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Evaluating the TinyRad 24 GHz Demonstration Platform

FEATURES

24 GHz to 24.25 GHz MIMO FMCW radar
Flexible FMCW measurement timing
Suitable for target detection and tracking
Range resolution of 60 cm, range = 100 m (for RCS = 1 m^2)
3 dB beam width = 75° in azimuth and 15° in elevation, azimuth resolution using MIMO angle estimation = 20°
1 PCB, 85 mm × 55 mm
2 front side transmit antennas
4 front side receive antennas
Reverse side ADF5901 24 GHz transmit monolithic microwave integrated circuit (MMIC)
Reverse side ADF5904 24 GHz receive MMIC
Reverse side ADF4159 13 GHz phase-locked loop (PLL)
Reverse side ADAR7251 16-bit, 4-channel ADC
Reverse side ADSP-BF706 Blackfin DSP
Accompanying software controls all functions from a PC
Externally powered via the USB connection

DEMONSTRATION PLATFORM CONTENTS

EV-TINYRAD24G
USB memory stick containing software
Board mount with USB-C cable
Corner reflector

EQUIPMENT NEEDED

PC with Windows 7 (or more recent version)

DOCUMENTS NEEDED

ADAR7251 data sheet
ADF4159 data sheet
ADF5901 data sheet
ADF5904 data sheet
ADSP-BF706 data sheet

REQUIRED SOFTWARE

TinyRadTool-x32 demonstration platform software (included with accompanying memory stick)

GENERAL DESCRIPTION

The EV-TINYRAD24G is a radar evaluation module that allows the implementation and testing of radar sensing applications in the 24 GHz industrial, scientific, and medical (ISM) band. The EV-TINYRAD24G uses frequency modulated continuous wave (FMCW) radio signals and an integrated antenna array in a multiple input multiple output (MIMO) radar scheme. The combined antennas, similar to digital beamforming (DBF), allow the TinyRad module to detect the distance, speed, and angular position of multiple targets simultaneously. The raw analog-to-digital converter (ADC) data is forwarded by the on-board Blackfin® ADSP-BF706 digital signal processor (DSP) to the PC. The PC evaluation software, with an included graphical user interface (GUI), performs radar signal processing steps to yield radar point clouds that can be visualized as range doppler or range angle plots. The radar algorithms are also available as MATLAB™ and Python™ code and enable quick development of user defined, application specific code.

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REVISION HISTORY

2/2020—Revision 0: Initial Version

RADAR MODULE PHOTOGRAPHS

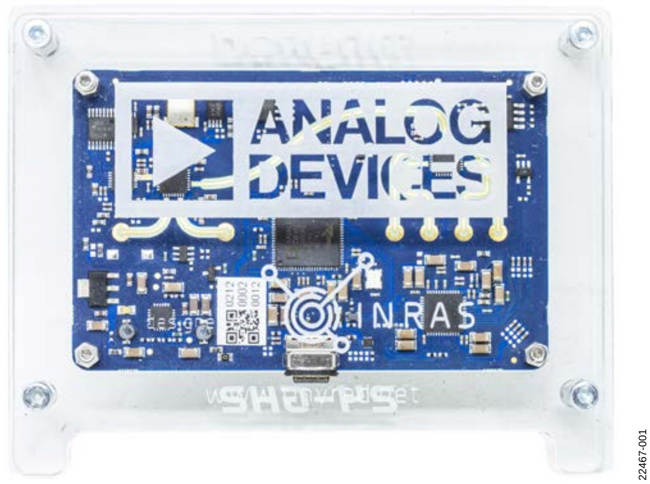


Figure 1. TinyRad Bottom Side

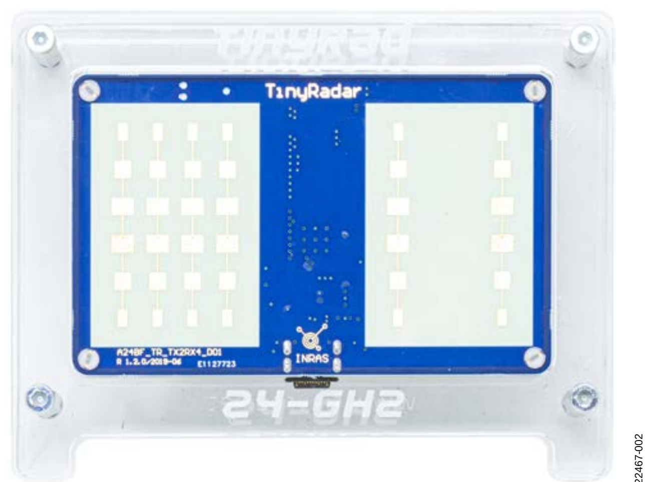


Figure 2. TinyRad Top Side Showing Antenna Arrangement

MODULE HARDWARE

The dimensions of the EV-TINYRAD24G, including the positions of the mounting holes, are shown in Figure 3. EV-TINYRAD24G is built using a 6-layer printed circuit board (PCB) with Rogers RO-4350 used for the RF substrate.

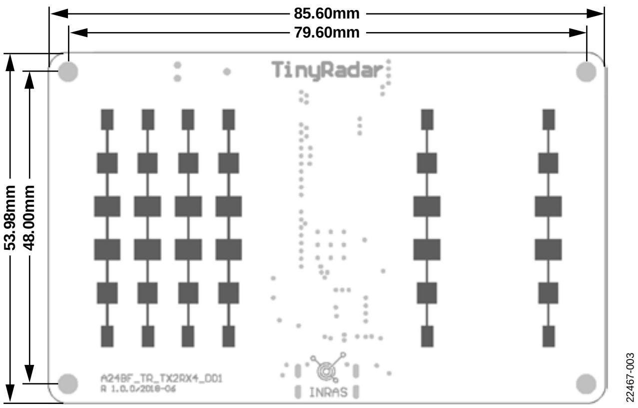


Figure 3. EV-TINYRAD24G Dimensions

MODULE OVERVIEW

Figure 4 shows a block diagram of the EV-TINYRAD24G. A Blackfin ADSP-BF706 DSP controls the RF front-end and processes the measured radar signals from the receive channels. On the transmit path, the ADF5901 24 GHz, dual-channel transmitter, together with the ADF4159 direct modulation frequency synthesizer, generate the FMCW transmit signal. The two transmit antennas (Tx1 and Tx2) are fed from the ADF5901 transmitter. On the receive path, the four receive antennas (Rx1, Rx2, Rx3, and Rx4) are connected to the ADF5904 quad-channel receiver downconverter. The ADAR7251 ADC amplifies and samples the IF signals from the ADF5904 receiver. The data samples are processed by the DSP before being accessed via the USB interface.

The EV-TINYRAD24G features a maximum FMCW sweep bandwidth of 250 MHz, which corresponds to an achievable range resolution of approximately 60 cm. The maximum range is dependent on the radar cross section (RCS) of the target. A maximum range of 100 m can be achieved for a target with an RCS of 1 m^2.

POWER SUPPLY

The EV-TINYRAD24G is powered by a USB-C cable connection that is supplied with the evaluation module kit. The USB-C cable connection is the power and data interface from the PC to the EV-TINYRAD24G.

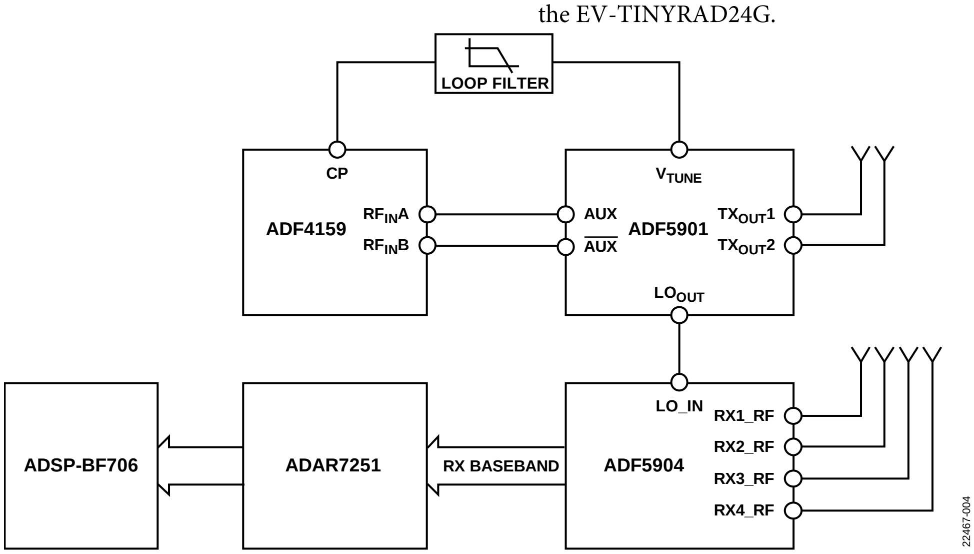


Figure 4. Simplified Block Diagram

ANTENNA ARRANGEMENT

The serial fed patch antennas feature six elements with an amplitude taper and are fed from the backside of the PCB. The antennas are fabricated on a Rogers RO-4350 substrate. The resulting beam pattern for the electric field vector (E plane) and magnetic field vector (H plane) of the antenna is shown in Figure 5. The sidelobe suppression for the E plane is approximately 20 dB.

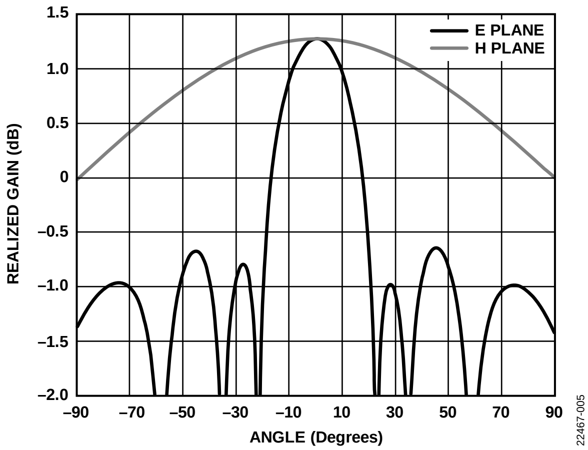


Figure 5. Power Gain for a Single Transmit Antenna

Table 1. Antenna Parameters

Parameter	Description	Value
G	Gain	12.6 dBi
ΔS	Sidelobe suppression	−20 dB
θ_H	Horizontal 3 dB beam width	76.5°
θ_V	Vertical 3 dB beam width	17.6°

The arrangement of the antennas is chosen to enable a virtual, seven element array with a spacing of λ/2. Two elements overlap to allow the implementation of motion compensation algorithms. Use MIMO radar techniques (switching between the two transmit antennas) to increase the number of virtual antennas to correspondingly increase the angular resolution. Figure 6 shows the configuration of the virtual array.

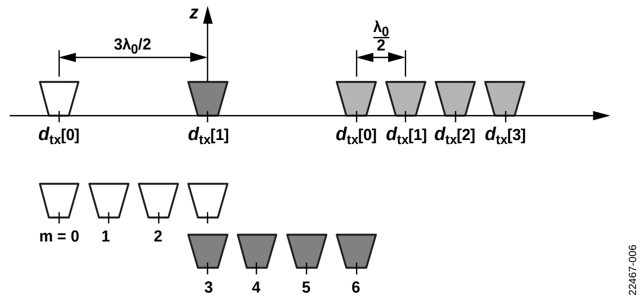


Figure 6. Antenna Arrangement with Virtual Antenna Positions

Table 2 shows the coordinates of the antennas where the second transmit antenna is located at the origin.

Table 2. Antenna Positions

Antenna	Position (mm)
Tx1	−18.654
Tx2	0.000
Rx1	31.014
Rx2	37.231
Rx3	43.449
Rx4	49.666

Based on the array design, the 3 dB beam width is approximately 75° in azimuth and 15° in elevation. The azimuth resolution when using MIMO angle estimation is approximately 20°. See the Digital Beamforming Mode section for more information on MIMO operation.

ELECTRICAL PARAMETERS

Table 3 shows the general operating parameters of the TinyRad module.

Table 3. Electrical Parameters

Parameter	Min	Typ	Max	Unit
Supply Voltage		5		V
Supply Current, All Receive Channels Enabled		780		mA
Maximum RF Output Power		8		dBm
Transmit On/Off Isolation		30		dB
Transmit Frequency	24		24.25	GHz

TINYRAD DRIVER INSTALLATION

Each time the EV-TINYRAD24G is connected to a PC for the first time, a one-time manual installation is required. To start the installation, take the following steps:

1. Connect the EV-TINYRAD24G to the PC using the USB-C cable. The USB connection supplies power to the EV-TINYRAD24G.
2. Connect the USB memory stick to the PC and unzip the **Demo_Driver.zip** file in the software folder of this drive.
3. Install the EV-TINYRAD24G drivers (see the TinyRad Driver Installation section).

The described installation is completed on Windows® 7. There may be differences when using other operating systems.

EV-TINYRAD24G Driver Installation

Take the following steps to complete the manual installation of the TinyRad drivers:

1. Find the device in the **Devices and Printers** window that is listed as **BF707 Bulk Device** (see Figure 7).

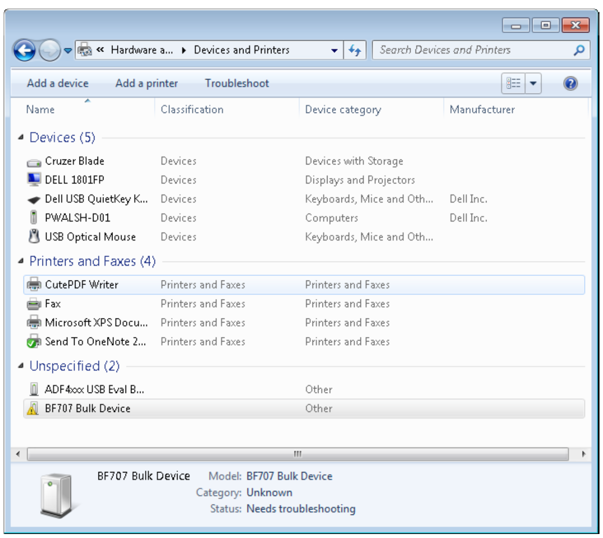


*Figure 7. **Devices and Printers** Window*

2. Click **Properties** in the **Hardware** tab (see Figure 8).

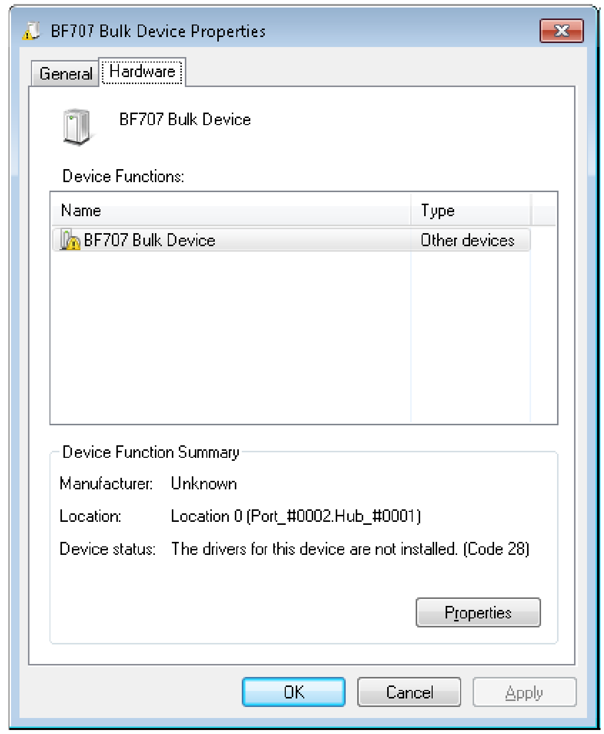


*Figure 8. **Hardware** Tab*

3. Click **Change settings** in the **BF707 Bulk Device Properties** window (see Figure 9). This action requires administration rights.

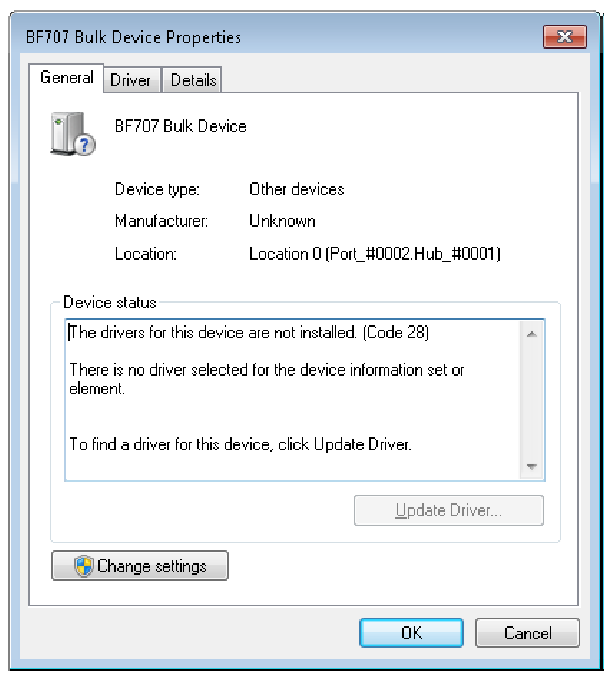


*Figure 9. **BF707 Bulk Device Properties** Window*

4. To install the drivers for the device, click **Browse my computer for driver software** in the update driver software pop-up that appears (see Figure 10).

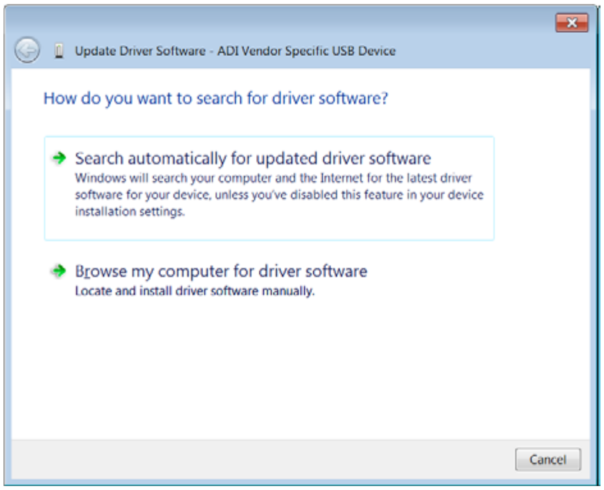


Figure 10. Update Driver Pop-Up

5. Choose the unzipped **D:\ADI_Demo_Driver\Demo_Driver** folder and then click **Next** (see Figure 11).

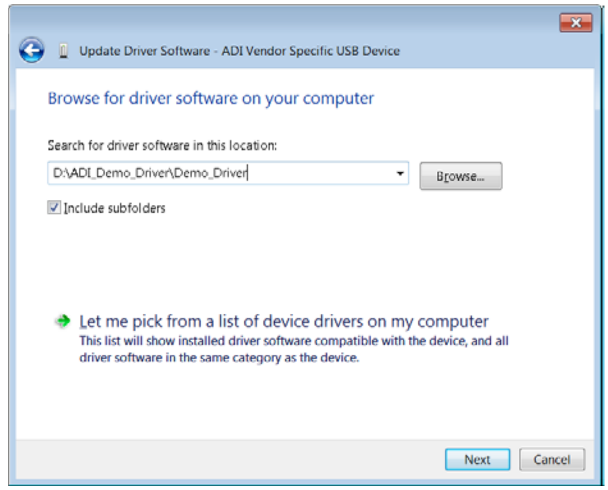


Figure 11. Browse for Driver Software Window

TINYRAD MODULE SOFTWARE

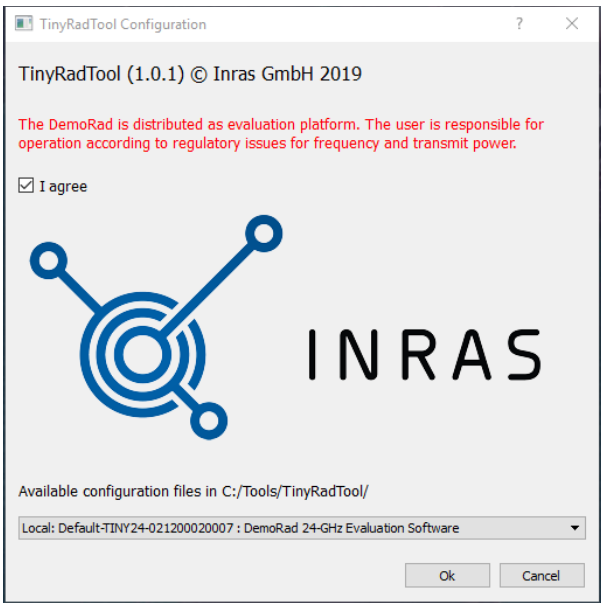
TINYRADTOOL

The EV-TINYRAD24G kit contains a software GUI to initialize and display the measured range, velocity, and angle information from the TinyRad module. This software is also backwards compatible with previous generation EVAL-DEMORAD evaluation kits. Therefore, there are naming conventions used in the software that reflect this backwards compatibility.

MATLAB and Python libraries are supplied to allow users to configure the FMCW waveform and perform radar processing on the raw data.

TinyRadTool License

Run the **TinyRadTool-x32.exe** file from the USB memory stick. The user must possess the correct license located in the **Default-TINY24-x.rtc** file (the x represents a 12 digit string of numbers that is unique to each kit) and agree to the terms of use, as shown in Figure 12.



22467-013

Figure 12. TinyRadTool License

FMCW MODE

When the radar module is operating in FMCW mode, the distance to stationary targets can be estimated. The frequency of the received IF signal for a single target is proportional to the distance from the signal to the radar.

FMCW Tab

The FMCW tab is the default mode when the application is open. Click **Initialize** and then click **Measure** to start measuring for a specified number of frames (see Figure 13). In FMCW mode, the distance to the targets taken by the radar module can be visualized. This mode displays the sampled IF signals for a single chirp, as shown in Figure 14. To explore the frequency content of the IF signals, select the **FFT** processing checkbox (see Figure 15). In this case, the magnitude spectrum is plotted vs. the range, as shown in Figure 15. It is also possible to display the average spectrum by selecting the **Average** checkbox.

Figure 16 shows the **Configuration** tab of the FMCW mode window. The following parameters can be adjusted for the application:

- **Start frequency (MHz)**.
- **Stop frequency (MHz)**.
- Number of samples for one chirp, N.
- Time interval between measurements, **TInt (ms)**.
- Channel 1 to Channel 4 enable.

The timing used by the TinyRad module is explained in the FMCW Timing section.

22467-014

Figure 13. TinyRadTool FMCW Mode Initialize

22467-015

Figure 14. TinyRadTool IF Signals in FMCW Mode

Figure 15. TinyRadTool Spectrum of IF Signal in FMCW Mode

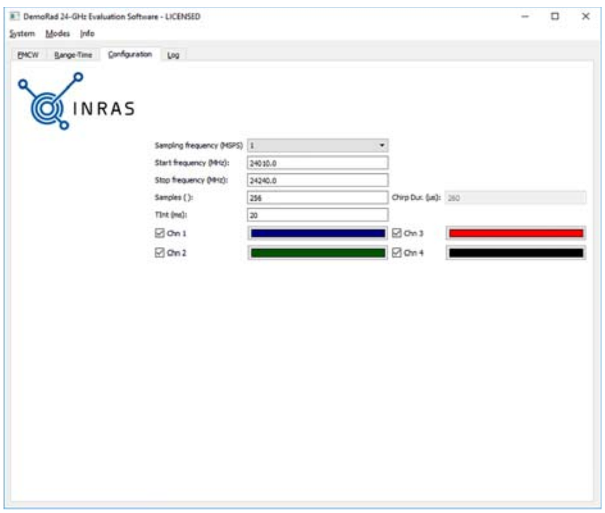


Figure 16. TinyRadTool **Configuration** Tab

FMCW Range-Time Tab

The FMCW mode **Range-Time** tab displays an image of the history of the range profiles. The number of stored range profiles and the displayed range interval can be configured.

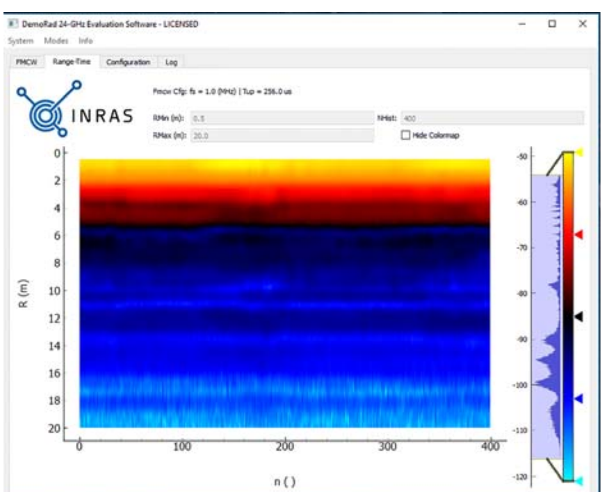


Figure 17. TinyRadTool Range Profile over Time in FMCW Mode

RANGE DOPPLER MODE

When using the TinyRad module in range doppler mode, the radial distribution of the targets, as well as the instantaneous velocities of the targets, are displayed (see Figure 18).

The range doppler mode allows the separation of targets with different velocities, even if the targets are located at the same distance. In this mode, using the **Configuration** tab, the chirp repetition interval (period) and the number of adjacent chirps used for the measurement (Np) are configured, in addition to the parameters configurable in FMCW mode. In range doppler mode, Np chirps are processed simultaneously by evaluating a two-dimensional fast Fourier transform (FFT). The phase information between subsequent chirps is used to extract the velocity information to be displayed in the range doppler map.

To change modes, stop the FMCW measurement if it is still running, click **Modes** in the menu bar, and select **Range-Doppler** from the dropdown menu. Figure 18 shows the **Range-Doppler** tab.

Range-Doppler Tab

The **Initialize** and **Measure** options are also available in the **Range-Doppler** tab.

To configure the timing in range doppler mode, specify the chirp duration (µs), the chirp repetition period (µs), and Np in the **Configuration** tab.

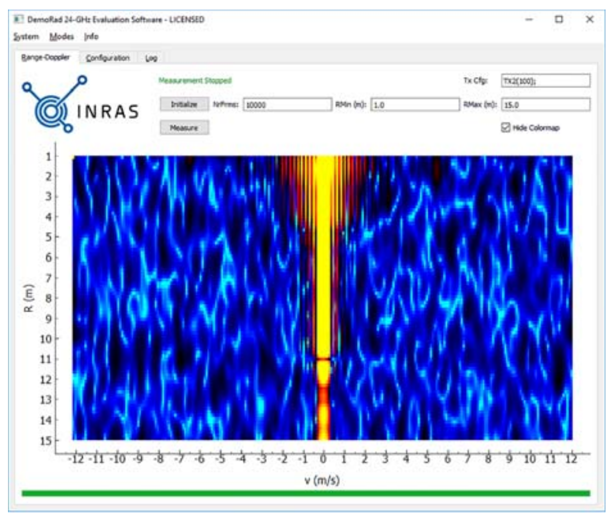


Figure 18. TinyRadTool in Range Doppler Mode

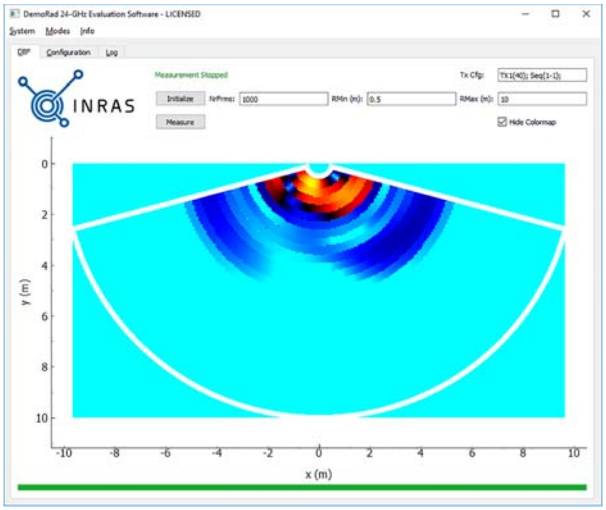
DIGITAL BEAMFORMING MODE

When the TinyRad module is operating in digital beamforming (DBF) mode, the module can be configured using the same method as FMCW operation. The only difference between FMCW mode and DBF mode is the processing of the sampled IF signals to calculate the angle of incidence. When the range profiles are calculated, evaluate the phase differences between the receive channels to calculate the angle of incidence. DBF mode uses MIMO processing where the Tx2 antenna, followed by the Tx1 antenna, is activated.

Each TinyRad module comes with calibration data that loads when the GUI is running, as well as sampled IF signals that calibrate before evaluating the data. The TinyRad module can be operated without applying calibration coefficients. However, using precise calibration improves the sidelobe characteristic.

DBF Tab

Click **Modes** in the menu bar and select **DBF Mode** from the dropdown menu. Click **Initialize** and then click **Measure** to start measuring. In the measurement view in Figure 19, the reflectivity of the illuminated scene is displayed.

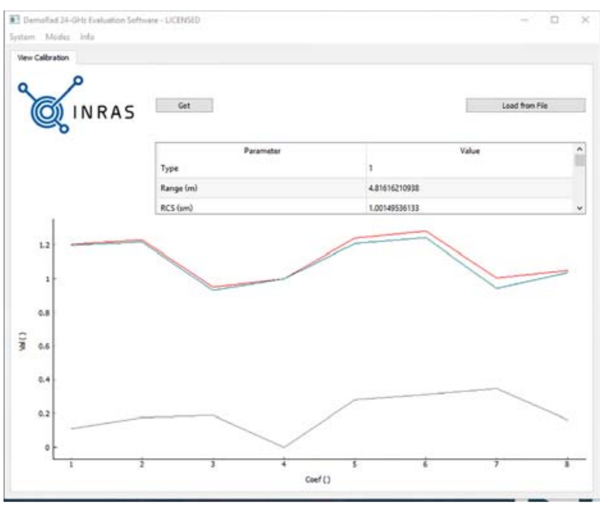


22467-019

Figure 19. TinyRadTool in DBF Mode

CALIBRATION MODE

Calibration mode allows the user to visualize and load new calibration data.

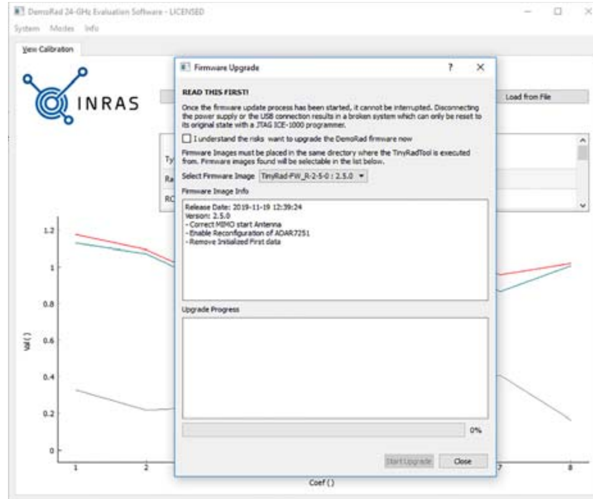


22467-020

Figure 20. TinyRadTool in Calibration Mode

SYSTEM FIRMWARE

Navigate to **System** in the menu bar and select **Firmware Upgrade** from the **System** dropdown menu to open the system update page, which allows the user to upload new firmware images without the need for a dedicated programmer.



22467-021

Figure 21. TinyRadTool Firmware Upgrade

COMMANDS

In the **FMCW** tab, use the keyboard shortcut Alt + F2 to open the **Command** line textbox under the plot.

22467-022

Figure 22. TinyRadTool Command Line

Commands

Type the desired command in the **Command** textbox (see Figure 22).

The **AddPlt(1)** command enables a second plot.

Figure 23. TinyRadTool FMCW with Second Plot Enabled

The **StoreIf("doppler.h5", 100)** command stores the received data to a .h5 file (see Figure 24). The files are stored in the **c:/Tools/TinyRadTool/;** folder. This folder must exist before storing. This command is applicable for range doppler mode only.

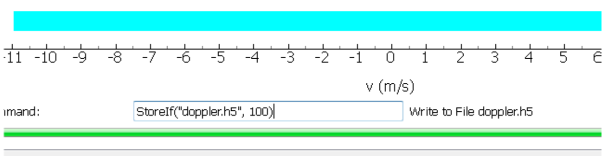
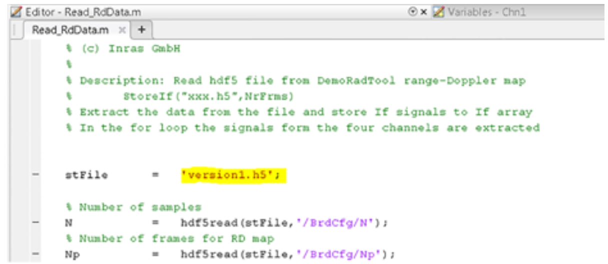


Figure 24. TinyRadTool Range Doppler Data to File Storage

This .h5 file can be read in MATLAB using the **Read_RdData.m** file. The **Read_RdData.m** file is found in the **Software** folder. Store the .h5 file in the same folder as the **Read_RdData.m** file. Modify the .m file to read in the .h5 file name (see Figure 25).




```
% (c) Inras GmbH
%
% Description: Read hdf5 file from DemoRadTool range-Doppler map
%       StoreIf("xxx.h5",NrFrms)
% Extract the data from the file and store If signals to If array
% In the for loop the signals form the four channels are extracted

stFile      =   'version1.h5';

% Number of samples
N           =   hdf5read(stFile,'/BrdCfg/N');
% Number of frames for RD map
Np          =   hdf5read(stFile,'/BrdCfg/Np');
```

Figure 25. MATLAB ***Read_RdData.m*** File

The **AddPosn(1)** command enables a position estimation page.

The **EstPosn(RMin,RMax,NrFrms)** command estimates the position between the minimum range (RMin) and the maximum range (RMax) for the number of frames (NrFrms).

For example, the **EstPosn(0,10,150)** command live plots a position estimate plot in the **Posn** tab (see Figure 26).

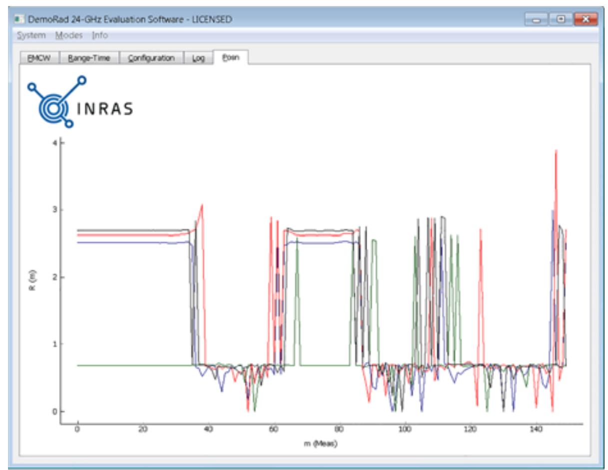


Figure 26. TinyRadTool Position Estimation Tab

MEASURING TINYRAD PERFORMANCE

FMCW MEASUREMENTS

This section describes the results of the FMCW performance measurements conducted in an anechoic measurement chamber. Table 4 lists the FMCW parameters used during the measurements.

Table 4. FMCW Measurement Parameters

Parameter	Description	Value	Unit
f_{START}	Start frequency	23.95	GHz
f_{STOP}	Stop frequency	24.25	GHz
Period	Chirp repetition interval	300	µs
f_S	Sampling frequency	1	MHz
N	Number of samples for one chirp	256	
G_{ADC}	Gain of the ADAR7251 ADC	21	dB
a_{CUBE}	Length of corner cube	78	mm
RCS_{CUBE}	Radar cross section	0.0065424	dBm^2

A corner cube with a radar cross section of 0.0065424 dBm^2 is placed a distance of 5 m from the TinyRad module. The results shown can be used to estimate the performance of the TinyRad module. The range profile is shown in Figure 27.

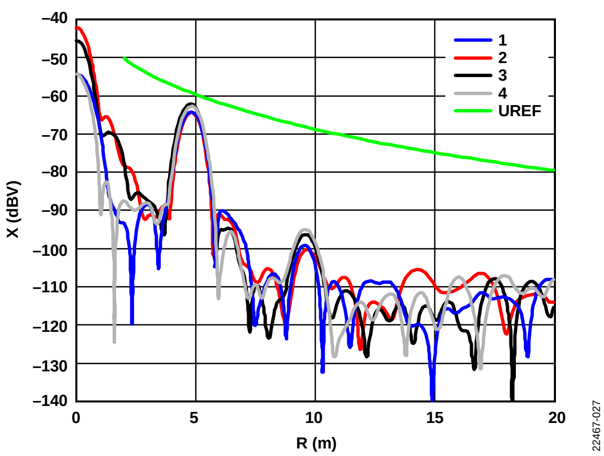


Figure 27. Averaged Range Profiles for the Corner Cube

The green reference curve (UREF) in Figure 27, in conjunction with the noise floor of the TinyRad module, can be used to estimate the maximum distance at which the corner cube can be detected for the given FMCW parameters.

FMCW TIMING

The FMCW timing of the TinyRad module uses two timers in pulse-width modulation (PWM) mode to control the start of the chirp and the sampling of the ADC. The TinyRad module uses separate device drivers for all RF components and the ADC (ADAR7251). The device driver for the ADF4159 configures the ramp mode as a single sawtooth using the TX_{DATA} pin to control the ramp start. The TX_{DATA} pin is driven by the PWM of the Blackfin ADSP-BF706 DSP.

This configuration eliminates the out of band radiation that may occur when the ramp is stopped during a continuous ramp mode operation.

In range doppler mode, Np and N are configurable, and arbitrary uniform range doppler measurements are possible.

MATLAB AND PYTHON LIBRARIES

LIBRARY OVERVIEW

In the standard TinyRad module configuration using the GUI, the TinyRad module expects USB commands from the PC evaluation software to configure automatically, and sends the raw data to the PC via the USB-C interface. Using either a MATLAB or Python platform with the relevant libraries provided, the TinyRad module similarly expects USB commands from the PC to configure automatically, and sends the raw data to the PC via the USB-C interface.

MATLAB CONTENTS

The TinyRad module MATLAB directory structure is described in the following sections.

TinyRad

This directory contains all example .m files. These files include the following:

- AN_01.m: set up connection.
- AN24_02.m: FMCW basics.
- AN24_04.m: accessing calibration data.
- AN24_05.m: calculate DBF with one transmit antenna.
- AN24_06.m: range doppler basics.
- AN24_07.m: calculate DBF with two transmit antenna.

Class

The class directory contains the common class codes used by the scripts. The classes implement the communication to the board, and an individual class for each RF chip is used to configure the device. Users can easily switch to different modes of operation without the need to recompile the applications.

DemoRadUsb

The DemoRadUsb directory contains the MATLAB USB mex driver. The same drivers used in the previous generation DemoRad module are used with the TinyRad module. See the TinyRadTool section for more information.

PYTHON CONTENTS

The RF chip Python directory structure is described in the following sections.

Python

The Python directory contains all example Python files. These files include the following:

- AN_01.py: set up connection.
- AN24_02.py: FMCW basics.
- AN24_04.py: accessing calibration data.
- AN24_05.py: calculate DBF with one transmit antenna.
- AN24_06.py: range doppler processing for a single channel.

Class

The class directory contains the common class codes used by the scripts.

DLL

The DLL directory contains the usb.dll file.

MATLAB TIMING

In MATLAB, the TinyRad class is used to configure the TinyRad module. For the configuration of the chirp sequence, the configuration structure shown in Table 5 is used.

Table 5. MATLAB Configuration Variables

Parameter	Description	Unit
f_{START}	Start frequency	Hz
f_{STOP}	Stop frequency	Hz
t_{RAMPUP}	Duration of the upchirp	sec
Period	Chirp repetition interval	sec
N	Number of samples for one chirp	
Seq	Array used to hold antenna sequence	
CycSiz	Number of buffers in the DSP to store the data (>2)	
FrmSiz	Number of chirps for one measurement cycle	
FrmSizMeas	Number of chirps where data is collected	

The period parameter defines the time between two adjacent measurements. The entries frame size (FrmSiz) and frame size measurement (FrmSizMeas) control the number of collected chirps and the time between two range doppler measurements in multiples of the PWM period. Therefore, the time between two measurement frames (FrmSizMeas) can be controlled in multiples of the configured period.

The number of samples collected during one chirp is independent of the chirp duration. In the current framework, the sampling rate is fixed to 1 MHz and the sampling period (t_S) is $t_S = 1$ µs. If $N \times t_S$ is smaller than the programmed chirp duration, only the first part of the chirp is sampled. If $N \times t_S$ is larger than the chirp duration, the downchirp is also sampled. The framework requires that $N \times t_S + 20$ µs is smaller than the PWM period value. The array Seq value is used to configure the desired antenna activation sequence.

Configuration with the Tx1 Antenna Activated

Table 6 shows the parameters used in the configuration with the Tx1 antenna activated. In this configuration, one transmit antenna is activated and two adjacent chirps are collected, as shown in Figure 28. Table 6 shows the configuration of the chirp sequence. When the two chirps for Frame 0 are collected, no data is collected for two chirps before the next measurement frame starts.

Table 6. Custom Timing Variables (Example 1)

Parameter	Value[1]	Unit
f_{START}	24e9	Hz
f_{STOP}	24.2e9	Hz
t_{RAMPUP}	512	µs
Period	1	ms
N	512	
Seq	[1]	
CycSiz	2	
FrmSiz	4	
FrmSizMeas	2	

[1] Where brackets are used, this indicates that the value is an array.

The IF signals for the first frame (Chirp 0 and Chirp 1) for all four IF channels are returned.

The FrmSiz parameter defines the duration between two measurement frames and the FrmSizMeas parameter defines the number of chirps during which measurement data is collected. FrmSizMeas must be less than or equal to FrmSiz.

Configuration with the Tx1 Antenna and Tx2 Antenna Activated

Table 7 shows the parameters used in the configuration with the Tx1 antenna and Tx2 antenna activated. In this configuration, the Tx1 antenna followed by the Tx2 antenna are activated and four adjacent chirps are collected, as shown in Figure 29. Table 7 shows the configuration of the chirp sequence.

Table 7. Custom Timing Variables (Example 2)

Parameter	Value[1]	Unit
f_{START}	24e9	Hz
f_{STOP}	24.2e9	Hz
t_{RAMPUP}	256	µs
Period	0.3	ms
N	256	
Seq	[1 2]	
CycSiz	2	
FrmSiz	3	
FrmSizMeas	2	

[1] Where brackets are used, this indicates that the value is an array.

The IF signals for the first frame (Chirp 0, Chirp 1, Chirp 2, and Chirp 3) for all four IF channels are returned. In this example, the duration between two frames is 2 × FrmSiz × period, because the measurement sequence consists of two entries from the Tx1 antenna followed by the Tx2 antenna. The duration between two frames is typically length(Seq) × FrmSiz × period.

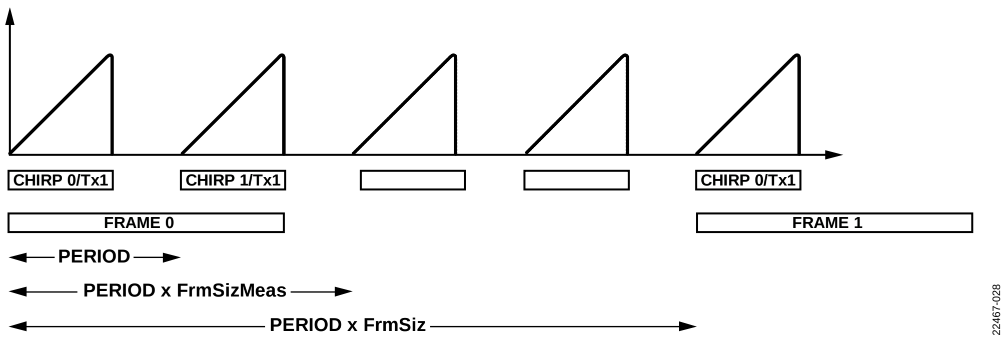


Figure 28. Example 1, Configuration with Tx1 Antenna Activated

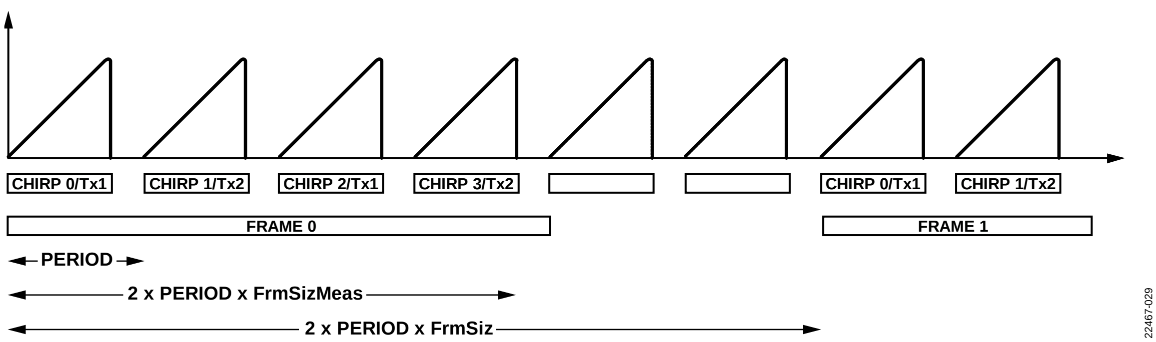


Figure 29. Example 2, Configuration with Tx1 Antenna and Tx2 Antenna Activated

ORDERING INFORMATION

BILL OF MATERIALS

Table 8. Bill of Materials

Qty.	Reference Designator	Description	Value	Manufacturer	Part Number
1	U15	Single inverter gate	Not applicable	Nexperia	74LVC1GU04GV,125
1	U5	Clock distribution with output divider	Not applicable	IDT	542MILFT
1	C3	Multilayer ceramic capacitor (MLCC), C0G, 5%, 50 V, −55°C to +125°C	330 pF	AVX	04025A331JAT2A
1	C2	MLCC, X7R, 10%, 50 V, −55°C to +125°C	5.6 nF	AVX	04025C562KAT2A
1	X1	USB 3.1 Type C connector, IPX8	Not applicable	TE Connectivity	2305018-5
1	U12	±0.5°C accurate, 10-bit digital temperature sensor in SOT-23	Not applicable	Analog Devices, Inc.	AD7415ARTZ-1500RL7
1	U1	4-channel, 16-bit, continuous time data acquisition ADC	Not applicable	Analog Devices	ADAR7251WBCSZ
1	U2	Direct modulation/fast waveform generating, 13 GHz, fractional-N frequency synthesizer	Not applicable	Analog Devices	ADF4159
1	U3	24 GHz voltage controlled oscillator (VCO) and programmable gain amplifier (PGA) with 2-channel power amplifier (PA) output	Not applicable	Analog Devices	ADF5901
1	U4	4-channel, 24 GHz, receiver downconverter	Not applicable	Analog Devices	ADF5904
1	U11	Dual 3 MHz, 1200 mA buck regulators with one 300 mA low dropout regulator (LDO)	Not applicable	Analog Devices	ADP5024ACPZ-R2
1	U9	Blackfin core embedded processor	Not applicable	Analog Devices	ADSP-BF706BCPZ-4
1	U25	Single-wire serial EEPROM	Not applicable	Microchip Technology	AT21CS01-STUM10-T
3	C8, C9, C12	MLCC, C0G ± 0.25 pF, 16 V, −55°C to +125°C	10 pF	TDK	C1005C0G1H100C050BA
1	C46	MLCC, C0G, 10%, 16 V, −55°C to +125°C	100 pF	TDK	C1005C0G1H101K050BA
1	C44	MLCC, C0G, 10%, 16 V, −55°C to +125°C	220 pF	TDK	C1005C0G1H221K050BA
21	C36, C39, C42, C50, C53, C56, C63, C69, C70, C72, C73, C76_IF1 to C76_IF4, C78_IF1 to C78_IF4, C145, C149	MLCC, X7R, 10%, 16 V, −55°C to +125°C, C series	10 nF	TDK	C1005X7R1C103K
52	C1, C4, C10, C16, C17, C20 to C25, C28, C34, C35, C38, C41, C48, C51, C54, C62, C66, C68, C87 to C91, C103 to C112, C117 to C128, C146 to C148	MLCC, X7R, 10%, 16 V, −55°C to +125°C, C series	100 nF	TDK	C1005X7R1C104K
5	C11, C26, C33, C57, C71	MLCC, X7R, 10%, 50 V, −55°C to +125°C, C series	1 nF	TDK	C1005X7R1H102K
1	C45	MLCC, X7R, 10%, 50 V, −55°C to +125°C, C series	4.7 nF	TDK	C1005X7R1H472K050BA
1	C60	MLCC, X7R, 10%, 50 V, −55°C to +125°C, C series	47 nF	TDK	C1005X7R1H473K050BB
12	C37, C40, C43, C49, C52, C55, C64, C65, C67, C94, C96, C144	MLCC, X7R, 10%, 16 V, −55°C to +125°C, C series	1 µF	TDK	C1608X7R1C105K
2	C59, C61	MLCC, X7R, 10%, 16 V, −55°C to +125°C, C series	220 nF	TDK	C1608X7R1C224K
2	C6, C7	MLCC, X7R, 10%, 16 V, −55°C to +125°C, C series	470 nF	TDK	C1608X7R1C474K
1	C92	MLCC, X5R, 20%, 16 V, −55°C to +85°C, C series	100 µF	TDK	C3216X5R1A107M
26	C5, C13 to C15, C18, C19, C27, C29 to C32, C58, C84 to C86, C93, C95, C97, C98, C100, C113 to C116, C142, C143	MLCC, X7R, 10%, 10 V, −55°C to +125°C, C series	10 µF	TDK	C3216X7R1A106K
1	U17	Clock buffer	Not applicable	Texas Instruments	CDCLVC1104PWR
2	L16, L22	Shielded SMD power inductors	1.5 µH	Sumida	CDRH2D14NP-1R5NC
1	Y3	High density complementary metal-oxide semiconductor (HCMOS), 3.3 V, 25 ppm, −55°C to +125°C	100 MHz	Connor-Winfield	CWX823-100.0M
1	L18	Common-mode choke coil, 330 mA	90 Ω	Murata	DLW21SN900SQ2L
1	Y1	Crystal, 24 MHz	Not applicable	Fox Electronics	FQ3225B-24.000
1	D6	LED, SMD, 20 mA, forward voltage (V_F) = 2.1 V	Not applicable	Kingbright	KP-2012YC

Qty.	Reference Designator	Description	Value	Manufacturer	Part Number
1	U10	1.5 A, low noise regulator	Not applicable	Analog Devices	LT1963AEST-3.3#TRPBF
1	U7	Ultra small, adjustable sequencing/supervisory circuits	Not applicable	Maxim Integrated	MAX6895AAZT
2	L9, L19	SMD chip beads, 200 mA	2.5 kΩ at 100 MHz	TDK	MMZ1608A252B
10	L1 to L8, L14, L21	SMD chip beads, 500 mA	600 Ω at 100 MHz	TDK	MMZ1608Y601B
1	T4	Tactile switch, low profile, 2.5 mm height	Not applicable	C&K	PTS636 SKG25 SMTR LFS
1	D10	Low capacitance transient voltage suppression diode (TVS) array	Not applicable	Semtech	RClamp0504S
3	R7, R77, R88	Thick film chip resistors, 0.063 W, 50 V	1 kΩ	Stackpole Electronics	RMCF0402FT1K00
3	R9, R12, R21	Thick film chip resistors, 0.063 W, 50 V	5.11 kΩ	Stackpole Electronics	RMCF0402FT5K11
33	R2, R3, R8, R13, R22, R24, R27, R29 to R32, R35, R46, R47, R49, R52 to R54, R56, R57, R63, R64, R72 to R74, R76, R81, R82, R84, R90 to R93	Thick film chip resistors, 0.063 W, 50 V	10 kΩ	Stackpole Electronics	RMCF0402FT10K0
1	R79	Thick film chip resistor, 0.063 W, 50 V	12 kΩ	Stackpole Electronics	RMCF0402FT12K0
3	R75, R86, R89	Thick film chip resistors, 0.063 W, 50 V	15.4 kΩ	Stackpole Electronics	RMCF0402FT15K4
1	R62	Thick film chip resistor, 0.063 W, 50 V	20.5 kΩ	Stackpole Electronics	RMCF0402FT20K5
11	R23, R25, R58 to R60, R87, R94, R101 to R103, R112	Thick film chip resistors, 0.063 W, 50 V	20.5 Ω	Stackpole Electronics	RMCF0402FT20R5
1	R85	Thick film chip resistor, 0.063 W, 50 V	40.2 kΩ	Stackpole Electronics	RMCF0402FT40K2
1	R83	Thick film chip resistor, 0.063 W, 50 V	56.2 kΩ	Stackpole Electronics	RMCF0402FT56K2
1	R117	Thick film chip resistor, 0.063 W, 50 V	100 kΩ	Stackpole Electronics	RMCF0402FT100K
1	R17	Thick film chip resistor, 0.063 W, 50 V	332 Ω	Stackpole Electronics	RMCF0402FT332R
2	R65, R100	Thick film chip resistors, 0.063 W, 50 V	562 Ω	Stackpole Electronics	RMCF0402FT562R
1	R36	Thick film chip resistor, 0.063 W, 50 V	909 kΩ	Stackpole Electronics	RMCF0402FT909K
1	R15	Thick film chip resistor, 0.063 W, 50 V	909 Ω	Stackpole Electronics	RMCF0402FT909R
11	R4 to R6, R16, R19, R28, R39, R41, R68, R69, R71	Thick film chip resistors, 1/16 W, 5%, 0402 SMD	0 Ω	Stackpole Electronics	RMCF0402ZT0R00
1	X2	1.27 mm through hole connector	Not applicable	Samtec	SHF-105-01-L-D-TH
1	U16	4-bit dual supply level translator	Not applicable	Texas Instruments	SN74AVCH4T245PWR
1	U8	Dual bit, dual supply bus transceiver	Not applicable	Texas Instruments	SN74LVC2T45DCTR
1	U6	USB Type C configuration channel logic and port control	Not applicable	Texas Instruments	TUSB321
1	U14	3 V, 32 Mb, serial flash memory	Not applicable	Winbond	W25Q32JVSSIQ

NOTES

ESD Caution

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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