

# 12-Bit Digital Pre-Distortion μModule Receiver Subsystem

## FEATURES

- **Fully Integrated Receiver Subsystem for Digital Pre-Distortion Applications**
- **Down-Converting Mixer with Wide RF Frequency Range: 400MHz to 3.8GHz**
- **125MHz Wide Bandpass Filter, <0.5dB Passband Ripple**
- **Low Power ADC with Up to 12-Bit Resolution, 250Msps Sample Rate**
- **-145.5dBm/Hz Input Noise Floor, 25.6dBm IIP3**
- **1.5W Total Power Consumption**
- **50Ω Single-Ended RF and LO Ports**
- **Internal Bypass Capacitance, No External Components**
- **ADC Clock Duty Cycle Stabilizer**
- **11.25mm × 15mm LGA package**

## APPLICATIONS

- Transmit ObservationPath Receivers
- Digital Pre-Distortion (DPD) Receivers
- Wideband Receiver
- Wideband Instrumentation

## DESCRIPTION

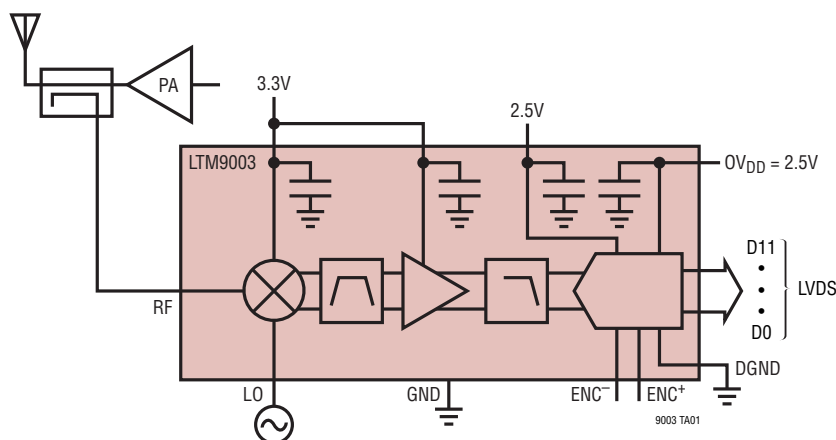
The LTM®9003 is a 12-bit digital pre-distortion µModule® receiver subsystem for the transmit path of cellular base stations. Utilizing an integrated system in a package (SiP) technology, it includes a downconverting mixer, wideband filter and analog-to-digital converter (ADC). The system is tuned for an intermediate frequency (IF) of 184MHz and a signal bandwidth of up to 125MHz. The 12-bit ADC samples at rates up to 250Mps. Contact Linear Technology regarding customization.

The high signal level downconverting active mixer is optimized for high linearity, wide dynamic range IF sampling applications. It includes a differential LO buffer amplifier driving a double-balanced mixer. Broadband, integrated transformers on the RF and LO inputs provide single ended 50Ω interfaces. The RF and LO inputs are internally matched to 50Ω from 1.1GHz to 1.8GHz.

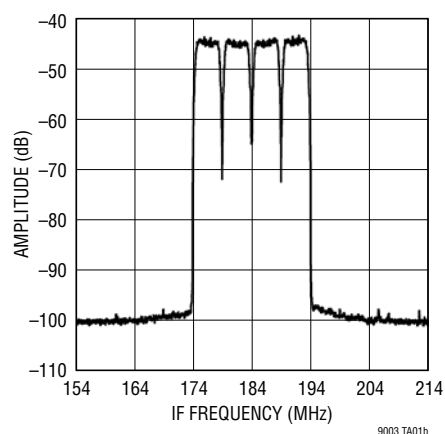
The CLK input controls converter operation and may be driven differentially or single-ended. An optional clock duty cycle stabilizer allows high performance at full speed for a wide range of clock duty cycles.

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## TYPICAL APPLICATION



### FFT of 4-Channel WCDMA Input at 2.14GHz



# LTM9003

## ABSOLUTE MAXIMUM RATINGS

(Notes 1, 2)

Supply Voltage ( $V_{CC1}$ )

LTM9003-AA ..... -0.3V to 4V

LTM9003-AB ..... -0.3V to 5.5V

Supply Voltage ( $V_{CC2}$ ) ..... -0.3V to 5.5V

Supply Voltage ( $V_{DD}$ ,  $OV_{DD}$ ) ..... -0.3V to 2.8V

Digital Output Ground Voltage ( $OGND$ ) ..... -0.3V to 1V

LO Input Power (380MHz to 4.2GHz) ..... 10dBm

LO Input DC Voltage ..... -1V to ( $V_{CC1} + 1V$ )

RF Input Power (400MHz to 3.8GHz) ..... 15dBm

RF Input DC Voltage .....  $\pm 0.1V$

MIX\_EN Voltage ..... -0.3V to ( $V_{CC1} + 0.3V$ )

AMP\_EN Input Current .....  $\pm 10mA$

Digital Input Voltage ..... -0.3V to ( $V_{DD} + 0.3V$ )

Digital Output Voltage ..... -0.3V to ( $OV_{DD} + 0.3V$ )

Operating Ambient Temperature Range

LTM9003CV ..... 0°C to 70°C

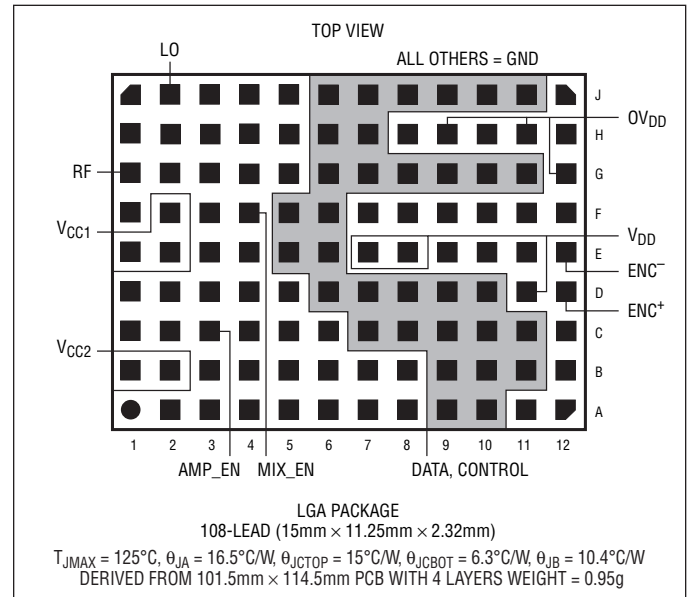
LTM9003IV ..... -40°C to 85°C

Storage Temperature Range ..... -40°C to 125°C

Maximum Junction Temperature ..... 125°C

**CAUTION:** The RF and LO inputs are sensitive to electrostatic discharge (ESD). It is very important that proper ESD precautions be observed when handling the LTM9003.

## PIN CONFIGURATION



## ORDER INFORMATION

| LEAD FREE FINISH | TRAY             | PART MARKING* | PACKAGE DESCRIPTION                   | TEMPERATURE RANGE |
|------------------|------------------|---------------|---------------------------------------|-------------------|
| LTM9003CV-AA#PBF | LTM9003CV-AA#PBF | LTM9003V AA   | 108-Lead (11.25mm × 15mm × 2.3mm) LGA | 0°C to 70°C       |
| LTM9003IV-AA#PBF | LTM9003IV-AA#PBF | LTM9003V AA   | 108-Lead (11.25mm × 15mm × 2.3mm) LGA | -40°C to 85°C     |
| LTM9003CV-AB#PBF | LTM9003CV-AB#PBF | LTM9003V AB   | 108-Lead (11.25mm × 15mm × 2.3mm) LGA | 0°C to 70°C       |
| LTM9003IV-AB#PBF | LTM9003IV-AB#PBF | LTM9003V AB   | 108-Lead (11.25mm × 15mm × 2.3mm) LGA | -40°C to 85°C     |

Consult LTC Marketing for parts specified with wider operating temperature ranges. \*The temperature grade is identified by a label on the shipping container.

For more information on lead free part marking, go to: <http://www.linear.com/leadfree/>

This product is only offered in trays. For more information go to: <http://www.linear.com/packaging/>

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 3)

| PARAMETER                 | CONDITIONS  | MIN      | TYP          | MAX    | UNITS      |
|---------------------------|---|----------|--------------|--------|------------|
| RF Input Frequency Range  | LTM9003-AA<br>No External Matching (Midband)<br>With External Matching (Low Band or High Band)              | 400      | 1100 to 1800 | 3800   | MHz<br>MHz |
|                           | LTM9003-AB<br>No External Matching (Midband)<br>With External Matching (Low Band or High Band)              | 400      | 1100 to 1800 | 3700   | MHz<br>MHz |
| LO Input Frequency Range  | LTM9003-AA<br>No External Matching<br>With External Matching  | 380      | 800 to 3500  |        | MHz<br>MHz |
|                           | LTM9003-AB<br>No External Matching<br>With External Matching  | 380      | 900 to 3500  |        | MHz<br>MHz |
| RF Input Return Loss      | $Z_0 = 50\Omega$ , 1100MHz to 1800MHz (No External Matching)<br>LTM9003-AA<br>LTM9003-AB                    |          | >12<br>>12   |        | dB<br>dB   |
| LO Input Return Loss      | $Z_0 = 50\Omega$ , 900MHz to 3500MHz (No External Matching)<br>LTM9003-AA<br>LTM9003-AB                     |          | >10<br>>10   |        | dB<br>dB   |
| RF Input Power for -1dBFS | LTM9003-AA<br>LTM9003-AB  |          | -1.7<br>-1.7 |        | dBm<br>dBm |
| LO Input Power            | 1200MHz to 4200MHz, LTM9003-AA or<br>1200MHz to 3500MHz, LTM9003-AB<br>380MHz to 1200MHz                    | -8<br>-5 | -3<br>0      | 2<br>5 | dBm<br>dBm |
| LO to RF Leakage          | LTM9003-AA<br>$f_{LO} = 380\text{MHz}$ to $1600\text{MHz}$<br>$f_{LO} = 1600\text{MHz}$ to $4000\text{MHz}$ |          | <-50<br><-45 |        | dBm<br>dBm |
|                           | LTM9003-AB<br>$f_{LO} = 400\text{MHz}$ to $2100\text{MHz}$<br>$f_{LO} = 2100\text{MHz}$ to $3200\text{MHz}$ |          | <-44<br><-36 |        | dBm<br>dBm |
| RF to LO Isolation        | LTM9003-AA<br>$f_{RF} = 400\text{MHz}$ to $1700\text{MHz}$<br>$f_{RF} = 1700\text{MHz}$ to $3800\text{MHz}$ |          | >50<br>>42   |        | dB<br>dB   |
|                           | LTM9003-AB<br>$f_{RF} = 400\text{MHz}$ to $2200\text{MHz}$<br>$f_{RF} = 2200\text{MHz}$ to $3700\text{MHz}$ |          | >43<br>>38   |        | dB<br>dB   |

## CONVERTER CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 3)

| PARAMETER                         | CONDITIONS     | MIN | TYP       | MAX | UNITS |
|-----------------------------------|----------------|-----|-----------|-----|-------|
| Resolution (No Missing Codes)     | ●              | 12  |           |     | Bits  |
| Integral Linearity Error (Note 4) | IF = 184.32MHz |     | $\pm 1$   |     | LSB   |
| Differential Linearity Error      | IF = 184.32MHz |     | $\pm 0.4$ |     | LSB   |

## FILTER CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .

| PARAMETER            | CONDITIONS         | MIN | TYP    | MAX | UNITS |
|----------------------|--------------------|-----|--------|-----|-------|
| Center Frequency     |                    |     | 184.32 |     | MHz   |
| Lower 3dB Bandedge   |                    |     | 84     |     | MHz   |
| Upper 3dB Bandedge   |                    |     | 304    |     | MHz   |
| Lower 20dB Stopband  |                    |     | 40     |     | MHz   |
| Upper 20dB Stopband  |                    |     | 450    |     | MHz   |
| Passband Flatness    | 129MHz to 239.6MHz |     | 0.5    |     | dB    |
|                      | 174MHz to 194MHz   |     | 0.15   |     | dB    |
| Group Delay Flatness | 129MHz to 239.6MHz |     | 1.2    |     | ns    |
|                      | 174MHz to 194MHz   |     | 0.1    |     | ns    |
| Absolute Delay       |                    |     | 2.7    |     | ns    |

## DYNAMIC ACCURACY

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 3)

| SYMBOL  | PARAMETER  | CONDITIONS   | MIN    | TYP                     | MAX | UNITS                   |
|---------|--|--|--------|-------------------------|-----|-------------------------|
| SNR     | Signal-to-Noise Ratio at -1dBFS                                    | RF = 1889MHz, LO = 1766MHz<br>RF = 1950MHz, LO = 1766MHz<br>RF = 2011MHz, LO = 1766MHz               | ● 141  | 143.6<br>143.6<br>143.6 |     | dB/Hz<br>dB/Hz<br>dB/Hz |
| IIP3    | Input 3rd Order Intercept, 2-Tone                                  | LTM9003-AA<br>RF = 1948MHz, 1952MHz, LO = 1766MHz  |        | 27                      |     | dBm                     |
|         |  | LTM9003-AB<br>RF = 1948MHz, 1952MHz, LO = 1766MHz  |        | 28                      |     | dBm                     |
| IIP2    | Input 2nd Order Intercept, 1-Tone                                  | LTM9003-AA<br>RF = 1950MHz, LO = 1766MHz   |        | 61                      |     | dBm                     |
|         |  | LTM9003-AB<br>RF = 1950MHz, LO = 1766MHz   |        | 61.4                    |     | dBm                     |
| SFDR    | Spurious Free Dynamic Range, 2nd or 3rd Harmonic at -1dBFS         | LTM9003-AA<br>RF = 1889MHz, LO = 1766MHz<br>RF = 1950MHz, LO = 1766MHz<br>RF = 2011MHz, LO = 1766MHz | ● 50.7 | 54.1<br>58.8<br>63.6    |     | dB<br>dB<br>dB          |
|         |  | LTM9003-AB<br>RF = 1889MHz, LO = 1766MHz<br>RF = 1950MHz, LO = 1766MHz<br>RF = 2011MHz, LO = 1766MHz | ● 52.0 | 57.3<br>62.4<br>66.3    |     | dB<br>dB<br>dB          |
| SFDR    | Spurious Free Dynamic Range, 4th or Higher at -1dBFS               | RF = 1889MHz, LO = 1766MHz<br>RF = 1950MHz, LO = 1766MHz<br>RF = 2011MHz, LO = 1766MHz               | ● 66.5 | 74<br>82<br>87          |     | dB<br>dB<br>dB          |
| S/(N+D) | Signal-to-Noise Plus Distortion Ratio at -1dBFS                    | RF = 1889MHz, LO = 1766MHz<br>RF = 1950MHz, LO = 1766MHz<br>RF = 2011MHz, LO = 1766MHz               | ● 50.3 | 54<br>58<br>60          |     | dB<br>dB<br>dB          |
| IMD3    | Intermodulation Distortion at -7dBFS per Tone                      | RF = 1950MHz, LO = 1766MHz   |        | -58                     |     | dB                      |
| ACPR    | Adjacent Channel Power Ratio at 2.4dBm per Carrier, Four Carriers  |  |        | 58.5                    |     | dB                      |
| ALTCPR  | Alternate Channel Power Ratio at 2.4dBm per Carrier, Four Carriers |  |        | 63.3                    |     | dB                      |

## DIGITAL INPUTS AND OUTPUTS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 3)

| SYMBOL  | PARAMETER                     | CONDITIONS   |        | MIN          | TYP        | MAX        | UNITS                          |
|---|-------------------------------|--|--------|--------------|------------|------------|--------------------------------|
| <b>Encode Inputs (ENC<sup>-</sup>, ENC<sup>+</sup>)</b> |                               |  |        |              |            |            |                                |
| $V_{ID}$  | Differential Input Voltage    | (Note 5)   |        | 0.2          |            |            | V                              |
| $V_{ICM}$   | Common Mode Input Voltage     | Internally Set<br>Externally Set (Note 5)                                  | ●      | 1.2          | 1.5<br>1.5 | 2          | V<br>V                         |
| $R_{IN}$  | Input Resistance              | Single-Ended   |        |              | 4.8        |            | $\Omega$                       |
| $R_{IN(DIFF)}$  | Input Resistance              | Differential   |        |              | 100        |            | $\Omega$                       |
| $C_{IN}$  | Input Capacitance             |  |        |              | 2          |            | pF                             |
| <b>Logic Inputs (OE, SHDN)</b>                          |                               |  |        |              |            |            |                                |
| $V_{IH}$  | High Level Input Voltage      | $V_{DD} = 2.5\text{V}$   | ●      | 1.7          |            |            | V                              |
| $V_{IL}$  | Low Level Input Voltage       | $V_{DD} = 2.5\text{V}$   | ●      |              |            | 0.7        | V                              |
| $I_{IN}$  | Input Current                 | $V_{IN} = 0\text{V to } V_{DD}$  | ●      | -10          |            | 10         | $\mu\text{A}$                  |
| $C_{IN}$  | Input Capacitance             | (Note 5)   |        |              |            | 3          | pF                             |
| <b>Mixer Enable</b>                                     |                               |  |        |              |            |            |                                |
| $V_{IH}$  | High Level Input Voltage      | $V_{CC1} = 3.3\text{V}$ , LTM9003-AA<br>$V_{CC1} = 5\text{V}$ , LTM9003-AB | ●<br>● | 2.7<br>3     |            |            | V<br>V                         |
| $V_{IL}$  | Low Level Input Voltage       | $V_{CC1} = 3.3\text{V}$ , LTM9003-AA<br>$V_{CC1} = 5\text{V}$ , LTM9003-AB | ●<br>● |              |            | 0.3<br>0.3 | V<br>V                         |
| $I_{IN}$  | Input Current                 | $V_{IN} = 0\text{V to } V_{CC1}$ , LTM9003-AA                              | ●      |              | 53         | 90         | $\mu\text{A}$                  |
|   | Turn-On Time                  |  |        |              | 2.8        |            | ms                             |
|   | Turn-Off Time                 |  |        |              | 2.9        |            | ms                             |
| <b>Amplifier Enable</b>                                 |                               |  |        |              |            |            |                                |
| $V_{IH}$  | High Level Input Voltage      | $V_{CC2} = 3.3\text{V}$  | ●      | 2            |            |            | V                              |
| $V_{IL}$  | Low Level Input Voltage       | $V_{CC2} = 3.3\text{V}$  | ●      |              |            | 0.8        | V                              |
| $I_{IN}$  | Input Current                 | $V_{IN} = 0.8\text{V}$<br>$V_{IN} = 2\text{V}$                             | ●<br>● | -200<br>-150 | -85<br>-30 | 0<br>0     | $\mu\text{A}$<br>$\mu\text{A}$ |
| <b>Control Inputs (SENSE, MODE, LVDS)</b>               |                               |  |        |              |            |            |                                |
| $I_{SENSE}$   | SENSE Input Leakage           | $0\text{V} < \text{SENSE} < 1\text{V}$                                     | ●      | -1           |            | 1          | $\mu\text{A}$                  |
| $I_{MODE}$  | MODE Pull-Down Current to GND | See Pin Functions for Voltage Levels                                       |        |              | 7          |            | $\mu\text{A}$                  |
| $I_{LVDS}$  | LVDS Pull-Down Current to GND | See Pin Functions for Voltage Levels                                       |        |              | 7          |            | $\mu\text{A}$                  |
| <b>Logic Outputs (LVDS Mode)</b>                        |                               |  |        |              |            |            |                                |
| <b>OV<sub>DD</sub> = 2.5V</b>                           |                               |  |        |              |            |            |                                |
| $V_{OD}$  | Differential Output Voltage   | 100 $\Omega$ Differential Load   | ●      | 247          | 350        | 454        | mV                             |
| $V_{OS}$  | Output Common Mode Voltage    | 100 $\Omega$ Differential Load   | ●      | 1.125        | 1.250      | 1.375      | V                              |

## POWER REQUIREMENTS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 3)

| SYMBOL                 | PARAMETER                         | CONDITIONS   |   | MIN   | TYP | MAX   | UNITS         |
|------------------------|-----------------------------------|--|---|-------|-----|-------|---------------|
| $V_{CC1}$              | Mixer Supply Range                | LTM9003-AA (Note 6)  | ● | 2.9   | 3.3 | 3.6   | V             |
|                        |                                   | LTM9003-AB (Note 6)  | ● | 4.5   | 5   | 5.25  | V             |
| $V_{CC2}$              | Amplifier Supply Range            | (Note 6)   | ● | 2.8   | 3.3 | 5.25  | V             |
| $V_{DD}$               | ADC Analog Supply Voltage         | (Note 6)   | ● | 2.375 | 2.5 | 2.625 | V             |
| $I_{CC1}$              | Mixer Supply Current              | MIX_EN = 3V, LTM9003-AA                                      | ● |       | 80  | 92    | mA            |
|                        |                                   | MIX_EN = 5V, LTM9003-AB                                      |   |       | 82  | 92    | mA            |
| $I_{CC1}(\text{SHDN})$ | Mixer Shutdown Supply Current     | MIX_EN = 0V  | ● |       |     | 100   | $\mu\text{A}$ |
| $I_{CC2}$              | Amplifier Supply Current          | AMP_EN = 3V  | ● |       | 104 | 140   | mA            |
| $I_{CC2}(\text{SHDN})$ | Amplifier Shutdown Supply Current | AMP_EN = 0V  | ● |       | 3   | 5     | mA            |
| $I_{DD}(\text{ADC})$   | ADC Supply Current                |  | ● |       | 285 | 320   | mA            |
| $P_D(\text{SHDN})$     | ADC Shutdown Power                | SHDN = $V_{DD}$ , $\overline{\text{OE}}$ = $V_{DD}$ , No CLK |   |       | 1.5 |       | mW            |
| $P_D(\text{NAP})$      | ADC Nap Mode Power                | SHDN = $V_{DD}$ , $\overline{\text{OE}}$ = 0V, No CLK        |   |       | 30  |       | mW            |

### LVDS Output Mode

|                        |                                   |   |   |       |      |       |    |
|------------------------|-----------------------------------|---|---|-------|------|-------|----|
| $OV_{DD}$              | ADC Digital Output Supply Voltage |   | ● | 2.375 | 2.5  | 2.625 | V  |
| $I_{OVDD}(\text{ADC})$ | ADC Digital Output Supply Current |   | ● |       | 58   | 74    | mA |
| $P_D(\text{ADC})$      | ADC Power Dissipation             |   | ● |       | 858  | 985   | mW |
| $P_D(\text{TOTAL})$    | Total Power Dissipation           | SHDN = 0V, MIX_EN = AMP_EN = 3V, $f_{\text{SAMPLE}} = \text{MAX}$<br>(LTM9003-AA) |   |       | 1465 |       | mW |
|                        |                                   | (LTM9003-AB)  |   |       | 1611 |       | mW |

## TIMING CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 3)

| SYMBOL       | PARAMETER                                     | CONDITIONS                         |   | MIN | TYP | MAX | UNITS             |
|--------------|---|------------------------------------|---|-----|-----|-----|-------------------|
| $f_s$        | Sampling Frequency                            | (Note 6)                           | ● | 1   |     | 250 | MHz               |
| $t_L$        | ENC Low Time                                  | Duty Cycle Stabilizer Off (Note 5) | ● | 1.9 | 2   | 500 | ns                |
|              |   | Duty Cycle Stabilizer On (Note 5)  | ● | 1.5 | 2   | 500 | ns                |
| $t_H$        | ENC High Time                                 | Duty Cycle Stabilizer Off (Note 5) | ● | 1.9 | 2   | 500 | ns                |
|              |   | Duty Cycle Stabilizer On (Note 5)  | ● | 1.5 | 2   | 500 | ns                |
| $t_{JITTER}$ | Sample-and-Hold Acquisition Delay Time Jitter |                                    |   |     | 95  |     | fs <sub>RMS</sub> |
| $t_{AP}$     | Sample-and-Hold Aperture Delay                |                                    |   |     | 0   |     | ns                |
| $t_{OE}$     | Output Enable Delay                           | (Note 5)                           | ● |     | 5   | 10  | ns                |

### LVDS Output Mode

|       |                     |                        |   |      |     |     |        |
|-------|---------------------|------------------------|---|------|-----|-----|--------|
| $t_D$ | ENC to DATA delay   | (Note 5)               | ● | 1    | 1.7 | 2.8 | ns     |
| $t_C$ | ENC to CLKOUT Delay | (Note 5)               | ● | 1    | 1.7 | 2.8 | ns     |
|       | DATA to CLKOUT Skew | $(t_C - t_D)$ (Note 5) | ● | -0.6 | 0   | 0.6 | ns     |
|       | Rise Time           |                        |   |      | 0.5 |     | ns     |
|       | Fall Time           |                        |   |      | 0.5 |     | ns     |
|       | Pipeline Latency    |                        |   |      | 5   |     | Cycles |

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** All voltage values are with respect to ground with GND and OGND wired together (unless otherwise noted).

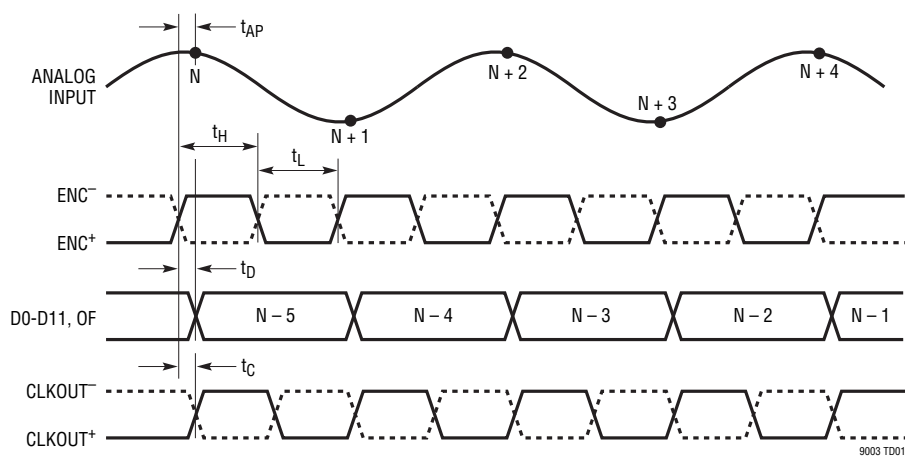
**Note 3:**  $V_{CC1} = V_{CC2} = 3.3\text{V}$  (LTM9003-AA) or  $V_{CC1} = 5\text{V}$ ,  $V_{CC2} = 3.3\text{V}$  (LTM9003-AB),  $V_{DD} = 2.5\text{V}$ ,  $OV_{DD} = 2.5\text{V}$ ,  $f_{SAMPLE} = 250\text{MHz}$ , input range = -1dBFS, differential  $ENC^+/ENC^- = 2V_{P-P}$  sine wave, unless otherwise noted.

**Note 4:** Integral nonlinearity is defined as the deviation of a code from a "best straight line" fit to the transfer curve. The deviation is measured from the center of the quantization band.

**Note 5:** Guaranteed by design, not subject to test.

**Note 6:** Recommended operating conditions.

TIMING DIAGRAM

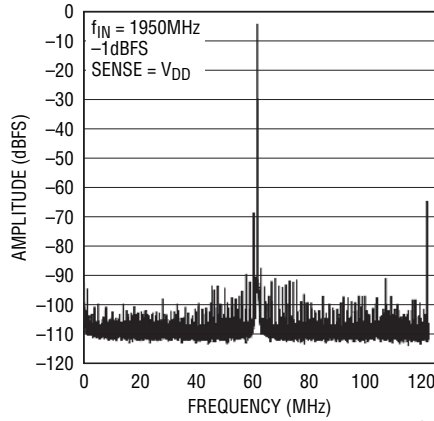


LVDS Output Mode Timing  
All Outputs Are Differential and Have LVDS Levels

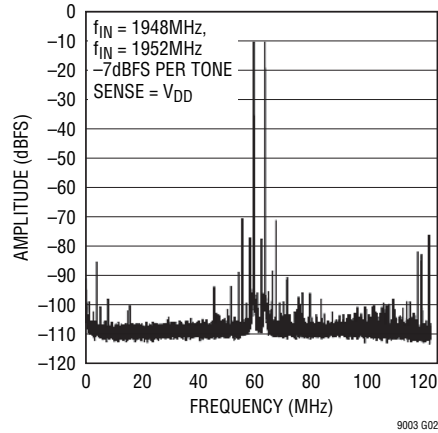


# TYPICAL PERFORMANCE CHARACTERISTICS $T_A = 25^\circ\text{C}$ .

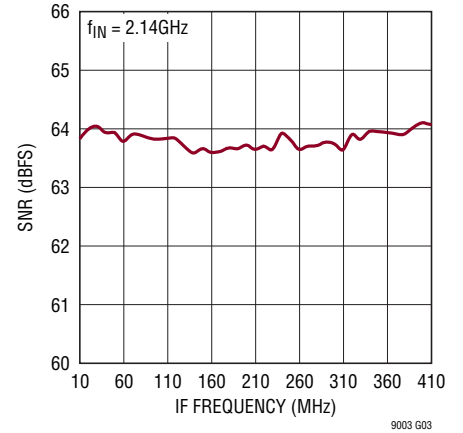
64k Point FFT, LTM9003-AA



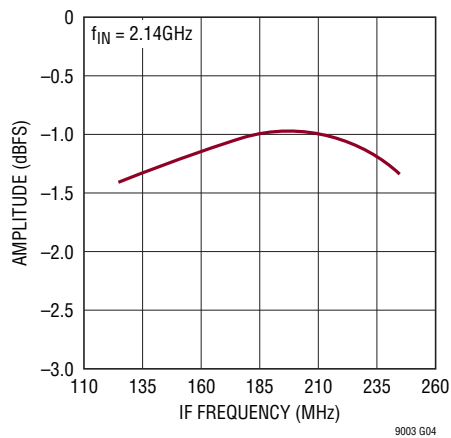
64k Point 2-Tone FFT, LTM9003-AA



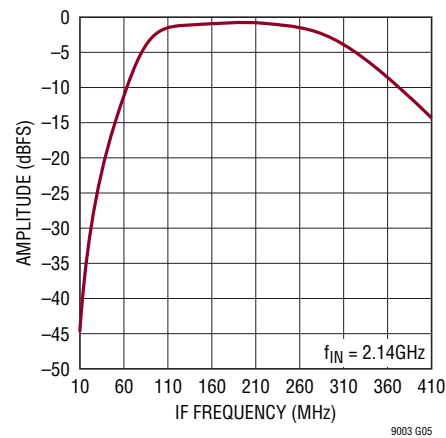
SNR vs Frequency, LTM9003-AA



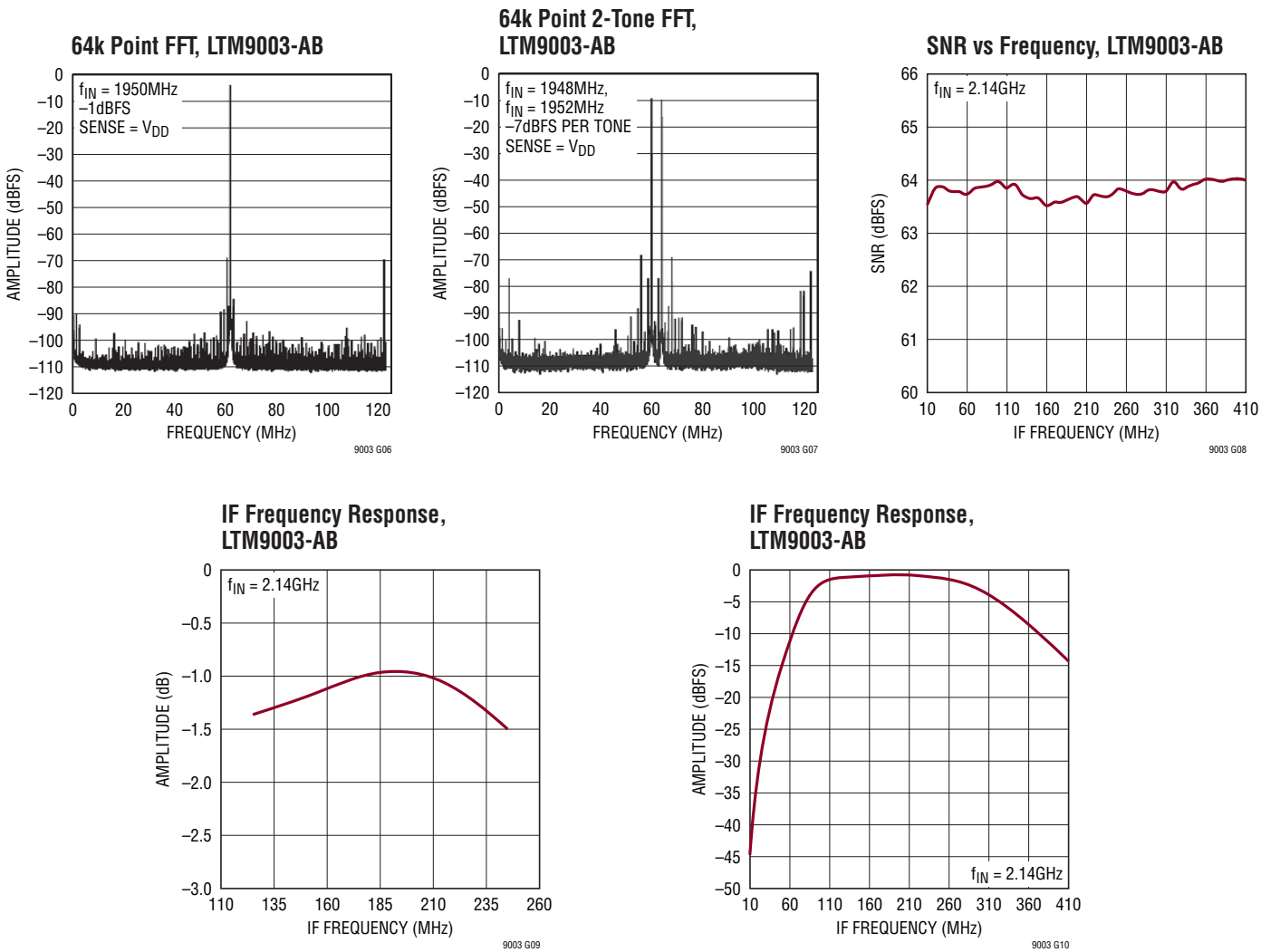
IF Frequency Response, LTM9003-AA



IF Frequency Response, LTM9003-AA



TYPICAL PERFORMANCE CHARACTERISTICS  $T_A = 25^{\circ}\text{C}$ .



## PIN FUNCTIONS

**V<sub>CC1</sub> (Pins E1, E2, F2):** 3.3V (LTM9003-AA) or 5V (LTM9003-AB) Supply Voltage for the Mixer. V<sub>CC1</sub> is internally bypassed to GND.

**V<sub>CC2</sub> (Pins B1, B2):** 3.3V Supply Voltage for the Amplifier. V<sub>CC2</sub> is internally bypassed to GND.

**V<sub>DD</sub> (Pins D11, E7, E8):** 2.5V Supply Voltage for ADC. V<sub>DD</sub> is internally bypassed to GND.

**OV<sub>DD</sub> (Pins G12, H9, H11):** 2.5V Supply for the Output Drivers. OV<sub>DD</sub> is internally bypassed to OGND.

**GND (See Table for Locations):** Module Ground.

**OGND (Pins F12, H8, H10, H12, J12):** Output Driver Ground.

**RF (Pin G1):** Single-Ended Input for the RF Signal. This pin is internally connected to the primary side of the RF input transformer, which has low DC resistance to ground. If the RF source is not DC blocked, then a series blocking capacitor must be used. The RF input is internally matched from 1.1GHz to 1.8GHz. Operation down to 400MHz or up to 3.8GHz is possible with simple external matching.

**LO (Pin J2):** Single-Ended Input for the Local Oscillator Signal. This pin is internally connected to the primary side of the LO transformer, which is internally DC blocked. An external blocking capacitor is not required. The LO input is internally matched from 0.9GHz to 3.5GHz. Operation down to 380MHz is possible with simple external matching.

**MIX\_EN (Pin F4):** Mixer Enable Pin. Connecting MIX\_EN to V<sub>CC1</sub> results in normal operation. Connecting MIX\_EN to GND disables the mixer. The MIX\_EN pin should not be left floating.

**AMP\_EN (Pin C3):** Amplifier Enable Pin. This pin is internally pulled high by a typically 30k resistor to V<sub>CC2</sub>. Connecting AMP\_EN to V<sub>CC2</sub> results in normal operation. Connecting AMP\_EN to GND disables the amplifier.

**ENC<sup>+</sup> (Pin D12):** ADC Encode Input. Conversion starts on the positive edge.

**ENC<sup>-</sup> (Pin E12):** ADC Encode Complement Input. Conversion starts on the negative edge. Bypass to ground with 0.1μF ceramic for single-ended ENCODE signal.

**SHDN (Pin B11):** ADC Shutdown Mode Selection Pin. Connecting SHDN to GND and  $\overline{OE}$  to GND results in normal operation with the outputs enabled. Connecting SHDN to GND and  $\overline{OE}$  to V<sub>DD</sub> results in normal operation with the outputs at high impedance. Connecting SHDN to V<sub>DD</sub> and  $\overline{OE}$  to GND results in nap mode with the outputs at high impedance. Connecting SHDN to V<sub>DD</sub> and  $\overline{OE}$  to V<sub>DD</sub> results in sleep mode with the outputs at high impedance.

**$\overline{OE}$  (Pin C11):** Output Enable Pin. Refer to SHDN pin function.

**MODE (Pin C7):** Output Format and Clock Duty Cycle Stabilizer Selection Pin. Connecting MODE to GND selects offset binary output format and turns the clock duty cycle stabilizer off. 1/3 V<sub>DD</sub> selects offset binary output format and turns the clock duty cycle stabilizer on. 2/3 V<sub>DD</sub> selects 2's complement output format and turns the clock duty cycle stabilizer on. V<sub>DD</sub> selects 2's complement output format and turns the clock duty cycle stabilizer off.

**SENSE (Pin G7):** Reference Programming Pin. Connecting SENSE to 1.25V selects the internal reference and a ±0.5V input range. V<sub>DD</sub> selects the internal reference and a ±1V input range. An external reference greater than 0.5V and less than 1V applied to SENSE selects an input range of ±V<sub>SENSE</sub>. ±1V is the largest valid input range.

**LVDS (Pin D7):** Output Mode Selection Pin. Connect LVDS to V<sub>DD</sub>.

### Digital Outputs

**D0<sup>-</sup>/D0<sup>+</sup> – D11<sup>-</sup>/D11<sup>+</sup> (See Table for Locations):** LVDS Digital Outputs. All LVDS outputs require differential 100Ω termination resistors at the LVDS receiver. D11<sup>-</sup>/D11<sup>+</sup> is the MSB.

**CLKOUT<sup>-</sup>/CLKOUT<sup>+</sup> (Pins J10/J11):** LVDS Data Valid Output. Latch data on rising edge of CLKOUT<sup>-</sup>, falling edge of CLKOUT<sup>+</sup>.

**OF<sup>-</sup>/OF<sup>+</sup> (Pins E5/F5):** LVDS Over/Under Flow Output. High when an over or under flow has occurred.

PIN FUNCTIONS

Pin Configuration

|   |                  |                  |        |        |     |      |                 |                 |                  |         |                  |                  |
|---|------------------|------------------|--------|--------|-----|------|-----------------|-----------------|------------------|---------|------------------|------------------|
| J | GND              | LO               | GND    | GND    | GND | D9+  | D8-             | D6+             | D6-              | CLKOUT+ | CLKOUT-          | OGND             |
| H | GND              | GND              | GND    | GND    | GND | D9-  | D8+             | OGND            | OV <sub>DD</sub> | OGND    | OV <sub>DD</sub> | OGND             |
| G | RF               | GND              | GND    | GND    | GND | D10- | SENSE           | D7+             | D7-              | D5+     | D5-              | OV <sub>DD</sub> |
| F | GND              | V <sub>CC1</sub> | GND    | MIX_EN | OFP | D10+ | GND             | GND             | GND              | GND     | GND              | OGND             |
| E | V <sub>CC1</sub> | V <sub>CC1</sub> | GND    | GND    | OFN | D11- | V <sub>DD</sub> | V <sub>DD</sub> | GND              | GND     | GND              | ENC-             |
| D | GND              | GND              | GND    | GND    | GND | D11+ | LVDS            | D4+             | D3+              | D1+     | V <sub>DD</sub>  | ENC+             |
| C | GND              | GND              | AMP_EN | GND    | GND | GND  | MODE            | D4-             | D3-              | D1-     | OE               | GND              |
| B | V <sub>CC2</sub> | V <sub>CC2</sub> | GND    | GND    | GND | GND  | GND             | GND             | D2+              | D0+     | SHDN             | GND              |
| A | GND              | GND              | GND    | GND    | GND | GND  | GND             | GND             | D2-              | D0-     | GND              | GND              |
|   | 1                | 2                | 3      | 4      | 5   | 6    | 7               | 8               | 9                | 10      | 11               | 12               |

Top View of LGA Package (Looking Through Component)

BLOCK DIAGRAM

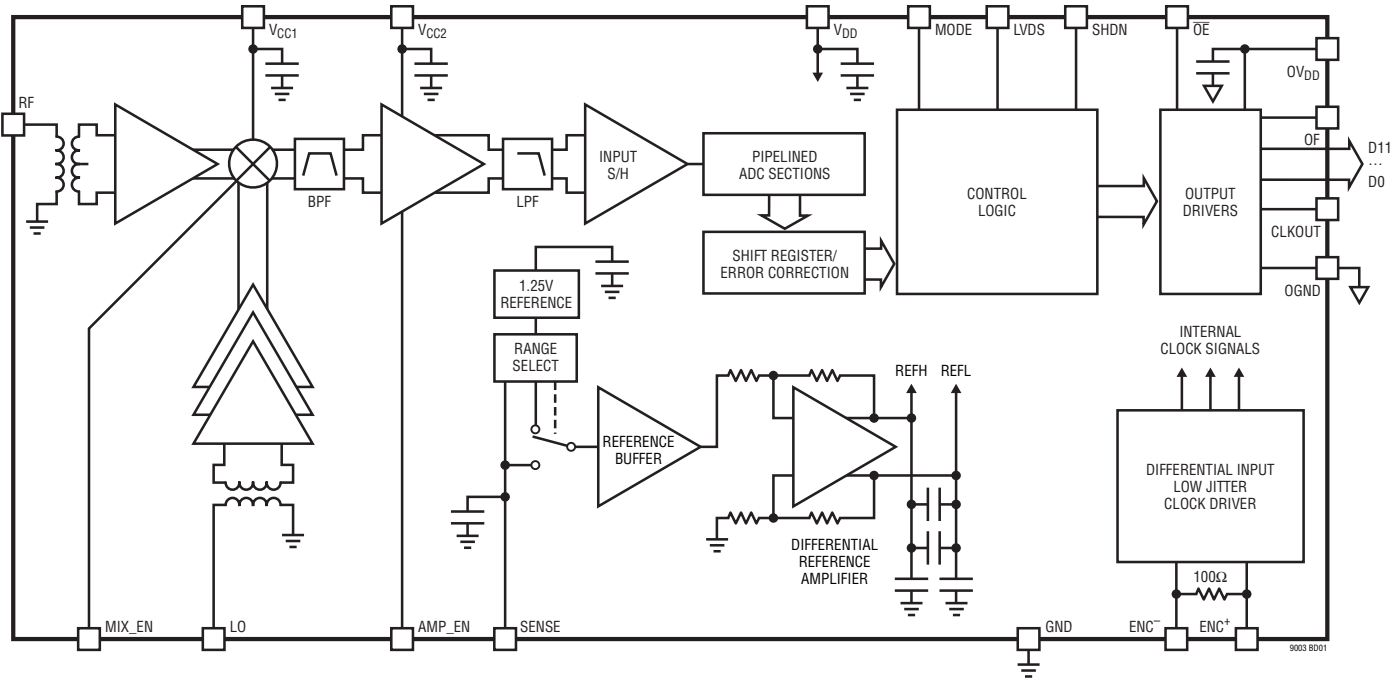


Figure 1. Simplified Block Diagram

## OPERATION

### DESCRIPTION

The LTM9003 is an integrated system in a package (SiP) that includes a high-speed 12-bit A/D converter, a wideband filter and an active mixer. The LTM9003 is designed for IF sampling, digital pre-distortion (DPD) applications, also known as transmit observation path receivers, with RF input frequencies up to 3.8GHz. Typical applications include multi-carrier base stations and telecom test instrumentation.

Digital pre-distortion is a technique often used in third-generation (3G) wireless base stations to improve the linearity of power amplifiers (PA). Improved PA linearity allows for a lower power PA to be used and therefore save a significant amount of power in the base station. The DPD receiver captures the PA output, digitizes it and feeds it back where the distortion can be analyzed. A complementary distortion is then introduced to the transmit DAC thereby pre-distorting the signal.

A significant factor in PA linearity is the distortion caused by the odd order intermodulation (IM) products. The bandwidth to be digitized is equivalent to the signal bandwidth multiplied by the order of the IM product to be canceled. For example, four carrier WCDMA consumes 20MHz of signal bandwidth; therefore, to capture the fifth order IM product requires 100MHz. The Nyquist theory requires that the ADC sample rate be at least twice that frequency.

However, simply doubling the captured bandwidth to set the sample rate may not be the best choice. Selecting the exact ADC sample rate and intermediate frequency (IF) depends on other factors within the system. To simplify filtering, the sample rate is often set at a multiple of the chip rate. The chip rate for WCDMA is 3.84MHz; selecting an ADC sample rate of 64 times the chip rate gives 245.76Msps. Placing the IF at 3/4ths the sample rate ( $f_s$ ) gives 184.32MHz and allows the entire bandwidth to fall within the second Nyquist zone. Many other frequency plans may be acceptable.

The following sections describe in further detail the operation of each functional element of the LTM9003. The SiP technology allows the LTM9003 to be customized and this is described in the Semi-Custom Options section. The outline of the remaining sections follows the basic functional elements as shown in Figure 2.

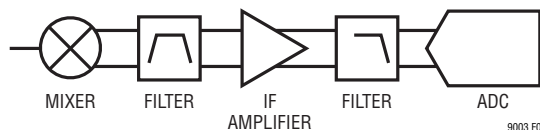


Figure 2. Basic Functional Elements

The mixer dominates the noise figure calculation as would be expected. The overall gain is optimized for the dynamic range of the ADC relative to the RF input level allowed by the mixer. The equivalent cascaded noise figure is 9.1dB (LTM9003-AA) and 9.9dB (LTM9003-AB). The bandpass filter is a second order L-C filter following the mixer and a lowpass filter following the amplifier provides anti-alias and noise limiting.

### SEMI-CUSTOM OPTIONS

The  $\mu$ Module construction affords a new level of flexibility in application-specific standard products. Standard ADC and amplifier components can be integrated regardless of their process technology and matched with passive components to a particular application. The LTM9003-AA, as the first example, is configured with a 12-bit ADC sampling at rates up to 250Msps. The total system gain is approximately 10.8dB. The IF is fixed by the bandpass filter at 184MHz with 125MHz bandwidth. The RF range is matched for 1.1GHz to 1.8GHz with low side LO.

However, other options are possible through Linear Technology's semi-custom development program. Linear Technology has in place a program to deliver other speed, resolution, IF range, gain and filter configurations for nearly any specified application. These semi-custom designs are based on existing ADCs and amplifiers with an appropriately modified matching network. The final subsystem is then tested to the exact parameters defined for the application. The final result is a fully integrated, accurately tested and optimized solution in the same package. For more details on the semi-custom receiver subsystem program, contact Linear Technology.

### Down-Converting Mixer

The mixer stage consists of a high linearity double-balanced mixer, RF buffer amplifier, high speed limiting LO buffer amplifier and bias/enable circuits. The RF and LO

## OPERATION

inputs are both single ended. Low side or high side LO injection can be used.

The mixer's RF input consists of an integrated transformer and a high linearity differential amplifier. The primary terminals of the transformer are connected to the RF input (Pin G1) and ground. The secondary side of the transformer is internally connected to the amplifier's differential inputs.

The mixer's LO input consists of an integrated transformer and high speed limiting differential amplifiers. The amplifiers are designed to precisely drive the mixer for the highest linearity and the lowest noise figure.

### Wideband Filter

Most of the IF filtering is done between the mixer and the IF amplifier. This network is a 2nd order Chebychev bandpass section, designed for 0.1dB passband ripple. The 3dB bandwidth is 220MHz, centered at 184MHz, see Figure 3. Additional lowpass filtering is done just before the ADC. This filter serves to bandlimit the out of band noise entering the converter, as well as to isolate the output of the IF amplifier from the sampling action of the converter.

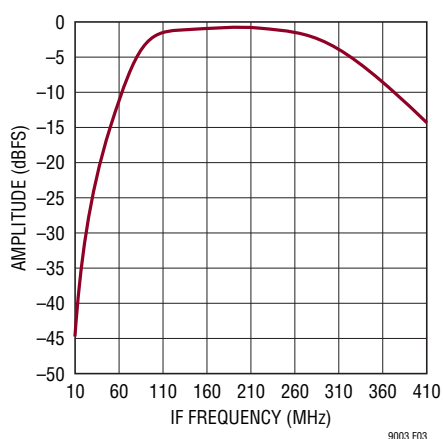


Figure 3. IF Filter Response

### Analog to Digital Converter

As shown in Figure 1, the analog-to-digital converter (ADC) is a CMOS pipelined multistep converter. The converter has five pipelined ADC stages; a sampled analog input will result in a digitized value five cycles later (see the Timing Diagram section). The encode input is differential for improved common mode noise immunity. The ADC has two phases of operation, determined by the state of the differential  $ENC^+/ENC^-$  input pins. For brevity, the text will refer to  $ENC^+$  greater than  $ENC^-$  as ENC high and  $ENC^+$  less than  $ENC^-$  as ENC low.

Each pipelined stage shown in Figure 1 contains an ADC, a reconstruction DAC and an interstage residue amplifier. In operation, the ADC quantizes the input to the stage and the quantized value is subtracted from the input by the DAC to produce a residue. The residue is amplified and output by the residue amplifier. Successive stages operate out of phase so that when the odd stages are outputting their residue, the even stages are acquiring that residue and visa versa.

When ENC is low, the analog input is sampled differentially directly onto the input sample-and-hold capacitors, inside the "Input S/H" shown in the Block Diagram. At the instant that ENC transitions from low to high, the sampled input is held. While ENC is high, the held input voltage is buffered by the S/H amplifier which drives the first pipelined ADC stage. The first stage acquires the output of the S/H during this high phase of ENC. When ENC goes back low, the first stage produces its residue which is acquired by the second stage. At the same time, the input S/H goes back to acquiring the analog input. When ENC goes back high, the second stage produces its residue which is acquired by the third stage. An identical process is repeated for the third and fourth stages, resulting in a fourth stage residue that is sent to the fifth stage ADC for final evaluation.

Each ADC stage following the first has additional range to accommodate flash and amplifier offset errors. Results from all of the ADC stages are digitally synchronized such that the results can be properly combined in the correction logic before being sent to the output buffer.

## APPLICATIONS INFORMATION

### RF Input Port

The mixer's RF input is shown in Figure 4 and is internally matched from 1.1GHz to 1.8GHz, requiring no external components over this frequency range. The input return loss, shown in Figure 5, is typically 12dB at the band edges. The input match at the lower band edge can be optimized with a shunt 3.3pF capacitor at Pin G1, which improves the 0.8GHz return loss to greater than 25dB. Likewise, the 2GHz match can be improved to greater than 25dB with a series 3.9nH inductor and a 1pF shunt capacitor. Measured RF input return losses for these three cases are plotted in Figure 5.

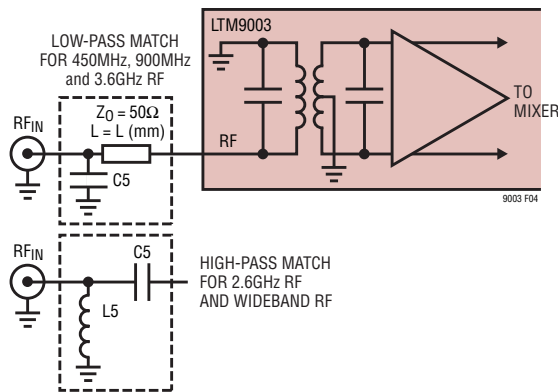


Figure 4. RF Input Schematic

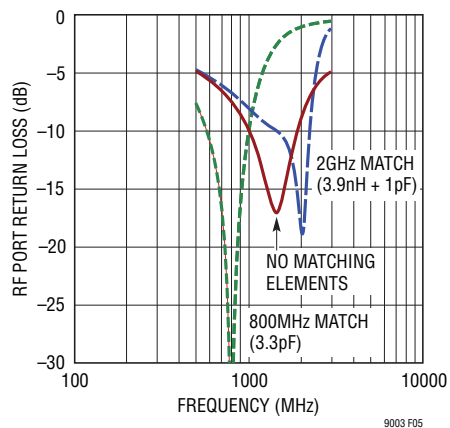


Figure 5. RF Input Return Loss with and without Matching

This series transmission line/shunt capacitor matching topology allows the LTM9003 to be used for multiple frequency standards without circuit board layout modifications. The series transmission line can also be replaced with a series chip inductor for a more compact layout.

RF input impedance and S11 versus frequency (with no external matching) are listed in Table 1 and referenced to Pin G1. The S11 data can be used with a microwave circuit simulator to design custom matching networks and simulate board-level interfacing to the RF input filter.

Table 1a. RF Input Impedance vs Frequency (LTM9003-AA)

| FREQUENCY (MHz) | INPUT IMPEDANCE | S11  |        |
|-----------------|-----------------|------|--------|
|                 |                 | MAG  | ANGLE  |
| 500             | 20.3 + j7       | 0.57 | 143    |
| 600             | 23.6 + j6.7     | 0.53 | 137.9  |
| 700             | 27.1 + j6.1     | 0.48 | 132.7  |
| 800             | 30.8 + j5.3     | 0.43 | 127    |
| 900             | 34.9 + j4.2     | 0.38 | 120.4  |
| 1000            | 39.4 + j2.9     | 0.33 | 112.6  |
| 1100            | 44.6 + j1.4     | 0.28 | 102.8  |
| 1200            | 50.1            | 0.22 | 89.8   |
| 1300            | 56 - j1         | 0.17 | 70.4   |
| 1400            | 61.5 - j1.2     | 0.14 | 42.2   |
| 1500            | 66 - j0.3       | 0.14 | 6.6    |
| 1600            | 68.7 + j1.4     | 0.17 | -21.5  |
| 1700            | 69 + j3.2       | 0.22 | -41    |
| 1800            | 67.5 + j4.5     | 0.27 | -54    |
| 1900            | 64.3 + j4.7     | 0.32 | -64.3  |
| 2000            | 60.8 + j4.1     | 0.36 | -72.2  |
| 2100            | 56.7 + j2.8     | 0.4  | -79.5  |
| 2200            | 52.7 + j1.2     | 0.43 | -85.8  |
| 2300            | 48.6 - j0.6     | 0.46 | -92.1  |
| 2400            | 44.7 - j2.3     | 0.48 | -98    |
| 2500            | 40.8 - j4       | 0.5  | -104.3 |
| 2600            | 37 - j5.3       | 0.51 | -110.5 |
| 2700            | 33.1 - j6.3     | 0.52 | -117.2 |
| 2800            | 29.4 - j6.9     | 0.53 | -124.3 |
| 2900            | 26 - j7         | 0.53 | -131.7 |
| 3000            | 22.9 - j6.7     | 0.53 | -139.6 |



## APPLICATIONS INFORMATION

Table 1b. RF Input Impedance vs Frequency (LTM9003-AB)

| FREQUENCY<br>(MHz) | INPUT IMPEDANCE | S11  |        |
|--------------------|-----------------|------|--------|
|                    |                 | MAG  | ANGLE  |
| 500                | 19.8 + j7.3     | 0.59 | 143    |
| 600                | 22.7 + j7       | 0.55 | 138.4  |
| 700                | 25.7 + j6.6     | 0.51 | 133.9  |
| 800                | 28.8 + j5.9     | 0.47 | 129.2  |
| 900                | 32.3 + j5.1     | 0.42 | 123.9  |
| 1000               | 36.1 + j3.9     | 0.38 | 117.9  |
| 1100               | 40.5 + j2.6     | 0.32 | 110.6  |
| 1200               | 45.4 + j1.1     | 0.26 | 101.3  |
| 1300               | 50.8 – j0.2     | 0.2  | 87.6   |
| 1400               | 56.3 – j0.9     | 0.15 | 65.6   |
| 1500               | 61.4 – j0.7     | 0.12 | 27.5   |
| 1600               | 65.3 + j0.5     | 0.14 | –13.1  |
| 1700               | 67.4 + j2.4     | 0.19 | –37.9  |
| 1800               | 67.3 + j4.1     | 0.25 | –52.4  |
| 1900               | 65.7 + j5.1     | 0.31 | –61.9  |
| 2000               | 63.2 + j5.2     | 0.37 | –68.9  |
| 2100               | 60.4 + j4.7     | 0.42 | –74.4  |
| 2200               | 57.6 + j3.7     | 0.46 | –79.1  |
| 2300               | 55 + j2.6       | 0.49 | –83    |
| 2400               | 52.4 + j1.3     | 0.51 | –86.7  |
| 2500               | 49.9            | 0.53 | –90.1  |
| 2600               | 47.4 – j1.4     | 0.54 | –93.7  |
| 2700               | 44.8 – j2.7     | 0.55 | –97.3  |
| 2800               | 41.9 – j3.9     | 0.55 | –101.6 |
| 2900               | 39 – j5         | 0.55 | –106.3 |
| 3000               | 35.7 – j5.9     | 0.54 | –111.9 |

## LO Input Port

The mixer's LO input, shown in Figure 6, is internally matched from 0.9GHz to 3.5GHz. LO input matching near 600MHz requires the series inductor (L4)/shunt capacitor (C4) network shown in Figure 6. Likewise, the 2GHz match can be improved by using  $L4 = 2.7\mu\text{H}$ ,  $C4 = 0.5\text{pF}$ . Measured LO input return losses for these three cases are plotted in Figure 7.

The optimum LO drive is –3dBm for LO frequencies above 1.2GHz, although the amplifiers are designed to accommodate several dB of LO input power variation without significant mixer performance variation. Below 1.2GHz, 0dBm LO drive is recommended for optimum noise figure, although –3dBm will still deliver good conversion gain and linearity.

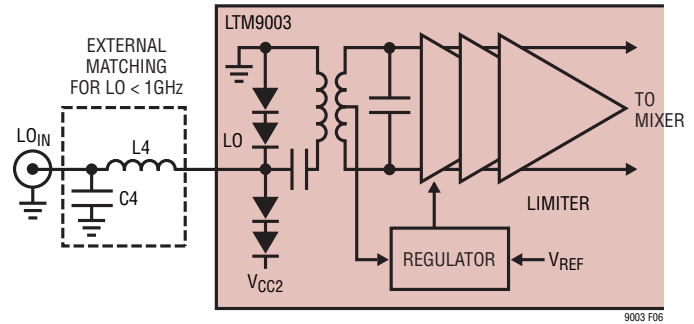


Figure 6. LO Input Schematic

Custom matching networks can be designed using the port impedance data listed in Table 2. This data is referenced to the LO pin with no external matching.

Table 2a. LO Input Impedance vs Frequency (LTM9003-AA)

| FREQUENCY<br>(MHz) | INPUT IMPEDANCE | S11  |        |
|--------------------|-----------------|------|--------|
|                    |                 | MAG  | ANGLE  |
| 500                | 10.3 – j6.1     | 0.73 | –159.1 |
| 600                | 9.7 + j2.2      | 0.68 | 172.4  |
| 700                | 18.7 + j8.2     | 0.64 | 141.8  |
| 800                | 37 + j6.2       | 0.6  | 108.4  |
| 900                | 64.5 – j9.9     | 0.59 | 72.7   |
| 1000               | 109.7 – j42.2   | 0.6  | 38.3   |
| 1100               | 206.6 – j35.9   | 0.63 | 7.9    |
| 1200               | 183.8 + j70     | 0.66 | –17.1  |
| 1300               | 115.4 + j59.4   | 0.68 | –37.3  |
| 1400               | 86.7 + j35.2    | 0.7  | –53.7  |
| 1500               | 70.7 + j18.5    | 0.71 | –67.4  |
| 1600               | 59.3 + j7.4     | 0.7  | –79.2  |
| 1700               | 50.2 + j0.2     | 0.7  | –89.7  |
| 1800               | 42.6 – j4.5     | 0.68 | –99.6  |
| 1900               | 35.9 – j7.2     | 0.66 | –109.2 |
| 2000               | 30.2 – j8.3     | 0.63 | –118.9 |
| 2100               | 25.6 – j8.1     | 0.59 | –129.2 |
| 2200               | 22.4 – j6.7     | 0.54 | –140.3 |
| 2300               | 20.8 – j4.6     | 0.48 | –152.3 |
| 2400               | 21.5 – j2.1     | 0.42 | –165.5 |
| 2500               | 24.2            | 0.35 | –179.8 |
| 2600               | 28.9 + j1.3     | 0.28 | 163.9  |
| 2700               | 35.3 + j1.5     | 0.21 | 145.1  |
| 2800               | 42.6 + j0.9     | 0.16 | 121.1  |
| 2900               | 50.3            | 0.12 | 88.6   |
| 3000               | 57.7 – j0.6     | 0.1  | 45.8   |



## APPLICATIONS INFORMATION

Table 2b. LO Input Impedance vs Frequency (LTM9003-AB)

| FREQUENCY<br>(MHz) | INPUT IMPEDANCE | S11  |        |
|--------------------|-----------------|------|--------|
|                    |                 | MAG  | ANGLE  |
| 500                | 14.3 – j7.5     | 0.68 | –150.6 |
| 600                | 12.6 – j2.4     | 0.61 | –170.4 |
| 700                | 15.8 + j1.9     | 0.53 | 170.8  |
| 800                | 22.7 + j4.1     | 0.44 | 151.5  |
| 900                | 32.5 + j3.8     | 0.35 | 130.2  |
| 1000               | 44.2 + j1.3     | 0.25 | 104.9  |
| 1100               | 56.3 – j1.2     | 0.18 | 70.3   |
| 1200               | 66 – j1.3       | 0.15 | 26.4   |
| 1300               | 70.7 + j1       | 0.18 | –12.8  |
| 1400               | 69.9 + j3.1     | 0.21 | –37.8  |
| 1500               | 66 + j3.7       | 0.25 | –54.1  |
| 1600               | 61.8 + j3.3     | 0.27 | –65.5  |
| 1700               | 58.1 + j2.4     | 0.28 | –73.4  |
| 1800               | 54.9 + j1.5     | 0.29 | –79.8  |
| 1900               | 52.7 + j0.8     | 0.28 | –84.2  |
| 2000               | 50.7 + j0.2     | 0.28 | –88.5  |
| 2100               | 49.4 – j0.2     | 0.27 | –91.4  |
| 2200               | 47.8 – j0.5     | 0.25 | –95.5  |
| 2300               | 46.7 – j0.7     | 0.23 | –98.9  |
| 2400               | 45.7 – j0.8     | 0.2  | –103.3 |
| 2500               | 45.5 – j0.7     | 0.17 | –106.8 |
| 2600               | 46.4 – j0.4     | 0.13 | –107.1 |
| 2700               | 48.7 – j0.1     | 0.1  | –97.9  |
| 2800               | 50.9 + j0.1     | 0.09 | –84.2  |
| 2900               | 52.9 + j0.3     | 0.09 | –72.5  |
| 3000               | 54.6 + j0.5     | 0.11 | –66.7  |

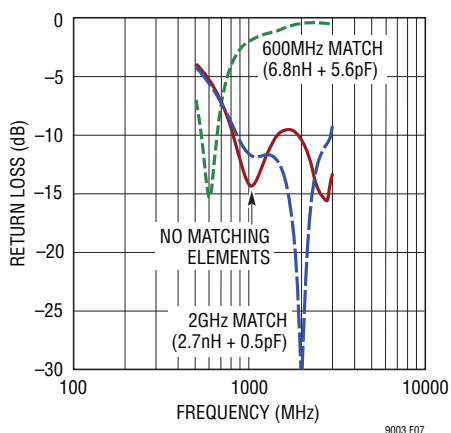


Figure 7. LO Input Return Loss with and without Matching

### Mixer Enable Interface

The voltage necessary to turn on the mixer is 2.7V. To disable the mixer, the enable voltage must be less than 0.3V. If the MIX\_EN pin is allowed to float, the mixer will tend to remain in its last operating state. Thus it is not recommended that the enable function be used in this manner. If the shutdown function is not required, then the MIX\_EN pin should be connected directly to  $V_{CC1}$ .

### Amplifier Enable Interface

The AMP\_EN pin self-biases to  $V_{CC2}$  through a 30k resistor. The pin must be pulled below 0.8V in order to disable the amplifier.

### Driving the ADC Clock Input

The noise performance of the ADC can depend on the encode signal quality as much as on the analog input. The ENC<sup>+</sup>/ENC<sup>–</sup> inputs are intended to be driven differentially, primarily for noise immunity from common mode noise sources. Each input is biased through a 4.8k resistor to a 1.5V bias. The bias resistors set the DC operating point for transformer coupled drive circuits and can set the logic threshold for single-ended drive circuits.

Any noise present on the encode signal will result in additional aperture jitter that will be RMS summed with the inherent ADC aperture jitter.

In applications where jitter is critical (high input frequencies) take the following into consideration:

1. Differential drive should be used.
2. Use as large an amplitude as possible; if transformer coupled use a higher turns ratio to increase the amplitude.
3. If the ADC is clocked with a sinusoidal signal, filter the encode signal to reduce wideband noise.
4. Balance the capacitance and series resistance at both encode inputs so that any coupled noise will appear at both inputs as common mode noise. The encode inputs have a common mode range of 1.2V to 2.0V. Each input may be driven from ground to  $V_{DD}$  for single-ended drive.

## APPLICATIONS INFORMATION

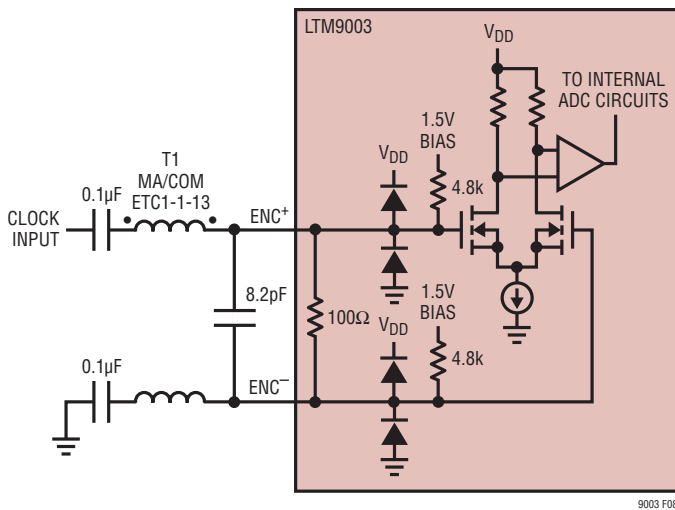


Figure 8. Transformer Driven ENC+/ENC-

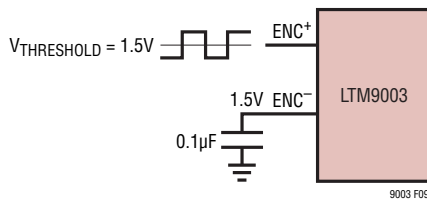


Figure 9. Single-Ended ENC Driver, Not Recommended for Low Jitter

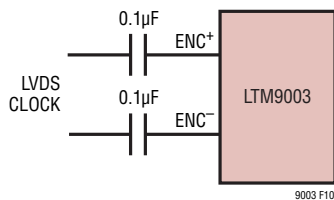


Figure 10. ENC Drive Using LVDS

## Maximum and Minimum Conversion Rates

The maximum conversion rate for the ADC is 250Mpsps. For the ADC to operate properly, the encode signal should have a 50% ( $\pm 5\%$ ) duty cycle. Each half cycle must have at least 1.9ns for the ADC internal circuitry to have enough settling time for proper operation. Achieving a precise 50% duty cycle is easy with differential sinusoidal drive using a transformer or using symmetric differential logic such as PECL or LVDS.

The lower limit of the sample rate is determined by the droop of the sample-and-hold circuits. The pipelined architecture of this ADC relies on storing analog signals on small valued capacitors. Junction leakage will discharge the capacitors. The specified minimum operating frequency for the LTM9003 is 1Mpsps.

## Clock Duty Cycle Stabilizer

An optional clock duty cycle stabilizer circuit can be used if the input clock has a non 50% duty cycle. This circuit uses the rising edge of the ENC+ pin to sample the analog input. The falling edge of ENC+ is ignored and the internal falling edge is generated by a phase-locked loop. The input clock duty cycle can vary from 40% to 60% and the clock duty cycle stabilizer will maintain a constant 50% internal duty cycle. If the clock is turned off for a long period of time, the duty cycle stabilizer circuit will require one hundred clock cycles for the PLL to lock onto the input clock. To use the clock duty cycle stabilizer, the MODE pin should be connected to  $1/3V_{DD}$  or  $2/3V_{DD}$  using external resistors.

## Clock Sources for Undersampling

Undersampling is especially demanding on the clock source and the higher the input frequency, the greater the sensitivity to clock jitter or phase noise. A clock source that degrades SNR of a full-scale signal by 1dB at 70MHz will degrade SNR by 3dB at 140MHz, and 4.5dB at 190MHz.

In cases where absolute clock frequency accuracy is relatively unimportant and only a single ADC is required, a canned oscillator from vendors such as Saronix or Vectron can be placed close to the ADC and simply connected directly to the ADC. If there is any distance to the ADC, some source termination to reduce ringing that may occur even over a fraction of an inch is advisable. You must not allow the clock to overshoot the supplies or performance will suffer. Do not filter the clock signal with a narrow band filter unless you have a sinusoidal clock source, as the rise and fall time artifacts present in typical digital clock signals will be translated into phase noise.

## APPLICATIONS INFORMATION

The lowest phase noise oscillators have single-ended sinusoidal outputs, and for these devices the use of a filter close to the ADC may be beneficial. This filter should be close to the ADC to both reduce roundtrip reflection times, as well as reduce the susceptibility of the traces between the filter and the ADC. If the circuit is sensitive to close-in phase noise, the power supply for oscillators and any buffers must be very stable, or propagation delay variation with supply will translate into phase noise. Even though these clock sources may be regarded as digital devices, do not operate them on a digital supply. If your clock is also used to drive digital devices such as an FPGA, you should locate the oscillator, and any clock fan-out devices close to the ADC, and give the routing to the ADC precedence. The clock signals to the FPGA should have series termination at the driver to prevent high frequency noise from the FPGA disturbing the substrate of the clock fan-out device. If you use an FPGA as a programmable divider, you must re-time the signal using the original oscillator, and the re-timing flip-flop as well as the oscillator should be close to the ADC, and powered with a very quiet supply.

For cases where there are multiple ADCs, or where the clock source originates some distance away, differential clock distribution is advisable. This is advisable both from the perspective of EMI, but also to avoid receiving noise from digital sources both radiated, as well as propagated in the waveguides that exist between the layers of multilayer PCBs. The differential pairs must be close together and distanced from other signals. The differential pair should be guarded on both sides with copper distanced at least 3x the distance between the traces, and grounded with vias no more than 1/4 inch apart.

### Digital Outputs

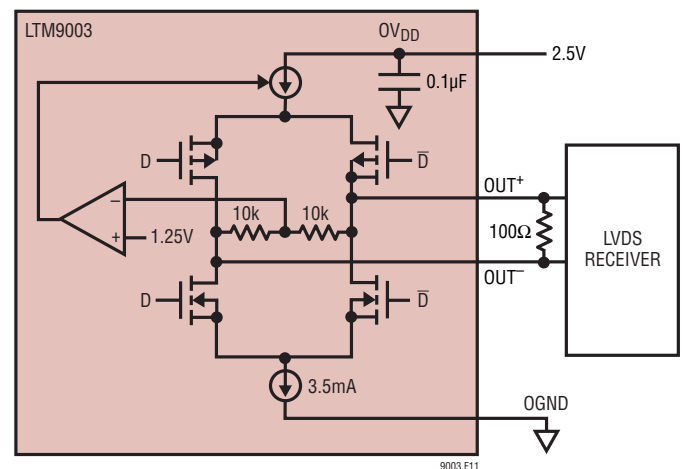
Table 3 shows the relationship between the analog input voltage, the digital data bits, and the overflow bit.

**Table 3. Output Codes vs Input Voltage**

| INPUT<br>(SENSE = $V_{DD}$ ) | OF | D11 – D0<br>(OFFSET BINARY) | D11 – D0<br>(2'S COMPLEMENT) |
|------------------------------|----|-----------------------------|------------------------------|
| Overvoltage                  | 1  | 1111 1111 1111              | 0111 1111 1111               |
| Maximum                      | 0  | 1111 1111 1111              | 0111 1111 1111               |
|                              | 0  | 1111 1111 1110              | 0111 1111 1110               |
| 0.000000V                    | 0  | 1000 0000 0001              | 0000 0000 0001               |
|                              | 0  | 1000 0000 0000              | 0000 0000 0000               |
|                              | 0  | 0111 1111 1111              | 1111 1111 1111               |
|                              | 0  | 0111 1111 1110              | 1111 1111 1110               |
| Minimum                      | 0  | 0000 0000 0001              | 1000 0000 0001               |
|                              | 0  | 0000 0000 0000              | 1000 0000 0000               |
| Undervoltage                 | 1  | 0000 0000 0000              | 1000 0000 0000               |

### Digital Output Buffers

Figure 11 shows an equivalent circuit for a differential output pair in the LVDS output mode. A 3.5mA current is steered from OUT+ to OUT– or vice versa which creates a  $\pm 350\text{mV}$  differential voltage across the  $100\Omega$  termination resistor at the LVDS receiver. A feedback loop regulates the common mode output voltage to 1.25V. For proper operation each LVDS output pair needs an external  $100\Omega$



**Figure 11. Digital Output in LVDS Mode**

## APPLICATIONS INFORMATION

termination resistor, even if the signal is not used (such as  $OF^+/OF^-$  or  $CLKOUT^+/CLKOUT^-$ ). To minimize noise the PC board traces for each LVDS output pair should be routed close together. To minimize clock skew all LVDS PC board traces should have about the same length.

### Data Format

The LTM9003 parallel digital output can be selected for offset binary or 2's complement format. The format is selected with the MODE pin. Connecting MODE to GND or  $1/3V_{DD}$  selects offset binary output format. Connecting MODE to  $2/3V_{DD}$  or  $V_{DD}$  selects 2's complement output format. An external resistor divider can be used to set the  $1/3V_{DD}$  or  $2/3V_{DD}$  logic values. Table 4 shows the logic states for the MODE pin.

Table 4. MODE Pin Function

| MODE PIN    | OUTPUT FORMAT   | CLOCK DUTY CYCLE STABILIZER |
|-------------|-----------------|-----------------------------|
| 0           | Straight Binary | Off                         |
| $1/3V_{DD}$ | Straight Binary | On                          |
| $2/3V_{DD}$ | 2's Complement  | On                          |
| $V_{DD}$    | 2's Complement  | Off                         |

### Overflow Bit

An overflow output bit indicates when the converter is overranged or underranged. A differential logic high on the  $OF^+/OF^-$  pins indicates an overflow or underflow.

### Output Clock

The LTM9003 has a delayed version of the  $ENC^+$  input available as a digital output, CLKOUT. The CLKOUT pin can be used to synchronize the converter data to the digital system. This is necessary when using a sinusoidal encode. Data will be updated just after  $CLKOUT^+/CLKOUT^-$  rises and can be latched on the falling edge of  $CLKOUT^+/CLKOUT^-$ .

### Output Driver Power

$OV_{DD}$  should be connected to a 2.5V supply and OGND should be connected to GND.

### Output Enable

The outputs may be disabled with the output enable pin,  $\overline{OE}$ . In LVDS output mode  $\overline{OE}$  high disables all data outputs including OF and CLKOUT. The data access and bus relinquish times are too slow to allow the outputs to be enabled and disabled during full speed operation. The output Hi-Z state is intended for use during long periods of inactivity.

The Hi-Z state is not a truly open circuit; the output pins that make an LVDS output pair have a 20k resistance between them.

### Sleep and Nap Modes

The converter may be placed in shutdown or nap modes to conserve power. Connecting SHDN to GND results in normal operation. Connecting SHDN to  $V_{DD}$  and  $\overline{OE}$  to  $V_{DD}$  results in sleep mode, which powers down all circuitry including the reference and the ADC typically dissipates 1.5mW. When exiting sleep mode, it will take milliseconds for the output data to become valid because the reference capacitors have to recharge and stabilize. Connecting SHDN to  $V_{DD}$  and  $\overline{OE}$  to GND results in nap mode and the ADC typically dissipates 30mW. In nap mode, the on-chip reference circuit is kept on, so that recovery from nap mode is faster than that from sleep mode, typically taking 100 clock cycles. In both sleep and nap modes, all digital outputs are disabled and enter the Hi-Z state.

### Supply Sequencing

The  $V_{CC1}$  and  $V_{CC2}$  pins provide the supply to the mixer and amplifier, respectively, and the  $V_{DD}$  pin provides the supply to the ADC. The mixer, amplifier and ADC are separate integrated circuits within the LTM9003. Separate linear regulators can be used without additional supply sequencing circuitry if they have common input supplies.

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### Grounding and Bypassing

The LTM9003 requires a printed circuit board with a clean unbroken ground plane; a multilayer board with an internal ground plane is recommended. The pinout of the LTM9003 has been optimized for a flow-through layout so that the interaction between inputs and digital outputs is minimized. Ample ground pads facilitate a layout that ensures that digital and analog signal lines are separated as much as possible.

The LTM9003 is internally bypassed with the ADC ( $V_{DD}$ ), amplifier ( $V_{CC2}$ ) and mixer ( $V_{CC1}$ ) supplies returning to a common ground (GND). The digital output supply ( $OV_{DD}$ ) is returned to OGND. Additional bypass capacitance is optional and may be required if power supply noise is significant.

### Heat Transfer

Most of the heat generated by the LTM9003 is transferred through the bottom-side ground pads. For good electrical and thermal performance, it is critical that all ground pins are connected to a ground plane of sufficient area with as many vias as possible.

### Recommended Layout

The high integration of the LTM9003 makes the PCB board layout very simple and easy. However, to optimize its electrical and thermal performance, some layout considerations are still necessary.

- Use large PCB copper areas for ground. This helps to dissipate heat in the package through the board and also helps to shield sensitive on-board analog signals. Common ground (GND) and output ground (OGND) are electrically isolated on the LTM9003, but can be connected on the PCB underneath the part to provide a common return path.
- Use multiple ground vias. Using as many vias as possible helps to improve the thermal performance of the board and creates necessary barriers separating analog and digital traces on the board at high frequencies.
- Separate analog and digital traces as much as possible, using vias to create high-frequency barriers. This will reduce digital feedback that can reduce the signal-to-noise ratio (SNR) and dynamic range of the LTM9003.

Figures 12 through 15 give a good example of the recommended layout.

The quality of the paste print is an important factor in producing high yield assemblies. It is recommended to use a type 3 or 4 printing no-clean solder paste. The solder stencil design should follow the guidelines outlined in Application Note 100.

The LTM9003 employs gold-finished pads for use with Pb-based or tin-based solder paste. It is inherently Pb-free and complies with the JEDEC (e4) standard. The materials declaration is available online at [http://www.linear.com/leadfree/mat\\_dec.jsp](http://www.linear.com/leadfree/mat_dec.jsp).

APPLICATIONS INFORMATION

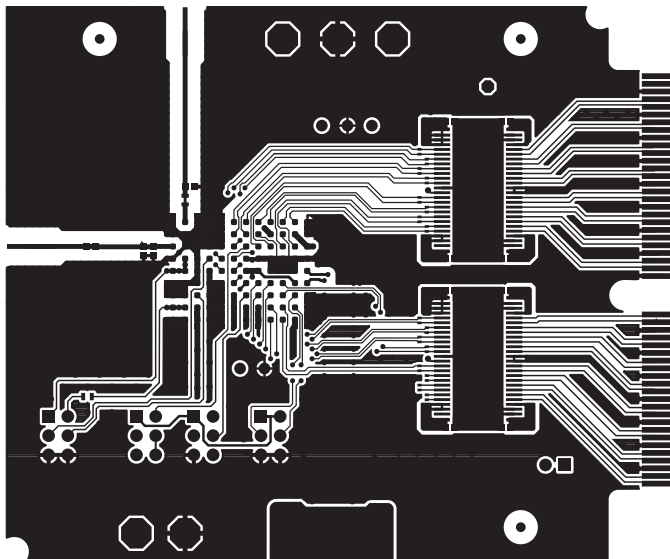


Figure 12. Layer 1 Component Side

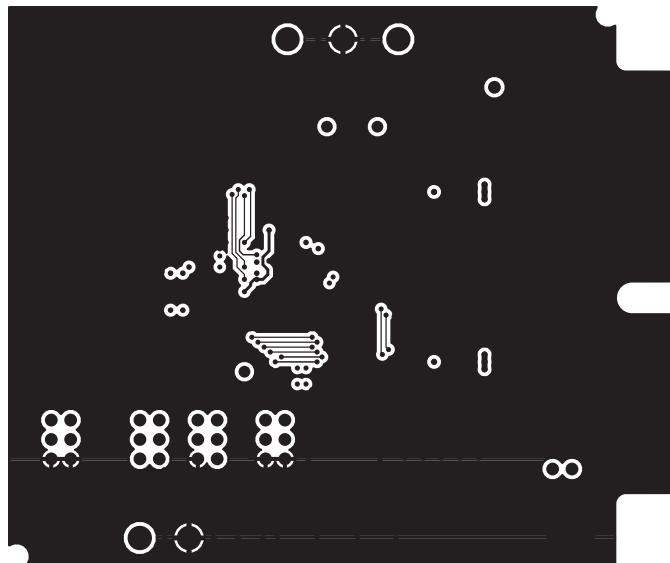


Figure 13. Layer 2

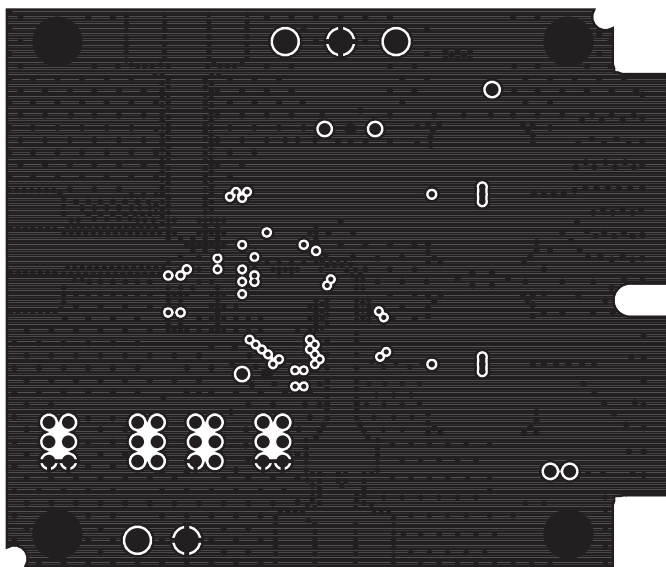


Figure 14. Layer 3

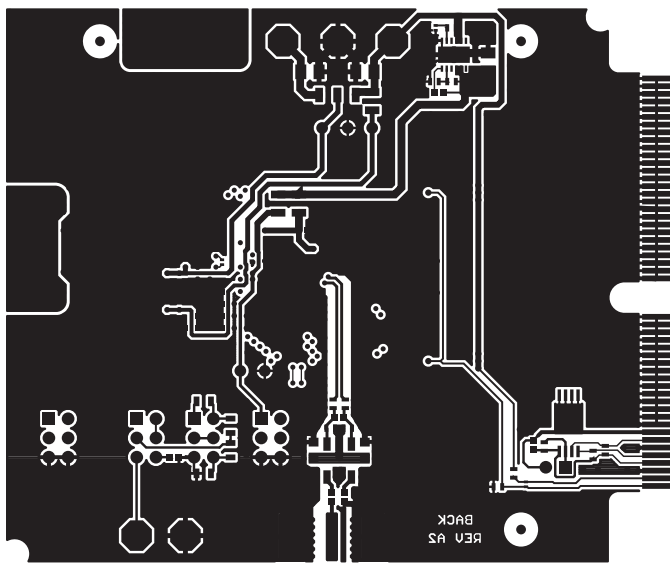
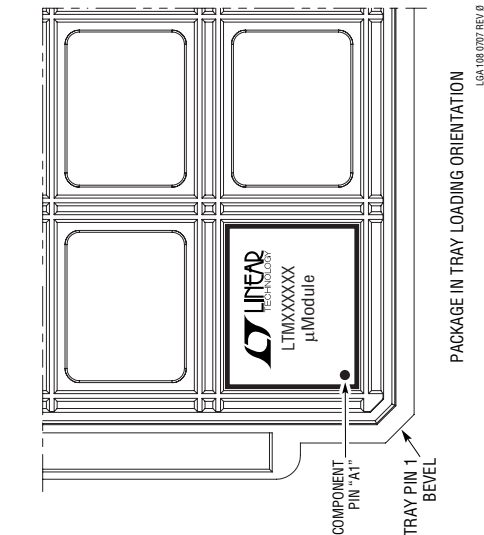
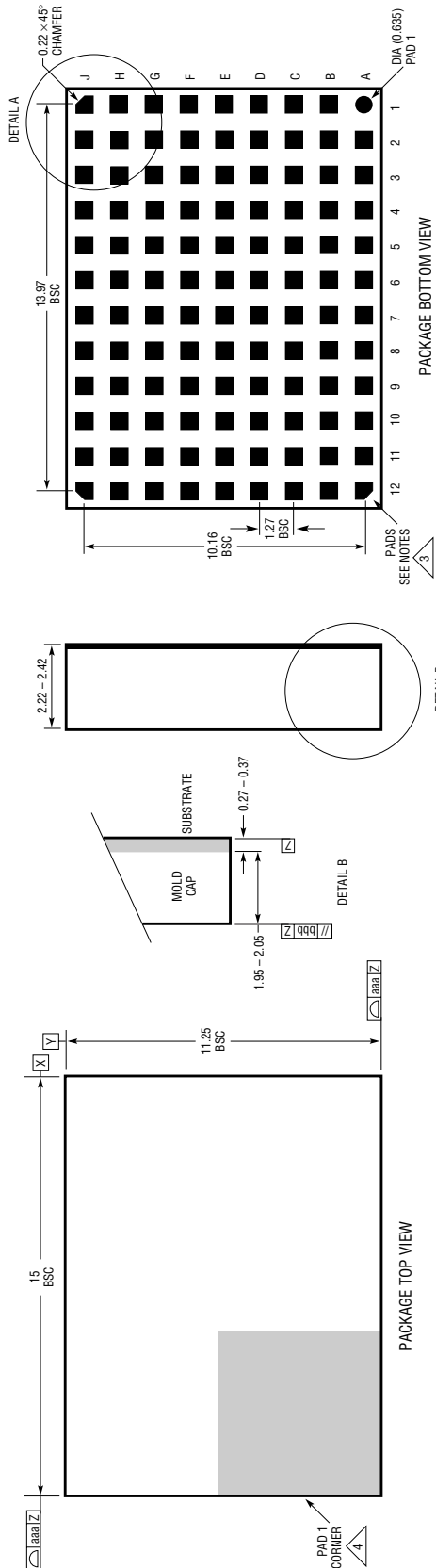


Figure 15. Backside

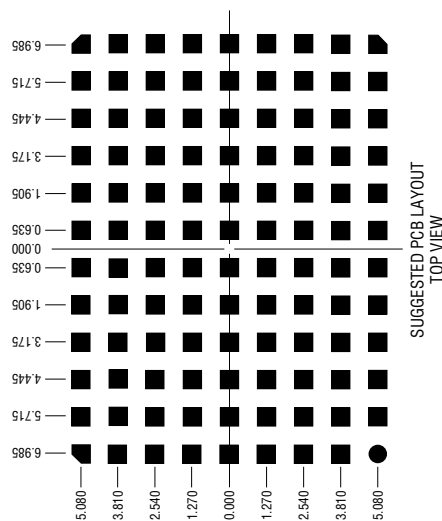


## PACKAGE DESCRIPTION

**LGA Package**  
**108-Lead (15mm × 11.25mm × 2.32mm)**  
 (Reference LTC DWG # 05-08-1757 Rev 0)



- NOTES:**
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994
  2. ALL DIMENSIONS ARE IN MILLIMETERS
  3. LAND DESIGNATION PER JEDEC MO-222, SPP-010
  4. DETAILS OF PAD #1 IDENTIFIER ARE OPTIONAL BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE PAD #1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE
  5. PRIMARY DATUM -Z- IS SEATING PLANE
  6. THE TOTAL NUMBER OF PADS: 108



| SYMBOL | TOLERANCE |
|--------|-----------|
| aaa    | 0.15      |
| bbb    | 0.10      |
| eee    | 0.05      |

**RELATED PARTS**

| PART NUMBER | DESCRIPTION   | COMMENTS  |
|-------------|---|---|
| LTC2240-10  | 10-Bit, 170Msps, 2.5V ADC, LVDS Outputs                       | 445mW, 60.6dB SNR, 78dB SFDR, 64-Pin QFN  |
| LTC2240-12  | 12-Bit, 170Msps, 2.5V ADC, LVDS Outputs                       | 445mW, 65.5dB SNR, 80dB SFDR, 64-Pin QFN  |
| LTC2241-10  | 10-Bit, 210Msps, 2.5V ADC, LVDS Outputs                       | 585mW, 60.6dB SNR, 78dB SFDR, 64-Pin QFN  |
| LTC2241-12  | 12-Bit, 210Msps, 2.5V ADC, LVDS Outputs                       | 585mW, 65.5dB SNR, 78dB SFDR, 64-Pin QFN  |
| LTC2242-10  | 10-Bit, 250Msps, 2.5V ADC, LVDS Outputs                       | 740mW, 60.5dB SNR, 78dB SFDR, 64-Pin QFN  |
| LTC2242-12  | 12-Bit, 250Msps, 2.5V ADC, LVDS Outputs                       | 740mW, 65.4dB SNR, 78dB SFDR, 64-Pin QFN  |
| LTC6410     | Differential IF Amplifier with Configurable Input Impedance   | 1.4GHz, -3dB BW, 6dB Fixed Voltage Gain (50 $\Omega$ System), 36dBm OIP3  |
| LT5527      | 400MHz to 3.7GHz, 5V High Signal Level Downconverting Mixer   | 23.5dBm IIP3 at 1.9GHz, NF = 12.5dB, Single-Ended RF and LO Ports   |
| LT5557      | 400MHz to 3.8GHz, 3.3V High Signal Level Downconverting Mixer | 24.7dBm IIP3 at 1.9GHz, NF = 11.7dB, Single-Ended RF and LO Ports, 3.3V Supply  |
| LTM9001-AA  | 16-Bit, IF/Baseband Receiver Subsystem                        | 16-Bit, 130Msps ADC, 20dB Gain Amplifier, Anti-Alias Filter, Internal Bypass Capacitance  |
| LTM9002-AA  | Dual 14-Bit, IF/Baseband Receiver Subsystem                   | Dual 14-Bit, 125Msps ADC, Dual 26dB Gain Amplifiers, Anti-Alias Filters, Auxiliary DAC for Gain Adjustment, Internal Bypass Capacitance |