



说明

此参考设计介绍采用时序交错配置射频采样模数转换器 (ADC) 的 20.8GSPS 采样系统。时序交错法是一种经实践检验可提高采样率的传统方法, 然而, 匹配个别 ADC 失调电压、增益和采样时间不匹配是实现性能的关键。随着采样时钟频率的增加, 交错复杂性也随之增加。ADC 之间的相位匹配是实现更出色的无杂散动态范围 (SFDR) 和有效位数 (ENOB) 的关键规格之一。本参考设计通过采用简化 20.8GSPS 交错实施的 19fs 精确相位控制措施, 在 ADC12DJ5200RF 器件上应用了无噪声孔径延迟调节功能。本参考设计基于符合 12 位系统性能要求的 LMK04828 和 LMX2594 器件, 采用了板载低噪声 JESD204B 时钟发生器。

资源

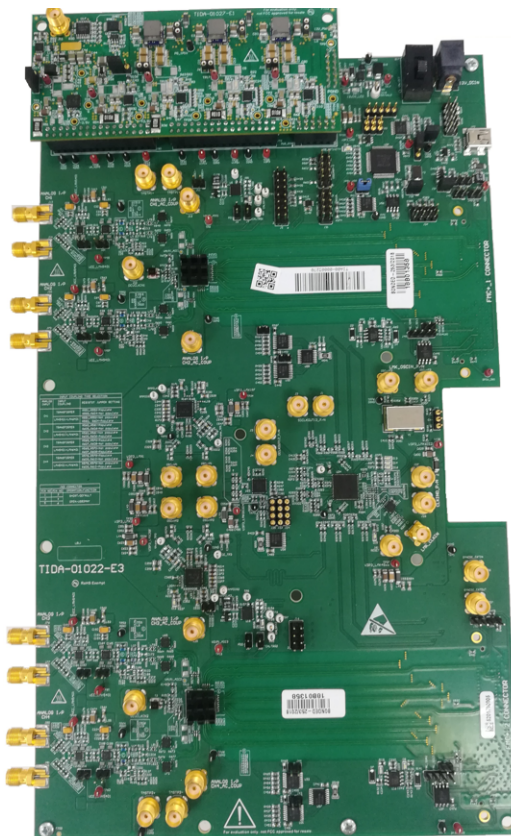
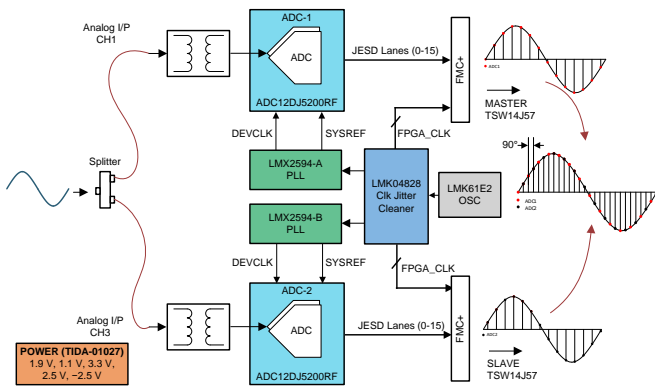
TIDA-010128	设计文件夹
ADC12DJ5200RF	产品文件夹
LMK04828、LMX2594、LMK61E2	产品文件夹
LMH5401、LMH6401	产品文件夹
TPS259261	产品文件夹
TIDA-01027	产品文件夹
ADC12DJ5200RFEVM	工具文件夹
TSW14J57EVM	工具文件夹

特性

- 采样率高达 20.8GSPS, 采用时序交错 12 位射频采样 ADC
- 6GHz 模拟前端
- 出色的采样时钟相位调整 (19fs 分辨率)
- 多个 ADC 的相位同步
- 输入电压为 12V 时, 配套电源参考设计的效率高于 85%
- JESD204B 支持 8 个、16 个或 32 个 JESD 通道, 每通道的数据速率高达 12.8Gbps
- 包含与 TI 的 TSW14J57EVM 采集卡兼容的 FMC+ 连接器

应用

- 示波器 (DSO)
- 数据采集 (DAQ)
- 电子战



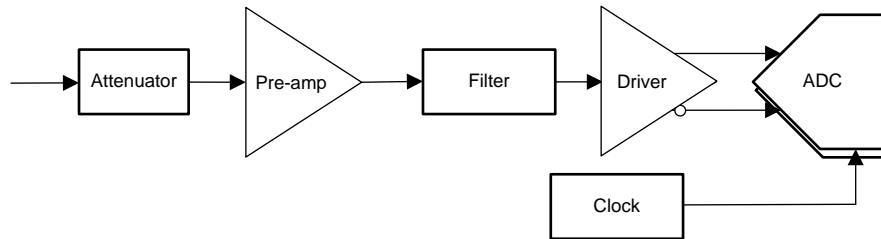


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1 System Description

图 1 显示了一个典型的高速数字化器前端块，其中大多数组件对于高速应用（如高速千兆采样示波器和高速数字化器）是通用的。关于分辨率、带宽和采样率的关键规格相似。数字化器可以在示波器的基础上，在术语前端衰减、通道数以及先进的触发能力方面有所变化。

图 1. Typical High-Speed Digitizer Analog Font End



5G-enabled systems require test instruments with fast sampling and enough bandwidth to allow for the increased the channel capacity. These system must provide high signal-to-noise ratio, and wide dynamic range with low noise to enable accurate measurement.

The ADC is the main component limiting the performance of the system. Single ADC cores with higher sample rates and wider bandwidths require large investments. However, time-interleaving multiple ADCs help achieve a higher sample rate with lower cost. Precise multi-channel clock-phase alignment capability and ADC channel characteristic matching is required to reduce interleaving sampling distortion and achieve the required system ENOB.

This reference design helps to address onboard time interleaving ADC design challenges and demonstrates how to minimize timing errors to achieve system signal-to-noise ratio (SNR), SFDR, and ENOB performance

1.1 Key System Specifications

表 1 列出了该参考设计的关键系统级规格。

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS			DETAILS
Input channels	2 channels (on-chip interleaving)			
	1 channel (onboard interleaving)			
Input type	Single ended			
Input impedance	50 Ω			
Input analog bandwidth (−3 dB)	6 GHz, transformer input			
Maximum sample rate	10.4 GSPS - 2 channels			节 3.2.3
	20.8 GSPS - 1 channel			
Resolution	12 bit			
System performance (−1 dB full scale) FS = 20.8 GHz	SNR	SFDR	ENOB	图 31
	53.6 dB at 797 MHz	67.01 dB at 797 MHz	8.5 bits at 797 MHz	
	53.5 dB at 997 MHz	66.4 dB at 997 MHz	8.5 bits at 997 MHz	
	49.7 dB at 4000 MHz	56.5 dB at 4000 MHz	7.7 bits at 4000 MHz	
Connectors	560-pin FMC+ interface connector supports TSW14J57 high-speed capture card			

表 1. Key System Specifications (continued)

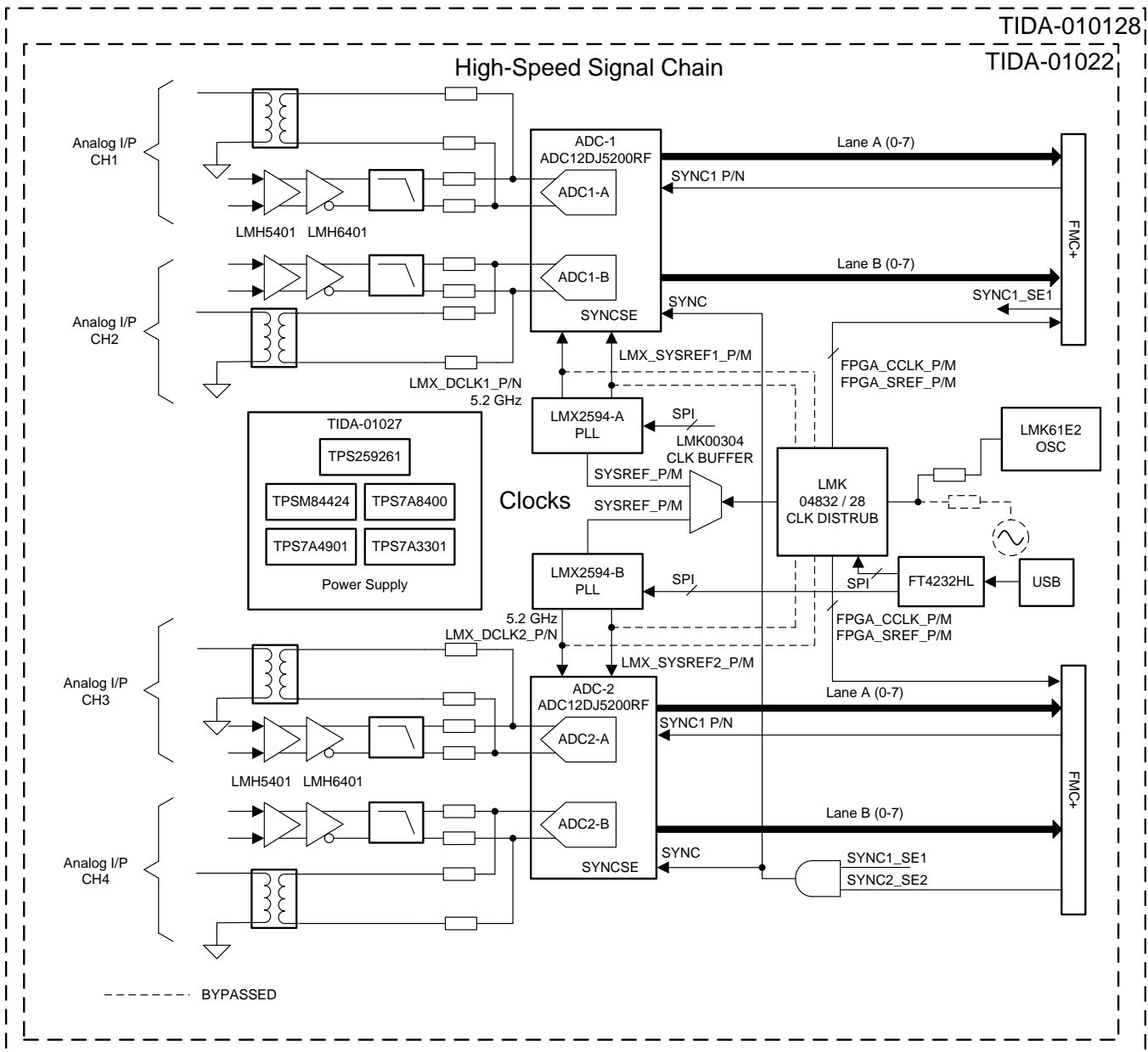
PARAMETER	SPECIFICATIONS	DETAILS
Power	12 V DC, 4 A	表 6
Form factor (L x W)	295 mm x 176 mm	

2 System Overview

2.1 Block Diagram

图 2 显示了 TIDA-01028 设计的系统级块图，该设计是使用来自 12.8-GSPS 模拟前端参考设计用于高速示波器和宽带数字转换器 (TIDA-01028) 的硬件开发的。

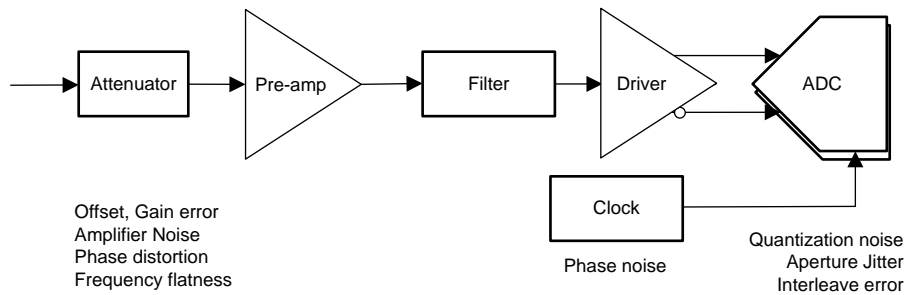
图 2. TIDA-01028 System Block Diagram



2.2 Design Considerations

In both high-speed oscilloscopes and digitizers, the total system performance is determined by the core ADC, jitter introduced by the clocking solution, and the analog front end signal chain, typically containing input attenuators, amplifiers, and filter blocks. To maximize system ENOB, the error sources from these companion devices must be minimized. 图 3 shows the subsystem block with the associated error sources which limits system performance.

图 3. Analog Front End With Error Sources



2.2.1 Interleave Design Challenges

To achieve higher sample rates, multiple ADCs are time-interleaved into a single or composite ADC. Each ADC is sampled at the same time period with equally-spaced time intervals and then the captured data is formatted to achieve higher sample rates. To achieve accurate sampling, the individual ADCs offset, gain, and phase between ADCs should be exactly matched. However, in practical terms this is not possible and mismatch must be managed and minimized, otherwise system performance is degraded by the introduction of interleaving spurs.

图 4. 2 × ADC Interleaved Non-Ideal ADC

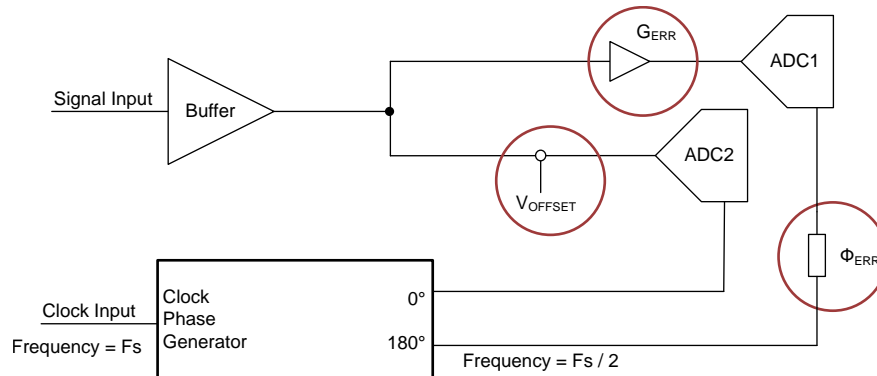


图 4 shows a two-ADC interleaved system with typical error sources like offset error, gain error, and time mismatch error between two ADCs which generate predictable spurs in the spectrum of the system.

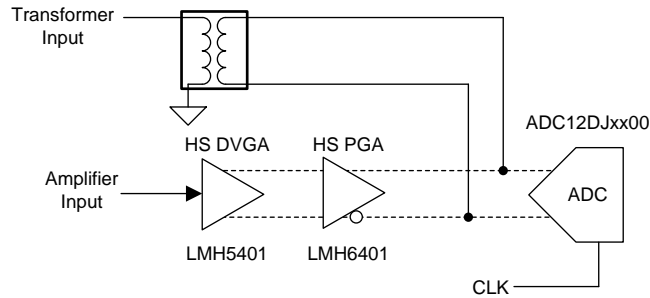
These error sources and their impact are explained in the [12.8-GSPS Analog Front End Reference Design for High-Speed Oscilloscope and Wide-Band Digitizer Design Guide](#) for the TIDA-01028 reference design.

2.2.2 Circuit Design

2.2.2.1 Analog Input Front End

图 5 显示了 TIDA-01022 参考设计的模拟前端电路。灵活的模拟输入允许验证系统性能，具有两种不同的输入路径；每个输入都可以接受来自变压器或放大器链的信号，基于硬件跳线选择。所有通道在路径延迟、时钟路由等方面都匹配得很好。

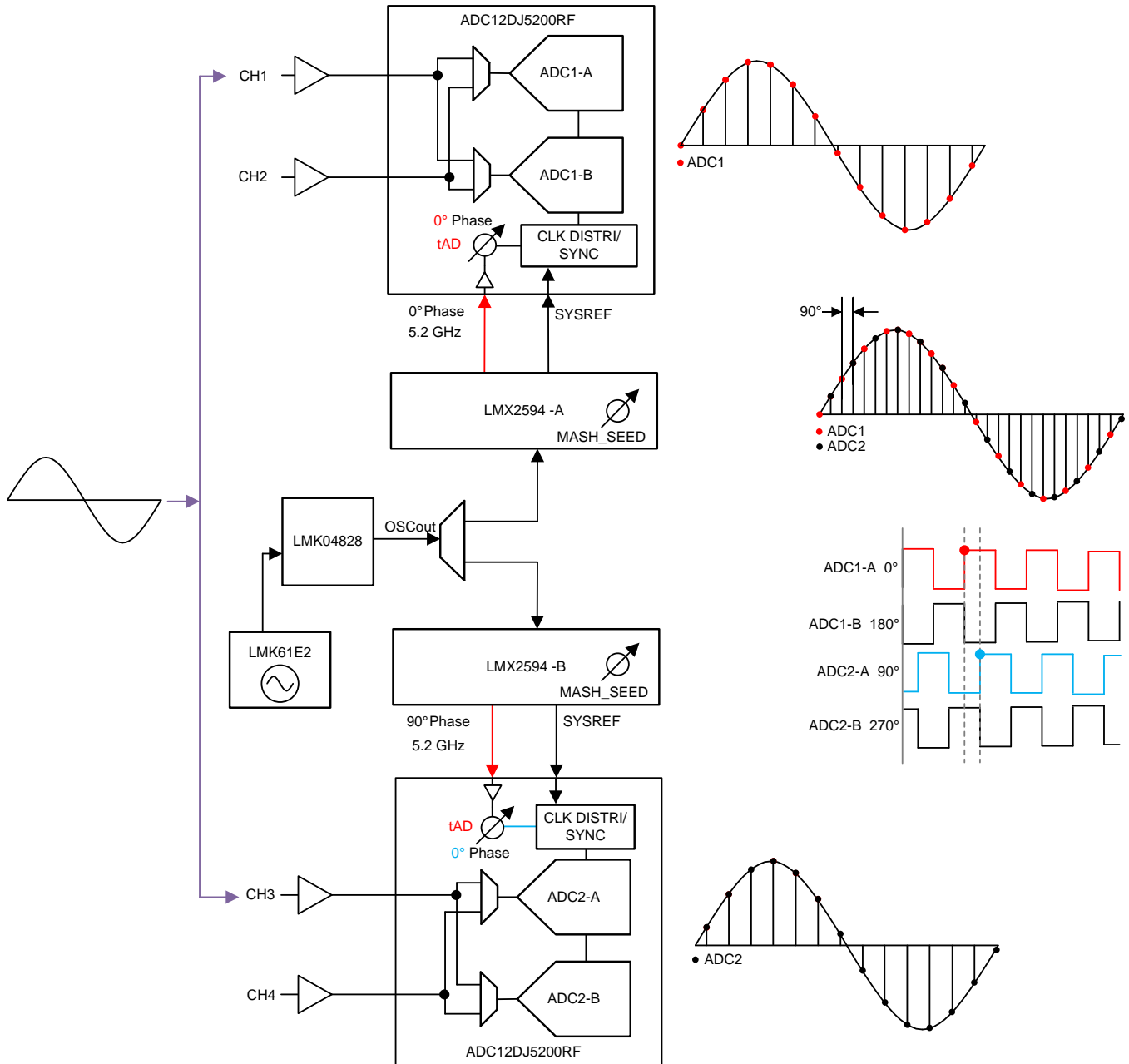
图 5. TIDA-01022 Analog Front End



2.2.2.2 Interleave Clock Requirement

The TIDA-01022 hardware has a flexible clocking platform which helps designers validate system performance with various clocking source options. The default onboard clocking solution uses the LMX2594 clock synthesizer which has excellent phase noise at high frequency. A clock distribution chip, the LMK04828 device, is used to provide the reference signal to the LMX2594 device, FPGA DCLK, FPGA_CORECLK, and FPGA_SYSREF.

图 6. TIDA-010128 Interleave Clock Architecture



The ADC_SYSREF, FPGA_CORECLK, FPGA_REFCLK, and FPGA_SYSREF are to be calculated based the ADC device clock (ADC_DEVCLK) requirement and SERDES lanes used for capture.

To achieve a 20.8-GSPS sample rate, the following clocks were generated by the onboard clocking solution provided in this design:

- ADC_DEVCLK = 5.2 GHz; to operate ADC in 10.4 GSPS single-channel mode
- ADC_SYSREF = 32.5 MHz
- FPGA_CORECLK = 260 MHz
- FPGA_SYSREF = 32.5 MHz SERDES lane rate = 16

Both the LMX2594-A and LMX2594-B devices are configured to generate 5.2 GHz at RFoutA for DEVCLK and 32.5 MHz at RFoutB for SYSREF from the 65-MHz reference at the OSCin input which is connected to the OSCout of the LMK04828 device via the LMK00304 clock buffer.

The LMK04828 device is used to provide the required FPGA clocks. 表 2, 表 3, and 表 4 show the signal definitions and clock output frequency.

表 2. LMK04828 Clock Definition for TIDA-010128

SLNO	LMK04828 SIGNALS	FREQUENCY OUTPUT	REMARKS
1	OSCout p/n	65 MHz	Connected to the LMX2594 reference input for generation of ADC, DEVCLK, and SYSREF
2	DCLKOUT0 p/n	-	Not used
3	SDCLKOUT1 p/n	-	Not used, LMX SYSREF or LMX SYSREFREQ
4	DCLKOUT2 p/n	-	Not used
5	SDCLKOUT3 p/n	-	Not used, LMX SYSREF or LMX SYSREFREQ
6	DCLKOUT4 p/n	260 MHz	FPGA_REF CLK, connected slave to capture FPGA (Optional)
7	SDCLKOUT5 p/n	-	SYNC signal to LMX2594-B
8	DCLKOUT6 p/n	260 MHz	FPGA_CORE CLK, connected slave to capture FPGA
9	SDCLKOUT7 p/n	32.5 MHz	FPGA_SYSREF, connected slave to capture FPGA
10	DCLKOUT8 p/n	260 MHz	FPGA_CORE CLK, connected master to capture FPGA
11	SDCLKOUT9 p/n	32.5 MHz	FPGA_SYSREF, connected master to capture FPGA
12	DCLKOUT10 p/n	260 MHz	FPGA_REF CLK, connected master to capture FPGA (Optional)
13	SDCLKOUT11 p/n	-	SYNC signal to LMX2594-A
14	DCLKOUT12 p/n	-	Not used
15	SDCLKOUT13 p/n	-	Not used

表 3. LMX2594-A Clock Definition for TIDA-010128

SLNO	LMX2594-A	FREQUENCY OUTPUT	REMARKS
1	OSCin p/n	65 MHz	Connected to the OSCout p/n of LMK04828
2	RFoutA p/n	5.2 GHz	Connected to ADC-1 device clock input
3	RFoutB p/n	32.5 MHz	Connected to ADC-1 SYSREF input

表 4. LMX2594-B Clock Definition for TIDA-010128

SLNO	LMX2594-B	FREQUENCY OUTPUT	REMARKS
1	OSCin p/n	65 MHz	Connected to OSCout p/n of LMK04828
2	RFoutA p/n	5.2 GHz	Connected to ADC-2 device clock input
3	RFoutB p/n	32.5 MHz	Connected to ADC-2 SYSREF input

Once all the clocks are generated, a 90° phase difference between the two ADC channels can be established with the following procedure:

The TICSPRO GUI helps to create the configuration files for the LMK61E2, LMK04828, and LMX2594 devices. Download the latest High-Speed Data Converter (HSDC) TID GUI software from: <http://www.ti.com/tool/TICSPRO-SW>.

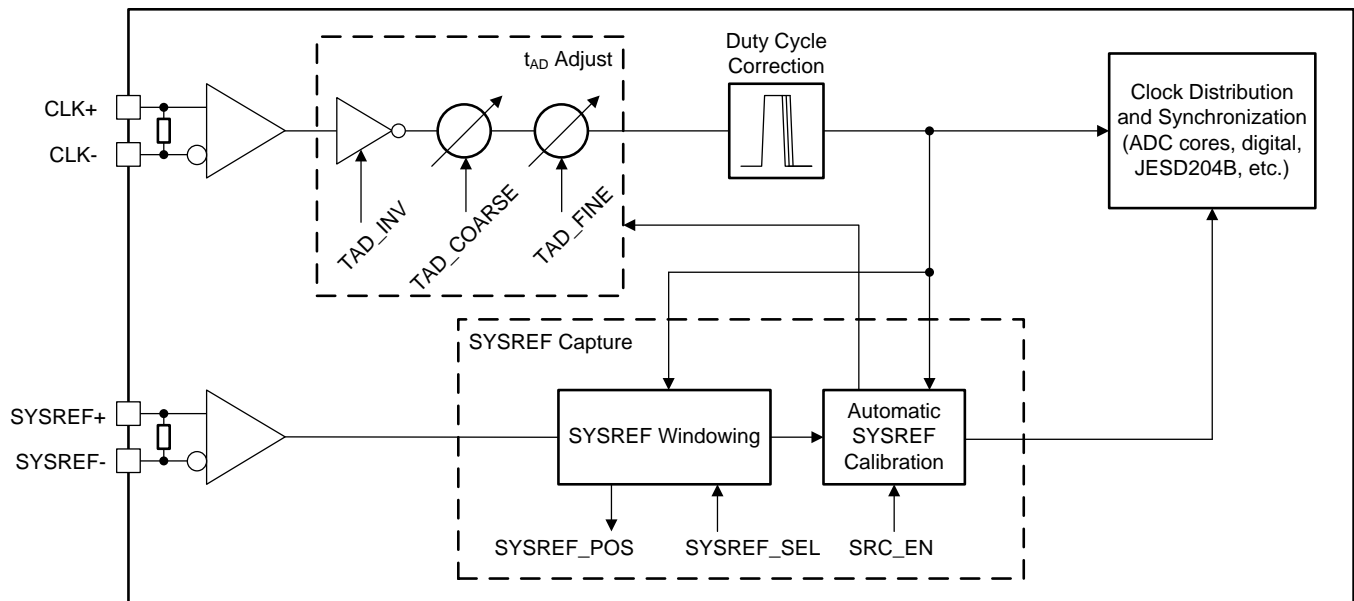
2.2.2.3 Establishing 90-Degree Phase Alignment

The TIDA-01022 hardware has a flexible clocking solution with a number of clocking options to allow users to validate system performance with various clocking configurations. One clocking option in this reference design is selected which satisfies the interleaving design clocking requirements. This clocking solution provides flexibility to adjust the clock delay in three places in the clocking path. This delay can be done on the LMK04828 output, LMX2594 output, the ADC12DJ5200RF device, or a combination of these devices.

The LMK04828 device has both analog and digital delay elements in each clock output. The LMX2594 has a MASH SEED register that can tune the delay in 9-ps increments and the ADC12DJ3200 device has Noiseless Aperture Delay Adjustment (t_{AD} adjust) features on the device clock path that can be used to shift the sampling instant in 19-fs steps.

图 7 shows the internal clock subsystem of the ADC12DJ5200RF device and highlights t_{AD} components (TAD_INV, TAD_COARSE, and TAD_FINE). These registers allow maximum aperture delay adjustment up to $t_{AD(max)} = 293$ ps and ultra-low aperture jitter $t_{AD(max)} = 70$ fs to satisfy the low-phase noise requirements.

图 7. ADC12DJ5200RF Clocking Subsystem



This t_{AD} feature gives the flexibility to adjust any one or both registers of the ADC to make required phase shift between ADCs with 19-fs resolution.

公式 1 helps to calculate the required phase delay between ADCs:

$$t_{PHASEDELAY} = \frac{t_{SAMPLECLK} \times \text{Req_phase}}{360}$$

where

- $t_{SAMPLECLK}$ = device clock time period . 1/Fs
 - Reg_Phase = required phase shift between two ADCs
 - $t_{PHASEDELAY}$ = phase delay between two ADCs
- (1)

To interleave the two ADC12DJ5200RF devices onboard, a 90° phase shift between ADC clocks is required by using 公式 2 for a 5.2-GHz device clock:

$$t_{SAMPLECLK} = \frac{1}{5200,000,000 \text{ Hz}} = 192.3 \text{ ps}$$

(2)

$$t_{PHASEDELAY} = \frac{192.3 \times 10^{-12} \times 90}{360} = 48.07ps \quad (3)$$

As previously discussed, a phase delay of 48.07 ps is attained either with the LMX2594 device using MASHSEED, or the ADC12DJ5200 device using t_{AD} , or a combination of both.

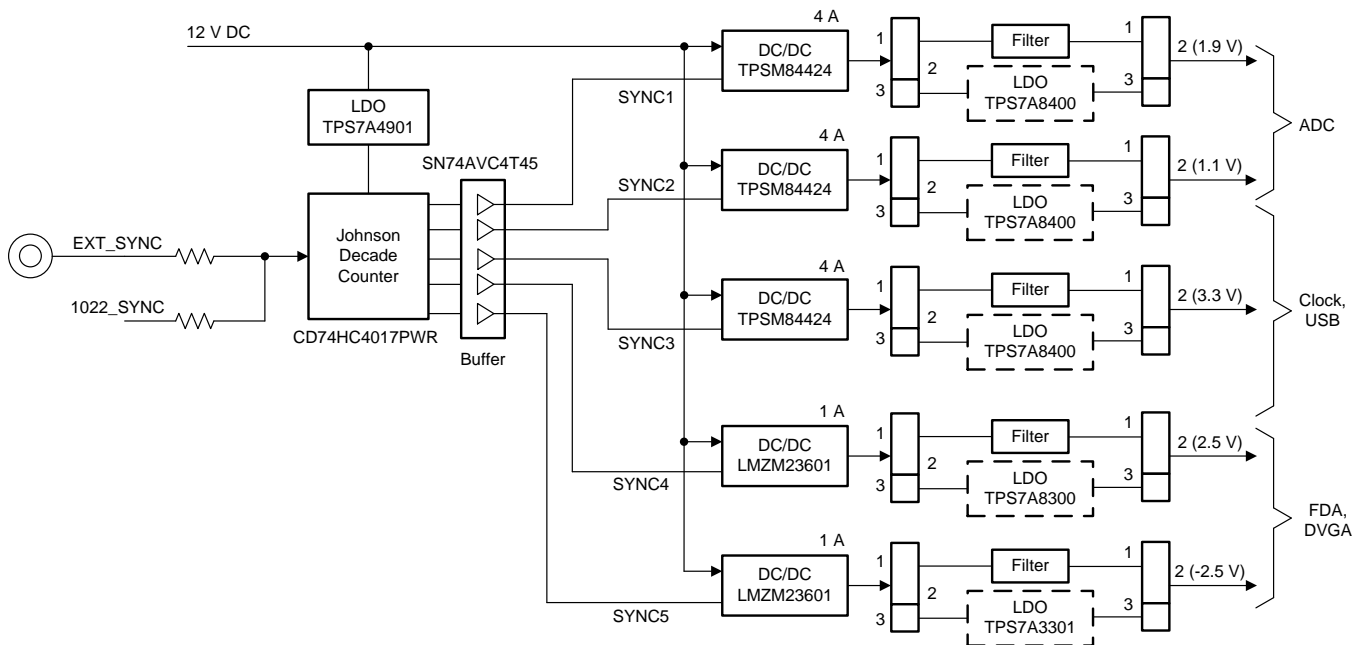
In this reference design, the required 90° (48.07 ps) phase shift was established with the LMX2594 device using the MASHSEED register.

2.2.2.4 Power Tree

This TI design uses a high-performance, optimized power solution from the TIDA-01027 reference design.

This power module satisfies the power requirements of the TIDA-01022. The module contains both DC/DC and LDO regulators with an external frequency SYNC feature for synchronization of multiple switching regulators. Also, a method of clock phase shifting enables users to reduce both conducted and radiated EMI.

图 8. TIDA-01027 Power Tree



For more information, see the [Low noise power-supply reference design maximizing performance in 12.8 GSPS data acquisition systems \(TIDA-01027\)](#).

2.3 Highlighted Products

2.3.1 ADC12DJ5200RF - 12-Bit, Dual 5.2-GSPS or Single 10.4-GSPS, RF-Sampling ADC

The ADC12DJ5200RF device is an RF-sampling giga-sample ADC that can directly sample input frequencies from DC to above 10 GHz. In dual-channel mode, it can sample up to 5.2-GSPS and in single channel mode up to 10.4-GSPS. It has full power input bandwidth (−3 dB) of 8.0 GHz, with usable frequencies exceeding the −3 dB point in both dual- and single-channel modes, and allows direct RF sampling of the L-band, S-band, C-band, and X-band for frequency agile systems.

2.3.1.1 Why Choose the ADC12DJ5200RF? Key Features

The ADC12DJ5200RF device has an integrated t_{AD} adjust feature which allows shifting of the clock instants in fine steps (19 fs) to achieve 90-degree phase between two ADCs for time interleave sampling. 图 7 shows the ADC12DJxx00 family internal clocking subsystem.

- Automatic SYSREF calibration, uses the t_{AD} adjust feature to shift the device clock to maximize the SYSREF setup and hold times or align the sampling instance based on the SYSREF rising edge.
- SYSREF Position Detector and Sampling Position Selection (SYSREF Windowing) The SYSREF windowing block is used to first detect the position of SYSREF relative to the CLK_{\pm} rising edge and then to select a desired SYSREF sampling instance, which is a delay version of CLK_{\pm} , to maximize setup and hold timing margins.

In addition to these features, this device family offers various sampling rates starting from 1600 MHz to 5200 MHz and 8 to 12 bits of resolution with the same pinout. It allows customers the flexibility to change the data converter speed and resolution based on their applications with the same printed circuit board (PCB). Also, there is no need for much hardware and software development.

In addition to the aperture adjustment, some of the key specifications taken into account include SNR, ENOB, and so forth – other similar devices considered are listed in 表 5.

表 5. ADC12DJ5200RF - Similar Devices

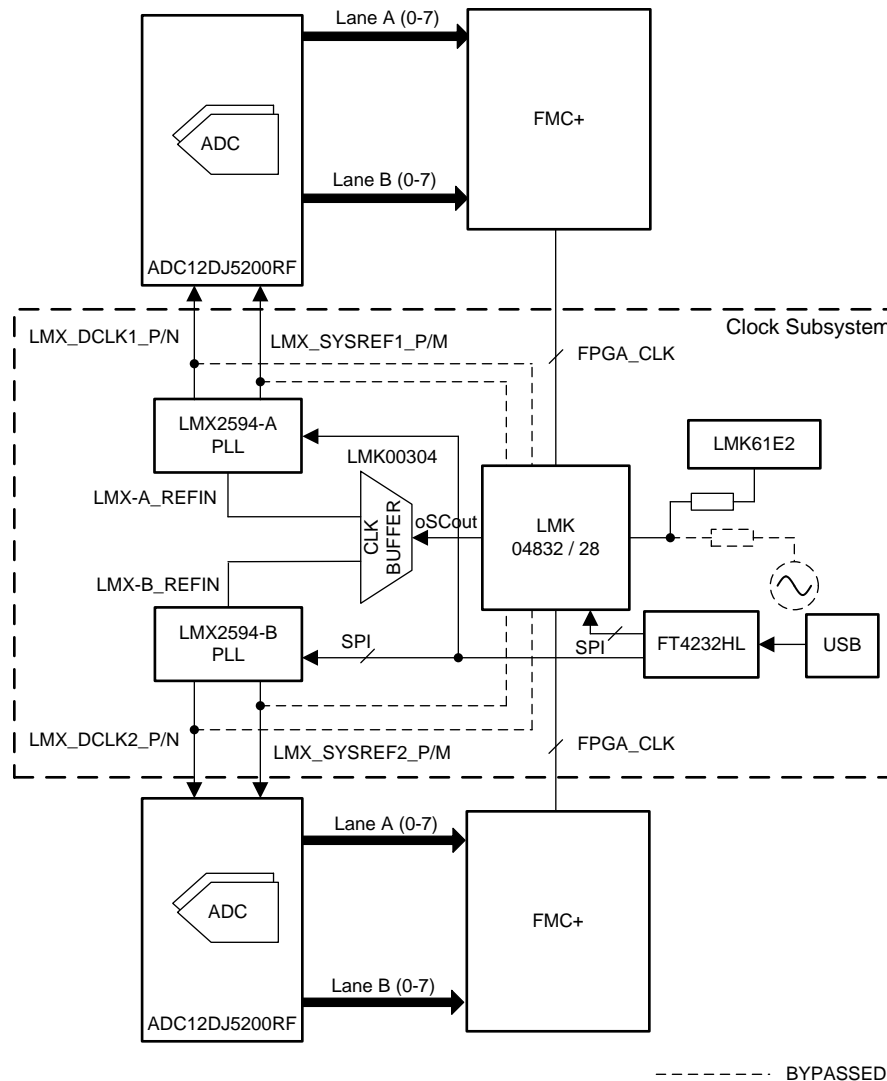
	ADC12DJ5200RF	ADC08DJ3200	ADC12DJ2700	ADC12DJ3200	ADC12J1600	ADC12J4000
	Order now	Order now	Order now	Order now	Order now	Order now
	Online Data Sheet	Online Data Sheet	Online Data Sheet	Online Data Sheet	Online Data Sheet	Online Data Sheet
	Data Sheet	Data Sheet	Data Sheet	Data Sheet	Data Sheet	Data Sheet
	Tools & Software	Tools & Software	Tools & Software	Tools & Software	Tools & Software	Tools & Software
Sample rate (Max) (MSPS)	5200	3200	2700	3200	1600	4000
	10400	6400	5400	6400		
Resolution (Bits)	12	8	12	12	12	12
Number of input channels	2	2	2	2	1	1
	1	1	1	1		
Interface	JESD204B	JESD204B	JESD204B	JESD204B	JESD204B	JESD204B
	JESD204C					
Analog input BW (MHz)	8000	8000	8000	8000	3300	3300
Features	Ultra-high speed	Ultra-high speed	Ultra-high speed	Ultra-high speed	Ultra-high speed	Ultra-high speed
Rating	Military	Catalog	Catalog	Catalog	Catalog	Catalog
Input range (Vp-p)	0.8	0.8	0.8	0.8	0.725	0.725
Approx. price (US\$)	-	896.50 100u	1619.50 100u	1919.50 100u	658.20 100u	1949.00 100u
Power consumption (Typ) (mW)	4010	2800	2700	3000	1600	2000
Architecture	Folding interpolating	Folding interpolating	Folding interpolating	Folding interpolating	Folding interpolating	Folding interpolating
SNR (dB)	55.1	49.1	56.7	56.6	55	55
ENOB (Bits)	8.7	7.8	9	9	8.8	8.8
SFDR (dB)	68	67	71	67	70	71
		62				
Operating temperature range (°C)	-40 to 85	-40 to 85	-40 to 85	-40 to 85	-40 to 85	-40 to 85

2.3.2 LMK04828- Ultra Low Noise JESD204B Compliant Clock Jitter Cleaner

The LMK0482x family is the highest performance clock conditioner with JESD204B support in the industry. The 14 outputs from PLL2 can drive up to seven JESD204B data convertors or other logic devices like FPGA. The device has both analog and digital delay in each clock output path and analog delay can be adjusted 25-ps fine steps.

图 9 shows by combining both LMK04828 and LMX2594 devices, high-performance, low-noise clocking subsystems are created that drive giga-sample speed data converters with JESD204B support.

图 9. Giga Sample Clocking Solution With LMX2594 + LMK04828



2.3.3 LMX2594- 15 GHz Wideband PLLatnum™ RF Synthesizer

The LMX2594 device is a high-performance, wideband PLL with integrated VCOs that can generate frequencies from 10 MHz to 15 GHz without using an internal doubler. The high-performance PLL with a figure of merit of -236 dBc/Hz and high-phase detector frequency can attain very low in-band noise and integrated jitter.

The LMK2594 device is an ideal companion part for the ADC12DJxx00 family. The LMK2594 generates a very low noise clock for high-speed data convertor and generates repeating SYSREF which is compliant with the JESD204B standard.

2.3.4 LMK61E2- Ultra-Low Jitter, Fully-Programmable Oscillator

The LMK61E2 device is an ultra-low jitter PLLatinum programmable oscillator with a fractional-N frequency synthesizer with integrated VCO that generates commonly-used reference clocks. The outputs can be configured as LVPECL, LVDS, or HCSL. The device offers ultra-low jitter, as low as 90-fs RMS and the maximum clock output can generate up to 1 GHz with 50 ppm frequency stability. In this reference design, the LMK61E2 device is used to provide a reference clock for the LMK04828 device.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The following hardware components are need to perform the test:

1. 1 × TIDA-01022 hardware
2. 2 × TSW14J57EVM
3. 1 × USB2ANY programmer
4. 1 × Splitter (supports up to 6 GHz)
5. 1 × Variable band-pass filter (100 MHz to 6 GHz)
6. 2 × Laptop or desktop PC (Microsoft® Windows® 10 OS installed)
7. 1 × 12 V, 4-A DC adapter or lab power supply

3.1.2 TIDA-01022 Hardware Functional Block

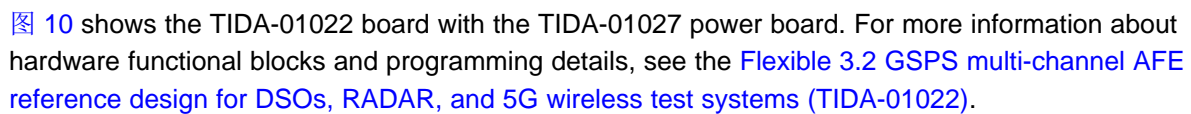
 **图 10** shows the TIDA-01022 board with the TIDA-01027 power board. For more information about hardware functional blocks and programming details, see the [Flexible 3.2 GSPS multi-channel AFE reference design for DSOs, RADAR, and 5G wireless test systems \(TIDA-01022\)](#).

图 10. TIDA-01022 Hardware Functional Block

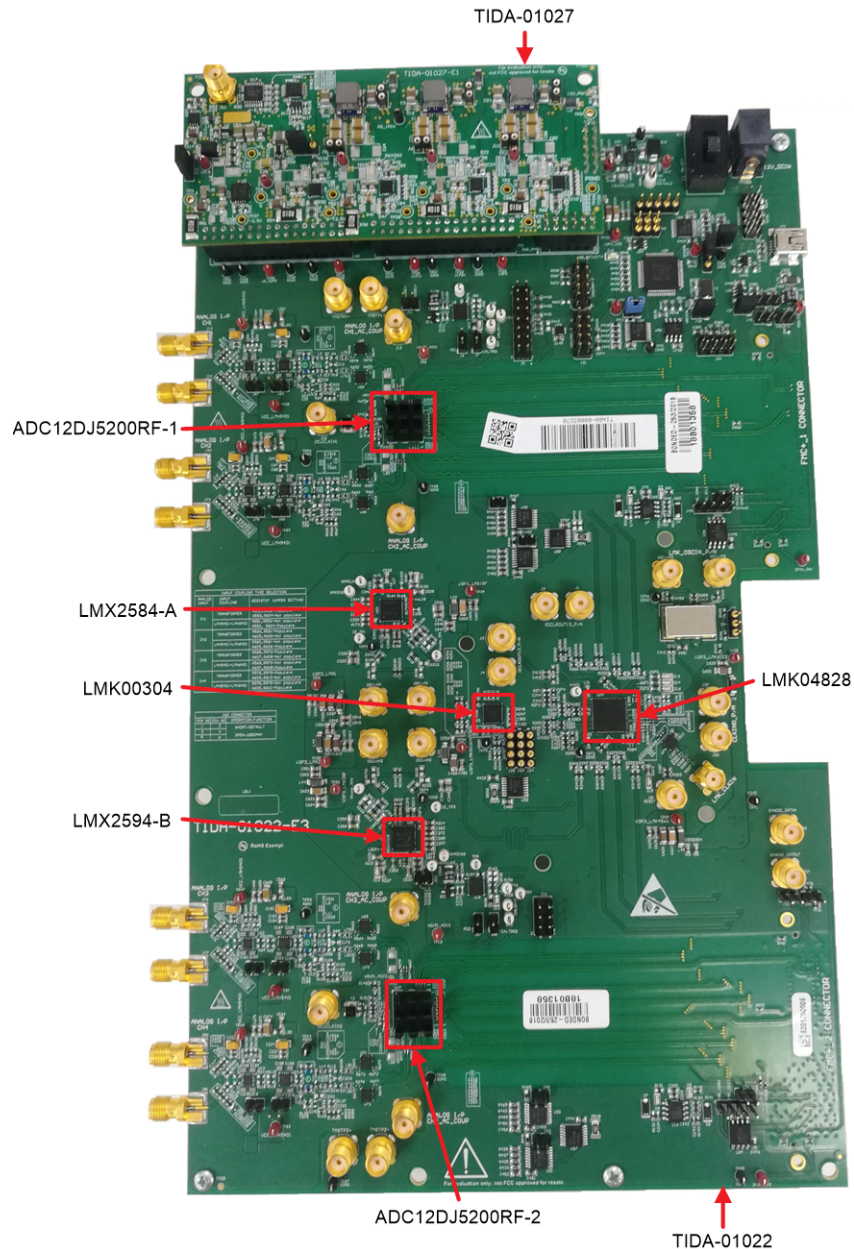


图 11 shows the TIDA-01027 board image, in this reference design the TIDA-01027 board is configured as DC/DC free-running mode (default mode). The TIDA-01027 output connectors are made compatible with the TIDA-01022 power input headers J58, J59, J60, and J63.

表 6 shows the input and output specification of the TIDA-01027 power-supply module.

表 6. TIDA-01027 Key Specification

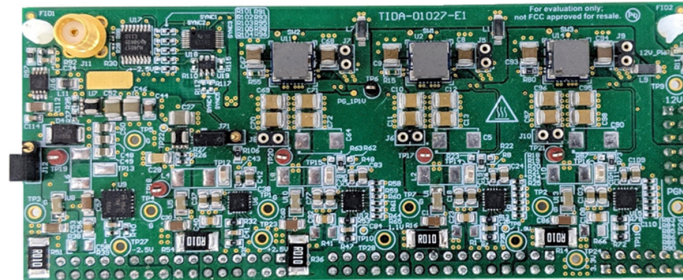
PARAMETER	SPECIFICATION
Input voltage range	5 V to 17 V
Number of outputs	5
Output voltage, maximum output current	1.9 V - 4 A, 1.1 V - 4 A, 3.3 V - 4 A, 2.5 V - 1 A, -2.5 V - 800 mA

表 6. TIDA-01027 Key Specification (continued)

PARAMETER	SPECIFICATION
Efficiency	85%

The board can be connected as 图 10 shows.

图 11. TIDA-01027 Hardware Image



3.1.3 Software

The TIDA-01022 board requires three application software GUIs for validation: HSDC TID GUI, HSDC Pro GUI, and the LMK61xx oscillator programming tool.

1. Use the HSDC TID GUI to configure the data converter (ADC12DJ3200), clocking devices (LMK4828, LMX2594, and LMK61E2), and digital VGA (LMH6401). Use the low-level page to program the device with the respective configuration file. Download the latest HSDC TID GUI software from: <http://www.ti.com/lit/zip/tidcfb3>
2. Use the HSDC Pro GUI to capture the digitized data with the assistance of a TSW14J57 capture card and provide a spectrum and time domain plot. Download the latest HSDC Pro GUI software at: <http://www.ti.com/tool/dataconverterpro-sw>
3. Use the LMK61xx Oscillator Programming Tool to program the LMK61E2 device. Download the latest LMK61xx software at <http://www.ti.com/lit/zip/snac074>.

3.1.3.1 Getting Started Application GUI

图 12, 图 13, and 图 14 show screenshots of starting the HSDC TID GUI configuration and the Programming tab for the low-level view, respectively.

图 12. HSDC TID GUI – Top-Level Navigation View

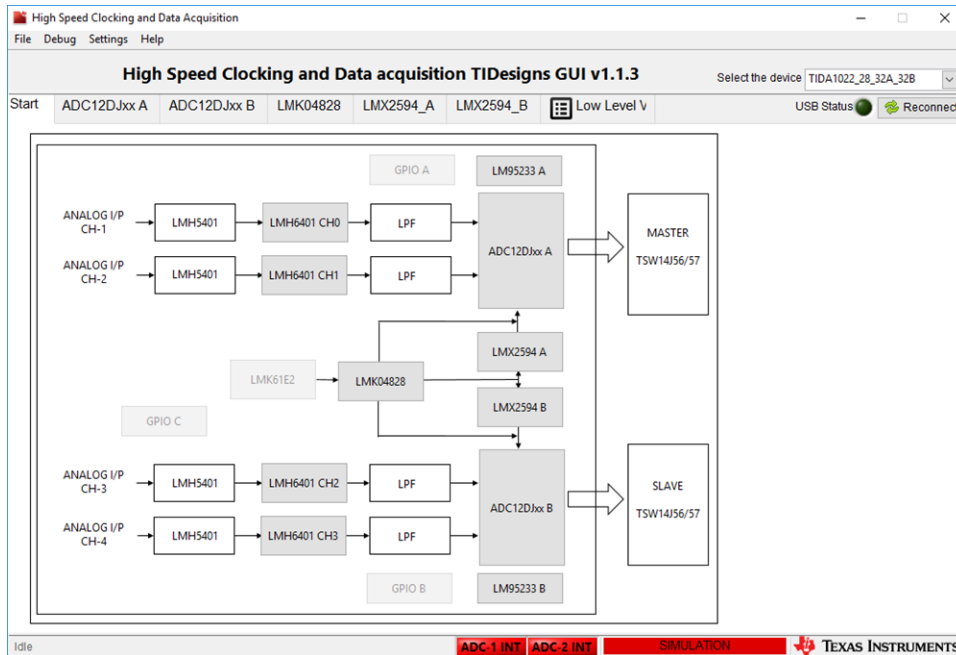


图 13. HSDC TID GUI – Low-Level Programming View

Register Name	Address	Default	Mode	Size	Value	15	14	13	12	11	10	9	8
ADC12Djxx00_A													
CONFIG_A	0x00	0x30	R/W	8	0x30								
DEVICE_CONFIG	0x02	0x00	R/W	8	0x00								
CHIP_TYPE	0x03	0x03	R/W	8	0x03								
CHIP_ID_0	0x04	0x20	R/W	8	0x20								
CHIP_ID_1	0x05	0x00	R/W	8	0x00								
CHIP_VER	0x06	0x01	R/W	8	0x01								
VENDOR_ID_0	0x0C	0x51	R/W	8	0x51								
VENDOR_ID_1	0x0D	0x04	R/W	8	0x04								
USR0	0x10	0x00	R/W	8	0x00								
RESERVED_0	0x20	0x00	R/W	8	0x00								
RESERVED_1	0x21	0x00	R/W	8	0x00								
RESERVED_2	0x22	0x00	R/W	8	0x00								
AC_CTRL1	0x23	0x00	R/W	8	0x00								
RESERVED_4	0x24	0x00	R/W	8	0x00								
RESERVED_5	0x25	0x00	R/W	8	0x00								
RESERVED_6	0x26	0x00	R/W	8	0x00								
RESERVED_7	0x27	0x00	R/W	8	0x00								
RESERVED_8	0x28	0x00	R/W	8	0x00								
CLK_CTRL0	0x29	0x00	R/W	8	0x00								

图 14. HSDC TID GUI - NCO Programming, Alarm Monitor View

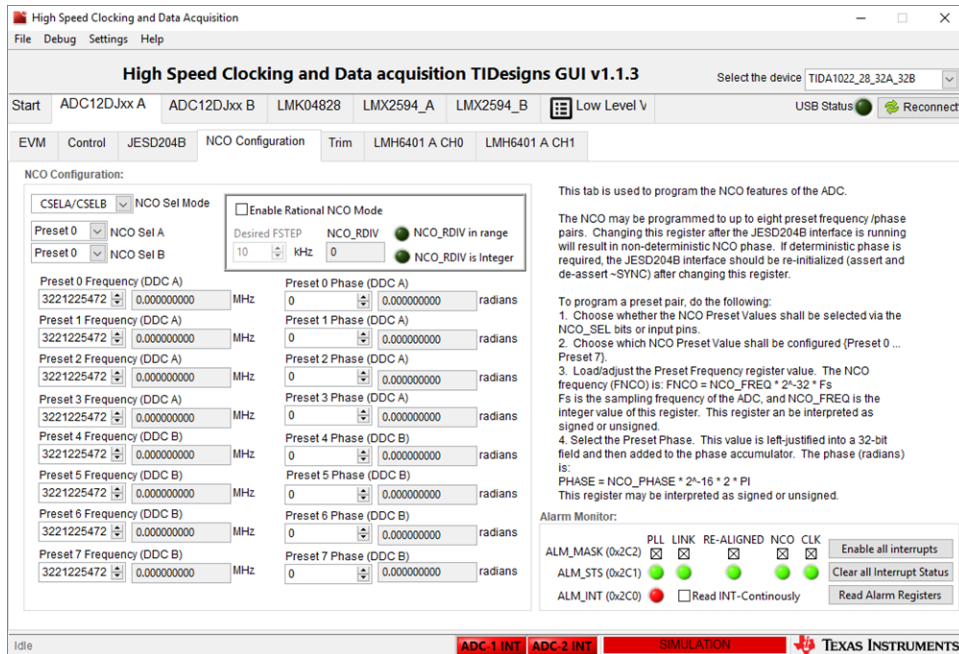
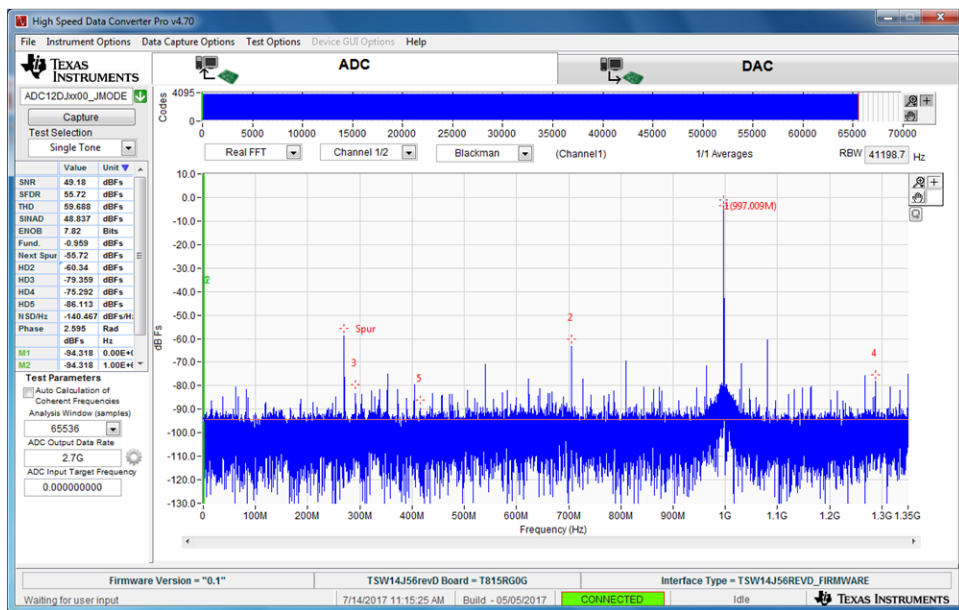


图 15 shows the ADC capture screen in HSDC Pro GUI

图 15. HSDC Pro ADC Capture GUI (Spectrum)



3.1.3.2 Hardware Programming

The TIDA-01022 hardware has an onboard FTDI-brand USB controller which is for programming the LMK61E2, LMK4828, and LMX2594 clocking devices and the LMH6401 amplifier using an SPI or I2C interface. The High-Speed Data Converter (HSDC TID) graphical user interface (GUI) supports low-level pages, which can be used to program these devices.

The board also features a USB2ANY programming interface which helps the user to evaluate hardware by using the respective evaluation module (EVM) GUI.

图 16 shows the location of programming connector

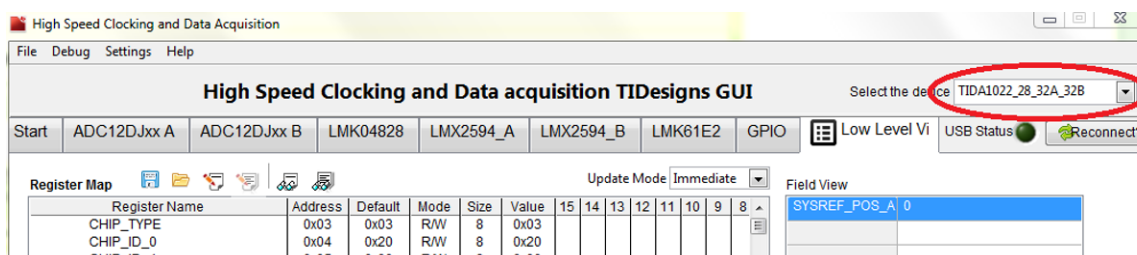
图 16. Programming Connector Interface



The programming procedure for the built-in programming interface is as follows:

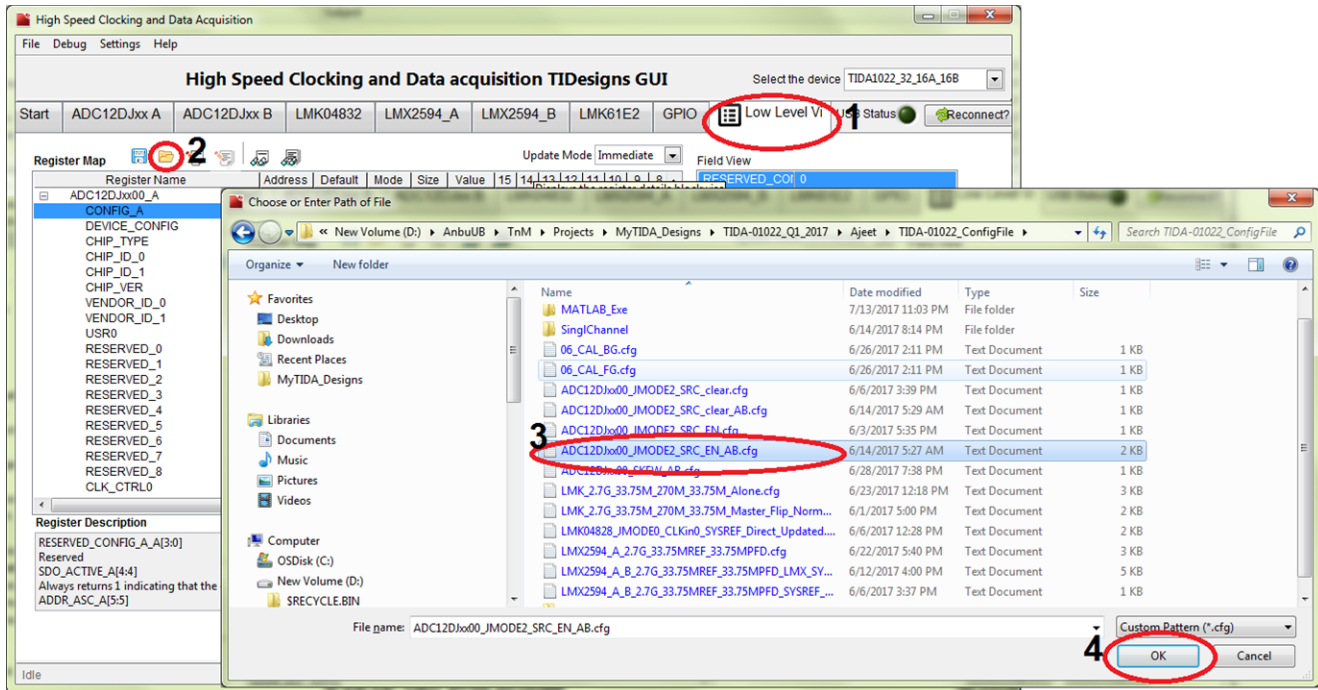
1. Open the HSDC TID GUI and select the "TIDA1022_28_32A_32B" from device selection drop-down menu.

图 17. Select a Device in the HSDC TID GUI



2. Navigate to the *Low Level* tab, select the configuration files to be programmed, and click the *OK* button. Follow these steps as numbered and encircled in the screen shot in 图 18.

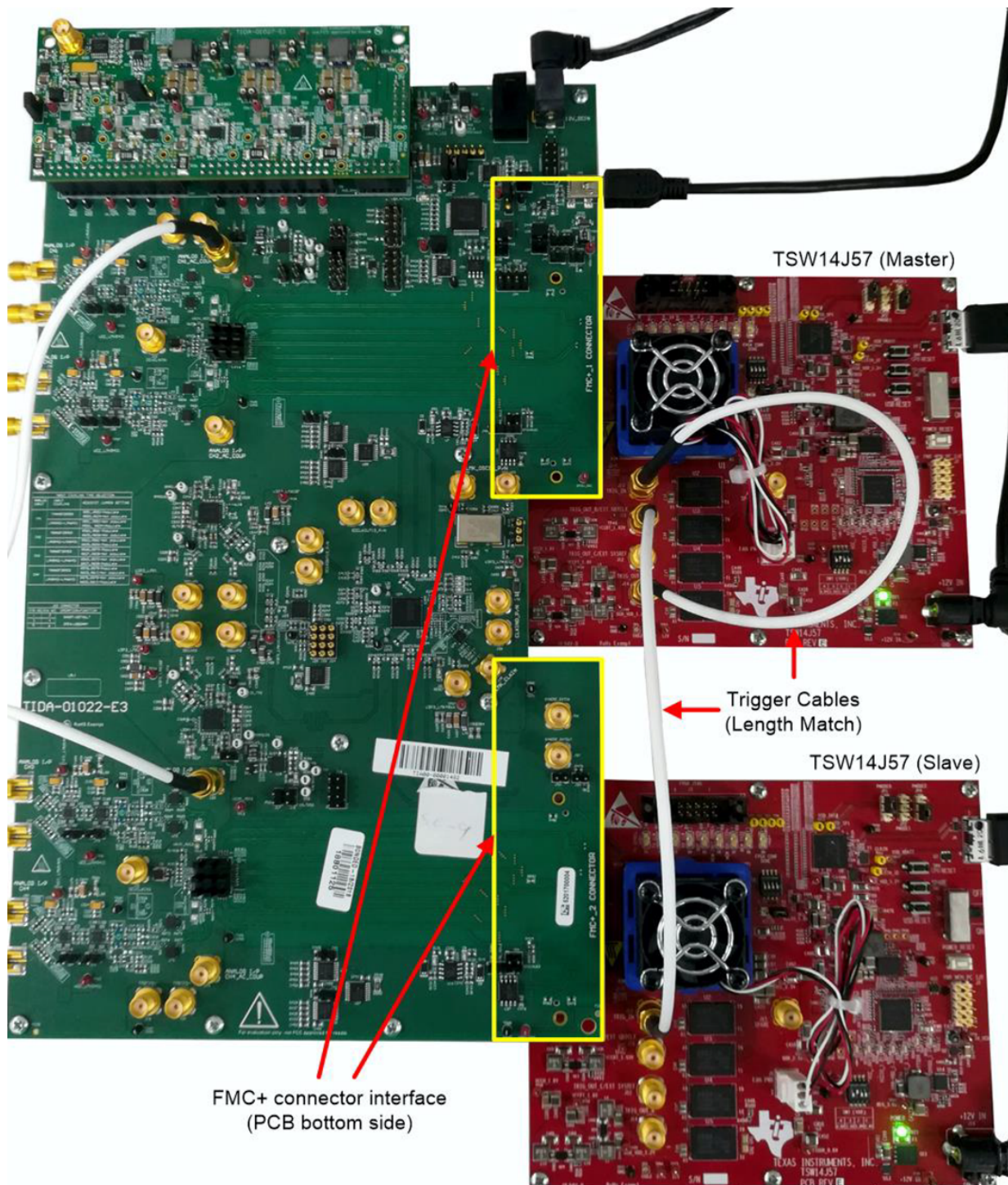
图 18. Selecting Configuration Files to be Programmed



3.1.4 Host Interface

The TIDA-01028 time interleaved system performance can be evaluated using TI's TSW14J57 JESD204B High-Speed Data Capture and Pattern Generator Card. Populated with an Intel® Arria® 10 FPGA device and using the Intel Altera® products JESD204B IP solution, the TSW14J57 device can be dynamically configured to support all lane speeds from 1.6 Gbps to 15 Gbps - from 1 to 16 lanes. Together with the accompanying High-Speed Data Converter Pro Graphic User Interface (GUI), it is a complete system that captures and evaluates data samples from the TIDA-01022 reference design. The TIDA-01022 can be directly interfaced with the TSW14J57 device using the FMC+ connector interface. 图 19 shows the TIDA-01022 interface with the TSW14J57 capture module and trigger cable connection.

图 19. TIDA-01022 Interface With TSW14J57 Capture Card



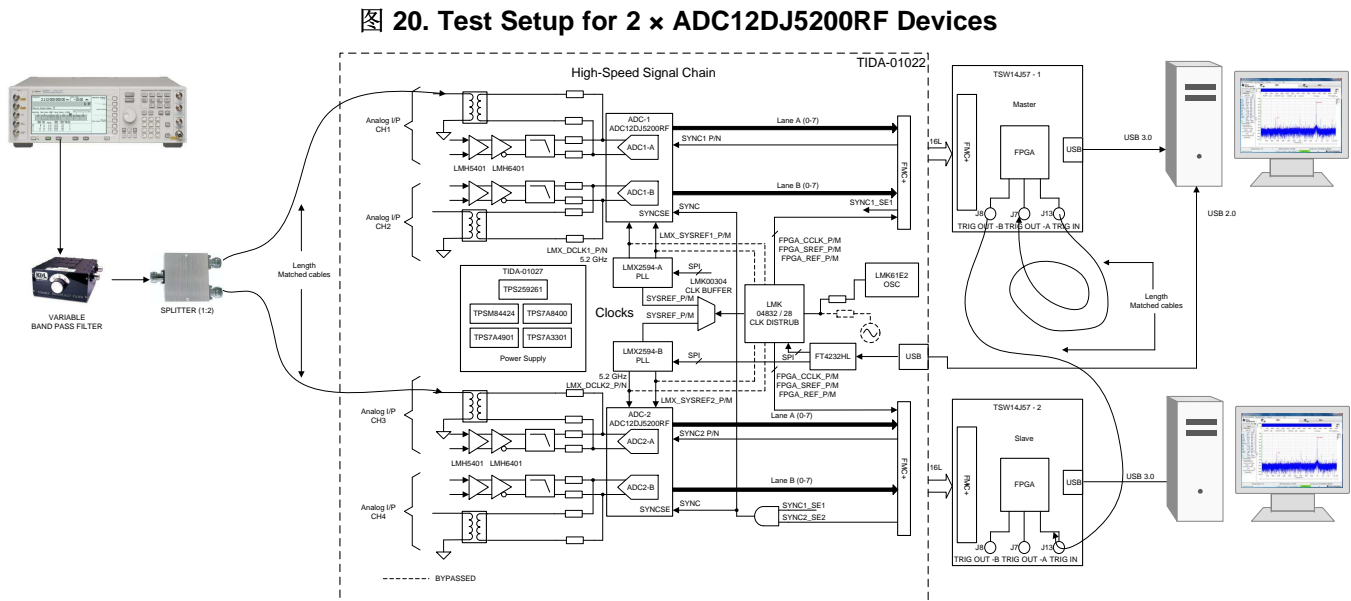
For more information on the TSW14J57 EVM, see the [TSW14J57 JESD204B High-Speed Data Capture and Pattern Generator Card User's Guide](#).

3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Hardware Setup

图 20 shows the test setup for onboard time interleaving using the TIDA-01022 reference design with transformer input.

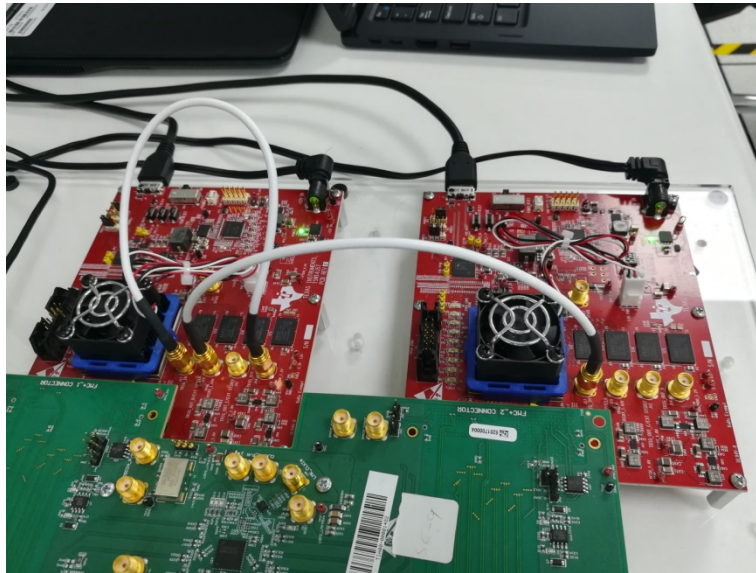


3.2.1.2 Master Slave Trigger Capture

The output data from the ADC is captured using the TSW14J57 capture card since TIDA-01028 has 2 × ADC12DJ5200RF devices, 2 × TSW14J57 devices are needed for capture. To enable synchronous capture, these two TSW14J57 devices can be configured as master and slave mode then enable the software trigger in HSDC Pro GUI software.

- 图 21 shows the TSW14J57 master slave trigger connection.
- Connect master TSW14J57, J7(TRIG OUT –A) to J13 (TRIG IN) using a high-speed SMA cable for master self-triggering
- Connect the master TSW14J57, J8 (TRIG OUT-B) to J13 (TRIG IN) of the slave TSW14J57 module using a high-speed SMA cable.

图 21. Master Slave Trigger Connection



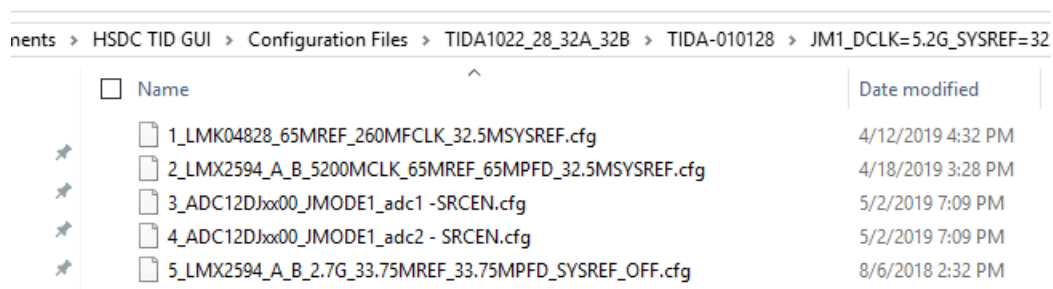
注: 图 21 illustrates that the length of cable must be length matched

3.2.2 Onboard Interleaving Measurement

3.2.2.1 Configure Hardware Using HSDC TID and HSDC Pro GUI:

1. Use the J32 connector to program the LMK61E2 device at 65 MHz using the USB2ANY programmer associated with the LMK61E2 oscillator programming tool. Set the device address as 0x5A before programming.
2. Load the following configuration file in the LMK04828, LMX2594 and ADC12DJ5200RF using the HSDC TID GUI as 图 22 shows. This generates 5.2-GHz DEVCLK and SYSREF 32.5 MHz for both ADC1 and ADC2. It also generates the FPGA reference at 260 MHz, the FPGA core clock at 260 MHz, and the FPGA SYSREF at 32.5 MHz for the FPGA capture card.

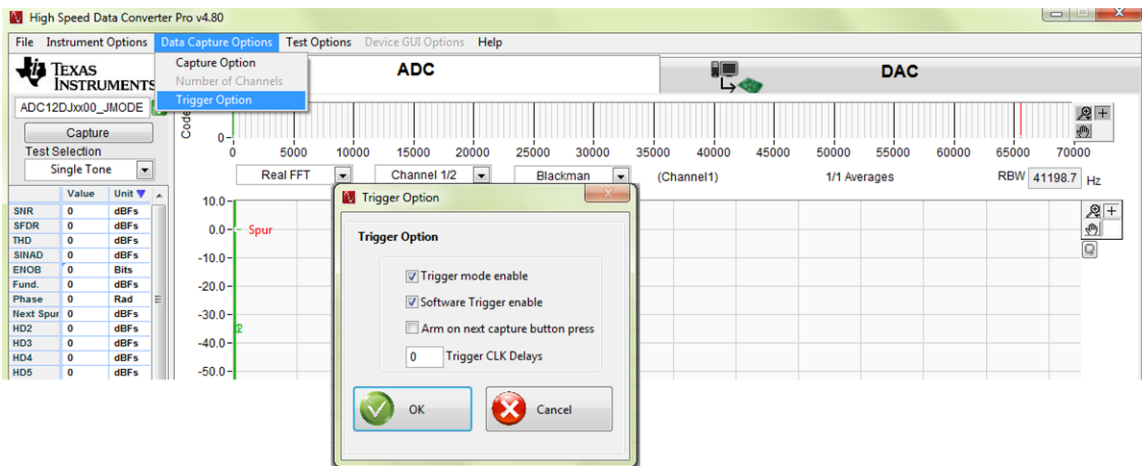
图 22. Device Configuration File Loading



3. Configure both ADC12DJ5200RF devices to JMODE1 (single-channel mode) by loading the configuration file in the low level page of HSDC Pro GUI in the following order for both master and slave capture card.
 - a. Master capture card:
 - i. After powering up the TSW14J57 mater capture card, establish the hardware connection.
 - ii. Load “ADC12DJxx00_JMODE1_trig_sysref.ini” from the select ADC drop-down menu and then update ADC Output Data Rate as 10.4 GHz
 - iii. Read capture and see the ADC1 spectrum

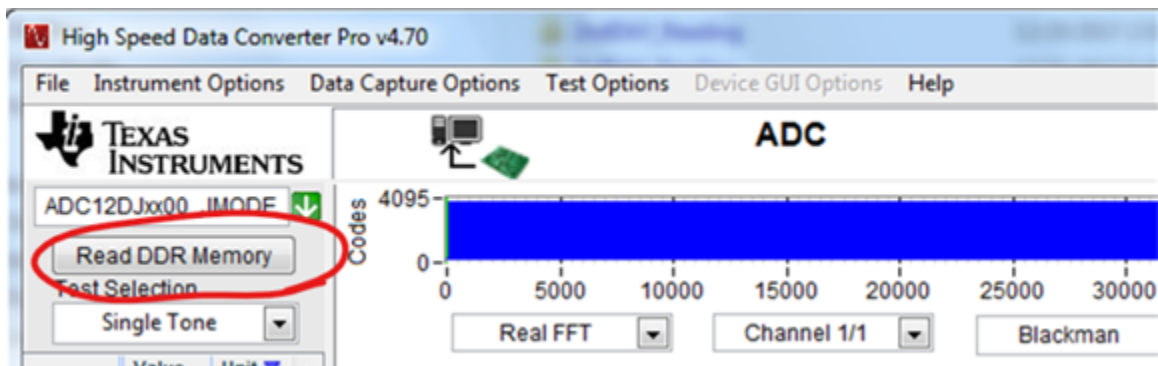
- b. Slave capture card:
 - i. Power on the TSW14J57 slave capture card then establish the connection with hardware similar to the master card.
 - ii. Load “ADC12DJxx00_JMODE1_trig_sysref.ini” from the select ADC drop-down menu then update ADC Output Data Rate as 10.4 GHz
 - iii. Read capture and see the ADC2 spectrum
 - iv. Load “ADC12DJxx00_JMODE1_trig_sysref_skipeconfig.ini” from the select ADC drop-down menu
 - v. Select *Trigger Option* from the *Data Capture Options* menu., In the *Trigger Option* selection menu item; select only *Trigger mode enable*:

图 23. Trigger Option Selection: Trigger mode enable



- vi. After enabling the trigger, the *Capture* button becomes *Read DDR Memory* (see 图 24):

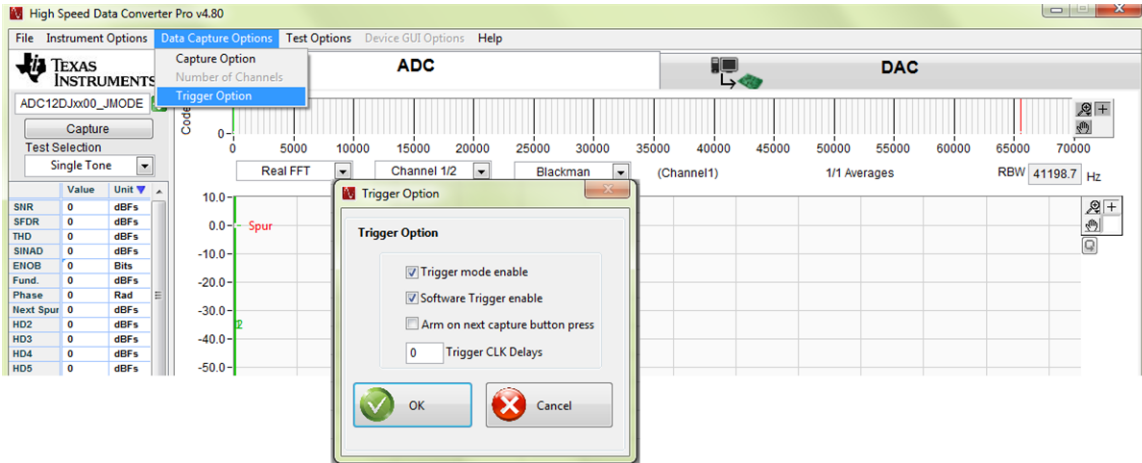
图 24. HSDC Pro Slave Capture Read: Read DDR Memory



c. Master capture card:

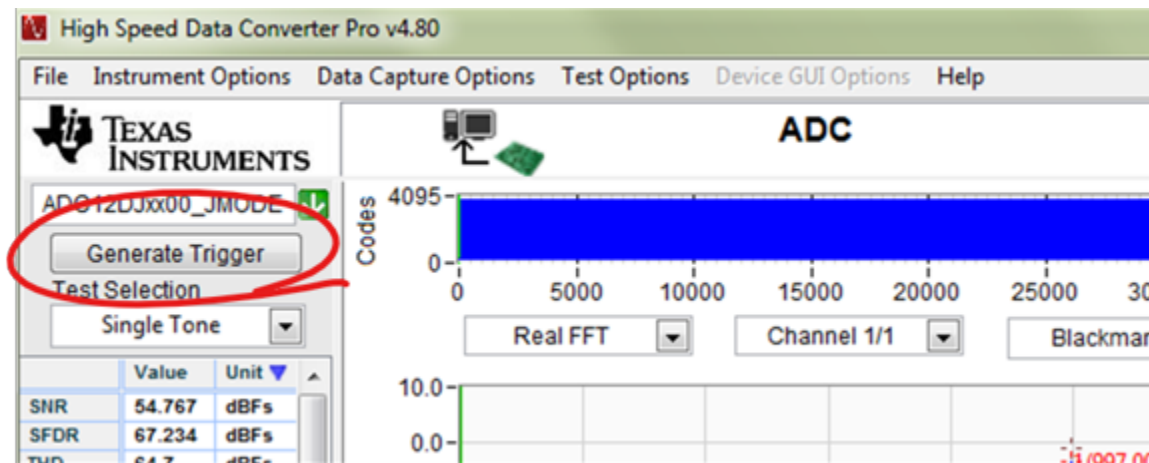
- i. Select *Trigger Option* from the *Data Capture Options* menu. In the selection menu item, enable both the *Trigger mode enable* and *Software Trigger enable* options:

图 25. Trigger Option Selection: 'Trigger mode enable' and 'Software Trigger enable'



- ii. After enabling the triggers, the *Capture* button becomes *Generate Trigger* (see 图 26):

图 26. HSDC Pro Slave Capture Read: Generate Trigger



3.2.2.2 Interleave Capture

1. Feed the input signal frequency 997 MHz, -1 dBFS to channel 1 (J12) and channel 3(J29) from the signal source via splitter.
2. “Read DDR memory” from the slave capture card, make sure the slave is ready for trigger input for capture.
3. Apply “Generate Trigger” from the master capture card, this captures data from both ADCs.
4. Export both ADC1 and ADC2 data, then extract the phase information from the spectrum using the MATLAB® program and plot the data in the time domain for a channel-to-channel skew measurement.
5. Adjust MASHSEED of the LMZ2594 device or the t_{AD} adjust register values to make channel-to-channel skew as 48.07 ps for 90° phase clock shift between CH1 and CH3.
6. After establishing a 90° phase shift, combine both ADC1 and ADC2 data to form interleaved data for a 20.8-GSPS sample rate.

3.2.3 Test Results

In this reference design, interleaving performance is measured with $F_s = 20.8$ GSPS, $F_{in} = 300$ MHz to 6 GHz input signal frequency. 图 27 and 图 28 show the measured spectrum of the TIDA-010128 design at a 997-MHz input, 10.4-GSPS sample rate of ADC1 and ADC2 with 90 degree time-interval sampling.

图 27. ADC1 Spectrum 10.4 GSPS

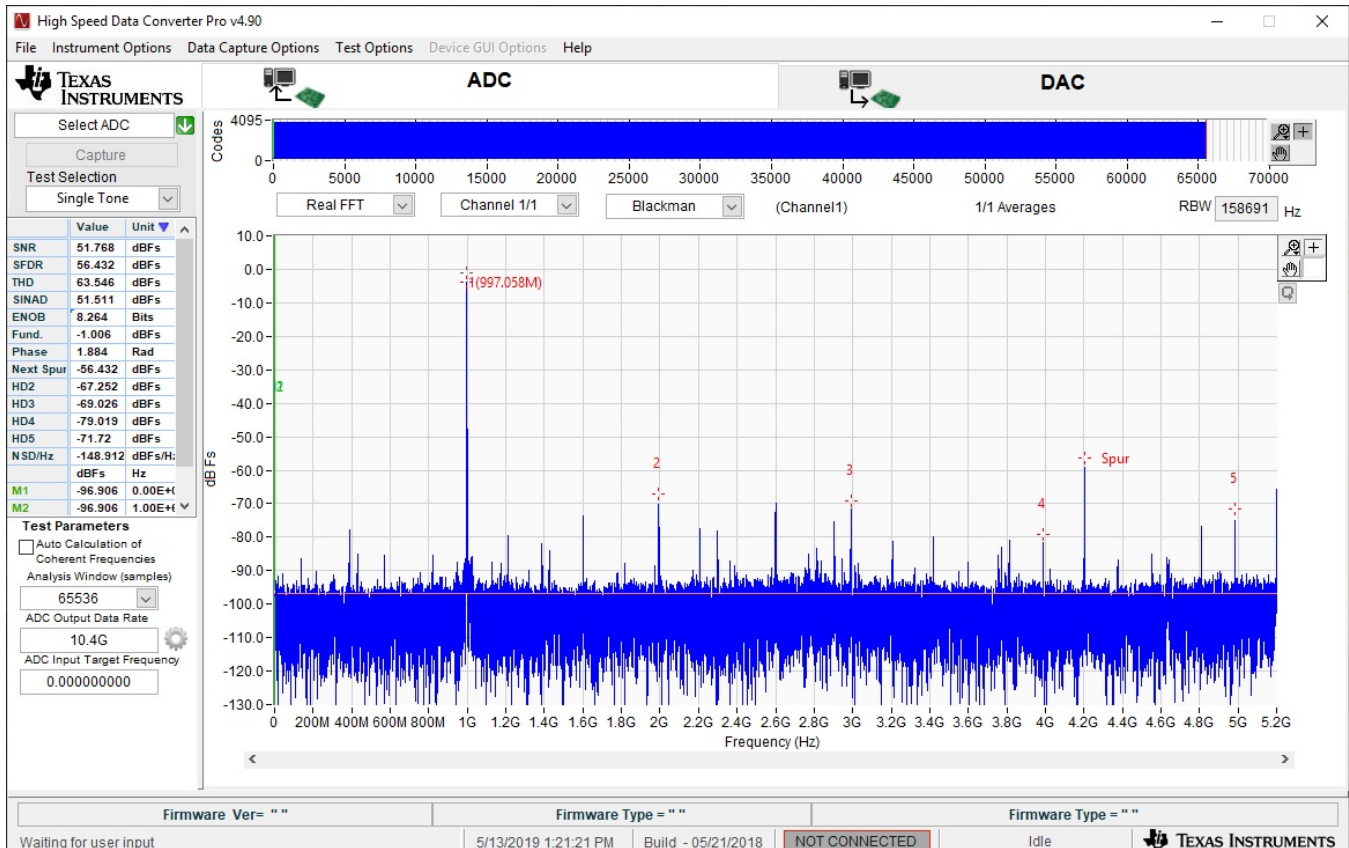


图 28. ADC2 Spectrum 10.4 GSPS

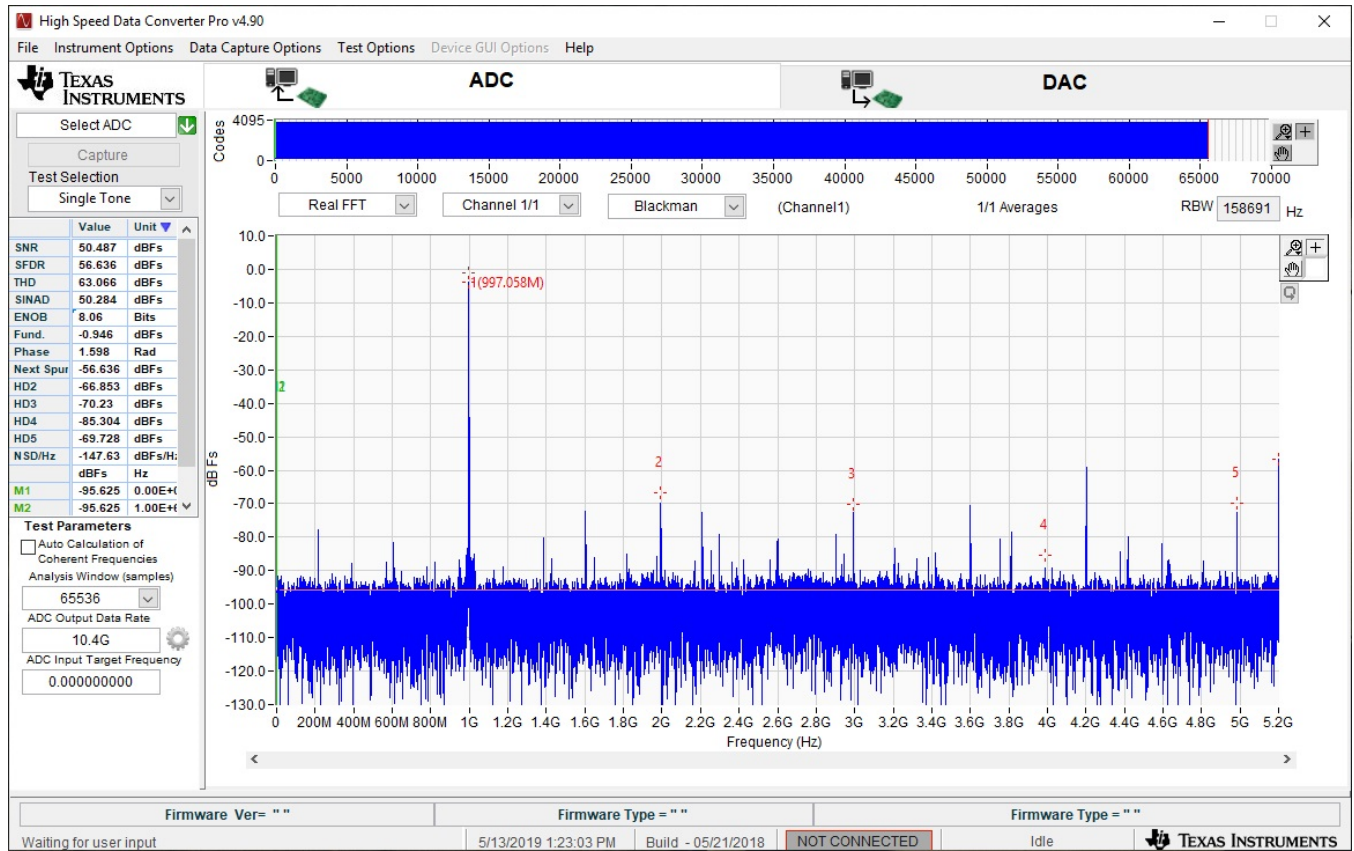


图 29 和 图 30 显示 20.8 GSPS 有和没有 I_L 杂音的结果谱。图 29 显示 interleave spur 在位置 $FS/2$, $FS/4$, $FS/2-FIN$, $FS/4-FIN$, 和 $FS/4+FIN$ 与采样时钟 $F_s = 20.8$ GHz 对于输入信号 $F_{in} = 997$ MHz。

图 29. $F_{in} = 977$ MHz, 20.8 GSPS Interleave Spectrum With IL Spur

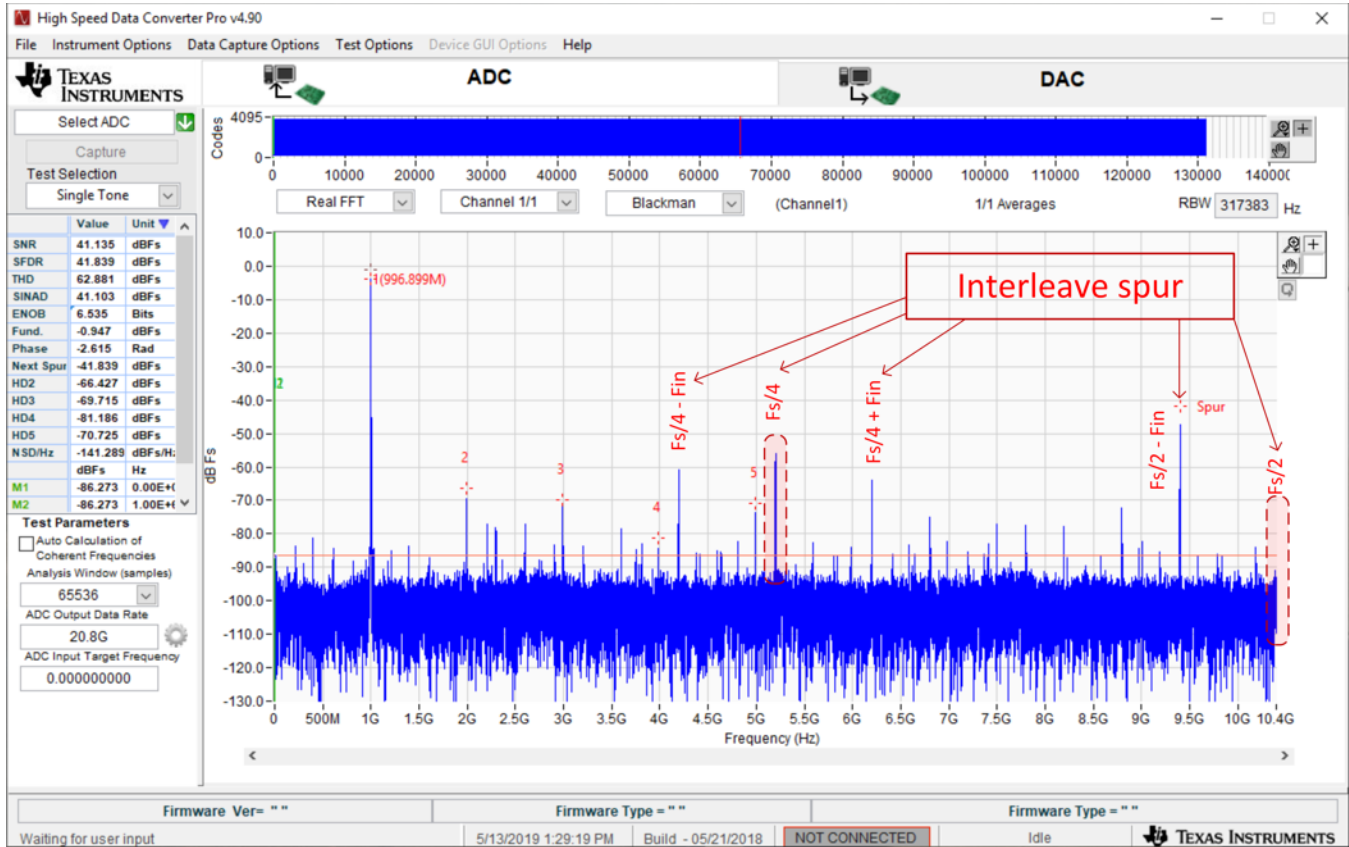
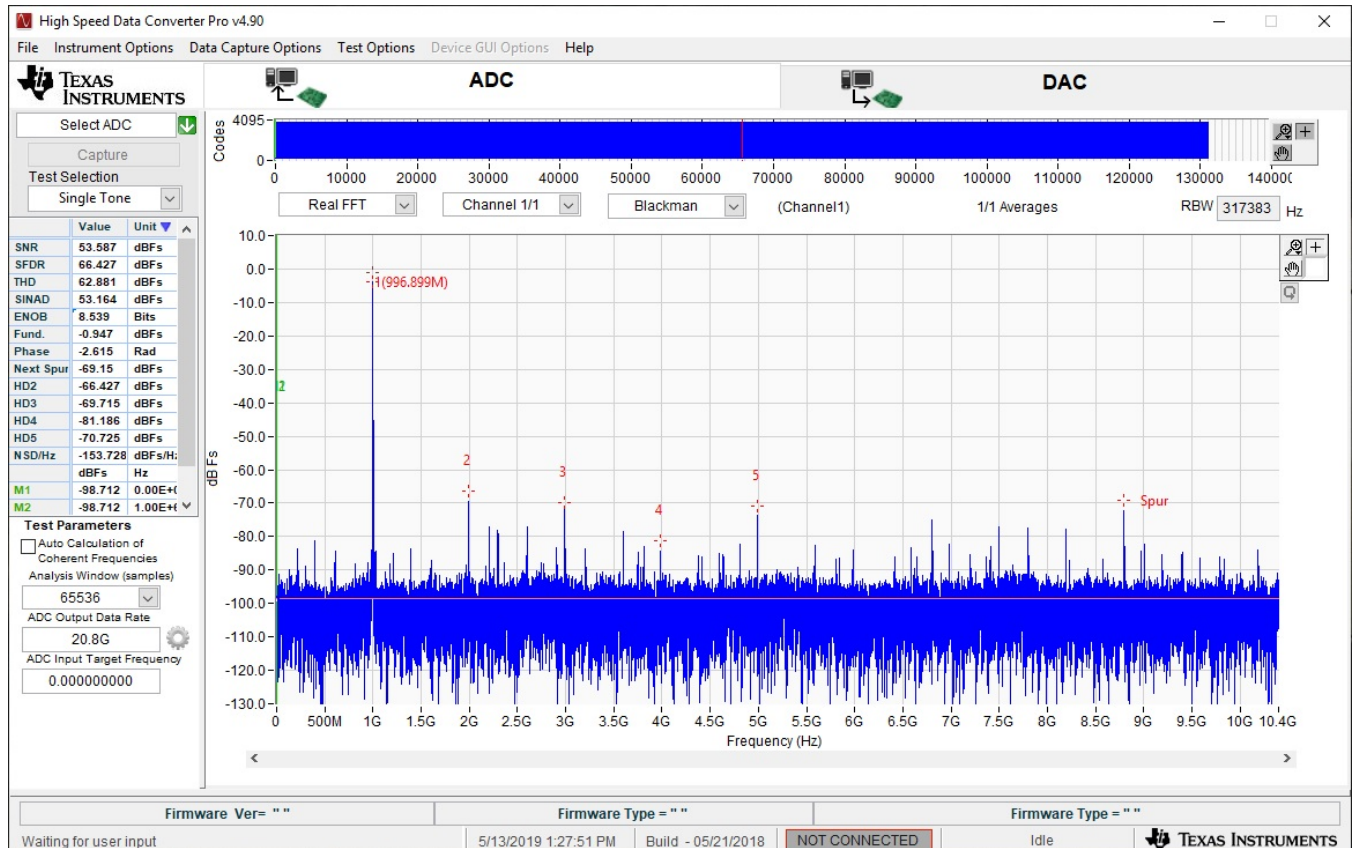


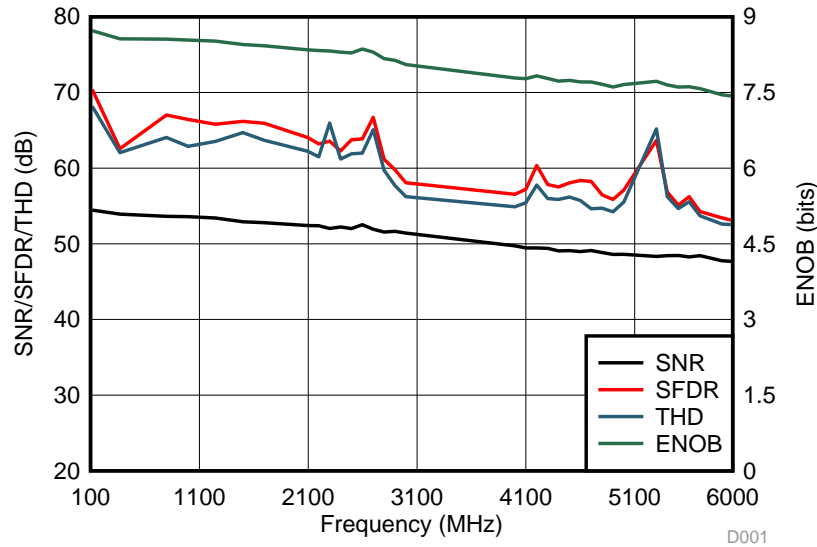
图 30. FIN = 997 MHz, 20.8 GSPS Interleave Spectrum Without IL Spur



The *Interleave Design Challenges* section of the [12.8-GSPS Analog Front End Reference Design for High-Speed Oscilloscope and Wide-Band Digitizer Design Guide](#) discusses more on interleave spur and its effects. Even when the input signal chain path and clock sample timing are closely matched, there will always be some mismatch in the system. This will vary due to temperature and process variations which can be reduced with the help of an on-line calibration process.

图 31 shows the 20.8 GSPS interleaved plots for input signal frequencies from 100 MHz to 6 GHz without I_L spurs. Interleaving spurs will reduce if the gain, offset, and time skew are matched.

图 31. 20.8 GSPS Interleave Plot vs Input Frequency Without I_L Spur



In summary, the TIDA-010128 is a 20.8-GSPS interleaved reference design with an onboard high-performance clock and power solution that can be used for high-speed DSO and wideband digitizer applications where higher sampling rate and wider instantaneous bandwidth is required. This reference design demonstrates the ADC12DJ5200RF interleaving features to achieve a 20.8-GSPS sample rate with usable bandwidth greater than 6 GHz with ENOB better than 7.5 bits, excluding interleaving spurs.

This reference design demonstrates the t_{AD} adjust feature of the ADC12DJ5200RF device that eases interleaving at 20.8 GSPS. The reference design also demonstrates a low-noise multichannel JESD204B clock generator based on the LMK04828 and LMX2594 devices that help designers to achieve low phase noise, high-frequency clock up to 15 GHz for time interleaved sampling applications.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-010128](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-010128](#).

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-010128](#).

4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-010128](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-010128](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-010128](#).

5 Related Documentation

5.1 Related Reference Designs

1. Texas Instruments, [12.8-GSPS analog front end reference design for high-speed oscilloscope and wide-band digitizer \(TIDA-01028\)](#)
2. Texas Instruments, [Flexible 3.2 GSPS multi-channel AFE reference design for DSOs, RADAR, and 5G wireless test systems \(TIDA-01022\)](#)
3. Texas Instruments, [50-Ohm 2-GHz oscilloscope front-end reference design \(TIDA-00826\)](#)
4. Texas Instruments, [Multi-channel JESD204B 15 GHz clocking reference design for DSO, Radar and 5G wireless testers \(TIDA-01021\)](#)
5. Texas Instruments, [High speed multi-channel ADC clock reference design for oscilloscopes, wireless testers and Radars \(TIDA-01017\)](#)

5.2 Summary of Related Reference Designs

表 7 details of similar and associated reference designs.

表 7. Summary of Related Reference Designs

REFERENCE DESIGN NUMBER	MAXIMUM CLOCK FREQUENCY (GHz)	PHASE NOISE AT MAX FREQUENCY (dBc/Hz)	CLOCK SKEW (ps)	# OF CHANNELS DEMONSTRATED [THEORETICAL MAXIMUM]	SAMPLING RATE (GSPS)	SNR @ 1 GHz (dB)	SFDR (dBc)	MAXIMUM BANDWIDTH (GHz)	DESCRIPTION, FOCUS
TIDA-010128	15.0	-105.9	-	2[4]	20.8	53.5	66.4	8.0	20.8 GSPS AFE with Interleaved ADCs (ADC12DJ5200RF)
TIDA-01028	15.0	-105.9	-	2[4]	12.8	55.0	63.5	8.0	12.8 GSPS AFE with Interleaved ADCs (ADC12DJ3200)
TIDA-00626	10.0	-107.1	-	1	-	-	-	-	9.8 GHz RF CW Signal Generator
TIDA-01016	6.0	-114.0	-	1	3.0	60.0	-	3.2	Clocking Reference Design for ADC32RF45 (RF Sampling ADC)
TIDA-01021	15.0	-105.9	9.2	2[6]	2.7	55.7	68.8	8.0	Clocking and Synchronization of Multiple JESD204B ADCs
TIDA-01023	15.0	-105.9	8.0	2[42]	3.0	55.5	68.8	8.0	[Tree Structure] Clocking and Synchronization of JESD204B ADCs
TIDA-01024	15.0	-105.9	2.0	2[18]	3.0	55.4	69.1	8.0	[Daisy Chain] Clocking and Synchronization of JESD204B ADCs
TIDA-01022	15.0	-105.9	1.0	4	3.2	55.5	71.3	8.0	Quad Channel 3.2 GSPS Digitizer System (Integrating ADC, Clocking and Power)
TIDA-010122	15.0	-105.9	10.0	2[4]	1.4	60.5	70.1	8.0	Synchronizing Data Converter DDC and NCO Features
TIDA-01027	Power design for optimal ENOB in high-speed DAQ								

5.3 Other Related Documents

1. Texas Instruments, [Interleaving ADCs for Higher Sample Rates Technical White Paper](#)
2. Texas Instruments, [Maximizing SFDR Performance in the GSPS ADC: Spur Sources and Methods of Mitigation Application Report](#)
3. Texas Instruments, [Defining Skew, Propagation-Delay, Phase Offset \(Phase Error\) Application Report](#)

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7 Acknowledgment

The authors would like to thank their colleagues Bryan Bloodworth, Taras Dudar, Victor Salomon, Jason Clark and Matthew Guibord for their unconditional support and critical feedback during the development of this design and design guide review.

Appendix A

Example MATLAB program for analyzing skew:

```

%-----%
% Import Data %
%-----%
function varargout = SkewCheck_v5(varargin)
close all;

global N;
global samples_all;
global ax;
global num_bits;
global Fs;
global Fin;

global Decimation;
global popupA;
global popupB;

% Declare variables for imported data
data1 = xlsread('read_csv1.csv');
data2 = xlsread('read_csv2.csv');

Fs = 2700e6;
Fin = 997e6;
Fnco = 0;
Decimation = 1;
N = length(data1);
num_bits = 15;

%Removing DC in all the channels
samples_board_1 = data1;
samples_board_1 = samples_board_1 - repmat(mean(samples_board_1),size(samples_board_1,1),1);

samples_board_2 = data2;
samples_board_2 = samples_board_2 - repmat(mean(samples_board_2),size(samples_board_2,1),1);

samples_all = [samples_board_1 samples_board_2];

fig=figure('Units', 'normalized', 'Position',[0.1,0.1,0.5,0.8]);
set(0, 'CurrentFigure', fig);

for i = 1:size(samples_board_1,2)
    waveDataSrc{i} = sprintf('File1_Ch%d',i);
end

for k = 1:size(samples_board_2,2)
    waveDataSrc{size(samples_board_1,2)+k} = sprintf('File2_Ch%d',k);
end

popupA = uicontrol('Style', 'popup', 'Units', 'normalized',...
    'String', waveDataSrc,...
    'Position', [0.76,0.935, 0.2, 0.05],...
    'Tag', 'PUA1', 'Callback', @setmap);

popupB = uicontrol('Style', 'popup', 'Units', 'normalized',...
    'String', waveDataSrc,...
    'Position', [0.76,0.905, 0.2, 0.05],...
    'Tag', 'PUB1', 'Callback', @setmap);

ax(1) = axes('DataAspectRatioMode', 'auto', 'PlotBoxAspectRatioMode', 'auto',
    'CameraViewAngleMode', 'auto',...
    'Units', 'normalized', 'Position', [0.06+0,0.06+0.48*1,0.9,0.38]);
    
```

```
ax(2) = axes('DataAspectRatioMode', 'auto', 'PlotBoxAspectRatioMode', 'auto',
'CameraViewAngleMode', 'auto',...
'Units', 'normalized', 'Position', [0.06+0,0.06+0.48*0,0.9,0.38]);
```

```
PlotData(1, 1)
```

```
CalcSkewData
```

```
end
```

```
function PlotData(PUPA, PUPB)
global samples_all;
global ax;
global N;
global num_bits;
global Fs;
global Fin;

global Decimation;

Fsd = Fs/Decimation;

global popupA;
global popupB;

popupAStr = get(popupA, 'String');
popupBStr = get(popupB, 'String');

samples_board_1 = samples_all(:,PUPA);
samples_board_2 = samples_all(:,PUPB);

subplot(ax(1));
% Get FFT of for each board.
window = blackman(N);
X=fftshift(fft(window.*samples_board_2));
Y=fftshift(fft(window.*samples_board_1));
X = X(N/2:end);
Y = Y(N/2:end);
A = 2^(num_bits-1);

% Find the bin with the largest amplitude. This is the sine wave.
[mag_x index_x] = max(abs(X));
[mag_y index_y] = max(abs(Y));

%magitude correction
samples_board_1 = samples_board_1 * (mag_x/mag_y);

plot((0:length(samples_board_1)-1)*(1/Fsd),samples_board_1,...
((0:length(samples_board_2)-1)*(1/Fsd))-(0/(2*Fsd)),samples_board_2);
str_trace1 = sprintf('%s',popupAStr{PUPA});
str_trace2 = sprintf('%s',popupBStr{PUPB});
leg = legend(str_trace1, str_trace2);
set(leg, 'Interpreter', 'none');
title('Time Domain Plot');
```

```
% Get FFT of for each board.
window = blackman(N);
X=fftshift(fft(window.*samples_board_2));
Y=fftshift(fft(window.*samples_board_1));
X = X(N/2:end);
Y = Y(N/2:end);
A = 2^(num_bits-1);
```

```

% Find the bin with the largest amplitude. This is the sine wave.
[mag_x index_x] = max(abs(X));
[mag_y index_y] = max(abs(Y));

subplot(ax(2));
plot((0:N/2)*(Fsd/N), 20*log10(abs(X*2/N/A)), (0:N/2)*(Fsd/N), 20*log10(abs(Y*2/N/A)));
title('FFT Plot of ADC 1');

fprintf('\nIndex_x:%d; Index_y:%d\n',index_x, index_y);

% Get the phase of each signal at the appropriate bin.
phase_x = angle(X(index_x));
phase_y = angle(Y(index_x));

% Calculate the phase difference and time skew.
phase_diff = phase_y - phase_x;
phase_diff = mod(phase_diff, 2*pi);
%phase_diff_deg = mod(phase_diff / pi * 180, 360);
boardstring = '';
if phase_diff > pi
    boardstring = 'Brd1 Lags Brd2';
    phase_diff = 2*pi-phase_diff;
else
    boardstring = 'Brd2 Lags Brd1';
    phase_diff = phase_diff;
end

phase_diff_deg = phase_diff / pi * 180;

skew_ps = phase_diff_deg / (360*Fin) / 1e-12;

abc_title1 = sprintf('%s by %3.3f deg or %3.3f ps', boardstring, phase_diff_deg, skew_ps);
subplot(ax(1));
title(abc_title1);

abc_title2 = sprintf('Fin = %3.3f MHz', Fin*1e-6);
subplot(ax(2));
title(abc_title2);
end

function skewdata=CalcSkewData()
global samples_all;
global N;
global num_bits;
global Fs;
global Fin;

global Decimation;

Fsd = Fs/Decimation;

for row = 1:size(samples_all,2)
    for col = 1:size(samples_all,2)
        samples_board_1 = samples_all(:,row);
        samples_board_2 = samples_all(:,col);

        % Get FFT of for each board.
        window = blackman(N);
        X=fftshift(fft(window.*samples_board_2));
        Y=fftshift(fft(window.*samples_board_1));
        X = X(N/2:end);
        Y = Y(N/2:end);
        A = 2^(num_bits-1);
    end
end

```

```

% Find the bin with the largest amplitude. This is the sine wave.
[mag_x index_x] = max(abs(X));
[mag_y index_y] = max(abs(Y));

%magitude correction
samples_board_1 = samples_board_1 * (mag_x/mag_y);

% Get FFT of for each board.
window = blackman(N);
X=fftshift(fft(window.*samples_board_2));
Y=fftshift(fft(window.*samples_board_1));
X = X(N/2:end);
Y = Y(N/2:end);
A = 2^(num_bits-1);

% Find the bin with the largest amplitude. This is the sine wave.
[mag_x index_x] = max(abs(X));
[mag_y index_y] = max(abs(Y));

% Get the phase of each signal at the appropriate bin.
phase_x = angle(X(index_x));
phase_y = angle(Y(index_x));

% Calculate the phase difference and time skew.
phase_diff = phase_y - phase_x;

phase_diff_deg = phase_diff / pi * 180;

skew_ps = phase_diff_deg / (360*Fin) / 1e-12;

abc_title = sprintf('%3.3f°/%3.3fps', phase_diff_deg, skew_ps);
skewdata{row,col}=abc_title;
end
end

f = figure;
t =uitable(f,'Data',skewdata, 'Units', 'Normalized', 'Position',[0, 0, 1, 1],
'ColumnWidth',{150});

end

function setmap(source,callbackdata)
global popupA;
global popupB;

PlotData(get(popupA, 'Value'), get(popupB, 'Value'));
end

```

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