down the system when not in use. These steps are taken to reduce the average power required to take periodic measurements—an important goal for industrial applications. The MSP432 will remain in a low-power mode whenever not processing a measurement or UART command.

2 System Overview

The IWR1443 is loaded with a flashed image that, once booted and initialized, will take a single range measurement using a built-in chirp configuration (statically set at build time), identify the strongest reflections, and report the reflections to the MSP432 through the SPI interface. Once the MSP432 receives the SPI transfer that contains the range measurements, the device will power down the IWR1443, report the results to the UART interface, and go to sleep until further instruction.

2.1 Block Diagram

2.1.1 Hardware Block Diagram

From a user perspective, there are two ARM® cores used in this hardware design:

- **IWR1443 MSS R4F**: A 200-MHz ARM core that is user programmed to configure and control the BSS radar subsystem (radar front end). The application for this core is flashed, loaded to RAM, and executed through the bootloader.

- **MSP432 Cortex® M4F**: A 48-MHz ARM core that is the system master. The running application controls the power cycling of the IWR1443 and reports measurement data to a UART terminal.
2.1.2 Software Block Diagram

On the IWR1443 side, the user application communicates with the mmWave software development kit (SDK) primarily through the mmWave application program interface (API), which is a simple, very high-level API with calls like MMWave_init, MMWave_config, and MMWave_execute. These calls communicate with the lower layers including the mmWave drivers that communicate to peripherals, such as ADCBuf and HWA and the mmWave link API that communicates to the BSS firmware through the mailbox peripheral.

On the MSP432 side, the user application communicates to the IWR1443 and the user through application-specific peripheral drivers, such as UART, GPIO, SPI, and timer. These drivers make use of the generic SimpleLink™ and RTOS APIs.
2.2 Highlighted Products

2.2.1 IWR1443

The IWR1443 is a highly-integrated, single-chip RADAR device for industrial applications in TI’s 45-nm, low-power RFCMOS technology, which is a FCBGA, 0.65-mm pitch package.

The RADAR subsystem (BSS) is responsible for the RF and analog functionality of the device. The subsystem incorporates a built-in self-test (BIST) processor for the continuous motoring and calibration of the analog and RF modules.

The master subsystem (MSS) contains a user programmable ARM core, user accessible memories, and peripherals for the configuration and control of the entire device. The MSS communicates with the BSS through the mmWave link API and the mailbox peripheral.
2.2.2  MSP432P401R

The MSP432P401R is the first MSP432 family device featuring low-power performance with an ARM Cortex-M4F core. Device features include:

- Low-power ARM Cortex-M4F MSP432P401R
- Up to 48-MHz system clock
- 256-KB flash memory, 64-KB SRAM, and 32-KB ROM with MSPWare™ software libraries
- Four 16-bit timers with capture, compare, and PWM, two 32-bit timers, and a real-time clock (RTC)
- Up to eight serial communication channels (I²C, SPI, UART, and IrDA)
- Analog: 14-bit SAR analog-to-digital converter (ADC), capacitive touch, and comparator
3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The following hardware is required to get the level-sensing demonstration running and set up to develop custom applications:

- An MSP432P401R LaunchPad EVM
- An IWR1443 EVM
- A 5-V, 2.5-A power supply for IWR1443 EVM
- A PC for Code Composer Studio™ (CCS) 7.x and the demonstration UART terminal

To run the demonstration, the IWR1443EVM requires one modification and has an optional second modification. Both modifications add a 0-Ω resistor to the EVM to enable functionality.

The first, mandatory modification requires soldering 0-Ω resistor R102 to the EVM. This modification completes the circuit of PMIC_EN to header pin J6-pin16. Adding this resistor allows the MSP432 to toggle the corresponding header pin, thus controlling the power of the IWR1443 as necessary. The demonstration will not operate without this resistor. See schematics in Section 4.1 for more details.

The second, optional modification involves soldering 0-Ω resistor R164 to the EVM. This optional modification completes the circuit of GPIO_0 to header pin J6-pin15. If the executables are built with the #define REPORT_IR14_TIME_MEASUREMENTS, the code in the IWR1443 will toggle GPIO_0 at various times, and the code in the MSP432 will detect the times when it is toggled, thus measuring boot, config, chirp, and transfer times.
3.1.2 Software

There are two executables required for this design. The first runs in the IWR1443's MSS R4F, and the second runs in the MSP432's M4F. The software required to build the MSS (IWR1443) executable is:

- **Latest mmWave SDK.** The SDK now will automatically install the required component versions. These components are listed in the SDK's release notes and in the Getting Started Guide located in the /docs folder of the software package. Install the SDK and all required components before installing and building the demonstration source.
- **Code Composer Studio (CCS).** See the Getting Started Guide for the required version.

The software required for the MSP432 executable is:

- **MSP432 SimpleLink SDK,** version specified in the Getting Started Guide.
- **TI ARM compiler,** version specified in the Getting Started Guide.

3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Building the Demonstration

3.2.1.1.1 Building the MSP432™ Executable

Step-by-step instructions for creating the MSP432 CCS Project and executable are located in the Getting Started Guide, located in the /docs folder inside the software package.

3.2.1.1.2 Building the IWR1443 Executable

Step-by-step instructions for creating the IWR1443 CCS Project and executable are located in the Getting Started Guide, located in the /docs folder inside the software package.
3.2.1.1.3 Running the Demonstration

Figure 6 shows the proper configuration of the boards for running the demonstration (when both boards have been flashed). The Tx antennas project their beams perpendicularly to the front of the EVM, so position the EVMs facing the object to be measured. Also, the jumper has been removed from SOP2 (required for flashing); place the jumper on only one side of SOP2, so that it does not become lost. Complete step-by-step instructions for flashing and running the demo are provided in the Getting Started Guide in the software package.

CCS is not used for running the demonstration, but the software can be debugged using CCS. Full instructions for debugging are provided in the Getting Started Guide.

Figure 6. Level Sensing Demonstration Hardware

Copyright © 2017, Texas Instruments Incorporated
3.2.2 Test Results

3.2.2.1 Timing Measurements

Determining power usage requires knowing how much current is drawn versus the length of time the current is drawn. To determine run times of the various processing steps, an MSP432 48-Mhz timer is used, which captures the clock time at the start of each step then converts the time to milliseconds. This is possible because the MSP432 is controlling the power and reset of the IWR1443. IWR1443's GPIO_0 is also used, toggling up and down throughout a measurement cycle. These changes are captured and timed by the MSP432. If this time measurement is enabled (a build-time option), the results are output to the UART terminal along with the range data.

The times that are captured are:

- IWR boot time: This is the time from when PMIC_EN is pulled high to the time when the MSP432 detects GPIO_0 going high. This marks the start of the IWR application.
- IWR config time: This is time from when GPIO_0 goes high in the previous step to when it goes low. This marks the time when BSS calibration and MSS configuration have run.
- IWR chirp time: This is the time from when GPIO_0 goes low in the previous step to when it goes high a second time. This marks the time of the radar chirp.
- IWR post processing time: This is the time from when GPIO_0 goes high in the previous step to when the SPI transfer is received. This is the amount of time for the chirp outputs to be scanned and transmitted to the MSP432.

![Figure 7. Example of Demonstration Output](image-url)
3.2.2.2 Power Measurements

Power measurements were performed using scopes connected to the system power supply and to the IWR1443 and MSP432 GPIOs. GPIOs were toggled at various processing points (see Section 3.2.2.1 for more information) to provide the data in Figure 8. The data in Figure 8 is from ES2.0 EVM.

The peak power usage time Radio Test, shown in Figure 8, consists of the config, chirp, and post processing times discussed in Section 3.2.2.1.

![Figure 8. IWR1443 ES2.0 Power Consumption](image)

Notes:
- MSP432 power and PMIC_EN signal overlaps with IWR1443BOOST measurement.
- IWR1443 boot and BSS configuration times vary from ES1 to ES2.
- ES3.0 will have reduced consumption levels due to the following changes:
  - BSS image will be in ROM, which requires no loading during boot.
  - 40-MHz QSPI clock (versus 18 MHz in ES2.0) will result in faster MSS image loading.
Figure 9. IWR1443 ES2.0 Energy Consumption

Figure 10. MSP432™ Energy Consumption
3.2.2.3 Range Measurements

Because the accuracy of the IWR1443’s range measurement has been demonstrated elsewhere, the goal for this testing was not to repeat those tests but simply to show that the built-in chirp configuration is functioning correctly. Testing was performed in an anechoic chamber using a simple tape measure and a 2” corner reflector for the target.

![Range Measurement Setup](image)

**Table 1. Testing Results**

<table>
<thead>
<tr>
<th>ACTUAL DISTANCE (METERS)</th>
<th>MEASURED DISTANCE (METERS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.078</td>
</tr>
<tr>
<td>2</td>
<td>2.117</td>
</tr>
<tr>
<td>3</td>
<td>3.080</td>
</tr>
<tr>
<td>4</td>
<td>4.158</td>
</tr>
<tr>
<td>5</td>
<td>5.159</td>
</tr>
<tr>
<td>9</td>
<td>9.163</td>
</tr>
<tr>
<td>10</td>
<td>10.087</td>
</tr>
</tbody>
</table>

More accurate results can be obtained by using a more sophisticated method to set the actual distance at each test point.
4 Design Files

4.1 Schematics
To download the schematics, see the design files at TIDEP-0091.

4.2 Bill of Materials
To download the bill of materials (BOM), see the design files at TIDEP-0091.

4.3 Altium Project
To download the Altium project files, see the design files at TIDEP-0091.

4.4 Gerber Files
To download the Gerber files, see the design files at TIDEP-0091.

5 Software Files
To download the software files, see the design files at TIDEP-0091.

6 Related Documentation
4. Texas Instruments, *IWR1443 EVM*, Tool Folder

6.1 Trademarks
MSP432, LaunchPad, SimpleLink, MSPWare, Code Composer Studio are trademarks of Texas Instruments, Inc..
ARM, Cortex are registered trademarks of ARM Limited.
All other trademarks are the property of their respective owners.
**Revision History A**

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

<table>
<thead>
<tr>
<th>Changes from Original (April 2017) to A Revision</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Updated the Building the MSP432™ Executable section.</td>
<td>7</td>
</tr>
<tr>
<td>• Updated the Building the IWR1443 Executable section.</td>
<td>7</td>
</tr>
<tr>
<td>• Updated the Running the Demonstration section.</td>
<td>8</td>
</tr>
</tbody>
</table>
IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI’s provision of TI Resources does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT. AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI’s standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated