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Tel: +86-755-8981 8866 Fax: +86-755-8427 6832
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Address: A1208, Overseas Decoration Building, #122 Zhenhua RD., Futian, Shenzhen, China

30MHz to 1300MHz Low Power Direct Quadrature Modulator

FEATURES

- **Frequency Range: 30MHz to 1300MHz**
- **Low Power: 2.7V to 3.6V Supply; 28mA**
- **Low LO Carrier Leakage: –51.5dBm at 500MHz**
- **Side-Band Suppression: –52.6dBc at 500MHz**
- **Output IP3: 20.8dBm at 500MHz**
- **Low RF Output Noise Floor: –156dBm/Hz at 6MHz Offset, P_{RF} = 3dBm**
- **Sine Wave or Square Wave LO Drive**
- **SPI Control:**
  Adjustable Gain: –19dB to 0dB in 1dB Steps
  Effecting Supply Current from 8mA to 35mA
  I/Q Offset Adjust: –65dBm LO Carrier Leakage
  I/Q Gain/Phase Adjust: –60dBc Side-Band Suppressed
- **24-Lead QFN 4mm × 4mm Package**

APPLICATIONS

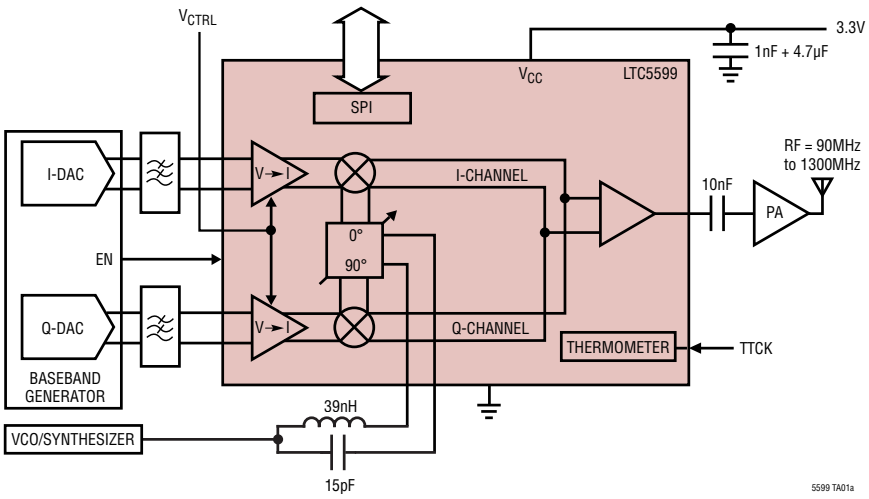
- Wireless Microphones
- Battery Powered Radios
- Ad-Hoc Wireless Infrastructure Networks
- “White-Space” Transmitters
- Software Defined Radios (SDR)
- Military Radios

DESCRIPTION

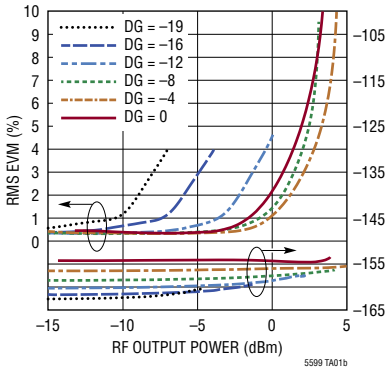
The LTC®5599 is a direct conversion I/Q modulator designed for low power wireless applications that enable direct modulation of differential baseband I and Q signals on an RF carrier. Single side-band modulation or side-band suppressed upconversion can be achieved by applying 90° phase-shifted signals to the I and Q inputs. The I/Q baseband input ports can be either AC or DC coupled to a source with a common mode voltage level of about 1.4V. The SPI interface controls the supply current, modulator gain, and allows optimization of the LO carrier feedthrough and side-band suppression, with sine wave or square wave LO drive. A fixed LC network on the LO and RF ports covers a continuous 90MHz to 1300MHz operation. An on-chip thermometer can be activated to compensate for gain-temperature variations. More accurate temperature measurements can be made using an on-chip diode. In addition, a continuous analog gain control (V_{CTRL}) pin can be used for fast power control.

TYPICAL APPLICATION

90MHz to 1300MHz Direct Conversion Transmitter Application



EVM and Noise Floor vs RF Output Power and Digital Gain Setting with 1Ms/s 16-QAM Signal

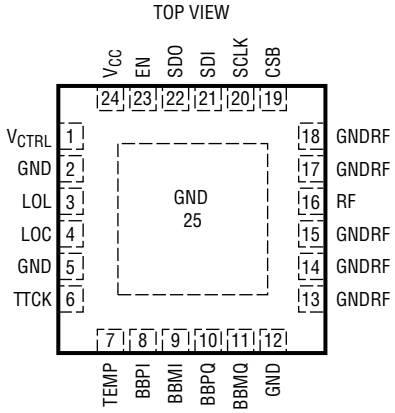


ABSOLUTE MAXIMUM RATINGS

(Note 1)

Supply Voltage 3.8V
Common Mode Level of BBPI, BBMI, and BBPQ, BBMQ 2V
LOL, LOC DC Voltage ..... ±0.1V
LOL, LOC Input Power (Note 15) 20dBm
Current Sink of TEMP, SDO 10mA
Voltage on Any Pin (Note 16) ..... –0.3V to V_{CC} + 0.3V
T_{JMAX} ..... 150°C
Case Operating Temperature Range ..... –40°C to 105°C
Storage Temperature Range ..... –65°C to 150°C

PIN CONFIGURATION



UF PACKAGE
24-LEAD (4mm × 4mm) PLASTIC QFN

T_{JMAX} = 150°C, θ_{JA} = 43°C/W, θ_{JC} = 4.5°C/W (AT EXPOSED PAD)
EXPOSED PAD (PIN 25) IS GND, MUST BE SOLDERED TO PCB

ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING	PACKAGE DESCRIPTION	CASE TEMPERATURE RANGE
LTC5599IUF#PBF	LTC5599IUF#TRPBF	5599	24-Lead (4mm × 4mm) Plastic QFN	–40°C to 105°C

Consult LTC Marketing for parts specified with wider operating temperature ranges.
Consult LTC Marketing for information on non-standard lead based finish parts.

For more information on lead free part marking, go to: http://www.linear.com/leadfree/
For more information on tape and reel specifications, go to: http://www.linear.com/tapeandreel/
Please refer to: http://www.linear.com/designtools/packaging/ for the most recent package drawings.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_C = 25°C. V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, P_{LO} = 0dBm, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, all registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
f_{LO} = 150MHz, f_{RF1} = 147.9MHz, f_{RF2} = 148MHz, Register 0x00 = 0x62							
$S_{22(ON)}$	RF Port Return Loss				–26		dB
$f_{LO(MATCH)}$	LO Match Frequency Range	S11 < –10dB			116 to 272		MHz
Gain	Conversion Voltage Gain	20 • Log ($V_{RF(OUT)(50Ω)}/V_{IN(DIFF)(I or Q)}$)			–7.5		dB
P_{OUT}	Absolute Output Power	1$V_{P-P(DIFF)}$ CW Signal, I and Q			–3.5		dBm
OP1dB	Output 1dB Compression				5		dBm
OIP2	Output 2nd Order Intercept	(Note 5)			70.5		dBm
OIP3	Output 3rd Order Intercept	(Note 6)			21.7		dBm
NFloor	RF Output Noise Floor	No Baseband AC Input Signal (Note 3)			–155.3		dBm/Hz
SB	Side-Band Suppression	(Note 7)			–61.4		dBc
LOFT	Carrier Leakage (LO Feedthrough)	(Note 7) EN = Low (Note 7)			–52.8 –84.8		dBm dBm
2LOFT	LO Feedthrough at 2xLO				–59		dBm

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_C = 25°C. V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, P_{LO} = 0dBm, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, all registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
2LO	Signal Powers at 2xLO	Maximum of $2f_{LO} - 2f_{BB}$; $2f_{LO} - f_{BB}$; $2f_{LO} + f_{BB}$, $2f_{LO} + 2f_{BB}$			–51		dBc
3LOFT	LO Feedthrough at 3xLO				–57		dBm
3LO	Signal Powers at 3xLO	Maximum of $3f_{LO} - f_{BB}$; $3f_{LO} + f_{BB}$			–10.7		dBc
$BW1dB_{BB}$	–1dB Baseband Bandwidth	R_{SOURCE} = 50Ω, Differential			15		MHz
$BW3dB_{BB}$	–3dB Baseband Bandwidth	R_{SOURCE} = 50Ω, Differential			28		MHz
f_{LO} = 500MHz, f_{RF1} = 497.9MHz, f_{RF2} = 498MHz, Register 0x00 = 0x2D							
$S_{22(ON)}$	RF Port Return Loss				–26		dB
$f_{LO(MATCH)}$	LO Match Frequency Range	S11 < –10dB			180 to 1900		MHz
Gain	Conversion Voltage Gain	20 • Log ($V_{RF(OUT)(50Ω)}/V_{IN(DIFF)(I or Q)}$)			–7.7		dB
P_{OUT}	Absolute Output Power	1$V_{P-P(DIFF)}$ CW Signal, I and Q			–3.7		dBm
OP1dB	Output 1dB Compression				5.0		dBm
OIP2	Output 2nd Order Intercept	(Note 5)			63.6		dBm
OIP3	Output 3rd Order Intercept	(Note 6)			20.8		dBm
NFloor	RF Output Noise Floor	No Baseband AC Input Signal (Note 3) P_{OUT} = 3dBm (Note 3)			–156.7 –156.0		dBm/Hz dBm/Hz
SB	Side-Band Suppression	(Note 7)			–52.6		dBc
LOFT	Carrier Leakage (LO Feedthrough)	(Note 7) EN = Low (Note 7)			–51.5 –67.5		dBm dBm
2LOFT	LO Feedthrough at 2xLO				–61		dBm
2LO	Signal Powers at 2xLO	Maximum of $2f_{LO} - 2f_{BB}$; $2f_{LO} - f_{BB}$; $2f_{LO} + f_{BB}$, $2f_{LO} + 2f_{BB}$			–51		dBc
3LOFT	LO Feedthrough at 3xLO				–62		dBm
3LO	Signal Powers at 3xLO	Maximum of $3f_{LO} - f_{BB}$; $3f_{LO} + f_{BB}$			–11.8		dBc
$BW1dB_{BB}$	–1dB Baseband Bandwidth	R_{SOURCE} = 50Ω, Differential			29		MHz
$BW3dB_{BB}$	–3dB Baseband Bandwidth	R_{SOURCE} = 50Ω, Differential			57		MHz
f_{LO} = 900MHz, f_{RF1} = 897.9MHz, f_{RF2} = 898MHz, Register 0x00 = 0x12							
$S_{22(ON)}$	RF Port Return Loss				–28		dB
$f_{LO(MATCH)}$	LO Match Frequency Range	S11 < –10dB			223 to 1902		MHz
Gain	Conversion Voltage Gain	20 • Log ($V_{RF(OUT)(50Ω)}/V_{IN(DIFF)(I or Q)}$)			–8.9		dB
P_{OUT}	Absolute Output Power	1$V_{P-P(DIFF)}$ CW Signal, I and Q			–4.9		dBm
OP1dB	Output 1dB Compression				4.1		dBm
OIP2	Output 2nd Order Intercept	(Note 5)			63.5		dBm
OIP3	Output 3rd Order Intercept	(Note 6)			18.4		dBm
NFloor	RF Output Noise Floor	No Baseband AC Input Signal (Note 3)			–155.6		dBm/Hz
SB	Side-Band Suppression	(Note 7)			–61.3		dBc
LOFT	Carrier Leakage (LO Feedthrough)	(Note 7) EN = Low (Note 7)			–58.6 –62.3		dBm dBm
2LOFT	LO Feedthrough at 2xLO				–59		dBm
2LO	Signal Powers at 2xLO	Maximum of $2f_{LO} - 2f_{BB}$; $2f_{LO} - f_{BB}$; $2f_{LO} + f_{BB}$, $2f_{LO} + 2f_{BB}$			–51		dBc

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_C = 25°C. V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, P_{LO} = 0dBm, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, all registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
3LOFT	LO Feedthrough at 3xLO				–60		dBm
3LO	Signal Powers at 3xLO	Maximum of $3f_{LO} - f_{BB}$; $3f_{LO} + f_{BB}$			–19.2		dBc
$BW1dB_{BB}$	–1dB Baseband Bandwidth	R_{SOURCE} = 50Ω, Differential			37		MHz
$BW3dB_{BB}$	–3dB Baseband Bandwidth	R_{SOURCE} = 50Ω, Differential			69		MHz
Variable Gain Control (V_{CTRL})							
$V_{CTRL}R$	Gain Control Voltage Range	Set Bit 6 in Register 0x01			0.9 to 3.3		V
τ_{CTRL}	Gain Control Response Time	Set Bit 6 in Register 0x01 (Note 8)			20		ns
Z_{CTRL}	Gain Control Input Impedance	Set Bit 6 in Register 0x01			10		pF
I_{CTRL}	DC Input Current	Set Bit 6 in Register 0x01 Clear Bit 6 in Register 0x01			2.58 0		mA mA
Baseband Inputs (BBPI, BBMI, BBPQ, BBMQ)							
V_{CMBB}	DC Common Mode Voltage	Internally Generated			1.42		V
$R_{IN(DIFF)}$	Input Resistance	Differential			1.8		kΩ
$R_{IN(CM)}$	Common Mode Input Resistance	Four Baseband Pins Shorted			350		Ω
$I_{BB(OFF)}$	Baseband Leakage Current	Four Baseband Pins Shorted, EN = Low			1.3		nA
V_{SWING}	Amplitude Swing	No Hard Clipping, Single-Ended, Digital Gain (DG) = –10			1.2		V_{P-P}
Power Supply (V_{CC})							
V_{CC}	Supply Voltage			2.7	3.3	3.6	V
$V_{RET(MIN)}$	Minimum Data Retention Voltage	(Note 14)		1.6	1.3		V
$I_{CC(ON)}$	Supply Current	EN = High		20	28	37	mA
$I_{CC(RANGE)}$	Supply Current Range	EN = High, Register 0x01 from 0x00 to 0x13			8 to 36		mA
$I_{CC(OFF)}$	Supply Current, Sleep Mode	EN = 0V			0.7	9	µA
t_{ON}	Turn-On Time	EN = Low to High (Notes 8, 12)			167		ns
t_{OFF}	Turn-Off Time	EN = High to Low (Notes 9, 12)			53		ns
t_{SB}	Side-Band Suppression Settling	Register 0x00 Change, <–50dBc (Note 12)			500		ns
t_{LO}	LO Suppression Settling	Register 0x02 Change, <–60dBm (Note 12)			90		ns
Serial Port (CSB, SCLK, SDI, SDO), Enable (EN) and TTCK, SCLK = 20MHz							
V_{IH}	Input High Voltage		●	1.1			V
V_{IL}	Input Low Voltage		●			0.2	V
I_{IH}	Input High Current				0.02		nA
I_{IL}	Input Low Current				–0.4		nA
V_{OH}	Output High Voltage	(Note 13)	●	V_{CC_L} – 0.2			V
V_{OL}	Output Low Voltage	I_{SINK} = 8mA (Note 10)	●			0.7	V
I_{OH}	SDO Leakage Current	for SDO = High			0.5		nA
V_{HYS}	Input Trip Point Hysteresis				110		mV
t_{CKH}	SCLK High Time		●	22.5	25		ns

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_C = 25°C. V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, P_{LO} = 0dBm, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, all registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
t_{CSS}	CSB Setup Time		●	20			ns
t_{CSH}	CSB High Time		●	30			ns
t_{CS}	SDI to SCLK Setup Time		●	20			ns
t_{CH}	SDI to SCLK Hold Time		●	10			ns
t_{DO}	SCLK to SDO Time		●	45			ns
$t_{C\%}$	SCLK Duty Cycle		●	45	50	55	%
f_{CLK}	Maximum SCLK Frequency		●	20			MHz
V_{TEMP}	Temperature Diode Voltage	I_{TEMP} = 100µA			763		mV
	Temperature Slope	I_{TEMP} = 100µA			1.6		mV/°C

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: The LTC5599 is guaranteed functional over the operating case temperature range from –40°C to 105°C.

Note 3: At 6MHz offset from the LO signal frequency. 100nF between BBPI and BBMI, 100nF between BBPQ and BBMQ.

Note 4: The Default Register Settings are listed in Table 1.

Note 5: IM2 is measured at f_{LO} – 4.1MHz.

Note 6: IM3 is measured at f_{LO} – 2.2MHz and f_{LO} – 1.9MHz. OIP3 = lowest of (1.5 • P{f_{LO} – 2.1MHz} – 0.5 • P{f_{LO} – 2.2MHz}) and (1.5 • P{f_{LO} – 2MHz} – 0.5 • P{f_{LO} – 1.9MHz}).

Note 7: Without side-band or LO feedthrough nulling (unadjusted).

Note 8: RF power is within 10% of final value.

Note 9: RF power is at least 30dB down from its ON state.

Note 10: V_{OL} voltage scales linear with current sink. For example for $R_{PULL-UP}$ = 1kΩ, V_{CC_L} = 3.3V the SDO sink current is about (3.3 – 0.2) /1kΩ = 3.1mA. Max V_{OL} = 0.7 • 3.1/8 = 0.271V, with $R_{PULL-UP}$ the SDO pull-up resistor and V_{CC_L} the digital supply voltage to which $R_{PULL-UP}$ is connected to.

Note 11: I and Q baseband Input signal = 2MHz CW, 0.8$V_{P-P, DIFF}$ each, I and Q 0° shifted.

Note 12: f_{LO} = 500MHz, P_{LO} = 0dBm, C4 = 1.5nF

Note 13: Maximum V_{OH} is derated for capacitive load using the following formula: V_{CC_L} • exp (–0.5 • T_{CLK}/($R_{PULL-UP}$ • C_{LOAD}), with T_{CLK} the time of one SCLK cycle, $R_{PULL-UP}$ the SDO pull-up resistor, V_{CC_L} the digital supply voltage to which $R_{PULL-UP}$ is connected to, and C_{LOAD} the capacitive load at the SDO pin. For example for T_{CLK} = 100ns (10MHz SCLK), $R_{PULL-UP}$ = 1kΩ, C_{LOAD} = 10pF and V_{CC_L} = 3.3V the derating is 3.3 • exp(–5) = 22.2mV, thus maximum V_{OH} = 3.3V – 0.1 – 0.0222 = 3.177V.

Note 14: Minimum V_{CC} in order to retain register data content.

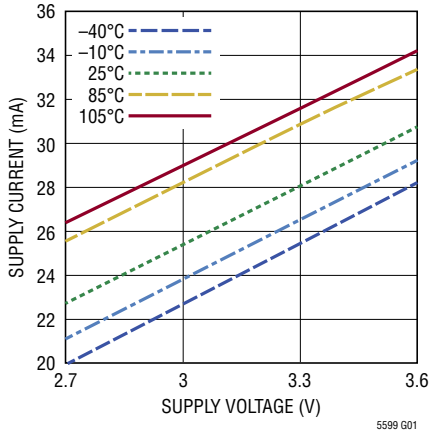
Note 15: Guaranteed by design and characterization. This parameter is not tested.

Note 16: RF pin guaranteed by design while using a 10nF coupling capacitor. The RF pin is not tested.

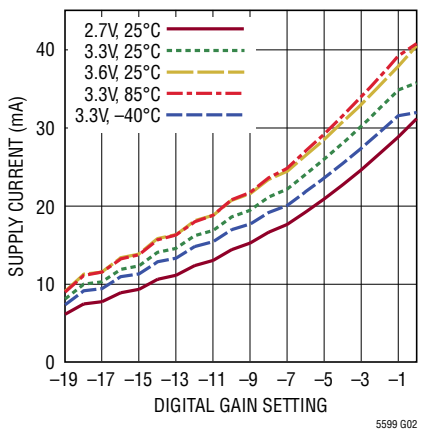
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

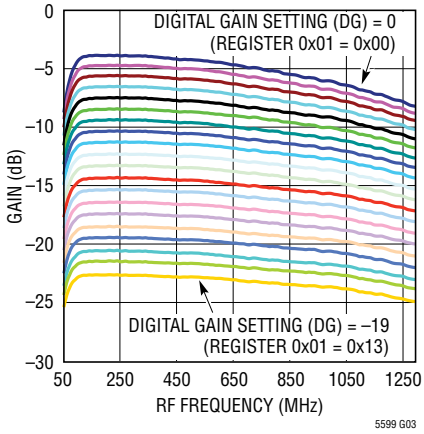
Supply Current vs Supply Voltage



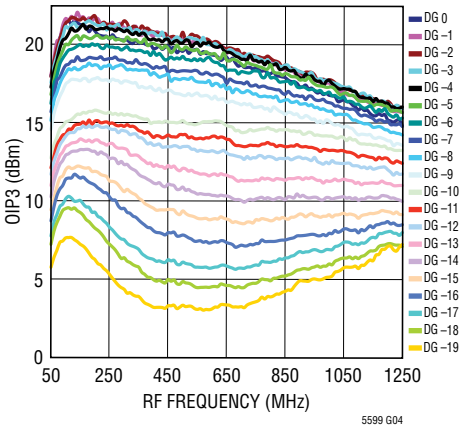
Supply Current vs Digital Gain Setting



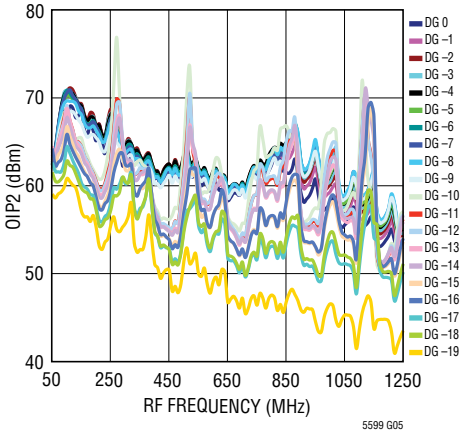
Gain vs RF Frequency and Digital Gain Setting



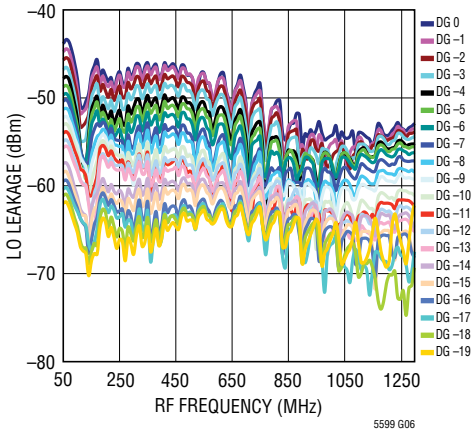
Output IP3 vs RF Frequency and Digital Gain Setting



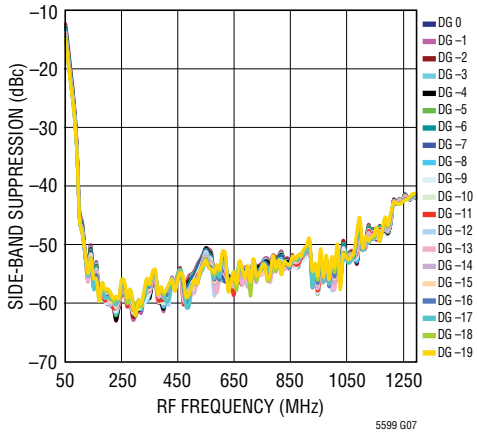
Output IP2 vs RF Frequency and Digital Gain Setting



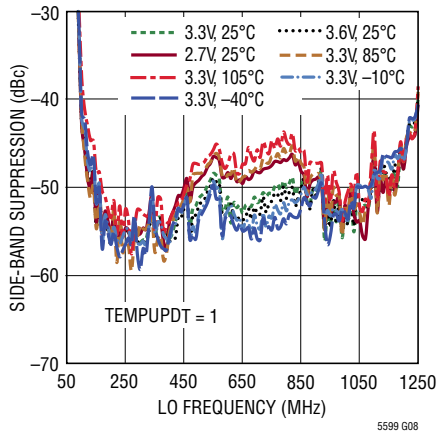
LO Leakage vs RF Frequency and Digital Gain Setting



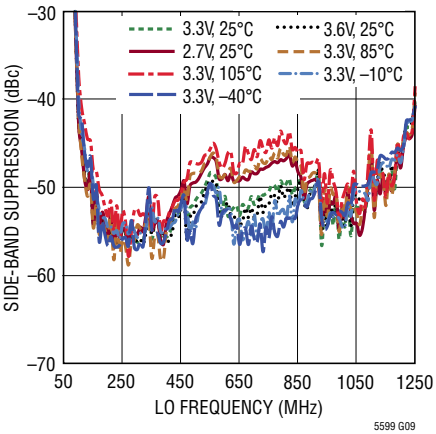
Side-Band Suppression vs RF Frequency and Digital Gain Setting



Side-Band Suppression vs LO Frequency for Gain TempComp Off



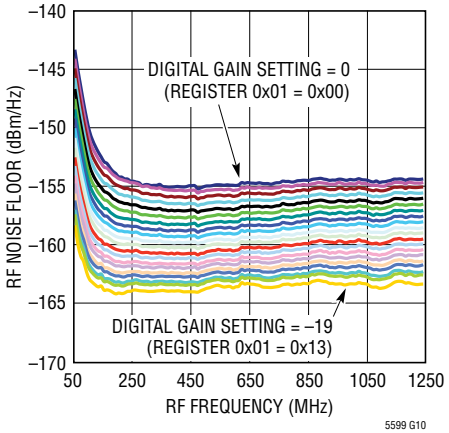
Side-Band Suppression vs LO Frequency for Gain TempComp On



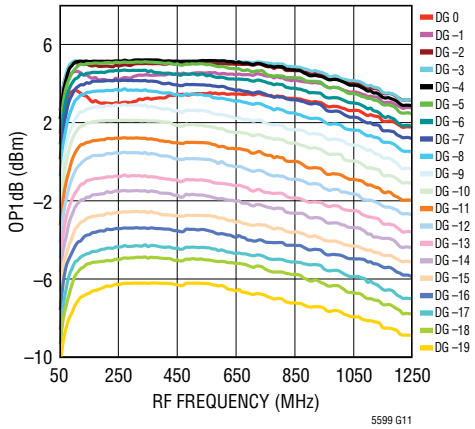
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

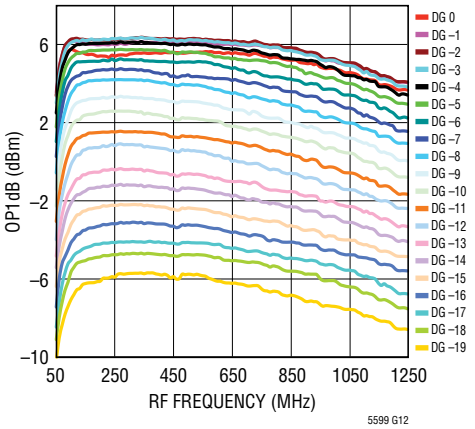
Noise Floor vs RF Frequency and Digital Gain Setting



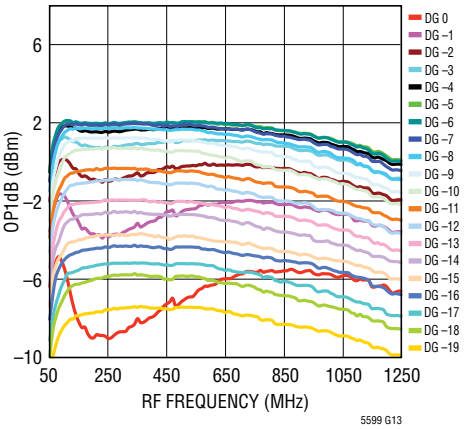
Output 1dB Compression Point vs RF Frequency and Digital Gain Setting and 3.3V Supply



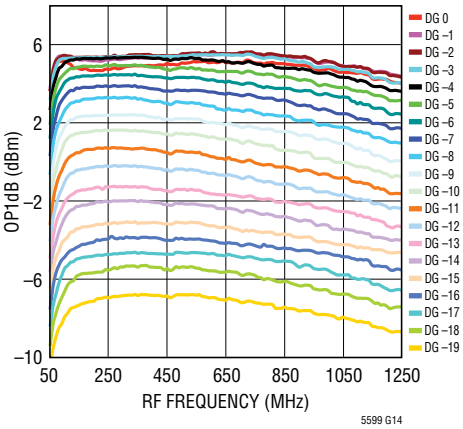
Output 1dB Compression Point vs RF Frequency and Digital Gain Setting and 3.6V Supply



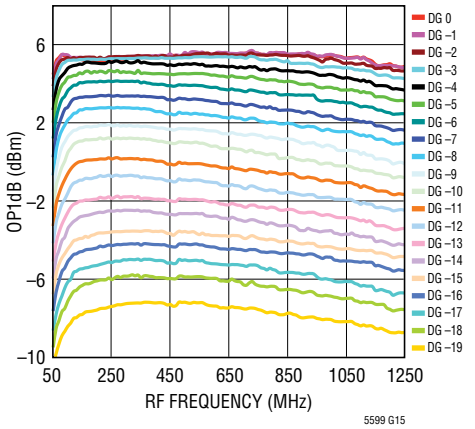
Output 1dB Compression Point vs RF Frequency and Digital Gain Setting and 2.7V Supply



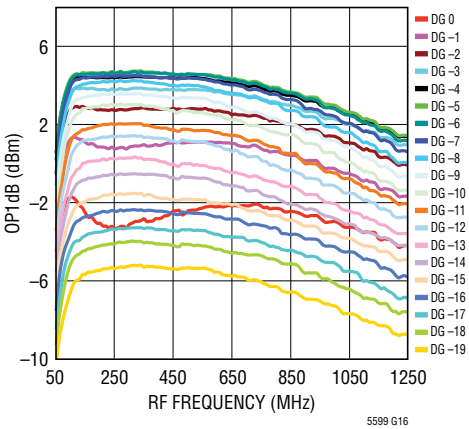
Output 1dB Compression Point vs RF Frequency and Digital Gain Setting at –10°C



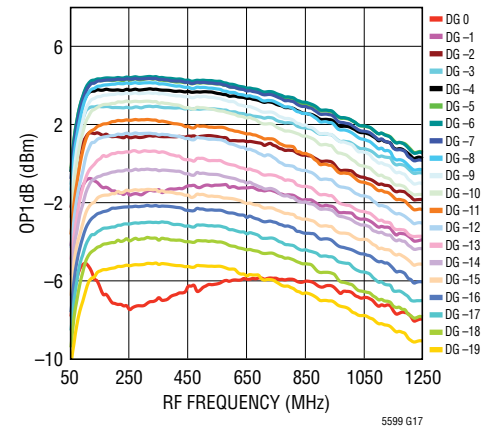
Output 1dB Compression Point vs RF Frequency and Digital Gain Setting at –40°C



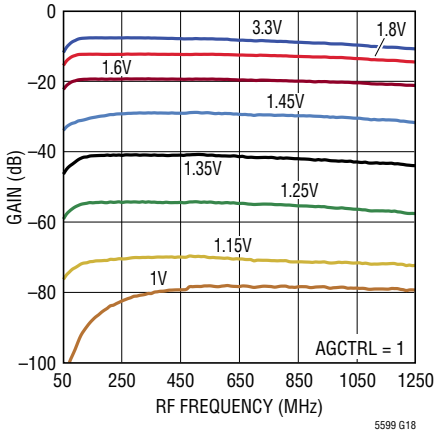
Output 1dB Compression Point vs RF Frequency and Digital Gain Setting at 85°C



Output 1dB Compression Point vs RF Frequency and Digital Gain Setting at 105°C



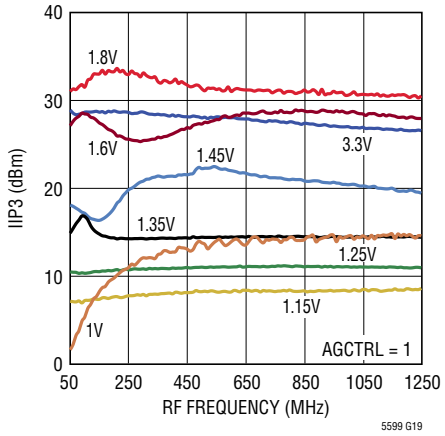
Gain vs RF Frequency and V_{CTRL}



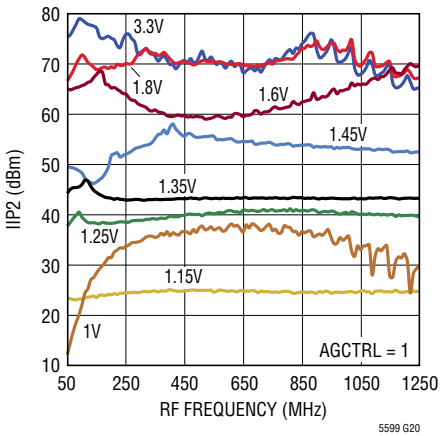
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

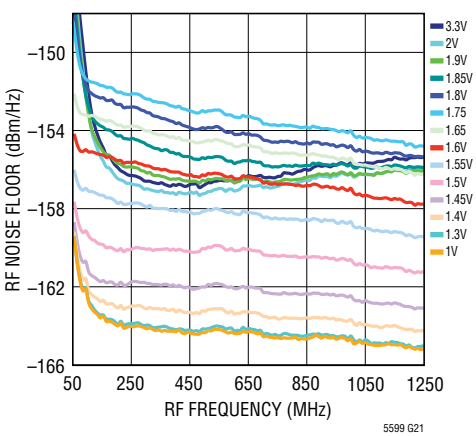
Input IP3 vs RF Frequency and V_{CTRL}



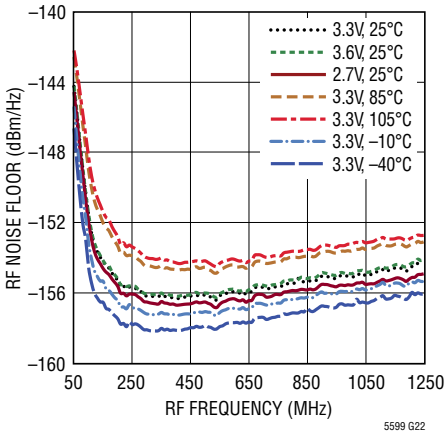
Input IP2 vs RF Frequency and V_{CTRL}



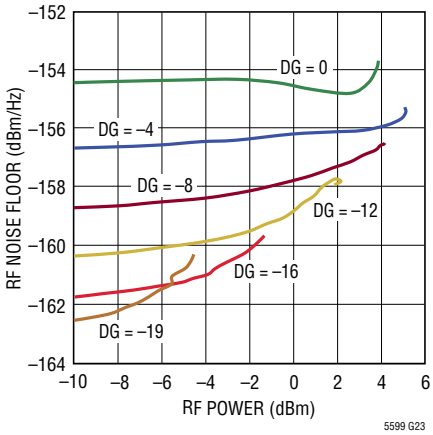
Noise Floor vs RF Frequency and V_{CTRL}



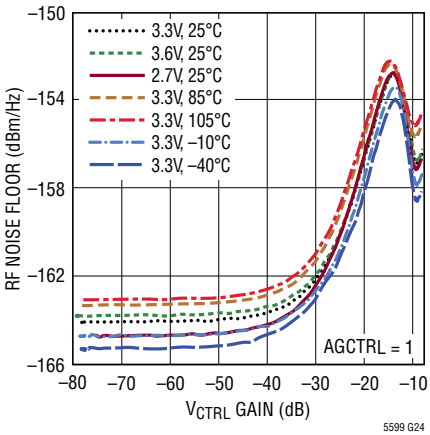
Noise Floor vs RF Frequency



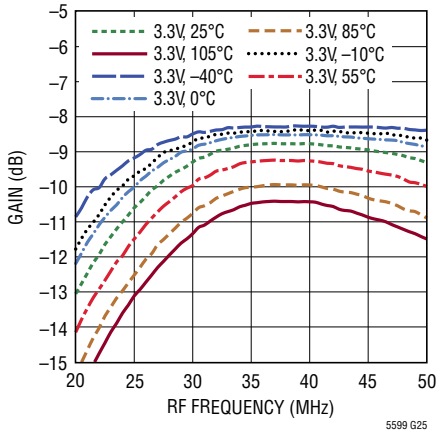
Noise Floor vs RF Power



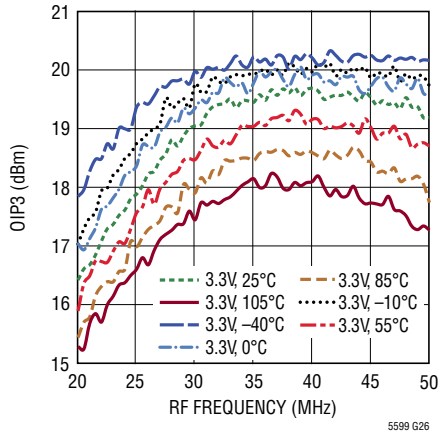
Noise Floor vs V_{CTRL} Gain



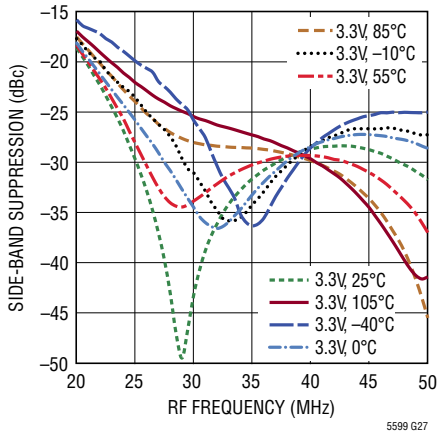
Gain vs RF Frequency for 30MHz LO Match



Output IP3 vs RF Frequency for 30MHz LO Match



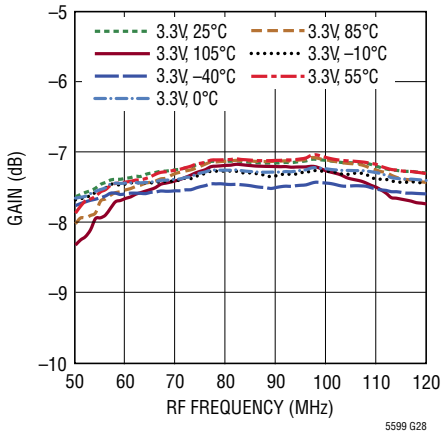
Side-Band Suppression vs RF Frequency for 30MHz LO Match



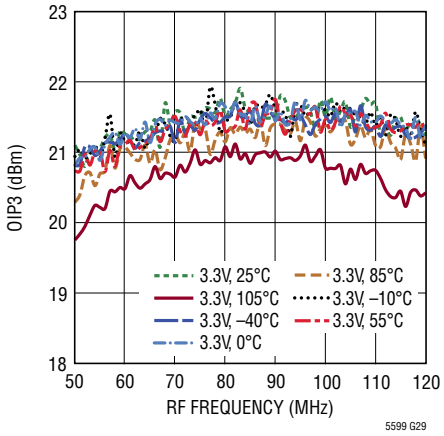
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

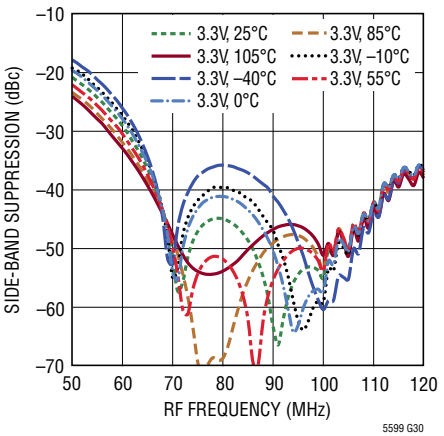
Gain vs RF Frequency for 70MHz LO Match



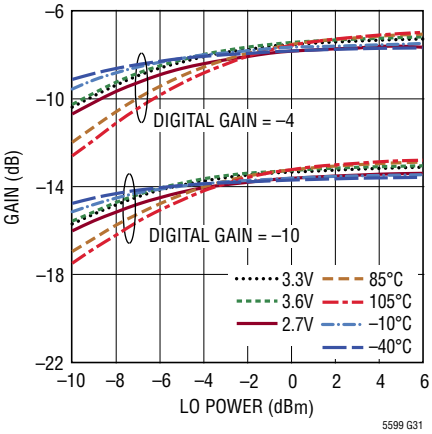
Output IP3 vs RF Frequency for 70MHz LO Match



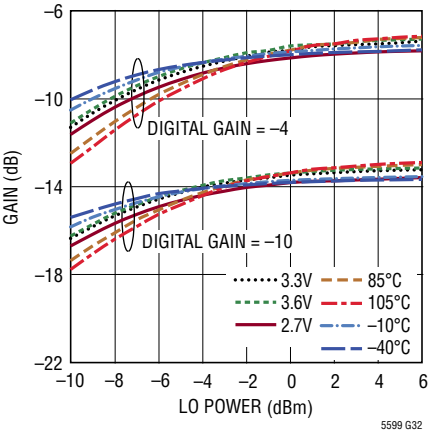
Side-Band Suppression vs RF Frequency for 70MHz LO Match



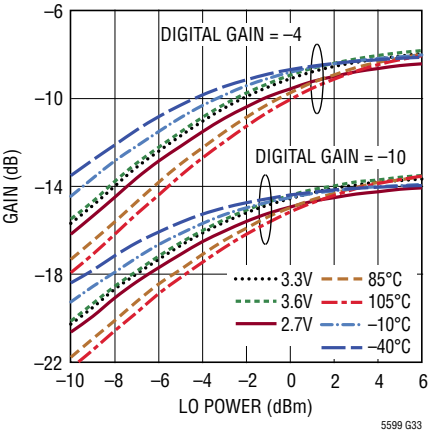
Gain vs LO Power at f_{LO} = 150MHz



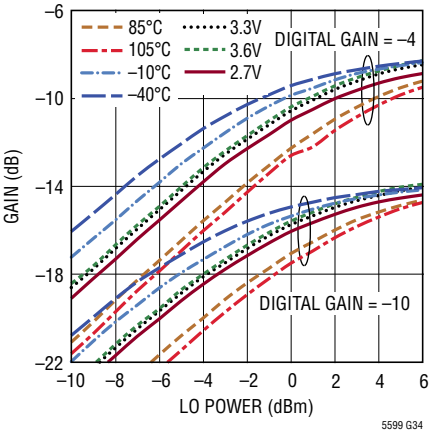
Gain vs LO Power at f_{LO} = 500MHz



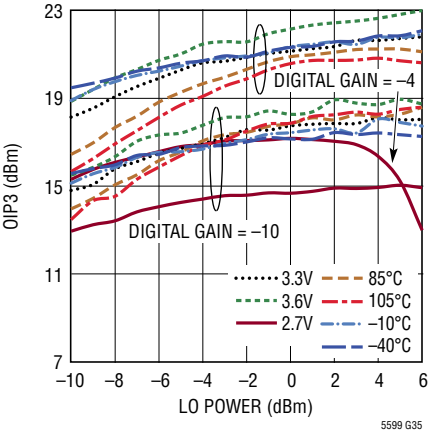
Gain vs LO Power at f_{LO} = 900MHz



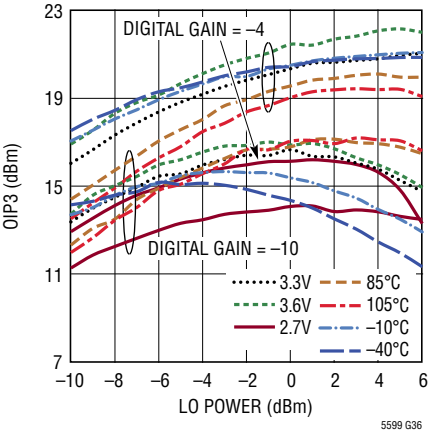
Gain vs LO Power at f_{LO} = 1260MHz



Output IP3 vs LO Power at f_{LO} = 150MHz



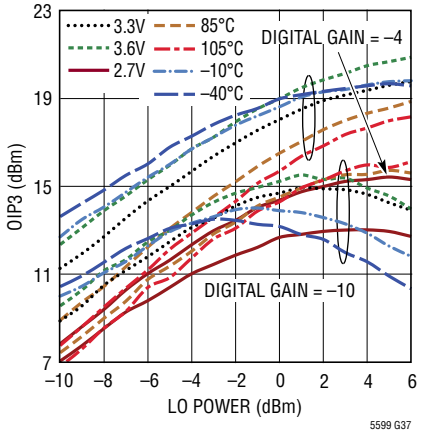
Output IP3 vs LO Power at f_{LO} = 500MHz



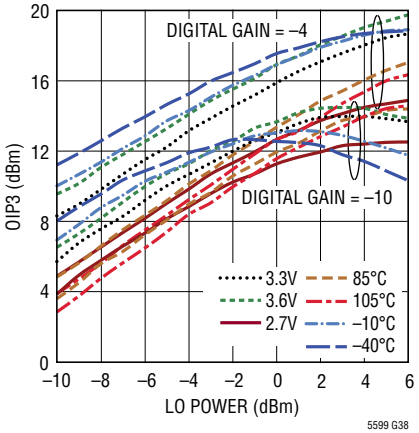
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

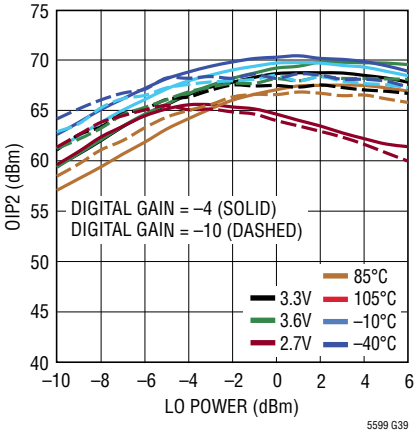
Output IP3 vs LO Power at f_{LO} = 900MHz



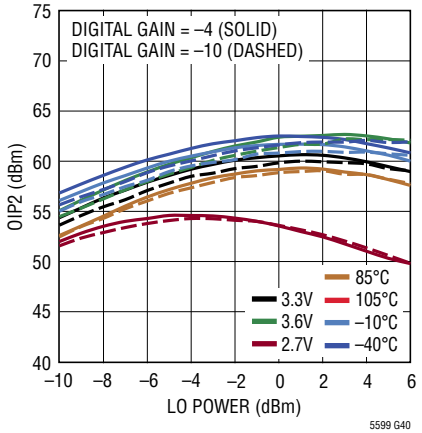
Output IP3 vs LO Power at f_{LO} = 1260MHz



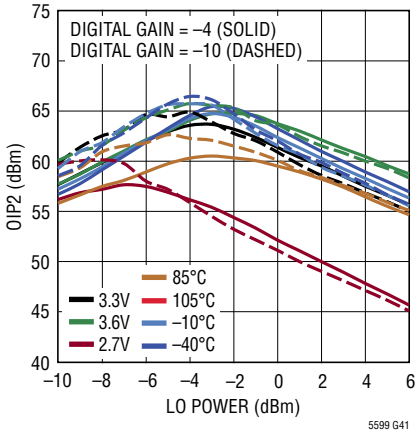
Output IP2 vs LO Power at f_{LO} = 150MHz



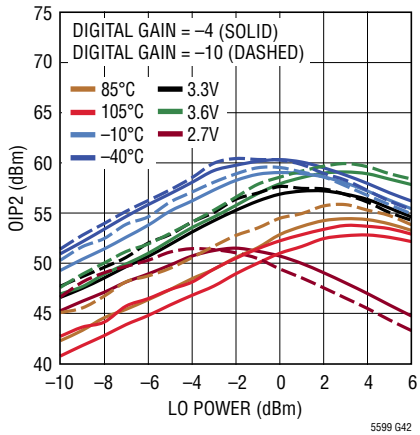
Output IP2 vs LO Power at f_{LO} = 500MHz



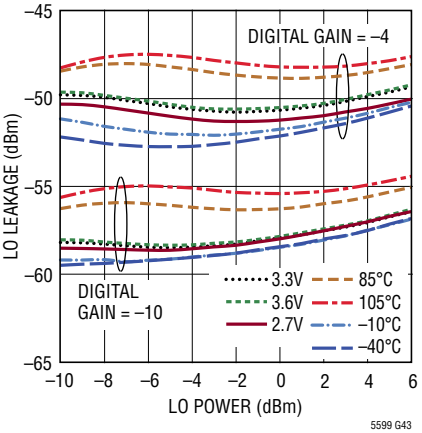
Output IP2 vs LO Power at f_{LO} = 900MHz



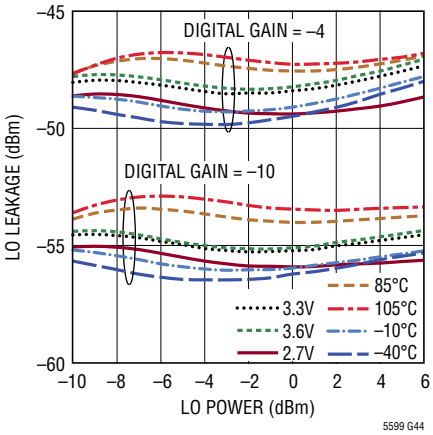
Output IP2 vs LO Power at f_{LO} = 1260MHz



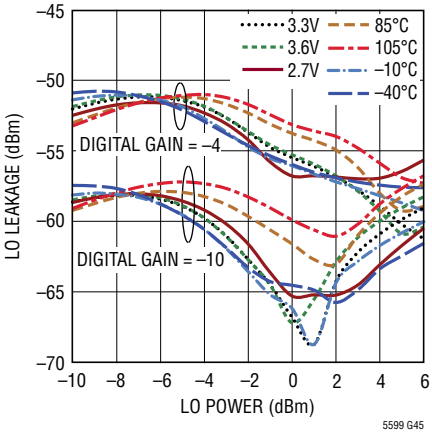
LO Leakage vs LO Power at f_{LO} = 150MHz



LO Leakage vs LO Power at f_{LO} = 500MHz



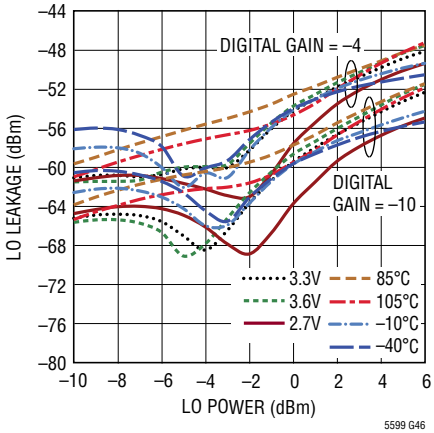
LO Leakage vs LO Power at f_{LO} = 900MHz



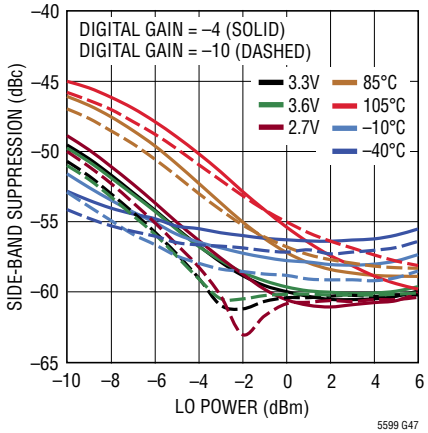
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

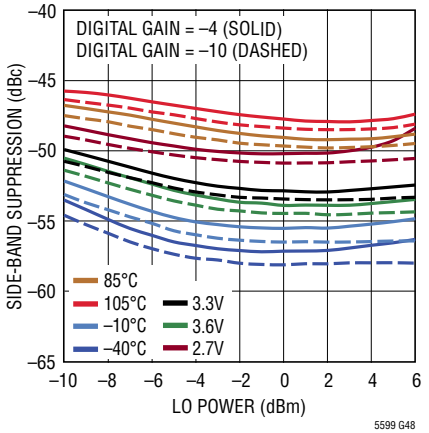
LO Leakage vs LO Power at f_{LO} = 1260MHz



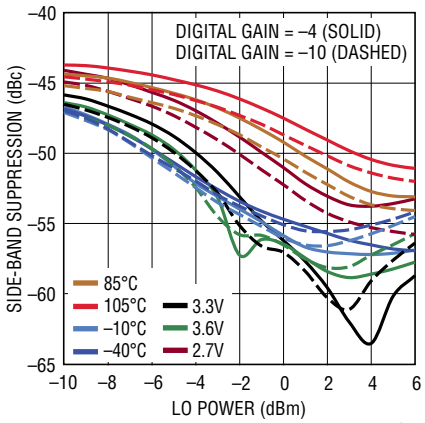
Side-Band Suppression vs LO Power at f_{LO} = 150MHz



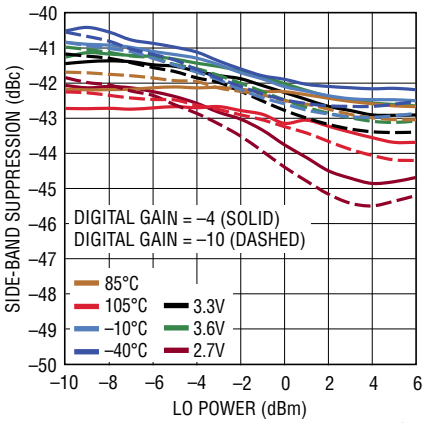
Side-Band Suppression vs LO Power at f_{LO} = 500MHz



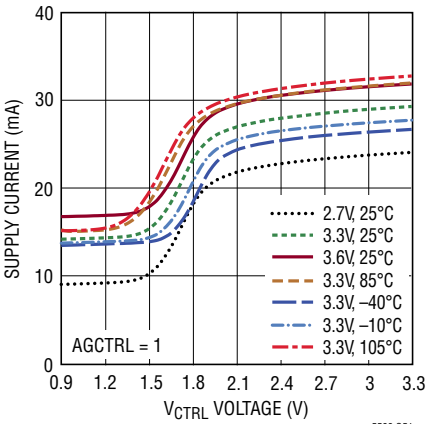
Side-Band Suppression vs LO Power at f_{LO} = 900MHz



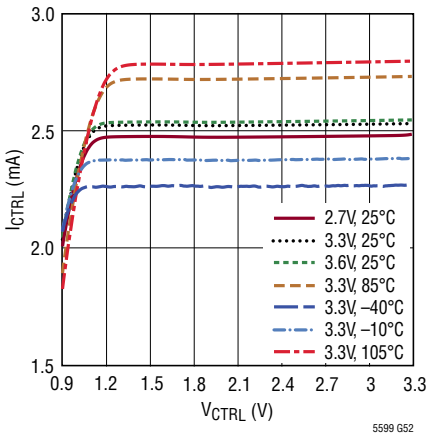
Side-Band Suppression vs LO Power at f_{LO} = 1260MHz



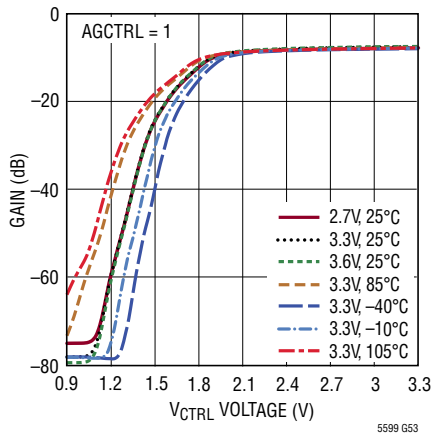
Supply Current vs V_{CTRL} Voltage



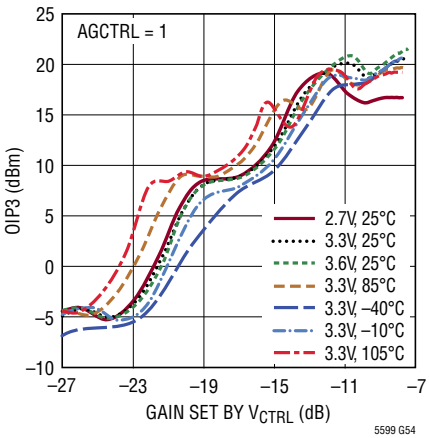
V_{CTRL} Current vs V_{CTRL} Voltage



Gain vs V_{CTRL} Voltage



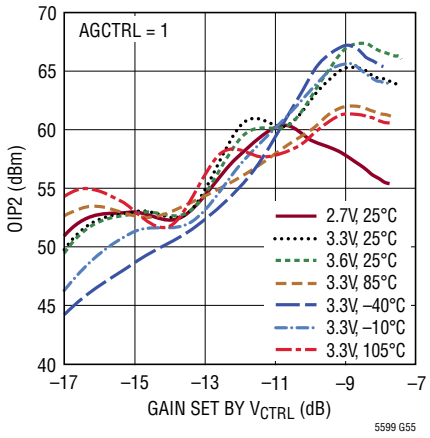
Output IP3 vs V_{CTRL} Gain



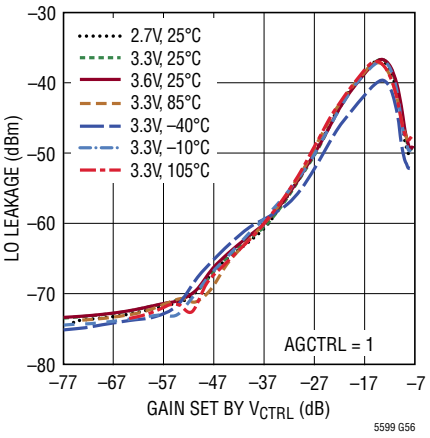
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

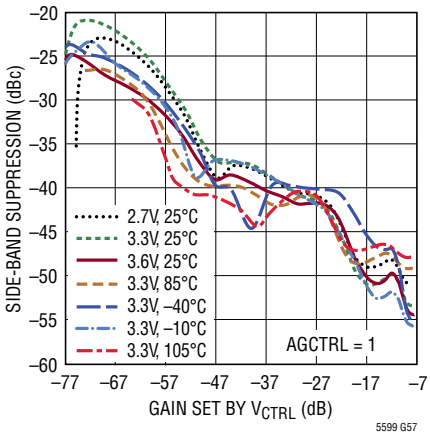
Output IP2 vs V_{CTRL} Gain



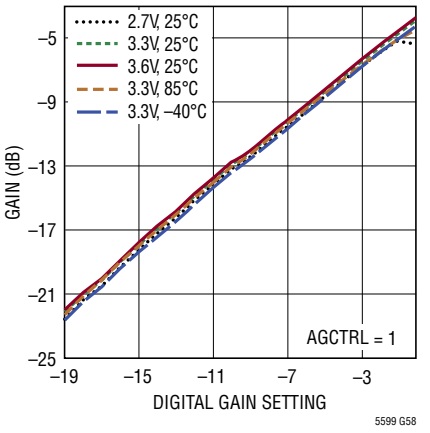
LO Leakage vs V_{CTRL} Gain



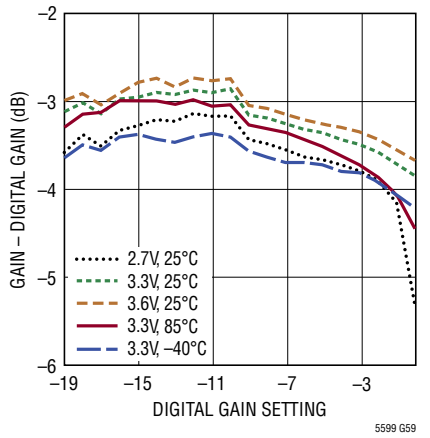
Side-Band Suppression vs V_{CTRL} Gain



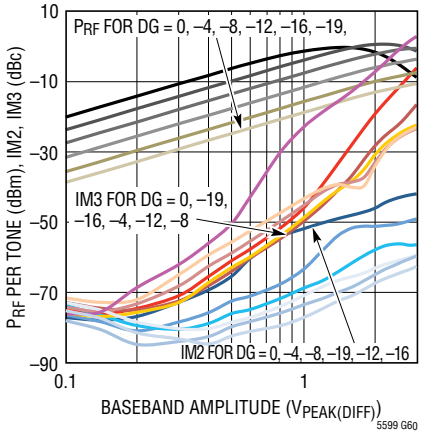
Gain vs Digital Gain Setting



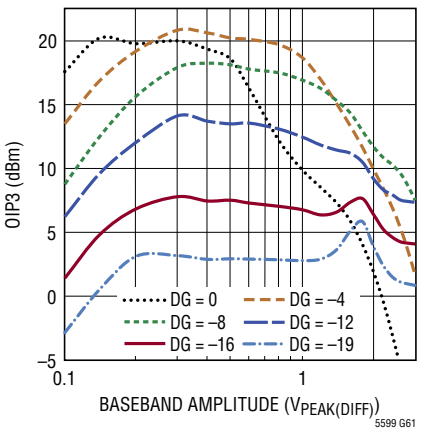
Gain Minus Digital Gain vs Digital Gain Setting



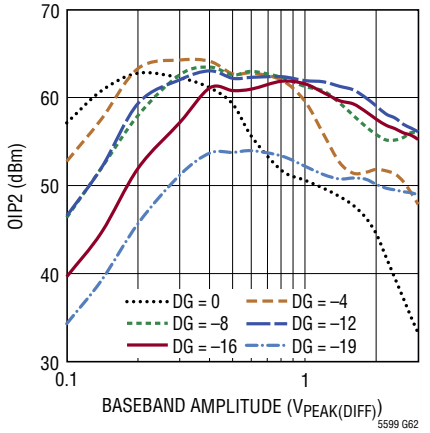
P_{RF}, IM2, IM3 vs Baseband Amplitude



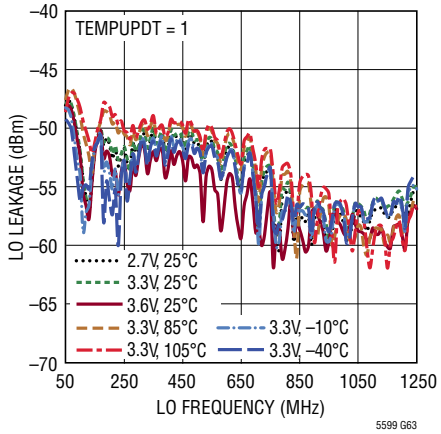
Output IP3 vs Baseband Amplitude



Output IP2 vs Baseband Amplitude



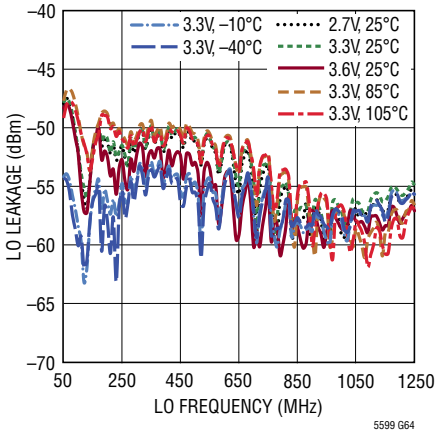
LO Leakage vs LO Frequency for Gain TempComp Off



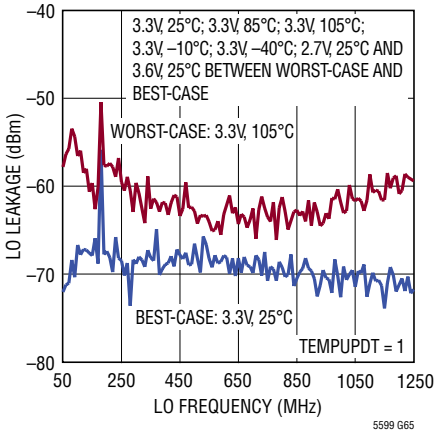
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

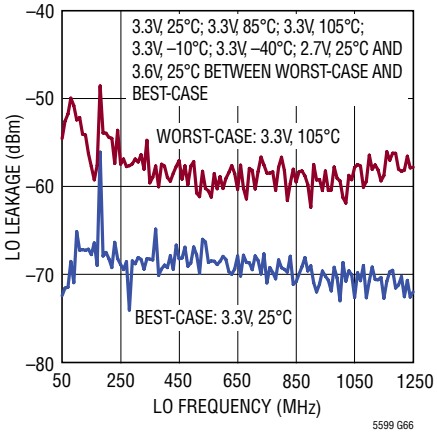
LO Leakage vs LO Frequency for Gain TempComp On



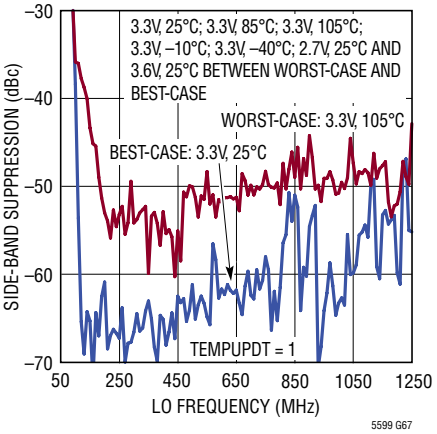
Worst-Case LO Leakage Over Five Parts vs LO Frequency After 25°C Calibration for Gain TempComp Off



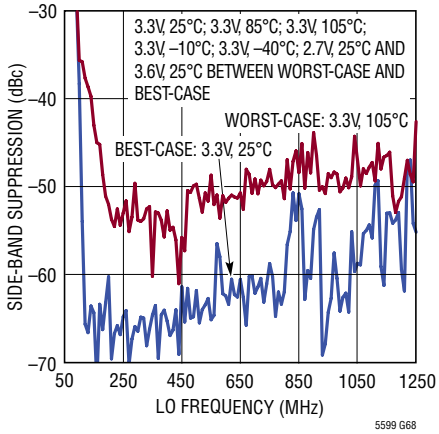
Worst-Case LO Leakage Over Five Parts vs LO Frequency After 25°C Calibration for Gain TempComp On



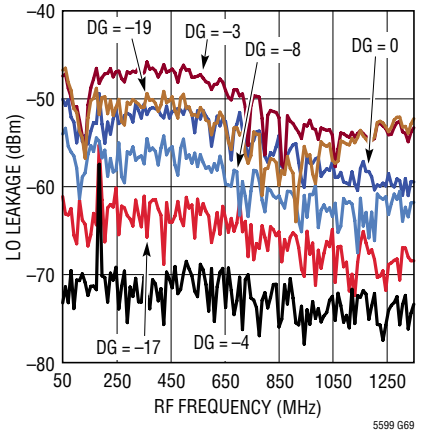
Worst-Case Side-Band Suppression Over Five Parts vs LO Frequency After 25°C Calibration for Gain TempComp Off



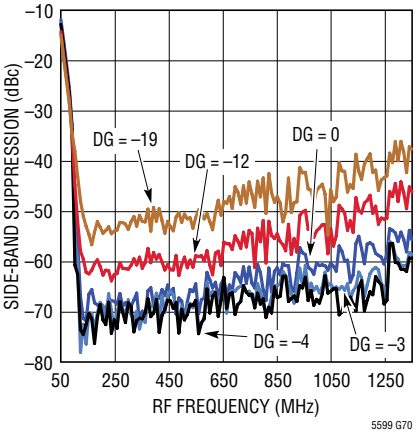
Worst-Case Side-Band Suppression Over Five Parts vs LO Frequency After 25°C Calibration for Gain TempComp On



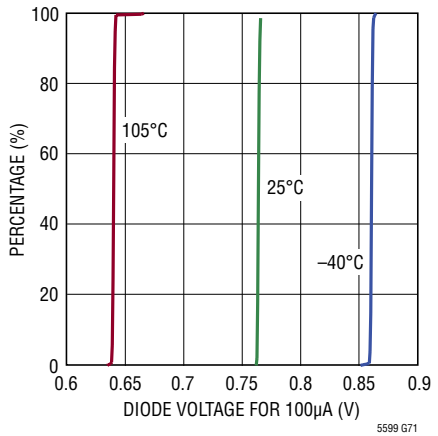
LO Leakage vs LO Frequency and Digital Gain Setting After Calibration at DG = –4



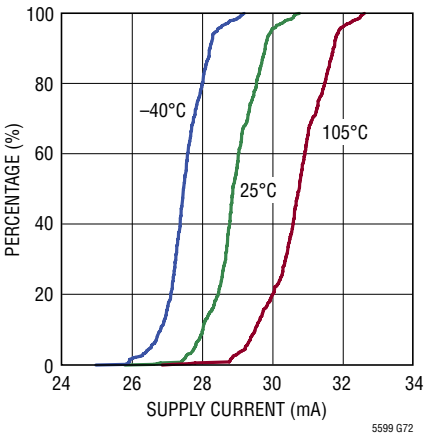
Side-Band Suppression vs LO Frequency and Digital Gain Setting After Calibration at DG = –4



Temperature Sensing Diode Voltage Cumulative Distribution



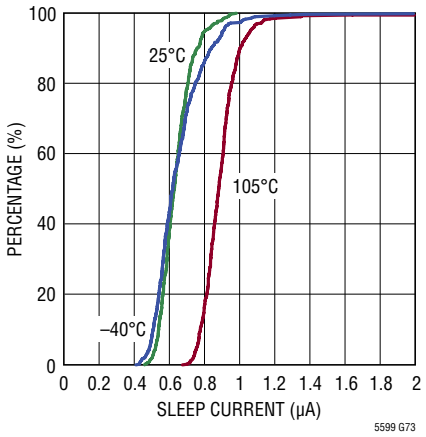
Supply Current Cumulative Distribution



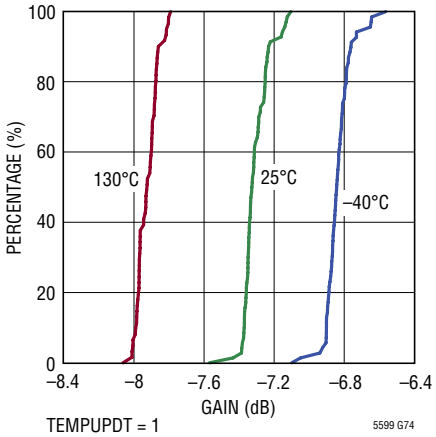
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

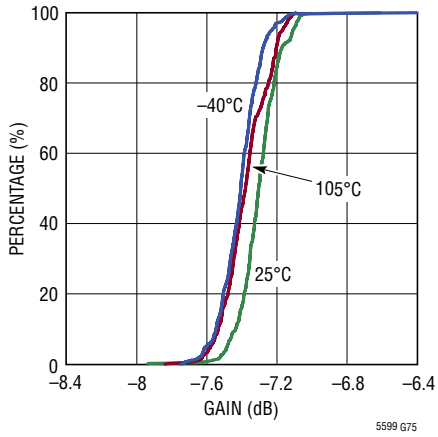
Sleep Current Cumulative Distribution



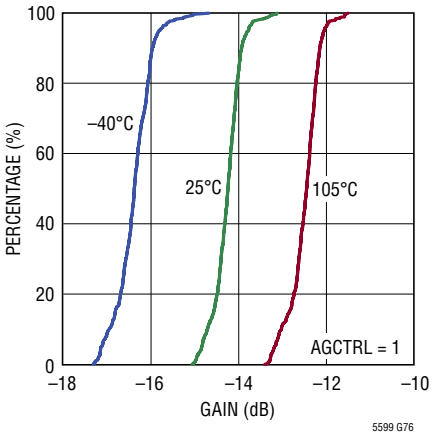
Gain Cumulative Distribution for Gain TempComp Off



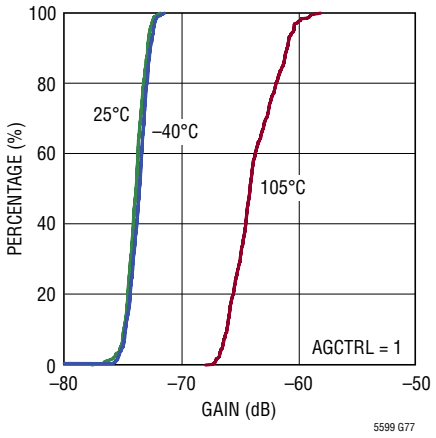
Gain Cumulative Distribution for Gain TempComp On



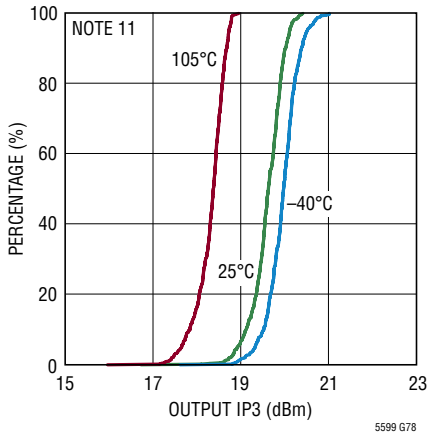
Gain Cumulative Distribution for V_{CTRL} = 1.75V



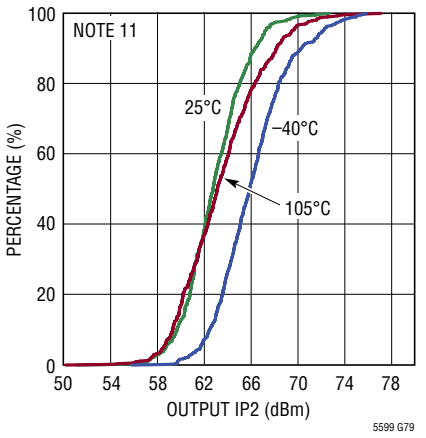
Gain Cumulative Distribution for V_{CTRL} = 1V



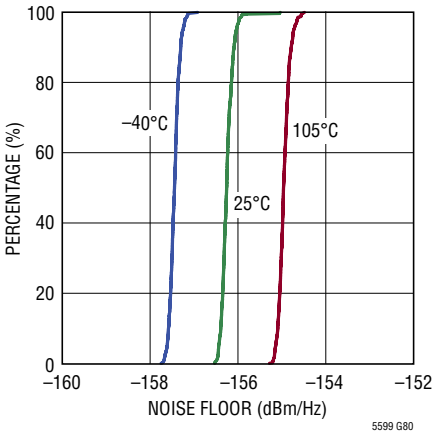
Output IP3 Cumulative Distribution



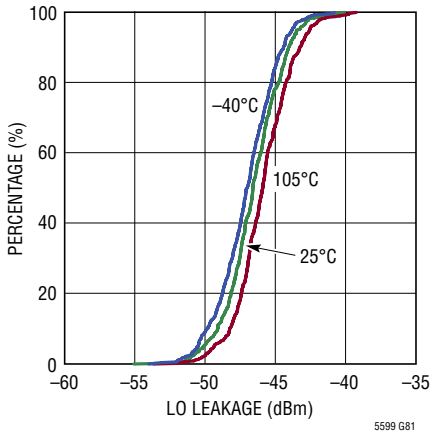
Output IP2 Cumulative Distribution



Noise Floor Cumulative Distribution



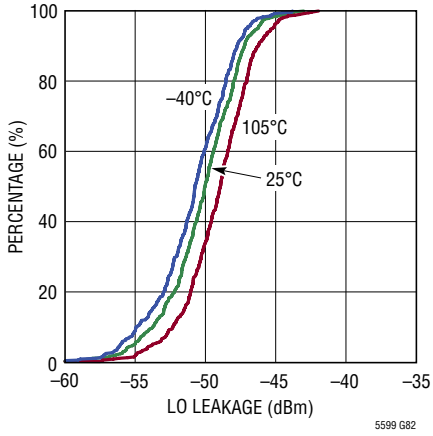
LO Leakage Cumulative Distribution for Floating Baseband Pins



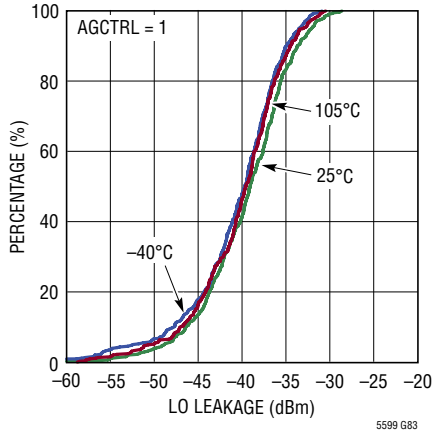
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

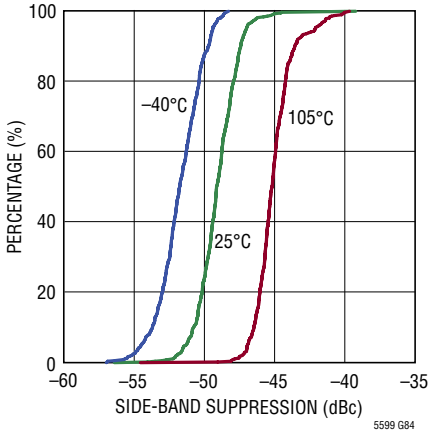
LO Leakage Cumulative Distribution



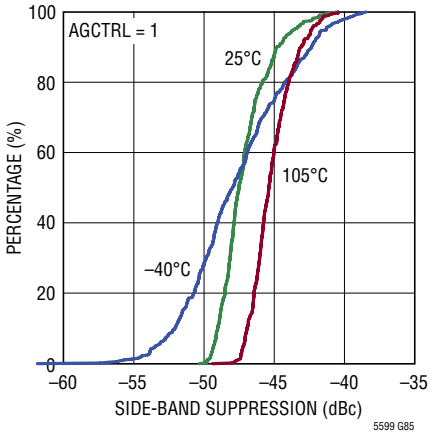
LO Leakage Cumulative Distribution for V_{CTRL} = 1.75V



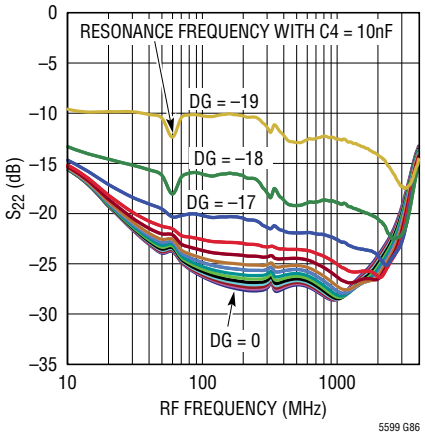
Side-Band Suppression Cumulative Distribution



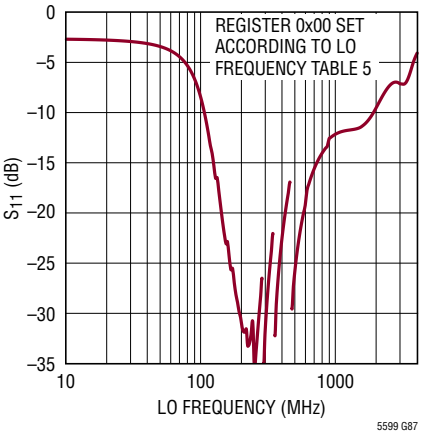
Side-Band Suppression Cumulative Distribution for V_{CTRL} = 1.75V



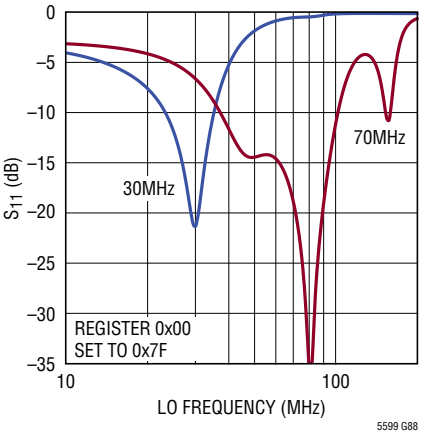
RF Return Loss



LO Return Loss



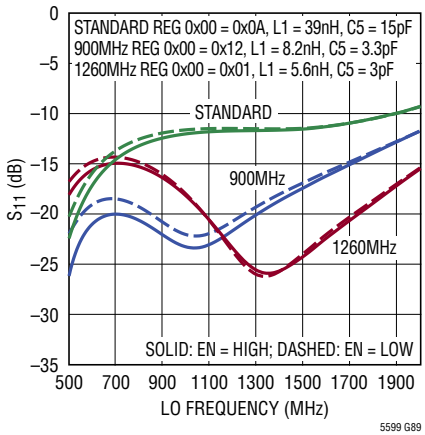
LO Return Loss for 30MHz and 70MHz Match, Schematic in Figure 3



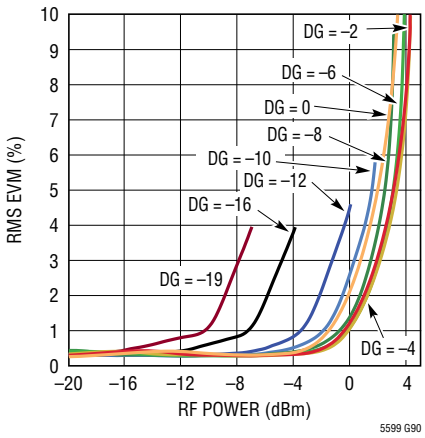
TYPICAL PERFORMANCE CHARACTERISTICS

V_{CC} = 3.3V, EN = 3.3V, V_{CTRL} = 3.3V, T_C = 25°C, P_{LO} = 0dBm, f_{LO} = 500MHz, BBPI, BBMI, BBPQ, BBMQ common mode DC voltage V_{CMBB} = 1.4V_{DC}, I and Q baseband input signal = 2MHz, 2.1MHz, 1$V_{P-P(DIFF, I or Q)}$, I and Q 90° shifted, lower sideband selection, TEMPUPDT = 0, register 0x00 value according to Table 5, all other registers set to default values, unless otherwise noted. Test circuit is shown in Figure 13.

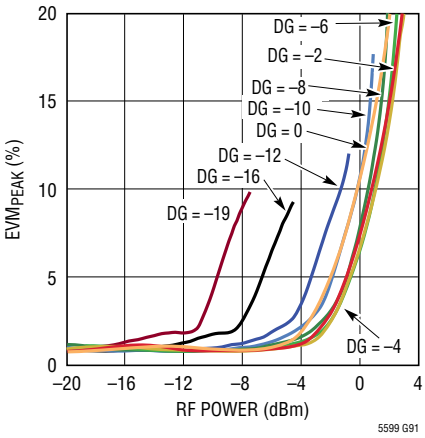
LO Return Loss for Standard, 900MHz and 1260MHz Match



RMS EVM vs RF Output Power with 1Ms/s 16-QAM Signal



Peak EVM vs RF Output Power with 1Ms/s 16-QAM Signal



PIN FUNCTIONS

V_{CTRL} (Pin 1): Variable Gain Control Input. This analog control pin sets the gain. Write a "1" to bit 6 in register 0x01 (AGCTRL = 1) to activate this pin, resulting in about 2.58mA current draw from a positive supply. Typical V_{CTRL} voltage range is 0.9V to 3.3V. Gain transfer function is not linear-in-dB. Tie to V_{CC} when not used.

GND (Pins 2, 5, 12, Exposed Pad 25): Ground. All these pins are connected together internally. For best RF performance all ground pins should be connected to RF ground.

LOL, LOC (Pins 3, 4): LO Inputs. This is not a differential input. Both pins are 50Ω inputs. An LC diplexer is recommended to be used at these pins (see Figure 13). AC-coupling capacitors are required at these pins if the applied DC level is higher than ±100mV.

TTCK (Pin 6): Temperature Update. When the TTCK temperature update mode is selected in register 0x01 (bit 7 = High, TEMPUPDT = 1), the temperature readout and digital gain compensation vs temperature can be updated through a logic low to logic high transition at this pin. Do not float.

TEMP (Pin 7): Temperature Sensing Diode. This pin is connected to the anode of a diode that may be used to measure the die temperature, by forcing a current and measuring the voltage. This diode is not part of the on-chip thermometer.

BBPI, BBMI (Pins 8, 9): Baseband Inputs of the I-Channel. The input impedance of each input is about 1kΩ. It should be externally biased to a 1.4V common mode level, or AC-coupled. Do not apply common mode voltage beyond $2V_{DC}$.

BBPQ, BBMQ (Pins 10, 11): Baseband Inputs of the Q-Channel. The input impedance of each input is about 1kΩ. It should be externally biased to a 1.4V common mode level, or AC-coupled. Do not apply common mode voltage beyond $2V_{DC}$. Float if Q-channel is disabled.

GNDRF (Pins 13, 14, 15, 17, 18): RF Ground. These pins are connected together internally. For best RF performance all ground pins should be connected to RF ground.

RF (Pin 16): RF Output. The output impedance at RF frequencies is 50Ω. Its DC output voltage is about 1.7V if enabled. An AC-coupling capacitor should be used at this pin with a recommended value of 10nF.

CSB (Pin 19): Serial Port Chip Select. This CMOS input initiates a serial port transaction when driven low, ending the transaction when driven back high. Do not float.

SCLK (Pin 20): Serial Port Clock. This CMOS input clocks serial port input data on its rising edge. Do not float.

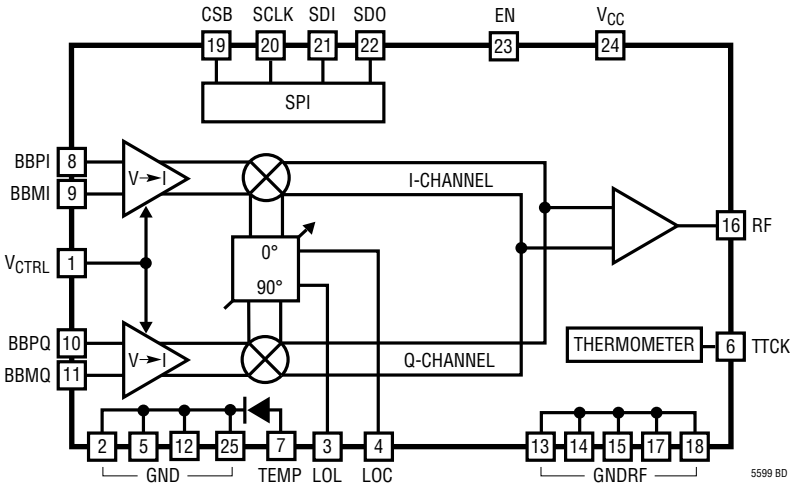
SDI (Pin 21): Serial Port Data Input. The serial port uses this CMOS input for data. Do not float.

SDO (Pin 22): Serial Port Data Output. This NMOS output presents data from the serial port during a read transaction. Connect this pin to the digital supply voltage through a pull-up resistor of sufficiently large value, to ensure that the current does not exceed 10mA when pulled low.

EN (Pin 23): Enable Pin. The chip is completely turned on when a logic high voltage is applied to this pin, and completely turned off for a logic low voltage. Do not float.

V_{CC} (Pin 24): Power Supply. It is recommended to use 1nF and 4.7µF capacitors for decoupling to ground on this pin.

BLOCK DIAGRAM



APPLICATIONS INFORMATION

The LTC5599 consists of I and Q input differential voltage-to-current converters, I and Q upconverting mixers, an RF output buffer and an LO quadrature phase generator. An SPI bus addresses nine control registers, enabling optimization of side-band suppression, LO leakage, and adjustment of the modulator gain. See Table 1 for a summary of the writable registers and their default values. A full map of all the registers in the LTC5599 is listed in Table 10 and Table 11 in the Appendix.

Table 1. SPI Writable Registers and Default Register Values.

ADDRESS	DEFAULT VALUE	SETTING	REGISTER FUNCTION
0x00	0x2E	490MHz	LO Frequency Tuning
0x01	0x84	DG = –4	Gain
0x02	0x80	0mV	Offset I-Channel
0x03	0x80	0mV	Offset Q-Channel
0x04	0x80	0dB	I/Q Gain Ratio
0x05	0x10	0°	I/Q Phase Balance
0x06	0x50	OFF	LO Port Matching Override
0x07	0x06	OFF	Temperature Correction Override
0x08	0x00	NORMAL	Operating Mode

Without using the SPI the registers will use the default values which may not result in the optimum side-band suppression (SB). For example: for LO frequency from about 400MHz to about 580MHz, the SB is about –45dBc; from 380MHz to 400MHz and 580MHz to 630MHz it falls to about –40dBc; from 350MHz to 380MHz and 630MHz to 690MHz the SB falls to about –35dBc.

Aside of powering up the LTC5599, the register values can be reset to the default values by setting SRESET = 1 (bit 3, register 0x08). After about 50ns SRESET is automatically set back to 0.

External I and Q baseband signals are applied to the differential baseband input pins: BBPI, BBMI and BBPQ, BBMQ. These voltage signals are converted to currents and translated to RF frequency by means of double-balanced upconverting mixers. The mixer outputs are combined at the inputs of the RF output buffer, which also transforms the output impedance to 50Ω. The center frequency of the resulting RF signal is equal to the LO signal frequency. The LO inputs drive a phase shifter which splits the LO signal into in-phase and quadrature signals which drive the upconverting mixers. In most applications, the LOL input is driven by the LO source via a 39nH inductor, while the LOC input is driven by the LO source via a 15pF capacitor. This inductor and capacitor form a diplexer circuit tuned to 200MHz. The RF output is single-ended and internally 50Ω matched across a wide RF frequency range from 0.6MHz to 6GHz with better than 10dB return loss using C4 = 10nF. See Figure 13.

Baseband Interface

The baseband inputs (BBPI, BBMI, BBPQ, BBMQ) present a differential input impedance of about 1.8kΩ, as depicted in Figure 1. The baseband bandwidth depends on the source impedance and the frequency setting (register 0x00). It is recommended to compensate the baseband input impedance in the baseband lowpass filter design in order to achieve best gain flatness vs baseband frequency. The S-parameters for (each of) the baseband inputs are given in Table 2 for various LO frequency and gain settings.

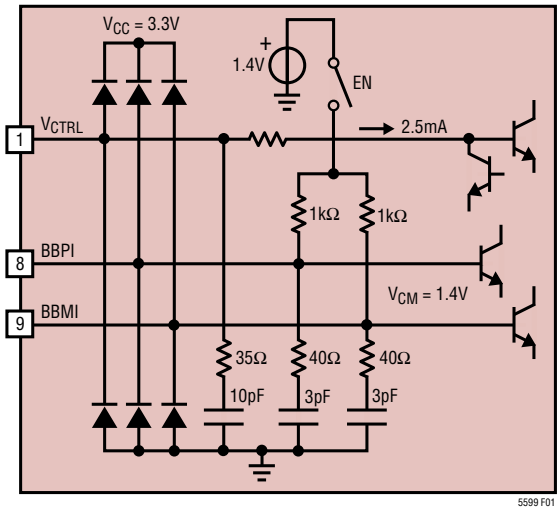


Figure 1. Simplified Circuit Schematic of the Base Band Input Interface (Only One Channel Is Shown).

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Table 2. Differential Baseband (BB) Input Impedance vs Frequency for EN = High and V_{CMBB} = 1.4V

BB FREQUENCY (MHz)	INPUT IMPEDANCE (Ω)		REFL COEFFICIENT	
	REAL*	IMAG* (CAP)	MAG	ANGLE
LO FREQUENCY = 92MHz (REGISTER 0x00 = 0x79), DIGITAL GAIN = –4dB				
1	1.90k	–7.17k (22.2pF)	0.900	–1.6
4	1.76k	–1.82k (21.9pF)	0.893	–6.3
10	1.25k	–751 (21.2pF)	0.854	–15
20	678	–429 (18.6pF)	0.755	–27
40	342	–308 (12.9pF)	0.585	–39
LO FREQUENCY = 150MHz (REGISTER 0x00 = 0x62), DIGITAL GAIN = –4dB				
1	1.90k	–9.11k (17.5pF)	0.900	–1.3
4	1.82k	–2.30k (17.3pF)	0.896	–5.0
10	1.45k	–935 (17.0pF)	0.872	–12
20	887	–507 (15.7pF)	0.804	–23
40	441	–325 (12.2pF)	0.658	–36
100	226	–252 (6.3pF)	0.457	–51
LO FREQUENCY = 500MHz (REGISTER 0x00 = 0x2D), DIGITAL GAIN = –4dB				
1	1.91k	–14.7k (10.6pF)	0.900	–0.8
4	1.89k	–3.74k (10.7pF)	0.899	–3.0
10	1.72k	–1.50k (10.7pF)	0.891	–7.7
20	1.35k	–769 (10.4pF)	0.864	–15
40	786	–426 (9.4pF)	0.785	–27
100	323	–251 (6.4pF)	0.583	–47
200	212	–190 (4.2pF)	0.478	–65
LO FREQUENCY = 500MHz (REGISTER 0x00 = 0x2D), DIGITAL GAIN = 0dB				
1	1.56k	–15.0k (10.6pF)	0.879	–0.8
4	1.56k	–3.84k (10.4pF)	0.880	–3.0
10	1.48k	–1.52k (10.4pF)	0.874	–7.5
20	1.21k	–784 (10.2pF)	0.849	–15
40	753	–432 (9.2pF)	0.776	–27
100	323	–251 (6.3pF)	0.582	–47
200	213	–190 (4.2pF)	0.478	–65
LO FREQUENCY = 900MHz (REGISTER 0x00 = 0x12), DIGITAL GAIN = –4dB				
1	1.91k	–17.0k (9.4pF)	0.901	–0.7
2	1.90k	–4.3k (9.3pF)	0.900	–2.7
10	1.77k	–1.72k (9.3pF)	0.893	–6.7
20	1.46k	–878 (9.1pF)	0.873	–13
40	915	–475 (8.4pF)	0.811	–24
100	371	–261 (6.1pF)	0.622	–45
200	233	–193 (4.1pF)	0.506	–62

Table 2. Differential Baseband (BB) Input Impedance vs Frequency for EN = High and V_{CMBB} = 1.4V (continued)

BB FREQUENCY (MHz)	INPUT IMPEDANCE (Ω)		REFL COEFFICIENT	
	REAL*	IMAG* (CAP)	MAG	ANGLE
EN = Low (Chip Disabled, REGISTER 0X00 = 0x2E)				
1	2.04k	–18.2k (8.8pF)	0.906	–0.6
2	2.02k	–4.59k (8.7pF)	0.906	–2.5
10	1.91k	–1.84k (8.7pF)	0.901	–6.3
20	1.59k	–935 (8.5pF)	0.893	–12
40	1.01k	–502 (7.9pF)	0.826	–23
100	402	–269 (5.9pF)	0.644	–43
200	246	–197 (4.0pF)	0.522	–60

*Parallel Equivalent

The circuit is optimized for a common mode voltage of 1.4V which can be internally or externally applied. In case of AC-coupling to the baseband pins (1.4V internally generated bias) make sure that the high pass filter corner is not affecting the low frequency components of the baseband signal. Even a small error for low baseband frequencies can result in degraded EVM.

The baseband input offset voltage depends on the source resistance. In case of AC-coupling the 1 sigma offset is about 1.1mV, resulting in about –46.6dBm LO leakage. For shorted baseband pins (0Ω source resistance), the LO leakage improves to about –50.1dBm. In case of AC-coupling the LO leakage can be reduced by connecting a resistor in parallel with the baseband inputs, thus lowering baseband input impedance and offset. Further, the low combined baseband input leakage current of 1.3nA in shutdown mode retains the voltage over the coupling capacitors, which helps to settle faster when the part is enabled again. It is recommended to drive the baseband inputs differentially to improve the linearity. When a DAC is used as the signal source, a reconstruction filter should be placed between the DAC output and the LTC5599 baseband inputs to avoid aliasing.

Internal Gain Trim DACs

Four internal gain trim DACs (one for each baseband pin) are configured as 11-bit each. The usable DAC input value range is integer continuous from 64 to 2047 and 0 for shutdown. The DACs are not intended for baseband signal

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generation but for gain and offset setting only, because there are no reconstruction filters between the DACs and the mixer core, and there is only indirect access between the DAC values and the register settings. The following functions are implemented in this way:

- Coarse digital gain control with 1dB steps
- Fine digital gain control with 0.1dB steps
- Gain-temperature correction
- DC offset adjustment in the I-channel
- DC offset adjustment in the Q-channel
- I/Q gain balance control
- Disable Q-channel
- Continuous variable gain control

Coarse Digital Gain Control (DG) with 1dB Steps (Register 0x01)

Twenty digital gain positions 1dB apart are implemented by hardwiring a corresponding DAC code for all four DACs. The coarse digital gain is set by writing to the five least-significant bits in register 0x01, see Table 10 and 11. The gain is the highest for code 00000 (code 0 = 0dB, DG = 0) and the lowest for code 10011 (code 19 = –19dB, DG = –19). Note that the gain 0dB set by the digital gain control is not the same as the voltage gain of the part. The remaining 12 codes (decimal 20 to 31) are reserved.

The digital gain in dB equals minus the decimal value written into the 5 least-significant bits of the gain register. The formula relating the modulator gain G(in V/V) relative to the maximum conversion gain therefore equals:

$$G(V/V) = 10^{(DG/20)}$$

Fine Digital Gain Control(FDG) with 0.1dB Steps and Gain-Temperature Correction (Register 0x07)

Sixteen digital gain positions about 0.1dB apart can be set directly using the four least-significant bits in register 0x07 combined with bit 2 = 1 in register 0x08 (TEMPCORR = 1). For coarse digital gain settings code 9 and higher some or more subsequent codes of the fine digital gain positions may be the same due to the limited resolution of the 11-bit DACs. The main purpose of these 0.1dB gain steps is to implement an automatic gain/temperature correction which can be activated by setting TEMPCORR = 1. In that case, the input of the fine digital gain control will be the on-chip thermometer. The on-chip thermometer generates a 4-bit digital code with code 0 corresponding to –30°C and code 15 corresponding to 120°C and 10°C spacing between the codes. The on-chip thermometer output code can be updated continuous (by clearing TEMPUPDT, bit 7 in register 0x01, see Table 10) or can be updated by bringing the external pin TTCK from low to high (and setting TEMPUPTD = 1). In case of continuous update the code will be an asynchronous update whenever the temperature crosses a certain threshold. In some cases it is desired to prevent a gain update to happen in the middle of a data frame. In that case, the gain/temperature update can be synchronized using the TTCK pin for example at the beginning or end of a data frame. The on-chip temperature can be read back by reading register 0x1F (TEMP[3:0]).The decimal value of TEMP[3:0] is given by:

$$TEMP[3:0] = round(T/10) + 3$$

with T the actual on-chip temperature in °C. It's accuracy is about ±10°C. TEMP[3:0] defaults to 7 after an EN low to high transition with TEMPUPDT = 1. Switching from TEMPUPDT = 0 to TEMPTUPDT = 1, TEMP[3:0] indicates the temperature during the last time TTCK went from low to high. Note that the actual on-chip temperature cannot be read if TEMPCORR = 1 or when TEMPUPDT = 1 without toggling TTCK.

Analog Gain Control

The LTC5599 supports analog control of the conversion gain through a voltage applied to V_{CTRL} (pin 1). The gain can be controlled downward from the digital gain setting (DG) programmed in register 0x01. In order to minimize distortion in the RF output signal the AGCTRL bit (bit 6 in register 0x01) should be set to 1. If analog gain control is not used, V_{CTRL} should be connected to V_{CC} and AGCTRL set to 0; this saves about 2.58mA of supply current. The typical usable gain control range is from 0.9V to 3.3V. Setting V_{CTRL} to a voltage lower than V_{CC} with AGCTRL = 0 significantly impairs the linearity of the RF output signal and lowers the V_{CTRL} response time. A simplified schematic is shown in Figure 1.

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I/Q DC Offset Adjustment (Registers 0x02 and 0x03) and LO Leakage

Offsets in the I- and Q-channel translates into LO leakage at the RF port. This offset can either be caused by the I/Q modulator or, in case the baseband connections are DC-coupled, applied externally. Registers 0x02 and 0x03 (I-offset and Q-offset) can be set to cancel this offset and hence lower the LO leakage. To adjust the offset in the I-channel, the BBPI DAC is set to a (slightly) different value than the BBMI DAC, introducing an offset. These 8-bit registers defaults are 128 and represents 0 offset. The register value can be set from 1 to 255. The value 0 represents an unsupported code and should not be used. Since the input referred offset depends on the gain the input offset value (V_{OS}) can be calculated as:

$$V_{OS} = 1260/((3632 \bullet G)/(N_{OS} - 128) - (N_{OS} - 128)/(3632 \bullet G))$$

and $V_{os} = 0$ for $N_{os} = 128$. G represents the gain from Table 3.

Table 3. Coarse Digital Gain (DG) Register Settings.

DG (dB)	G(V/V)	DEC	BINARY	HEX
0	1.000	0	00000	0x00
–1	0.891	1	00001	0x01
–2	0.794	2	00010	0x02
–3	0.708	3	00011	0x03
–4	0.631	4	00100	0x04
–5	0.562	5	00101	0x05
–6	0.501	6	00110	0x06
–7	0.447	7	00111	0x07
–8	0.398	8	01000	0x08
–9	0.355	9	01001	0x09
–10	0.316	10	01010	0x0A
–11	0.282	11	01011	0x0B
–12	0.251	12	01100	0x0C
–13	0.224	13	01101	0x0D
–14	0.200	14	01110	0x0E
–15	0.178	15	01111	0x0F
–16	0.158	16	10000	0x10
–17	0.141	17	10001	0x11
–18	0.126	18	10010	0x12
–19	0.112	19	10011	0x13

A positive offset means that the voltage of the positive input terminal (BBPI or BBPQ) is increased relative to the negative input terminal (BBMI or BBMQ).

I/Q Gain Ratio (Register 0x04) and Side-Band Suppression

The 8-bit I/Q gain ratio register 0x04 controls the ratio of the I-channel mixer conversion gain G_I and the Q-channel mixer conversion gain G_Q. Together with the quadrature phase imbalance register 0x05, register 0x04 allows further optimization of the modulator side-band suppression.

The expression relating the gain ratio G_I/G_Q to the contents of the 8-bit register 0x04, represented by decimal N_{IQ} and the nominal conversion gain G equals:

$$20 \log (G_I/G_Q) = 20 \log ((3632 \bullet G - (N_{IQ} - 128))/(3632 \bullet G + (N_{IQ} - 128))) \text{ (dB)}$$

The step size of the gain ratio trim in dB vs N_{IQ} is approximately constant for the same digital gain setting. For digital gain setting = –4, for example, the step size is about 7.6mdB. Table 4 lists the gain step size for each digital gain setting that follows from the formula above.

Table 4. I/Q Gain Ratio Step Size vs Digital Gain Setting

DG (dB)	G (V/V)	$\Delta G_I/G_Q$ (mdB)
0	1.000	4.8
–1	0.891	5.4
–2	0.794	6.0
–3	0.708	6.8
–4	0.631	7.6
–5	0.562	8.5
–6	0.501	9.6
–7	0.447	10.7
–8	0.398	12.0
–9	0.355	13.5
–10	0.316	15.1
–11	0.282	17.1
–12	0.251	19.2
–13	0.224	21.5
–14	0.200	24.2
–15	0.178	27.3

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Table 4. I/Q Gain Ratio Step Size vs Digital Gain Setting (continued)

DG (dB)	G (V/V)	$\Delta G_I/G_Q$ (mdB)
–16	0.158	30.7
–17	0.141	34.6
–18	0.126	39.0
–19	0.112	44.1

The conversion gain of the I-channel and Q-channel are equal for N_{IQ} = 128. The I-channel gain is larger than the Q-channel gain for N_{IQ} > 128.

Disable Q-Channel

If bit 5 in register 0x01 (QDISABLE) is set, the Q-channel is switched off, turning the I/Q modulator into an upconversion mixer. It is recommended to float the BBPQ and BBMQ pins in this mode. The default mode is Q-channel is on (QDISABLE = 0).

LO Section (Register 0x00)

The internal LO chain consists of a poly-phase filter which generates the I and Q signals for the image-reject double-balanced mixer. The center frequency of the poly-phase filter is set by the lower seven bits of register 0x00. The recommended settings vs LO frequency are given in Table 5 (see the QuikEval™ GUI).

Table 5. Register 0x00 Setting vs LO Frequency

REGISTER VALUE			LO FREQUENCY RANGE (MHz)	
DECIMAL	BINARY	HEX	LOWER BOUND	UPPER BOUND
0	0000000	00	N/A	N/A
1	0000001	01	1249.1	1300.0
2	0000010	02	1248.6	1249.0
3	0000011	03	1238.1	1248.5
4	0000100	04	1214.1	1238.0
5	0000101	05	1191.2	1214.0
6	0000110	06	1165.6	1191.1
7	0000111	07	1141.0	1165.5
8	0001000	08	1120.6	1140.9
9	0001001	09	1100.5	1120.5
10	0001010	0A	1069.5	1100.4
11	0001011	0B	1039.6	1069.4
12	0001100	0C	1023.1	1039.5
13	0001101	0D	1007.1	1023.0
14	0001110	0E	988.3	1007.0

Table 5. Register 0x00 Setting vs LO Frequency (continued)

REGISTER VALUE			LO FREQUENCY RANGE (MHz)	
DECIMAL	BINARY	HEX	LOWER BOUND	UPPER BOUND
15	0001111	0F	961.8	988.2
16	0010000	10	941.3	961.7
17	0010001	11	921.5	941.2
18	0010010	12	895.2	921.4
19	0010011	13	877.6	895.1
20	0010100	14	863.6	877.5
21	0010101	15	843.2	863.5
22	0010110	16	826.9	843.1
23	0010111	17	807.0	826.8
24	0011000	18	792.3	806.9
25	0011001	19	772.2	792.2
26	0011010	1A	752.7	772.1
27	0011011	1B	734.0	752.6
28	0011100	1C	724.2	739.9
29	0011101	1D	704.6	724.1
30	0011110	1E	688.7	704.5
31	0011111	1F	673.2	688.6
32	0100000	20	655.2	673.1
33	0100001	21	638.1	655.1
34	0100010	22	624.6	638.0
35	0100011	23	611.9	624.5
36	0100100	24	598.4	611.8
37	0100101	25	585.1	598.3
38	0100110	26	573.9	585.0
39	0100111	27	563.1	573.8
40	0101000	28	548.1	563.0
41	0101001	29	538.1	548.0
42	0101010	2A	529.1	538.0
43	0101011	2B	518.5	529.0
44	0101100	2C	507.0	518.4
45	0101101	2D	497.7	506.9
46	0101110	2E	488.0	497.6
47	0101111	2F	471.5	487.9
48	0110000	30	457.7	471.4
49	0110001	31	448.7	457.6
50	0110010	32	437.4	448.6
51	0110011	33	426.6	437.3
52	0110100	34	417.5	426.5
53	0110101	35	407.5	417.4
54	0110110	36	398.0	407.4

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Table 5. Register 0x00 Setting vs LO Frequency (continued)

REGISTER VALUE			LO FREQUENCY RANGE (MHz)	
DECIMAL	BINARY	HEX	LOWER BOUND	UPPER BOUND
55	0110111	37	390.1	397.9
56	0111000	38	382.8	390.0
57	0111001	39	376.6	382.7
58	0111010	3A	369.8	376.5
59	0111011	3B	353.1	369.7
60	0111100	3C	339.0	353.0
61	0111101	3D	332.6	338.9
62	0111110	3E	327.2	332.5
63	0111111	3F	320.6	327.1
64	1000000	40	313.7	320.5
65	1000001	41	309.1	313.6
66	1000010	42	304.5	309.0
67	1000011	43	288.1	304.4
68	1000100	44	278.3	288.0
69	1000101	45	274.2	278.2
70	1000110	46	270.3	274.1
71	1000111	47	266.0	270.2
72	1001000	48	261.9	265.9
73	1001001	49	258.2	261.8
74	1001010	4A	254.1	258.1
75	1001011	4B	243.6	254.0
76	1001100	4C	233.8	243.5
77	1001101	4D	230.8	233.7
78	1001110	4E	228.0	230.7
79	1001111	4F	220.2	227.9
80	1010000	50	212.6	220.1
81	1010001	51	210.0	212.5
82	1010010	52	207.6	209.9
83	1010011	53	202.1	207.5
84	1010100	54	196.2	202.0
85	1010101	55	193.7	196.1
86	1010110	56	191.2	193.6
87	1010111	57	186.6	191.1
88	1011000	58	182.0	186.5
89	1011001	59	179.4	181.9
90	1011010	5A	176.0	179.3
91	1011011	5B	170.1	175.9
92	1011100	5C	165.0	170.0
93	1011101	5D	162.5	164.9
94	1011110	5E	160.0	162.4
95	1011111	5F	156.7	159.9

Table 5. Register 0x00 Setting vs LO Frequency (continued)

REGISTER VALUE			LO FREQUENCY RANGE (MHz)	
DECIMAL	BINARY	HEX	LOWER BOUND	UPPER BOUND
96	1100000	60	153.6	156.6
97	1100001	61	151.1	153.5
98	1100010	62	148.6	151.0
99	1100011	63	142.5	148.5
100	1100100	64	139.6	142.4
101	1100101	65	136.5	139.5
102	1100110	66	134.3	136.4
103	1100111	67	131.2	134.2
104	1101000	68	128.1	131.1
105	1101001	69	126.0	128.0
106	1101010	6A	123.8	125.9
107	1101011	6B	121.3	123.7
108	1101100	6C	118.3	121.2
109	1101101	6D	115.7	118.2
110	1101110	6E	113.5	115.6
111	1101111	6F	111.3	113.4
112	1110000	70	109.5	111.2
113	1110001	71	107.6	109.4
114	1110010	72	105.6	107.5
115	1110011	73	103.0	105.5
116	1110100	74	100.3	102.9
117	1110101	75	98.5	100.2
118	1110110	76	96.6	98.4
119	1110111	77	94.7	96.5
120	1111000	78	93.0	94.6
121	1111001	79	30.0	92.9
122	1111010	7A	N/A	N/A
123	1111011	7B	N/A	N/A
124	1111100	7C	N/A	N/A
125	1111101	7D	N/A	N/A
126	1111110	7E	N/A	N/A
127	1111111	7F	N/A	N/A

A simplified circuit schematic of the LOL and LOC interfaces is depicted in Figure 2. The LOL and LOC inputs are not differential LO inputs. They are 50Ω inputs and are intended to be driven with an inductor going to the LOL input and a capacitor to the LOC input. Do not switch the capacitor and inductor, as this will result in very poor performance. For a wideband LO range an inductor value of 39nH and a capacitor value of 15pF (standard LO match)

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is recommended at these pins, forming a diplexer circuit with center frequency of 200MHz. This diplexer helps to improve the uncalibrated side-band suppression significantly around 200MHz. Even for LO frequencies far from 200MHz the diplexer performs better than a single-ended LO drive or a differential drive. Due to factory calibration of the poly-phase filter the typical side-band suppression is about 50dBc for frequencies from 100MHz to 700MHz and 45dBc from 700MHz to 1300MHz. For narrow-band applications far from 200MHz it may help to tune the diplexer to a different frequency which can improve the uncalibrated side-band suppression and the gain vs LO drive level. The Typical Performance Characteristics section shows the return loss for a 900MHz match (L1 = 8.2nH, C5 = 3.3pF) and a 1260MHz match (L1 = 5.6nH, C5 = 3pF). To get a performance with the standard 200MHz match equivalent to the 900MHz and 1260MHz match, the LO power should be increased by 1.5dB and 2dB respectively. Register 0x00 values of Table 5 may have to be adjusted as well, in case the standard match is not used.

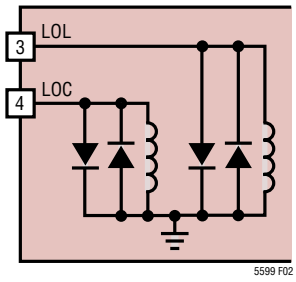

Figure 2. Simplified Circuit Schematic for the LOL and LOC Inputs

Below 100MHz the matching network of Figure 3 can be used.The side-band suppression in that case is largely defined by the diplexer L1, C5 and the (temperature dependent) LOL and LOC input impedance. See measured performance in the Typical Performance Characteristics section.

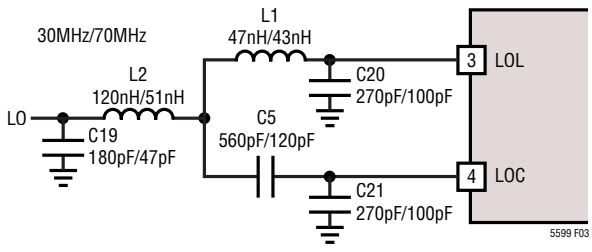

Figure 3. Impedance Matching Network for LOL and LOC Interfaces Matched at 30MHz/70MHz

Table 6 lists LOL and LOC port input impedance vs frequency at EN = High and P_{LO} = 0dBm. The other LO port (LOC or LOL) is terminated in a 50Ω.

Table 6. LOL, LOC Port Input Impedance vs Frequency for EN = High and P_{LO} = 0dBm (Other LO Port Terminated with 50Ω to Ground)

FREQ (MHz)	REG 0x00	LOL/LOC PORT IMPEDANCE (Ω)		REFL COEFFICIENT	
		REAL*	IMAG* (IND)	MAG	ANGLE
20	79	7.9	24.3 (194nH)	0.750	175
30	79	9.1	19.0 (101nH)	0.743	172
40	79	10.8	17.4 (69nH)	0.732	169
50	79	13.0	17.6 (56nH)	0.716	165
60	79	15.7	18.9 (50nH)	0.693	162
70	79	18.6	21.4 (49nH))	0.661	158
80	79	21.6	25.0 (50nH)	0.618	154
90	79	24.4	30.3 (54nH)	0.564	151
100	75	27.0	38.3 (61nH))	0.497	148
110	70	29.0	51.4 (74nH)	0.419	146
120	6C	30.3	76.1 (101nH)	0.338	149
130	68	32.3	109.3 (134nH)	0.276	150
140	64	34.3	121.6 (138nH)	0.247	148
150	62	36.2	119.4 (127nH)	0.234	142
160	5E	37.4	149.1 (148nH))	0.201	143
170	5C	37.1	357.5 (335nH)	0.160	162
180	59	39.6	188.6 (167nH)	0.164	141
190	57	41.4	192.0 (161nH))	0.150	135
200	54	40.7	418.6 (333nH)	0.116	156

*Parallel Equivalent

The circuit schematic of the demo board is shown in Figure 13.

I/Q Phase Balance Adjustment Register 0x05 and Side-Band Suppression

Ideally the I-channel LO phase is exactly 90° ahead of the Q-channel LO phase, so called quadrature. In practice however, the I/Q phase difference differs from exact quadrature by a small error due to component parameter variations and harmonic content in the LO signal (see below).

The I/Q phase imbalance register (0x05) allows adjustment of the I/Q phase shift to compensate for such errors. Together with gain ratio register 0x04, it can thus be used to optimize the side-band suppression of the modulator.