# LMX2216

*LMX2216 0.1 GHz to 2.0 GHz Low Noise Amplifier/Mixer for RF Personal Communications*

TEXAS INSTRUMENTS

**N**ational *Semiconductor*

# LMX2216
# 0.1 GHz to 2.0 GHz Low Noise Amplifier/Mixer for RF Personal Communications

## General Description

The LMX2216 is a monolithic, integrated low noise amplifier (LNA) and mixer suitable as a first stage amplifier and down-converter for RF receiver applications. The wideband operating capabilities of the LMX2216 allow it to function over frequencies from 0.1 GHz to 2.0 GHz. It is fabricated using National Semiconductor's ABiC IV BiCMOS process.

All input and output ports of the LMX2216 are single-ended. The LNA input and output ports are designed to interface to a 50Ω system. The Mixer input ports are matched to 50Ω. The output port is matched to 200Ω. The only external components required are DC blocking capacitors. The balanced architecture of the LMX2216 maintains consistent operating parameters from unit to unit, since it is implemented in a monolithic device. This consistency provides manufacturers a significant advantage since tuning procedures—often needed with discrete designs—can be reduced or eliminated.

The low noise amplifier produces very flat gain over the entire operating range. The doubly-balanced, Gilbert-cell mixer provides good LO-RF isolation and cancellation of second-order distortion products. A power down feature is implemented on the LMX2216 that is especially useful for standby operation common in Time Division Multiple Access (TDMA) and Time Division Duplex (TDD) systems.

The LMX2216 is available in a narrow-body 16-pin surface mount plastic package.

## Features

- Wideband RF operation from 0.1 GHz to 2.0 GHz
- No external biasing components necessary
- 3V operation
- LNA input and output ports matched to 50Ω
- Mixer input ports matched to 50Ω, output port matched to 200Ω.
- Doubly balanced Gilbert cell mixer (single ended input and output)
- Low power consumption
- Power down feature
- Small outline, plastic surface mount package

## Applications

- Digital European Cordless Telecommunications (DECT)
- Portable wireless communications (PCS/PCN, cordless)
- Wireless local area networks (WLANs)
- Digital cellular telephone systems
- Other wireless communications systems

## Functional Block/Pin Diagram
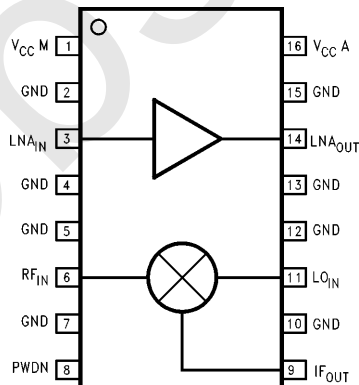


TL/W/11814–1

**Order Number LMX2216M**
**See NS Package Number M16A**

## Pin Description

| Pin No. | Pin Name | I/O | Description |
|---|---|---|---|
| 1 | $V_{CC}$ M | I | Voltage supply for the mixer. The input voltage level to this pin should be a DC Voltage ranging from 2.85V to 3.15V. |
| 2 | GND | | Ground |
| 3 | $LNA_{IN}$ | I | RF input signal to the LNA. External DC blocking capacitor is required. |
| 4 | GND | | Ground |
| 5 | GND | | Ground |
| 6 | $RF_{IN}$ | I | RF input to the mixer. The RF signal to be down converted is connected to this pin. External DC blocking capacitor is required. |
| 7 | GND | | Ground |
| 8 | PWDN | I | Power down signal pin. Both the LNA and mixer are powered down when a HIGH level is applied to this pin ($V_{IH}$). |
| 9 | $IF_{OUT}$ | O | IF output signal of the mixer. External DC blocking capacitor is required. |
| 10 | GND | | Ground |
| 11 | $LO_{IN}$ | I | Local oscillator input signal to the mixer. External DC blocking capacitor is required. |
| 12 | GND | | Ground |
| 13 | GND | | Ground |
| 14 | $LNA_{OUT}$ | O | Output of the LNA. This pin outputs the amplified RF signal. External DC blocking capacitor is required. |
| 15 | GND | | Ground |
| 16 | $V_{CC}$ A | I | LNA supply Voltage. DC Voltage ranging from 2.85V to 3.15V. |

## Absolute Maximum Ratings

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.**

Supply Voltage ($V_{CC}$)                6.5V

Storage Temperature ($T_S$)        −65°C to +150°C

Operating Temperature ($T_O$)      −40°C to +85°C

## Recommended Operating Conditions

Supply Voltage ($V_{CC}$)                      2.85V–3.15V

Operating Temperature ($T_A$)       −10°C to +70°C

$RF_{IN}$                                         0.1 GHz to 2.0 GHz

$LO_{IN}$                                         0.1 GHz to 2.0 GHz

## Electrical Characteristics: LNA

($V_{CC}$ = +3.0V ±5%, $T_A$ = 25°C, $Z_o$ = 50Ω and $f_{IN}$ = 2.0 GHz @ −30 dBm unless otherwise specified.)

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| $I_{CC}$ | Supply Current | In Operation | | 6.5 | 8.0 | mA |
| $I_{CC\text{-}PWDN}$ | Supply Current | In Power Down Mode | | | 10 | μA |
| G | Gain | | 9 | 10 | | dB |
| $P_{1dB}$ | Output 1 dB Compression Point | | −5.0 | −3.0 | | dBm |
| OIP3 | Output 3rd Order Intercept Point | | 5.0 | 7.0 | | dBm |
| NF | Single Side Band Noise Figure | | | 4.8 | 6.0 | dB |
| $RL_{IN}$ | Input Return Loss | | 10 | 15 | | dB |
| $RL_{OUT}$ | Output Return Loss | | 10 | 11 | | dB |

## Electrical Characteristics: Mixer ($V_{CC}$ = +3.0V ±5%, $T_A$ = 25°C, $Z_o$ = 50Ω, $f_{RF}$ = 2.0 GHz @ −30 dBm, $f_{LO}$ = 1.89 GHz @ 0 dBm; $f_{IF}$ = 110 MHz unless otherwise specified.)

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| $I_{CC}$ | Supply Current | In Operation | | 9.0 | 12.0 | mA |
| $I_{CC\text{-}PWDN}$ | Supply Current | In Power Down Mode | | | 10 | μA |
| $G_C$ | Conversion Gain (Single Side Band) | | 4.0 | 6.0 | | dB |
| $P_{1dB}$ | Output 1 dB Compression Point | | −13.0 | −9.0 | | dBm |
| OIP3 | Output Third Order Intercept Point | | −3.0 | 0.0 | | dBm |
| SSB NF | Single Side Band Noise Figure | | | 17 | 18 | dB |
| DSB NF | Double Side Band Noise Figure | | | 14 | 15 | dB |
| LO-RF | LO to RF Isolation | | 20 | 30 | | dB |
| LO-IF | LO to IF Isolation | | 20 | 30 | | dB |
| RF RL | RF Return Loss | | 10 | 15 | | dB |
| LO RL | LO Return Loss | | 10 | 15 | | dB |
| IF RL | IF Return Loss | | | 15 | | dB |
| $Z_{IF}$ | IF Port Impedance | | | 200 | | Ω |

## Electrical Characteristics: Power Down

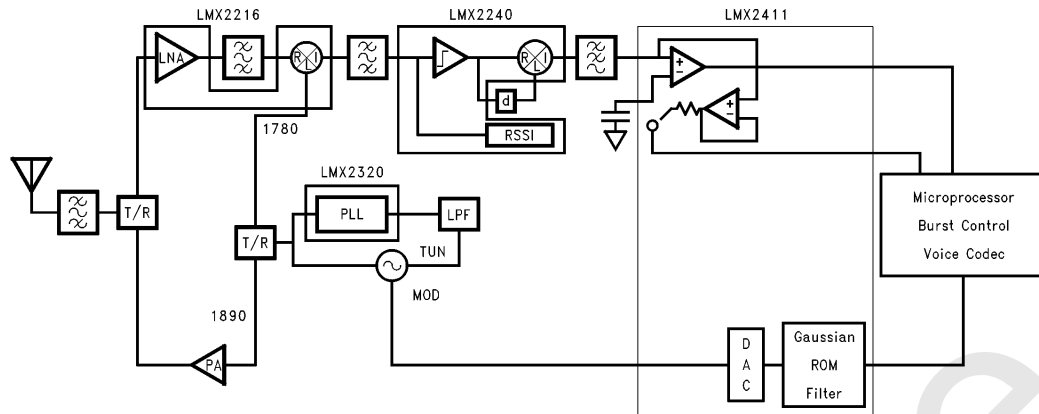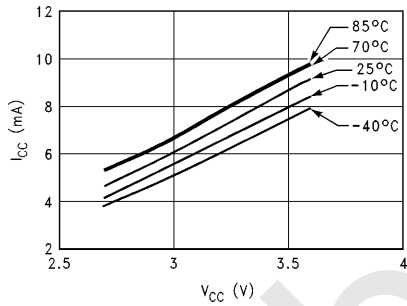| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| $V_{IH}$ | High Level Input Voltage | | $V_{CC}$ − 0.8 | | | V |
| $V_{IL}$ | Low Level Input Voltage | | | | 0.8 | V |
| $I_{IH}$ | High Level Input Current | $V_{IH}$ = $V_{CC}$ | −10.0 | | 10.0 | μA |
| $I_{IL}$ | Low Level Input Current | $V_{IL}$ = GND | −10.0 | | 10.0 | μA |

## Typical Application Block Diagram
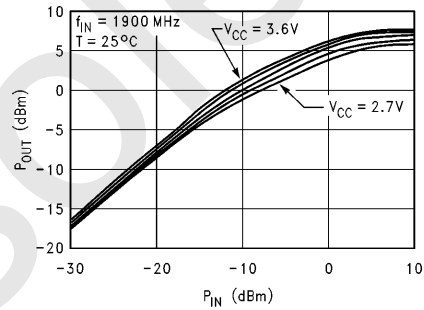


FIGURE 2

## Typical Characteristics

**LNA**

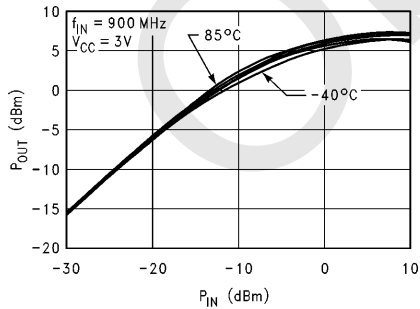### LNA Current Composition vs Supply Voltage with Temperature as a Parameter



TL/W/11814–3
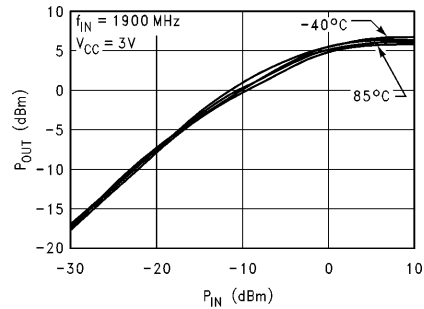
### LNA P_OUT vs P_IN with Supply Voltage as a Parameter



TL/W/11814–4

### LNA P_OUT vs P_IN with Temperature as a Parameter



TL/W/11814–6

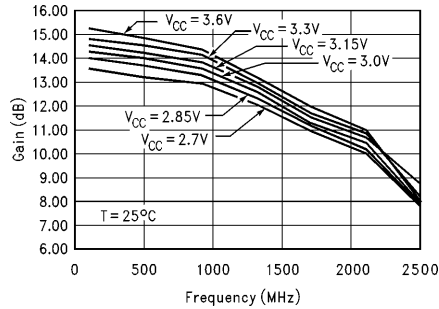### LNA P_OUT vs P_IN with Temperature as a Parameter



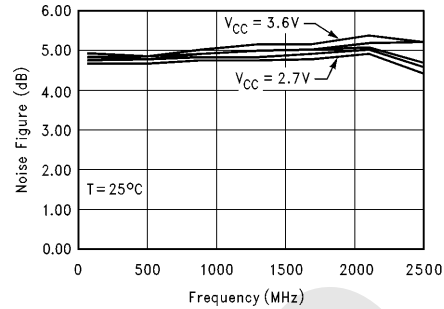TL/W/11814–7

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# Typical Characteristics (Continued)

**LNA** (Continued)

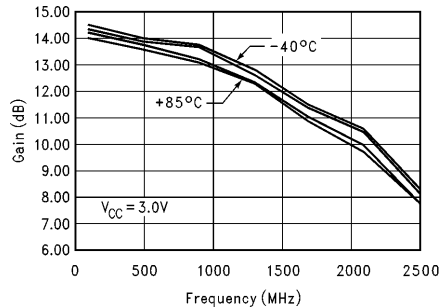### LNA Gain vs Frequency with Supply Voltage as a Parameter



TL/W/11814–8

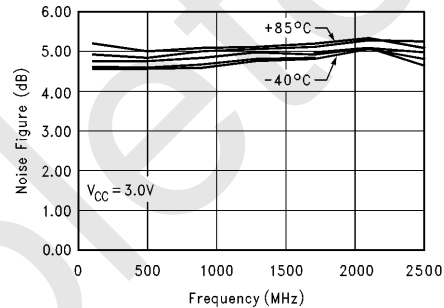### LNA Noise Figure vs Frequency with Supply Voltage as a Parameter



TL/W/11814–9

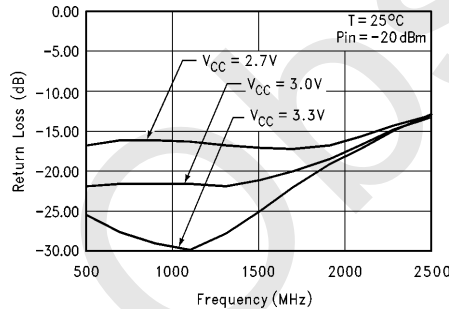### LNA Gain vs Frequency with Temperature as a Parameter



TL/W/11814–10

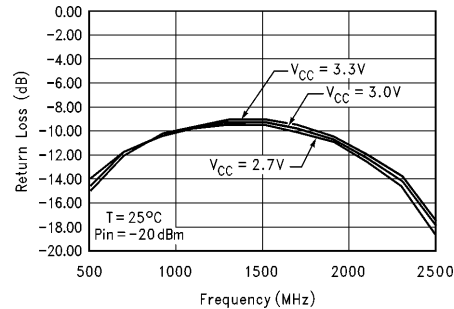### LNA Noise Figure vs Frequency with Temperature as a Parameter



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### LNA Input Return Loss vs Frequency with Voltage as a Parameter



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### LNA Output Return Loss vs Frequency with Voltage as a Parameter
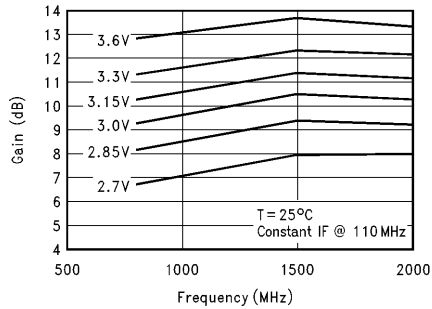


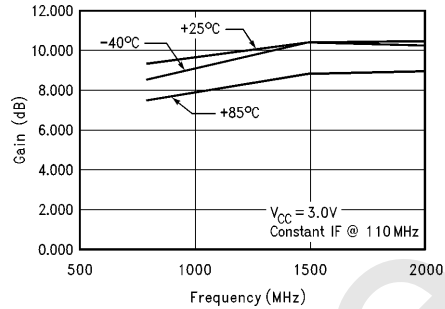TL/W/11814–19

# Typical Characteristics (Continued)

## MIXER

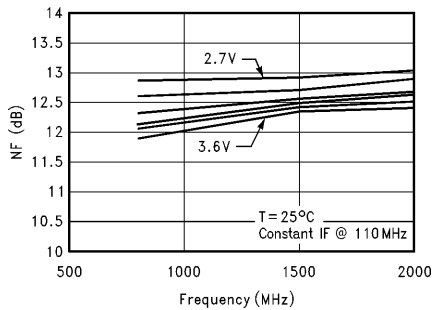**Mixer Gain (Double Sideband) vs Frequency with Supply Voltage as a Parameter**



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**Mixer Gain (Double Sideband) vs Frequency with Temperature as a Parameter**
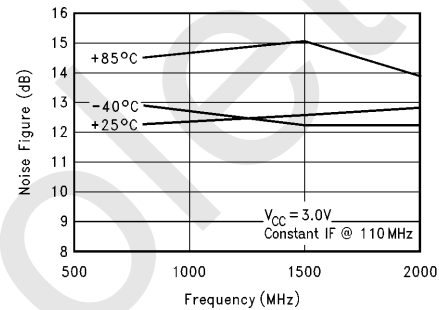


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**Mixer Noise Figure (Double Sideband) vs Frequency with Supply Voltage as a Parameter**



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**Mixer Noise Figure (Double Sideband) vs Frequency with Temperature as a Parameter**



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# Typical Characteristics (Continued)

**MIXER** (Continued)

### Mixer P_OUT vs P_IN with Supply Voltage as a Parameter
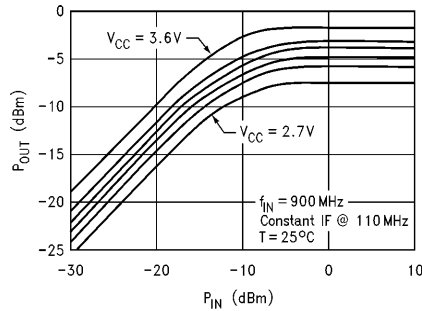


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### Mixer P_OUT vs P_IN with Supply Voltage as a Parameter
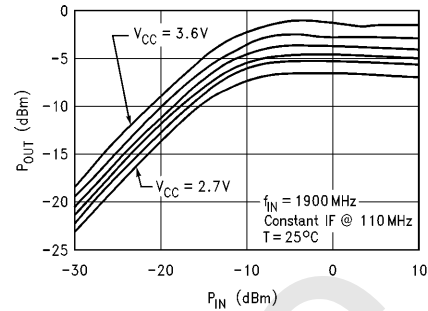


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### Mixer P_OUT vs P_IN with Temperature as a Parameter



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### Mixer P_OUT vs P_IN with Temperature as a Parameter
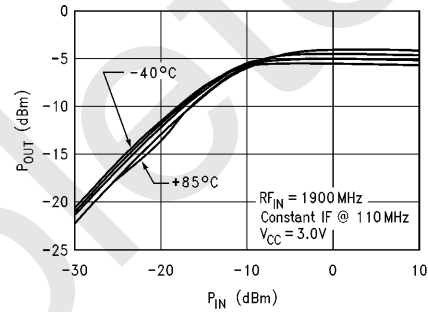


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### Mixer RF_IN Return Loss vs Frequency with Supply Voltage as a Parameter
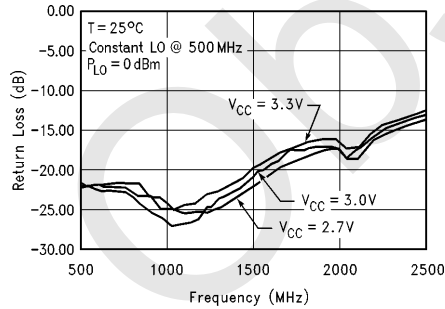


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### Mixer RF_IN Return Loss vs Frequency with Supply Voltage as a Parameter



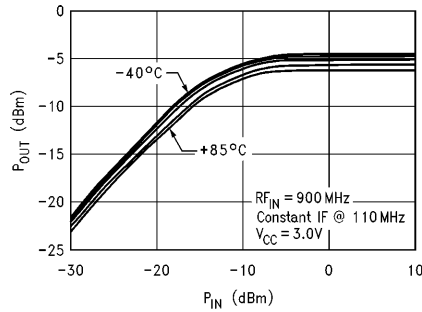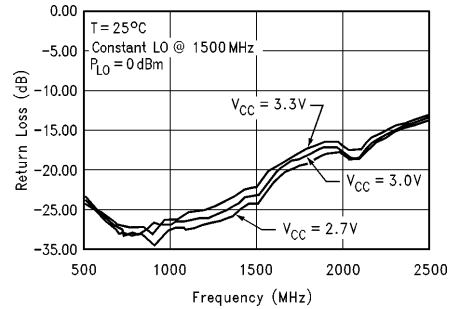TL/W/11814–29

## Typical Characteristics (Continued)

**MIXER** (Continued)

**Mixer RF$_{IN}$ Return Loss vs Frequency with Supply Voltage as a Parameter**

T = 25°C
Constant LO @ 2000 MHz
P$_{LO}$ = 0 dBm

V$_{CC}$ = 3.3V
V$_{CC}$ = 3.0V
V$_{CC}$ = 2.7V

Return Loss (dB) — Frequency (MHz)

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**Mixer IF$_{OUT}$ Return Loss vs Frequency with Supply Voltage as a Parameter**

T = 25°C
Z$_0$ = 50Ω
RF$_{IN}$ = −20 dBm

V$_{CC}$ = 2.7V
V$_{CC}$ = 3.0V
V$_{CC}$ = 3.3V

Return Loss (dB) — Frequency (MHz)
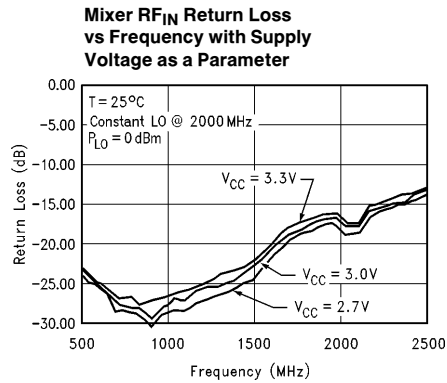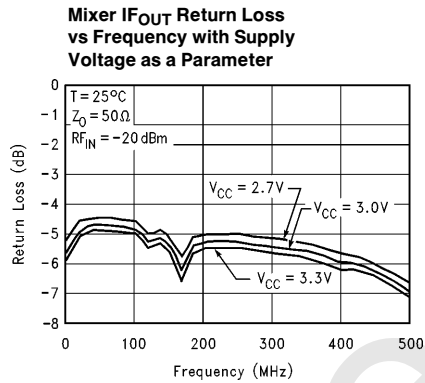
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## Functional Description

PWDN
BUFFER
PWDN SWITCH
V$_{CC}$ A
FEEDBACK
LNA$_{IN}$
AMP
LNA$_{OUT}$
V$_{CC}$ M
BUFFER
PWDN SWITCH
LO$_{IN}$
RF$_{IN}$
GILBERT CELL
IF$_{OUT}$

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**FIGURE 3. Block Diagram of the LMX2216**

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## Functional Description (Continued)

### THE LNA

The LNA is a common emitter stage with active feedback. This feedback network allows for wide bandwidth operation while providing the necessary optimal input impedance for low noise performance. The power down feature is implemented using a CMOS buffer and a power-down switch. The power down switch is implemented with CMOS devices. During power down, the switch is open and only leakage currents are drawn from the supply.

### THE MIXER

The mixer is a Gilbert cell architecture, with the RF input signal modulating the LO signal and single ended output taken from the collector of one of the upper four transistors. The power down circuitry of the mixer is similar to that of the LNA. The power down switch is used to provide or cut off bias to the Gilbert cell.

## Typical Low Noise Amplifier



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**FIGURE 4. Typical LNA Structure**

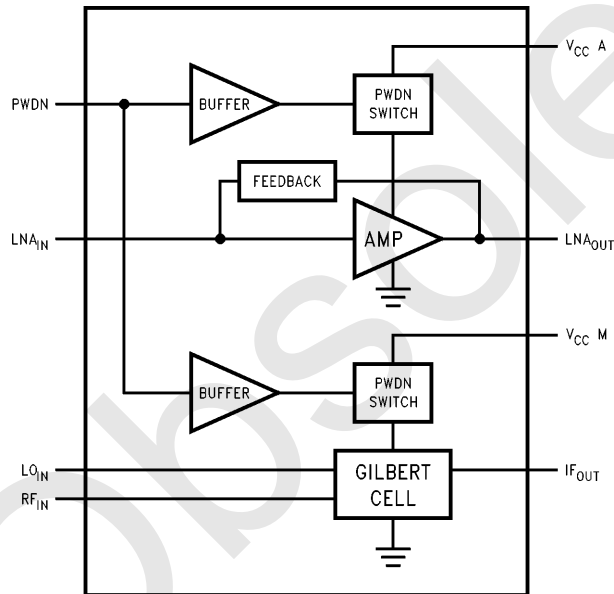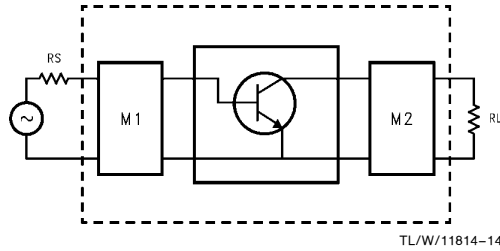A typical low noise amplifier consists of an active amplifying element and input and output matching networks. The input matching network is usually optimized for noise performance, and the output matching network for gain. The active element is chosen such that it has the lowest optimal noise figure, $F_{MIN}$, an intrinsic property of the device. The noise figure of a linear two-port is a function of the source admittance and can be expressed by

$$F = F_{MIN} + \frac{R_n}{G_G}[(G_{ON} - G_G)^2 + (B_{ON} - B_G)^2]$$

where $G_G + jB_G$ = generator admittance presented to the input of the two port,

$G_{ON} + jB_{ON}$ = generator admittance at which optimum noise figure occurs,

$R_n$ = empirical constant relating the sensitivity of the noise figure to generator admittance.

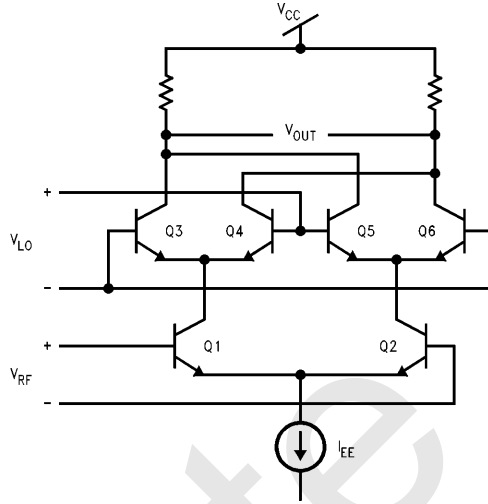## Typical Gilbert Cell



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**FIGURE 5. Typical Gilbert Cell Circuit Diagram**

The Gilbert cell shown above is a circuit which multiplies two input signals, RF and LO. The input RF voltage differentially modulates the currents on the collectors of the transistors Q1 and Q2, which in turn modulate the LO voltage by varying the bias currents of the transistors Q3, Q4, Q5, and Q6. Assuming that the two signals are small, the result is a product of the two signals, producing at the output a sum and difference of the frequencies of the two input signals. If either of these two signals are much larger than the threshold voltage $V_T$, the output will contain other mixing products and higher order terms which are undesirable and may need to be attenuated or filtered out.

Analysis of the Gilbert cell shows that the output, which is the difference of the collector currents of Q3 and Q6, is related to the two inputs by the equation:

$$\Delta I = I_{C3} - I_{C6} = I_{EE} \left[ \tanh \left( \frac{V_{RF}}{2V_T} \right) \right] \left[ \tanh \left( \frac{V_{LO}}{2V_T} \right) \right]$$

and the hyperbolic tangent function can be expressed as a Taylor series

$$\tanh(x) = x - \frac{x^3}{3} + \frac{x^5}{5} - \ldots$$

Assuming that the RF and LO signals are sinusoids.

$$V_{RF} = A\cos(\omega_{RF} t + \phi_{RF})$$
$$V_{LO} = B\cos(\omega_{LO} t + \phi_{LO})$$

then

$$\Delta I = I_{EE} \left[ A\cos(\omega_{RF} t + \phi_{RF}) - \frac{A^3}{3}\cos^3(\omega_{RF} t + \phi_{RF}) + \ldots \right]$$

$$\bullet \left[ B\cos(\omega_{LO} t + \phi_{LO}) - \frac{B^3}{3}\cos^3(\omega_{LO} t + \phi_{LO}) + \ldots \right]$$

The lowest order term is a product of two sinusoids, yielding a sum of two sinusoids,

$$I_{EE}\frac{AB}{2} \left[ \begin{array}{l} \cos((\omega_{RF} + \omega_{LO}) t + \phi_{RF} + \phi_{LO}) \\ + \cos((\omega_{RF} - \omega_{LO}) t + \phi_{RF} - \phi_{LO}) \end{array} \right]$$

one of which is the desired intermediate frequency signal.

# Figures of Merit

## GAIN (G)

Many different types of gain are specified in RF engineering. The type referred to here is called transducer gain and is defined as the ratio of the power delivered to the load to the available power from the source,

$$G = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT}^2/R_L}{V_{IN}^2/R_S} = 4\,\frac{R_S}{R_L}\frac{V_{OUT}^2}{V_{IN}^2}$$

where $V_{OUT}$ is the voltage across the load $R_L$ and $V_{IN}$ is the generator voltage with internal resistance $R_S$. In terms of scattering parameters, transducer gain is defined as

$$G = 20 \log (|S_{21}|)$$

where $S_{21}$ is the forward transmission parameter, which can be measured using a network analyzer.

## 1 dB COMPRESSION POINT ($P_{1dB}$)

A measure of amplitude linearity, 1 dB compression point is the point at which the actual gain is 1dB below the ideal linear gain. For a memoryless two-port with weak nonlinearity, the output can be represented by a power series of the input as

$$v_o = k_1 v_i + k_2 v_i^2 + k_3 v_i^3 + \ldots$$

For a sinusoidal input,

$$v_i = A\cos \omega_1 t$$

the output is

$$v_o = \frac{1}{2} k_2 A^2 + \left( k_1 A + \frac{3}{4} k_3 A^3 \right) \cos \omega_1 t$$
$$+ \frac{1}{2} k_2 A^2 \cos 2\omega_1 t + \frac{1}{4} k_3 A^3 \cos 3\omega_1 t$$

assuming that all of the fourth and higher order terms are negligible. For an amplifier, the fundamental component is the desired output, and it can be rewritten as

$$k_1 A \left[ 1 + \frac{3}{4} (k_3/k_1) A^2 \right].$$

This fundamental component is larger than $k_1 A$ (the ideally linear gain) if $k_3 > 0$ and smaller if $k_3 < 0$. For most practical devices, $k_3 < 0$, and the gain compresses as the amplitude A of the input signal gets larger. The 1 dB compression point can be expressed in terms of either the input power or the output power. Measurement of $P_{1dB}$ can be made by increasing the input power while observing the output power until the gain is compressed by 1 dB.

## THIRD ORDER INTERCEPT ($OIP_3$)

Third order intercept is another figure of merit used to characterize the linearity of a two-port. It is defined as the point at which the third order intermodulation product equals the ideal linear, uncompressed, output. Unlike the $P_{1dB}$, $OIP_3$ involves two input signals. However, it can be shown mathematically (similar derivation as above) that the two are closely related and $OIP_3 \approx P_{1dB} + 10$ dB. Theses two figures of merit are illustrated in *Figure 6*.
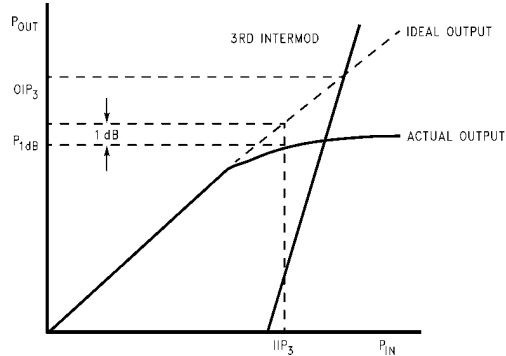


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**FIGURE 6. Typical $P_{OUT}$–$P_{IN}$ Characteristics**

## NOISE FIGURE (NF)

Noise figure is defined as the input signal to noise ratio divided by the output signal to noise ratio. For an amplifier, it can also be interpreted as the amount of noise introduced by the amplifier itself seen at the output. Mathematically,

$$F = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i/N_i}{G_a S_i/(N_a + G_a N_i)} = \frac{N_a + G_a N_i}{G_a N_i}$$

$$NF = 10 \log (F)$$

where $S_i$ and $N_i$ represent the signal and noise power levels available at the input to the amplifier, $S_o$ and $N_o$ the signal and noise power levels available at the output, $G_a$ the available gain, and Na the noise added by the amplifier. Noise figure is an important figure of merit used to characterize the performance of not only a single component but also the entire system. It is one of the factors which determine the system sensitivity.

## IMAGE FREQUENCY, DSB/SSB NF

Image frequency refers to that frequency which is also down-converted by the mixer, along with the desired RF component, to the intermediate frequency. This image frequency is located at the same distance away from the LO, but on the opposite side of the RF. For most mixers, it must be filtered out before the signal is down-converted; otherwise, an image-reject mixer must be used. *Figure 7* illustrates the concept.
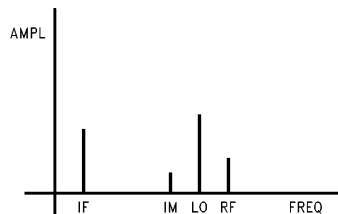


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**FIGURE 7. Input and Output Spectrum of Mixers**

# Figures of Merit (Continued)

Due to the presence of image frequencies and the method in which noise figure is defined, noise figures can be measured and specified in two ways: double side band (DSB) or single side band (SSB). In DSB measurements, the image frequency component of the input noise source is not filtered and contributes to the total output noise at the intermediate frequency. In SSB measurements. the image frequency is filtered and the output noise is not caused by this frequency component. In most mixer applications where only one side band is wanted, SSB noise figure is 3 dB *higher* than DSB noise figure.

In this application, the LMX2216 is used in a radio receiver front end, where it amplifies the signal from the antenna and then down converts it to an intermediate frequency. The image filter placed between the LNA and the mixer attenu-

ates the image frequency. The mixer is shown to use an LO signal generated by a PLL synthesizer, but, depending on the type of application, the LO signal could be generated by a device as simple as a free-running oscillator. The IF output is then typically filtered by a channel-select filter following the mixer, and this signal can then be demodulated or go through another down conversion, depending upon the intermediate frequency and system requirements. This external filter rejects adjacent channels and also attenuates any LO feed through. Figure 9 shows a cascade analysis of a typical RF front-end subsystem in which the LMX2216 is used. It includes the bandpass filter and the switch through which the input RF signal goes in a radio system before reaching the LNA. Typical values are used for the insertion loss of the various filters in this example.
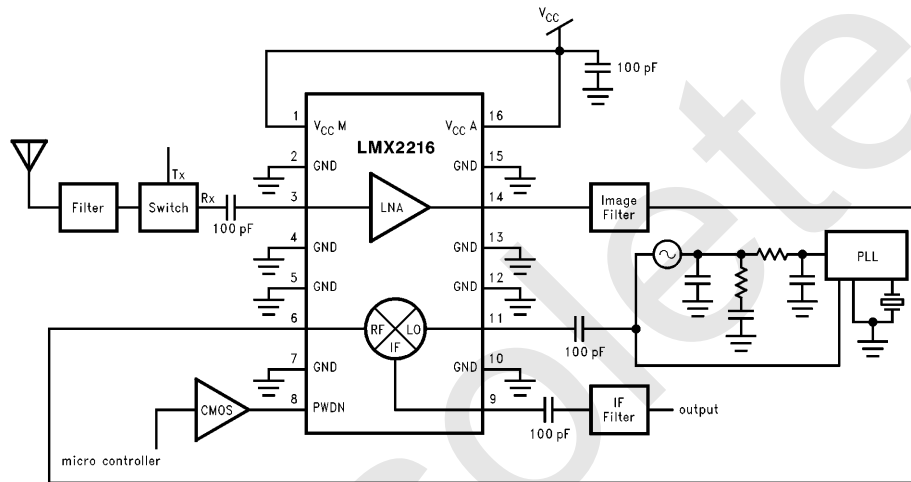


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**FIGURE 8. Typical Applications Circuit of the LMX2216**

| | Data per Stage | | | | Cumulative Data | | | |
|---|---|---|---|---|---|---|---|---|
| # Comp | Gain | N Fig | OIP3 | # | Gain | N Fig | IIP3 | OIP3 |
| 1 Filter | −2.0 | 2.0 | 100.0 | 1 | −2.0 | 2.0 | 97.9 | 95.9 |
| 2 Switch | −0.6 | 0.6 | 100.0 | 2 | −2.6 | 2.6 | 96.6 | 94.0 |
| 3 LNA | 12.3 | 3.7 | 6.0 | 3 | 9.7 | 6.3 | −3.7 | 6.0 |
| 4 Filter | −3.0 | 3.0 | 100.0 | 4 | 6.7 | 6.4 | −3.7 | 3.0 |
| 5 Mixer | 5.8 | 13.7 | 3.0 | 5 | 12.5 | 9.6 | −10.5 | 2.0 |
| 6 Filter | −3.0 | 3.0 | 100.0 | 6 | 9.5 | 9.7 | −10.5 | −1.0 |

System Cumulative Values

| | |
|---|---|
| Gain | 9.5 dB |
| N Fig | 9.7 dB |
| $IIP_3$ | −10.5 dBm |
| $OIP_3$ | −1.0 dBm |

**FIGURE 9. Cascade Analysis Example**

## Physical Dimensions inches (millimeters)

0.386 − 0.394
(9.804 − 10.00)

16 15 14 13 12 11 10 9

0.228 − 0.244
(5.791 − 6.198)

30°
TYP

LEAD NO.1
IDENT

1 2 3 4 5 6 7 8

0.010 MAX
(0.254)

0.150 − 0.157
(3.810 − 3.988)

0.010 − 0.020
(0.254 − 0.508) ×45°

8° MAX TYP
ALL LEADS

0.008 − 0.010
(0.203 − 0.254)
TYP ALL LEADS

0.004
(0.102)
ALL LEAD TIPS

0.016 − 0.050
(0.406 − 1.270)
TYP ALL LEADS

0.053 − 0.069
(1.346 − 1.753)

0.004 − 0.010
(0.102 − 0.254)

SEATING
PLANE

0.014
(0.356)

0.050
(1.270)
TYP

0.008
(0.203) TYP

0.014 − 0.020
(0.356 − 0.508) TYP

M16A (REV H)

**JEDEC 16-Lead (0.150″ Wide) Small Outline Molded Package (M)**
**Order Number LMX2216M**
**For Tape and Reel Order Number LMX2216MX**
**NS Package Number M16A**

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