

# 16 CHANNEL VARIABLE GAIN AMPLIFIER (VGA) WITH OCTAL HIGH SPEED ADC

Check for Samples: [AFE5851](#)

## FEATURES

- **16 Variable Gain Amplifiers (VGA)**
  - **16 Single-Ended Buffered Inputs With  $1V_{PP}$  Maximum Swing**
  - **$5.5nV/\sqrt{Hz}$  VCA Input Noise (31dB Gain).**
  - **Variable Gain –5dB to 31dB With 0.125dB Steps**
  - **Digital Gain Control**
- **3<sup>rd</sup> Order Anti-Aliasing Filter With Programmable Cut-Off Frequency (7.5, 10 and 14MHz).**
- **Clamping**
- **Analog-to-Digital Converter (ADC)**
  - **Octal channel 12-bit, 65 MSPS**
  - **32.5 MSPS Maximum per Input Channel**
  - **2 VGA Outputs Alternately Sampled by Each ADC**
  - **Internal and External Reference Support**
  - **No External Decoupling Required for References**
  - **Serial LVDS Outputs**
- **1.8V and 3.3V Supply**
- **39 mW Total Power per Channel at 32.5 MSPS**
- **64-QFN Package (9mm × 9mm)**

## APPLICATIONS

- **Imaging: Ultrasound, PET**

## RELATED DEVICES

- **AFE5801: Octal VGA+ADC, 65 MSPS/channel**

## DESCRIPTION

The AFE5851 is an analog front-end targeting applications where the power and level of integration are critical. The device contains 16 variable gain amplifiers (VGA), followed by an octal high speed (up to 65 MSPS) analog to digital converter (ADC).

Each of the 16 single ended inputs is buffered, accepts up to  $1V_{PP}$  maximum input swing and it is followed by a VGA with a gain range from –5dB to 31dB. The VGA gain is digitally controlled and the gain curves versus time can be stored in memory, integrated within the device using the serial interface.

A selectable clamping and anti-alias low pass filter (with 3dB attenuation at 7.5, 10 or 14MHz) is also integrated between the VGA and ADC for every channel. The VGA/anti-alias filter outputs are differential (limited to  $2V_{PP}$ ) and drive the on-board 12-bit 65MSPS ADC that is shared between two VGAs to optimize the power dissipation. Each VGA output is sampled at alternate clock cycles, making the effective sampling frequency half the input clock rate. The ADC also scales down its power consumption should a lower sampling rate be selected.

The ADC outputs are serialized in LVDS streams further minimizing power and board area. The AFE5851 is available in a 64-pin QFN package ( $9 \times 9mm^2$ ) and is specified over the full industrial temperature range ( $-40^{\circ}C$  to  $85^{\circ}C$ ).



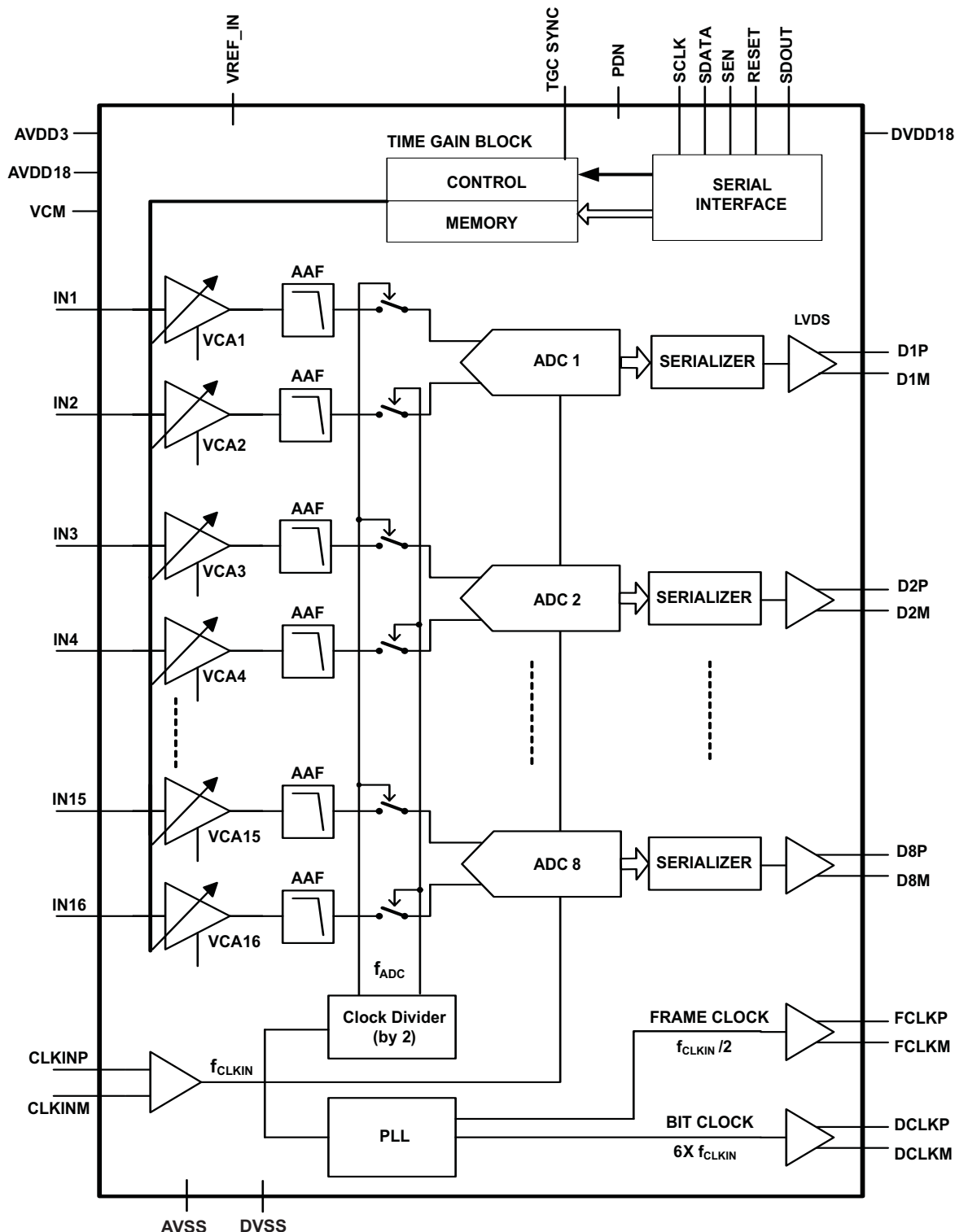
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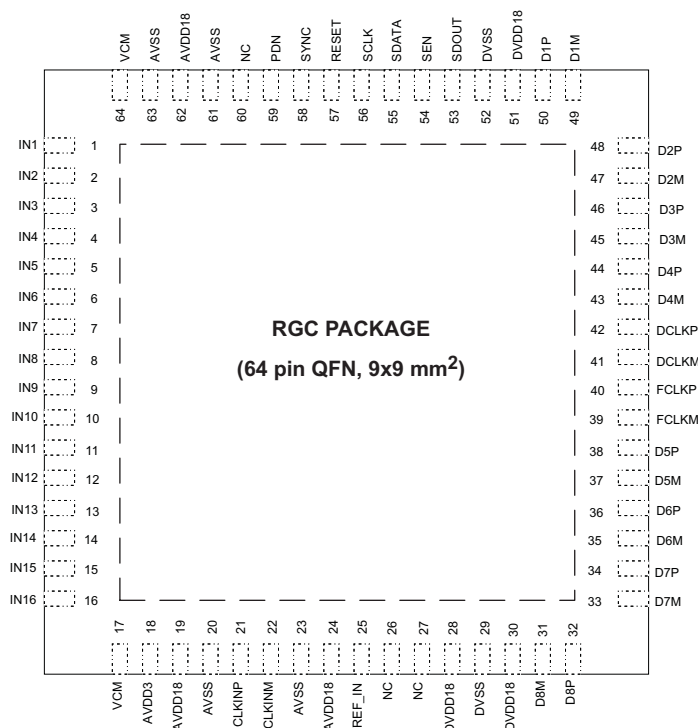
This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### BLOCK DIAGRAM



## PINOUT



## PIN FUNCTIONS

| NAME                             | NUMBER                | DESCRIPTION                                                                                                  |
|----------------------------------|-----------------------|--------------------------------------------------------------------------------------------------------------|
| IN1–IN16                         | 1–16                  | Single-ended analog input pins for channel 1 to 16.                                                          |
| CLKINP, CLKINM                   | 21, 22                | Differential clock input pins. Single-ended clock also supported (See <a href="#">Clock Inputs</a> Section). |
| VCM                              | 17, 64                | Common-mode output pins for possible bias of the analog input signals.                                       |
| VREF_IN                          | 25                    | Reference input in the external reference mode.                                                              |
| RESET                            | 57                    | Hardware reset pin (active high).                                                                            |
| SCLK                             | 56                    | Serial interface clock input.                                                                                |
| SDATA                            | 55                    | Serial interface data input.                                                                                 |
| $\overline{\text{SEN}}$          | 54                    | Serial interface enable.                                                                                     |
| SDOUT                            | 53                    | Serial interface data readout.                                                                               |
| PDN                              | 59                    | Global power down control input (active high).                                                               |
| SYNC                             | 58                    | TGC/VGA synchronization signal input                                                                         |
| D1P/M... D4P/M<br>D5P/M... D8P/M | 50... 43<br>38... 31  | LVDS output for channels 1 and 2, 3 and 4, 5 and 6.... to 15 and 16.                                         |
| FCLKM, FCLKP                     | 39, 40                | LVDS frame clock output.                                                                                     |
| DCLKM,DCLP                       | 41, 42                | LVDS bit clock output.                                                                                       |
| AVDD3                            | 18                    | 3.3V Analog supply voltage.                                                                                  |
| AVDD18                           | 19, 24, 62            | 1.8V Analog supply voltage.                                                                                  |
| DVDD18                           | 28, 30, 51            | 1.8V LVDS buffer supply voltage.                                                                             |
| AVSS                             | 20, 23, 61, 63        | Analog ground.                                                                                               |
| DVSS                             | 29, 52                | Digital ground.                                                                                              |
| NC                               | 26, 27, 60            | Do not connect.                                                                                              |
| Thermal Pad                      | Bottom of the package | Connect to AVSS.                                                                                             |

**PACKAGING/ORDERING INFORMATION<sup>(1)</sup>**

| PRODUCT | PACKAGE-LEAD          | PACKAGE DESIGNATOR | SPECIFIED TEMPERATURE RANGE | PACKAGE MARKING | ORDERING NUMBER | TRANSPORT MEDIA, QUANTITY |
|---------|-----------------------|--------------------|-----------------------------|-----------------|-----------------|---------------------------|
| AFE5851 | QFN-64 <sup>(2)</sup> | RGC                | –40°C to 85°C               | AFE5851         | AFE5851IRGCT    | Tape/Reel, 250            |
|         |                       |                    |                             | AFE5851         | AFE5851IRGCR    | Tape/Reel, 2000           |

- (1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at [www.ti.com](http://www.ti.com).
- (2) For the thermal pad size on the package, see the mechanical drawings at the end of this document

**ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>**

over operating free-air temperature range (unless otherwise noted)

|                                                       | RANGE                             | UNIT |
|-------------------------------------------------------|-----------------------------------|------|
| AVDD3 to AVSS                                         | –0.3 to 3.8                       | V    |
| AVDD18 to AVSS                                        | –0.3 to 2.2                       | V    |
| DVDD18 to DVSS                                        | –0.3 to 2.2                       | V    |
| Voltage between AVSS and DVSS                         | –0.3 to 0.3                       | V    |
| Analog input pins (IN <sub>i</sub> ) to AVSS          | –0.3V to Minimum (3.6, AVDD3+0.3) | V    |
| VREF_IN to AVSS                                       | –0.3 to 2.2                       | V    |
| V <sub>CLKP</sub> , V <sub>CLKM</sub> to AVSS         | –0.3 to 2.2                       | V    |
| Digital control pins to DVSS                          | –0.3 to 2.2                       | V    |
| ESD Human body model                                  | 2                                 | kV   |
| T <sub>J</sub> Maximum operating junction temperature | 125                               | °C   |
| T <sub>stg</sub> Storage temperature range            | –60 to 150                        | °C   |

- (1) Stresses above those listed under absolute maximum ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute maximum rated conditions for extended periods may degrade device reliability.

**THERMAL CHARACTERISTICS**

over operating free-air temperature range (unless otherwise noted)

|                                                                                                            | TYP   | UNIT |
|------------------------------------------------------------------------------------------------------------|-------|------|
| θ <sub>JA</sub> 0LFM air flow                                                                              | 23.17 | °C/W |
| θ <sub>JC</sub> 2 oz. copper trace and pad soldered directly to a JEDEC standard 4-layer 3inch × 3inch PCB | 22.1  | °C/W |

**RECOMMENDED OPERATING CONDITIONS**

| PARAMETER              |                                                    | MIN     | TYP | MAX     | UNIT |
|------------------------|----------------------------------------------------|---------|-----|---------|------|
| T <sub>A</sub>         | Ambient Temperature                                | –40     |     | 85      | °C   |
| <b>SUPPLIES</b>        |                                                    |         |     |         |      |
| AVDD3                  | Analog Supply Voltage (VGA)                        | 3.0     | 3.3 | 3.6     | V    |
| AVDD18                 | Analog Supply Voltage (ADC)                        | 1.7     | 1.8 | 1.9     | V    |
| DVDD18                 | Digital Supply Voltage (ADC, LVDS)                 | 1.7     | 1.8 | 1.9     | V    |
| <b>ANALOG INPUTS</b>   |                                                    |         |     |         |      |
| IN <sub>i</sub>        | Input voltage                                      | VCM–0.5 |     | VCM+0.5 | V    |
| VREF_IN                | in external reference mode                         | 1.35    | 1.4 | 1.45    | V    |
| VCM load               |                                                    |         | 3   |         | mA   |
| <b>CLOCK INPUT</b>     |                                                    |         |     |         |      |
| f <sub>CLKIN</sub>     | Input clock frequency                              | 5       |     | 65      | MHz  |
| f <sub>Channel</sub>   | Channel sampling frequency (f <sub>CLKIN</sub> /2) | 2.5     |     | 32.5    | MSPS |
| Input Clock Duty Cycle |                                                    | 40%     | 50% | 60%     |      |

## RECOMMENDED OPERATING CONDITIONS (continued)

| PARAMETER              |                                                                       | MIN | TYP | MAX | UNIT            |
|------------------------|-----------------------------------------------------------------------|-----|-----|-----|-----------------|
| V <sub>CLKP-CLKM</sub> | Sine wave, AC-coupled                                                 | 0.5 |     |     | V <sub>PP</sub> |
|                        | LVPECL, AC-coupled                                                    |     | 1.6 |     | V <sub>PP</sub> |
|                        | LVDS, AC-coupled                                                      |     | 0.7 |     | V <sub>PP</sub> |
| V <sub>CLKP</sub>      | LVC MOS, single-ended, V <sub>CLKM</sub> connected to AVSS            |     | 1.8 |     | V <sub>PP</sub> |
| <b>DIGITAL OUTPUT</b>  |                                                                       |     |     |     |                 |
| C <sub>LOAD</sub>      | External load capacitance from each output pin to DVSS                |     | 5   |     | pF              |
| R <sub>LOAD</sub>      | Differential load resistance (external) between the LVDS output pairs |     | 100 |     | Ω               |

## ELECTRICAL CHARACTERISTICS

Unless otherwise noted, typical values are at 25°C, min and max values are across full temperature range T<sub>min</sub> = –40°C to T<sub>max</sub> = 85°C, AVDD3=3.3V, AVDD18=1.8V, DVDD18=1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVC MOS (single-ended) clock, 50% duty cycle, anti-aliasing filter set at 14MHz (3dB corner), output clamp disabled and analog high-pass filter enabled.

| PARAMETER                     |                              | TEST CONDITIONS                                         |  | MIN           | TYP  | MAX  | UNIT   |
|-------------------------------|------------------------------|---------------------------------------------------------|--|---------------|------|------|--------|
| VARIABLE GAIN AMPLIFIER (VGA) |                              |                                                         |  |               |      |      |        |
|                               | Max input voltage swing      | Linear operation                                        |  | 1             |      |      | Vpp    |
| VCM                           | Common-mode voltage          | DC level at the input                                   |  | 1.6           |      |      | V      |
|                               | Gain range                   | Maximum gain – minimum gain                             |  | 36            |      |      | dB     |
|                               | Maximum Gain                 |                                                         |  | 29.5          | 31   | 32.5 |        |
|                               | Gain resolution              |                                                         |  | 0.125<br>or 1 |      |      | dB     |
|                               | Input resistance             | From input to dc bias level                             |  | 5             |      |      | kΩ     |
|                               | Input capacitance            | From input to AVSS                                      |  | 2             |      |      | pF     |
| ANTIALIAS FILTER (AAF)        |                              |                                                         |  |               |      |      |        |
| AAF cutoff frequency          | 7.5 MHz filter selected      | –3 dB                                                   |  | 7.5           |      |      | MHz    |
|                               | 10 MHz filter selected       |                                                         |  | 10            |      |      |        |
|                               | 14 MHz filter selected       |                                                         |  | 14            |      |      |        |
| AAF stop-band attenuation     | 7.5 MHz filter selected      | –6 dB                                                   |  | 10            |      |      | MHz    |
|                               | 10 MHz filter selected       |                                                         |  | 14            |      |      |        |
|                               | 14 MHz filter selected       |                                                         |  | 20            |      |      |        |
|                               | 7.5 MHz filter selected      | –12 dB                                                  |  | 18            |      |      | MHz    |
|                               | 10 MHz filter selected       |                                                         |  | 24            |      |      |        |
|                               | 14 MHz filter selected       |                                                         |  | 30            |      |      |        |
| In-band attenuation           | 7.5 MHz filter selected      | At 3.2 MHz                                              |  | 1.2           |      |      | dB     |
|                               | 10 MHz filter selected       |                                                         |  | 0.5           |      |      |        |
|                               | 14 MHz filter selected       |                                                         |  | 0.2           |      |      |        |
| FULL-CHANNEL CHARACTERISTICS  |                              |                                                         |  |               |      |      |        |
|                               | Gain matching                | Across channels and parts                               |  |               | +0.1 | +0.6 | dB     |
|                               | Gain error                   | –5 to 28dB gain                                         |  | –1.2          | ±0.3 | 1.2  | dB     |
|                               |                              | Gain > 28dB gain                                        |  | –1.8          | ±0.5 | 1.8  |        |
|                               | Offset error                 | 31dB gain                                               |  | –50           |      | 50   | LSB    |
|                               | Input-referred noise voltage | 5 MHz, 31dB VGA gain, low-noise mode                    |  |               | 5    | 6.5  | nV/√Hz |
|                               |                              | 5 MHz, 31dB VGA gain, default-noise mode                |  |               | 5.5  |      |        |
| SNR                           | Signal-to-noise ratio        | –1dBFS ADC input, 6dB gain                              |  |               | 66   |      | dBFS   |
| HD2                           | Second-harmonic distortion   | –1dBFS ADC input, 17dB VGA gain, f <sub>in</sub> = 2MHz |  | –48           | –55  |      | dBc    |
|                               |                              | –1dBFS ADC input, 31dB VGA gain, f <sub>in</sub> = 2MHz |  | –55           | –65  |      |        |
| HD3                           | Third-harmonic distortion    | –1dBFS ADC input, 17dB VGA gain, f <sub>in</sub> = 2MHz |  | –52           | –63  |      | dBc    |
|                               |                              | –1dBFS ADC input, 31dB VGA gain, f <sub>in</sub> = 2MHz |  | –48           | –58  |      |        |

## ELECTRICAL CHARACTERISTICS (continued)

Unless otherwise noted, typical values are at 25°C, min and max values are across full temperature range  $T_{min} = -40^{\circ}\text{C}$  to  $T_{max} = 85^{\circ}\text{C}$ , AVDD3=3.3V, AVDD18=1.8V, DVDD18=1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle, anti-aliasing filter set at 14MHz (3dB corner), output clamp disabled and analog high-pass filter enabled.

| PARAMETER               | TEST CONDITIONS                                                                                                 | MIN                                                                                            | TYP  | MAX | UNIT               |
|-------------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|------|-----|--------------------|
| SFDR                    | Spurious free dynamic range                                                                                     | –1dBFS ADC input, 17dB VGA gain, $f_{in} = 2\text{MHz}$                                        | 55   |     | dBc                |
| THD                     | Total harmonic distortion                                                                                       | –1dBFS ADC input, 17dB VGA gain, $f_{in} = 2\text{MHz}$                                        | 54   |     | dBc                |
| IMD                     | Intermodulation distortion                                                                                      | $f_{in1}=1\text{MHz}$ , $f_{in2}=2\text{MHz}$ , $A_{in1, in2} = -7\text{dBFS}$ , 30dB VGA gain | –70  |     | dBFS               |
| Group delay variation   | $f_{in}$ from 100kHz to 14MHz, across gain settings and channels                                                |                                                                                                | ±3.5 |     | ns                 |
|                         | $f_{in}$ from 100kHz to 14MHz, across channels                                                                  |                                                                                                | ±1.5 |     |                    |
| Input overload recovery | ≤6dB overload to within 1%                                                                                      |                                                                                                | 1    |     | Input clock cycles |
| Clamp level             | After amplification. Clamp enabled by default                                                                   |                                                                                                | 3    |     | dB                 |
| ADC number of bits      |                                                                                                                 |                                                                                                | 12   |     |                    |
| Crosstalk               | Aggressor: $f_{in} = 2\text{MHz}$ , 1dB below ADC full-scale<br>Victims (channel sharing same ADC): 50Ω to AVSS |                                                                                                | 65   |     | dB                 |
| <b>POWER</b>            |                                                                                                                 |                                                                                                |      |     |                    |
| Total power dissipation | Default-noise mode                                                                                              |                                                                                                | 633  | 723 | mW                 |
|                         | Low-noise mode                                                                                                  |                                                                                                | 715  | 831 |                    |
| $I_{AVDD3}$             | AVDD3 Current consumption                                                                                       |                                                                                                | 4.7  | 7   | mA                 |
| $I_{AVDD18}$            | AVDD18 Current consumption                                                                                      | Default-noise mode                                                                             | 259  | 290 | mA                 |
|                         |                                                                                                                 | Low-noise mode                                                                                 | 310  | 350 |                    |
| $I_{DVDD18}$            | DVDD18 Current consumption                                                                                      |                                                                                                | 81   | 100 | mA                 |
| Power down              | Standby mode                                                                                                    |                                                                                                | 64   |     | mW                 |
|                         | Full power down mode                                                                                            |                                                                                                | 5    | 30  | mW                 |
| AC PSRR                 | Power-supply rejection ratio                                                                                    |                                                                                                | 30   |     | dBc                |

## DIGITAL CHARACTERISTICS<sup>(1)</sup>

The DC specifications refer to the condition where the digital outputs are not switching, but permanently at a valid logic level 0 or 1. Unless otherwise noted, typical values are at 25°C, min and max values are across full temperature range  $T_{min} = -40^{\circ}\text{C}$  to  $T_{max} = 85^{\circ}\text{C}$ , AVDD3=3.3V, AVDD18=1.8V, DVDD18=1.8V, external differential load resistance between the LVDS output pair  $R_{load}=100\Omega$ .

| PARAMETER                              | TEST CONDITIONS                                                  | MIN | TYP  | MAX | UNIT |
|----------------------------------------|------------------------------------------------------------------|-----|------|-----|------|
| <b>DIGITAL INPUTS</b>                  |                                                                  |     |      |     |      |
| High-level input voltage               |                                                                  | 1.4 |      | 3.6 | V    |
| Low-level input voltage                |                                                                  |     |      | 0.8 | V    |
| High-level input current               |                                                                  |     | 10   |     | μA   |
| Low-level input current                |                                                                  |     | 10   |     | μA   |
| Input Capacitance                      |                                                                  |     | 4    |     | pF   |
| <b>DIGITAL OUTPUTS</b>                 |                                                                  |     |      |     |      |
| High-level output voltage              |                                                                  |     | 1375 |     | mV   |
| Low-level output voltage               |                                                                  |     | 1025 |     |      |
| Output differential voltage $ V_{OD} $ |                                                                  | 270 | 380  | 490 |      |
| Output offset voltage $V_{OS}$         | Common-mode voltage of $D_P$ and $D_M$                           | 0.9 | 1.15 | 1.5 | V    |
| Output capacitance                     | Output capacitance inside the device, from either output to DVSS |     | 2    |     | pF   |

(1) Note: All LVDS specifications have been characterized but not production tested.

## OUTPUT INTERFACE TIMING<sup>(1)</sup>

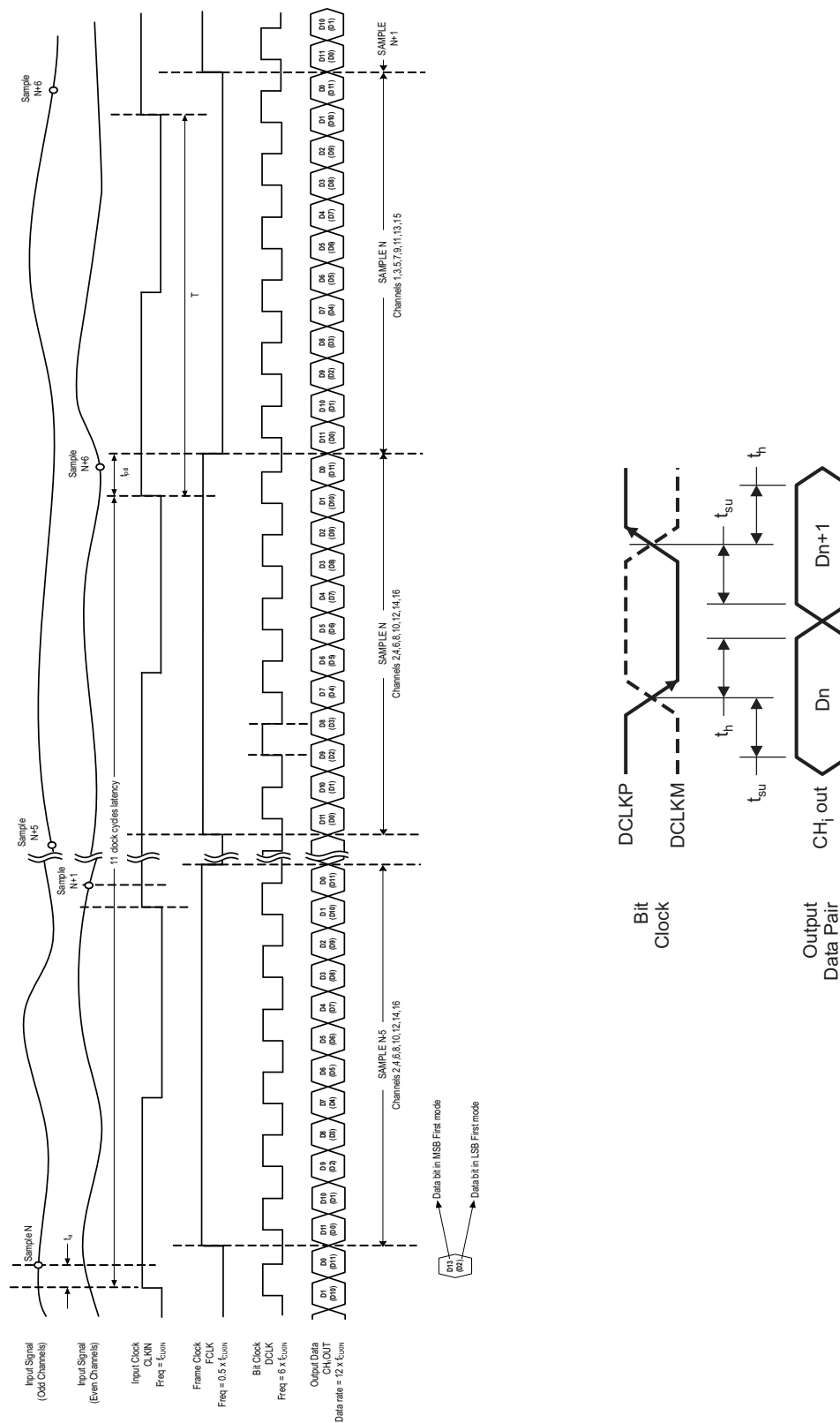
Typical values are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD = 1.8V, LVCMOS (single ended) clock, C<sub>LOAD</sub> = 5pF, R<sub>LOAD</sub> = 100Ω, I<sub>O</sub> = 3.5mA, unless otherwise noted. Minimum and maximum values are across the full temperature range T<sub>MIN</sub> = –40°C to T<sub>MAX</sub> = 85°C.

| PARAMETER                                      | TEST CONDITIONS                                                                                                     | MIN | TYP  | MAX  | UNIT               |
|------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-----|------|------|--------------------|
| t <sub>a</sub>                                 | Aperture delay                                                                                                      | 0.7 | 3    |      | ns                 |
|                                                | Aperture delay matching                                                                                             |     | ±150 |      | ps                 |
| t <sub>j</sub>                                 | Aperture jitter                                                                                                     |     | 450  |      | fs rms             |
| Wake-up time                                   | Time to valid data after coming out of STANDBY mode                                                                 |     | 10   | 50   | μs                 |
|                                                | Time to valid data after coming out of PDN GLOBAL mode                                                              |     | 50   | 200  |                    |
|                                                | Time to valid data after stopping and restarting the input clock                                                    |     | 30   | 200  |                    |
| ADC latency                                    | Default, after reset                                                                                                |     | 11   |      | Input clock cycles |
| t <sub>delay</sub>                             | Input clock rising edge (zero cross) to frame clock rising edge (zero cross) minus half the input clock period (T). | 3   | 4.7  | 6.4  | ns                 |
| t <sub>delay</sub>                             | Variation                                                                                                           | –1  |      | 1    | ns                 |
| t <sub>RISE</sub><br>t <sub>FALL</sub>         | Data rise time<br>Data fall time                                                                                    | 0.1 | 0.25 | 0.4  | ns                 |
| t <sub>FCLKRISE</sub><br>t <sub>FCLKFALL</sub> | Frame clock rise time<br>Frame clock fall time                                                                      | 0.1 | 0.25 | 0.4  | ns                 |
|                                                | Frame clock duty cycle                                                                                              | 48  | 50   | 52   | ns                 |
| t <sub>DCLKRISE</sub><br>t <sub>DCLKFALL</sub> | Bit clock rise time<br>Bit clock fall time                                                                          | 0.1 | 0.2  | 0.35 | ns                 |
|                                                | Bit clock duty cycle                                                                                                | 44% | 50%  | 56%  |                    |

**Table 1. Output Interface Timing<sup>(1)</sup>**

| fCLKIN, Input Clock Frequency<br>[2x Channel Sampling frequency] | Period (T) | Setup Time (tsu), ns                             |      |     | Hold Time (th), ns                               |      |     | tpdi = 0.5 × Ts + tdelay, ns                                             |       |     |
|------------------------------------------------------------------|------------|--------------------------------------------------|------|-----|--------------------------------------------------|------|-----|--------------------------------------------------------------------------|-------|-----|
| MHz                                                              | ns         | Zero-Cross Data to Zero-Cross Clock (both edges) |      |     | Zero-Cross Clock to Zero-Cross Data (both edges) |      |     | Input Clock Zero-Cross (rise edge) to Frame Clock Zero-Cross (rise-edge) |       |     |
|                                                                  |            | MIN                                              | TYP  | MAX | MIN                                              | TYP  | MAX | MIN                                                                      | TYP   | MAX |
| 65                                                               | 15         | 0.35                                             | 0.65 |     | 0.3                                              | 0.6  |     |                                                                          | 12.35 |     |
| 50                                                               | 20         | 0.5                                              | 0.8  |     | 0.5                                              | 0.8  |     |                                                                          | 14.6  |     |
| 40                                                               | 25         | 0.75                                             | 1.05 |     | 0.75                                             | 1.05 |     |                                                                          | 17.04 |     |
| 30                                                               | 33         | 1                                                | 1.4  |     | 1                                                | 1.4  |     |                                                                          | 21.19 |     |
| 20                                                               | 50         | 1.7                                              | 2.1  |     | 1.7                                              | 2.1  |     |                                                                          | 29.52 |     |
| 10                                                               | 100        | 3.8                                              | 4.2  |     | 3.8                                              | 4.2  |     |                                                                          | 54.71 |     |

(1) See timing diagrams on the following page.



## TYPICAL CHARACTERISTICS

All graphs are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle,  $f_{IN} = 2\text{MHz}$ , anti-aliasing filter set at 14MHz (3dB corner), output clamp disable and analog high-pass filter enabled.

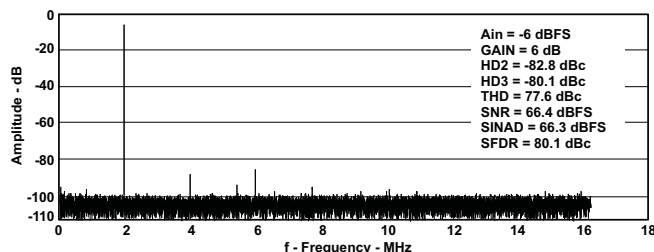


Figure 1. FFT for 2MHz Input Signal and 6dB Gain

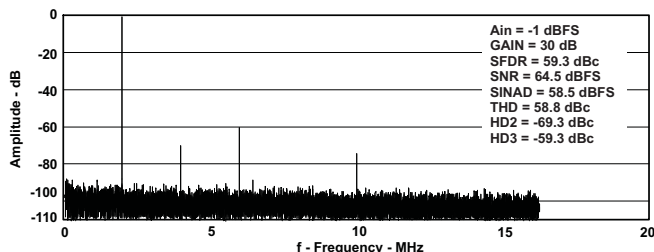


Figure 2. FFT for 2MHz Input Signal and 30dB Gain

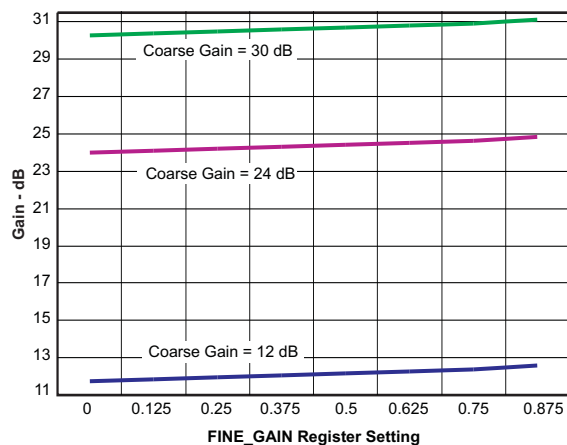


Figure 3. Fine Gain versus Gain Code

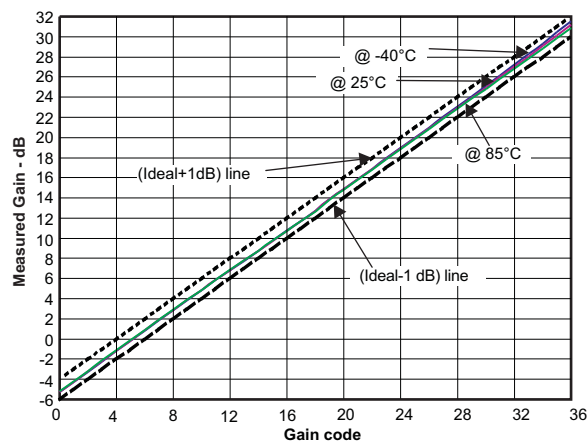


Figure 4. Measured Gain versus Gain Code and Temperature

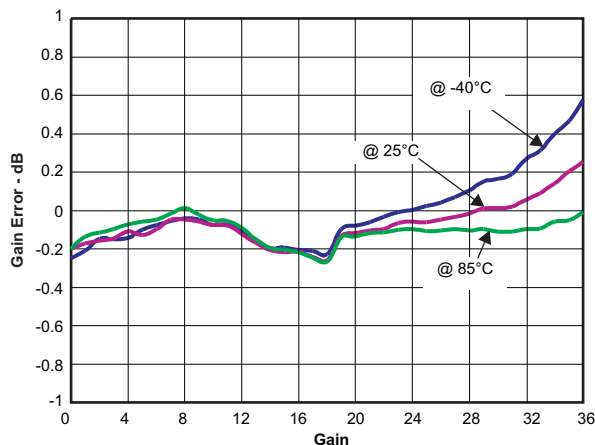


Figure 5. Gain Error versus Gain Code and Temperature

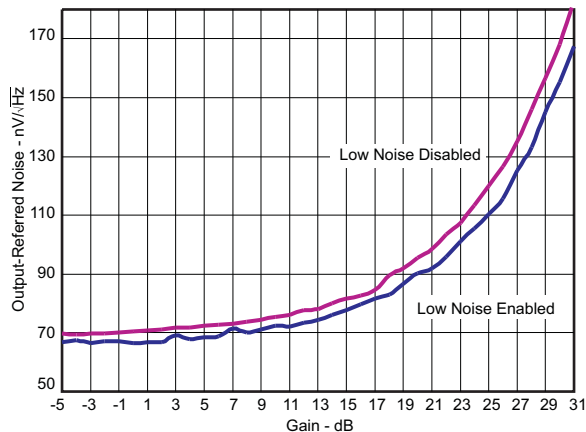


Figure 6. Output-Referred Noise versus Gain

### TYPICAL CHARACTERISTICS (continued)

All graphs are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle,  $f_{IN} = 2\text{MHz}$ , anti-aliasing filter set at 14MHz (3dB corner), output clamp disable and analog high-pass filter enabled.

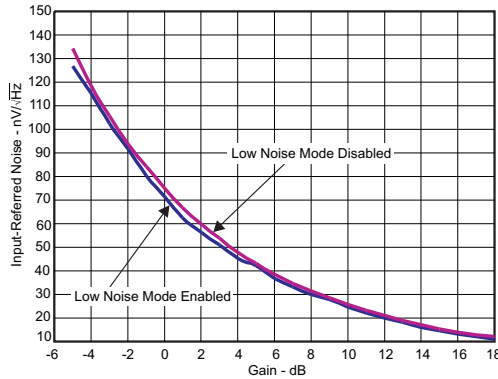


Figure 7. Input-Referred Noise for Low Gains

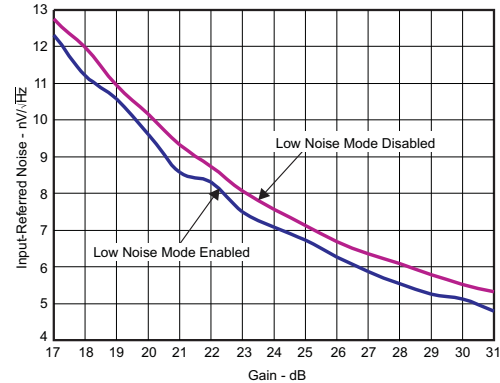
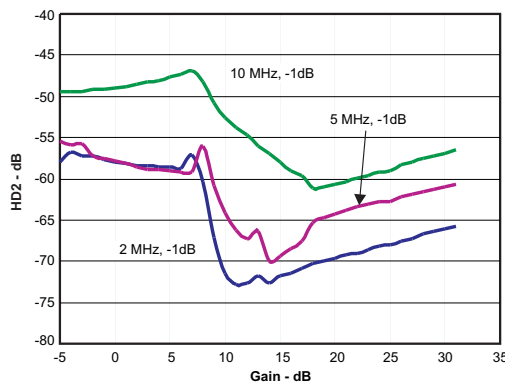
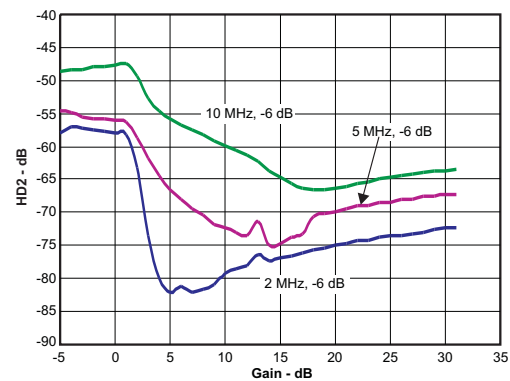
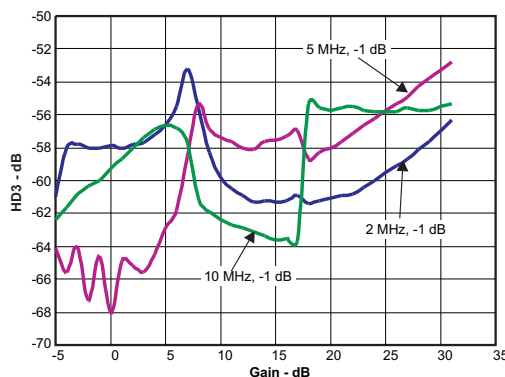
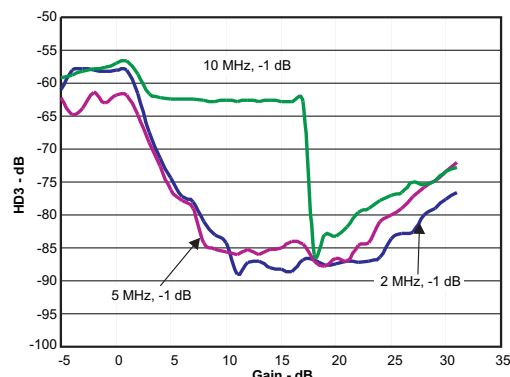


Figure 8. Input-Referred Noise for High Gains

Figure 9. HD2 Across Coarse Gain and 3 Fin (–1dBFS)<sup>(1)</sup>Figure 10. HD2 Across Coarse Gain and 3 Fin (–6dBFS)<sup>(2)</sup>Figure 11. HD3 Across Coarse Gain and 3 Fin (–1dBFS)<sup>(1)</sup>Figure 12. HD3 Across Coarse Gain and 3 Fin (–6dBFS)<sup>(2)</sup>

- (1) For gains  $\geq 5\text{dB}$ , the input amplitude is adjusted to give –1dBFS. At 5dB gain, input amplitude is 4dBm (corresponding to –1dBFS). For gains less than 5dB, the input is kept constant at 4dBm.
- (2) For gains  $\geq 0\text{dB}$ , the input amplitude is adjusted to give –6dBFS. At 0dB gain, input amplitude is 4dBm (corresponding to –6dBFS). For gains less than 0dB, the input is kept constant at 4dBm.

## TYPICAL CHARACTERISTICS (continued)

All graphs are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle,  $f_{IN} = 2\text{MHz}$ , anti-aliasing filter set at 14MHz (3dB corner), output clamp disable and analog high-pass filter enabled.

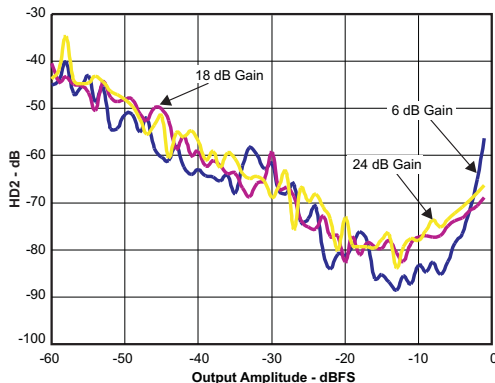


Figure 13. HD2 versus Output Amplitude

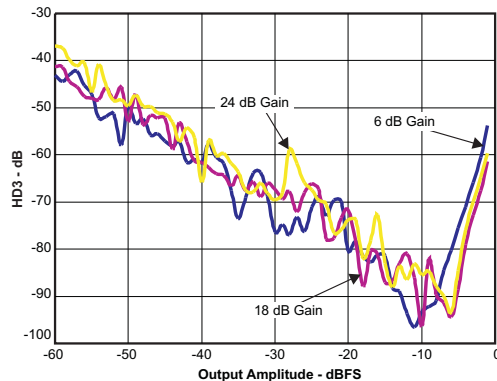


Figure 14. HD3 versus Output Amplitude

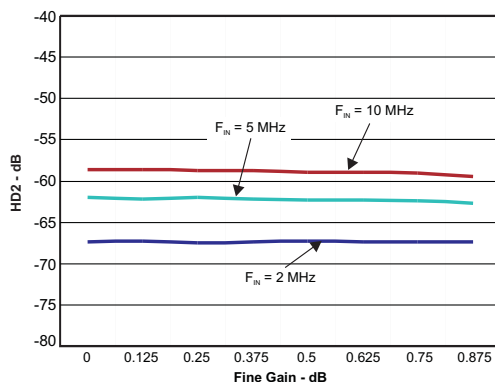


Figure 15. HD2 (at 24 dB Gain) Across Fine Gain

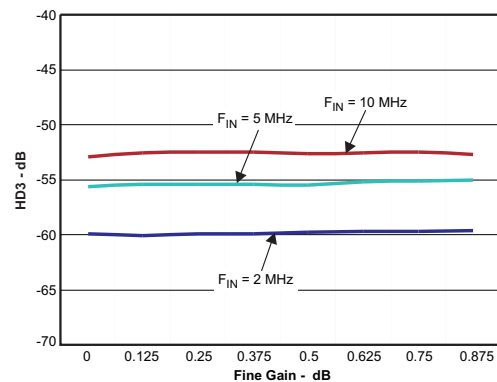


Figure 16. HD3 (at 24 dB Gain) Across Fine Gain

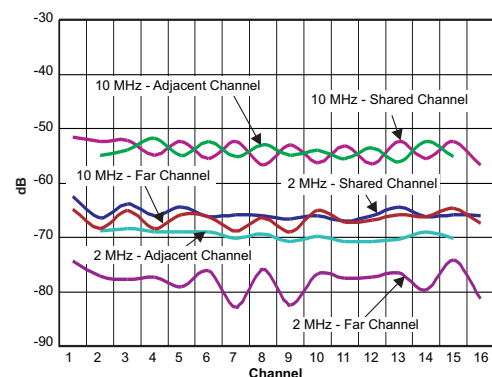


Figure 17. Crosstalk<sup>(3)</sup>

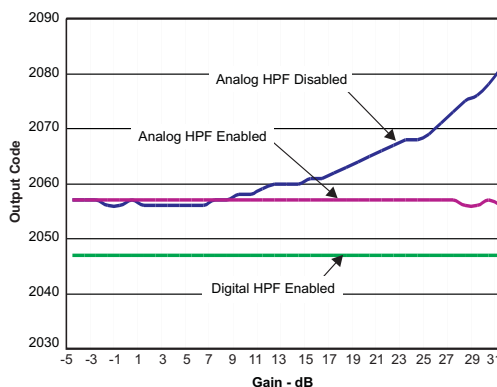


Figure 18. Output Offset Across TGC Gain

- (3) -1dB signal applied on one channel at a time and output is observed on:
1. Shared channel - second channel in the pair having a common ADC
  2. Adjacent channel - channel next to the aggressor channel, but not a shared channel
  3. Far channel - all other channels (neither shared or adjacent)

### TYPICAL CHARACTERISTICS (continued)

All graphs are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle,  $f_{IN} = 2\text{MHz}$ , anti-aliasing filter set at 14MHz (3dB corner), output clamp disable and analog high-pass filter enabled.

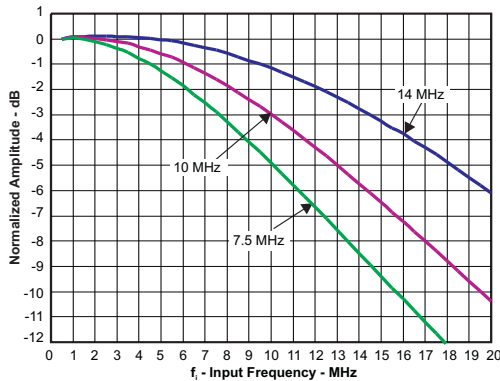


Figure 19. Antialiasing Filter Frequency Response

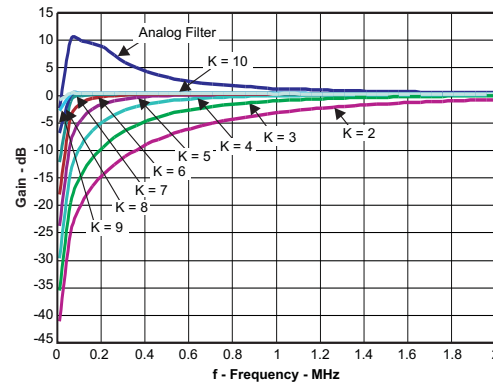


Figure 20. Highpass Filter Options

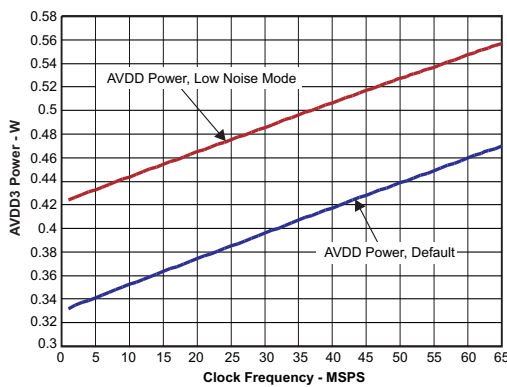


Figure 21. Analog Power versus Input Clock Frequency

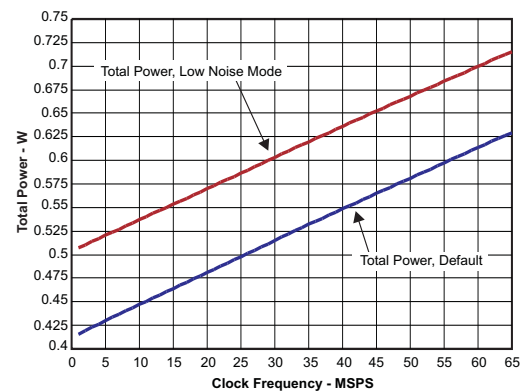


Figure 22. Total Power versus Input Clock Frequency

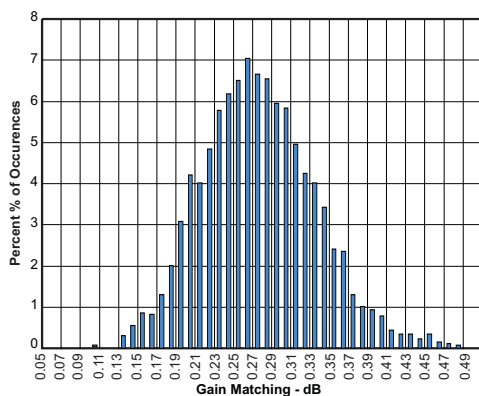


Figure 23. Gain Matching Measured at a Single Gain (30 dB) as Peak-to-Peak Variation of Gain Across Channels on Every Device and Measured at 3 Temperatures. Every Device at Each Temperature is Counted as One Event.

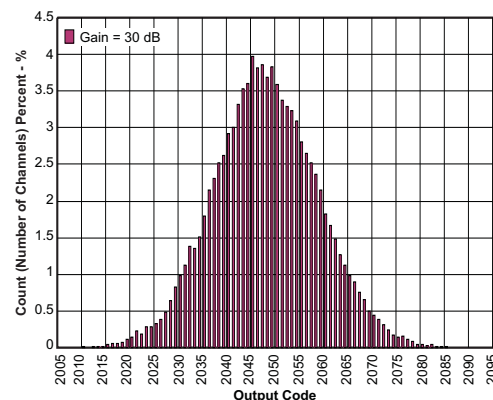


Figure 24. Offset (Average Code) with Signal. Every Channel Counted as One Event.

## TYPICAL CHARACTERISTICS (continued)

All graphs are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V, –1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle,  $f_{IN} = 2\text{MHz}$ , anti-aliasing filter set at 14MHz (3dB corner), output clamp disable and analog high-pass filter enabled.

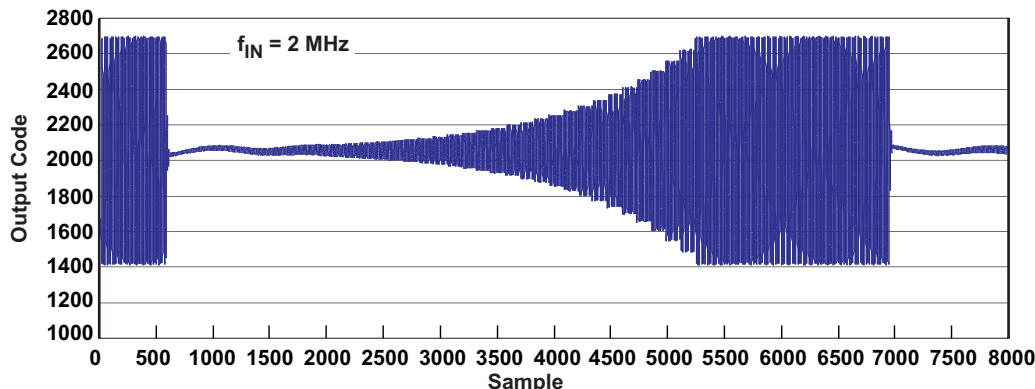


Figure 25. TGC Sweep with Interpolation Disabled and High-Pass Filter Enabled

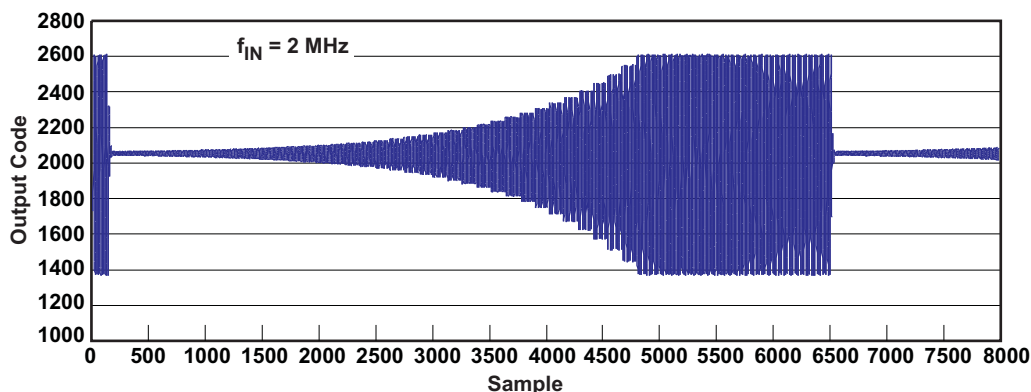


Figure 26. TGC Sweep with Interpolation Disabled and High-Pass Filter Disabled

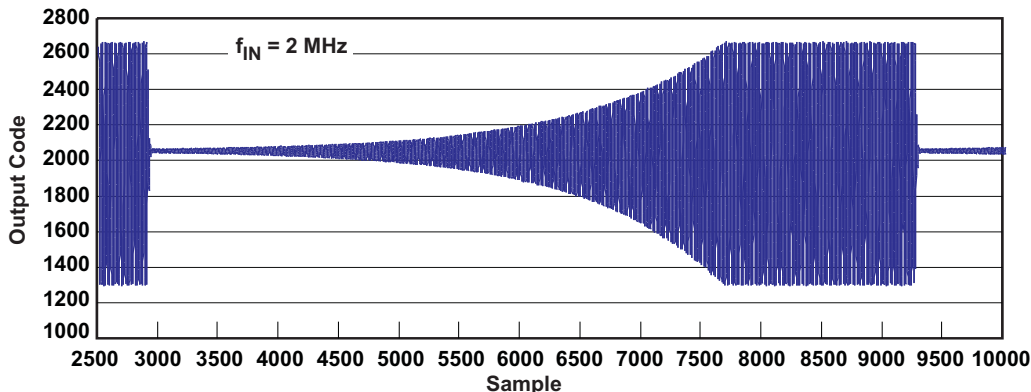


Figure 27. TGC Sweep with Interpolation Enabled and High-Pass Filter Disabled

### TYPICAL CHARACTERISTICS (continued)

All graphs are at 25°C, AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V, -1dBFS analog input AC coupled with 0.1μF, internal reference mode, maximum rated channel sampling frequency (32.5 MSPS), LVCMOS (single-ended) clock, 50% duty cycle,  $f_{IN} = 2\text{MHz}$ , anti-aliasing filter set at 14MHz (3dB corner), output clamp disable and analog high-pass filter enabled.

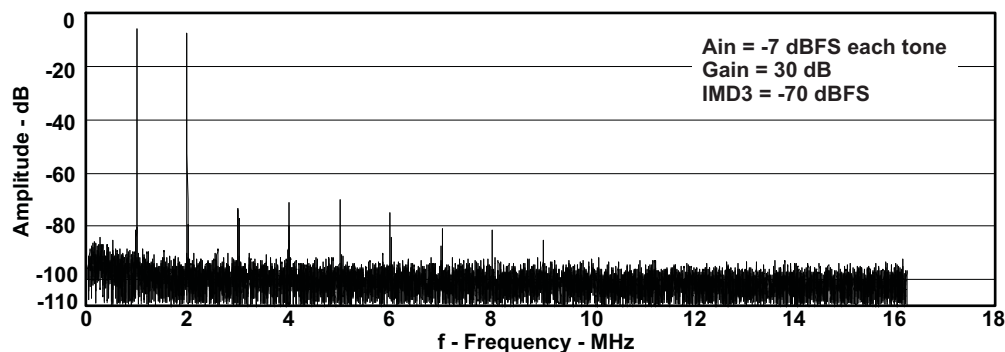


Figure 28. Intermodulation Distortion

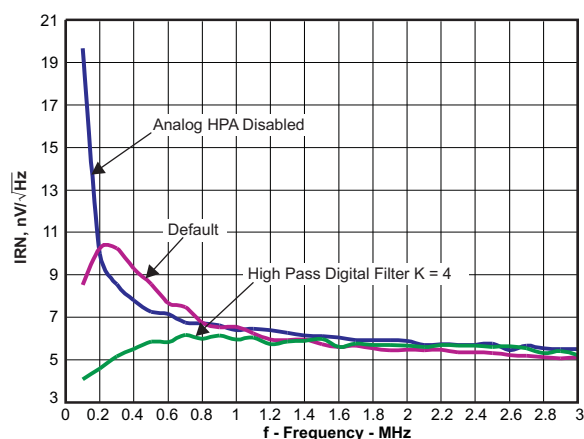


Figure 29. IRN versus Frequency (Gain = 31dB)

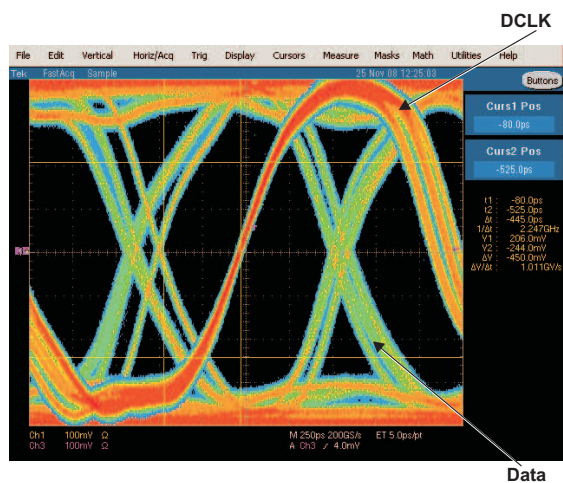


Figure 30. LVDS Eye Pattern

## APPLICATION INFORMATION

### THEORY OF OPERATION

The AFE5851 is a low power CMOS monolithic analog front end that includes a 16-channel variable gain amplifier (VGA) followed by an 8-channel 12-bit high speed pipeline analog to digital converter (ADC) based on switched capacitor architecture.

Each of the 16 VGA single ended inputs is buffered and accepts a maximum swing of  $1V_{PP}$  centered at a DC level (VCM) of about 1.6V.

Each VGA has a gain range from –5dB to 31dB and it is digitally controlled, with a resolution of 0.125 dB. The gain curves (common to all VGAs) versus time can be stored in memory integrated within the device using the serial interface.

A hardware sync input pin is available (SYNC). When a pulse is applied to this pin, all the VGAs in the device start stepping through the selected time-gain curve at the same clock cycle. This sync can also be initiated by software using the serial interface.

A selectable anti-alias low pass filter (AAF) with 6 dB attenuation at 7.5MHz, 10MHz or 14MHz, is also integrated, together with clamping (which can be disabled).

The VGA/AAF can output  $2V_{PP}$  differential swing without degradation in the specified linearity, and drive an on-board 12-bit ADC shared between two VGAs to optimize power dissipation. Each VGA output is sampled at the rising edge of alternating clock cycles, making the effective sampling frequency half the input clock rate. For instance, in order to sample each analog channel at 30 MSPS, the input clock frequency needs to be 60 MHz. This effectively introduces a half (sampling) clock delay between the sampling instants of the two analog channels.

After the input signals are captured by the sample and hold circuit, the samples are sequentially converted by a series of low resolution stages. The stage outputs are combined in a digital correction logic block to form the final 12-bit word with a latency of 11 clock cycles (without taking into account the delays introduced by the optional digital signal processing functions). The 12-bit words of each channel are serialized and output as LVDS levels in straight offset binary format. In addition to the data streams, a bit clock and frame clock are also output. The frame clock is aligned with the 12-bit word boundary.

Notice that for the correct operation of the device (see Serial Interface Section) a positive pulse must be applied to the Reset pin. This sets the internal control registers to zero. There is, nevertheless, no need for any type of power-up sequencing.

### INPUT CONFIGURATION

The analog input for the AFE5851 ([Figure 31](#)) consists of an analog buffer input gate biased to a value of 1.6V (usually referred as voltage common mode, VCM). The biasing is done with an internal resistor of 5k $\Omega$ . For proper operation, the input signal should be in the recommended input range. The maximum input swing is limited to  $1V_{PP}$  before distortion/saturation of the input stage occurs. As the input DC level (VCM) is about 1.6V, the input of the VGA should stay between 1.1V and 2.1V. If the information in the low frequencies of the signal is irrelevant AC coupling can be used. As the input capacitor forms a high-pass filter with the internal bias resistor (5k $\Omega$ ), the value of the capacitor should allow the lowest frequency of interest to pass with minimum attenuation. For the typical frequencies used in ultrasound (>1MHz) a value of 10nF or greater is recommended. If DC coupling is preferred, the user can tap the VCM output pins to set the DC level of the input signal. VCM output should be connected to high input impedance circuits as its driving capability is limited. Regardless of the chosen input configuration, a capacitor of 100nF should be connected on each VCM input to AVSS.

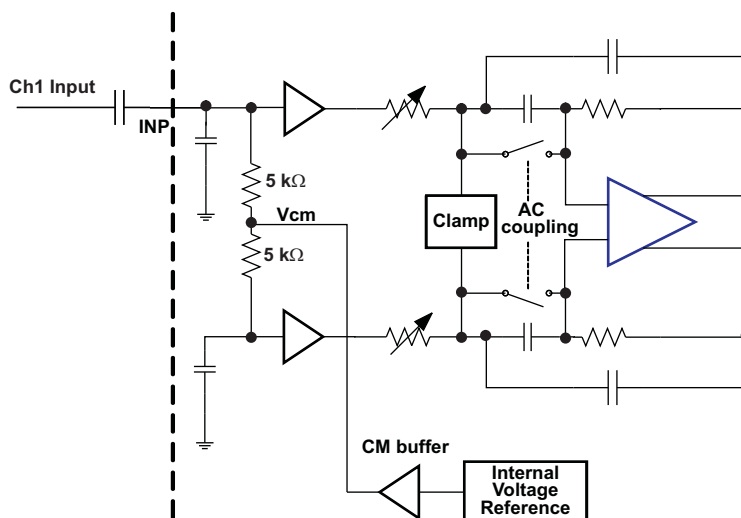


Figure 31. Input Equivalent Circuit

## SERIAL INTERFACE

### Register Initialization

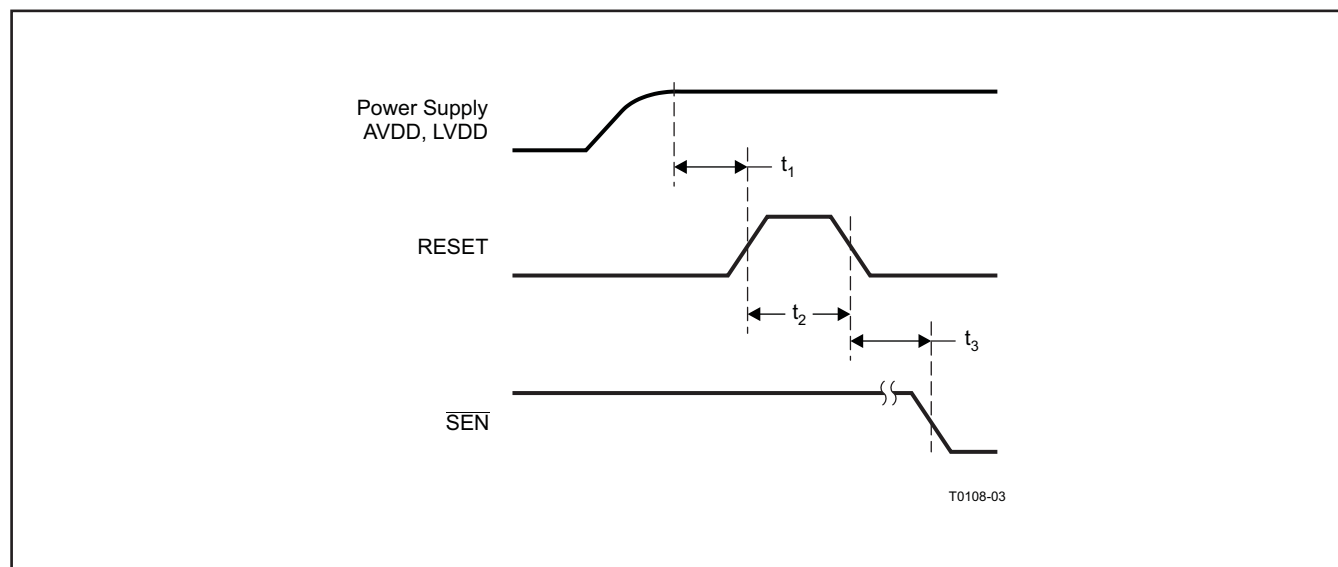
After power-up, the internal registers must be initialized to the default value (zero). Initialization can be done in one of two ways:

1. Through a hardware reset, by applying a positive pulse in the RESET pin
2. Through a software reset, using the serial interface, by setting the SOFTWARE RESET bit to high. Setting this bit initializes the internal registers to the respective default values (all zeros) and then self-resets the SOFTWARE RESET bit to low. In this case, the RESET pin can stay low (inactive).

### Reset Timing

Typical values at 25°C, min and max values across the full temperature range  $T_{MIN} = -40^{\circ}\text{C}$  to  $T_{MAX} = 85^{\circ}\text{C}$ , AVDD3 = 3.3V, AVDD18 = DVDD18 = 1.8V unless otherwise noted.

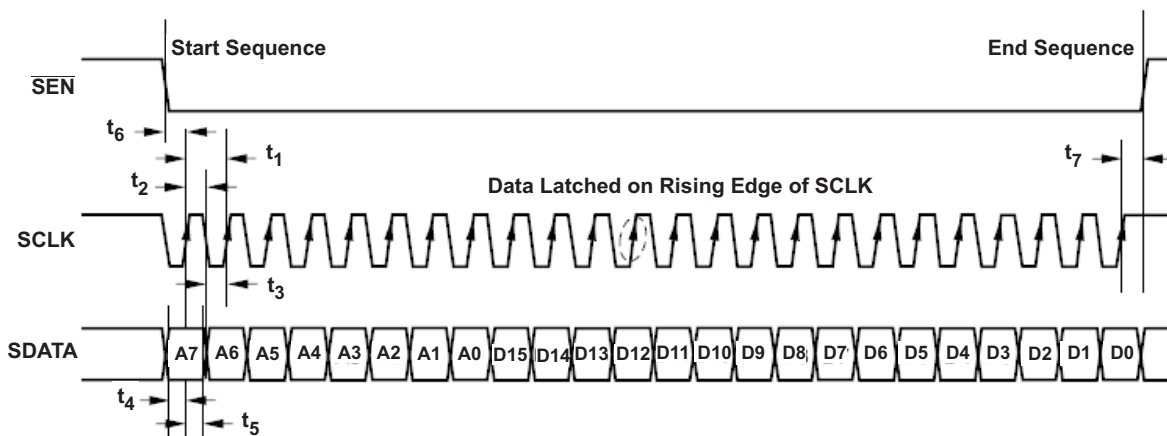
| PARAMETER | CONDITIONS                | MIN                                                        | TYP | MAX | UNIT |
|-----------|---------------------------|------------------------------------------------------------|-----|-----|------|
| $t_1$     | Power-on delay time       | Delay from power-up of AVDD and LVDD to RESET pulse active |     |     | ms   |
| $t_2$     | Reset pulse width         | Pulse width of active RESET signal                         |     |     | ns   |
| $t_3$     | Register write delay time | Delay from RESET disable to SEN active                     |     |     | ns   |
| $t_{PO}$  | Power-up delay time       | Delay from power-up of AVDD and LVDD to output stable      |     |     | ms   |



**Figure 32. Reset Timing Diagram**

Programming of different modes can be done through the serial interface formed by pins  $\overline{\text{SEN}}$  (serial interface enable), SCLK (serial interface clock),  $\overline{\text{SDATA}}$  (serial interface data) and RESET. SCLK and  $\overline{\text{SDATA}}$  have a pull-down resistor to GND of 100k $\Omega$  and  $\overline{\text{SEN}}$  has a 100k $\Omega$  pullup resistor to DVDD18. Serial shift of bits into the device is enabled when  $\overline{\text{SEN}}$  is low. Serial data  $\overline{\text{SDATA}}$  is latched at every rising edge of SCLK when  $\overline{\text{SEN}}$  is active (low). The serial data is loaded into the register at every 24th SCLK rising edge when  $\overline{\text{SEN}}$  is low. If the word length exceeds a multiple of 24 bits, the excess bits are ignored. Data can be loaded in multiple of 24-bit words within a single active  $\overline{\text{SEN}}$  pulse (there is an internal counter that counts groups of 24 clocks after the falling edge of  $\overline{\text{SEN}}$ ). The interface can work with the SCLK frequency from 20 MHz down to low speeds (few Hertz) and even with non-50% duty cycle SCLK.

The data is divided into two main portions: a register address (8 bits) and the data itself, to load on the addressed register (16bits). When writing to a register with unused bits, these should be set to 0. The following timing diagram illustrates this process:



**Figure 33. Serial Interface Register Write**

Minimum values across the full temperature range,  $T_{\text{MIN}} = -40^{\circ}\text{C}$  to  $T_{\text{MAX}} = 85^{\circ}\text{C}$ ,  $\text{AVDD3} = 3.3\text{V}$ ,  $\text{AVDD18} = \text{DVDD18} = 1.8\text{V}$ .

| PARAMETER | DESCRIPTION                                           | MIN | TYP | MAX | UNIT |
|-----------|-------------------------------------------------------|-----|-----|-----|------|
| $t_1$     | SCLK period                                           | 50  |     |     | ns   |
| $t_2$     | SCLK high time                                        | 20  |     |     | ns   |
| $t_3$     | SCLK low time                                         | 20  |     |     | ns   |
| $t_4$     | Data setup time                                       | 5   |     |     | ns   |
| $t_5$     | Data hold time                                        | 5   |     |     | ns   |
| $t_6$     | SEN fall to SCLK rise                                 | 8   |     |     | ns   |
| $t_7$     | Time between last SCLK rising edge to SEN rising edge | 8   |     |     | ns   |

### General Purpose Register Map

The internal registers can be divided into two groups. A group of registers to control all the general functions and settings of the device, and a bank of registers to control the TGC/gain curves operation. Those two sets of registers overlap in all the address space, except for the address 0 which holds the control of the register bank. One of the bits of this register, TGC\_REG\_WREN (see table below) is used to access one set of registers or the other. Its default value is zero and gives access to the general purpose registers. The TGC control registers (described after the general purpose registers) can be accessed by writing '1' to TGC\_REG\_WREN.

The following table describes the function of the general purpose registers (when TGC\_REGISTER\_WREN is zero, default). The address format is "address[bit of the register]":

| ADDRESS   | FUNCTION                            | DESCRIPTION                                                                                                                                                         |
|-----------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0[2]      | TGC_REGISTER_WREN                   | 0: Access to general-purpose registers. 1: Access to TGC registers                                                                                                  |
| 0[1]      | REGISTER_READOUT_ENABLE             | 1: Enables readout of the registers                                                                                                                                 |
| 0[0]      | SOFTWARE_RESET                      | 1: Resets the device and self-resets the bit to zero                                                                                                                |
| 1[13]     | EXTERNAL_REFERENCE                  | 0: Internal reference. 1: External reference                                                                                                                        |
| 1[11]     | LOW_FREQUENCY_NOISE_SUPPRESSION     | 0: No suppression. 1: Suppresses noise at low frequencies and pushes it to $f_{\text{channel}}/2$                                                                   |
| 1[10]     | STDBY                               | 0: Power up. 1: Standby (fast power-up mode)                                                                                                                        |
| 1[9:2]    | PDN_CHANNEL<7:0>                    | PDN for each individual channel (VCA+ADC). LVDS outputs logic 0.                                                                                                    |
| 1[1]      | OUTPUT_DISABLE                      | 0: Output enabled. 1: Output disabled                                                                                                                               |
| 1[0]      | GLOBAL_PDN                          | 0: Power up. 1: Global power down (slow power-up mode)                                                                                                              |
| 2[15:13]  | PATTERN_MODE                        | Pattern modes for serial LVDS. 000: No pattern. 001: Sync. 010: Deskew. 011: Custom reg. 100: All 1s. 101: toggle. 110: All 0s. 111: Ramp                           |
| 2[11]     | AVERAGING_ENABLE                    | 0: Default (no averaging). 1: Average two channels to increase SNR.                                                                                                 |
| 2[10:3]   | PDN_LVDS                            | Power down the eight data-output LVDS pairs.                                                                                                                        |
| 3[14:13]  | SERIALIZED_DATA_RATE                | Serialization factor. 00: 12×. 01: 10×. 10: 16×. 11: 14×                                                                                                            |
| 3[12]     | DIGITAL_GAIN_ENABLE                 | 0: Default (no gain). 1: Apply digital gain set by the following registers.                                                                                         |
| 3[8]      | REGISTER_OFFSET_SUBTRACTION_ENABLE  | 0: Default (no subtraction). 1: Subtract offset value set in the corresponding registers.                                                                           |
| 4[3]      | DFS                                 | Data format select. 0: 2s complement. 1: Offset binary                                                                                                              |
| 5[13:0]   | CUSTOM_PATTERN                      | Custom pattern data for LVDS (PATTERN_MODE = 011)                                                                                                                   |
| 7[10]     | VCA_LOW_NOISE_MODE_(INCREASE_POWER) | 0: Low power. 1: Low noise, at the expense of increased power (5mW per channel)                                                                                     |
| 7[8:7]    | SELF_TEST                           | 00, 10: No self-test. 01: Self-test enabled. 100 mV DC applied to the input of the channels. 11: Self-test enabled. 150 mV DC applied to the input of the channels. |
| 7[3:2]    | FILTER_BW                           | 00: 14MHz. 01: 10MHz. 10: 7.5MHz. 11: Not used.                                                                                                                     |
| 7[1]      | INTERNAL_AC_COUPLING                | VGA coupling. 0: AC-coupled. 1: DC-coupled                                                                                                                          |
| 13[15:11] | DIG_GAIN1                           | 0dB to 6dB in steps of 0.2dB                                                                                                                                        |
| 13[9:2]   | OFFSET_CH1                          | Value to be subtracted from channel 1                                                                                                                               |
| 14[15:11] | DIG_GAIN2                           | 0dB to 6dB in steps of 0.2dB                                                                                                                                        |

| ADDRESS   | FUNCTION                                              | DESCRIPTION                                                                                                            |
|-----------|-------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| 14[9:2]   | OFFSET_CH2                                            | Value to be subtracted from channel 2                                                                                  |
| 15[15:11] | DIG_GAIN3                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 15[9:2]   | OFFSET_CH3                                            | Value to be subtracted from channel 3                                                                                  |
| 16[15:11] | DIG_GAIN4                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 16[9:2]   | OFFSET_CH4                                            | Value to be subtracted from channel 4                                                                                  |
| 17[15:11] | DIG_GAIN5                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 17[9:2]   | OFFSET_CH5                                            | Value to be subtracted from channel 5                                                                                  |
| 18[15:11] | DIG_GAIN6                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 18[9:2]   | OFFSET_CH6                                            | Value to be subtracted from channel 6                                                                                  |
| 19[15:11] | DIG_GAIN7                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 19[9:2]   | OFFSET_CH7                                            | Value to be subtracted from channel 7                                                                                  |
| 20[15:11] | DIG_GAIN8                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 20[9:2]   | OFFSET_CH8                                            | Value to be subtracted from channel 8                                                                                  |
| 21[4:1]   | DIGITAL_HIGH_PASS_FILTER_CORNER_FREQ_FOR_CHANNELS_1–4 | Sets k for the high-pass filter as described in <a href="#">General-Purpose Register Description</a> (k from 2 to 10). |
| 21[0]     | DIGITAL_HIGH_PASS_FILTER_ENABLE_FOR_CHANNELS_1–4      | 0: No high-pass filter. 1: High-pass filter enabled                                                                    |
| 25[15:11] | DIG_GAIN15                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 25[9:2]   | OFFSET_CH15                                           | Value to be subtracted from channel 16                                                                                 |
| 26[15:11] | DIG_GAIN16                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 26[9:2]   | OFFSET_CH16                                           | Value to be subtracted from channel 15                                                                                 |
| 27[15:11] | DIG_GAIN13                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 27[9:2]   | OFFSET_CH13                                           | Value to be subtracted from channel 14                                                                                 |
| 28[15:11] | DIG_GAIN14                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 28[9:2]   | OFFSET_CH14                                           | Value to be subtracted from channel 13                                                                                 |
| 29[15:11] | DIG_GAIN11                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 29[9:2]   | OFFSET_CH11                                           | Value to be subtracted from channel 12                                                                                 |
| 30[15:11] | DIG_GAIN12                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 30[9:2]   | OFFSET_CH12                                           | Value to be subtracted from channel 11                                                                                 |
| 31[15:11] | DIG_GAIN9                                             | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 31[9:2]   | OFFSET_CH9                                            | Value to be subtracted from channel 10                                                                                 |
| 32[15:11] | DIG_GAIN10                                            | 0dB to 6dB in steps of 0.2dB                                                                                           |
| 32[9:2]   | OFFSET_CH10                                           | Value to be subtracted from channel 9                                                                                  |
| 33[4:1]   | DIGITAL_HIGH_PASS_FILTER_CORNER_FREQ_FOR_CHANNELS_5–8 | Sets k for the high-pass filter as described in <a href="#">General-Purpose Register Description</a> (k from 2 to 10). |
| 33[0]     | DIGITAL_HIGH_PASS_FILTER_ENABLE_FOR_CHANNELS_5–8      | 0: No high-pass filter. 1: High-pass filter enabled                                                                    |
| 70[14]    | CLAMP_DISABLE                                         | 0: Enabled. 1: Disabled                                                                                                |

## General Purpose Register Description

### **AVERAGING\_ENABLE**

Address: 2[11]

When set to one, two samples, corresponding to two different channels on the same pair, are averaged (channel 1 with 3, 2 with 4, 5 with 7, 6 with 8, 9 with 11, 10 with 12, 13 with 15 and 14 with 16). If both channels receive the same input, the net effect is an improvement on SNR. The averaging is performed as:

1. Channel 1 with channel 3 comes out on channel 3 LVDS pair, followed by the average of channels 2 and 4 (on the same pair).
2. Channel 5 with channel 7 comes out on channel 4 LVDS pair, followed by the average of channels 6 and 8 (on the same pair).
3. Channel 9 with channel 11 comes out on channel 5 LVDS pair, followed by the average of channels 10 and 12 (on the same pair).
4. Channel 13 with channel 15 comes out on channel 6 LVDS pair, followed by the average of channels 14 and 16 (on the same pair).

### **CUSTOM\_PATTERN**

Address: 5[13:0]

This register stores the code that will be output when PATTERN\_MODE equal to '011'. See PATTERN\_MODE for more details.

### **DFS**

Address: 4[3]

DFS stands for Data Format Select. The ADC output, by default, is in 2s complement mode. Programming the DFS bit to '1' inverts the MSB, and the output becomes straight offset binary mode.

### **DIGITAL\_GAIN\_ENABLE**

Address: 3[12]

Setting this bit to '1' applies to each channel *i* the corresponding gain given by DIG\_GAIN<sub>*i*</sub><15:11>. The gain is given as 0dB+0.2dB\*DIG\_GAIN<sub>*i*</sub><15:11>. For instance, if DIG\_GAIN<sub>5</sub><15:11>=3, channel 5 is increased by 0.6dB gain. DIG\_GAIN<sub>*i*</sub><15:11>=31 produces the same effect as DIG\_GAIN<sub>*i*</sub><15:11>=30 setting the gain of channel *i* to 6dB.

### **DIGITAL\_HIGH\_PASS\_FILTER and DIGITAL\_HIGH\_PASS\_FILTER\_CORNER\_FREQ**

Address: 21[0]

Address: 33[0]

Address: 21[4:1]

Address: 33[4:1]

This group of 4 registers controls the characteristics of a digital high pass transfer function applied to the output data, following the formula:  $y(n) = 2^k / (2^k + 1) [x(n) - x(n-1) + y(n-1)]$ . *K* is set as described by the DIGITAL\_HIGH\_PASS\_FILTER\_CORNER\_FREQ registers (one for the first 8 channels and one for the second group of 8 channels).

### **EXTERNAL\_REFERENCE**

Address: 1[13]

Internal reference mode (default) uses approximately 3mW more power on AVDD (already included in all the specification tables). The AFE5851 can operate in external reference mode by programming EXTERNAL\_REFERENCE to '1'. In this mode, drive the VREF\_IN pin with 1.4V. Due to the high input impedance of this pin, no special drive capabilities are required. The advantage of using the external reference mode is that multiple AFE5851 units can be made to operate with the same external reference, thereby improving parameters such as gain matching across devices.

### **FILTER\_BW**

Address: 7[3:2]

This bit sets the 3dB attenuation frequency for the anti-aliasing filter (AAF).

### GLOBAL\_PDN

Address: 1[0]

The Global PDN bit is ORed with the signal in the external PDN pin (59). Hereby, a '1' on this bit shuts down the device completely.

### INTERNAL\_AC\_COUPLING

Address: 7[1]

This bit controls an internal high pass filter, [Figure 31](#), set between the input buffer and the VCA. This filter removes the input offset to avoid its amplification by the TGC. An alternative method is to remove the offset effect on the digital domain, either on the device following the ADC or at the ADC output, by using the DIGITAL HIGH PASS FILTER registers (see above).

### LOW\_FREQUENCY\_NOISE\_SUPPRESSION

Address: 0[11]

low-frequency noise suppression mode is specifically useful in applications where good noise performance is desired in the frequency band of 0MHz to 1MHz (around DC). Setting this mode shifts the low-frequency noise of the ADC in the AFE5851 to approximately  $f_{channel}/2$ , thereby reducing the noise floor around DC to a much lower value.

### OUTPUT\_DISABLE

Address: 1[1]

A '1' on this bit sets the outputs into high-impedance state.

### PATTERN\_MODE

Address: 2[15:13]

AFE5851 can output a variety of test patterns on the LVDS outputs. These test patterns replace the normal ADC data output and help on debugging and synchronization with the device reading the output of the ADC:

1. PATTERN\_MODE equal to '000' is the default and disables this test mode, i.e., the output data is the same as the ADC data.
2. PATTERN\_MODE equal to '001' (SYNC mode) replaces the normal ADC word by a fixed 111111000000 word.
3. PATTERN\_MODE equal to '010' sets the DESKEW mode, where the 12-bit ADC output  $D<11:0>$  is replaced with the '101010101010' word, creating a continuous stream of ones and zeros in the data line. The exact sequence (first a zero or a one) depends on power-up. This mode only ensures alternating ones and zeros at the output.
4. PATTERN\_MODE equal to '011' will output a constant code set by the bits in CUSTOM\_PATTERN<13:0>. Depending on the value of SERIALIZED\_DATA\_RATE (see below) the output bits follow these rules:
  - (a) On the default case, where SERIALIZED\_DATA\_RATE is '00', for a 12-bit ADC data at the output, CUSTOM\_PATTERN<13:2> would be used, replacing the sampled data. These would still be controlled by LSB-first and MSB-first modes in the same way as normal ADC data are.
  - (b) For SERIALIZED\_DATA\_RATE= '01', 10-bit output mode is selected, and bits CUSTOM\_PATTERN<13:4> are used.
  - (c) For SERIALIZED\_DATA\_RATE= '10', 16-bit output mode is selected. On this case, CUSTOM\_PATTERN<13:0> are used for the first 14 most significant bits, and two zeros take the place of the LSBs.
  - (d) For SERIALIZED\_DATA\_RATE= '11', 14-bit mode is selected, and CUSTOM\_PATTERN<13:0> takes the place of the output word.
5. PATTERN\_MODE equal to '100' makes it always '1', while setting it to '110' makes the output always '0'.
6. PATTERN\_MODE equal to '101' makes the output of the device toggle between all zeros and all ones. On the  $n$ th sample clock, the data would be '000000000000' and on the following one ( $n+1$ ) it would be '111111111111'.
7. PATTERN\_MODE equal to '111' causes all the channels to output a repeating full-scale ramp pattern. The ramp increments from zero code to full-scale code in steps of 1LSB every clock cycle. After hitting the full-scale code, it returns back to zero code and ramps again.

***PDN\_Channel<7:0>***

Address: 1[9:2]

Each bit controls the power down of a pair of consecutive channels (that share the same ADC). For example: PDN\_Channel<0> powers down channels 1 and 2 and the corresponding LVDS pair become high impedance. DCLK and FCLK are not powered down; they will be active if terminated with 100Ω.

***PDN\_LVDS***

Address: 2[10:3]

PDN\_LVDS<7..0> selects which LVDS pairs become inactive (zero output). The frame and clock LVDS streams get powerdown only when OUTPUT\_DISABLE or GLOBAL\_PDN are set.

***REGISTER\_OFFSET\_SUBTRACTION\_ENABLE***

Address: 3[8]

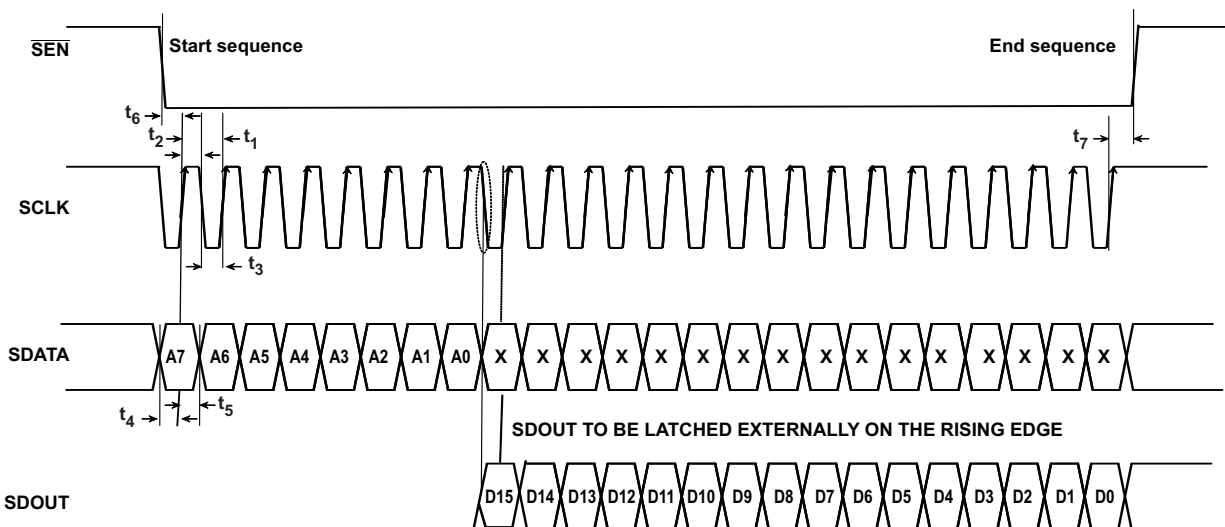
Setting this bit to '1' enables the subtraction of the value on the corresponding OFFSET\_CHANNEL<sub>i</sub><9:2> from the ADC output. The number is specified in 2s complement format. For example, OFFSET\_CHANNEL<sub>i</sub><9:2>='1000000' means "subtract -128". For OFFSET\_CHANNEL<sub>i</sub><9:2>='01111111' the effect will be to subtract 127. Hereby, both addition and subtraction can be done.

Notice that the offset is applied before the digital gain (see next). In fact, digital gain is the last step and the whole data path is 2s complement through out internally. Only when DFS='1' (straight binary output format), the 2s complement word is translated into offset binary right at the end.

***REGISTER\_READOUT\_ENABLE***

Address: 0[1]

The device includes an option where the contents of the internal registers can be read back. This may be useful as a diagnostic to verify the serial interface communication between the external controller and the AFE. First, the <REGISTER READOUT ENABLE> bit needs to be set to '1'. Then the user should initiate a serial interface cycle specifying the address of the register (A7-A0) whose content has to be read. The data bits are "don't care". The device will output the contents (D15-D0) of the selected register on the SDOUT pin. The external controller can latch the contents at the rising edge of SCLK. To enable serial register writes, set the <REGISTER READOUT ENABLE> bit back to '0'. The following timing diagram shows this operation (the time specifications follow the same information provided on the table for a serial interface register write):



### SERIALIZED\_DATA\_RATE

Address: 3[14:13]

These two bits control the length of the data word, i.e., the number of DCLK per FCLK periods. It is possible, for instance, to output 16bit data stream, even with a 12bit ADC. In this case, the last 4 LSBs are padded with zeros. The pass from higher resolution to lower serialization is not supported though; i.e, it is not possible to select a 10bit stream with a 12bit ADC.

### TGC\_REGISTER\_WREN

Address: 0[2]

Set this bit to '1' to access the TGC table and '0' (default after reset) to access the general purpose register table. As explained before, the same address may point to one bank of registers or to the other. Nevertheless, observe that register 0 of the general purpose registers is always accessible, regardless of the value of TGC\_REGISTER\_WREN. The TGC table starts at address 1.

### VCA\_LOW\_NOISE\_MODE

Address: 7[10]

Setting this bit to '1' reduces the equivalent input noise of the channel to  $5\text{nV}/\sqrt{\text{Hz}}$  (for a 31dB gain) at the expense of an increase in power consumption (5mW/channel).

### TGC CONTROL REGISTER MAP

The TGC operation is described in the [VGA/TGC Operation](#) section below. This section describes the TGC control registers which can be accessed by writing '1' to TGC\_REG\_WREN bit. The following table describes the register map for all the registers involved in the TGC operation.

| ADDRESS     | D[15:7]  | D[8]               | D[7] | D[6]        | D[5]                    | D[4]          | D[3]      | D[2] | D[1] | D[0] |
|-------------|----------|--------------------|------|-------------|-------------------------|---------------|-----------|------|------|------|
| 0x01...0x94 |          | REG_VALUES         |      |             |                         |               |           |      |      |      |
| 0x95        | NOT USED | START_INDEX        |      |             |                         |               |           |      |      |      |
| 0x96        |          | STOP_INDEX         |      |             |                         |               |           |      |      |      |
| 0x97        |          | INTERP<br>ENABLE   | 0    | START_GAIN  |                         |               |           |      |      |      |
| 0x98        |          | HOLD_GAIN_TIME     |      |             |                         |               |           |      |      |      |
| 0x99        |          | 0                  | 0    | SOFT SYNC   | UNIFORM<br>GAIN<br>MODE | STATIC<br>PGA | FINE_GAIN |      |      |      |
| 0x9A        |          | 0                  | 0    | COARSE_GAIN |                         |               |           |      |      |      |
| 0x9B        |          | UNIFORM_GAIN_SLOPE |      |             |                         |               |           |      |      |      |

### REG\_VALUE

Address: 0x01[8:0] to 0x94[8:0]

Each of these 9 bit registers (148 of them) stores the time to stay at a given gain setting, during the gain ramp. The most significant bit of each register (REG\_VALUE<8>) denotes either increment or decrement gain from current gain value. The other 8 bits (REG\_VALUE<7:0>) denote the time (a multiple of  $8 \times \text{Tclk}$ ; Tclk being the channel sampling clock, i.e., double the period of the device input clock) for the change of the gain from the CURRENT\_GAIN to  $\text{CURRENT\_GAIN} \pm 1\text{dB}$  (depending on the REG\_VALUE<8>). The fastest ramp (shortest time) for this 1dB gain change is set by REG\_VALUE<7:0> equal to 0x00 and it is  $8 \times \text{Tclk}$ . The slowest ramp (longest time) for this 1dB gain change is set by REG\_VALUE<7:0> equal to 0xFF and it is  $255 \times 8 \times \text{Tclk}$  (see VGA operation – described later).

### START\_INDEX

Address: 0x95[7:0]

This 8 bit register specifies/points to the first REG\_VALUE register of the TGC curve (i.e., where the curve starts) and can have values ranging from 1 to 148 (in decimal).

### STOP\_INDEX

Address: 0x96[7:0]

This 8 bit register specifies/points to the last REG\_VALUE register of the TGC curve (i.e., where the curve finishes) and can have values ranging from 1 to 148 (in decimal).

**START\_GAIN**

Address: 0x97[5:0]

This 6 bit register specifies the start gain value from –5dB to 31dB.

$$\text{START\_GAIN} = [-5 + \text{REG\_VALUE}] \text{ dB}$$

| REG_VALUE | GAIN  |
|-----------|-------|
| 0x0       | –5 dB |
| 0x1       | –4 dB |
| 0x24      | 31 dB |

**STOP\_GAIN****(Not a programmable register, it is an internally computed value)**

Case 1:

INTERP\_ENABLE=1,

$$\text{STOP\_GAIN} = \text{START\_GAIN} + (\text{STOP\_INDEX} - \text{START\_INDEX}) - (2 * \text{Number of decrements}) + 0.875\text{dB}.$$

Case 2:

INTERP\_ENABLE='0',

$$\text{STOP\_GAIN} = \text{START\_GAIN} + (\text{STOP\_INDEX} - \text{START\_INDEX}) - (2 * \text{Number of Decrements}).$$
**HOLD\_GAIN\_TIME**

Address: 0x98[7:0]

This 8 bit register specifies the time for holding of the STOP\_GAIN, after reaching either the STOP\_GAIN value as computed earlier or the maximum/minimum gain. After this time, the TGC starts stepping down to the START\_GAIN value in 1dB steps every Tclk. The STOP\_GAIN value is held for the following number of clocks:

$$\text{HOLD\_GAIN\_TIME} = [33 * \text{REG\_VALUE}] \text{ Tclks}$$

where Tclk is the channel sampling clock.

| REG_VALUE | HOLD_GAIN_TIME |
|-----------|----------------|
| 0x0       | 0 Tclks        |
| 0x1       | 33 Tclks       |
| 0xFF      | 8415 Tclks     |

**INTERP\_ENABLE**

Address: 0x97[7]

This 8 bit register sets the ramp rate. When INTERP\_ENABLE='1' the ramp rate is 0.125dB for every number of clocks stored in REG\_VALUE:

| REG_VALUE | SLOPE                |
|-----------|----------------------|
| 0x0       | 0.125dB per Tclk     |
| 0x1       | 0.125dB per Tclk     |
| 0x2       | 0.125dB per 2*Tclk   |
| 0xFF      | 0.125dB per 255*Tclk |

When INTERP\_ENABLE='0' the ramp rate is 1dB for every 8 times the number of clocks stored in REG\_VALUE:

| REG_VALUE | SLOPE                                 |
|-----------|---------------------------------------|
| 0x0       | 1dB per $8 \times T_{clk}$            |
| 0x1       | 1dB per $8 \times T_{clk}$            |
| 0x2       | 1dB per $16 \times T_{clk}$           |
| 0xFF      | 1dB per $255 \times 8 \times T_{clk}$ |

#### **SOFT\_SYNC**

Address 0x99[5]

Setting SOFT\_SYNC bit to '1' enables the TGC engine to run periodically following a given TGC curve, without the need for a high pulse signal in the SYNC pin (see more details below).

#### **UNIFORM\_GAIN\_MODE**

Address 0x99[4]

Setting this bit to '0' (default) directs the TGC engine to follow an arbitrary gain versus time curve. If this bit to '1' the gain is ramped up with a slope set by the UNIFORM\_GAIN\_SLOPE register. (See more details below)

#### **UNIFORM\_GAIN\_SLOPE**

Address 0x9B[7:0]

See Uniform Gain Increment Mode section below.

#### **STATIC\_PGA**

Address 0x99[3]

Setting this bit to '1' disables the TGC engine. COARSE\_GAIN and FINE\_GAIN will control the gain value, which will be independent of time.

#### **COARSE\_GAIN**

Address 0x9A[5:0]

This 6 bit register specifies the coarse gain from –5 to 31dB, in 1dB steps. Observe that only values from 0x00 to 0x24, both included, are valid. Setting a value bigger than 0x24 on the COARSE\_GAIN register is the same as setting 0x24.  $COARSE\_GAIN = [-5 + REG\_VALUE] \text{ dB}$

| REG_VALUE | GAIN |
|-----------|------|
| 0x0       | –5dB |
| 0x1       | –4dB |
| 0x24      | 31dB |

#### **FINE\_GAIN**

Address 0x99[2:0]

This 3 bit register specifies the fine gain in steps of 0.125dB resolution, from 0dB to 0.875dB.  $FINE\_GAIN = [0.125 \times REG\_VALUE] \text{ dB}$

| REG_VALUE | GAIN    |
|-----------|---------|
| 0x0       | 0dB     |
| 0x1       | 0.125dB |
| 0x7       | 0.875dB |

### **VGA/TGC OPERATION**

The gain variation of the variable gain amplifier (VGA) versus time is called TGC function and on the AFE5851 is controlled digitally. The gain is implemented by a switched network where the switches controlling the gain are synchronized with the ADC sampling instant to minimize glitches on the output data. The gain setting depends on the mode of operation selected by the user. There are 3 possible modes of operation: non-uniform gain, uniform gain, and static mode. The following sections describe each in detail.

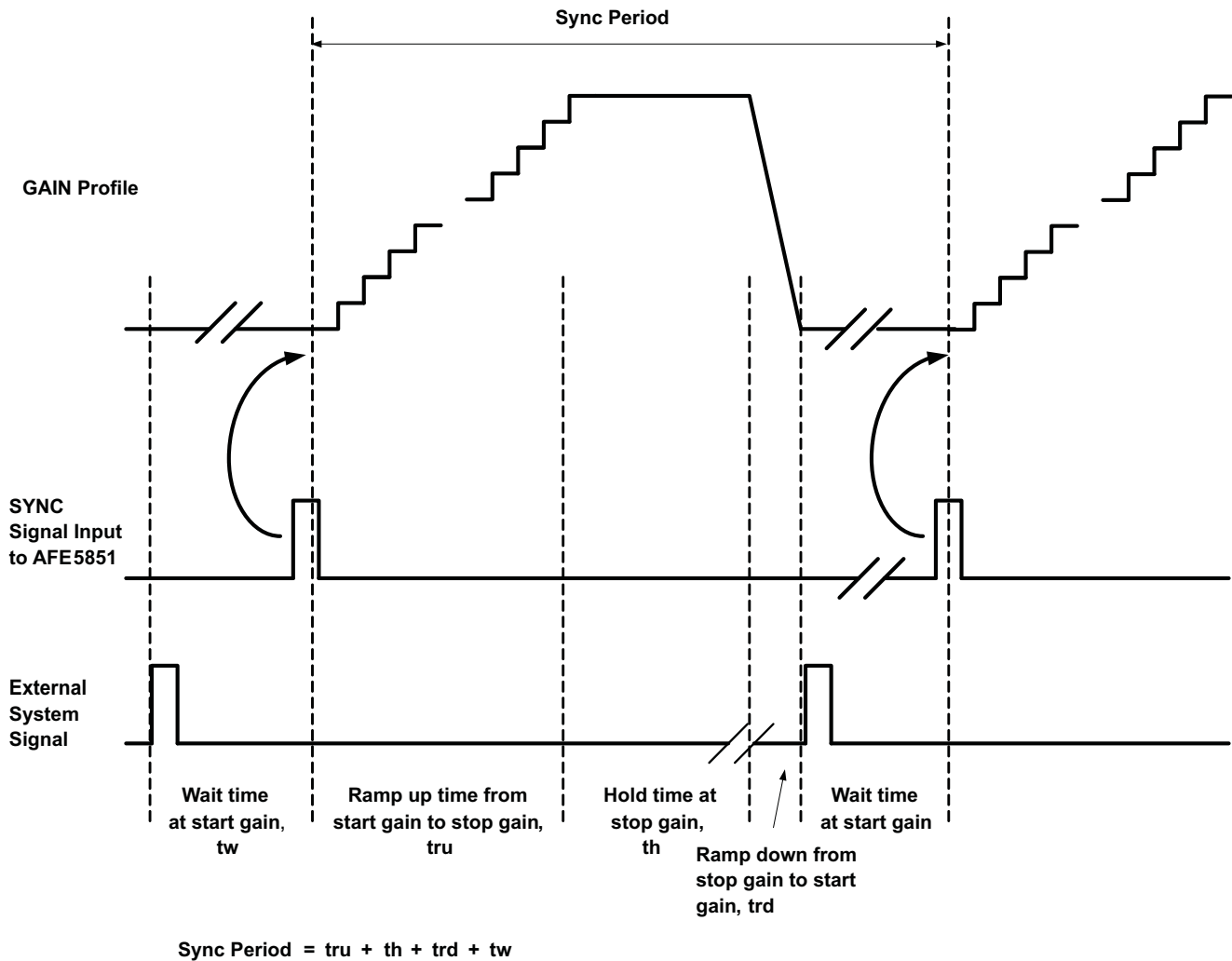


Figure 34. SYNC Period

### Non-Uniform Gain Increment Mode

In the non-uniform gain increment mode, the user sets an arbitrary shape for the gain versus time curve. For a given time/sampling instant, the digital gain setting is obtained from an internal memory of 148 positions/registers (named REG\_VALUES), each 9 bits wide, loaded by the user through the serial port (see Serial Interface section). Addresses 1 to 148 can be used to access these registers, while TGC\_REGISTER\_WREN='1'.

As explained above, the most significant bit of each register (REG\_VALUE<8>) denotes either increment or decrement gain from current gain value. The other 8 bits (REG\_VALUE<7:0>) denote the time (a multiple of  $8 \times T_{clk}$ , being  $T_{clk}$  the sampling clock) for the change of the gain from the CURRENT\_GAIN to CURRENT\_GAIN  $\pm 1$ dB (depending on the REG\_VALUE<8>). The fastest ramp (shortest time) for this 1dB gain change is set by REG\_VALUE<7:0> equal to 0x00 and it is  $8 \times T_{clk}$ . The slowest ramp (longest time) for this 1dB gain change is set by REG\_VALUE<7:0> equal to 0xFF and it is  $255 \times 8 \times T_{clk}$ .

INTERP\_ENABLE sets the way the gain is increased/decreased. By default the gain ramp is implemented in steps of 1dB (INTERP\_ENABLE equal to 0). If INTERP\_ENABLE is equal to 1, the actual 1dB gain step is implemented in 8 steps of 0.125dB.

The 148 REG\_VALUE registers can be used to store either a single curve or multiple TGC curves. The START\_INDEX register points to the REG\_VALUE register where the TGC curve starts and the STOP\_INDEX register points to the REG\_VALUE register where the TGC curve stops. Using the START\_INDEX and STOP\_INDEX registers the desired TGC curves can be chosen.

As shown in [Figure 34](#), a pulse high signal on the SYNC pin will set the starting gain value of the TGC curve to the START\_GAIN register value, and it will initiate the progression through the different REG\_VALUES, starting at START\_INDEX. Observe that there is no option to delay the start of gain stepping after the SYNC pulse is received. Then, the progression continues until either the STOP\_INDEX is reached or maximum/minimum gain is exceeded. After that, the last valid value of gain is held for an extra given number of clocks set by the register HOLD\_GAIN\_TIME.

After the elapsing of clocks mentioned by the HOLD\_GAIN\_TIME register, the TGC starts to step down (or up) to the START\_GAIN in steps of 1dB every Tclk (channel sampling clock) in preparation for the next TGC profile. The TGC will start updating/following the REG\_VALUES again after a new high pulse on the SYNC pin is given.

The SYNC signal is latched by the rising edge of the channel sampling clock. In other words, the gain increments at the rising edge of the channel sampling clock. Setup time with rising edge is 7ns, and hold time 4ns.

### SOFT\_SYNC

The TGC can run periodically following a given TGC curve but without the need for a high pulse signal in the SYNC pin. This is done by setting SOFT\_SYNC bit to '1'. Once this bit is set, the sequence of events is the same as with the hardwired SYNC pulse. The TGC curve updates from START\_INDEX to STOP\_INDEX. After reaching STOP\_INDEX or the maximum/minimum gain, the STOP\_GAIN value is held for HOLD\_VALUE\_TIME and then the gain ramps up or down to START\_GAIN. After this the TGC update starts again automatically and repeats all these steps periodically till the SOFT\_SYNC bit becomes zero.

The SYNC process through register write occurs at the serial clock edge where the register is written. If serial clock and sample clock (channel sampling clock) are synchronous then the described relation in the hardwired SYNC section will hold and the SYNC bit is latched by the rising edge of the channel sampling clock, respecting a setup time with rising edge of 7ns and hold time of 4ns. If sample clock and serial clock are not synchronous then this relationship does not apply and a clock uncertainty of  $\pm 1$  sample will apply in respect to the nearest sample clock rising edge.

Example 1: In the following example of non-uniform gain mode, all the 148 registers are loaded. Nevertheless, the start address for the TGC is set in START\_INDEX to 2 and the stop address (STOP\_INDEX) to 7. The START\_GAIN is set to 6 and HOLD\_GAIN\_TIME is 4.

With a high pulse on the SYNC pin the gain starts from 1dB (START\_GAIN=0x06). 1dB to 2dB ramp is done in 120Tclks, using eight 0.125dB steps (as INTERP\_ENABLE is set to 1), each 15Tclks long. The ramp from 2dB to 3dB is done in 64Tclks, also in 0.125dB steps. The ramp from 3dB to 4dB is done in 40 Tclks. Decrement from 4dB to 3dB in 64Tclks. Gain increment from 3dB to 4dB in 56 Tclks and from 4dB to 4.875dB in 80 Tclks.

Observe that in the case where INTERP\_ENABLE=1, STOP\_GAIN = START\_GAIN + (STOP\_INDEX - START\_INDEX) - ( 2 × Number of decrements) + 0.875dB. In the case where INTERP\_ENABLE='0', STOP\_GAIN = START\_GAIN + (STOP\_INDEX - START\_INDEX) - ( 2 × Number of Decrements). This is due to the fact that the interpolation engine keeps the gain increasing or decreasing when INTERP\_ENABLE=1, while the gain is frozen when INTERP\_ENABLE=0.

| TGC REG INDEX | REG_VALUE[8:0] | Number of Tclks | Direction of Gain Change |
|---------------|----------------|-----------------|--------------------------|
| 1             | 0x004          | 4 × 8 = 32      | Increment                |
| 2             | 0x00F          | 15 × 8 = 120    | Increment                |
| 3             | 0x008          | 8 × 8 = 64      | Increment                |
| 4             | 0x005          | 5 × 8 = 40      | Increment                |
| 5             | 0x108          | 8 × 8 = 64      | Decrement                |
| 6             | 0x007          | 7 × 8 = 56      | Increment                |
| 7             | 0x00A          | 10 × 8 = 80     | Increment                |
| ...           | ...            | ...             | ...                      |
| 147           | 0x00F          | 15 × 8 = 120    | Increment                |
| 148           | 0x00F          | 15 × 8 = 120    | Increment                |

| NAME              | VALUE |
|-------------------|-------|
| START_INDEX       | 0x02  |
| STOP_INDEX        | 0x07  |
| START_GAIN        | 0x06  |
| HOLD_GAIN_TIME    | 0x04  |
| INTERP_ENABLE     | 1     |
| UNIFORM_GAIN_MODE | 0     |

### Uniform Gain Increment Mode

By setting UNIFORM\_GAIN\_MODE to '1', the TGC engine can also be configured for a uniform increment gain ramp mode where the gain is ramped up from the START\_GAIN value to the STOP\_GAIN with a slope set by the UNIFORM\_GAIN\_SLOPE register. Note: STOP\_GAIN is not a programmable register, but just an internally computed value from START\_GAIN, UNIFORM\_GAIN\_SLOPE, START\_INDEX and STOP\_INDEX.

If INTERP\_ENABLE=1, UNIFORM\_GAIN\_SLOPE sets the number of Tclk (channel sampling clock) at a given gain before incrementing or decrementing 0.125dB. If INTERP\_ENABLE=0, this register sets the number of 8\*Tclk (eight sampling periods) at a given gain before incrementing or decrementing 1dB. Observe that in both cases the time it takes to step by 1dB is the same. In INTERP\_ENABLE=0 the gain is stationary at the same setting for the given time, while in the other case the gain increments in fine gain steps of 0.125dB to cover that 1dB step

When INTERP\_ENABLE is zero, the STOP\_GAIN is computed as START\_GAIN + (STOP\_INDEX-START\_INDEX). Nevertheless, when INTERP\_ENABLE = '1', the STOP\_GAIN is equal to START\_GAIN + (STOP\_INDEX - START\_INDEX) + 0.875dB. This is basically due to the fact that the interpolation engine keeps the gain increasing on the second case, while, as explained above, is frozen on the first case. Observe that START\_INDEX and STOP\_INDEX are not used in this case as pointers to the REG\_VALUES table. Instead, only the difference between the two is important to compute STOP\_GAIN. As such, START\_INDEX can be set to zero and STOP\_INDEX will store STOP\_GAIN – START\_GAIN. Observe that only positive slope ramps are possible.

Example 1: setting START\_GAIN=0x2 (–3dB), START\_INDEX=0x00, STOP\_INDEX=0x06, INTERP\_ENABLE=0 and UNIFORM\_GAIN\_SLOPE=0x8, will set the gain at –3dB for  $8 \times 8 \times \text{Tclk}$ , then to –2dB for another 64 Tclk, and so on, through –1, 0, 1, 2 and 3. After spending  $64 \times \text{Tclk}$  in 3dB, the gain will stay at that gain setting for HOLD\_GAIN\_TIME and start stepping down back to START\_GAIN, with 1dB per Tclk.

Example 2: for the same settings, START\_GAIN=0x2 (–3dB), START\_INDEX=0x00, STOP\_INDEX=0x06, and UNIFORM\_GAIN\_SLOPE=0x8, if we set INTERP\_ENABLE=1, the gain will start at –3dB for 8Tclk, then –2.875dB for another 8Tclk, then –2.750dB and so on, till 3dB. At this point, while in example 1, with INTERP\_ENABLE=0 the gain would be frozen for another 64 Tclk, in this example, the gain will continue to increase with 0.125dB steps every 8Tclk till 3.875dB is reached. There will stay for another 8Tclk before starting to wait for HOLD\_GAIN\_TIME and start stepping down.

Example 3: for START\_GAIN=0x2(–3dB) , START\_INDEX=0x00, STOP\_INDEX=0x00, INTERP\_ENABLE=1 and UNIFORM\_GAIN\_SLOPE=0x1, the gain will step through –3dB, –2.875, –2.75, –2.625, –2.5, –2.375, –2.25 and –2.125, staying at each of these 8 values 1 clock cycle (8 total). Then it will wait for HOLD\_GAIN\_TIME in –2.125dB and then it will start stepping down back to –3dB.

Example 4: same settings as example 3, but with INTERP\_ENABLE=0, would simply set the VGA gain to –3dB for 8 clock cycles and then the logic would wait for HOLD\_GAIN\_TIME.

### Static PGA Mode

The 3rd mode of operation is actually a mode where the TGC engine is disabled by writing '1' into the STATIC\_PGA bit. This enables the use of a fixed gain mode where the gain is obtained by the sum of a coarse and a fine gain. Coarse gain can be set from –5 to 31dB, in 1dB steps, by the register COARSE\_GAIN (6 bit word from 0x00 to 0x24). Setting a value bigger than 0x24 on the COARSE\_GAIN register is the same as setting 0x24. The fine gain can be set in steps of 0.125dB resolution, from 0dB to 0.875dB by the FINE\_GAIN register (3 bit word with range from 0x00 to 0x07). Observe that the maximum gain, when both registers are set to their maximum gains, is actually 31.875dB.

## ANTI ALIAS FILTER (AAF)

The AFE5851 integrates a selectable 3 order low pass filter for each of the 16 channels. The cutoff frequency can be set for all the channels simultaneously through the serial interface (see FILTER\_BW register, in the General Purpose Register table) between 3 possible settings: 7.5, 10 and 14MHz. Figure 19 shows the frequency response for each of these settings. The filter characteristics are set by passive components which are subject to variations over process and temperature. A typical variation of  $\pm 5\%$  on the frequency characteristics is expected.

## CLAMPING CIRCUIT AND OVERLOAD RECOVERY

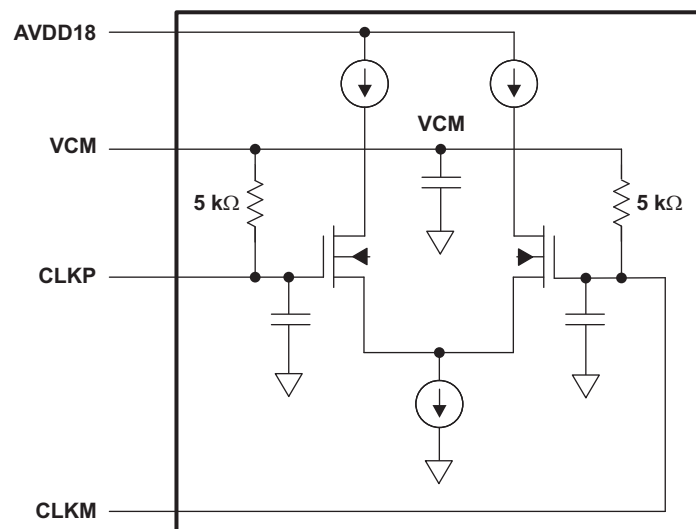
The AFE5851 is designed in particular for ultrasound applications where the front-end device is required to recover very quickly from an overload condition. Such overload can either be the result of a transmit pulse feed-through or a strong echo, which can cause overload of the VGA and ADC.

Enabled by default, the AFE5851 includes a clamping circuit to further optimize the overload recovery behavior of the complete channel (see Figure 31). The circuit can be disabled by writing a '1' in the bit 14 of the address 70 (decimal) of the General Purpose Register Map. The clamp is set to limit the signal at 3dB above the full scale of the ADC (2Vpp).

## CLOCK INPUTS

The 16 channels on the device operate from a single clock input. To ensure that the aperture delay and jitter are the same for all channels, the AFE5851 uses a clock tree network to generate individual sampling clocks to each channel. The clock channels for all the channels are matched from the source point to the sampling circuit of each of the eight internal ADCs. The variation on this delay is described in the Aperture Delay parameter of the Output Interface Timing. Its variation over time is described in the Aperture Jitter number of the same table. Observe that the rising edges of the input clock are used to sample the even channels in one input clock period and the odd channels in the next. Using an input clock double the speed of the channel sampling clock ensures that the sampling instant between even and odd channels is exactly an input clock period apart and does not depend on its duty cycle..

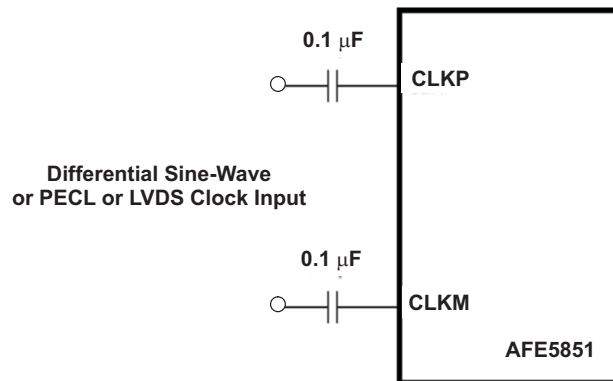
The AFE5851 clock input can be driven differentially (sinewave, LVPECL or LVDS) or single-ended (LVCMOS). The clock input of the device has an internal buffer/clock amplifier (see Figure 35) which is enabled or disabled automatically depending on the type of clock provided (autodetect feature). When enabled, the device will consume 6mW more power from the AVDD18 supply rail, but it will also accept differential or single ended inputs of smaller swing.



**Figure 35. Internal Clock Buffer for Differential Clock Mode**

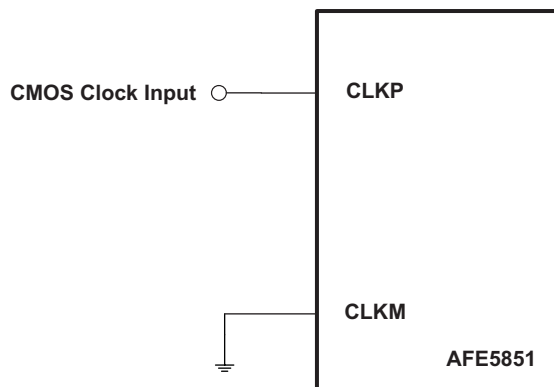
If the preferred clocking scheme for the device is single-ended, CLKINM pin should be connected to ground, i.e., shorted directly to AVSS (see [Figure 37](#)). In this case, the autodetect feature will shut down the internal clock buffer and the device will go into single-ended clock input automatically. The user should connect the single-ended clock source directly (no decoupling) to CLKINP pin, which would be the only device clock input. In that case, it is recommended the use of low jitter square signals (LVCMOS levels, 1.8V amplitude) to drive the ADC (see [SLYT075](#) for further details on the theory).

For single ended sinusoidal clocks or for differential clocks (differential sinewave, LVPECL, LVDS...), the clock amplifier should be enabled. For that, the connection scheme of [Figure 36](#) should be used. The common-mode voltage of the clock source should match one of the clock inputs of the AFE5851 (VCM) which is set internally using 5kΩ resistors, as shown in [Figure 35](#). The easiest way to ensure this is to AC couple the inputs as shown in [Figure 36](#). The same scheme applies to the case where the clock is single ended but its amplitude is small or its edges are not sharp (for instance, with a sinusoidal single-ended clock). In this case, the input clock signal can be connected with a capacitor to CLKINP (as in [Figure 36](#)) and the CLKINM should be connected to ground also through a capacitor, i.e., AC coupled to AVSS.



**Figure 36. Differential Clock Driving Circuit**

If a transformer is used with the secondary floating (for instance, to pass from single-ended to differential) , it can then obviously be connected directly to the clock inputs, without the need of the 100nF series capacitors.



**Figure 37. Single-Ended Clock Driving Circuit**

Finally, on the differential clock configurations, [Figure 38](#) shows the use of the CDCM7005 to generate the AFE5851 clock signals.

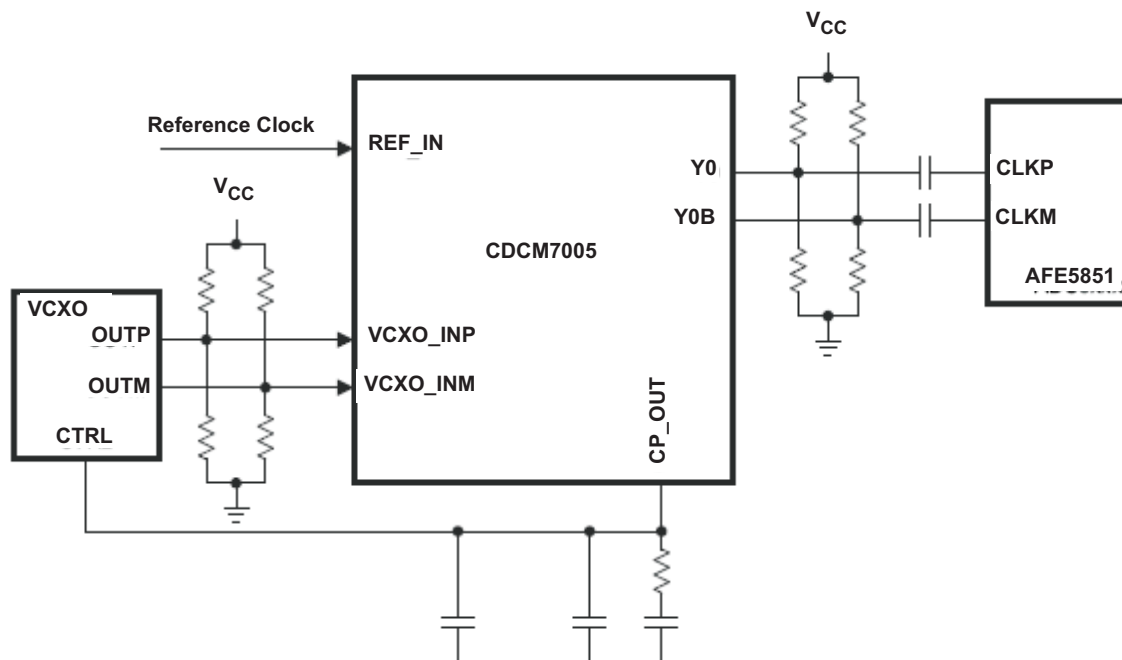


Figure 38. PECL Clock Drive Using CDCM7005

## DIGITAL OUTPUTS

The conversion results from all 8 ADCs are serialized and output using one LVDS data pair per ADC, at 12 times the device input clock rate. Besides that, two more LVDS pairs are used to facilitate the interface to the circuit reading the ADC output. For one side, a reference frame LVDS signal running at the channel rate (half the input clock rate) indicates the beginning and end of the sample word. On top of that, the device outputs a reference clock running at 6 times the input clock rate, with rise and fall times aligned with the individual bits. See the Output Interface Timing section for a description of the timing diagram as well as details on the timing margins.

[Figure 39](#) represents the device LVDS output circuit. Observe that for an LVDS output high (OUTP=1.375V, OUTM=1.025V) the "high" switches would be closed and the "low" switches would be open. For LVDS output low (OUTP=1.025V, OUTM=1.375V) the "low" switches would be closed and the "high" left open. As the "high" and "low" switches have a nominal  $R_{ON}$  of  $50\Omega \pm 10\%$ , notice that the output impedance will be nominally  $100\Omega$  in any of those two configurations ("high" or "low" switches closed).

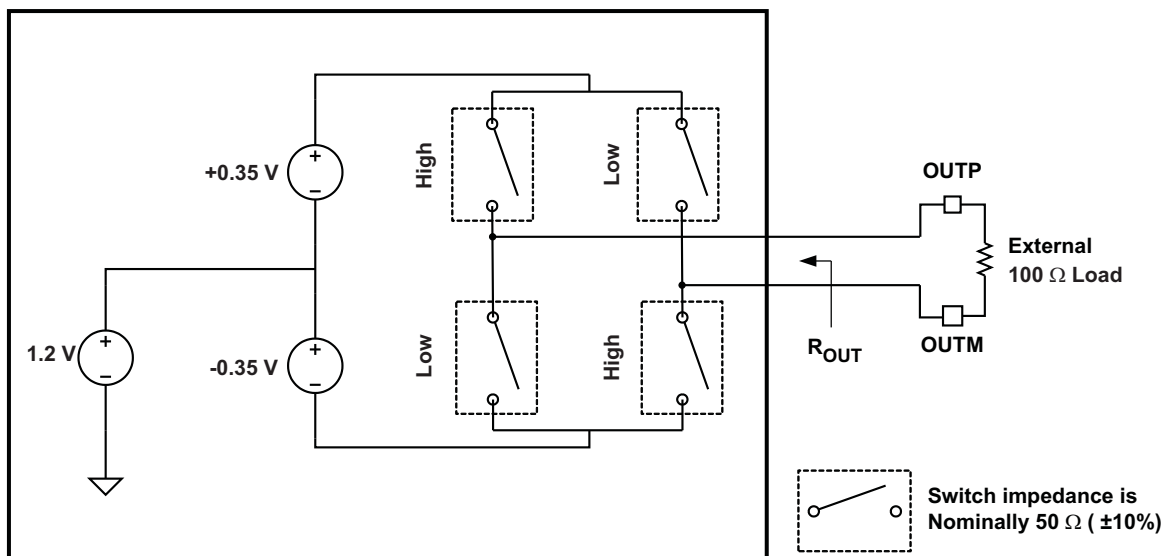


Figure 39. LVDS Output Circuit

## EXTERNAL/INTERNAL REFERENCE

See EXTERNAL\_REFERENCE register description in the General Purpose Register Description Section.

## POWER SUPPLIES

The use of low noise power supplies with adequate decoupling is recommended, being the linear supplies the first choice vs switched ones, which tend to generate more noise components that can be coupled to the AFE5851.

There is no need of any type of power-up sequencing, although a positive pulse must be applied to the Reset pin once the power supplies are considered stable (see Serial Interface Section)

There are several types of powerdown modes. On the standby mode all circuits but the reference generator are powered-down. This enables for a fast recovery from power down to full operation. On the full power down mode, all the blocks are powered down (except some digital circuits). The power savings are bigger but the power-up will also be slower (see specification tables for more details). The device includes also the possibility of powering down pairs of channels (corresponding to the same ADC) through the use of PDN\_Channel<7:0> and powering down the LVDS outputs by using PDN\_LVDS.

Finally, notice that the metallic heat sink under the package is also connected to analog ground.

## LAYOUT INFORMATION

The evaluation board represents a good guideline of how to layout the board to obtain the maximum performance out of the AFE5851. General design rules as the use of multilayer boards, single ground plane for both, analog and digital ADC ground connections, and local decoupling ceramic chip capacitors should be applied. The input traces should be isolated from any external source of interference or noise, including the digital outputs as well as the clock traces. Clock should also be isolated from other signals although the low frequencies of the input signal relaxes the jitter requirements.

In order to maintain proper LVDS timing, all LVDS traces should follow a controlled impedance design (for example, 100Ω differential). In addition, all LVDS trace lengths should be equal and symmetrical. It is recommended to keep trace length variations less than 150mil (0.150in or 3.81mm).

It is necessary to solder the exposed pad at the bottom of the package to a ground plane for best thermal performance. For detailed information, see application notes QFN Layout Guidelines ([SLOA122A](#)) and QFN/SON PCB Attachment ([SLUA271A](#)).

## DEFINITION OF SPECIFICATIONS

**Analog Bandwidth** – The analog input frequency at which the power of the fundamental is reduced by 3 dB with respect to the low frequency value.

**Aperture Delay** – The delay in time between the rising or the falling edge of the input sampling clock (depending on the channel) and the actual time at which the sampling occurs. This delay will be different across channels. The maximum variation is specified as aperture delay variation (channel-channel).

**Aperture Uncertainty (Jitter)** – The sample-to-sample variation in aperture delay.

**Clock Pulse Width/Duty Cycle** – The duty cycle of a clock signal is the ratio of the time the clock signal remains at a logic high (clock pulse width) to the period of the clock signal. Duty cycle is typically expressed as a percentage. A perfect differential sine-wave clock results in a 50% duty cycle.

**Maximum Conversion Rate** – The maximum sampling rate at which certified operation is given. All parametric testing is performed at this sampling rate unless otherwise noted.

**Minimum Conversion Rate** – The minimum sampling rate at which the ADC functions.

**Differential Nonlinearity (DNL)** – An ideal ADC exhibits code transitions at analog input values spaced exactly 1 LSB apart. The DNL is the deviation of any single step from this ideal value, measured in units of LSBs.

**Integral Nonlinearity (INL)** – The INL is the deviation of the ADC's transfer function from a best fit line determined by a least squares curve fit of that transfer function, measured in units of LSBs.

**Gain Error** – The difference between the actual gain of a channel & its ideal (theoretical) gain, i.e., the error in the absolute gain of the channel.

**Gain Matching** – The gain difference between two channels with same theoretical gain setting. For perfect matching, the difference should be zero. On the context of this device, the gain matching is obtained in two different ways:

1. The values on the specification table represent the expected gain matching between any two channels on the system. The gain is measured on every channel of every device, for a given gain setting, at any temperature. The difference between the maximum recorded gain and the minimum recorded gain represents the gain matching at that given gain setting. The same is done for every gain setting and the maximum difference for any gain setting is presented on the table.
2. The gain matching histogram represents the channel to channel matching inside the same device, i.e., the maximum expected gain difference between any two channels of the same device, or in other words, the peak-to-peak variation of absolute gains across all channels in the device. At a given gain setting for all the channels of a given device (at one temperature assumed common to the whole device), the difference between the channel with maximum gain and the channel with minimum gain represents one count. The same thing is done for all the devices and for 3 temperatures (–40C, 25C and 85C). Every measurement of a device at one given temperature represents one count.

**Offset Error** – The offset error is the difference, given in mV, between the ADC's actual average idle channel output code and the ideal average idle channel output code.

**Temperature Drift** – The temperature drift coefficient (with respect to gain error and offset error) specifies the change per degree Celsius of the parameter from  $T_{MIN}$  to  $T_{MAX}$ . It is calculated by dividing the maximum deviation of the parameter across the  $T_{MIN}$  to  $T_{MAX}$  range by the difference  $T_{MAX} - T_{MIN}$ .

**Signal-to-Noise Ratio** – SNR is the ratio of the power of the fundamental (PS) to the noise floor power (PN), excluding the power at DC and the first nine harmonics.

$$SNR = 10 \log_{10} \frac{P_S}{P_N} \quad (1)$$

SNR is either given in units of dBc (dB to carrier) when the absolute power of the fundamental is used as the reference, or dBFS (dB to full scale) when the power of the fundamental is extrapolated to the converter's full-scale range.

**Signal-to-Noise and Distortion (SINAD)** – SINAD is the ratio of the power of the fundamental ( $P_S$ ) to the power of all the other spectral components including noise ( $P_N$ ) and distortion ( $P_D$ ), but excluding dc.

$$\text{SINAD} = 10 \log_{10} \frac{P_S}{P_N + P_D} \quad (2)$$

SINAD is either given in units of dBc (dB to carrier) when the absolute power of the fundamental is used as the reference, or dBFS (dB to full scale) when the power of the fundamental is extrapolated to the converter's full-scale range.

**Effective Number of Bits (ENOB)** – The ENOB is a measure of a converter's performance as compared to the theoretical limit based on quantization noise.

$$\text{ENOB} = \frac{\text{SINAD} - 1.76}{6.02} \quad (3)$$

**Spurious Free Dynamic Range (SFDR)** – SFDR is the ratio of the power of the fundamental (PS) to the highest FFT bin, harmonic or not, excluding DC. SFDR is typically given in units of dBc (dB to carrier).

**Second Harmonic Distortion (HD2)** – HD2 is the ratio of the power of the fundamental (PS) to the second harmonic, typically given in units of dBc (dB to carrier).

**Third Harmonic Distortion (HD3)** – HD3 is the ratio of the power of the fundamental (PS) to the third harmonic, typically given in units of dBc (dB to carrier).

**Total Harmonic Distortion (THD)** – THD is the ratio of the power of the fundamental (PS) to the power of the first nine harmonics (PD).

$$\text{THD} = 10 \log_{10} \frac{P_S}{P_D} \quad (4)$$

THD is typically given in units of dBc (dB to carrier).

**AC Power Supply Rejection Ratio (AC PSRR)** – A measure of the device immunity to variations in its supply voltage. In this datasheet, if  $\Delta V_{\text{SUP}}$  represents the change in supply voltage and  $\Delta V_{\text{OUT}}$  is the resultant change of the ADC output code (referred to the input), then:

$$\text{PSRR} = 20 \log \left( \frac{\Delta V_{\text{out}}}{\Delta V_{\text{sup}}} \right) \quad (5)$$

## REVISION HISTORY

NOTE: Page numbers of current version may differ from previous versions.

### Changes from Original (September 2008) to Revision A Page

- Changed document status from Product Preview to Production Data ..... [1](#)

### Changes from Revision A (March 2009) to Revision B Page

- Deleted Registers 3[7:0] INVERT\_CHANNEL and 4[4] MSB\_FIRST from General Purpose Register Map ..... [18](#)
- Deleted description for Registers 3[7:0] INVERT\_CHANNEL; and, 4[4] MSB\_FIRST ..... [21](#)

**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| AFE5851IRGCR | VQFN         | RGC             | 64   | 2000 | 330.0              | 16.4               | 9.3     | 9.3     | 1.5     | 12.0    | 16.0   | Q2            |
| AFE5851IRGCT | VQFN         | RGC             | 64   | 250  | 180.0              | 16.4               | 9.3     | 9.3     | 1.5     | 12.0    | 16.0   | Q2            |

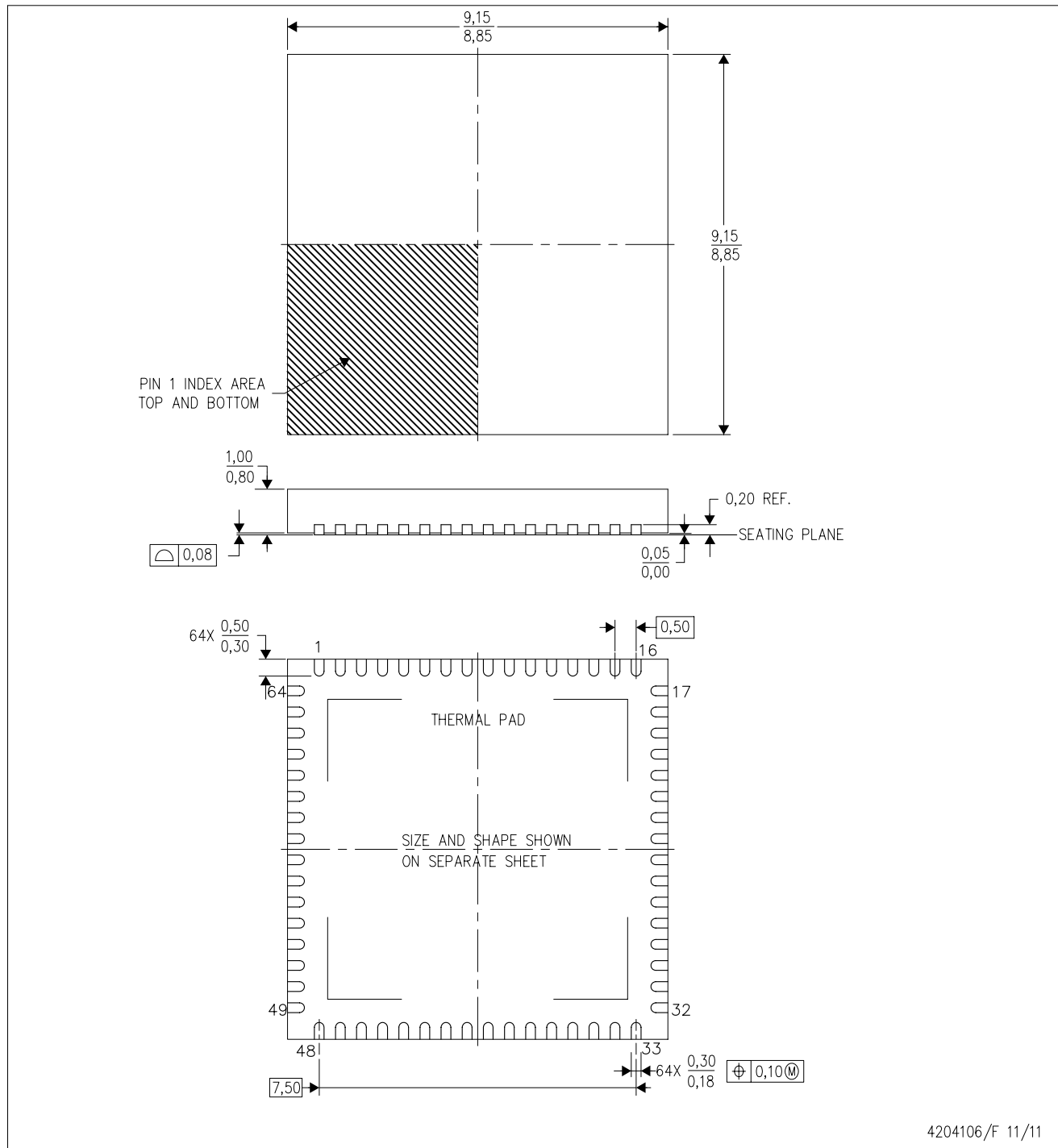
## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| AFE5851IRGCR | VQFN         | RGC             | 64   | 2000 | 336.6       | 336.6      | 28.6        |
| AFE5851IRGCT | VQFN         | RGC             | 64   | 250  | 213.0       | 191.0      | 55.0        |

RGC(S-PVQFN-N64) CUSTOM DEVICE PLASTIC QUAD FLATPACK NO-LEAD



4204106/F 11/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5-1994.
  - B. This drawing is subject to change without notice.
  - C. Quad Flatpack, No-leads (QFN) package configuration.
  - D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
  - E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.

## THERMAL PAD MECHANICAL DATA

RGC (S-PVQFN-N64)

PLASTIC QUAD FLATPACK NO-LEAD

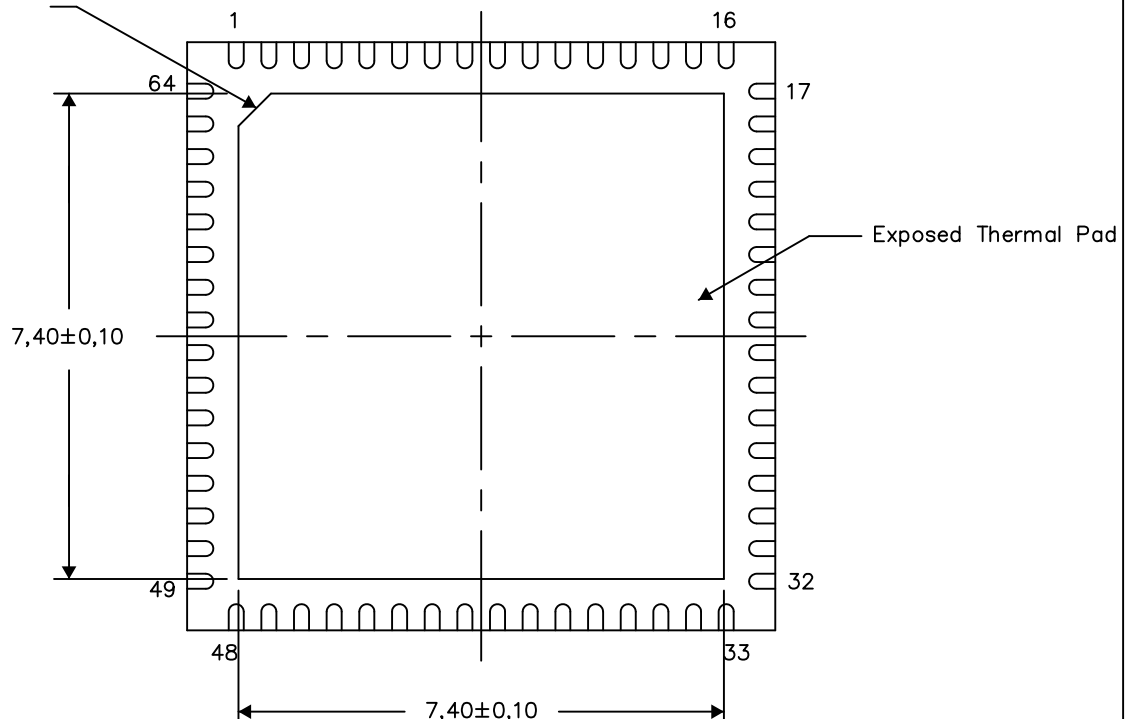
### THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at [www.ti.com](http://www.ti.com).

The exposed thermal pad dimensions for this package are shown in the following illustration.

PIN 1 INDICATOR  
CO,35



Bottom View

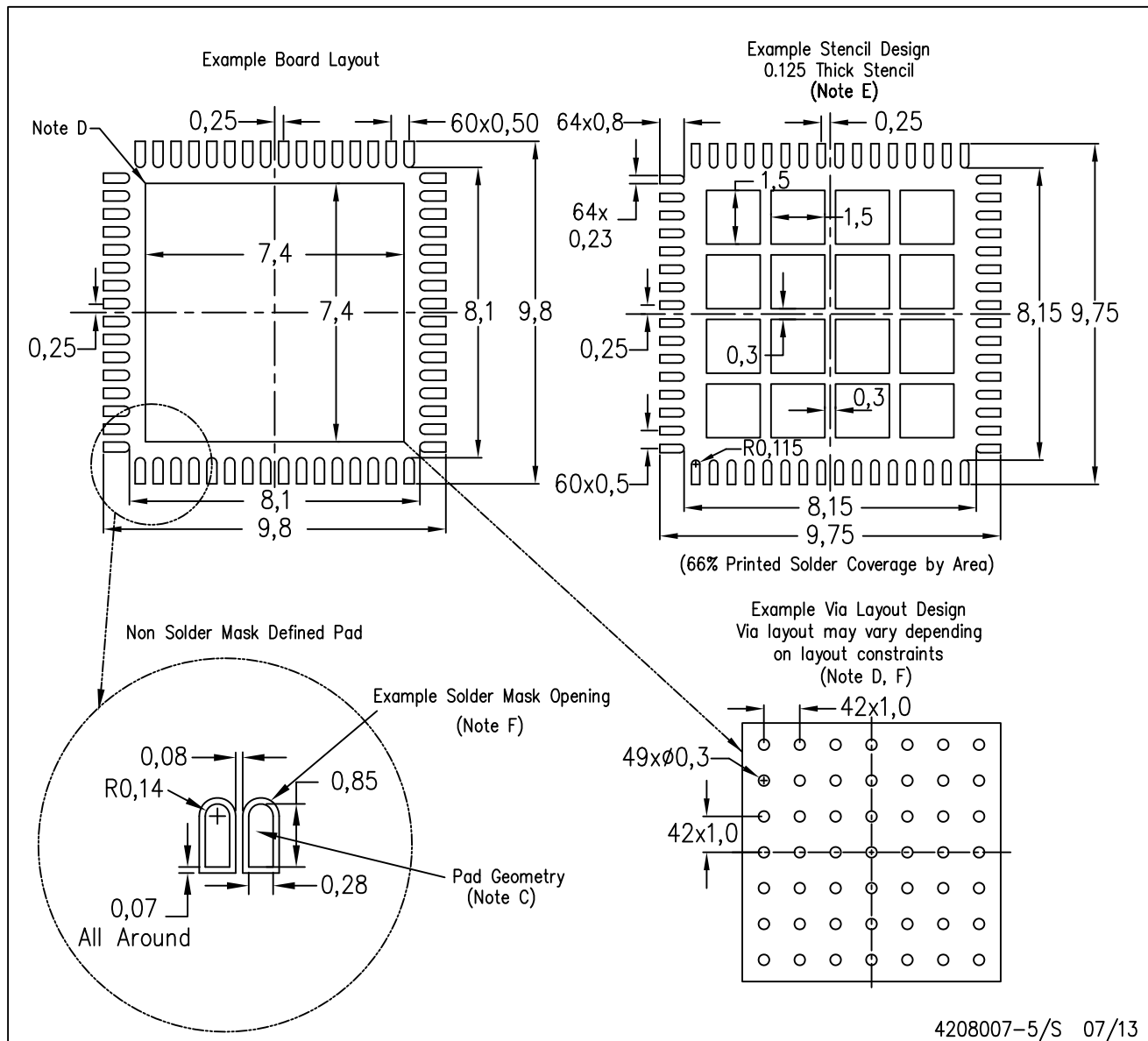
Exposed Thermal Pad Dimensions

4206192-4/AC 10/13

NOTE: A. All linear dimensions are in millimeters

RGC (S-PVQFN-N64)

PLASTIC QUAD FLATPACK NO-LEAD



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat-Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at [www.ti.com](http://www.ti.com) <<http://www.ti.com>>.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
  - Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in thermal pad.

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