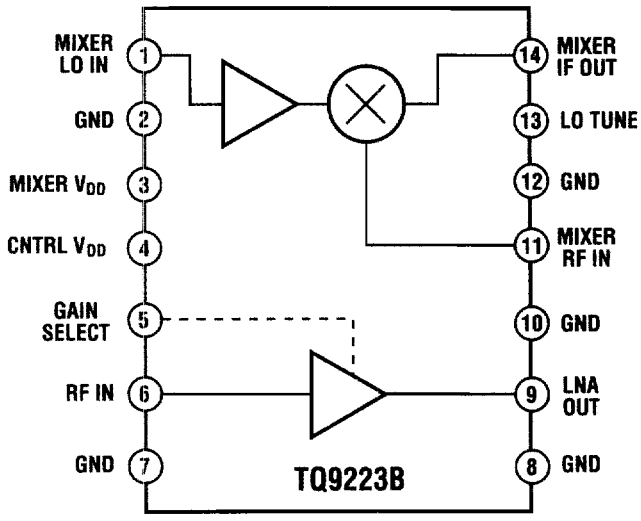
# TQ9223B

## 3-V Low-Current Downconverter IC






The TQ9223B 3V RFIC Downconverter is an RF receiver IC front end designed for the high dynamic range cellular communications standards. The TQ9223B provides a 2.8 dB system noise figure for excellent sensitivity, and a good signal range with -11 dBm input IP3. Its low current consumption, single +3 V operation and small, plastic surface-mount package are ideally suited for cost-competitive, space-limited and portable applications. The TQ9223B will operate over an RF frequency range of 800 to 1000 MHz, and therefore may be used for any of the cellular and cordless telephony standards.

### *Electrical Specifications – Downconverter*[1]

***Test Conditions: $V_{DD}$ = 3.75 V, $T_A$ = 25°C, Filter IL = 3 dB; unless otherwise specified***

| *Parameter* | *Min.* | *Typ.* | *Max.* | *Units* |
|---|---|---|---|---|
| Conversion Gain | 17 | 19 | | dB |
| Noise Figure[2] | | 2.6 | 3.5 | dB |
| Supply Current | | | 12 | mA |

*Notes: 1. All min/max values are 100% RF tested.*
*2. Specified with external noise-matching circuit elements, with image-stripping BPF.*

### *Features*

- *+ 3-V single supply*
- *On-chip LO buffer*
- *Mixer LO and RF matched to 50 Ω*
- *Low-cost SO-14 plastic package*
- *Gain Select (high/low)*

### *Applications*

- *Analog Cellular Phones*
- *Digital Cellular Phones*
- *Cordless Telephones*
- *CDPD terminals*

## Electrical Specifications – Downconverter

### Operating Range

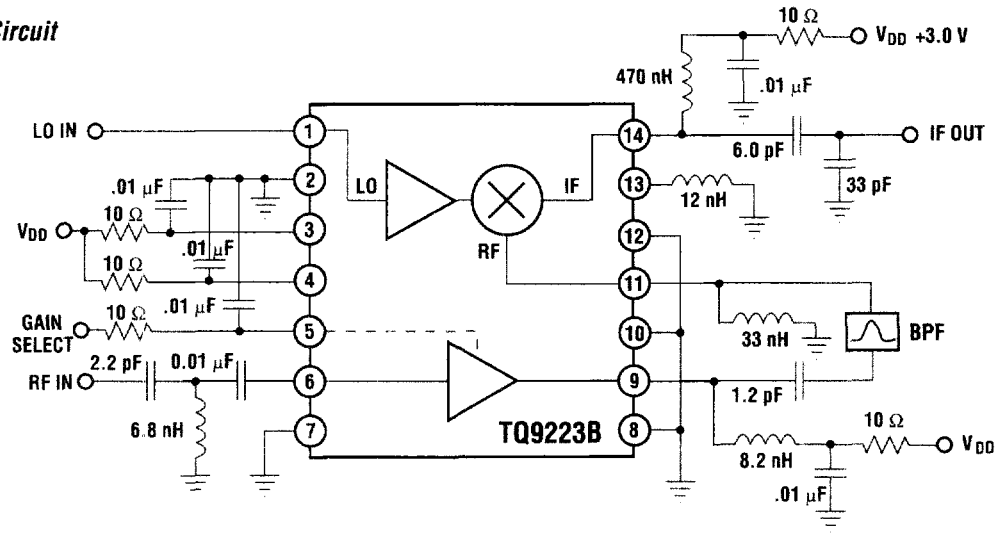
| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| RF Frequency Range | Tuned external match | 800 | | 1000 | MHz |
| LO Frequency Range | Tuned external match | 500 | | 1300 | MHz |
| IF Frequency Range | Tuned external match | 45 | | 300 | MHz |
| Supply Voltage | | 3.0 | | 5.5 | V |
| Temperature | | -40 | | 85 | °C |
| LO Input Power | | | -4 | 0 | dBm |

***Test Conditions: $V_{DD}$ = 3.75 V, $T_A$ = 25 °C, Filter IL = 3 dB, RF = 881 MHz, LO = 966 MHz, IF = 85 MHz; unless otherwise specified***

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Conversion Gain | | 17 | 19 | | dB |
| Noise Figure | | | 2.6 | 3.5 | dB |
| Input 3rd Order Intercept | | | -11 | | dBm |
| MIXER RF Return Loss | | | 10 | | dB |
| MIXER LO Return Loss | | | 10 | | dB |
| LO to RF Input Isolation | | | 45 | | dB |
| Mixer LO to IF Isolation | After external match | | 40 | | dB |
| Supply Current | | | | 12 | mA |

*Notes: 1. Conversion gain, noise figure, and IP3 assume an image stripping band-pass filter between the LNA section and the Mixer section with a 3 dB insertion loss.*

### Test Circuit



## Electrical Specifications – LNA Section

***Test Conditions: $V_{DD}$ = 3.75 V, $T_A$ = 25 °C, Frequency = 881 MHz, external input and output match; unless otherwise specified***

| LNA | Conditions | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|
| Gain | | | 18.5 | | dB |
| Noise Figure | | | 1.8 | | dB |
| Input 3rd Order Intercept | | | -6.0 | | dBm |
| Reverse Isolation | | | 28.0 | | dB |
| Supply Current | | | 5 | | mA |

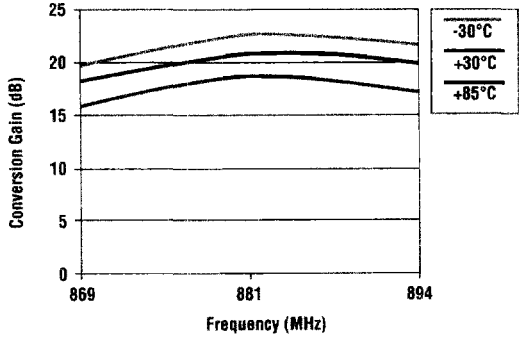
## Electrical Specifications – Mixer Section

***Test Conditions: $V_{DD}$ = 3.75 V, $T_A$ = 25 °C, Image Filter IL = 3 dB, RF = 881 MHz, LO = 966 MHz, IF = 85 MHz, LO Power Level = -4 dBm; unless otherwise specified***

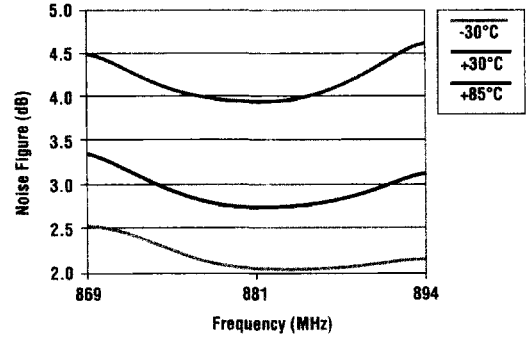
| Mixer | Conditions | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|
| Conversion Gain | | | 0 | | dB |
| Noise Figure | | | 12 | | dB |
| Output 3rd Order Intercept | | | 10 | | dBm |
| Mixer RF Return Loss | | | 15 | | dB |
| Mixer LO Return Loss | | | 10 | | dB |
| LO Input Power | | | -6 | | dBm |
| LO to IF Isolation | | | 40 | | dB |
| LO to RF Isolation | | | 5 | | dB |
| RF to IF Isolation | | | 40 | | dB |
| Supply Current | | | 4 | | mA |

## Typical Performance – Downconverter

### Conversion Gain vs. Frequency vs. Temperature



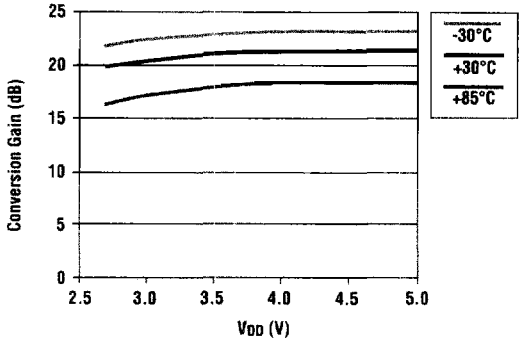

### NF vs. Frequency vs. Temperature



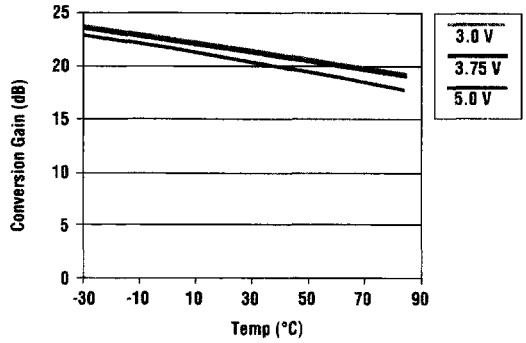
## Typical Performance – Downconverter

***Test Conditions:*** $V_{DD}$ = 3.75 V, $T_A$ = 25 °C, Image Filter IL = 3 dB, RF = 881 MHz, LO = 966 MHz, IF = 85 MHz; unless otherwise specified

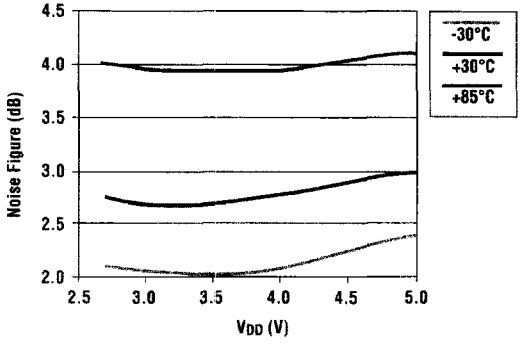
### Conversion Gain vs. $V_{DD}$ vs. Temperature



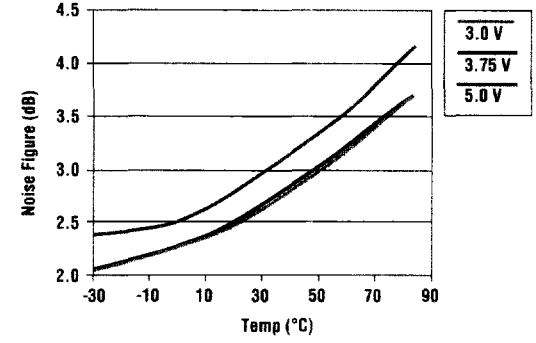

### Conversion Gain vs. Temperature vs. $V_{DD}$



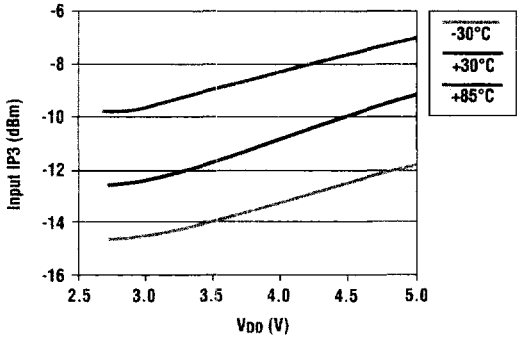

### NF vs. $V_{DD}$ vs. Temperature



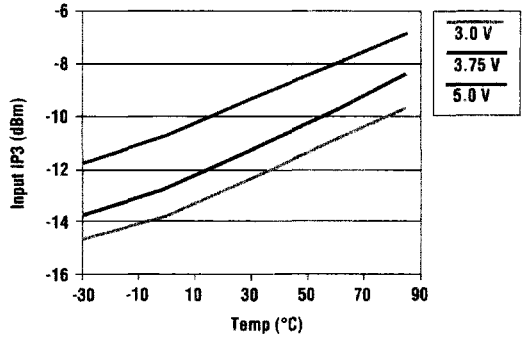

### NF vs. Temperature vs. $V_{DD}$




### Input IP3 vs. $V_{DD}$ vs. Temperature



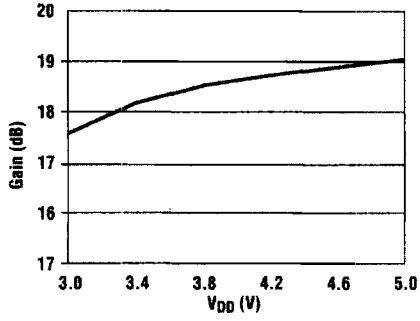

### Input IP3 vs. Temperature vs. $V_{DD}$



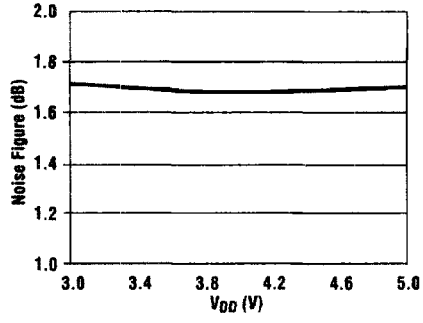
## Typical Performance – LNA

**Test Conditions: $T_A$ = 25 °C, Frequency = 881 MHz**

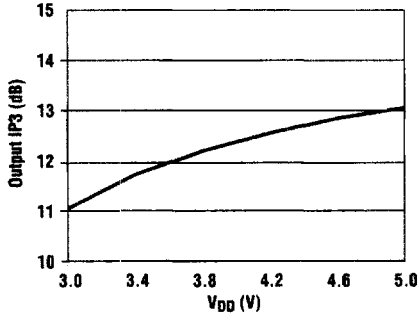
### Gain vs. $V_{DD}$




### NF vs. $V_{DD}$



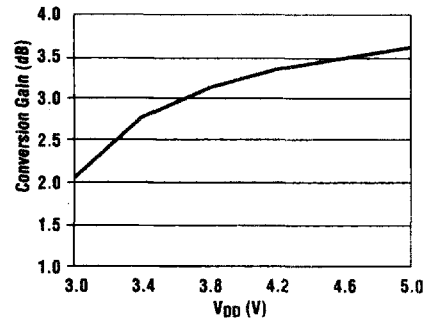

### Output IP3 vs. $V_{DD}$



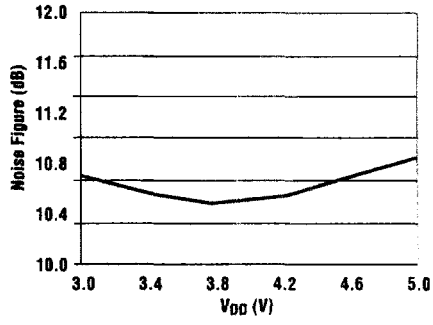

## Typical Performance – Mixer

**Test Conditions: $T_A$ = 25 °C, Image Filter IL = 3 dB, RF = 881 MHz, LO = 966 MHz, IF = 85 MHz, LO Power Level = -4 dBm**

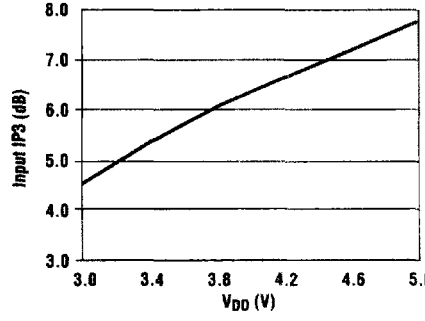
### Gain vs. $V_{DD}$




### NF vs. $V_{DD}$




### Input IP3 vs. $V_{DD}$



### LNA S-Parameters, $V_{DD}$ = 3V (typical)

| Freq (GHz) | \|S11\| | S11 | \|S21\| | S21 | \|S12\| | S12 | \|S22\| | S22 |
|---|---|---|---|---|---|---|---|---|
| 0.100 | 0.99 | -5 | 2.99 | 172 | 0.002 | 93 | 0.97 | -3 |
| 0.200 | 0.98 | -11 | 2.97 | 165 | 0.003 | 87 | 0.97 | -5 |
| 0.300 | 0.97 | -16 | 2.96 | 158 | 0.005 | 84 | 0.96 | -7 |
| 0.400 | 0.95 | -22 | 2.93 | 150 | 0.006 | 81 | 0.95 | -9 |
| 0.500 | 0.94 | -27 | 2.90 | 143 | 0.008 | 79 | 0.95 | -12 |
| 0.600 | 0.91 | -33 | 2.88 | 136 | 0.009 | 75 | 0.94 | -14 |
| 0.700 | 0.89 | -39 | 2.82 | 129 | 0.010 | 74 | 0.93 | -16 |
| 0.800 | 0.86 | -44 | 2.79 | 122 | 0.012 | 71 | 0.92 | -19 |
| 0.900 | 0.83 | -50 | 2.75 | 114 | 0.013 | 68 | 0.91 | -21 |
| 1.000 | 0.80 | -56 | 2.69 | 107 | 0.014 | 66 | 0.90 | -23 |
| 1.100 | 0.77 | -61 | 2.65 | 101 | 0.015 | 64 | 0.89 | -25 |
| 1.200 | 0.74 | -67 | 2.63 | 94 | 0.017 | 61 | 0.88 | -27 |
| 1.300 | 0.70 | -72 | 2.49 | 86 | 0.017 | 59 | 0.88 | -29 |
| 1.400 | 0.67 | -78 | 2.49 | 81 | 0.019 | 58 | 0.87 | -30 |
| 1.500 | 0.63 | -84 | 2.45 | 73 | 0.019 | 55 | 0.85 | -31 |
| 1.600 | 0.60 | -91 | 2.34 | 67 | 0.020 | 54 | 0.85 | -32 |
| 1.700 | 0.56 | -98 | 2.32 | 61 | 0.022 | 53 | 0.85 | -32 |
| 1.800 | 0.52 | -105 | 2.27 | 53 | 0.022 | 51 | 0.84 | -33 |
| 1.900 | 0.48 | -114 | 2.14 | 47 | 0.024 | 51 | 0.83 | -34 |
| 2.000 | 0.44 | -123 | 2.13 | 41 | 0.025 | 48 | 0.82 | -35 |

### LNA Noise Parameters, $V_{DD}$ = 3V (typical)

| Freq | $F_{MIN}$ | $\Gamma_{OPT}$ (mag) | $\Gamma_{OPT}$ (ang) | Rnoise |
|---|---|---|---|---|
| 0.500 | 0.618 | 0.678 | 10.7 | 0.59 |
| 0.750 | 0.791 | 0.656 | 27.9 | 0.51 |
| 0.900 | 1.102 | 0.573 | 34.3 | 0.45 |
| 1.225 | 1.311 | 0.548 | 48.4 | 0.42 |
| 1.575 | 1.292 | 0.522 | 63.5 | 0.38 |
| 1.900 | 1.408 | 0.429 | 73.6 | 0.30 |

### LNA S-Parameters, $V_{DD}$ = 5V (typical)

| Freq (GHz) | \|S11\| | ∠S11 | \|S21\| | ∠S21 | \|S12\| | ∠S12 | \|S22\| | ∠S22 |
|---|---|---|---|---|---|---|---|---|
| 0.100 | 0.99 | -6 | 3.02 | 172 | 0.001 | 96 | 0.98 | -3 |
| 0.200 | 0.98 | -11 | 3.00 | 165 | 0.003 | 89 | 0.97 | -5 |
| 0.300 | 0.97 | -16 | 2.98 | 157 | 0.004 | 84 | 0.97 | -7 |
| 0.400 | 0.95 | -22 | 2.95 | 150 | 0.005 | 81 | 0.96 | -9 |
| 0.500 | 0.93 | -27 | 2.92 | 143 | 0.006 | 80 | 0.95 | -11 |
| 0.600 | 0.91 | -33 | 2.90 | 135 | 0.007 | 77 | 0.94 | -14 |
| 0.700 | 0.88 | -39 | 2.84 | 128 | 0.008 | 74 | 0.93 | -16 |
| 0.800 | 0.86 | -45 | 2.80 | 121 | 0.010 | 72 | 0.93 | -18 |
| 0.900 | 0.83 | -50 | 2.76 | 114 | 0.011 | 70 | 0.92 | -20 |
| 1.000 | 0.80 | -56 | 2.70 | 106 | 0.011 | 68 | 0.91 | -23 |
| 1.100 | 0.77 | -61 | 2.66 | 101 | 0.013 | 66 | 0.90 | -25 |
| 1.200 | 0.74 | -67 | 2.64 | 93 | 0.014 | 63 | 0.89 | -26 |
| 1.300 | 0.70 | -73 | 2.49 | 86 | 0.014 | 63 | 0.89 | -28 |
| 1.400 | 0.67 | -79 | 2.49 | 80 | 0.015 | 62 | 0.88 | -29 |
| 1.500 | 0.63 | -84 | 2.44 | 73 | 0.016 | 59 | 0.87 | -30 |
| 1.600 | 0.59 | -91 | 2.34 | 66 | 0.017 | 58 | 0.87 | -31 |
| 1.700 | 0.56 | -98 | 2.31 | 60 | 0.018 | 57 | 0.86 | -31 |
| 1.800 | 0.51 | -105 | 2.26 | 52 | 0.018 | 55 | 0.86 | -32 |
| 1.900 | 0.48 | -114 | 2.13 | 47 | 0.019 | 55 | 0.85 | -33 |
| 2.000 | 0.44 | -123 | 2.12 | 41 | 0.021 | 53 | 0.84 | -34 |

### LNA Noise Parameters, $V_{DD}$ = 5V (typical)

| Freq | $F_{MIN}$ | $\Gamma_{OPT}$ (mag) | $\Gamma_{OPT}$ (ang) | Rnoise |
|---|---|---|---|---|
| 0.500 | 0.575 | 0.717 | 11.8 | 0.55 |
| 0.750 | 0.788 | 0.651 | 27.7 | 0.48 |
| 0.900 | 1.076 | 0.557 | 34.6 | 0.43 |
| 1.225 | 1.326 | 0.516 | 48.3 | 0.40 |
| 1.575 | 1.272 | 0.515 | 64.3 | 0.37 |
| 1.900 | 1.422 | 0.414 | 74.2 | 0.29 |

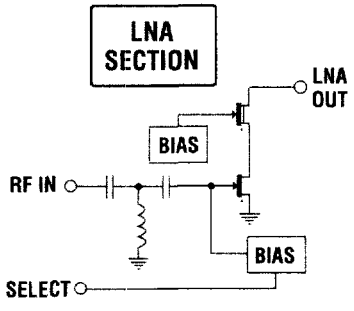
### Mixer S-Parameters (typical)

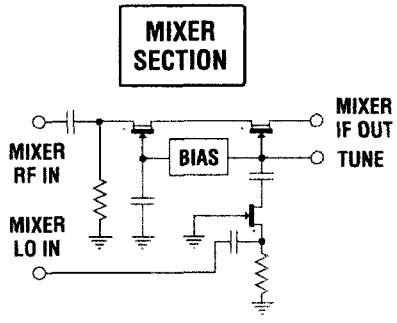
| | Mixer RF IN | | Mixer LO IN | |
|---|---|---|---|---|
| Freq | \|S11\| | ∠S11 | \|S11\| | ∠S11 |
| 0.500 | 0.41 | -22 | 0.12 | 140 |
| 0.600 | 0.42 | -20 | 0.30 | 59 |
| 0.700 | 0.42 | -23 | 0.47 | 28 |
| 0.800 | 0.41 | -26 | 0.57 | 4 |
| 0.900 | 0.40 | -30 | 0.61 | -16 |
| 1.000 | 0.39 | -34 | 0.61 | -34 |
| 1.100 | 0.39 | -38 | 0.58 | -50 |
| 1.200 | 0.37 | -42 | 0.55 | -65 |
| 1.300 | 0.37 | -47 | 0.51 | -80 |
| 1.400 | 0.36 | -52 | 0.46 | -96 |
| 1.500 | 0.35 | -57 | 0.43 | -113 |
| 1.600 | 0.34 | -63 | 0.42 | -130 |
| 1.700 | 0.33 | -70 | 0.41 | -146 |
| 1.800 | 0.32 | -77 | 0.42 | -160 |
| 1.900 | 0.32 | -85 | 0.44 | -172 |
| 2.000 | 0.32 | -93 | 0.46 | 180 |

### Mixer S-Parameters (typical)

| | Mixer IF OUT | |
|---|---|---|
| Freq | \|S11\| | ∠S11 |
| 0.045 | 0.988 | 0.6 |
| 0.055 | 0.987 | 0.6 |
| 0.065 | 0.983 | 1.4 |
| 0.075 | 0.984 | 1.5 |
| 0.085 | 0.983 | 1.8 |
| 0.095 | 0.983 | 2.1 |
| 0.105 | 0.982 | 2.3 |
| 0.115 | 0.982 | 2.6 |
| 0.125 | 0.981 | 2.8 |
| 0.135 | 0.982 | 3.1 |
| 0.145 | 0.981 | 3.3 |
| 0.155 | 0.981 | 3.6 |
| 0.165 | 0.981 | 3.8 |
| 0.175 | 0.981 | 4.1 |
| 0.185 | 0.982 | 4.3 |
| 0.195 | 0.981 | 4.6 |
| 0.205 | 0.980 | 4.8 |
| 0.215 | 0.981 | 5.0 |
| 0.225 | 0.980 | 5.2 |
| 0.235 | 0.980 | 5.5 |
| 0.245 | 0.981 | 5.7 |
| 0.255 | 0.981 | 6.0 |
| 0.265 | 0.980 | 6.2 |
| 0.275 | 0.981 | 6.4 |
| 0.285 | 0.980 | 6.7 |
| 0.295 | 0.981 | 6.9 |

### Simplified Circuit Schematic



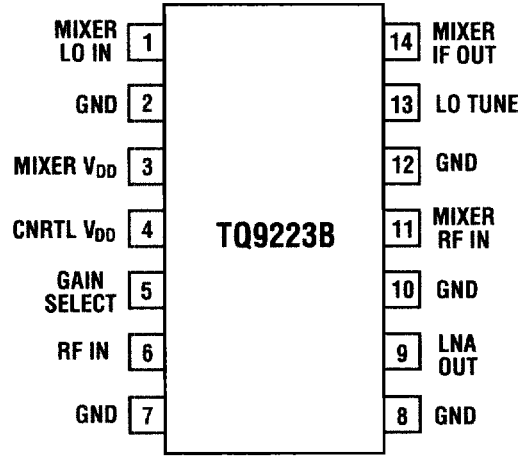



### *Pin Descriptions*

| *Pin Name* | *Pin #* | *Description* |
|---|---|---|
| MIXER LO IN | 1 | Mixer LO input. Matched to 50 Ω. Internally DC blocked. |
| MIXER VDD | 3 | Mixer LO buffer $V_{DD}$. Bypass cap required. |
| CNTRL VDD | 4 | LNA gain select control $V_{DD}$. Bypass cap required. |
| GAIN SELECT | 5 | LNA gain select line. Logic HIGH = high gain, logic LOW = low gain. |
| RF IN | 6 | LNA RF Input port. Noise matching required. External DC blocking required. |
| LNA OUT | 9 | LNA Output port. Open drain output requires connection to $V_{DD}$ and optimal impedance matching. |
| MIXER RF IN | 11 | Mixer RF Input port. Matched to 50 Ω. Internally DC blocked. |
| LO TUNE | 13 | LO buffer tuning, inductor to ground. |
| MIXER IF OUT | 14 | Mixer IF signal port. Open drain output requires connection to $V_{DD}$ and impedance matching to load. |
| GND | 2, 7, 8, 10, 12 | Ground connection. Keep physically short for stability and performance. Use several via holes immediately adjacent to the pins down to backside ground plane. |

*Note: Refer to block diagram for pin location*

### *TQ9223B Pinout*



## General Description

The TQ9223B efficiently integrates a low-noise amplifier and high-intercept mixer, with performance equal to a discrete implementation, through use of circuit techniques from monolithic and discrete design practices. The LNA consists of a common-source amplifier cascoded to a common-gate amplifier using a DC-stacked topology. The same DC current flows through both stages. An external noise match is used to achieve optimum noise figure. LNA input and output matching is performed with PC board microstrip lines or lumped-element surface-mount components, using simple, well understood networks.

The mixer is implemented as a "cascode" stage operating like a dual-gate FET mixer. A common-gate LO buffer provides the necessary gain to drive the mixer FET gate and establishes a good input match. The on-chip buffer amplifier allows for direct connection to a commercial VCO at drive levels down to -6 dBm. An "open collector" IF output allows for flexibility, matching to various IFs and filter types.

The two topologies efficiently use the supply current for low-power operation, approximately 10 mA with a 3 V supply. The overall circuit provides a distinct performance edge over silicon monolithic designs in terms of input intercept, noise figure and gain. Specifically, the circuit was intended for use in the following applications: cellular (AMPS, NADC, GSM, JDC, ETACS, etc.) and ISM band (902 - 928 MHz).

## Gain Select

In a strong signal environment, the LNA can be shut down by applying 0 V to Pin 5. The result is that the LNA gain decreases from a nominal of +18 dB to -19 dB. The current in the LNA decreases to 1 mA. In addition, the input IP3 for the LNA increases from -6 dB to +5 dB, and for the downconverter from -11 dBm to -7.5 dBm.

## Power Supply Connection

The TQ9223B was designed to operate within specifications over the power supply range of 3.0 to 5.5 V. The internal biasing maintains stable operating points with varying supply voltage. However, the electrical parameters do vary slightly with supply voltage.

Internally, the downconverter has internal capacitance from $V_{DD}$ to ground for RF decoupling of the supply line. This should be augmented with additional decoupling capacitance: 1000 pF connected externally within 5 mm of the package pin. A 10-ohm series resistor in the $V_{DD}$ line may also be added (optionally) to provide some filtering of supply line noise. Connections to ground should go directly to a low-impedance ground plane. Therefore, it is recommended that multiple via holes to the ground plane occur within 2 mm on the inside of the package pins .

## LNA Input Interfacing

The TQ9223B LNA was designed for low-noise operation. It makes use of an optimum noise-matching network at the input, not a conjugate match, as would be used for maximum power transfer. Gamma optimum is referenced from the LNA input into the noise-match network in series with 50 ohms. The gamma optimum and the noise parameters for selected frequencies are shown in the LNA Noise Parameters table.

There are several options for the physical realization of gamma optimum: a series-shunt microstrip transmission line network or a series capacitor/shunt inductor. The microstrip transmission lines can easily be constructed on FR-4 or G-10 circuit boards, using standard design techniques. The lumped-element components are surface-mount elements designed for RF use. It is important that the board-level circuit establishes an impedance of gamma optimum, measured at the solder pad of pin 6. Proper board design for gamma optimum eliminates the need for tuning adjustments and produces a low-noise circuit which is tolerant of component variations.

## LNA Out (Pin 9)

The TQ9223B low-noise amplifier requires external output matching to transform the amplifier's output impedance to the desired system impedance (typically 50 Ω) and to provide a DC bias path. The recommended output matching circuit is illustrated in the figure below and consists of a shunt low-Q chip inductor and a series chip capacitor. The inductor provides a path for DC current to flow into the amplifier while simultaneously operating as the first element in the impedance transforming filter. The series capacitor acts as a block to DC current and operates as the final element in the impedance transforming filter.

A number of inductor/capacitor values can be selected that will effectively transform the LNA output impedance to the system impedance. The actual values selected will be governed by the trade-off between optimum impedance match and maximum IP3 match.

### Mixer RF Input

The mixer RF input is matched close to 50 ohms and is internally DC-blocked. Pin 11 may be directly connected to the filter output. The filter must be as close as possible to the mixer RF input to maintain the proper termination impedance at the LO frequency. Include a shunt inductor of 33 nH at the mixer RF input to improve the mixer noise performance by providing a short to ground at the IF frequency. This provides a secondary benefit of slightly improved input match.

### Mixer LO Input

The mixer LO input is matched close to 50 ohms and is internally DC-blocked. Pin 1 may be directly connected to the LO input signal. A level greater than -6 dBm is recommended. Standard VCO outputs of -2 dBm work well.

### LO Tuning (Pin 13)

A shunt L on pin 13 resonates with some internal capacitance to produce a bandpass frequency response of the LO buffer amplifier. This attenuates noise at ± one IF frequency away from the LO frequency. The approximate value of L is determined by the following equation:

$$L = \frac{1}{C(2\pi f)^2}, \text{ where } C = 2.2 \text{ pF}$$

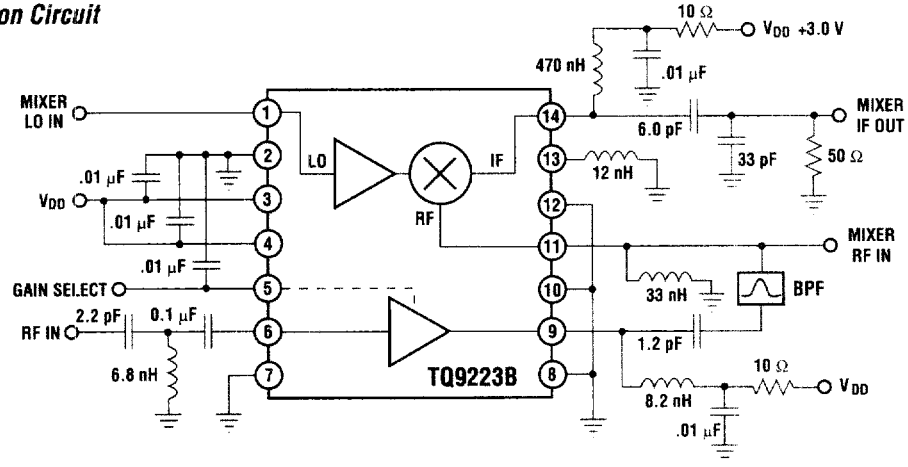
In practice, the value (and/or placement) of L should be empirically determined for a particular layout, since stray capacitance on the PCB layout can move the resident frequency from the expected ideal. The actual value of L should be adjusted until the buffer response (pin 1 -> pin 13) produces a peak at the LO frequency. A measurement of the response may be accomplished with a simple coaxial probe "sniffer," in which the end is positioned 50 -100 mils from the inductor at pin 13. The frequency response of the LC buffer amplifier (pin 13) is directly measured on a network analyzer as the LO input (pin 1) is swept in frequency. The LO drive level should be set at approximately the operating level (-6 to -3 dBm) for this measurement. This "tuning" needs to be done only in design, not in production.

### Mixer IF Interfacing

The mixer IF port is a high-impedance, open-drain output. The impedance is a few K ohms in parallel with less than 1 pF capacitance. The IF port S-parameters (S11) are listed in the table over the frequency range of 45 MHz to 250 MHz. It is possible to use IFs above and below this range; however, at low frequencies the noise increases, and at high frequencies the LO/IF, RF/IF isolation decreases.

The open-drain output permits matching to any chosen filter impedance. In general, a conjugate impedance match is recommended on this port to achieve best power gain, noise figure and output 3rd-order intercept. It is also important to properly center the tuned circuit at the desired IF. This maximizes circuit robustness to component tolerances. For proper mixer operation, pin 14, the open-drain output, must also be biased to $V_{DD}$. A practical matching network which includes biasing is shown.

### Application Circuit

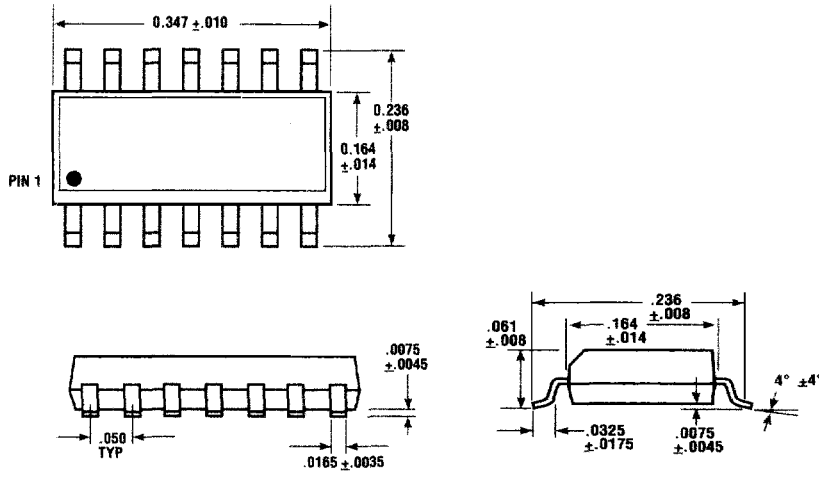


## Absolute Maximum Ratings

| Parameter | Min. | Typ. | Max. | Units |
|---|---|---|---|---|
| DC Power Supply | | | 8.0 | V |
| RF Input Power | | | TBD | dBm |
| Storage Temperature | -55 | | +150 | °C |
| Operating Temperature | -40 | | + 85 | °C |

*ESD-sensitive device - Class 1*

## SO-14 Plastic Package
## (J Suffix)



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