

设计指南: TIDA-010122

可同步适用于多通道射频系统的数据转换器 DDC 和 NCO 特性的参考设计



说明

由于 5G 的兴起, 大规模多输入多输出 (mMIMO)、相控阵雷达和通信有效载荷等应用 需要调整, 由此产生了同步设计难题, 此参考设计针对此类难题提供了解决方案。典型射频前端包括模拟域中的天线、低噪声放大器 (LNA)、混合器、本机振荡器 (LO), 以及数字域中的模数转换器、数字控制振荡器 (NCO) 和数字下变频器 (DDC)。要实现总体系统同步, 这些数字块需要与系统时钟进行同步。此参考设计使用 ADC12DJ3200 数据转换器, 通过将片上 NCO 与 SYNC~ 进行同步获得确定性延迟, 以此在多个接收器上获得小于 5ps 的通道间偏移, 并使用无噪声孔径延迟调节 (t_{AD} 调节) 功能来进一步减少偏移。

资源

[TIDA-010122](#)、[TIDA-01027](#)

[ADC12DJ3200](#)、[TPS259261](#)

[LMK04828](#)、[LMX2594](#)、[LMK61E2](#)

[LMH6401](#)、[LMH5401](#)

[TSW14J57EVM](#)

设计文件夹

产品文件夹

产品文件夹

产品文件夹

工具文件夹



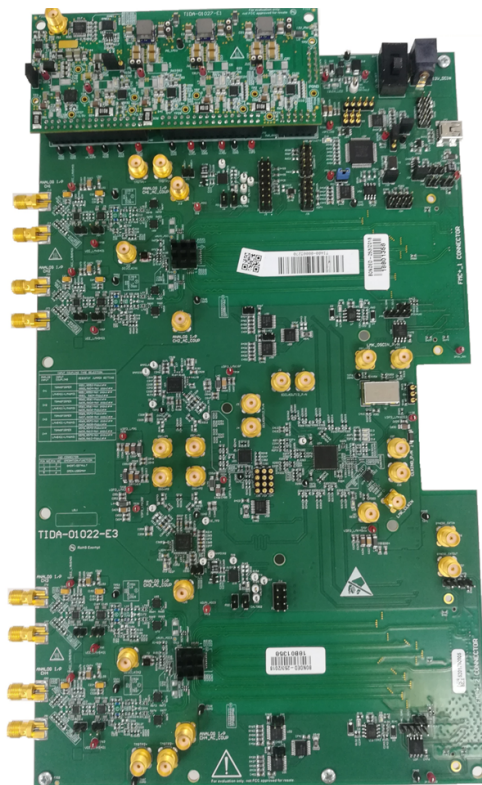
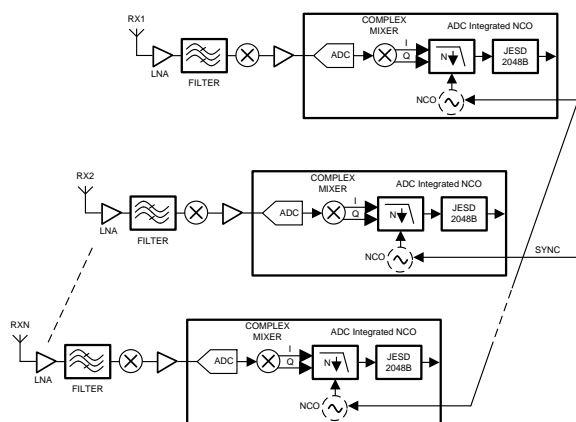
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特性

- 4 通道、3.2GSPS、6GHz 高速模拟前端
- 片上 NCO 同步允许使用 SYNC~ 在多个 ADC 间进行同步
- 符合 JESD204B 标准的多通道时钟
- 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
- 输入电压为 12V 时, 配套电源参考设计的效率高于 85%
- 包括理论、计算、组件选择、PCB 设计和测量结果

应用

- 雷达
- 通信有效载荷
- 无线通信测试设备
- 矢量信号收发器 (VST)、矢量信号分析器 (VSA) 和矢量信号生成器 (VSG)



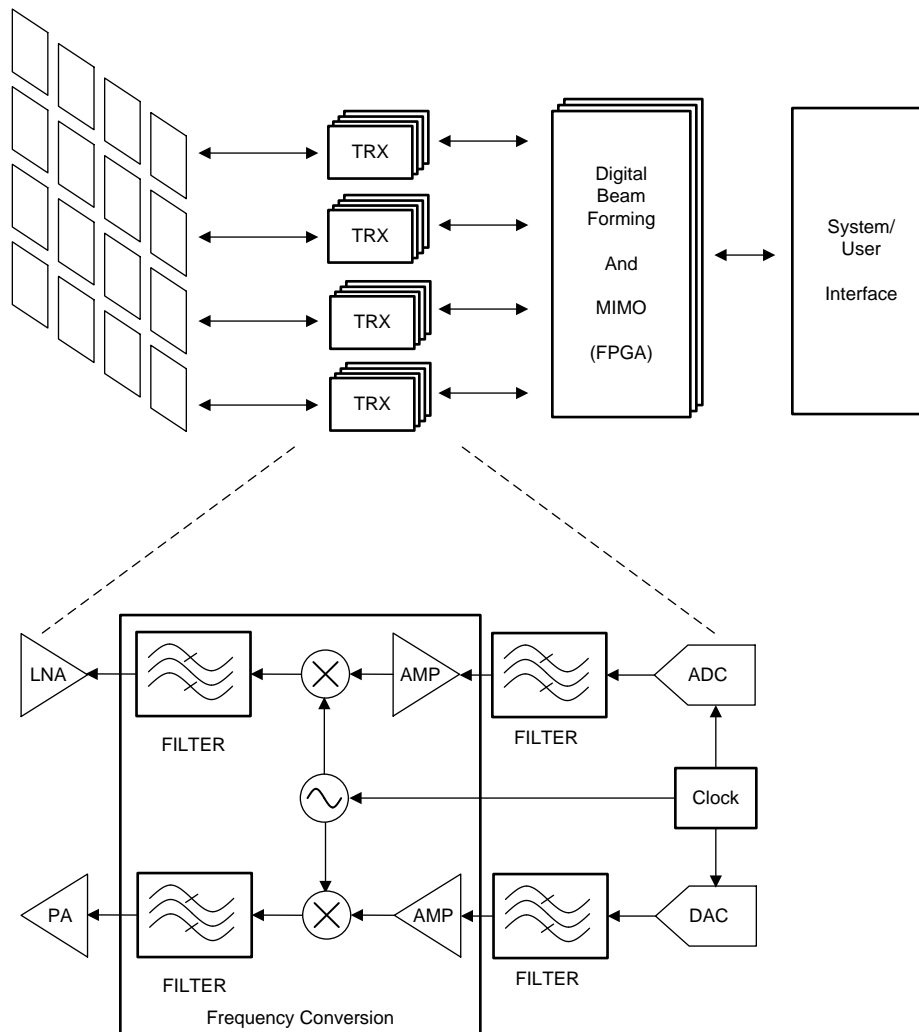


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1 System Description

Emerging network communication systems like 5G technology (5G NR), WLAN 802.11ax standards use massive Multiple input multiple output (MIMO), digital beam forming which improves network throughput by spectral efficiency to cover large users. This is achieved by many parallel transmissions using spatially placed antennas instead of a single antenna transmission. Signal directivity increases with more antennas with same the transmit power; therefore, users get a strong signal and less leakage in the other direction.

图 1. Typical 5G System Block Diagram



Similarly RADAR, electronic warfare, satellite communication payloads require large numbers of transceivers (transmit and receive signal chain) in their applications.

These high-performance multi-channel receivers require a signal chain with wide bandwidth, high dynamic range, high sample rate, low channel-to-channel skew with deterministic latency.

This reference focuses on the most critical design challenges in receiver synchronization across multiple channels with deterministic latency.

1.1 Key System Specifications

表 1 lists the key system level specifications for the TIDA-010122 board.

表 1. Key System Specifications

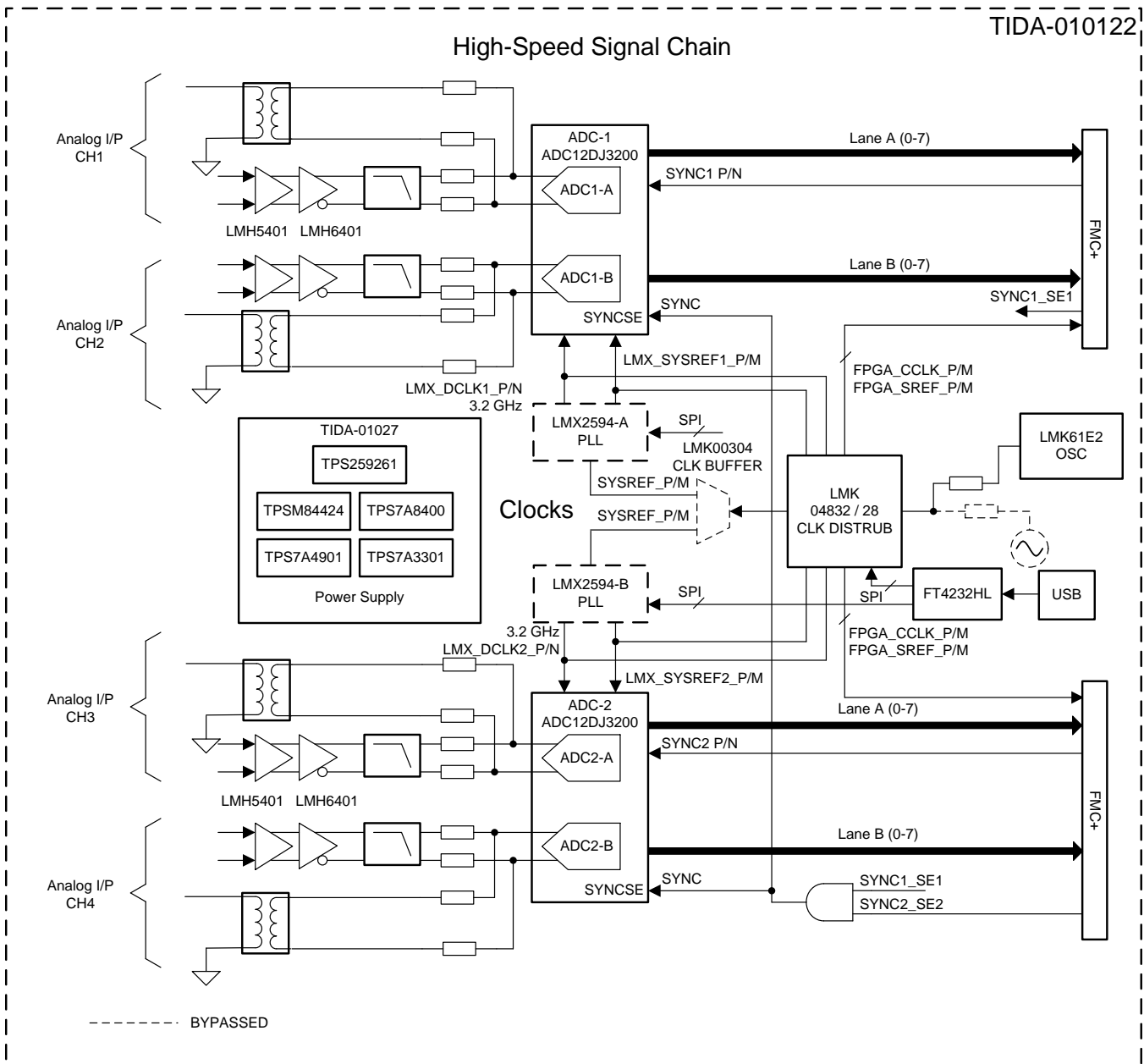
PARAMETER	SPECIFICATIONS			DETAILS
Input channels	4			
Input type	Single ended, differential ended			
Input analog bandwidth(−3 dB)	3.2 GSPS / Channel			
Resolution	12 bit			
Decimation mode	16 × decimation (JMODE15/16), 15 bit - complex data			
System performance (−7 dB FS) $F_S = 1480$ MHz, $F_{NCO} = 1270$ MHz and $F_{IN} = 1250$ MHz	SNR	SFDR	THD	图 35
	60.56	70.13	89.48	
Channel-to-channel skew	< 5 ps			
Connector	560 Pin FMC+ interface connector Supports TSW14J57 high-speed capture card			
Power	12-V DC, 4 A			TIDA-01027
Form factor (L × W)	295 mm × 176 mm			

2 System Overview

2.1 Block Diagram

图 2 展示了 TIDA-010122 设计的系统级块图，该设计是使用来自灵活的 3.2 GSPS 多通道 AFE 参考设计用于 DSOs、RADAR 和 5G 无线测试系统 (TIDA-01022) 以及用于最大化信号链 ENOB 的功率参考设计 (TIDA-01027) 在非常高速的 DAQ 系统中 (TIDA-01027)。

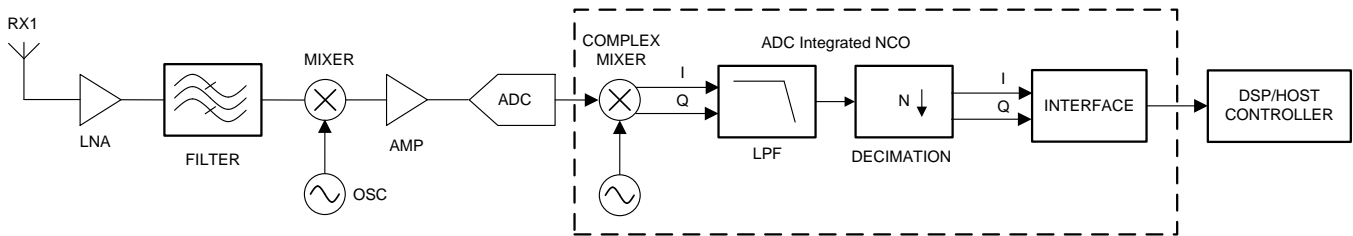
图 2. TIDA-010122 System Block Diagram



2.2 Design Considerations

In traditional RF front end architecture, at the receiver the high-frequency radio wave from the antenna are down-converted to intermediate (IF) or baseband frequency using a mixer and local oscillator (LO) and this baseband signal further down converted to lower data rate with optional stages then digitized using baseband or low-speed data converter and transmitter to DSP or FPGA for further processing. This is called traditional IF sampling, 图 3 shows the block diagram of traditional IF sampling architecture.

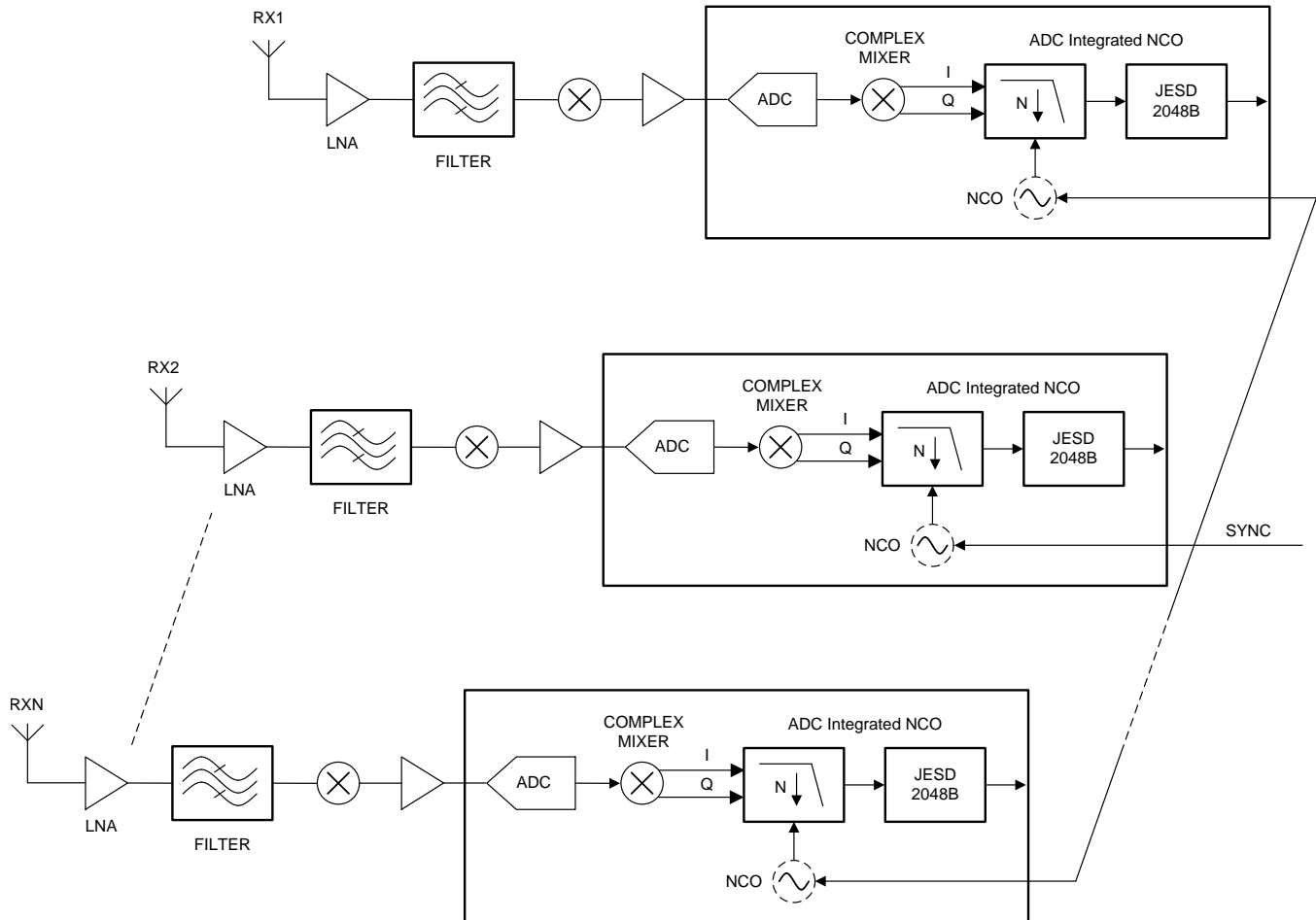
图 3. Generic RF Receiver Signal Chain



2.2.1 Design Challenges

The number of channel counts are increasing to improve system performance like receiver bandwidth, sensitivity and channel capacity in wireless networks that use massive MIMO architecture and similar applications such as phase array RADARs get the phase information across multiple receivers to identify targets in cluttered environments with better resolution. 图 4 shows a typical multi-channel RF receiver signal chain block diagram.

图 4. Typical Multi-Channel RF Receiver Signal Chain



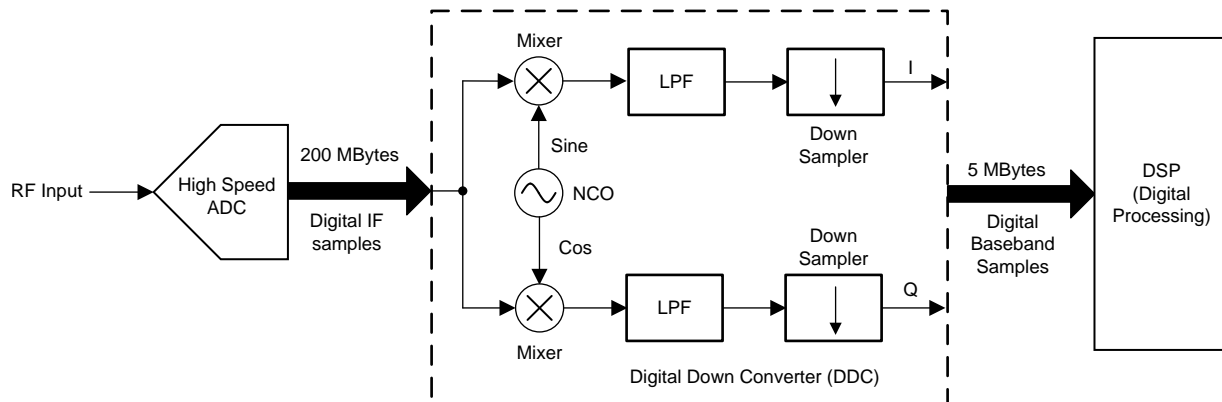
However, in multi-chip synchronization in sampled systems, it is crucial that samples from multiple receivers are aligned exactly with each other. Even a single clock cycle misalignment cannot be tolerated. Synchronization of multiple receivers requires timing calibration, careful routing, and a detailed timing analysis to ensure that the propagation delay across different analog-to-digital converters (ADCs) does not result in channel-to-channel skew that is greater than one clock cycle.

Considering RF signals lying in the frequency range from 300 MHz to 12 GHz supports UHF (300–1000 MHz), L band (1–2 GHz), S band (2–4 GHz), C band (4–8 GHz) and X band (8–12 GHz). In radio systems, receivers typically have high-speed ADC to digitize the band-limited RF or IF signals and these are very high data rates; but in many cases the signal interest is a very small bandwidth; typically in the MHz range and requires a large filter to extract the information.

Digital down conversion (DDC) is a fundamental block in many communication systems which allows the frequency of interest to move down to the spectrum. Therefore, the sample rate, filter requirements and further digital processing complexities are greatly reduced.

图 5 shows the overview of DDC in RF systems

图 5. DDC Functional Block



Due to applications needs, digital down conversions are done at the RF front end (analog domain) or after digitization in FPGA or DSP processors (digital domain), or a combination of both approaches. These digital features are built into new RF ADCs which further reduces system complexity, software flexibility to choose decimation, NCO frequency, and footprint.

However, overall system synchronization can be achieved with entire signal chains like RF front end, data converter, mixer and NCO which are aligned with the system clock.

This reference design focuses on how to achieve system synchronization in the ADC12DJ3200 JESD204B-based RF ADC and how on chip NCO features allow multi-device synchronization across data converters to achieve deterministic latency.

Furthermore, this reference design addresses critical design challenges to generate precise, low jitter, fast clocking solutions to clock multiple high-speed data converter, mixers, and high-speed FPGA logic devices.

2.3 Circuit Design

This reference design is developed based on the TIDA-01022 hardware platform and its internal circuits satisfy the requirements of JESD204B synchronization standards to achieve deterministic latency.

2.3.1 Multi-Chip Synchronization Requirements - JESD204B Subclass1

The following basic requirements must be met to achieve data convertor synchronization in JESD204B subclass1 based systems:

1. Phase-aligned device clocks for each data converter
2. Meet SYSREF setup *and* hold time requirements relative to the device clock
3. Choose appropriate elastic buffer release point at the receiver to ensure deterministic latency
4. Meet SYNC~ signal timing requirements in time-critical application

2.3.2 Multi-Channel Giga-Sample Clocking

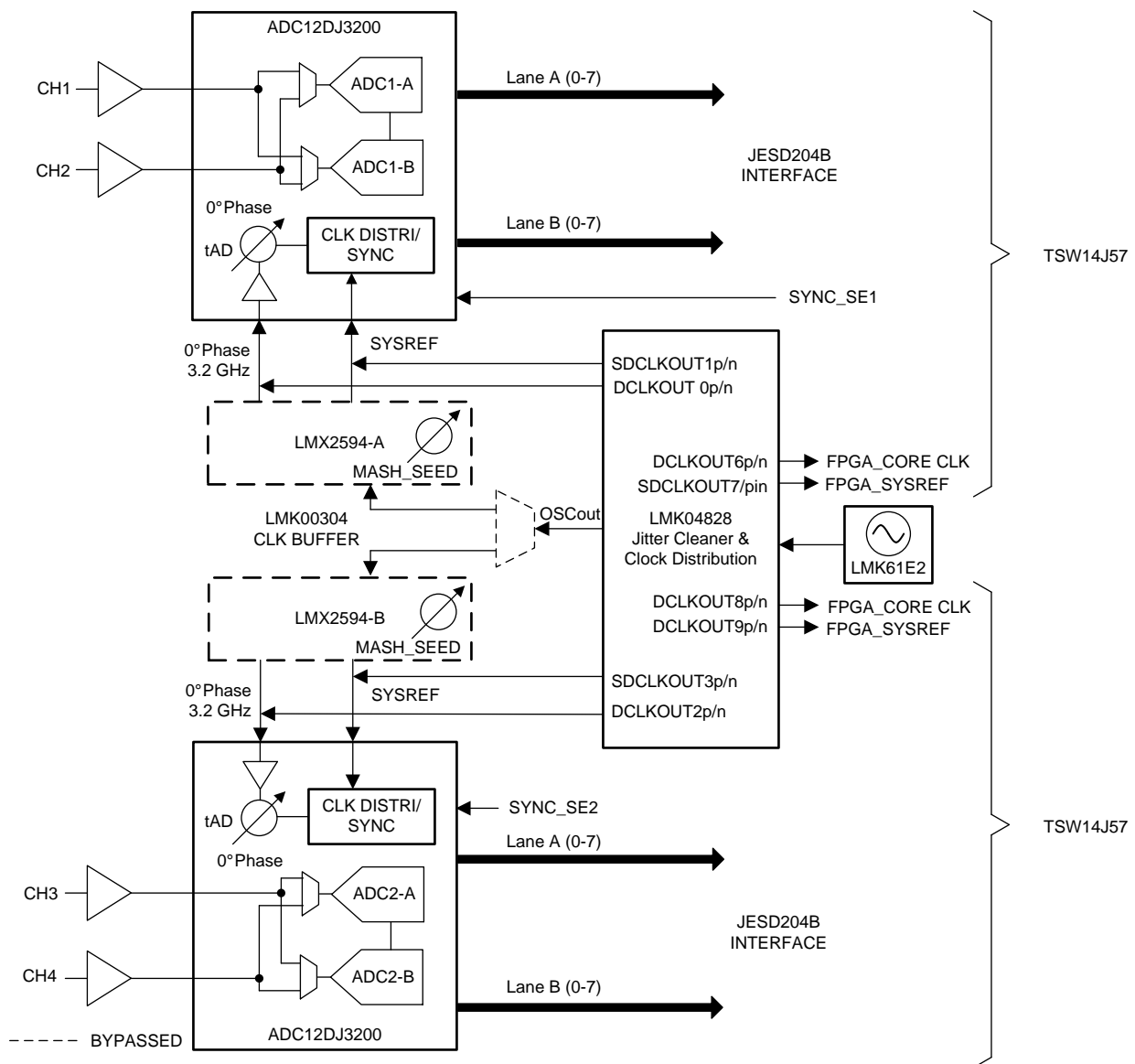
The TIDA-01022 hardware has a flexible clocking platform which helps designers validate system performance with various clocking source options. The default onboard clocking solution uses the LMX2594 clock synthesizer which has excellent phase noise at high frequency. A clock distribution chip called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

The clocking devices LMK4828, LMX2594, and ADC12DJ3200 are fully compliant with JESD204B subclass 1 requirements.

2.3.2.1 Clock Tree Selection - ADC Clock, SYSREF, and FPGA Clock

图 6 shows the clock architecture of the TIDA-010122, the ADC and FPGA clock are generated based on application requirements.

图 6. TIDA-010122 Clock Architecture



In this reference design ADC12DJ3200 operated in decimation mode (JMODE15 and JMODE16).

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

The system performance like channel to channel skew, SNR, SFDR performance validated with following test condition,.

ADC_DEVCLK = 1480 MHz;

ADC_SYSREF = 18.5 MHz

FPGA_CORECLK = 185 MHz

FPGA_REFCLK = 185 MHz

FPGA_SYSREF = 18.5 MHz

SERDES lane rate = 8

The LMK04828 is used to generate ADC device clock, SYSREF and also provides the required FPGA clocks. 表 2 shows the signal definitions and clock output frequency.

表 2. LMK04828 Clock Definition for TIDA-010122

Sino	LMK04828 SIGNALS	FREQUENCY OUTPUT	REMARKS
1	OSCOut p/n	-	Connected to LMX2594 reference input for generation ADC DEVCLK and SYSREF
2	DCLKOUT0 p/n	1480 MHz	Connected to ADC-1 device clock input
3	SDCLKOUT1 p/n	18.5 MHz	Connected to ADC-1 SYSREF input
4	DCLKOUT2 p/n	1480 MHz	Connected to ADC-2 device clock input
5	SDCLKOUT3 p/n	18.5 MHz	Connected to ADC-2 SYSREF input
6	DCLKOUT4 p/n	185 MHz	FPGA_REF CLK, connected slave to capture FPGA
7	SDCLKOUT5 p/n	-	SYNC signal to LMX2594-B
8	DCLKOUT6 p/n	185 MHz	FPGA_CORE CLK, connected slave to capture FPGA
9	SDCLKOUT7 p/n	18.5 MHz	FPGA_SYSREF, connected slave to capture FPGA
10	DCLKOUT8 p/n	185 MHz	FPGA_CORE CLK, connected master to capture FPGA
11	SDCLKOUT9 p/n	18.5 MHz	FPGA_SYSREF, connected master to capture FPGA
12	DCLKOUT10 p/n	185 MHz	FPGA_REF CLK, connected master to capture FPGA
13	SDCLKOUT11 p/n	-	SYNC signal to LMX2594-A
14	DCLKOUT12 p/n	-	Not used
15	SDCLKOUT13 p/n	-	Not used

Once all the clocks are generated, establish NCO synchronization with the following procedure:

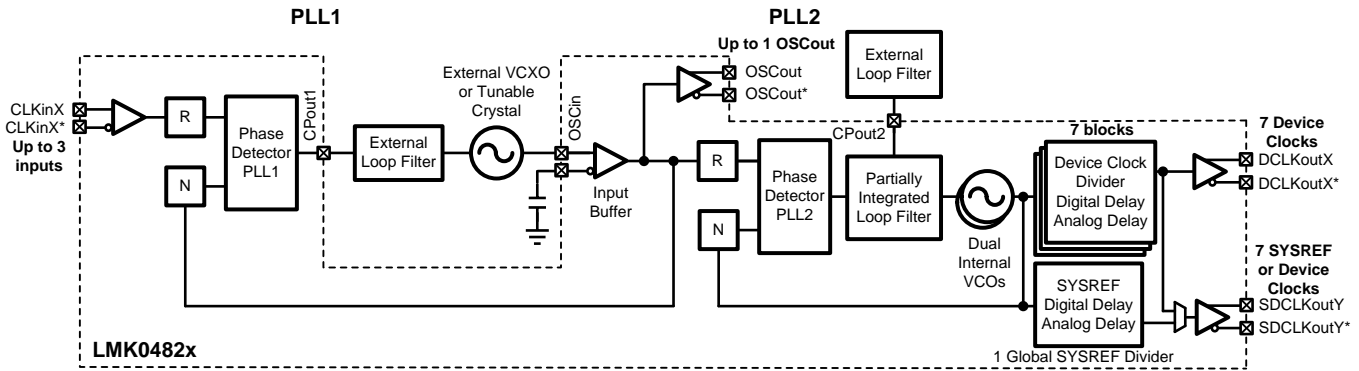
- The TICSPRO GUI helps to create the configuration files for the LMK61E2, LMK04828, and LMX2594 devices.
- Download the latest TICSPRO GUI software at: <http://www.ti.com/tool/TICSPRO-SW>

2.3.3 Clock 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. In this reference design, one clocking option is chosen which satisfies design clocking requirements. This clocking solution provides flexibility to adjust clock delay in two places in the clocking path. This delay can be done on the LMK04828 output, the ADC12DJ3200 device, or a combination of these devices.

The LMK04828 device has both analog and digital delay elements in each clock output. 图 7 shows highlights of the delay elements in the LMK04828 device.

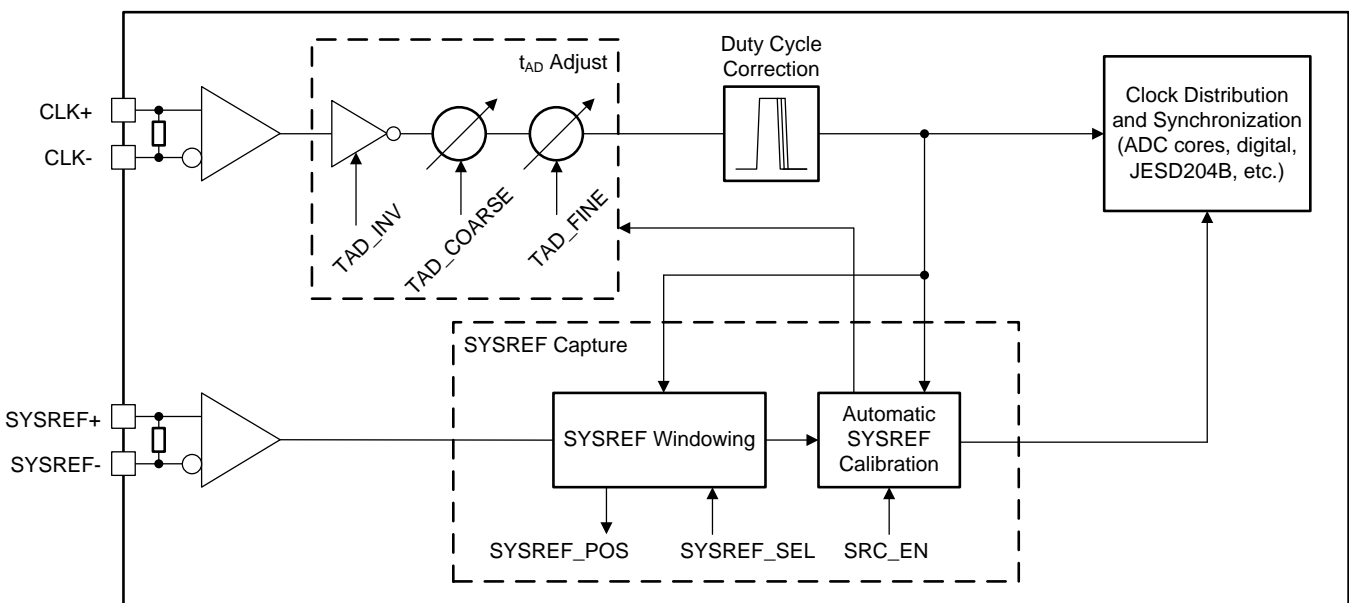
图 7. LMK04828 Simplified Block Diagram



The ADC12DJ3200 has t_{AD} adjust features on the device clock path that can be used to shift the sampling instant in 19-fs steps.

图 8 shows the internal clock subsystem of the ADC12DJ3200 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, $t_{AJ(max)} = 70$ fs, to satisfy the low phase noise requirements.

图 8. ADC12DJ3200 Clocking Subsystem



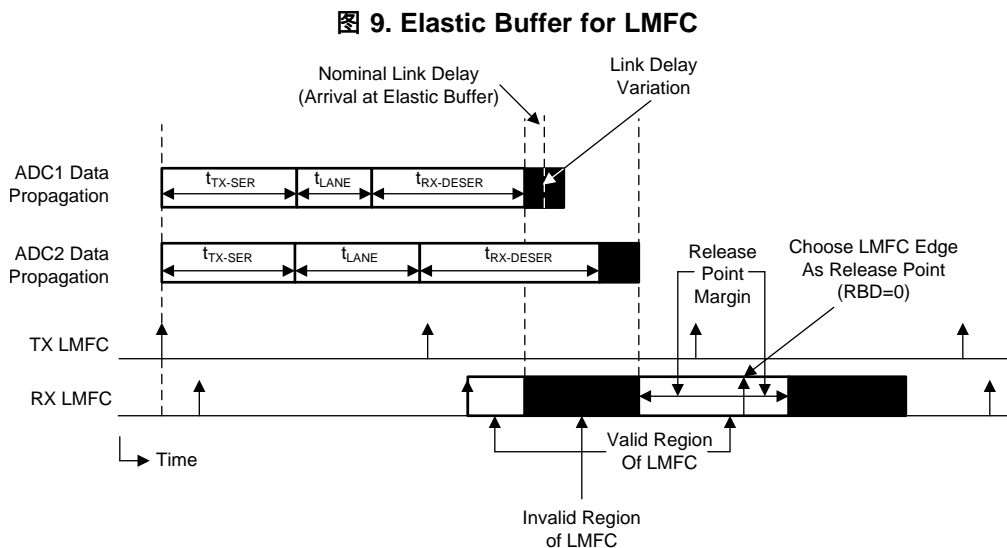
This t_{AD} feature gives the flexibility to adjust t_{AD} registers to align the sampling instants across multiple ADCs with 19-fs resolution.

After SYSREF calibration, the calibrated SYSREF values are loaded to the corresponding t_{AD} register:

1. Enable SYSREF calibration and check for SYSREF calibration done bit in 0x2B4 register
2. Load the SYSREF calibrated values of coarse (0x2B6) and fine(0x2B5) register with corresponding t_{AD} registers 0x2B3,0x2B2 after SYREF calibration is done.
3. Disable SYSREF calibration
4. Fine tune t_{AD} register for 0 deg phase delay between ADC1 and ADC2

2.3.4 Choose Proper Elastic Buffer Release Point

Another important requirement is to choose the appropriate elastic buffer release point at the receiver. Each ADC signal chain may have different propagation delay. 图 9 shows how to define the valid region of LMFC for the elastic buffer release point. Here, two ADCs in the receiver signal chain and the second ADC has a longer routing distance and results in a longer link delay. All the receiver link delays should be same, only then can deterministic latency across ADCs be achieved.



Determine the invalid region of LMFC period, then set the release buffer delay (RBD) parameter to shift the release point with number of frame clock from the LMFC edge so it occur within valid LMFC cycle.

2.3.5 SYNC~ Signal Timing Requirement

Digital features like digital up converters (DUCs) in DACs and digital down converters (DDCs) in ADCs greatly reduce system interface speeds for higher sample rates. These DUCs and DDCs uses numerically-controlled oscillators (NCOs) in the systems and these NCOs must be synchronized in all converters to achieve overall system synchronization.

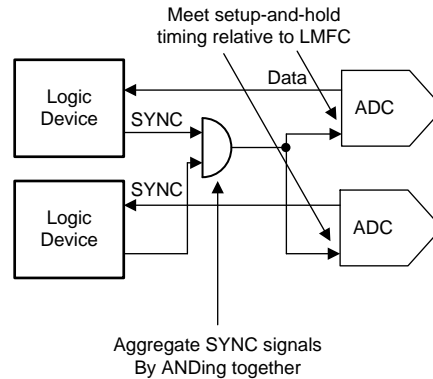
The most common approach is to synchronize the NCOs by using the LMFC rising edge and elastic-buffer release point. In ADCs, the NCOs can be synchronized using the first LMFC edge that occurs after the SYNC signal is de-asserted, which corresponds to the start of the initial lane alignment sequence (ILAS) transmission. In DACs, the typical approach is to synchronize the NCOs when the elastic buffer is released.

There is a timing requirement on the SYNC~ signal to achieve multi-device synchronization across multiple ADCs.

The SYNC~ signal must be de-asserted by all receivers (ADCs) on the same local multi-frame clock (LMFC) edge and received at the transmitter in the same LMFC cycle. This can be done by AND the SYNC signal from all receivers together, then distribute this aggregated signal to each transmitter (ADCs)

图 10 shows the SYNC~ signal implementation method for multiple ADCs.

图 10. Aggregate SYNC~ Generation for Multiple ADCs

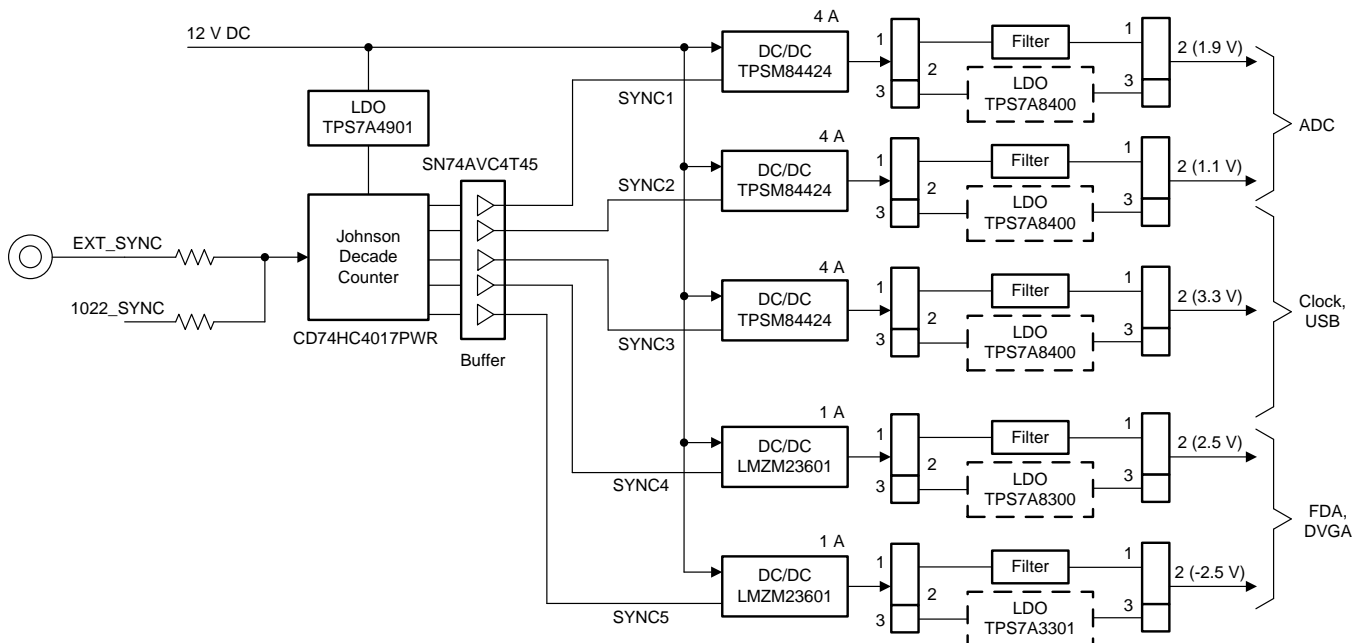


2.3.6 Power

This reference 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 design. 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 11 shows the TIDA-1027 power tree. The module provides 3.3-V, 1.9-V, 1.1-V, 2.5-V, and -2.5-V rails to various analog and digital sections of the TIDA-01022 reference design.

图 11. TIDA-01027 Power Tree



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

2.4 Highlighted Products

2.4.1 ADC12DJ3200: 12-bit, Dual 3.2-GSPS or Single 6.4-GSPS RF Sampling ADC

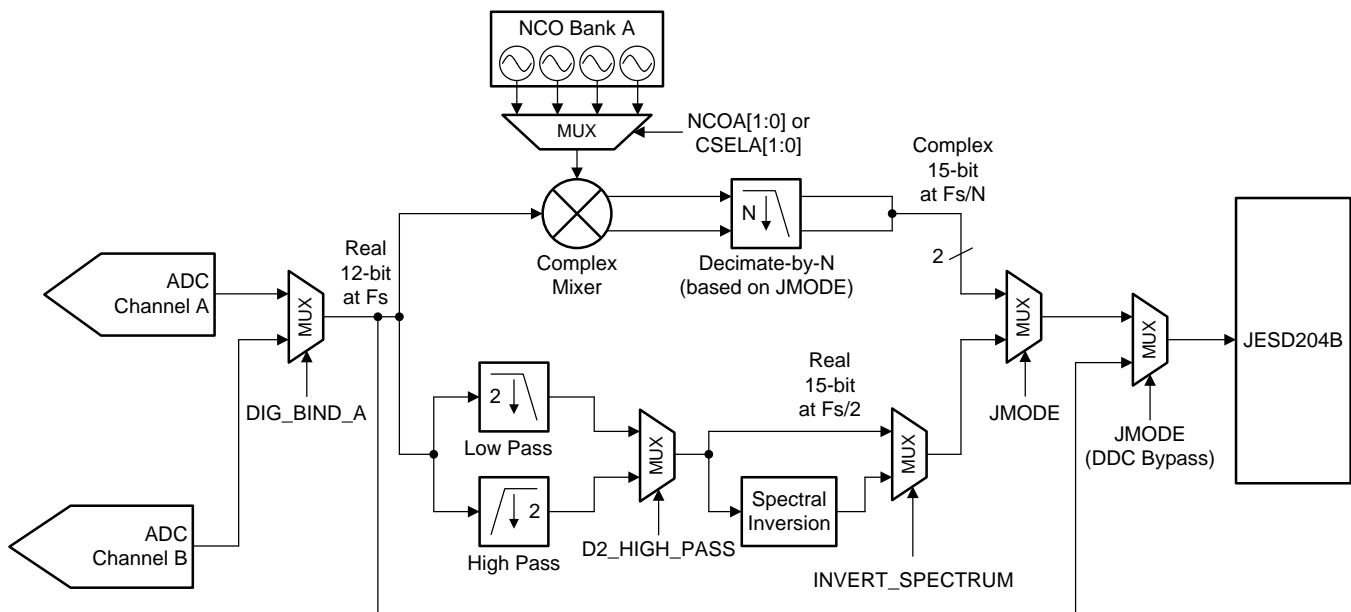
The ADC12DJ3200 device is an RF-sampling giga-sample ADC that can directly sample input frequencies from DC to above 10 GHz. In dual-channel mode, it can sample up to 3200-MSPS and in single channel mode up to 6400-MSPS, full power input bandwidth (−3 dB) of 8.0 GHz, with usable frequencies exceeding the −3-dB point in both dual- and single-channel modes, allows direct RF sampling of the L band, S-band, C-band, and X-band for frequency agile systems.

2.4.1.1 Why Choose the ADC12DJ3200? Key Features

This device offers digital features like digital down conversion (decimation factor 2 x, 4 x, 8 x, and 16 x), four 32-bit numerical controlled oscillators per DDC and complex mixer. The ADC12DJ3200 on-chip NCO synchronization feature allows NCO synchronization across multiple ADCs using SYSREF or the SYNC~ signal.

图 12 shows the DDC block diagram of the ADC12DJ3200 device.

图 12. ADC12DJ3200 Internal DDC Block Diagram



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. 表 3 lists other similar devices which may be considered.

表 3. ADC12DJ3200 - Similar Devices

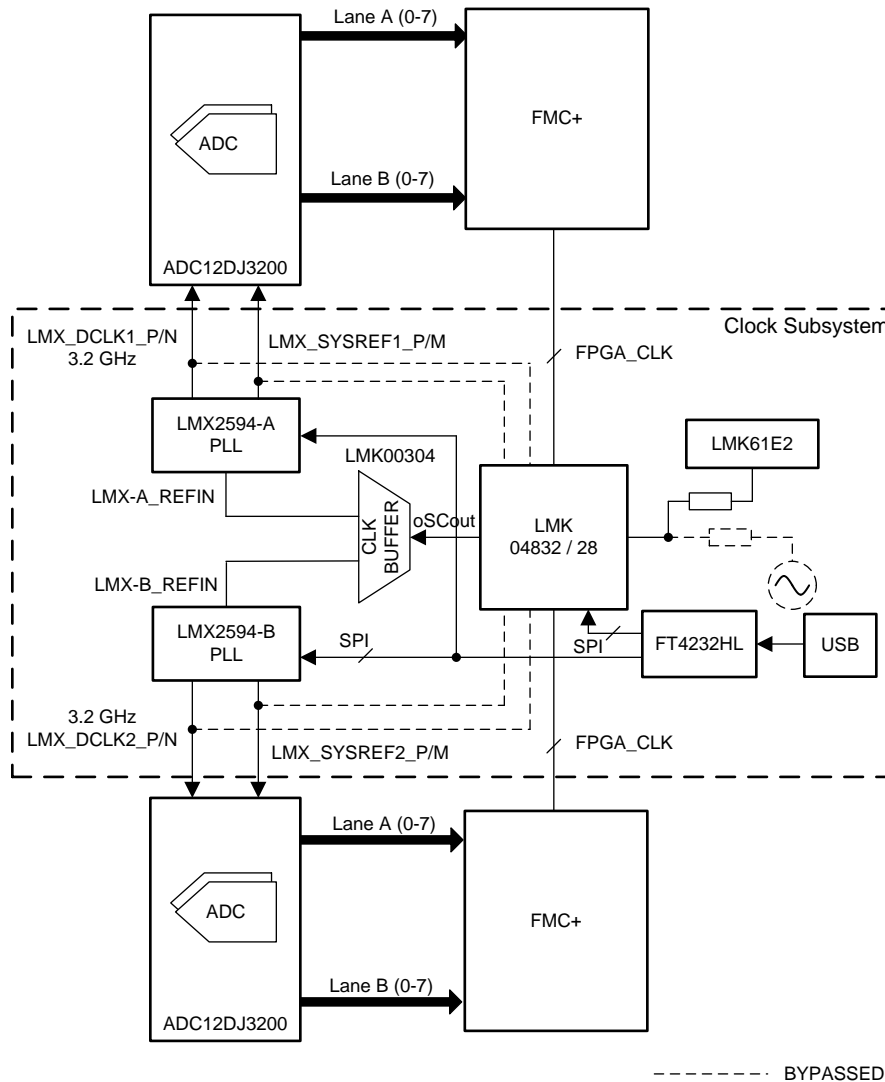
	ADC08DJ3200	ADC12DJ3200	ADC12DJ2700	ADC12J2700	ADC12J1600	ADC12J4000
	Order now	Order now	Order now	Order now	Order now	Order now
	Online datasheet	Online datasheet	Online datasheet	Online datasheet	Online datasheet	Online datasheet
	Datasheet	Datasheet	Datasheet	Datasheet	Datasheet	Datasheet
	Tools & Software	Tools & Software	Tools & Software	Tools & Software	Tools & Software	Tools & Software
Sample rate (Max) (MSPS)	3200	3200	2700	2700	1600	4000
	6400	6400	5400			
Resolution (bits)	8	12	12	12	12	12
Number of input channels	2	2	2	1	1	1
	1	1	1			
Interface	JESD204B	JESD204B	JESD204B	JESD204B	JESD204B	JESD204B
Analog input BW (MHz)	8000	8000	8000	3300	3300	3300
Features	Ultra High Speed	Ultra High Speed	Ultra High Speed	Ultra High Speed	Ultra High Speed	Ultra High Speed
Rating	Catalog	Catalog	Catalog	Catalog	Catalog	Catalog
Input range (Vp-p)	0.8	0.8	0.8	0.725	0.725	0.725
Approx. price (US\$)	896.50 100u	1919.50 100u	1619.50 100u	1024.80 100u	658.20 100u	1949.00 100u
Power consumption (Typ) (mW)	2800	3000	2700	1800	1600	2000
Architecture	Folding Interpolating	Folding Interpolating	Folding Interpolating	Folding Interpolating	Folding Interpolating	Folding Interpolating
SNR (dB)	49.1	56.6	56.7	55	55	55
ENOB (Bits)	7.8	9	9	8.8	8.8	8.8
SFDR (dB)	67	67	71	71	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

2.4.2 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 the analog delay can be adjusted 25-ps fine steps.

图 13 shows by combining both LMK04828 and LMX2594; high-performance, low-noise clocking subsystems are created that drive giga-sample speed data converters with JESD204B support.

图 13. Giga Sample Clocking Solution With LMX2594 + LMK04828



2.4.3 LMX2594; 15-GHz Wideband PLLatinum™ 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 LMX2594 device is an ideal companion part for the ADC12DJxx00 family. The LMX2594 generates a very low noise clock for high-speed data convertor and generates repeating SYSREF which is compliant with the JESD204B standard.

2.4.4 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 is used to provide a reference clock for the LMK04828.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The following hardware components are required to perform the test:

1. 1 × TIDA-01022 hardware
2. 2 × TSW14J57EVM
3. 1 × USB2ANY programmer
4. 1 × Splitter
5. 1 × Variable band pass filter
6. 1 × 6-GHz signal generator
7. 2 × Laptop or desktop PC (Windows 10 OS installed)
8. 1 × 12 V 4 A DC adapter or Lab power supply

3.1.2 TIDA-01022 Hardware Functional Block

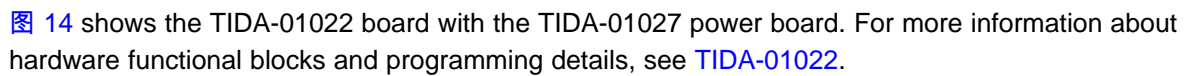
 Figure 14 shows the TIDA-01022 board with the TIDA-01027 power board. For more information about hardware functional blocks and programming details, see [TIDA-01022](#).

图 14. TIDA-01022 Hardware Functional Block

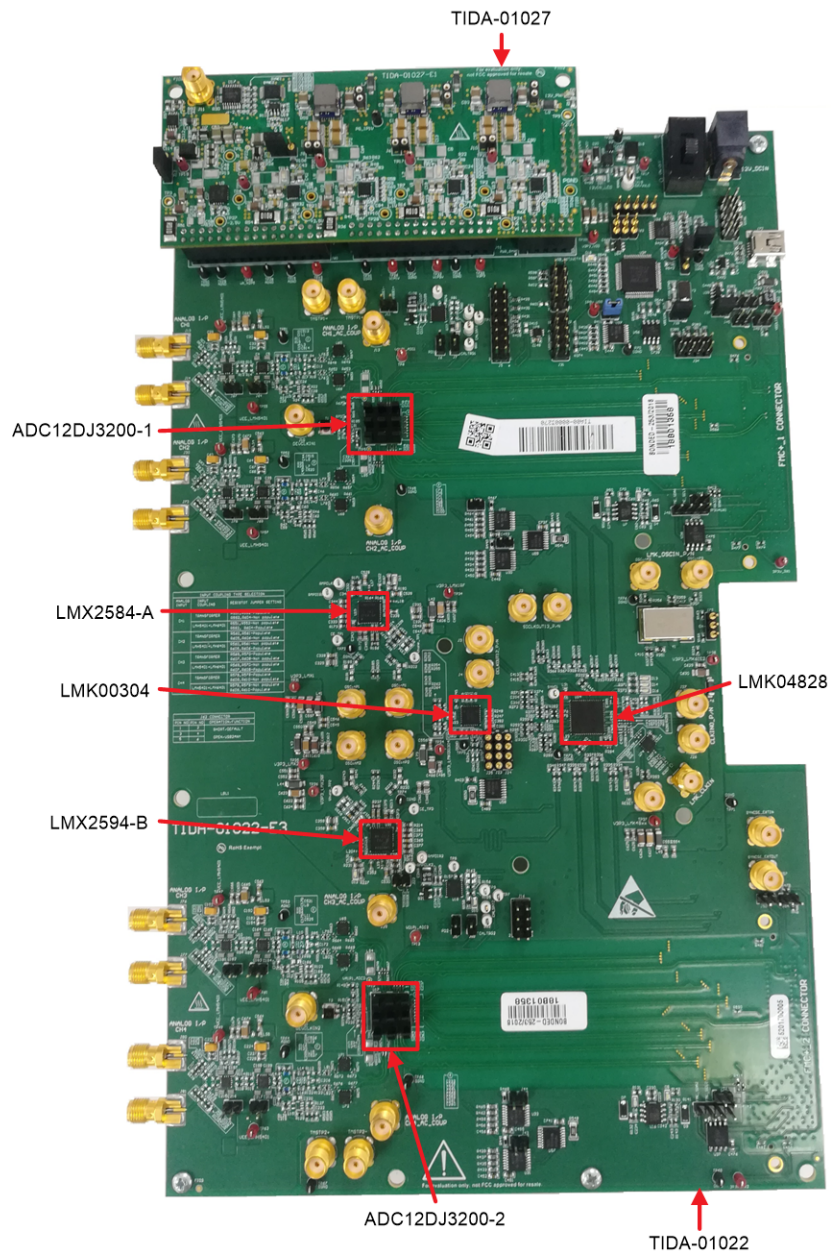


图 15 shows the TIDA-01027 board image, in this reference design the TIDA-01027 board is configured as DC/DC free running mode (default mode). The TIDA-01027 output connectors are made compatible with the TIDA-01022 power input headers J58, J59, J60, and J63.

表 4 shows the input and output specification of the TIDA-01027 power supply module.

表 4. TIDA-01027 Key Specification

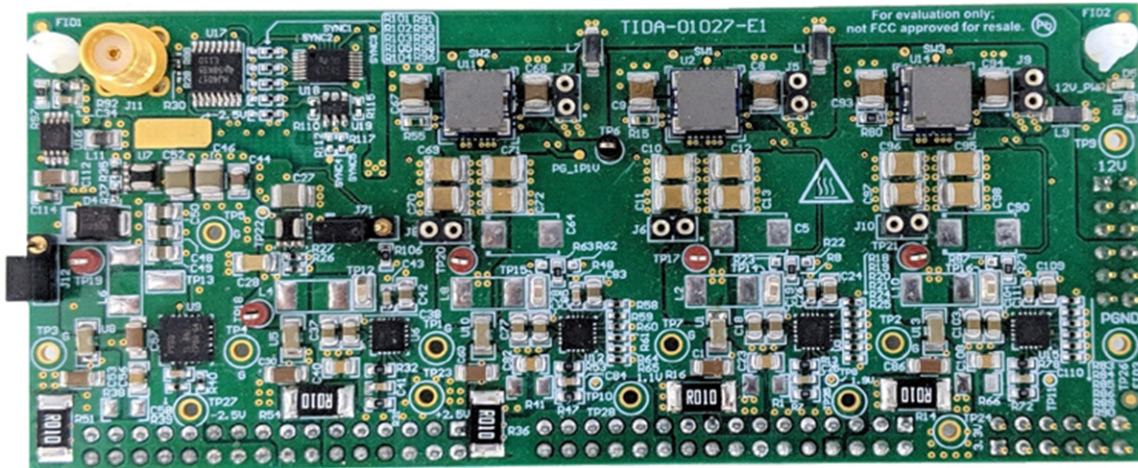
PARAMETER	SPECIFICATION
Input voltage range	5 V to 17 V
Number of outputs	5
Output voltage, maximum output current	1.9 V, 4 A 1.1 V, 4 A 3.3 V, 4 A 2.5 V, 1 A -2.5 V, 800 mA

表 4. TIDA-01027 Key Specification (continued)

PARAMETER	SPECIFICATION
Efficiency	85%

The board can be connected as 图 14 shows.

图 15. 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 16, 图 17, and 图 18 show screen shots of starting the HSDC TID GUI configuration and the Programming tab for the low-level view, respectively.

图 16. HSDC TID GUI – Top-Level Navigation View

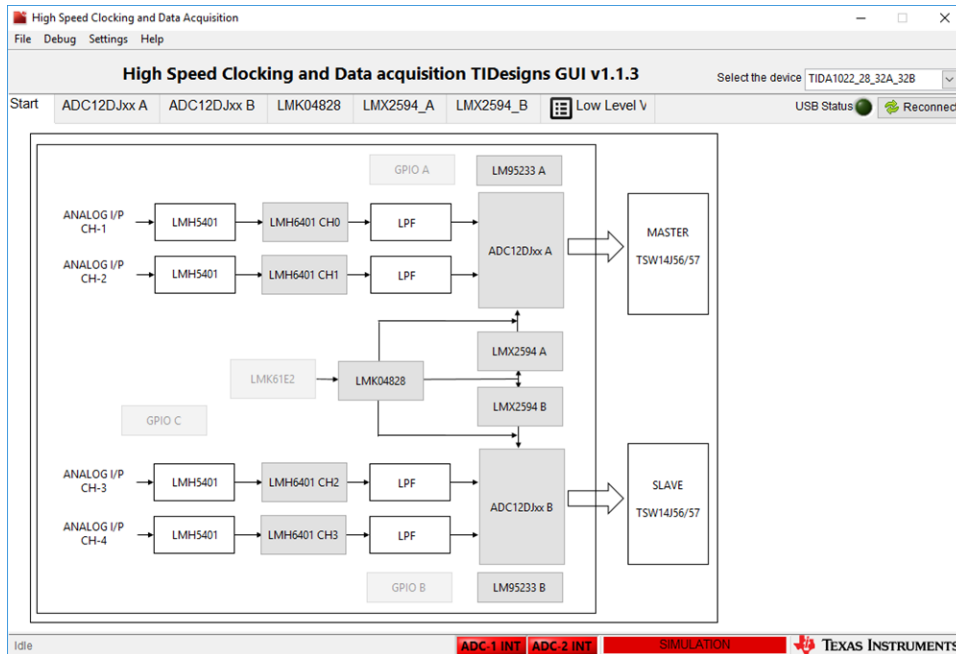


图 17. HSDC TID GUI – Low-Level Programming View

The screenshot shows the 'High Speed Clocking and Data Acquisition TIDesigns GUI v1.1.3' window in the 'Low Level Vi' view. The top menu bar and tabs are the same as in Figure 16. The 'Register Map' table is displayed, listing registers for 'ADC12D Jxx0_A'. The table has columns for Register Name, Address, Default, Mode, Size, Value, and bit fields 15, 14, 13, 12, 11, 10, 9, 8. The 'Field View' on the right shows bit fields for 'RESERVED_COI_0', 'SDO_ACTIVE_A', 'ADDR_ASC_A', and 'SOFT_RESET_A'. The 'Register Description' section shows details for 'RESERVED_CONFIG_A_A[3:0]', including 'Reserved', 'SDO_ACTIVE_A[4:4]', and 'ADDR_ASC_A[3:5]'. The status bar at the bottom shows 'Idle', 'ADC-1 INT', 'ADC-2 INT', 'SIMULATION', and 'TEXAS INSTRUMENTS'.

Register Name	Address	Default	Mode	Size	Value	15	14	13	12	11	10	9	8
ADC12D Jxx0_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 18. HSDC TID GUI - NCO Programming, Alarm Monitor View

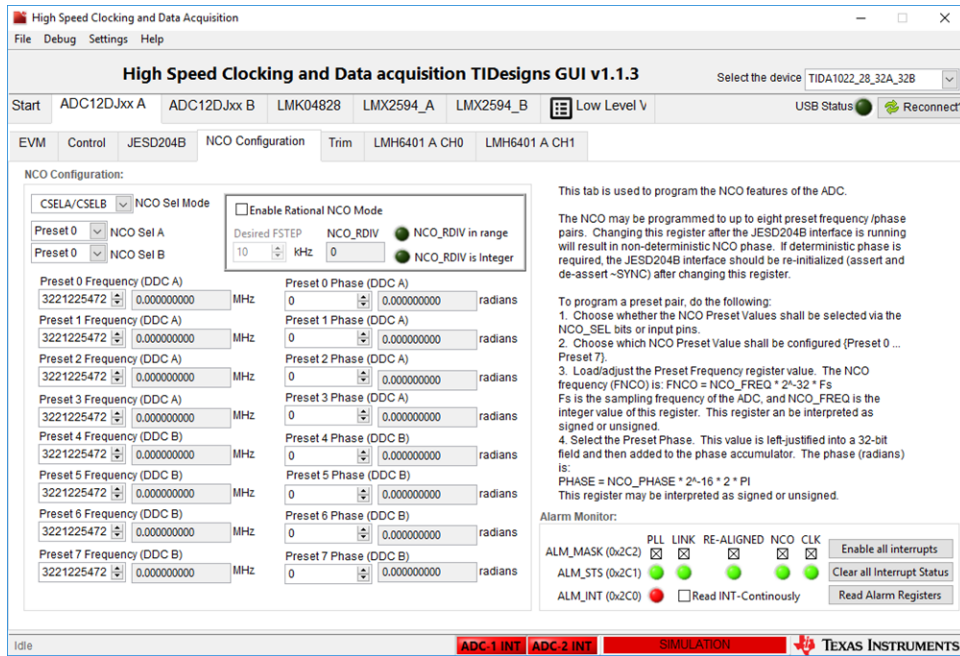
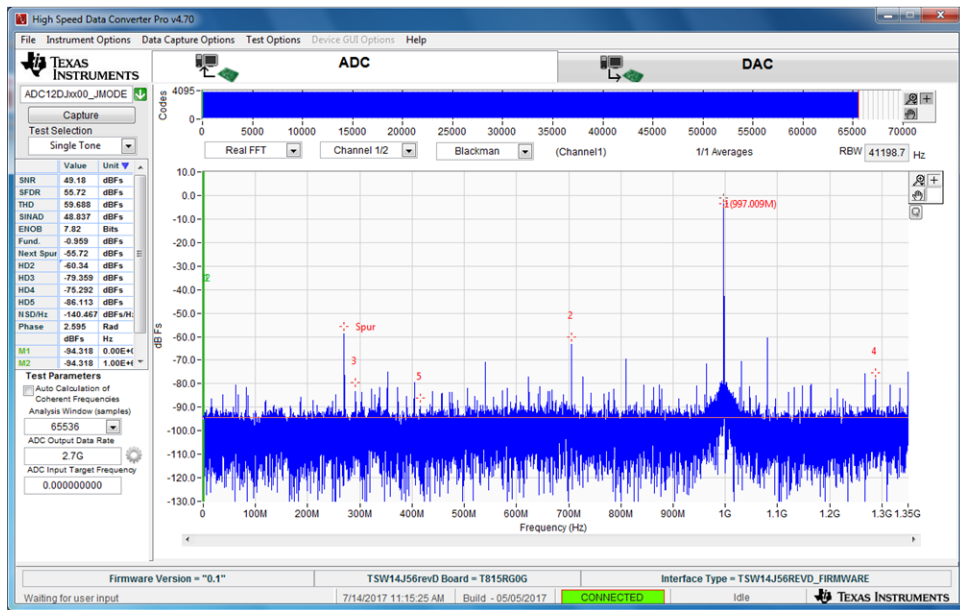


图 19 shows the ADC capture screen in HSDC Pro GUI

图 19. HSDC Pro ADC Capture GUI (Spectrum)



3.1.3.1.1 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 20 shows the location of programming connector

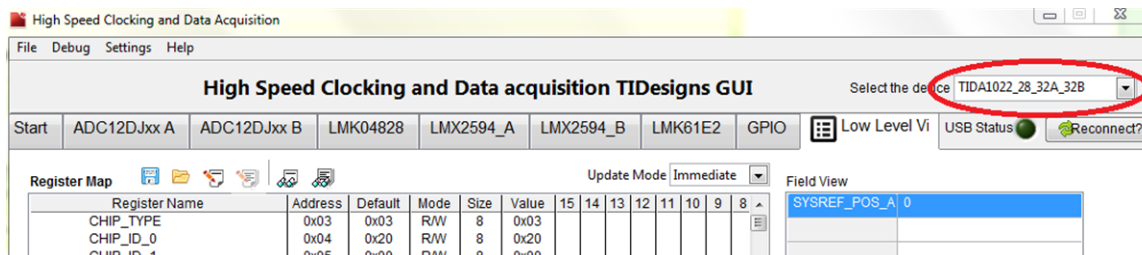
图 20. Programming Connector Interface



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

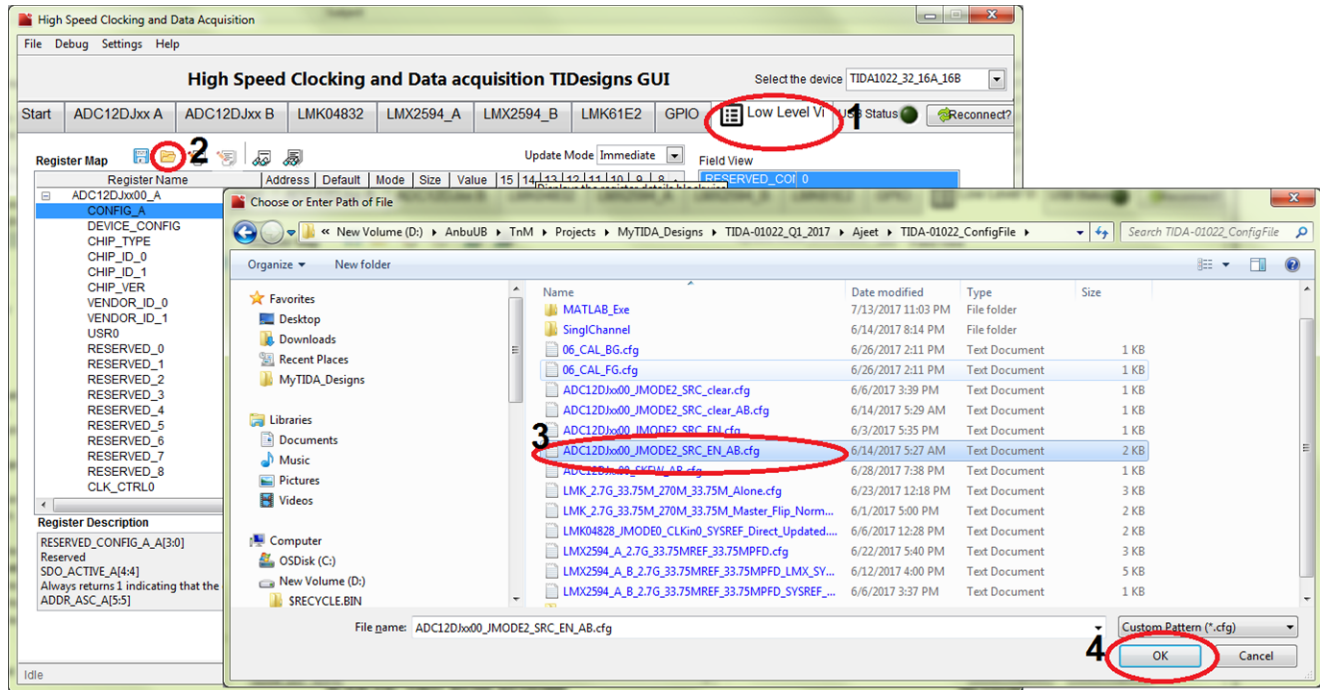
1. Open the HSDC TID GUI and select the “TIDA1022_28_32A_32B” from device selection drop-down menu.

图 21. 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 22.

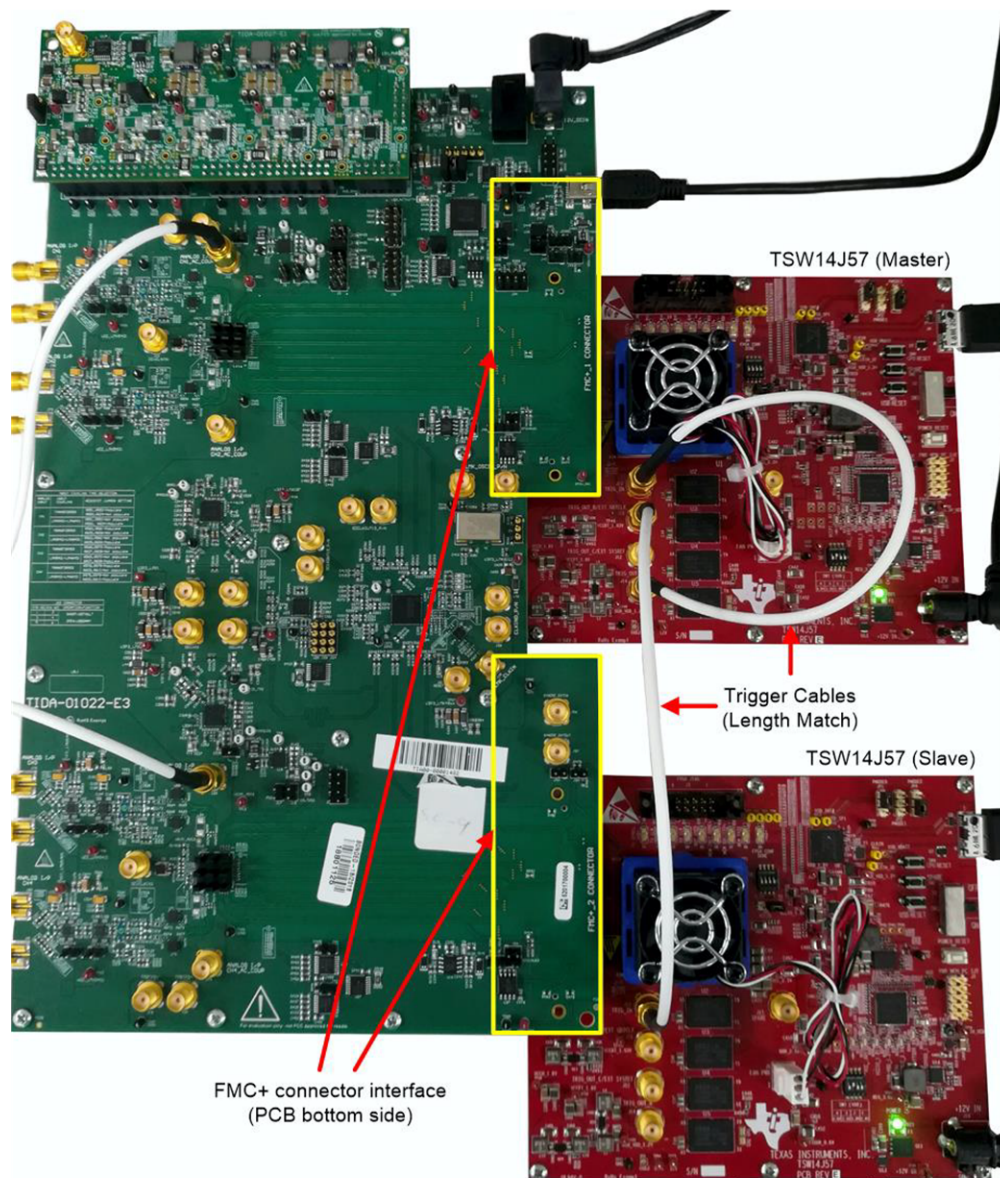
图 22. Selecting Configuration Files to be Programmed



3.1.3.2 Host Interface

The TIDA-01022 NCO synchronization can be evaluated using TI's TSW14J57 JESD204B High-Speed Data Capture and Pattern Generator Card. Populated with an Intel® Arria® 10 device and using the Altera® 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 23 shows the TIDA-01022 interface with the TSW14J57 capture module and trigger cable connection.

图 23. 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.

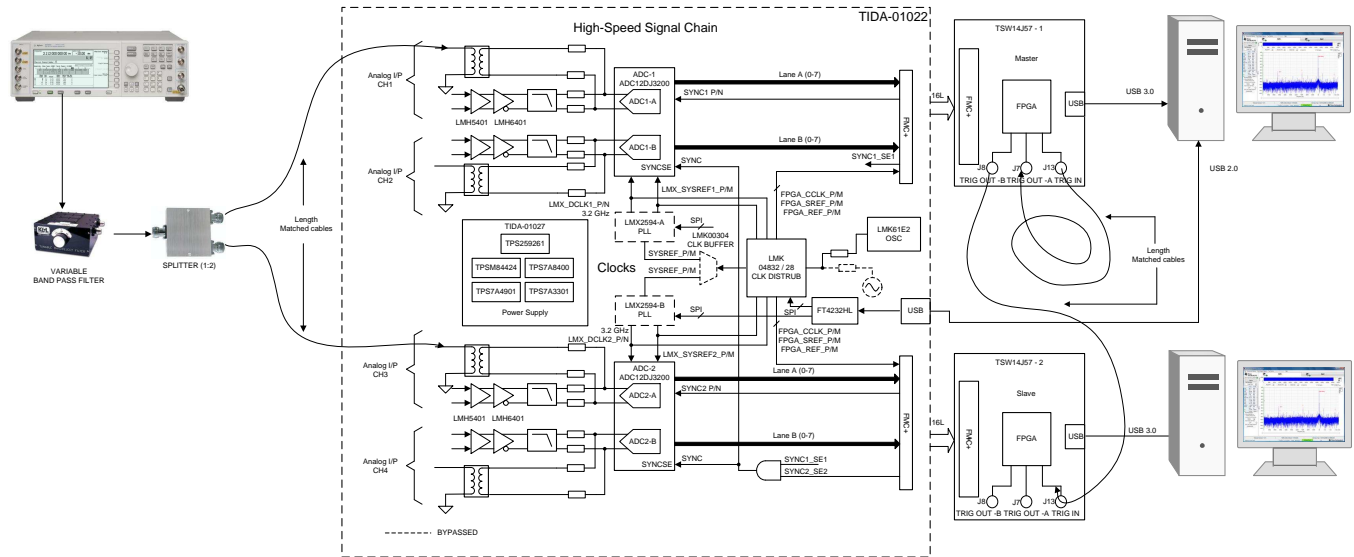
3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Hardware Setup

图 24 shows the test setup for NCO synchronization using the TIDA-01022 reference design with transformer input.

图 24. Test Setup for 2 x ADC12DJ3200 NCO Synchronization



3.2.1.1.1 SYNC~ Logic Implementation

Aggregated AND logic implemented in the TIDA-01022 hardware is discussed in 节 2.3.5. 图 25 shows an implementation circuit diagram. Here the SYNC1_SE and SYNC2_SE signal is coming from TSW14J57 capture cards and by combining these signals using AND logic, the output of AND logic is connected to the SYNC signal input of both ADC1 and ADC2. 表 5 shows the resistor jumpers required to implement the SYNC~ signal based synchronization.

图 25. TIDA-01022 SYNC~ Implementation Circuit Diagram

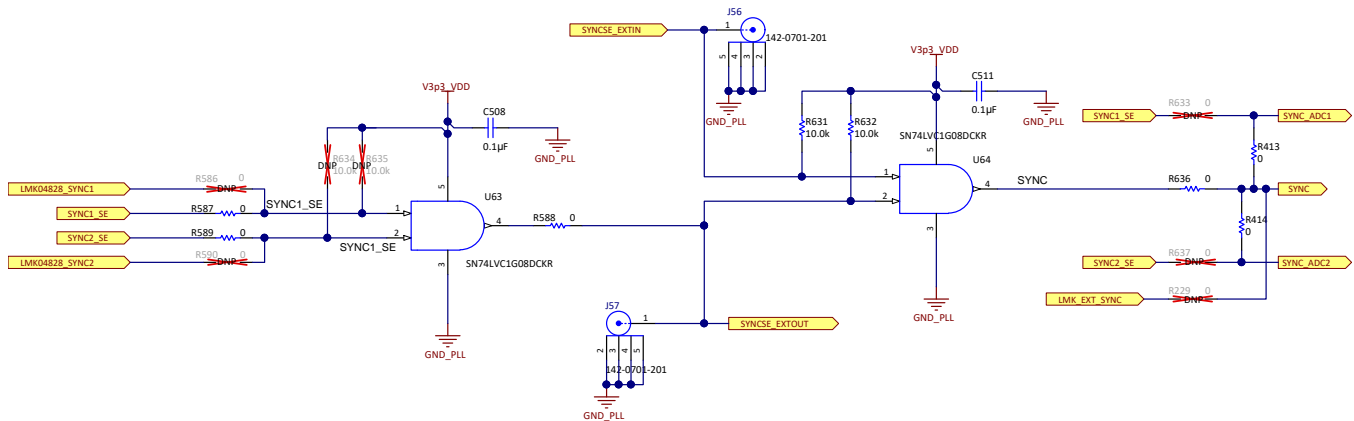
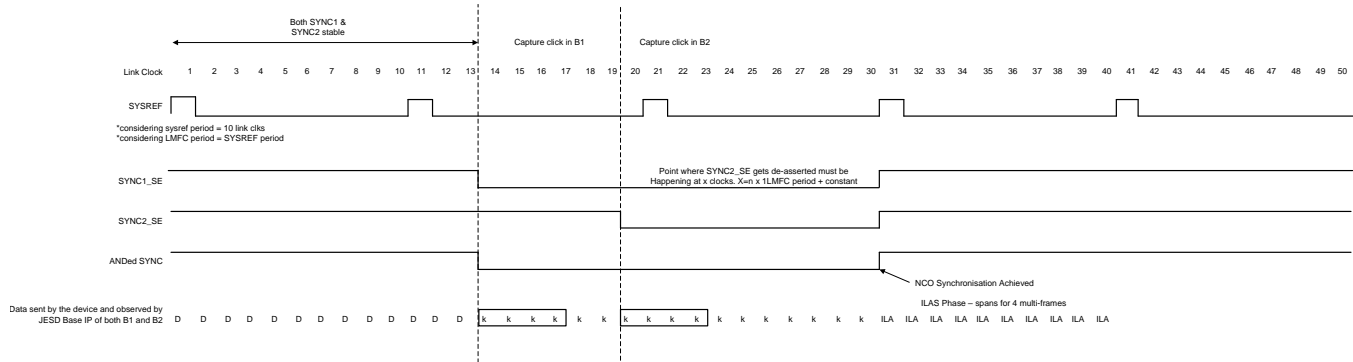


表 5. SYNC Logic Resistor Jumper Selection

IMPLEMENTATION METHOD	DO NOT POPULATE	POPULATE
SYNC~	R634, R635, R586, R590, R633, R637, R229	R413, R414, R587, R589
SYSREF	R413, R414, R587, R589	R633, R637,

图 26 shows the SYNC signal timing diagram of two TSW14J57 capture cards interfaced with two ADC12DJ3200 devices.

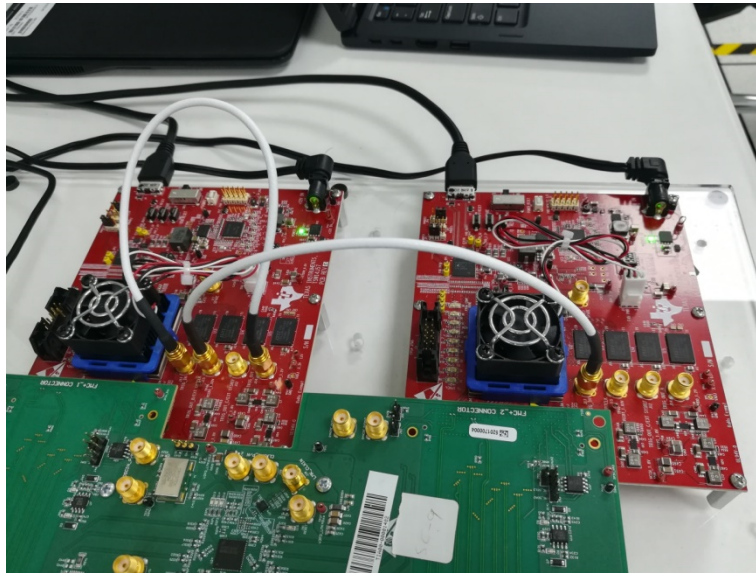
图 26. SYNC Timing of 2 × ADC12DJ3200 With 2 × TSW14J57



3.2.1.1.2 Master Slave Trigger Capture

The output data from the ADC is captured using the TSW14J57 capture card since the TIDA-01022 has 2 × ADC12DJ3200 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 the HSDC Pro GUI software.

- 图 27 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 27. Master Slave Trigger Connection


注：图 27 illustrates that the length of cable must be length matched.

3.2.2 Test Case

In this reference design, the NCO synchronization is performed with two channels (CH1 and CH3) and the same can be scaled up for high channel counts by using a similar approach.

3.2.2.1 Synchronization Performance in JMODE15

1. Emulate the hardware setup as shown in图 24, then provide the input signal to the J12 and J29 SMA connectors of channel 1 and 3 of the TIDA-01022 design through a variable bandpass filter and 2:1 splitter.
2. Connect a high-speed USB3.0 and USB2.0 cable to the capture PC's
3. Provide 12-V, 4-A DC supply to the power connector (J55) of the TIDA-01022 design and a 12-V supply to the TSW14J57 capture card.

Test condition

$$F_S = 1480 \text{ MHz}$$

$$F_{IN} = 1250 \text{ MHz}$$

$$F_{NCO} = 1270 \text{ MHz}$$

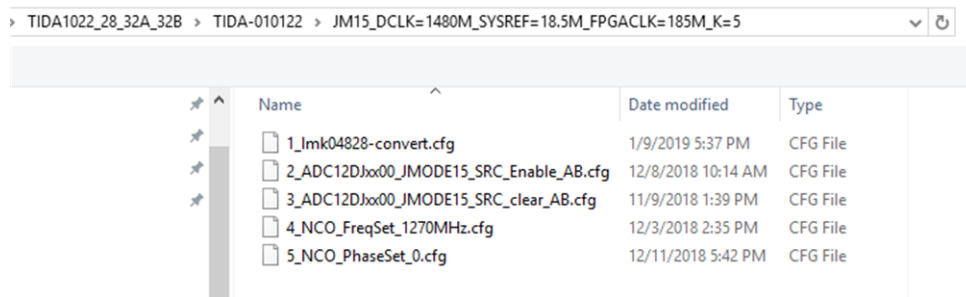
Mode = JMODE15 (x16 Decimation) - 8 lanes

3.2.2.1.1 Test Procedure

Configure the following using the HSDC TID GUI:

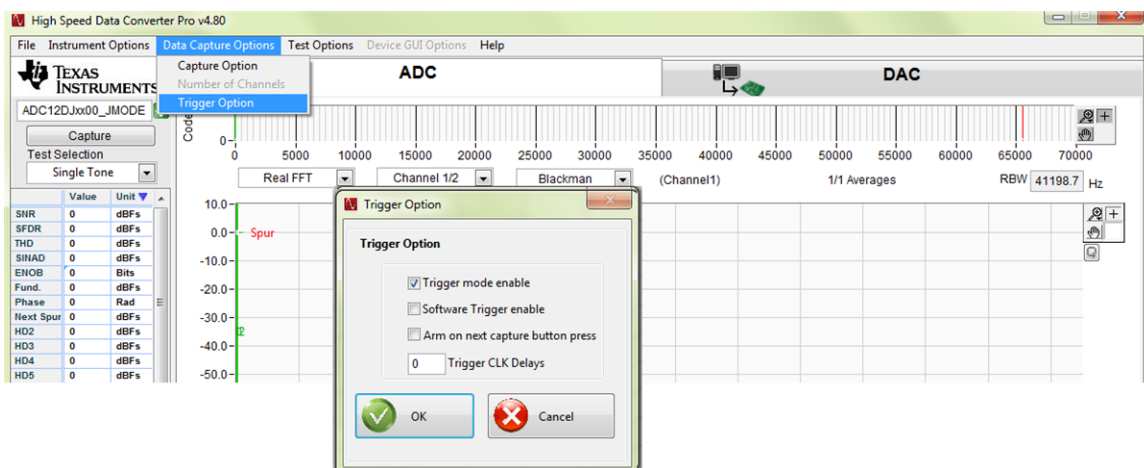
1. Use the J32 connector to program the LMK61E2 device at 18.5 MHz using the USB2ANY programmer associated with the LMK61E2 oscillator programming tool. Set the device address as 0x5A before programming.
2. Load the following configuration file in the LMK04828 using HSDC TID GUI as 图 28 shows. This generates 1480-MHz DEVCLK and SYSREF 18.5 MHz for both ADC1 and ADC2. This also generates the FPGA reference at 185 MHz, the FPGA core clock at 185 MHz, and the FPGA SYSREF at 18.5 MHz for the FPGA capture card.

图 28. Device Configuration File Loading



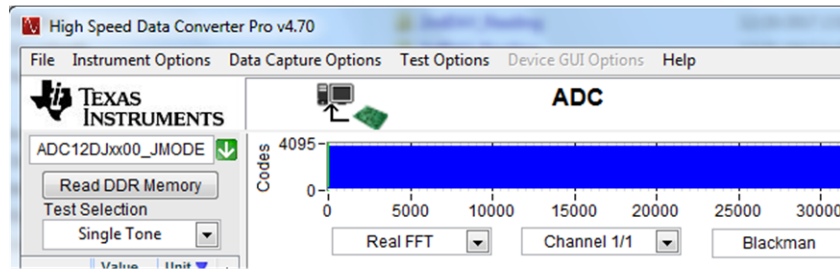
3. Configure both ADC12DJ3200 JMODE15 (x16 decimation) by loading the configuration file in the *Low Level* page of the HSDC Pro GUI in the following order for both master and slave capture card:
 - a. Master capture card:
 - i. After powering the TSW14J57 mater capture card, establish the hardware connection.
 - ii. Load “ADC12Djxx00_JMODE15_F&K_2_20_sysref.ini” from the *Select ADC* drop-down menu and then update the *ADC Output Data Rate* as 92.5 MHz which is a decimated data rate of 1480 MHz
 - 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 the hardware
 - ii. Load “ADC12Djxx00_JMODE15_F&K_2_20_sysref.ini” from the *Select ADC* drop-down menu, then update the *ADC Output Data Rate* as 92.5 MHz which is a decimated data rate of 1480 MHz
 - iii. Read capture and see the ADC2 spectrum
 - iv. Load “ADC12Djxx00_JMODE15_F&K_2_20_sysref_skipconfig.ini” from the *Select ADC* drop-down menu
 - v. Using the *Data Capture Options, Trigger Option* selection menu item; select only *Trigger mode enable*:

图 29. Trigger Option Selection: Trigger mode enable



- vi. After enabling the trigger, the *Capture* button becomes *Read DDR Memory* (see 图 30):

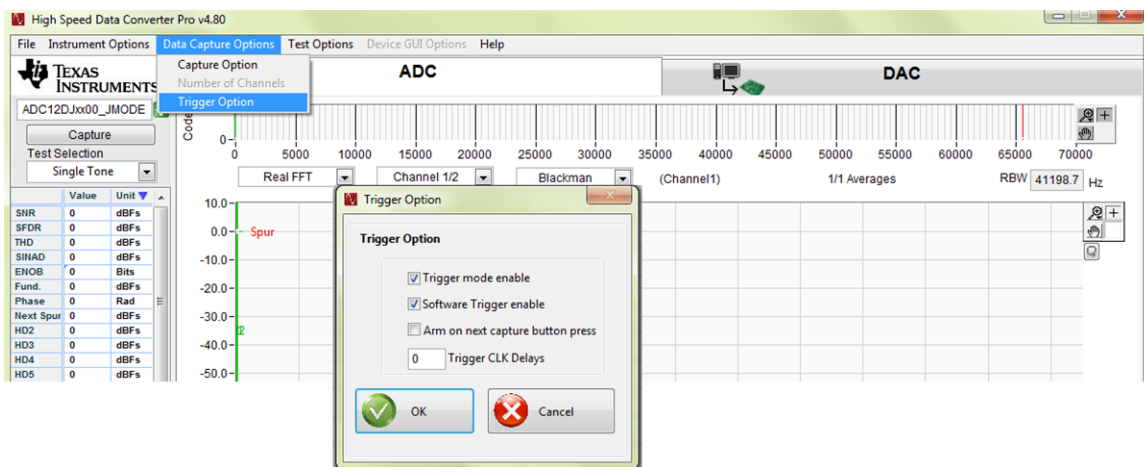
图 30. HSDC Pro Slave Capture Read: Read DDR Memory



c. Master capture card:

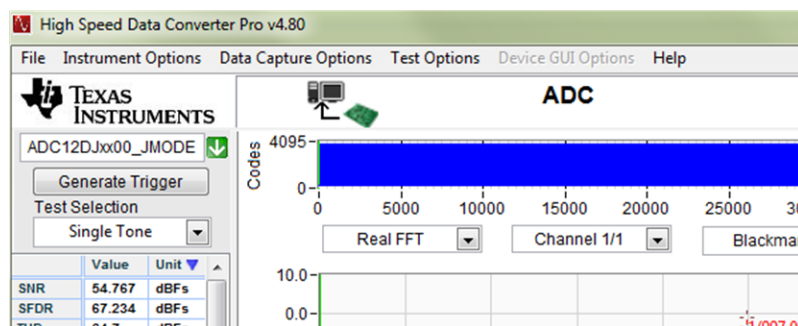
- i. Go to the *Data Capture Options* menu, enable both *Trigger mode enable* and *Software Trigger enable* options (see 图 31).

图 31. Trigger Option Selection: 'Trigger mode enable' and 'Software Trigger enable'



- ii. After enabling the triggers, the *Capture* button becomes *Generate Trigger* (see 图 32).

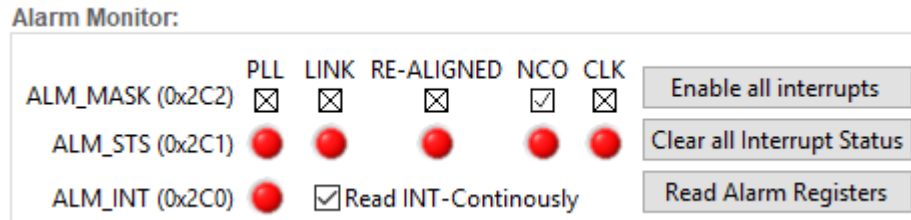
图 32. HSDC Pro Slave Capture Read: Generate Trigger



d. NCO Alarm Set:

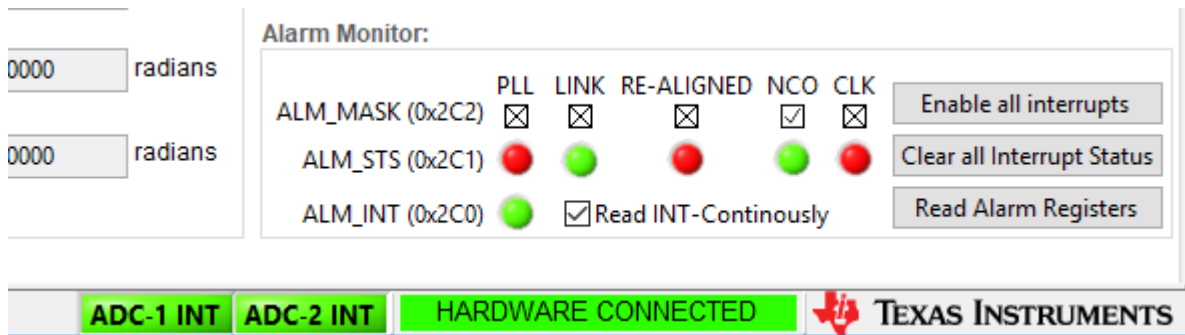
- i. Before doing synchronous capture, configure the NCO alarm register bit in the alarm register as 图 33 shows.

图 33. Alarm Monitor Register Settings



- ii. Set the “Enable NCO interrupt” bit for both ADCs and clear all interrupts using the *Clear all Interrupt Status* button.
 - iii. Check the “Read INT – continuously” bit for both ADCs.
4. **Synchronous Capture with Master Slave mode:**
1. Feed the input signal frequency 1250 MHz, -7 dBFS to channel 1 (J12) and channel 3(J29) from the signal source via splitter.dsds
 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 generates the SYNC pulse to both ADCs. The rising edge for SYNC~ pulse initiates ILA sequence at the same time for all transmitters with the same LFMC period.
 4. After NCO reset, the NCO ALM_STS bit sets and interrupt generates

图 34. NCO Alarm Status



5. After NCO synchronization is complete, load “ADC12DJxx00_JMODE15_F&K_2_20_sysref_skipconfig.ini” from the *Select ADC* drop-down menu, then repeat “Read DDR memory on slave” and *Generate Trigger* on the master for another synchronous capture.
6. Export both ADC1 and ADC2 data, then extract the phase and amplitude information from the spectrum using the MATLAB® program and plot the data in the time domain for a channel-to-channel skew measurement. The sample MATLAB code is provided in 附录 A.
7. Adjust the t_{AD} register values to make channel-to-channel skew as CH1 and CH3. See 节 2.3.3 for more details.

3.2.2.2 Synchronization Performance in JMODE16

Test condition

- $F_S = 3000$ MHz
- $F_{IN} = 54.7 - 2742$ MHz
- $F_{NCO} = 90 - 2700$ MHz
- Mode = JMODE16 (x16 Decimation) - 16 lanes

3.2.2.2.1 Test Procedure

1. Use the J32 connector to program the LMK61E2 device at 37.5 MHz using the USB2ANY programmer associated with the LMK61E2 oscillator programming tool. Set the device address as 0x5A before programming.
2. Load the configuration file in the LMK04828 from following location

```
“.. \TIDA1022_28_32A_32B\TIDA-010122\JM16_DCLK=3000M_SYSREF=37.5M_FPGACLK=187.5M_K=5”
```

 using HSDC TID GUI. This generates 3000-MHz DEVCLK and SYSREF 37.5 MHz for both ADC1 and ADC2. This also generates the FPGA reference at 187.5 MHz, the FPGA core clock at 187.5 MHz, and the FPGA SYSREF at 37.5 MHz for the FPGA capture card.
3. Configure both ADC12DJ3200 JMODE16 (x16 decimation) by loading the configuration file in the *Low Level*/page of HSDC Pro GUI for both the master and slave capture card
4. Perform channel-to-channel measurement across the input signal frequency and select the corresponding NCO frequency for sampling frequency $F_s = 3000$ MHz.

3.2.3 Performance Test Results

In this reference design, NCO synchronization done with decimation (x16) and the key test parameter like channel-to-channel skew, SNR, SFDR performance is measured with $F_s = 1480$ MHz, $F_{in} = 1250$ MHz input signal frequency in JMODE15.

The channel-to-channel skew performance is measured across the input signal frequency 54.7 MHz–2700 MHz with a different NCO frequency for the maximum sample rate at $F_s = 3000$ MHz in JMODE16.

图 35 and 图 36 show the measured spectrum of the TIDA-010122 design at a 1250-MHz input, 1480-MHz sample rate of ADC1 and ADC2 with 1270-MHz NCO frequency.

图 35. ADC1 Spectrum - I Data, $F_s = 1480 \text{ MHz}$, $F_{NCO} = 1270$, $F_{in} = 1250 \text{ MHz}$

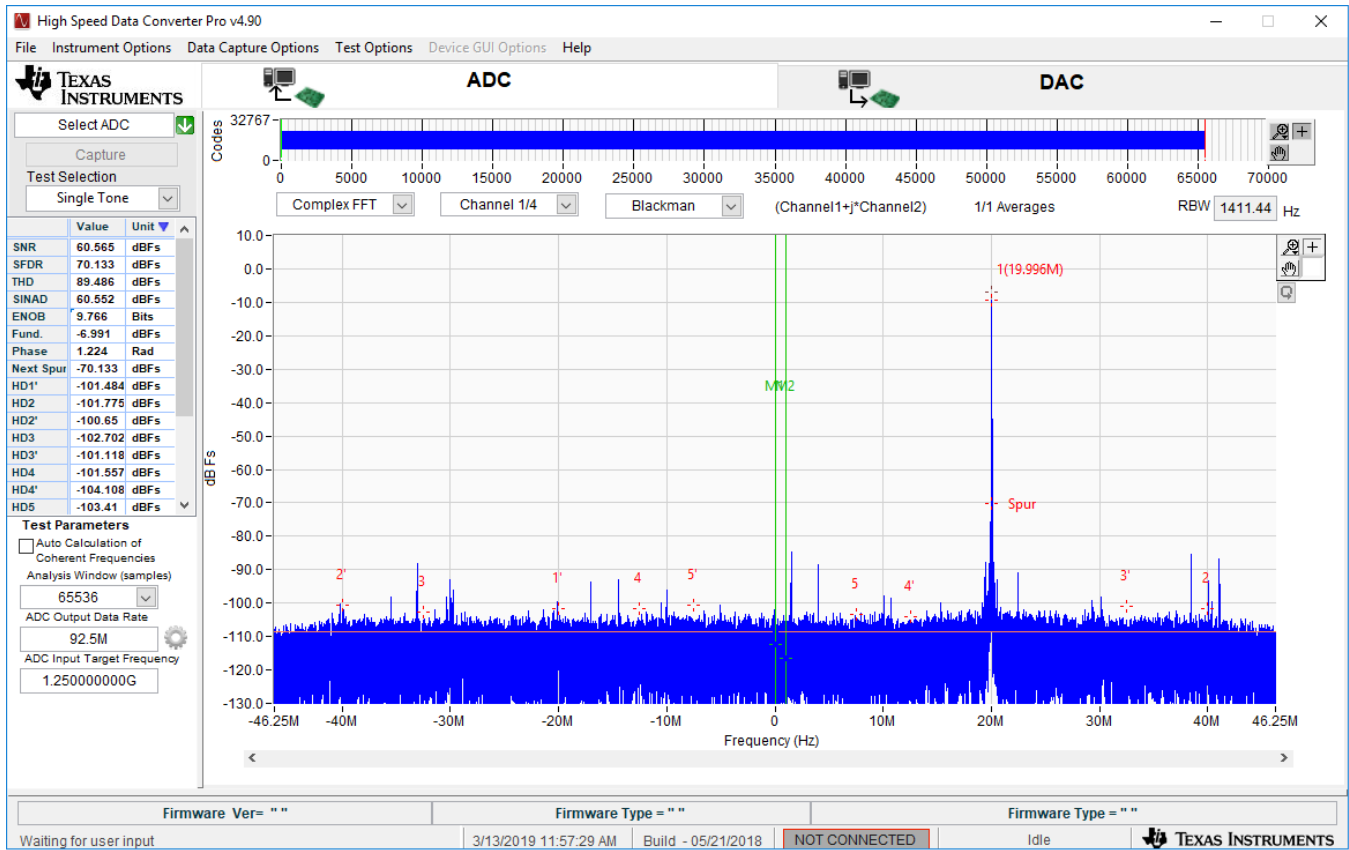


图 36. ADC2 Spectrum - Q Data, $F_s = 1480$ MHz, $F_{NCO} = 1270$, $F_{in} = 1250$ MHz

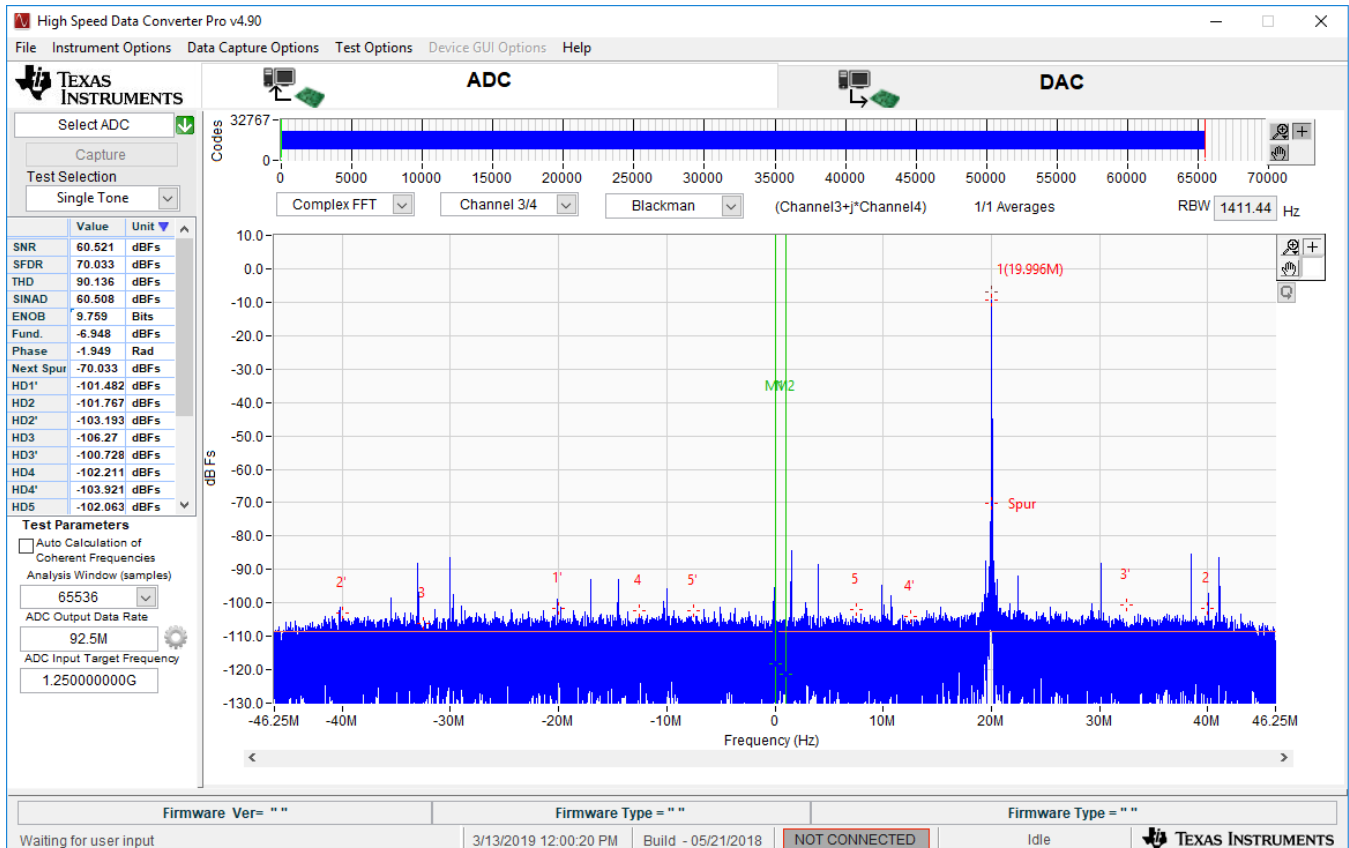


图 37 和 图 38 显示 SNR 和 SFDR 性能曲线，对于采样频率 $F_s = 1480$ MHz，NCO 频率 $F_{NCO} = 1250$ 和输入频率 F_{in} 1200 MHz 到 1290 MHz。

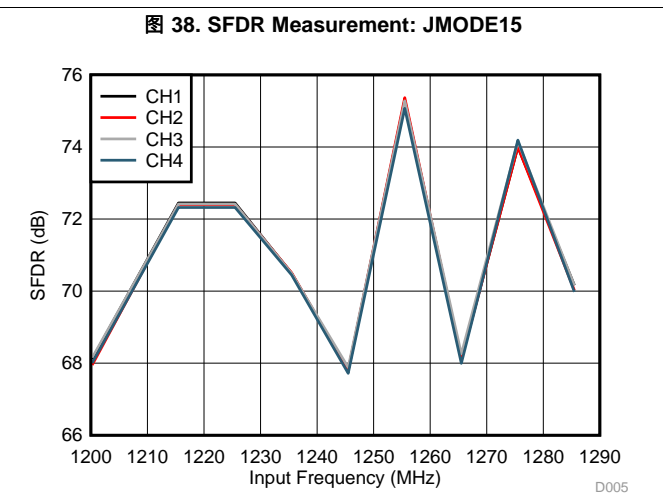
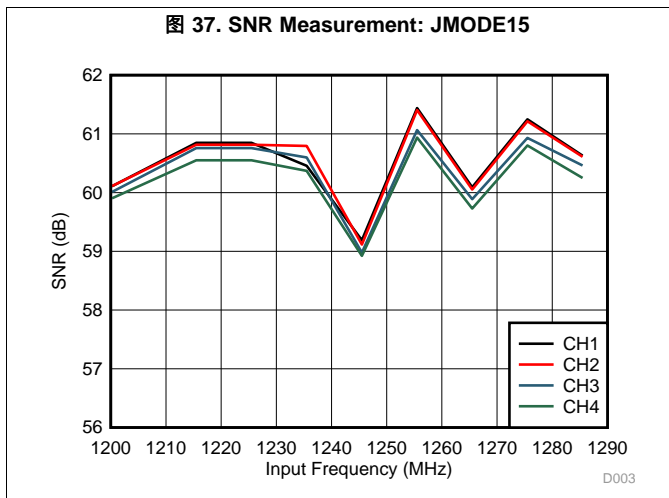
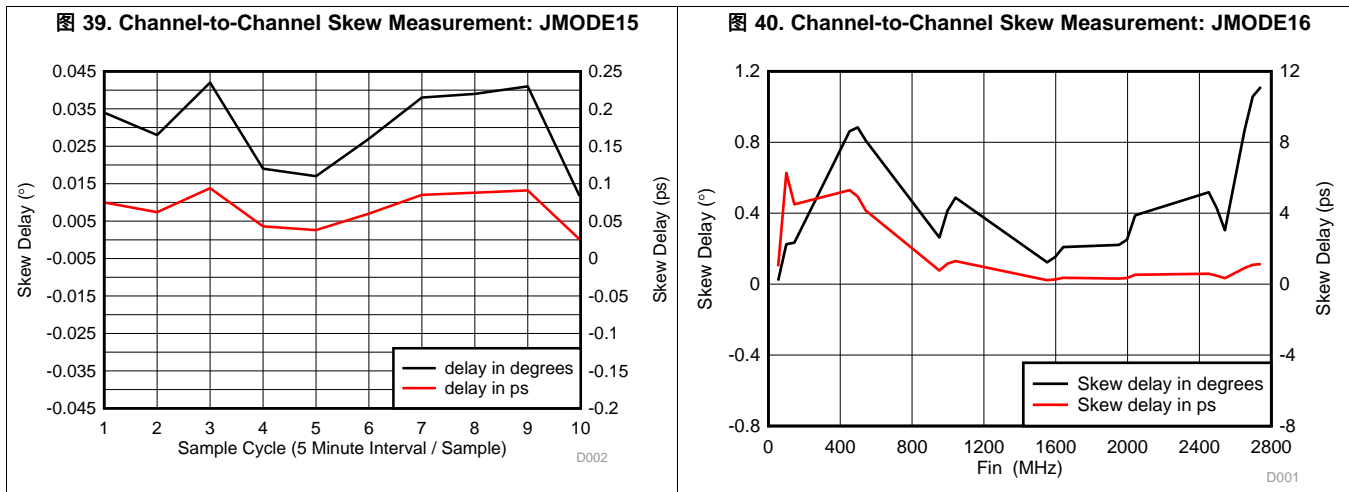


图 39 shows the measured time skew between two channels (CH1 and CH3) of the TIDA-010122 design at room temperature with a 1250-MHz input signal and at a sampling frequency of 1480 MHz with decimation x16 and NCO frequency configured as 1270 MHz. Evaluate this skew by calculating the phase difference between signals captured from each ADC. This measurement done with transformer inputs and the measured time skew was less than 1 ps for JMODE15.

图 40 shows channel-to-channel skew performance results for a sampling frequency at 3000 MHz with an input frequency from 54.7 MHz to 2742 MHz with a corresponding NCO frequency from 90 MHz to 2700 MHz for JMODE16. The skew variation between channels (CH1 and CH3) are observed at not more than 10 ps.



注: All the test are carried out at ambient temperature

In summary, the TIDA-010122 reference design demonstrates the ADC12DJ3200 synchronization features that allow multiple similar ADCs to be synchronized and achieves a channel-to-channel skew less than 10 ps with deterministic latency.

This reference design demonstrates the flexibility and features of clock devices such as the LMK04828 and the LMX2594 that help designers to achieve low phase noise, high-frequency clocks for gigahertz sampling applications.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-010122](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-010122](#).

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-010122](#).

4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-010122](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-010122](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-010122](#).

5 Related Documentation

5.1 Related Reference Designs

1. Texas Instruments, [Flexible 3.2 GSPS Multi-Channel AFE Reference Design for DSOs, RADAR, and 5G Wireless Test Systems](#)
2. Texas Instruments, [Multi-Channel JESD204B 15 GHz Clocking Reference Design for DSO, Radar and 5G Wireless Testers](#)

5.2 Other Related Documents

1. Texas Instruments, [JESD204B multi-device synchronization: Breaking down the requirements Analog Applications Journal](#)

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6 **About the Author**

ANBU MANI is a systems engineer in the Industrial Systems Engineering team at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Anbu has experience in analog circuit design and digital circuit design for the Automatic Test Equipment in Modular platform. He is also engaged with the design and development of embedded products. Anbu earned his bachelor of engineering (BE) in electronic and communication from the Anna University, Chennai.

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6.1 **Acknowledgment**

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

附录 A 用于分析偏移的示例 **MATLAB®** 程序

```

%-----%
% 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);
    end
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);

% 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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