# HT8121Q 12-Bit Micro Power, RRO Digital-to-Analog Converter

**(compatible to DAC121S101)**

The HT8121 device is a full-featured, general-purpose, 12-bit voltage-output digital-to-analog converter (DAC) that can operate from a single 2.7-V to 5.5-V supply and consumes just 177 µA of currentat 3.6 V. The on-chip output amplifier allows rail-to-rail output swing and the three wire serial interface operates at clock rates up to 30 MHz over the specified supply voltage range and is compatible with standard SPI™, QSPI, MICROWIRE and DSP interfaces. Competitive devices are limited to 20-MHz clock rates at supply voltages in the 2.7 V to 3.6 V range.The supply voltage for the HT8121 serves as its voltage reference, providing the widest possible output dynamic range. A power-on reset circuit ensures that the DAC output powers up to zero volts and remains there until there is a valid write to the device. A power-down feature reduces power consumption to less than a microWatt.The low power consumption and small packages of the HT8121 make it an excellent choice for use in battery operated equipment.

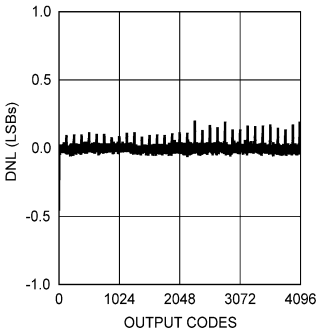
## Features

- HT8121Q is AEC-Q100 Grade 1 Qualified and is Manufactured on an Automotive Grade Flow.
- Ensured Monotonicity
- Low Power Operation
- Rail-to-Rail Voltage Output
- Power-on Reset to Zero Volts Output
- Wide Temperature Range of −40°C to +125°C
- Wide Power Supply Range of 2.7 V to 5.5 V
- Small Packages
- Power Down Feature
- Key Specifications
  - 12-Bit Resolution
  - DNL -0.15, +0.25 LSB (Typical)
  - 8-µs Output Settling Time (Typical)
  - 4-mV Zero Code Error (Typical)
  - Full-Scale Error at −0.06 %FS (Typical)
  - 0.64-mW (3.6-V) / 1.43-mW (5.5-V) Normal Mode Power Consumption (Typical)
  - 0.14-µW (3.6-V) / 0.39-µW (5.5-V) Power-Down Mode (Typical)

## Applications

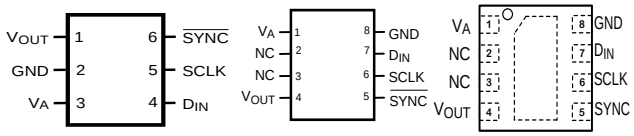
- Battery-Powered Instruments
- Digital Gain and Offset Adjustment
- Programmable Voltage and Current Sources
- Programmable Attenuators
- Automotive

**DNL vs. Output Code**




## PIN CONFIGURATION

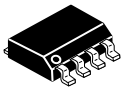
(TOP VIEW)




SOT(T),SOP (R), MSOP (M), DFN8 (D)

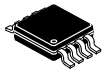
## ORDERINGINFORMATION

**SOT23-6 T SUFFIX HT8121QRTZ**



**SOP−8 R SUFFIX HT8121QRZ**

**DFN−8 D SUFFIX HT8121QRDZ**

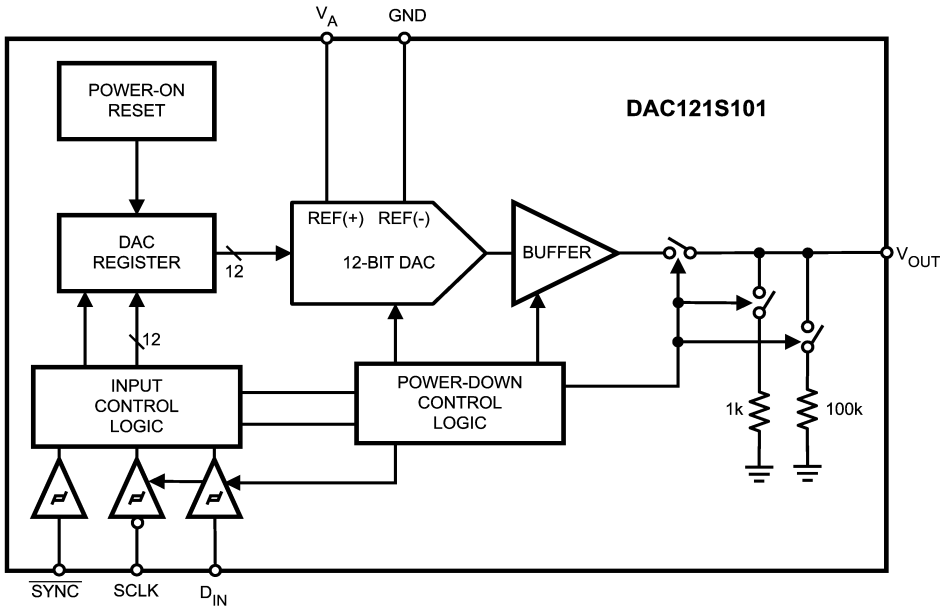


**MSOP−8 M SUFFIX HT8121QRMZ**

| | |
|---|---|
| &HT8121 | = Specific Device Code |
| &Q | = Version |
| &R | = Reel |
| &Z | = Pb−Free Package |
| &#xxxxxx | =Date Code |

$T_A$ = -40° to 125° C for all packages

### Simplified Block Diagram




## Pin Configuration and Functions

### Pin Functions

| PIN | | | I/O | DESCRIPTION |
|---|---|---|---|---|
| NAME | SOT NO. | M,S,D NO. | | |
| $D_{IN}$ | 4 | 7 | Input | Serial Data Input. Data is clocked into the 16-bit shift register on the falling edges of SCLK after the fall of SYNC. |
| GND | 2 | 8 | — | Ground reference for all on-chip circuitry. |
| NC | — | 2 | — | No Connect. There is no internal connection to these pins. |
| | | 3 | | |
| SCLK | 5 | 6 | Input | Serial Clock Input. Data is clocked into the input shift register on the falling edges of this pin. |
| $\overline{SYNC}$ | 6 | 5 | Input | Frame synchronization input for the data input. When this pin goes low, it enables the input shift register and data is transferred on the falling edges of SCLK. The DAC is updated on the 16th clock cycle unless SYNC is brought high before the 16th clock, in which case the rising edge of SYNC acts as an interrupt and the write sequence is ignored by the DAC. |
| $V_A$ | 3 | 1 | — | Power supply and Reference input. Should be decoupled to GND. |
| $V_{OUT}$ | 1 | 4 | Output | DAC Analog Output Voltage. |

## Specifications

### Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1) (2)

| | MIN | MAX | UNIT |
|---|---|---|---|
| Supply Voltage, $V_A$ | | 6.5 | V |
| Voltage on any Input Pin | −0.3 | ($V_A$ + 0.3) | V |
| Input Current at Any Pin (3) | | 10 | mA |
| Package Input Current (3) | | 20 | mA |
| Power Consumption at $T_A$ = 25°C | | See (4) | |
| Soldering Temperature, Infrared, 10 Seconds (5) | | 235 | °C |
| Storage Temperature, $T_{stg}$ | −65 | 150 | °C |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltages are measured with respect to GND = 0 V, unless otherwise specified
(3) When the input voltage at any pin exceeds the power supplies (that is, less than GND, or greater than $V_A$), the current at that pin must be limited to 10 mA. The 20-mA maximum package input current rating limits the number of pins that can safely exceed the power supplies with an input current of 10 mA to two.
(4) The absolute maximum junction temperature ($T_{JMAX}$) for this device is 150°C. The maximum allowable power dissipation is dictated by $T_{JMAX}$, the junction-to-ambient thermal resistance ($\theta_{JA}$), and the ambient temperature ($T_A$), and can be calculated using the formula $P_{DMAX} = (T_{JMAX} - T_A) / \theta_{JA}$. The values for maximum power dissipation will be reached only when the device is operated in a severe fault condition (e.g., when input or output pins are driven beyond the power supply voltages, or the power supply polarity is reversed). Obviously, such conditions must always be avoided.
(5) See the section entitled "Surface Mount" found in any post 1986 National Semiconductor Linear Data Book for methods of soldering surface mount devices.

### ESD Ratings

| | | VALUE | UNIT |
|---|---|---|---|
| $V_{(ESD)}$ Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001(1) | ±2500 | V |
| | Machine Model | ±250 | |

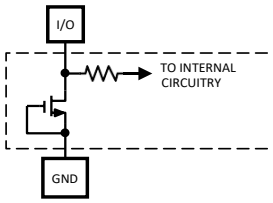
(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

## Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)(1) (2)

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| Operating Temperature Range | HT8121Q | −40 | $T_A$ | 125 | °C |
| Supply Voltage, $V_A$ | | 2.7 | | 5.5 | V |
| Any Input Voltage (3) | | −0.1 | | ($V_A$ + 0.1) | V |
| Output Load | | 0 | | 1500 | pF |
| SCLK Frequency | | | | 30 | MHz |

(1) *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur. *Recommended Operating Ratings* indicate conditions for which the device is functional, but do not ensure specific performance limits. For ensured specifications and test conditions, see the *Electrical Characteristics*. The ensured specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.
(2) All voltages are measured with respect to GND = 0 V, unless otherwise specified
(3) The analog inputs are protected as shown below. Input voltage magnitudes up to $V_A$ + 300 mV or to 300 mV below GND will not damage this device. However, errors in the conversion result can occur if any input goes above $V_A$ or below GND by more than 100 mV. For example, if $V_A$ is 2.7$V_{DC}$, ensure that −100mV ≤ input voltages ≤2.8$V_{DC}$ to ensure accurate conversions.




## Electrical Characteristics

The following specifications apply for $V_A$ = 2.7 V to 5.5 V, $R_L$ = 2 kΩ to GND, $C_L$ = 200 pF to GND, $f_{SCLK}$ = 30 MHz, input code range 48 to 4047. All limits are for $T_A$ = 25°C, unless otherwise specified.

| PARAMETER | | TEST CONDITIONS | | MIN(1) | TYP(1) | MAX(1) | UNIT |
|---|---|---|---|---|---|---|---|
| **STATIC PERFORMANCE** | | | | | | | |
| | Resolution | $T_{MIN} \le T_A \le T_{MAX}$ | | 12 | | | Bits |
| | Monotonicity | $T_{MIN} \le T_A \le T_{MAX}$ | | 12 | | | Bits |
| INL | Integral Non-Linearity | Over Decimal codes 48 to 4047 | $T_A$ = 25°C | | | ±2.6 | LSB |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | ±8 | |
| DNL | Differential Non-Linearity | $V_A$ = 2.7 V to 5.5 V | $T_A$ = 25°C | −0.15 | | +0.25 | LSB |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | −0.7 | | +1 | LSB |
| | | $V_A$ = 4.5 V to 5.5 V (2) | $T_A$ = 25°C | | | ±0.11 | LSB |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | ±0.5 | |
| ZE | Zero Code Error | $I_{OUT}$ = 0 | $T_A$ = 25°C | | | +4 | mV |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | +15 | |
| FSE | Full-Scale Error | $I_{OUT}$ = 0 | $T_A$ = 25°C | | | −0.06 | %FSR |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | −1 | |
| GE | Gain Error | All ones Loaded to DAC register | $T_A$ = 25°C | | −0.1 | | %FSR |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | | ±1 | | |
| ZCED | Zero Code Error Drift | | | | −20 | | µV/°C |

(1) Typical figures are at $T_J$ = 25°C, and represent most likely parametric norms. Test limits are specified to TI's AOQL (Average Outgoing Quality Level).
(2) This parameter is specified by design and/or characterization and is not tested in production.

## Electrical Characteristics (continued)

The following specifications apply for $V_A$ = 2.7 V to 5.5 V, $R_L$ = 2 kΩ to GND, $C_L$ = 200 pF to GND, $f_{SCLK}$ = 30 MHz, input code range 48 to 4047. All limits are for $T_A$ = 25°C, unless otherwise specified.

| PARAMETER | | TEST CONDITIONS | | | MIN(1) | TYP(1) | MAX(1) | UNIT |
|---|---|---|---|---|---|---|---|---|
| TC GE | Gain Error Tempco | $V_A$ = 3 V | | | | −0.7 | | ppm/°C |
| | | $V_A$ = 5 V | | | | −1 | | ppm/°C |
| **OUTPUT CHARACTERISTICS** | | | | | | | | |
| | Output Voltage Range(2) | $T_{MIN} \le T_A \le T_{MAX}$ | | | 0 | | $V_A$ | V |
| ZCO | Zero Code Output | $V_A$ = 3 V, $I_{OUT}$ = 10 µA | | | | | 1.8 | mV |
| | | $V_A$ = 3 V, $I_{OUT}$ = 100 µA | | | | | 5 | mV |
| | | $V_A$ = 5 V, $I_{OUT}$ = 10 µA | | | | | 3.7 | mV |
| | | $V_A$ = 5 V, $I_{OUT}$ = 100 µA | | | | | 5.4 | mV |
| FSO | Full Scale Output | $V_A$ = 3 V, $I_{OUT}$ = 10 µA | | | | | 2.997 | V |
| | | $V_A$ = 3 V, $I_{OUT}$ = 100 µA | | | | | 2.99 | V |
| | | $V_A$ = 5 V, $I_{OUT}$ = 10 µA | | | | | 4.995 | V |
| | | $V_A$ = 5 V, $I_{OUT}$ = 100 µA | | | | | 4.992 | V |
| | Maximum Load Capacitance | $R_L$ = ∞ | | | | | 1500 | pF |
| | | $R_L$ = 2 kΩ | | | | | 1500 | pF |
| | DC Output Impedance | | | | | | 1.3 | Ohm |
| $I_{OS}$ | Output Short Circuit Current | $V_A$ = 5 V, $V_{OUT}$ = 0 V, Input code = FFFh | | | | | −63 | mA |
| | | $V_A$ = 3 V, $V_{OUT}$ = 0 V, Input code = FFFh | | | | | −50 | mA |
| | | $V_A$ = 5 V, $V_{OUT}$ = 5 V, Input code = 000h | | | | | 74 | mA |
| | | $V_A$ = 3 V, $V_{OUT}$ = 3 V, Input code = 000h | | | | | 53 | mA |
| **LOGIC INPUT** | | | | | | | | |
| $I_{IN}$ | Input Current (2) | $T_{MIN} \le T_A \le T_{MAX}$ | | | | | ±1 | µA |
| $V_{IL}$ | Input Low Voltage (2) | $V_A$ = 5 V, $T_{MIN} \le T_A \le T_{MAX}$ | | | | | 0.8 | V |
| | | $V_A$ = 3 V, $T_{MIN} \le T_A \le T_{MAX}$ | | | | | 0.5 | V |
| $V_{IH}$ | Input High Voltage (2) | $V_A$ = 5 V, $T_{MIN} \le T_A \le T_{MAX}$ | | | 2.4 | | | V |
| | | $V_A$ = 3 V, $T_{MIN} \le T_A \le T_{MAX}$ | | | 2.1 | | | V |
| $C_{IN}$ | Input Capacitance (2) | $T_{MIN} \le T_A \le T_{MAX}$ | | | | | 3 | pF |
| **POWER REQUIREMENTS** | | | | | | | | |
| $I_A$ | Supply Current (output unloaded) | Normal Mode $f_{SCLK}$ = 30 MHz | $V_A$ = 5.5 V | $T_A$ = 25°C | | | 260 | µA |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 312 | |
| | | | $V_A$ = 3.6 V | $T_A$ = 25°C | | | 177 | µA |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 217 | |
| | | Normal Mode $f_{SCLK}$ = 20 MHz | $V_A$ = 5.5 V | $T_A$ = 25°C | | | 224 | µA |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 279 | |
| | | | $V_A$ = 3.6 V | $T_A$ = 25°C | | | 158 | µA |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 197 | |
| | | Normal Mode $f_{SCLK}$ = 0 | $V_A$ = 5.5 V | | | | 153 | µA |
| | | | $V_A$ = 3.6 V | | | | 118 | µA |
| | | All PD Modes, $f_{SCLK}$ = 30 MHz | $V_A$ = 5 V | | | | 84 | µA |
| | | | $V_A$ = 3 V | | | | 42 | µA |
| | | All PD Modes, $f_{SCLK}$ = 20 MHz | $V_A$ = 5 V | | | | 56 | µA |
| | | | $V_A$ = 3 V | | | | 28 | µA |
| | | All PD Modes, $f_{SCLK}$ = 0 (2) | $V_A$ = 5.5 V | $T_A$ = 25°C | | | 0.07 | µA |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 1 | |
| | | | $V_A$ = 3.6 V | $T_A$ = 25°C | | | 0.04 | µA |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 1 | |

### Electrical Characteristics (continued)

The following specifications apply for $V_A$ = 2.7 V to 5.5 V, $R_L$ = 2 kΩ to GND, $C_L$ = 200 pF to GND, $f_{SCLK}$ = 30 MHz, input code range 48 to 4047. All limits are for $T_A$ = 25°C, unless otherwise specified.

| PARAMETER | | TEST CONDITIONS | | | MIN(1) | TYP(1) | MAX(1) | UNIT |
|---|---|---|---|---|---|---|---|---|
| $P_C$ | Power Consumption (output unloaded) | Normal Mode $f_{SCLK}$ = 30 MHz | $V_A$ = 5.5 V | $T_A$ = 25°C | | | 1.43 | mW |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 1.72 | |
| | | | $V_A$ = 3.6 V | $T_A$ = 25°C | | | 0.64 | mW |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 0.78 | |
| | | Normal Mode $f_{SCLK}$ = 20 MHz | $V_A$ = 5.5 V | $T_A$ = 25°C | | | 1.23 | mW |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 1.53 | |
| | | | $V_A$ = 3.6 V | $T_A$ = 25°C | | | 0.57 | mW |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 0.71 | |
| | | Normal Mode $f_{SCLK}$ = 0 | $V_A$ = 5.5 V | | | | 0.84 | µW |
| | | | $V_A$ = 3.6 V | | | | 0.42 | µW |
| | | All PD Modes, $f_{SCLK}$ = 30 MHz | $V_A$ = 5 V | | | | 0.42 | µW |
| | | | $V_A$ = 3 V | | | | 0.13 | µW |
| | | All PD Modes, $f_{SCLK}$ = 20 MHz | $V_A$ = 5 V | | | | 0.28 | µW |
| | | | $V_A$ = 3 V | | | | 0.08 | µW |
| | | All PD Modes, $f_{SCLK}$ = 0 (2) | $V_A$ = 5.5 V | $T_A$ = 25°C | | | 0.39 | µW |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 5.5 | |
| | | | $V_A$ = 3.6 V | $T_A$ = 25°C | | | 0.14 | µW |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 3.6 | |
| $I_{OUT}$ / $I_A$ | Power Efficiency | $I_{LOAD}$ = 2 mA | $V_A$ = 5 V | | | 91% | | |
| | | | $V_A$ = 3 V | | | 94% | | |

## 6.6 AC and Timing Characteristics

The following specifications apply for $V_A$ = 2.7 V to 5.5 V, $R_L$ = 2 kΩ to GND, $C_L$ = 200 pF to GND, $f_{SCLK}$ = 30 MHz, input code range 48 to 4047. All limits are for $T_A$ = 25°C, unless otherwise specified.

| PARAMETER | | TEST CONDITIONS | | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|---|
| $f_{SCLK}$ | SCLK Frequency | $T_{MIN} \le T_A \le T_{MAX}$ | | | | | 30 | MHz |
| $t_S$ | Output Voltage Settling Time (1) | 400h to C00h code change, $R_L$ = 2 kΩ | $C_L \le$ 200 pF | $T_A$ = 25°C | | | 8 | µs |
| | | | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 10 | |
| | | | $C_L$ = 500 pF | | | 12 | | µs |
| | | 00Fh to FF0h code change, $R_L$ = 2 kΩ | $C_L \le$ 200 pF | | | 8 | | µs |
| | | | $C_L$ = 500 pF | | | 12 | | µs |
| SR | Output Slew Rate | | | | | 1 | | V/µs |
| | Glitch Impulse | Code change from 800h to 7FFh | | | | 12 | | nV-s |
| | Digital Feedthrough | | | | | 0.5 | | nV-s |
| $t_{WU}$ | Wake-Up Time | $V_A$ = 5 V | | | | 6 | | µs |
| | | $V_A$ = 3 V | | | | 39 | | µs |
| $1/f_{SCLK}$ | SCLK Cycle Time | $T_{MIN} \le T_A \le T_{MAX}$ | | | 33 | | | ns |
| $t_H$ | SCLK High time | $T_A$ = 25°C | | | 5 | | | ns |
| | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 13 | | | |
| $t_L$ | SCLK Low Time | $T_A$ = 25°C | | | 5 | | | ns |
| | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 13 | | | |
| $t_{SUCL}$ | Set-up Time $\overline{SYNC}$ to SCLK Rising Edge | $T_A$ = 25°C | | | −15 | | | ns |
| | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 0 | | | |
| $t_{SUD}$ | Data Set-up Time | $T_A$ = 25°C | | | 2.5 | | | ns |
| | | $T_{MIN} \le T_A \le T_{MAX}$ | | | 5 | | | |

The following specifications apply for $V_A$ = 2.7 V to 5.5 V, $R_L$ = 2 kΩ to GND, $C_L$ = 200 pF to GND, $f_{SCLK}$ = 30 MHz, input code range 48 to 4047. All limits are for $T_A$ = 25°C, unless otherwise specified.

| PARAMETER | | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $t_{DHD}$ | Data Hold Time | $T_A$ = 25°C | | 2.5 | | | ns |
| | | $T_{MIN} \le T_A \le T_{MAX}$ | | 4.5 | | | |
| $t_{CS}$ | SCLK fall to rise of $\overline{SYNC}$ | $V_A$ = 5 V | $T_A$ = 25°C | 0 | | | ns |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | 3 | | | |
| | | $V_A$ = 3 V | $T_A$ = 25°C | –2 | | | ns |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | 1 | | | |
| $t_{SYNC}$ | $\overline{SYNC}$ High Time | 2.7 ≤ $V_A$ ≤ 3.6 | $T_A$ = 25°C | 9 | | | ns |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | 20 | | | |
| | | 3.6 ≤ $V_A$ ≤ 5.5 | $T_A$ = 25°C | 5 | | | ns |
| | | | $T_{MIN} \le T_A \le T_{MAX}$ | 10 | | | |

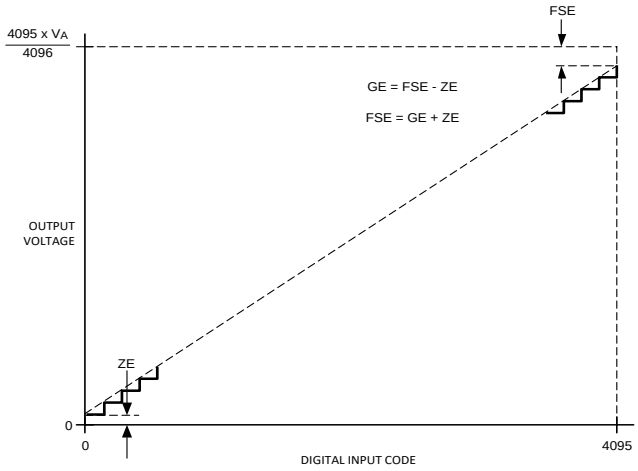



**Figure 1. Input / Output Transfer Characteristic**

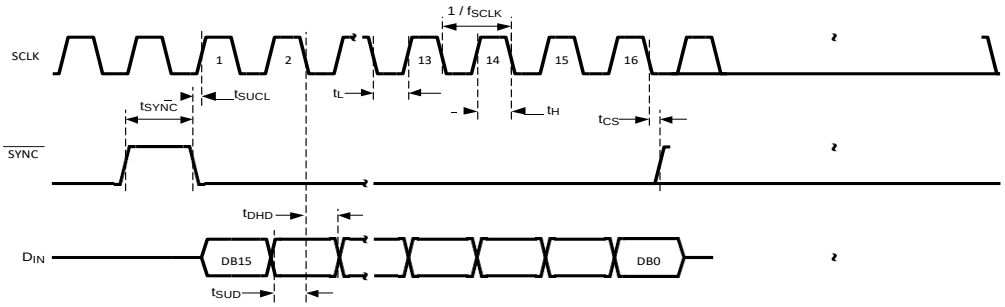
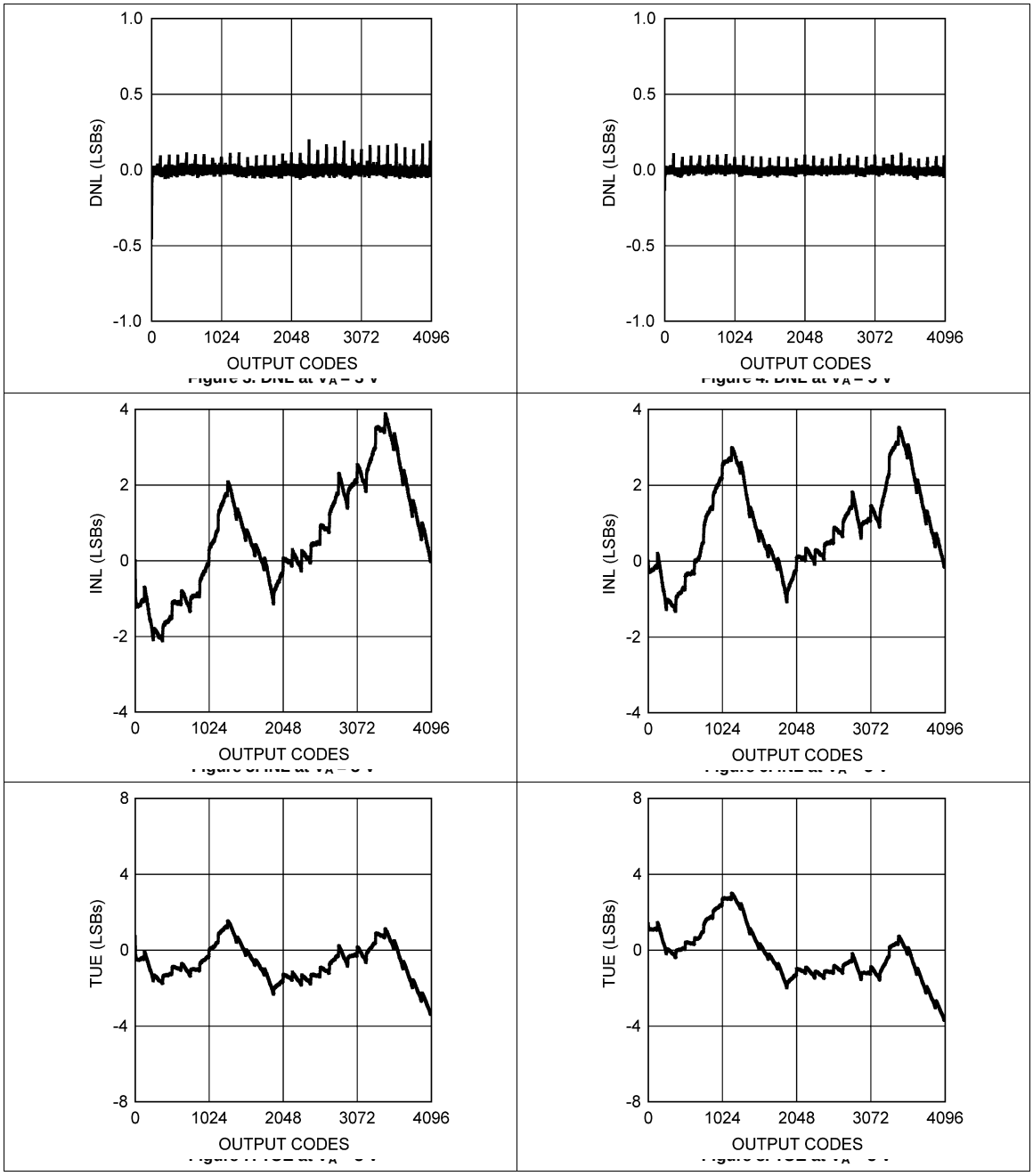



**Figure 2. HT8121 Timing**

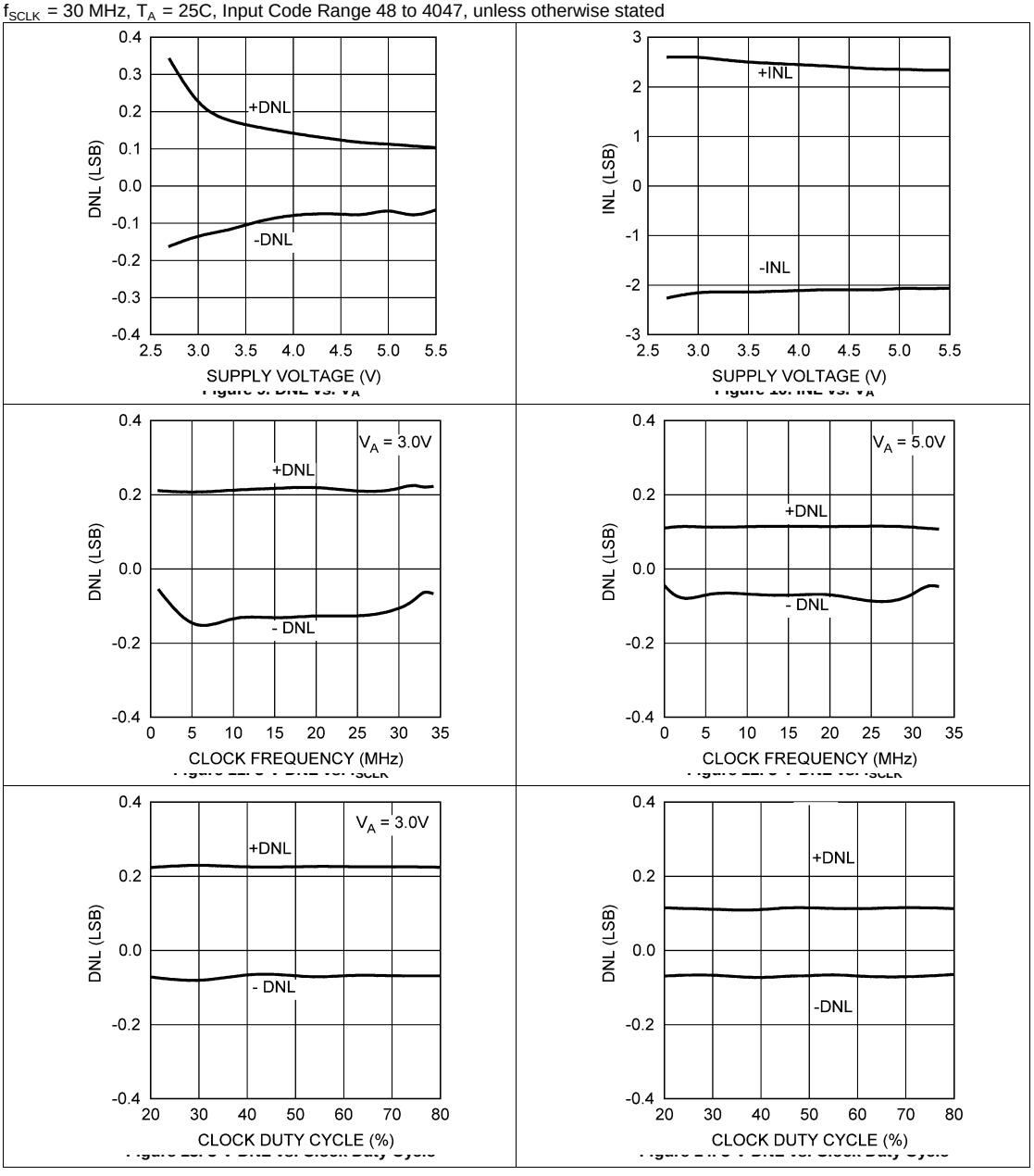
### Typical Characteristics

$f_{SCLK}$ = 30 MHz, $T_A$ = 25C, Input Code Range 48 to 4047, unless otherwise stated



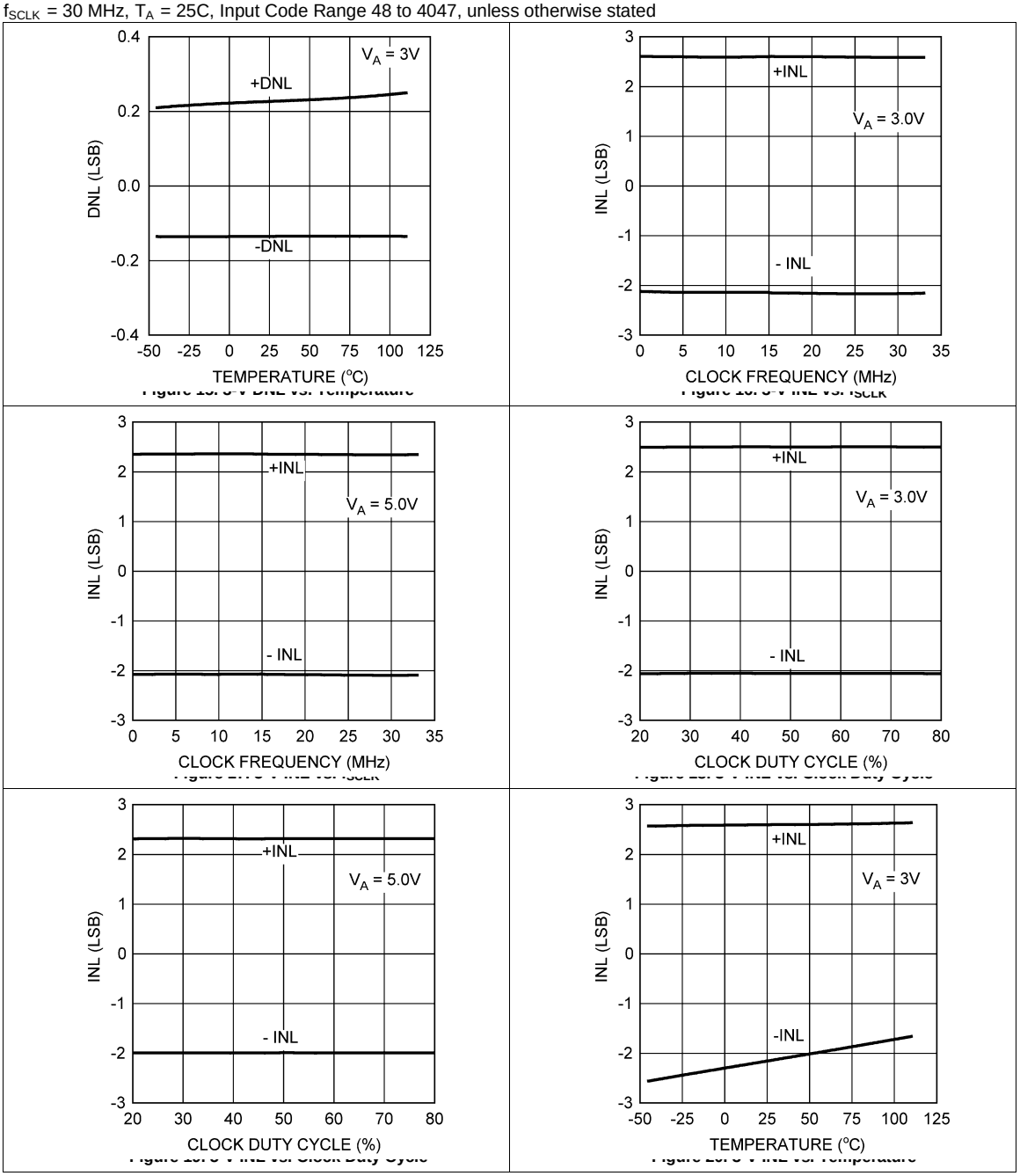
## Typical Characteristics (continued)

$f_{SCLK}$ = 30 MHz, $T_A$ = 25C, Input Code Range 48 to 4047, unless otherwise stated



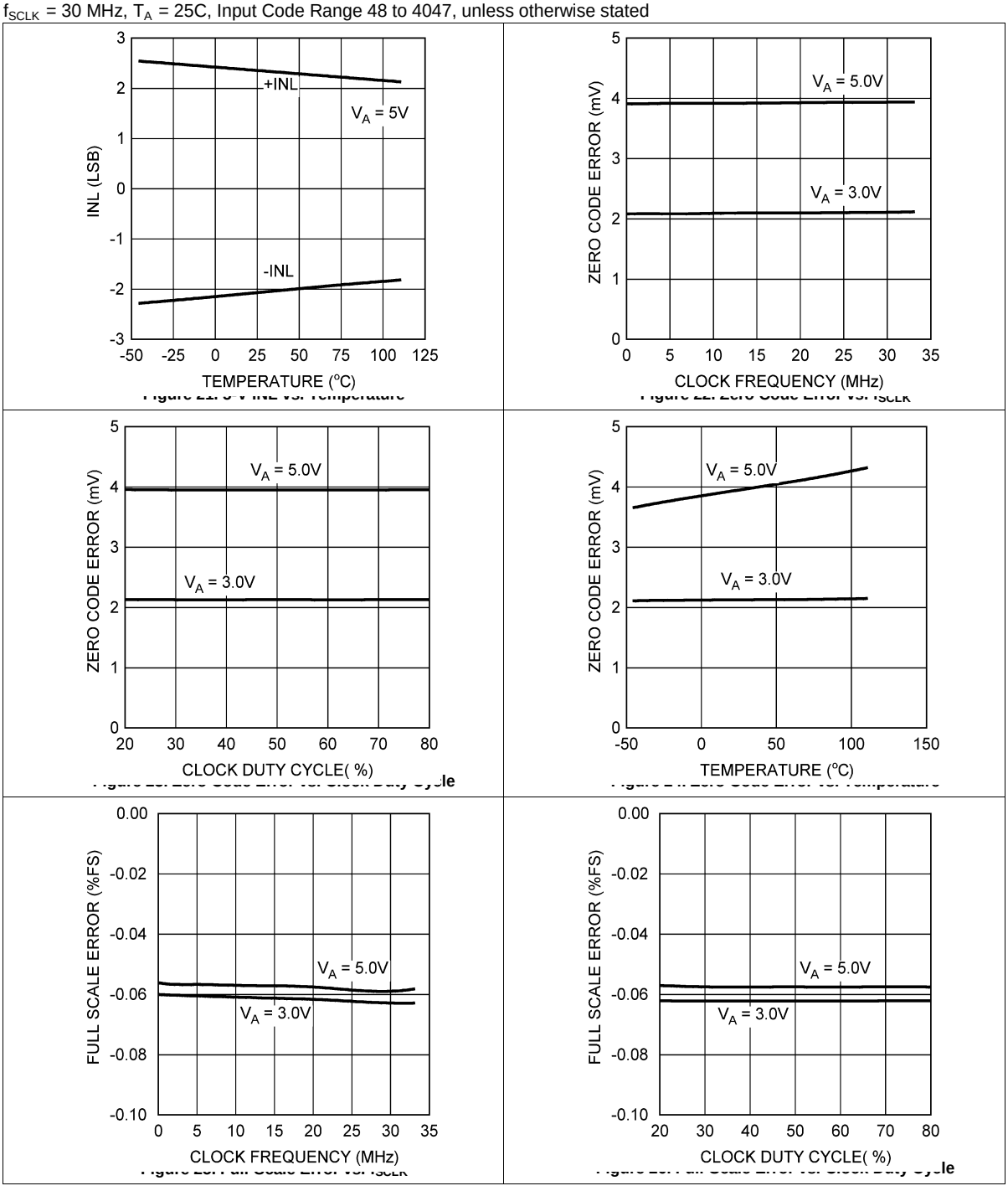
## Typical Characteristics (continued)

$f_{SCLK}$ = 30 MHz, $T_A$ = 25C, Input Code Range 48 to 4047, unless otherwise stated



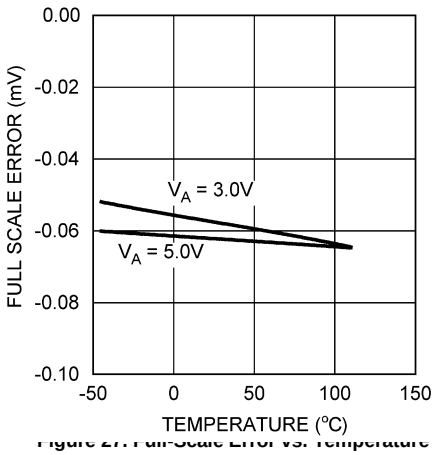
## Typical Characteristics (continued)

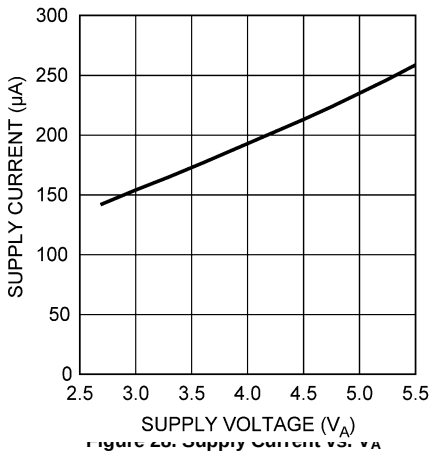
$f_{SCLK}$ = 30 MHz, $T_A$ = 25C, Input Code Range 48 to 4047, unless otherwise stated

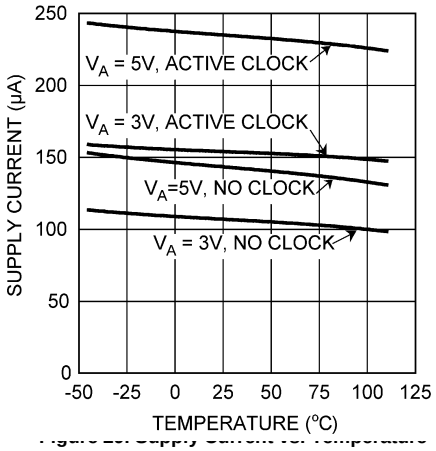


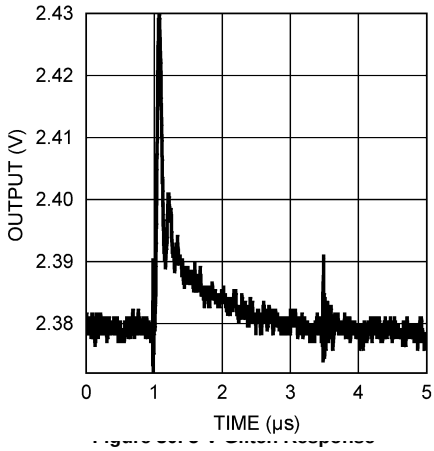
## Typical Characteristics (continued)

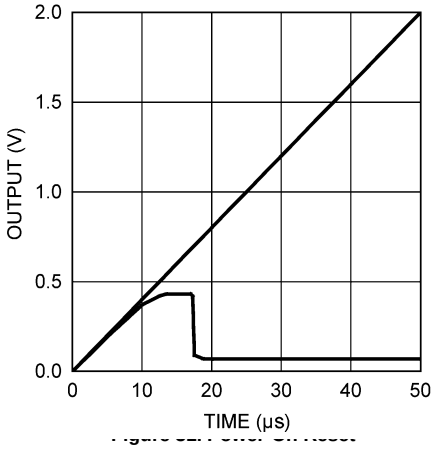
$f_{SCLK}$ = 30 MHz, $T_A$ = 25C, Input Code Range 48 to 4047, unless otherwise stated

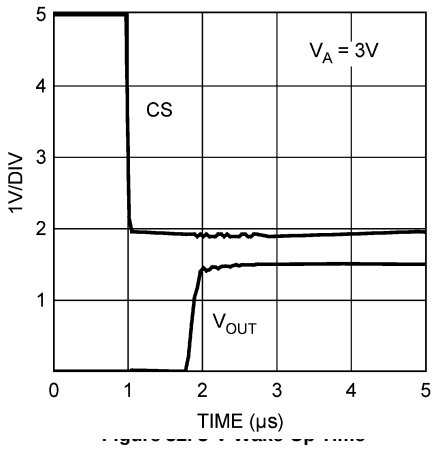


## Typical Characteristics (continued)

$f_{SCLK}$ = 30 MHz, $T_A$ = 25C, Input Code Range 48 to 4047, unless otherwise stated

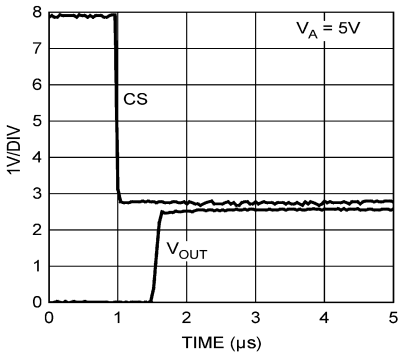



**Figure 33. 5-V Wake-Up Time**

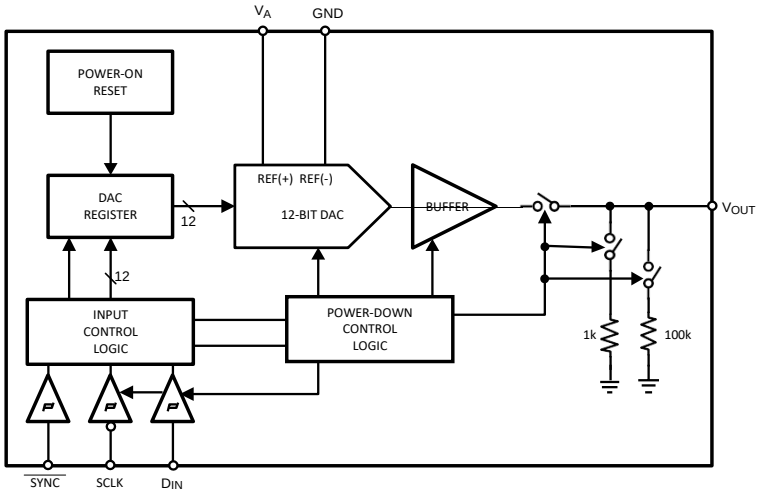
## Detailed Description

### Overview

The HT8121 device is a full-featured, general purpose 12-bit voltage-output digital-to-analog converter (DAC) with 10-µs settling time. Control of the output of the DAC is achieved over a 3-wire SPI interface. Once the DAC output has been set, additional communication with the DAC is not required unless the output condition needs to be changed. Likewise, the HT8121 power on state is 0 V. The DAC output will remain at 0 V until a valid write sequence is made.

A unique benefit of the HT8121 is the logic levels of the SPI™ input pins. The logic levels of SCLK, DIN, and SYNCB are independent of VA. As a result, the HT8121 can operate at a supply voltage ($V_A$) that is higher than the microcontroller that is controlling the DAC. This feature is advantageous in applications where the analog circuitry is being run at 5 V in order to maximize signal-to-noise ratio and digital logic is running at 3 V in order to conserve power.

### Functional Block Diagram




### Feature Description

#### DAC Section

The HT8121 is fabricated on a CMOS process with an architecture that consists of switches and a resistor string that are followed by an output buffer. The power supply serves as the reference voltage. The input coding is straight binary with an ideal output voltage of:

$$V_{OUT} = V_A \times (D / 4096)$$

where

- *D* is the decimal equivalent of the binary code that is loaded into the DAC register and can take on any value between 0 and 4095. (1)

#### Resistor String

The resistor string is shown in Figure 34. This string consists of 4096 equal valued resistors with a switch at each junction of two resistors, plus a switch to ground. The code loaded into the DAC register determines which switch is closed, connecting the proper node to the amplifier. This configuration ensures that the DAC is monotonic.

**Feature Description (continued)**

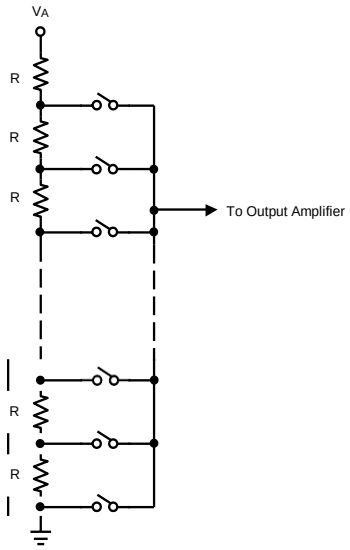



**Figure 34. DAC Resistor String**

### 7.3.3 Output Amplifier

The output buffer amplifier is a rail-to-rail type, providing an output voltage range of 0 V to $V_A$. All amplifiers, even rail-to-rail types, exhibit a loss of linearity as the output approaches the supply rails (0 V and $V_A$, in this case). For this reason, linearity is specified over less than the full output range of the DAC. The output capabilities of the amplifier are described in the *Electrical Characteristics*.

## 7.4 Device Functional Modes

### 7.4.1 Power-On Reset

The power-on reset circuit controls the output voltage during power-up. Upon application of power the DAC register is filled with zeros and the output voltage is 0 V and remains there until a valid write sequence is made to the DAC.

### 7.4.2 Power-Down Modes

The HT8121 has four modes of operation. These modes are set with two bits (DB13 and DB12) in the control register.

**Table 1. Modes of Operation**

| DB13 | DB12 | OPERATING MODE |
|---|---|---|
| 0 | 0 | Normal Operation |
| 0 | 1 | Power-Down with 1kΩ to GND |
| 1 | 0 | Power-Down with 100kΩ to GND |
| 1 | 1 | Power-Down with Hi-Z |

When both DB13 and DB12 are 0, the device operates normally. For the other three possible combinations of these bits the supply current drops to its power-down level and the output is pulled down with either a 1-kΩ or a 100-KΩ resistor, or is in a high-impedance state, as described in Table 1.

The bias generator, output amplifier, the resistor string and other linear circuitry are all shut down in any of the power-down modes. However, the contents of the DAC register are unaffected when in power-down, so when coming out of power down the output voltage returns to the same voltage it was before entering power down. Minimum power consumption is achieved in the power-down mode with SCLK disabled and $\overline{SYNC}$ and $D_{IN}$ idled low. The time to exit power-down (Wake-Up Time) is typically $t_{WU}$ µsec as stated in the A.C. and Timing Characteristics Table.

## 8.5 Programming

### 8.5.1 Serial Interface

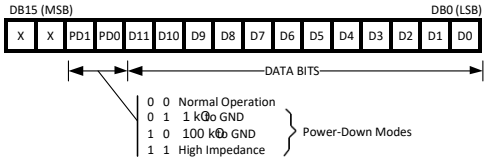
The three-wire interface is compatible with SPI, QSPI and MICROWIRE, as well as most DSPs. See the Timing Diagram for information on a write sequence.

A write sequence begins by bringing the $\overline{SYNC}$ line low. Once $\overline{SYNC}$ is low, the data on the $D_{IN}$ line is clocked into the 16-bit serial input register on the falling edges of SCLK. On the 16th falling clock edge, the last data bit is clocked in and the programmed function (a change in the mode of operation and/or a change in the DAC register contents) is executed. At this point the $\overline{SYNC}$ line may be kept low or brought high. In either case, it must be brought high for the minimum specified time before the next write sequence as a falling edge of $\overline{SYNC}$ can initiate the next write cycle.

Since the $\overline{SYNC}$ and $D_{IN}$ buffers draw more current when they are high, they must be idled low between write sequences to minimize power consumption.

### 8.5.2 Input Shift Register

The input shift register, , has sixteen bits. The first two bits are don't cares and are followed by two bits that determine the mode of operation (normal mode or one of three power-down modes). The contents of the serial input register are transferred to the DAC register on the sixteenth falling edge of SCLK. See Figure 2.




**Input Register Contents**

Normally, the $\overline{SYNC}$ line is kept low for at least 16 falling edges of SCLK and the DAC is updated on the 16th SCLK falling edge. However, if $\overline{SYNC}$ is brought high before the 16th falling edge, the shift register is reset and the write sequence is invalid. The DAC register is not updated and there is no change in the mode of operation or in the output voltage.

# 9 Application and Implementation

**NOTE**

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

## 9.1 Application Information

### 9.1.1 DSP and Microprocessor Interfacing

The simplicity of the HT8121 implies ease of use. However, it is important to recognize that any data converter that uses its supply voltage as its reference voltage will have essentially zero PSRR (power supply rejection ratio). Therefore, it is necessary to provide a noise-free supply voltage to the device.

Interfacing the HT8121 to microprocessors and DSPs is quite simple. The following guidelines are offered to hasten the design process.

#### *9.1.1.1 ADSP-2101/ADSP2103 Interfacing*

Figure 35 shows a serial interface between the HT8121 and the ADSP-2101/ADSP2103. The DSP must be set to operate in the SPORT Transmit Alternate Framing Mode. It is programmed through the SPORT control register and must be configured for Internal Clock Operation, Active Low Framing and 16-bit Word Length. Transmission is started by writing a word to the Tx register after the SPORT mode has been enabled.

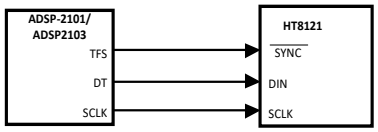



**Figure 35. ADSP-2101/2103 Interface**

#### 9.1.1.1.1 80C51/80L51 Interface

A serial interface between the HT8121 and the 80C51/80L51 microcontroller is shown in Figure 36. The SYNC signal comes from a bit-programmable pin on the microcontroller. The example shown here uses port line P3.3. This line is taken low when data is to transmitted to the HT8121. Because the 80C51/80L51 transmits 8-bit bytes, only eight falling clock edges occur in the transmit cycle. To load data into the DAC, the P3.3 line must be left low after the first eight bits are transmitted. A second write cycle is initiated to transmit the second byte of data, after which port line P3.3 is brought high. The 80C51/80L51 transmit routine must recognize that the 80C51/80L51 transmits data with the LSB first while the HT8121 requires data with the MSB first.

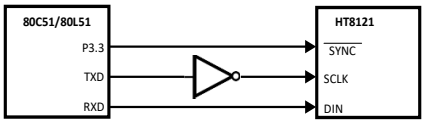



**Figure 36. 80C51/80L51 Interface**

#### 9.1.1.1.2 68HC11 Interface

A serial interface between the HT8121 and the 68HC11 microcontroller is shown in Figure 37. The SYNC $\overline{\text{line}}$ of the HT8121 is driven from a port line (PC7 in the figure), similar to the 80C51/80L51.

## Application Information (continued)

The 68HC11 must be configured with its CPOL bit as a zero and its CPHA bit as a one. This configuration causes data on the MOSI output to be valid on the falling edge of SCLK. PC7 is taken low to transmit data to the DAC. The 68HC11 transmits data in 8-bit bytes with eight falling clock edges. Data is transmitted with the MSB first. PC7 must remain low after the first eight bits are transferred. A second write cycle is initiated to transmit the second byte of data to the DAC, after which PC7 must be raised to end the write sequence.

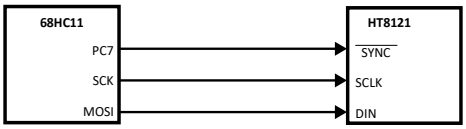



**Figure 37. 68HC11 Interface**

#### 9.1.1.1.3 Microwire Interface

Figure 38 shows an interface between a Microwire compatible device and the HT8121. Data is clocked out on the rising edges of the SCLK signal.

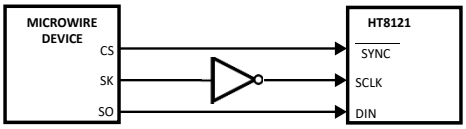



**Figure 38. Microwire Interface**

### 9.1.2 Bipolar Operation

The HT8121 is designed for single supply operation and thus has a unipolar output. However, a bipolar output may be obtained with the circuit in Figure 39. This circuit will provide an output voltage range of ±5 V. A rail-to-rail amplifier must be used if the amplifier supplies are limited to ±5 V.

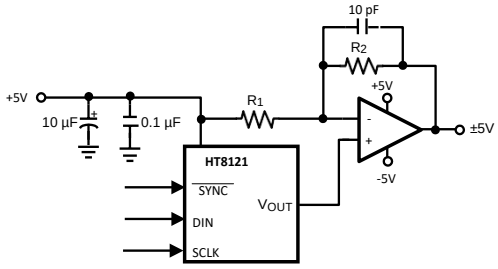



**Figure 39. Bipolar Operation**

The output voltage of this circuit for any code is found to be

$$V_O = (V_A \times (D / 4096) \times ((R1 + R2) / R1) – V_A \times R2 / R \quad (2)$$

where

- D is the input code in decimal form.

With VA = 5 V and R1 = R2,

$$V_O = (10 \times D / 4096) – 5\ V \quad (3)$$

A list of rail-to-rail amplifiers suitable for this application are indicated in Table 2.

**Table 2. Some Rail-to-Rail Amplifiers**

| AMP | PKGS | Typ $V_{OS}$ | Typ $I_{SUPPLY}$ |
|---|---|---|---|
| LMC7111 | PDIP<br>SOT-23 | 0.9 mV | 25 µA |
| LM7301 | SOIC<br>SOT-23 | 0.03 mV | 620 µA |
| LM8261 | SOT-23 | 0.7 mV | 1 mA |

## 9.2 Typical Application

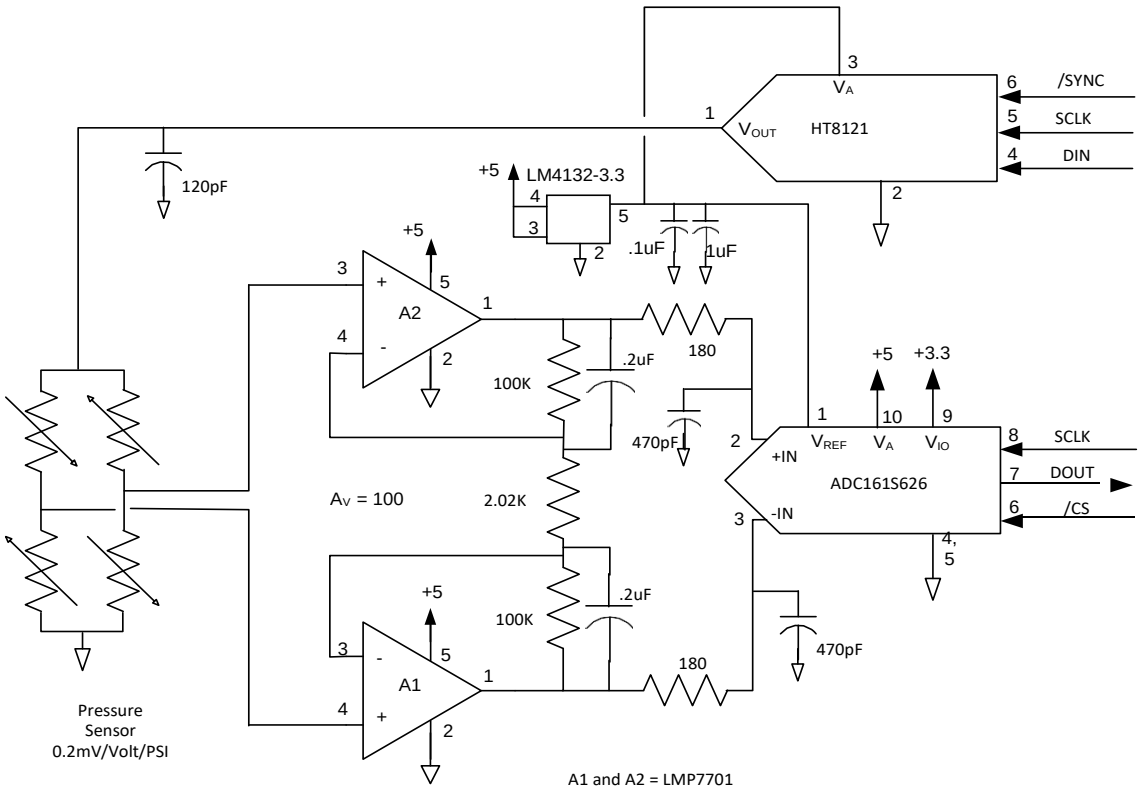



**Figure 40. Pressure Sensor Gain Adjust**

### 9.2.1 Design Requirements

A positive supply only data acquisition system capable of digitizing a pressure sensor output. In addition to digitizing the pressure sensor output, the system designer can use the HT8121 to correct for gain errors in the pressure sensor output by adjusting the bias voltage to the bridge pressure sensor.

## Typical Application (continued)

### 9.2.2 Detailed Design Procedure

As shown in Equation 4, the output of the pressure sensor is relative to the imbalance of the resistive bridge times the output of the HT8121, thus providing the desired gain correction.

$$\text{Pressure Sensor Output} = (\text{DAC\_Output} \times [(R2 / (R1 + R2) - (R4 / (R3 + R4)] \quad (4)$$

Likewise for the ADC161S626, Equation 5 shows that the ADC output is function of the Pressure Sensor Output times relative to the ratio of the ADC input divided by the HT8121 output voltage.

$$\text{ADC161S626 Output} = (\text{Pressure Sensor Output} \times 100 / (2 \times \text{VREF})) \times 2^{16} \quad (5)$$

### 9.2.3 Application Curve

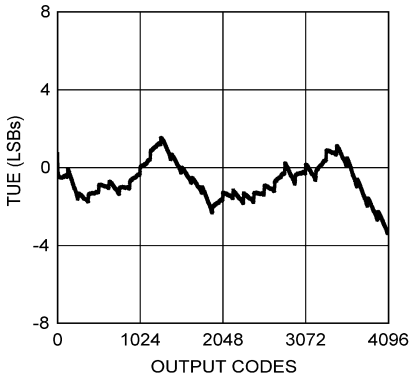



**Figure 41. Total Unadjusted Error vs. Output Code**

## 10 Power Supply Recommendations

**NOTE**

Information in the following power supply recommendations section is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 10.1 Using References as Power Supplies

Recall the need for a quiet supply source for devices that use their power supply voltage as a reference voltage.

Because the HT8121 consumes very little power, a reference source may be used as the supply voltage. The advantages of using a reference source over a voltage regulator are accuracy and stability. Some low noise regulators can also be used for the power supply of the HT8121. Listed below are a few power supply options for the HT8121.

#### 10.1.1 LM4130

The LM4130 reference, with its 0.05% accuracy over temperature, is a good choice as a power source for the HT8121. Its primary disadvantage is the lack of 3-V and 5-V versions. However, the 4.096-V version is useful if a 0 to 4.095-V output range is desirable or acceptable. Bypassing the LM4130 VIN pin with a 0.1-µF capacitor and the VOUT pin with a 2.2-µF capacitor will improve stability and reduce output noise. The LM4130 comes in a space-saving 5-pin SOT23.

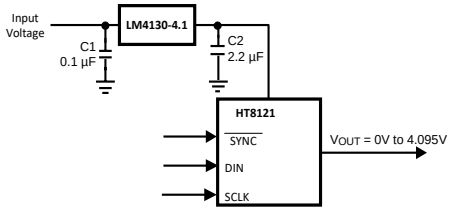



**Figure 42. The LM4130 as a Power Supply**

#### 10.1.2 LM4050

Available with accuracy of 0.44%, the LM4050 shunt reference is also a good choice as a power regulator for the HT8121. It does not come in a 3-V version, but 4.096-V and 5-V versions are available. It comes in a space-saving 3-pin SOT23.

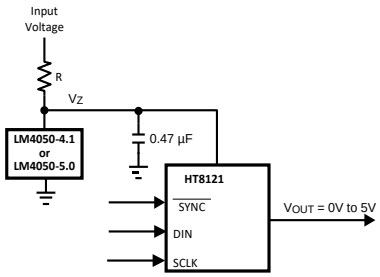



**Figure 43. The LM4050 as a Power Supply**

### Using References as Power Supplies (continued)

The minimum resistor value in the circuit of Figure 43 must be chosen such that the maximum current through the LM4050 does not exceed its 15-mA rating. The conditions for maximum current include the input voltage at its maximum, the LM4050 voltage at its minimum, the resistor value at its minimum due to tolerance, and the HT8121 draws zero current. The maximum resistor value must allow the LM4050 to draw more than its minimum current for regulation plus the maximum HT8121 current in full operation. The conditions for minimum current include the input voltage at its minimum, the LM4050 voltage at its maximum, the resistor value at its maximum due to tolerance, and the HT8121 draws its maximum current. These conditions can be summarized as

$$R(min) = ( V_{IN}(max) - V_Z(min) / (I_A(min) + I_Z(max)) \quad (6)$$

and

$$R(max) = ( V_{IN}(min) - V_Z(max) / (I_A(max) + I_Z(min) )$$

where

- $V_Z(min)$ and $V_Z(max)$ are the nominal LM4050 output voltages ± the LM4050 output tolerance over temperature,
- $I_Z(max)$ is the maximum allowable current through the LM4050,
- $I_Z(min)$ is the minimum current required by the LM4050 for proper regulation,
- $I_A(max)$ is the maximum HT8121 supply current,
- and $I_A(min)$ is the minimum HT8121 supply current. (7)

#### 10.1.3 LP3985

The LP3985 is a low noise, ultra-low dropout voltage regulator with a 3% accuracy over temperature. It is a good choice for applications that do not require a precision reference for the HT8121. It comes in 3-V, 3.3-V and 5-V versions, among others, and sports a low 30-µV noise specification at low frequencies. Because low- frequency noise is relatively difficult to filter, this specification could be important for some applications. The LP3985 comes in a space-saving 5-pin SOT-23 and 5-bump DSBGA packages.

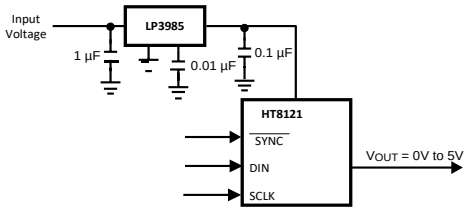



**Figure 44. Using the LP3985 Regulator**

An input capacitance of 1 µF without any ESR requirement is required at the LP3985 input, while a 1-µF ceramic capacitor with an ESR requirement of 5 mΩ to 500 mΩ is required at the output. Careful interpretation and understanding of the capacitor specification is required to ensure correct device operation.

### Using References as Power Supplies (continued)

#### 10.1.4 LP2980

The LP2980 is an ultra-low dropout regulator with a 0.5% or 1.0% accuracy over temperature, depending upon grade. It is available in 3-V, 3.3-V and 5-V versions, among others.

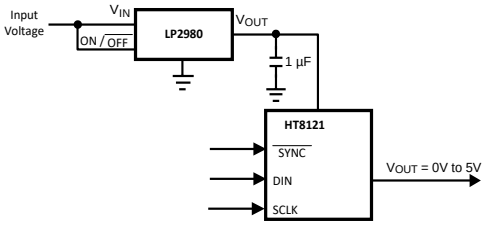



**Figure 45. Using the LP2980 Regulator**

Like any low dropout regulator, the LP2980 requires an output capacitor for loop stability. This output capacitor must be at least 1-µF over temperature, but values of 2.2 µF or more will provide even better performance. The ESR of this capacitor must be within the range specified in the LP2980 data sheet. Surface-mount solid tantalum capacitors offer a good combination of small size and ESR. Ceramic capacitors are attractive due to their small size but generally have ESR values that are too low for use with the LP2980. Aluminum electrolytic capacitors are typically not a good choice due to their large size and have ESR values that may be too high at low temperatures.

## 11 Layout

### 11.1 Layout Guidelines

A precision analog component requires careful layout, adequate bypassing, and clean, well-regulated power supplies. The power applied to VA must be well regulated and low noise. Switching power supplies and DC/DC converters will often have high-frequency glitches or spikes riding on the output voltage. In addition, digital components can create similar high-frequency spikes as their internal logic switches states. This noise can easily couple into the DAC output voltage through various paths between the power connections and analog output. As with the GND connection, VA must be connected to a power supply plane or trace that is separate from the connection for digital logic until they are connected at the power entry point.

The HT8121 power supply must be bypassed with a 10-µF and a 0.1-µF capacitor as close as possible to the device with the 0.1 µF right at the device supply pin. The 10-µF capacitor must be a tantalum type and the 0.1-µF capacitor must be a low ESL, low ESR type. The power supply for the HT8121 must only be used for analog circuits.

For best accuracy and minimum noise, the printed-circuit-board containing the HT8121 must have separate analog and digital areas. The areas are defined by the locations of the analog and digital power planes. Both of these planes must be located in the same board layer. There must be a single ground plane. A single ground plane is preferred if digital return current does not flow through the analog ground area. Frequently a single ground plane design will use a *fencing* technique to prevent the mixing of analog and digital ground current. Separate ground planes must only be used when the fencing technique is inadequate. The separate ground planes must be connected in one place, preferably near the HT8121. Take special care to ensure that digital signals with fast edge rates do not pass over split ground planes. They must always have a continuous return path below their traces.

Avoid crossover of analog and digital signals and keep the clock and data lines on the component side of the board. The clock and data lines must have controlled impedances.

**Layout Example**

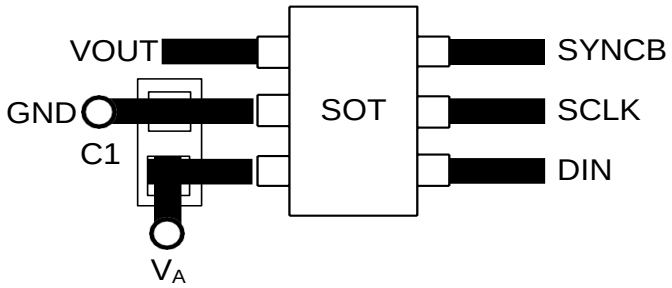



**Figure 46. Typical Layout**

## Device and Documentation Support

**DIFFERENTIAL NON-LINEARITY (DNL)** is the measure of the maximum deviation from the ideal step size of 1 LSB, which is $V_{REF}$ / 4096 = $V_A$ / 4096.

**DIGITAL FEEDTHROUGH** is a measure of the energy injected into the analog output of the DAC from the digital inputs when the DAC outputs are not updated. It is measured with a full-scale code change on the data bus.

**FULL-SCALE ERROR** is the difference between the actual output voltage with a full scale code (FFFh) loaded into the DAC and the value of $V_A$ x 4095 / 4096.

**GAIN ERROR** is the deviation from the ideal slope of the transfer function. It can be calculated from Zero and Full-Scale Errors as GE = FSE - ZE, where GE is Gain error, FSE is Full-Scale Error and ZE is Zero Error.

**GLITCH IMPULSE** is the energy injected into the analog output when the input code to the DAC register changes. It is specified as the area of the glitch in nanovolt-seconds.

**INTEGRAL NON-LINEARITY (INL)** is a measure of the deviation of each individual code from a straight line through the input to output transfer function. The deviation of any given code from this straight line is measured from the center of that code value. The end point method is used. INL for this product is specified over a limited range, per the *Electrical Characteristics*.

**LEAST SIGNIFICANT BIT (LSB)** is the bit that has the smallest value or weight of all bits in a word. This value is

$$LSB = V_{REF} / 2^n \quad (8)$$

where $V_{REF}$ is the supply voltage for this product, and "n" is the DAC resolution in bits, which is 12 for the HT8121.

**MAXIMUM LOAD CAPACITANCE** is the maximum capacitance that can be driven by the DAC with output stability maintained.

**MONOTONICITY** is the condition of being monotonic, where the DAC has an output that never decreases when the input code increases.

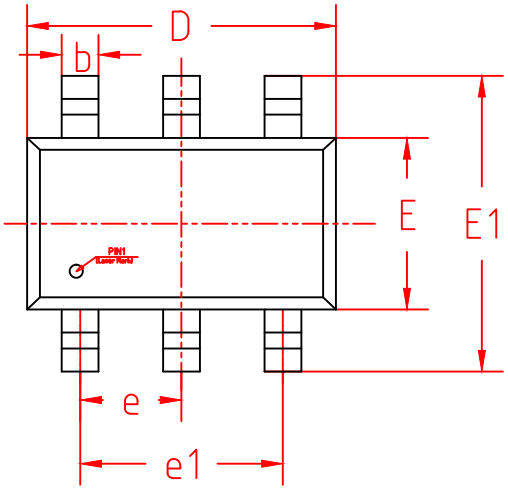
**MOST SIGNIFICANT BIT (MSB)** is the bit that has the largest value or weight of all bits in a word. Its value is 1/2 of $V_A$.

**POWER EFFICIENCY** is the ratio of the output current to the total supply current. The output current comes from the power supply. The difference between the supply and output currents is the power consumed by the device without a load.

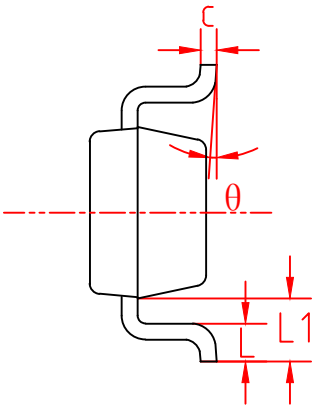
## PACKAGE DIMENSIONS

**SOT23-6**

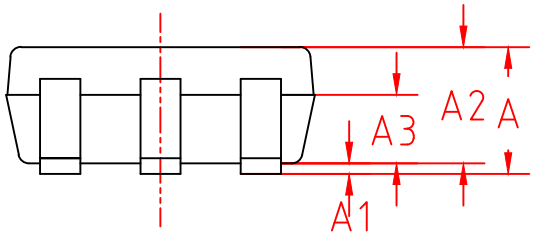
TOP VIEW
正视图




SIDE VIEW
侧视图




SIDE VIEW
侧视图

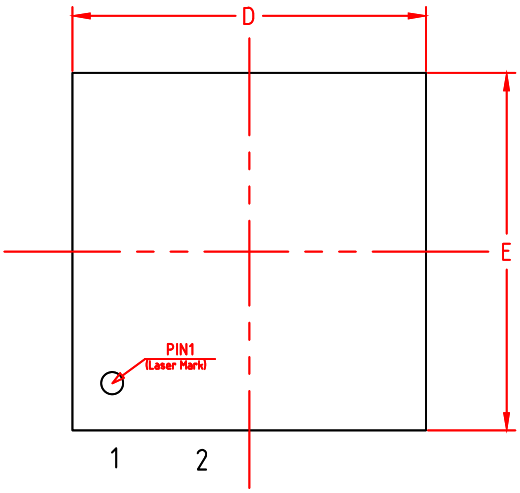



| 机械尺寸/mm Dimensions | | | |
|---|---|---|---|
| 字符 SYMBOL | 最小值 MIN | 典型值 NOMINAL | 最大值 MAX |
| A | - | - | 1.25 |
| A1 | 0.04 | - | 0.12 |
| A2 | 1.00 | 1.10 | 1.20 |
| A3 | 0.60 | 0.65 | 0.70 |
| b | 0.33 | - | 0.50 |
| c | 0.14 | - | 0.20 |
| D | 2.82 | 2.92 | 3.02 |
| E | 1.50 | 1.60 | 1.70 |
| E1 | 2.60 | 2.80 | 3.00 |
| e | 0.95 BSC | | |
| e1 | 1.90 BSC | | |
| L1 | 0.59 REF | | |
| L | 0.35 | 0.45 | 0.60 |
| θ | 0° | - | 8° |

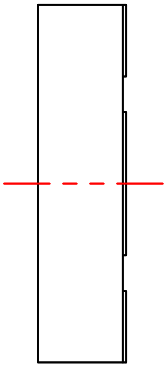
## PACKAGE DIMENSIONS

**DFN8 2x2, 0.5P**

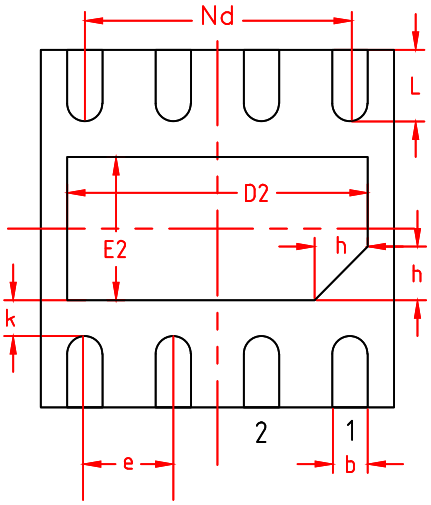
TOP VIEW
正视图



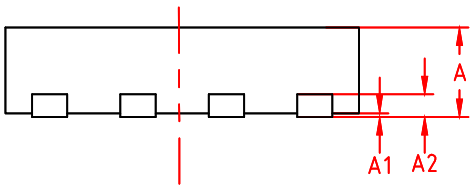

SIDE VIEW
侧视图



BOTTOM VIEW
背视图




SIDE VIEW
侧视图

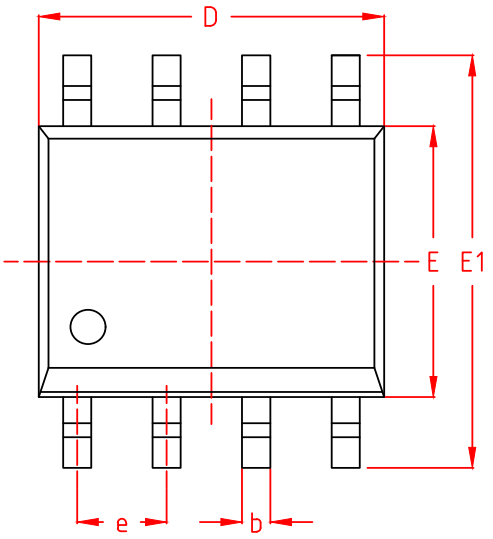



| 机械尺寸/mm | | | |
|---|---|---|---|
| 字符 SYMBOL | 最小值 MIN | 典型值 NOMINAL | 最大值 MAX |
| A | 0.45 | 0.50 | 0.55 |
| A1 | - | 0.02 | 0.05 |
| A2 | 0.203 REF | | |
| b | 0.15 | 0.20 | 0.25 |
| D | 1.90 | 2.00 | 2.10 |
| D2 | 1.60 | 1.70 | 1.80 |
| E | 1.90 | 2.00 | 2.10 |
| E2 | 0.80 | 0.90 | 1.00 |
| e | 0.50 BSC | | |
| K | 0.20 | 0.25 | 0.30 |
| L | 0.25 | 0.30 | 0.35 |
| h | 0.25 | 0.30 | 0.35 |
| Nd | 1.50 BSC | | |

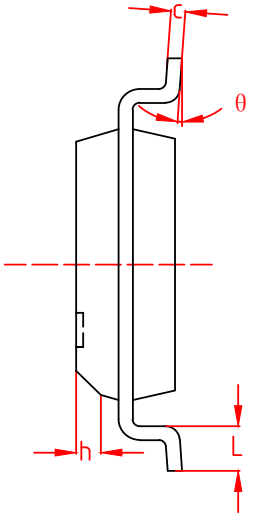
## PACKAGE DIMENSIONS

**SOP8**

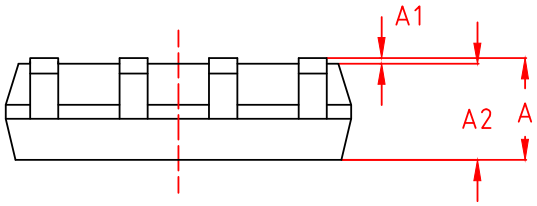
TOP VIEW
正视图




SIDE VIEW
侧视图




SIDE VIEW
侧视图

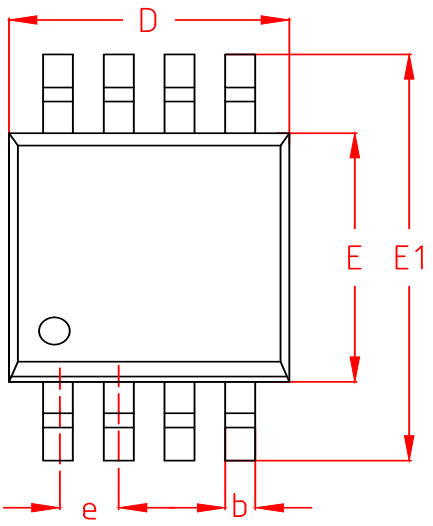



| 机械尺寸/mm Dimensions | | | |
|---|---|---|---|
| 字符 SYMBOL | 最小值 MIN | 典型值 NOMINAL | 最大值 MAX |
| A | – | – | 1.75 |
| A1 | 0.10 | 0.15 | 0.25 |
| A2 | 1.30 | 1.40 | 1.50 |
| b | 0.35 | – | 0.50 |
| c | 0.19 | – | 0.25 |
| D | 4.80 | 4.90 | 5.00 |
| E | 3.80 | 3.90 | 4.00 |
| E1 | 5.80 | 6.00 | 6.20 |
| e | 1.27 BSC | | |
| h | 0.25 | – | 0.45 |
| L | 0.50 | – | 0.80 |
| θ | 0° | – | 8° |

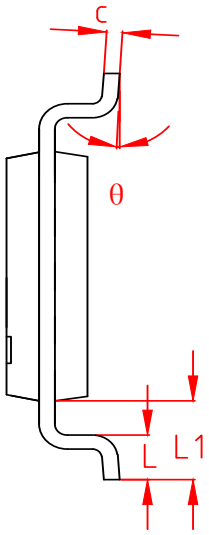
## PACKAGE DIMENSIONS

### MSOP8

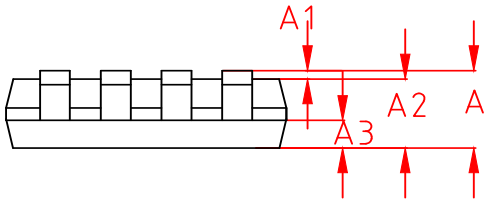
TOP VIEW
正视图




SIDE VIEW
侧视图




SIDE VIEW
侧视图




| 机械尺寸/mm Dimensions | | | |
|---|---|---|---|
| 字符 SYMBOL | 最小值 MIN | 典型值 NOMINAL | 最大值 MAX |
| A | – | – | 1.10 |
| A1 | 0.05 | – | 0.15 |
| A2 | 0.75 | 0.85 | 0.95 |
| A3 | 0.30 | 0.35 | 0.40 |
| b | 0.28 | – | 0.36 |
| c | 0.15 | – | 0.19 |
| D | 2.90 | 3.00 | 3.10 |
| E | 2.90 | 3.00 | 3.10 |
| E1 | 4.70 | 4.90 | 5.10 |
| e | 0.65 BSC | | |
| L1 | 0.95 REF | | |
| L | 0.40 | – | 0.70 |
| θ | 0° | – | 8° |