300-MHz to 4-GHz Quadrature Modulator

Check for Samples: TRF37T05

FEATURES

- **High Linearity:**
  - **Output IP3: 30 dBm at 1850 MHz**
- **Low Output Noise Floor: –160 dBm/Hz**
- **78-dBc Single-Carrier WCDMA ACPR at –10-dBm Channel Power**
- **Unadjusted Carrier Suppression: –40 dBm**
- **Unadjusted Sideband Suppression: –45 dBc**
- **Single Supply: 3.3-V Operation**
- **1-bit Gain Step Control**
- **Fast Power-Up/Power-Down**

APPLICATIONS

- **Cellular Base Station Transmitter**
- **CDMA: IS95, UMTS, CDMA2000, TD-SCDMA**
- **LTE (Long Term Evolution), TD-LTE**
- **TDMA: GSM, EDGE/UWC-136**
- **Multicarrier GSM (MC-GSM)**
- **Wireless MAN Wideband Transceivers**

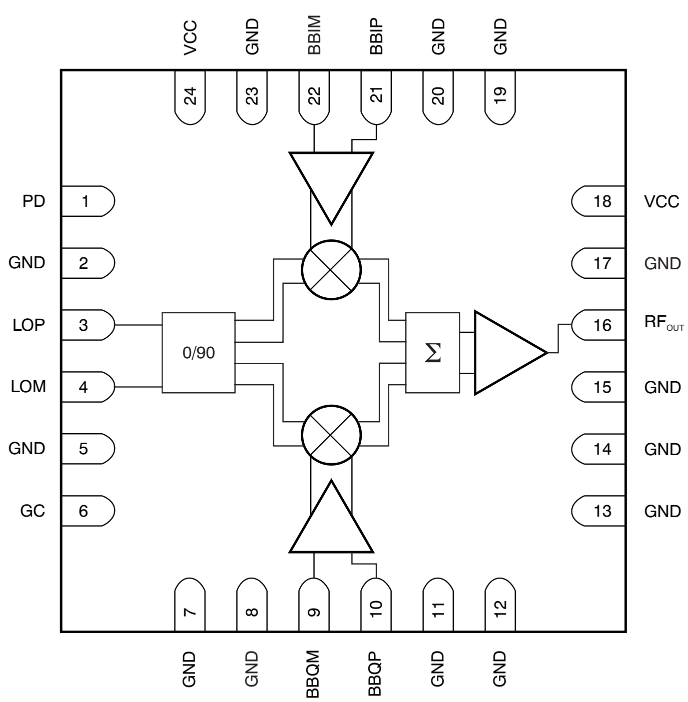
DESCRIPTION

The TRF37T05 is a low-noise direct quadrature modulator with exceptional TDD performance. It is capable of converting complex modulated signals from baseband or IF directly up to RF. The TRF37T05 is a high-performance, superior-linearity device that is ideal to up-convert to RF frequencies of 300 MHz (1) through 4 GHz. The modulator is implemented as a double-balanced mixer.

The RF output block consists of a differential-to-single-ended converter that is capable of driving a single-ended 50-Ω load. The TRF37T05 requires a 0.25-V common-mode voltage for optimum linearity performance. The TRF37T05 also provides a fast power-down pin that can be used to reduce power dissipation while maintaining optimized adjusted carrier feed-through performance in TDD applications.

The TRF37T05 is available in an RGE-24 VQFN package.

(1) Appropriate matching network is required for optimal performance at 300 MHz.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the device product folder at www.ti.com

ABSOLUTE MAXIMUM RATINGS(1)

Over operating free-air temperature range (unless otherwise noted).

		MIN	MAX	UNIT
Supply voltage range(2)		–0.3	6	V
Digital I/O voltage range		–0.3	V_{CC} +0.5	V
Operating virtual junction temperature range, T_J		–40	150	°C
Operating ambient temperature range, T_A		–40	85	°C
Storage temperature range, T_{stg}		–65	150	°C
ESD ratings	Human body model, HBM		4000	V
	Charged device model, CDM		250	V
	Machine model, MM		200	V

(1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to network ground terminal.

RECOMMENDED OPERATING CONDITIONS

Over operating free-air temperature range (unless otherwise noted).

		MIN	NOM	MAX	UNIT
V_{CC}	Power-supply voltage	3.15	3.3	3.6	V

THERMAL INFORMATION

THERMAL METRIC		TRF37T05	UNITS
		RGE (VQFN)	
		24 PINS	
θ_{JA}	Junction-to-ambient thermal resistance	38.4	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	42.5	
θ_{JB}	Junction-to-board thermal resistance	16.6	
ψ_{JT}	Junction-to-top characterization parameter	0.9	
ψ_{JB}	Junction-to-board characterization parameter	16.6	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	6.6	

ELECTRICAL CHARACTERISTICS: GENERAL

Over recommended operating conditions; at power supply = 3.3 V and T_A = 25°C, unless otherwise noted.

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
DC PARAMETERS						
I_{CC}	Total supply current	T_A = 25°C, device on (PD = low)		306		mA
		T_A = 25°C, device off (PD = high)		146		mA
LO INPUT						
f_{LO}	LO low frequency			300		MHz
	LO high frequency			4000		MHz
	LO input power		–10	0	+15	dBm
BASEBAND INPUTS						
V_{CM}	I and Q input dc common-mode voltage			0.25	0.5	V
BW	1-dB input frequency bandwidth			1000		MHz
Z_I	Input impedance	Resistance		8		kΩ
		Parallel capacitance		4.6		pF
POWER ON/OFF						
	Turn on time	PD = low to 90% final output power		0.2		μs
	Turn off time	PD = high to initial output power –30 dB		0.2		μs
DIGITAL INTERFACE						
V_{IH}	PD high-level input voltage		2			V
V_{IL}	PD low-level input voltage				0.8	V

ELECTRICAL CHARACTERISTICS

Over recommended operating conditions; at power supply = 3.3 V, T_A = 25°C, V_{CM} = 0.25 V; LO Power = 0 dBm, single-ended (LOP); GC set low, V_{IN} BB = 1 V_{PP} (diff) in quadrature, and f_{BB} = 5.5 MHz, standard broadband output matching circuit, unless otherwise noted.

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{LO} = 400 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		–4.7		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		–1.9		dB
P_{OUT}	Output power	GC set low		–0.7		dBm
		GC set high		2.1		dBm
P1dB	Output compression point	GC set low		8.5		dBm
		GC set high		9.1		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		26		dBm
		f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		25.4		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		60.2		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		61.9		dBm
SBS	Unadjusted sideband suppression			–57.4		dBc
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–51.6		dBm
		Measured at 2 x LO		–50		dBm
		Measured at 3 x LO		–49		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–166.7		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–67		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–64		dBc
f_{LO} = 750 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		0.2		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		3		dB
P_{OUT}	Output power	GC set low		4.2		dBm
		GC set high		7		dBm
P1dB	Output compression point	GC set low		13.3		dBm
		GC set high		13.9		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		31.5		dBm
		f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		30.8		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		73.6		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		80.5		dBm
SBS	Unadjusted sideband suppression			–45.2		dBc
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–45.7		dBm
		Measured at 2 x LO		–46		dBm
		Measured at 3 x LO		–53.5		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–159.9		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–70		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–66		dBc

ELECTRICAL CHARACTERISTICS (continued)

Over recommended operating conditions; at power supply = 3.3 V, T_A = 25°C, V_{CM} = 0.25 V; LO Power = 0 dBm, single-ended (LOP); GC set low, V_{IN} BB = 1 V_{PP} (diff) in quadrature, and f_{BB} = 5.5 MHz, standard broadband output matching circuit, unless otherwise noted.

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{LO} = 900 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		0.3		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		3.1		dB
P_{OUT}	Output power	GC set low		4.3		dBm
		GC set high		7.1		dBm
P1dB	Output compression point	GC set low		13.2		dBm
		GC set high		13.7		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		31.7		dBm
		f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		30.9		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		71.5		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		75.3		dBm
SBS	Unadjusted sideband suppression			–43.8		dBc
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–48.5		dBm
		Measured at 2 x LO		–53		dBm
		Measured at 3 x LO		–50		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–157.9		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–80		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–65		dBc
f_{LO} = 1840 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		–0.1		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		2.5		dB
P_{OUT}	Output power	GC set low		3.9		dBm
		GC set high		6.5		dBm
P1dB	Output compression point	GC set low		13.2		dBm
		GC set high		13.6		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		32.1		dBm
		f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		30.3		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		60.8		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		62		dBm
SBS	Unadjusted sideband suppression			–43.4		dBc
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–42.4		dBm
		Measured at 2 x LO		–41		dBm
		Measured at 3 x LO		–53		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–158.8		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–69		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–80		dBc

ELECTRICAL CHARACTERISTICS (continued)

Over recommended operating conditions; at power supply = 3.3 V, T_A = 25°C, V_{CM} = 0.25 V; LO Power = 0 dBm, single-ended (LOP); GC set low, V_{IN} BB = 1 V_{PP} (diff) in quadrature, and f_{BB} = 5.5 MHz, standard broadband output matching circuit, unless otherwise noted.

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{LO} = 2140 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		0.1		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		2.9		dB
P_{OUT}	Output power	GC set low		4.1		dBm
		GC set high		6.9		dBm
P1dB	Output compression point	GC set low		13.1		dBm
		GC set high		13.5		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		28.6		dBm
		f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		27.6		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		65.5		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		68.2		dBm
SBS	Unadjusted sideband suppression			–45.6		dBc
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–39.3		dBm
		Measured at 2 x LO		–37		dBm
		Measured at 3 x LO		–46		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–160.0		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–61		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–60		dBc
f_{LO} = 2600 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		–0.8		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		2		dB
P_{OUT}	Output power	GC set low		3.2		dBm
		GC set high		5.6		dBm
P1dB	Output compression point	GC set low		12.5		dBm
		GC set high		12.8		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		28		dBm
		Ff_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		27.2		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		67.9		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		66.4		dBm
SBS	Unadjusted sideband suppression			–52.9		dBm
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–37.8		dBm
		Measured at 2 x LO		–41		dBm
		Measured at 3 x LO		–42		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–160.6		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–67		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–59		dBc

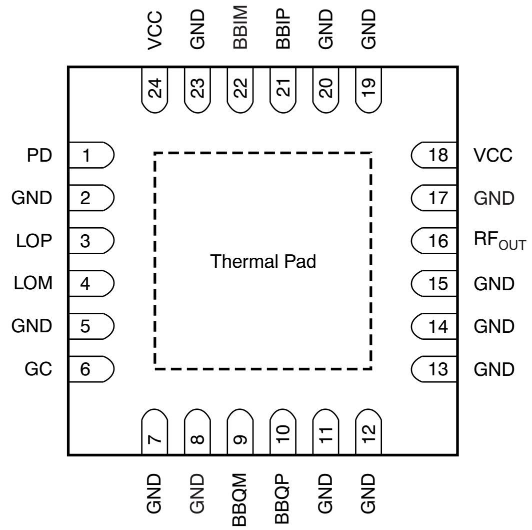
ELECTRICAL CHARACTERISTICS (continued)

Over recommended operating conditions; at power supply = 3.3 V, T_A = 25°C, V_{CM} = 0.25 V; LO Power = 0 dBm, single-ended (LOP); GC set low, V_{IN} BB = 1 V_{PP} (diff) in quadrature, and f_{BB} = 5.5 MHz, standard broadband output matching circuit, unless otherwise noted.

PARAMETERS		TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{LO} = 3500 MHz						
G	Voltage gain	Output RMS voltage over input I (or Q) RMS voltage, GC set low		–1		dB
		Output RMS voltage over input I (or Q) RMS voltage, GC set high		1.8		dB
P_{OUT}	Output power	GC set low		3		dBm
		GC set high		5.8		dBm
P1dB	Output compression point	GC set low		12.1		dBm
		GC set high		12.3		dBm
IP3	Output IP3	f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set low		23.8		dBm
		f_{BB1} = 4.5 MHz; f_{BB2} = 5.5 MHz; GC set high		25.3		dBm
IP2	Output IP2	Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set low		47.8		dBm
		Measured at f_{LO} + (f_{BB1}± f_{BB2}), GC set high		48.6		dBm
SBS	Unadjusted sideband suppression			–45.2		dBm
CF	Unadjusted carrier feedthrough	Measured at LO frequency		–31.6		dBm
		Measured at 2 x LO		–30		dBm
		Measured at 3 x LO		–53		dBm
	Output noise floor	DC only to BB inputs; 10-MHz offset from LO		–160.6		dBm/Hz
$HD2_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(2 x f_{BB})		–54		dBc
$HD3_{BB}$	Baseband harmonics	Measured with ±1-MHz tone at 0.5 V_{PP} each at f_{LO} ±(3 x f_{BB})		–50		dBc

DEVICE INFORMATION

**RGE PACKAGE
VQFN-24
(TOP VIEW)**



PIN FUNCTIONS

PIN		I/O	DESCRIPTION
NO.	NAME		
1	PD	I	Power-down digital input (high = device off)
2	GND	I	Ground
3	LOP	I	Local oscillator input
4	LOM	I	Local oscillator input
5	GND	I	Ground
6	GC	I	Gain control digital input (high = high gain)
7	GND	—	Ground or leave unconnected
8	GND	I	Ground
9	BBQM	I	In-quadrature input
10	BBQP	I	In-quadrature input
11	GND	I	Ground
12	GND	I	Ground
13	GND	I	Ground
14	GND	I	Ground
15	GND	I	Ground
16	RF_{OUT}	O	RF output
17	GND	I	Ground
18	VCC	I	Power supply
19	GND	I	Ground
20	GND	I	Ground
21	BBIP	I	In-phase input
22	BBIM	I	In-phase input
23	GND	I	Ground
24	VCC	I	Power supply

TYPICAL CHARACTERISTICS: Single-Tone Baseband

V_{CC} = 3.3 V; T_A = 25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 5.5 MHz; baseband I/Q amplitude = 1-V_{PP} differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

OUTPUT POWER vs LO FREQUENCY (f_{LO}) AND TEMPERATURE

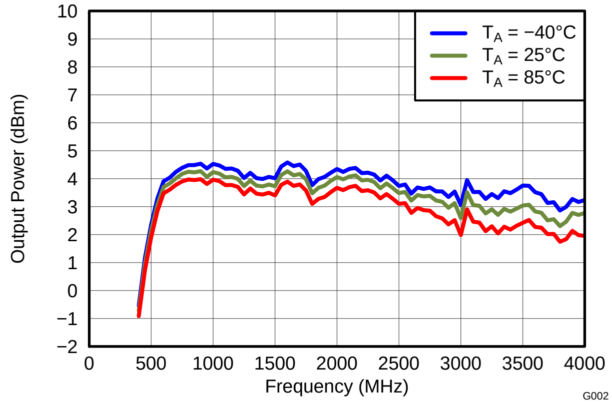


Figure 1.

OUTPUT POWER vs LO FREQUENCY (f_{LO}) AND SUPPLY VOLTAGE

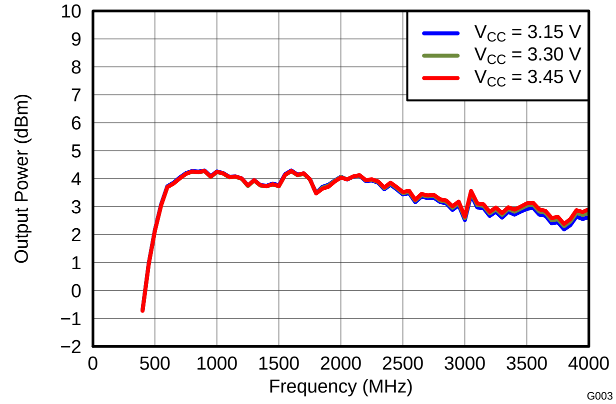


Figure 2.

OUTPUT POWER vs LO FREQUENCY (f_{LO}) OVER LO DRIVE LEVEL

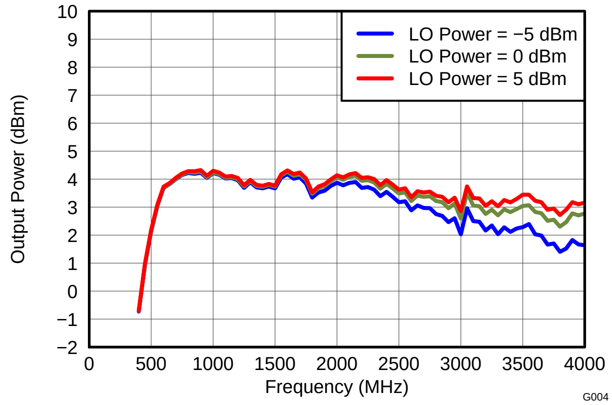


Figure 3.

OUTPUT POWER vs LO FREQUENCY (f_{LO}) AND GAIN SELECT SETTING

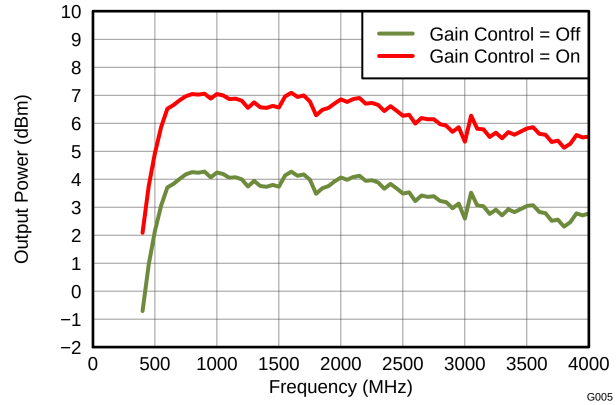


Figure 4.

OUTPUT POWER vs LO FREQUENCY (f_{LO}) AND TEMPERATURE AT V_{CM} = 0.5 V

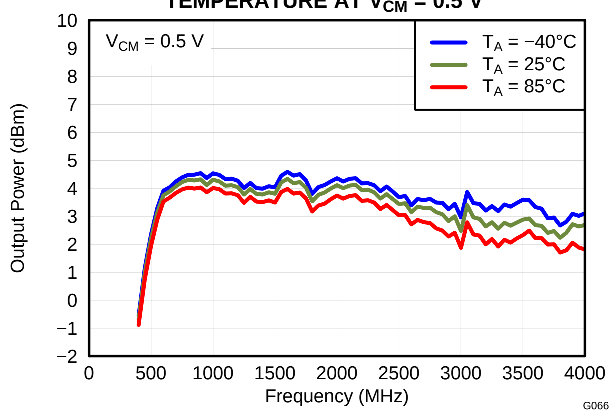


Figure 5.

OUTPUT POWER vs BASEBAND VOLTAGE AT 2140 MHz

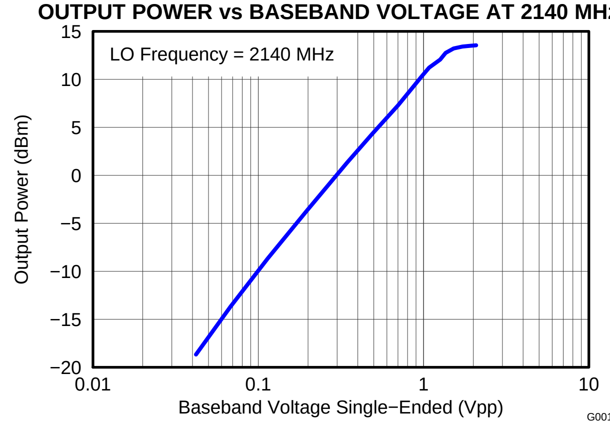


Figure 6.

TYPICAL CHARACTERISTICS: Single-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = 25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 5.5 MHz; baseband I/Q amplitude = 1-V_{PP} differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

P1dB vs LO FREQUENCY (f_{LO}) AND TEMPERATURE

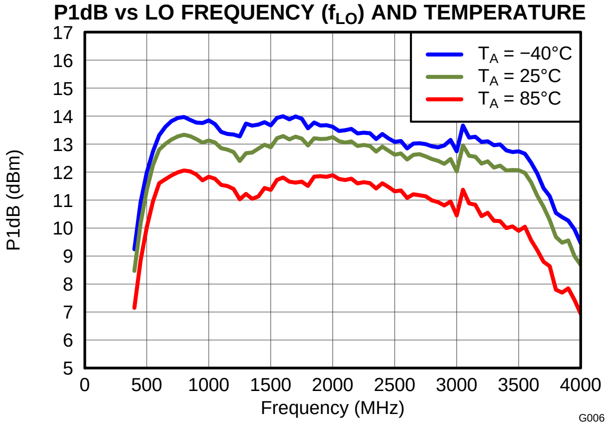


Figure 7.

P1dB vs LO FREQUENCY (f_{LO}) AND SUPPLY VOLTAGE

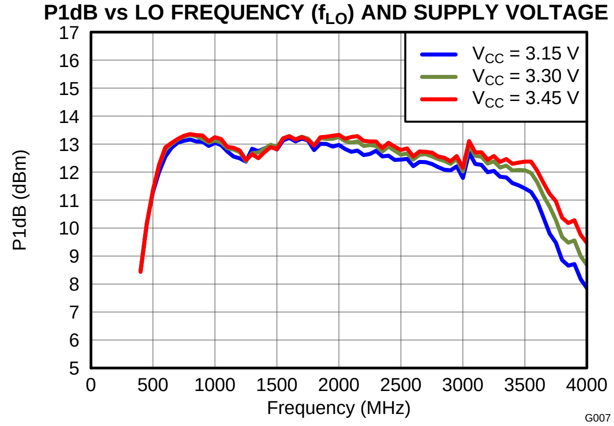


Figure 8.

P1dB vs LO FREQUENCY (f_{LO}) AND LO DRIVE LEVEL

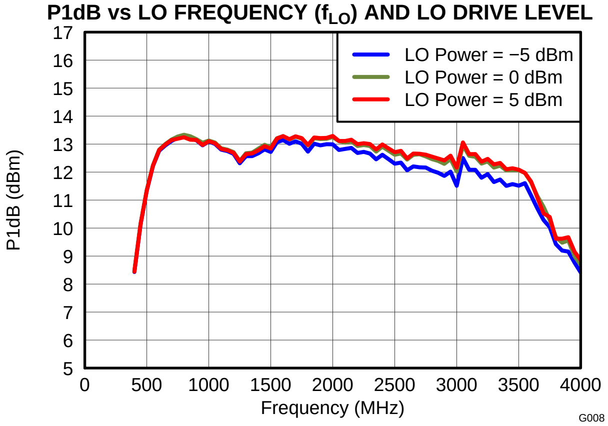


Figure 9.

P1dB vs LO FREQUENCY (f_{LO}) AND GAIN SELECT SETTING

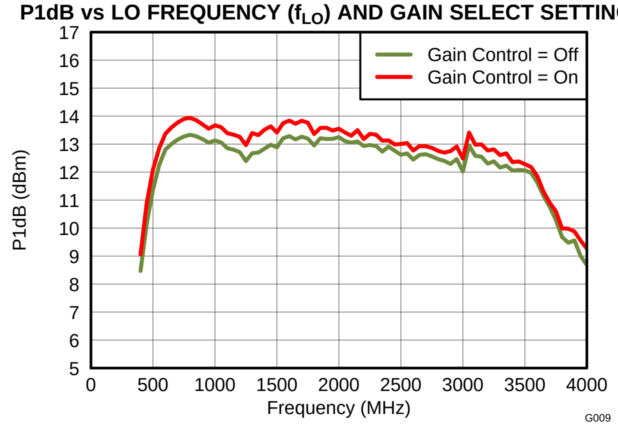


Figure 10.

P1dB vs LO FREQUENCY (f_{LO}) AND TEMPERATURE AT V_{CM} = 0.5 V

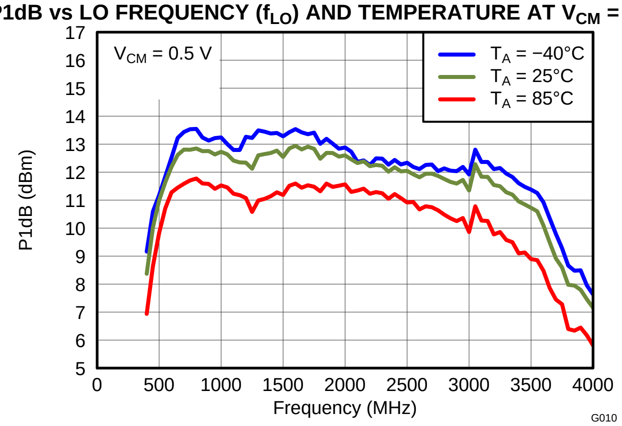


Figure 11.

TYPICAL CHARACTERISTICS: Two-Tone Baseband

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

TYPICAL CHARACTERISTICS: Two-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

OIP3 vs LO FREQUENCY (f_{LO}) AND TEMPERATURE

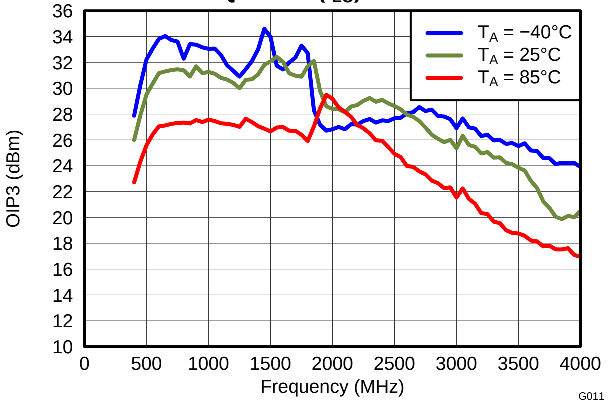


Figure 12.

OIP3 vs LO FREQUENCY (f_{LO}) AND SUPPLY VOLTAGE

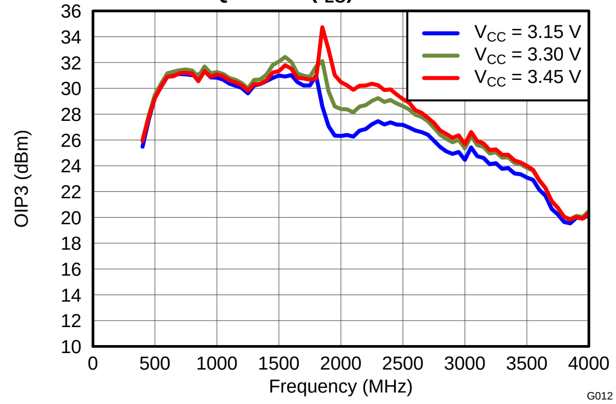


Figure 13.

OIP3 vs LO FREQUENCY (f_{LO}) AND LO DRIVE LEVEL

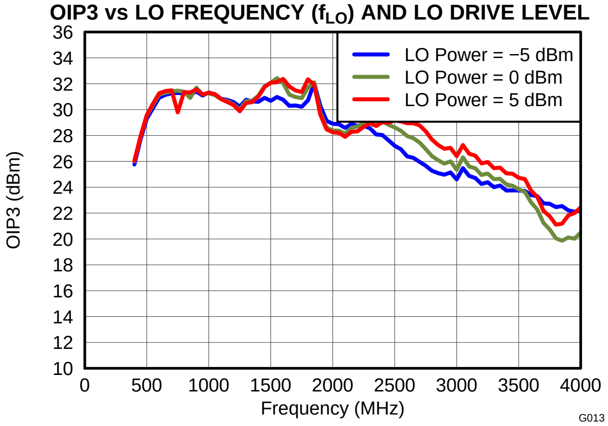


Figure 14.

OIP3 vs LO FREQUENCY (f_{LO}) AND GAIN SELECT SETTING

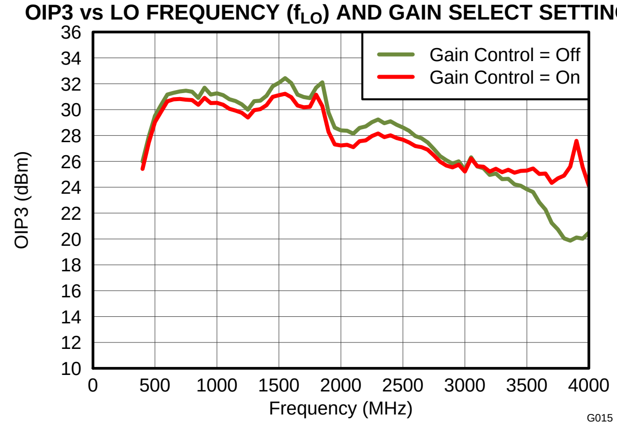


Figure 15.

OIP3 vs LO FREQUENCY (f_{LO}) AND TEMPERATURE AT V_{CM} = 0.5 V

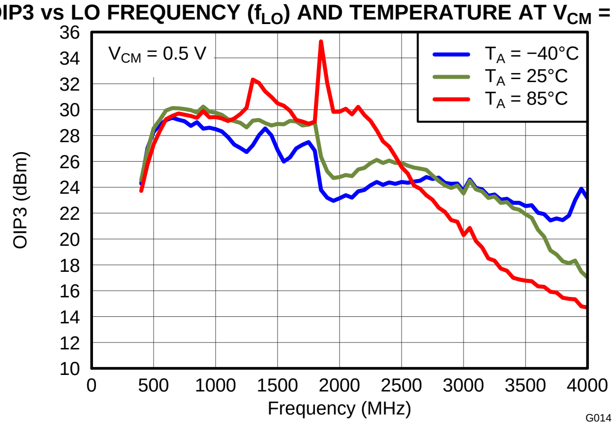


Figure 16.

TYPICAL CHARACTERISTICS: Two-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

OIP2 vs LO FREQUENCY (f_{LO}) AND TEMPERATURE

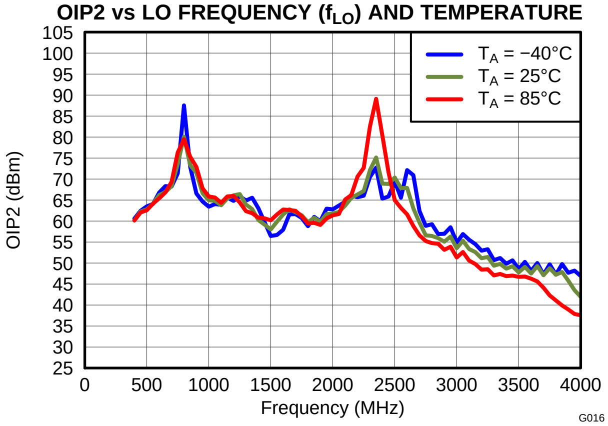


Figure 17.

OIP2 vs LO FREQUENCY (f_{LO}) AND SUPPLY VOLTAGE

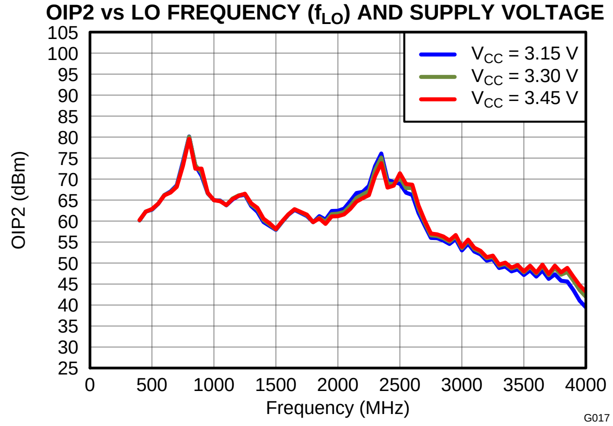


Figure 18.

OIP2 vs LO FREQUENCY (f_{LO}) AND LO DRIVE LEVEL

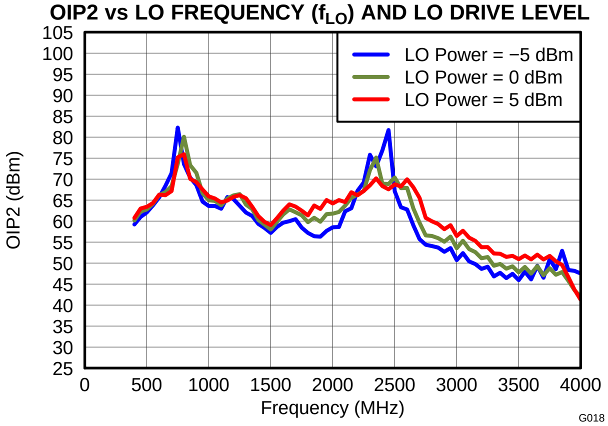


Figure 19.

OIP2 vs LO FREQUENCY (f_{LO}) AND GAIN SELECT SETTING

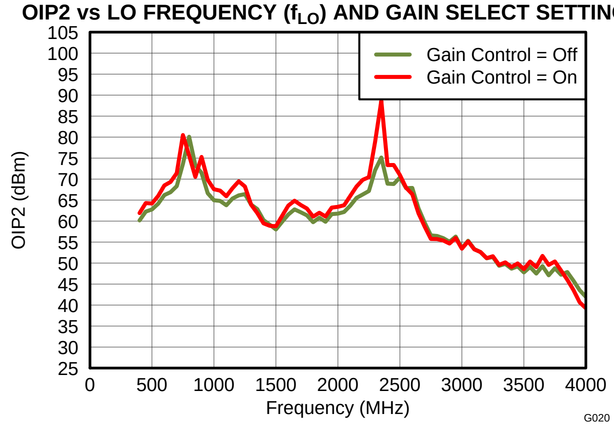


Figure 20.

OIP2 vs LO FREQUENCY (f_{LO}) AND TEMPERATURE AT V_{CM} = 0.5 V

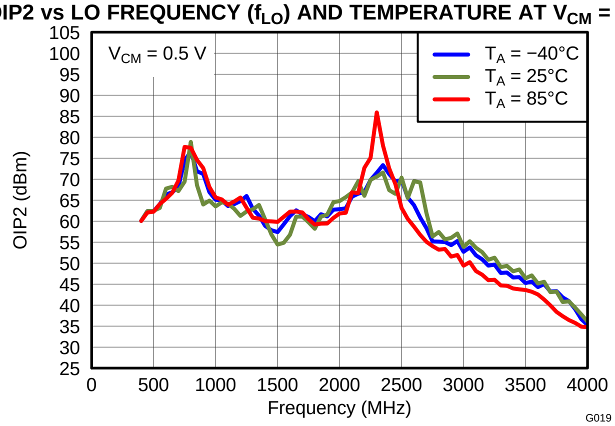


Figure 21.

TYPICAL CHARACTERISTICS: Two-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

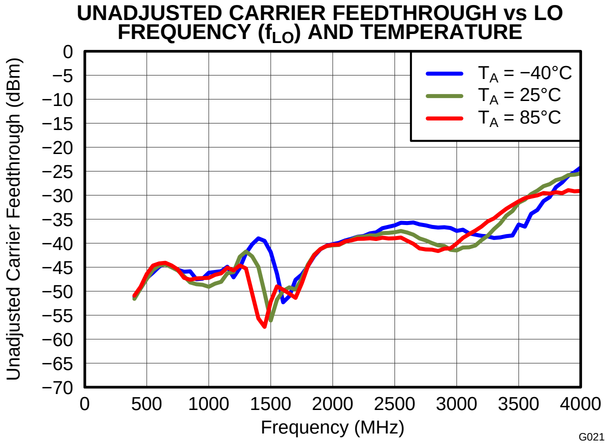


Figure 22.

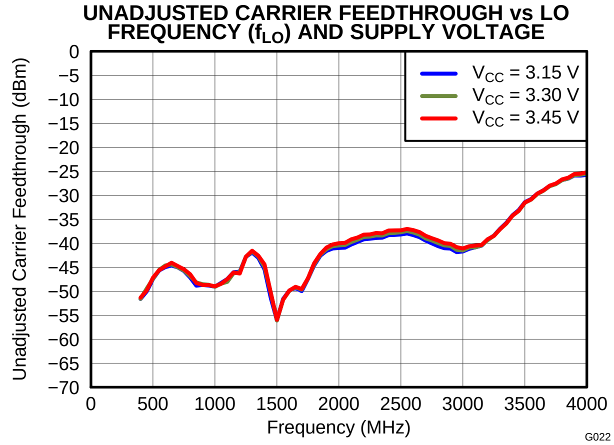


Figure 23.

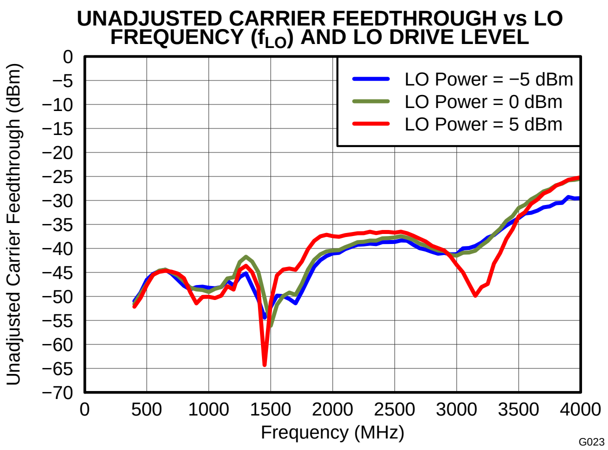


Figure 24.

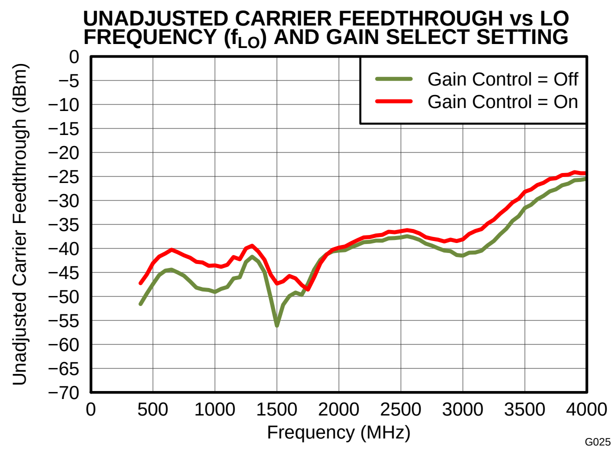


Figure 25.

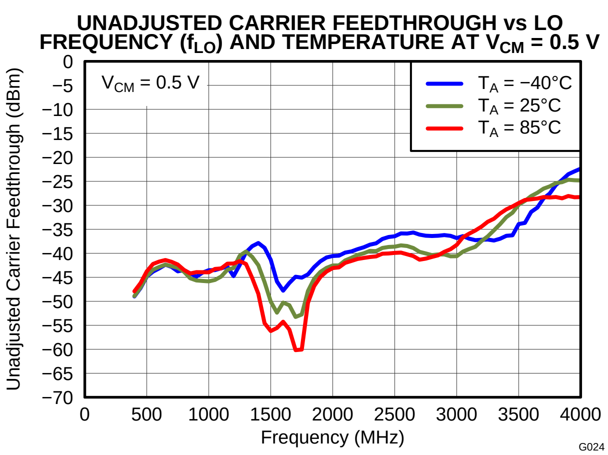


Figure 26.

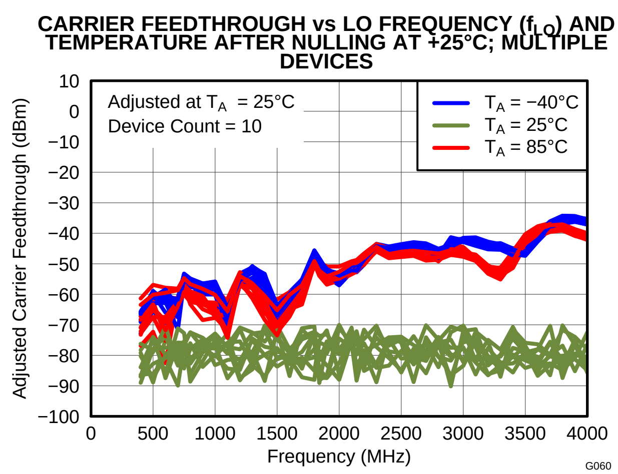


Figure 27.

TYPICAL CHARACTERISTICS: Two-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

UNADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY (f_{LO}) AND TEMPERATURE

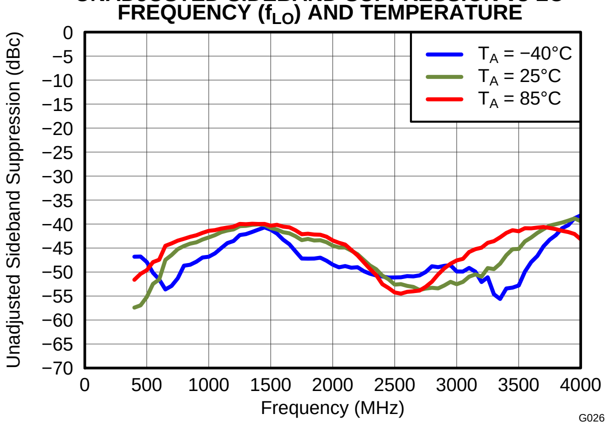


Figure 28.

UNADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY (f_{LO}) AND SUPPLY VOLTAGE

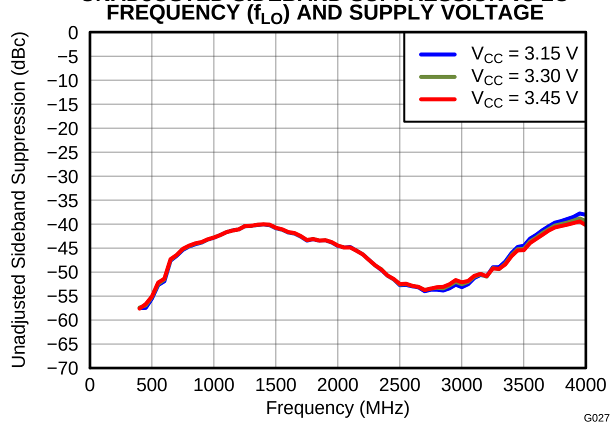


Figure 29.

UNADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY (f_{LO}) AND LO DRIVE LEVEL

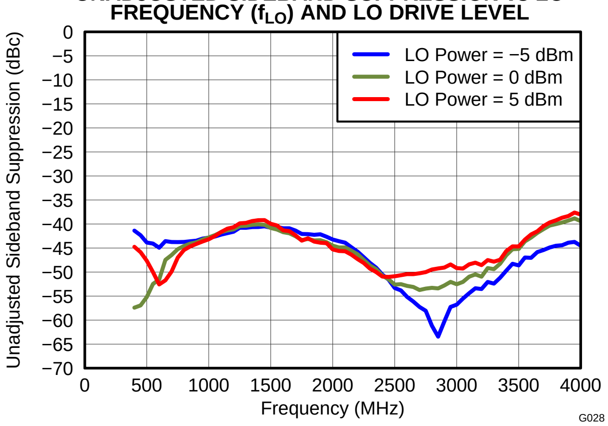


Figure 30.

UNADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY (f_{LO}) AND GAIN SELECT SETTING

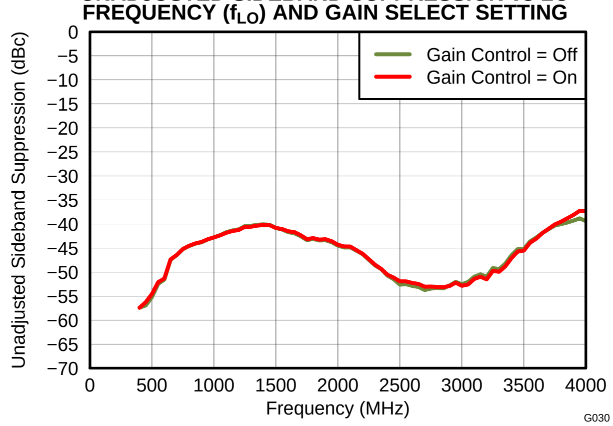


Figure 31.

UNADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY (f_{LO}) AND TEMPERATURE AT V_{CM} = 0.5 V

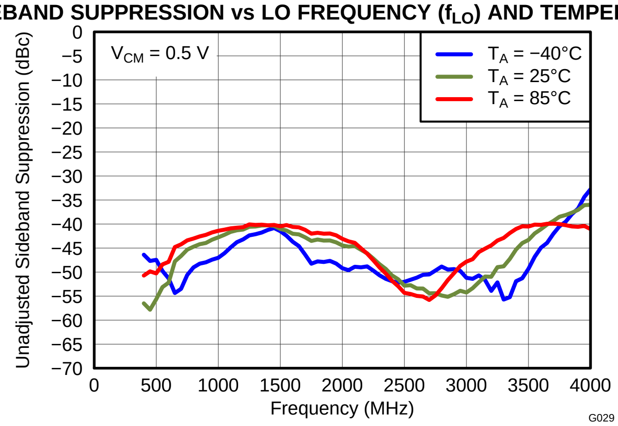


Figure 32.

TYPICAL CHARACTERISTICS: Two-Tone Baseband, Mid-Band Calibration

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted. Single point adjustment mid-band.

ADJUSTED CARRIER FEEDTHROUGH vs LO FREQUENCY AND TEMPERATURE (750 LTE Band)

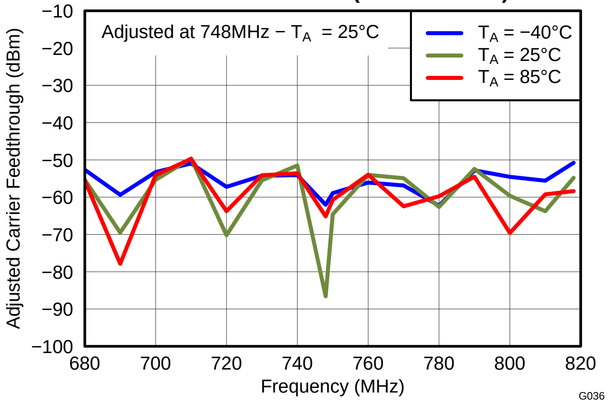


Figure 33.

ADJUSTED CARRIER FEEDTHROUGH vs LO FREQUENCY AND TEMPERATURE (GSM900 Band)

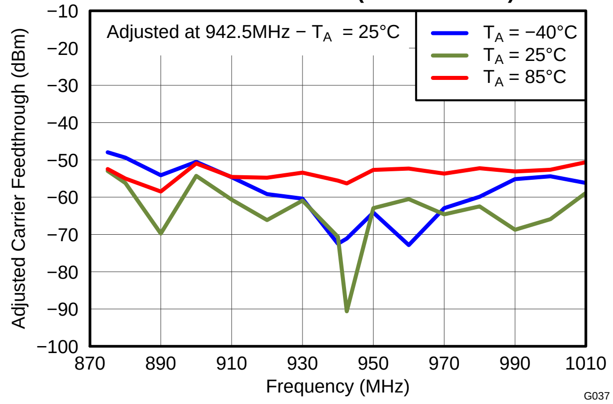


Figure 34.

ADJUSTED CARRIER FEEDTHROUGH vs LO FREQUENCY AND TEMPERATURE (PCS Band)

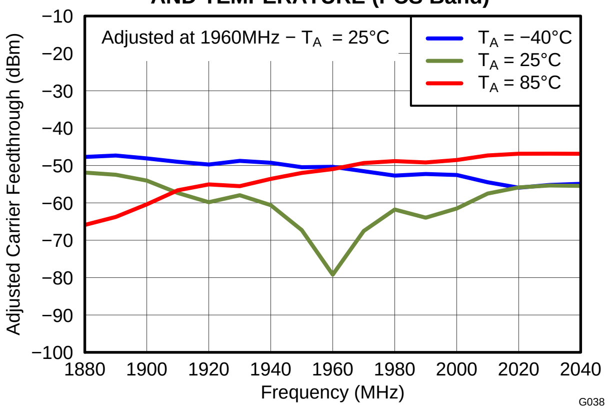


Figure 35.

ADJUSTED CARRIER FEEDTHROUGH vs LO FREQUENCY AND TEMPERATURE (UMTS Band)

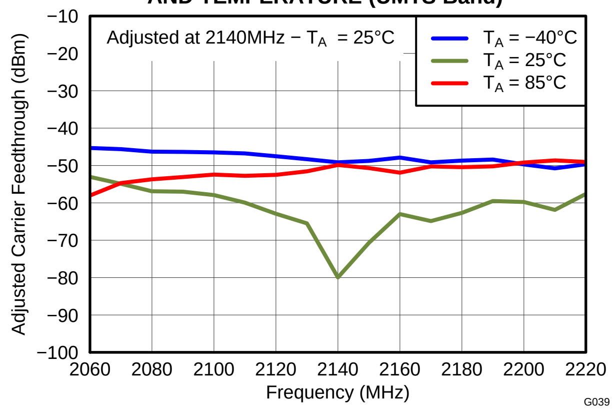


Figure 36.

ADJUSTED CARRIER FEEDTHROUGH vs LO FREQUENCY AND TEMPERATURE (2.6 GHz LTE Band)

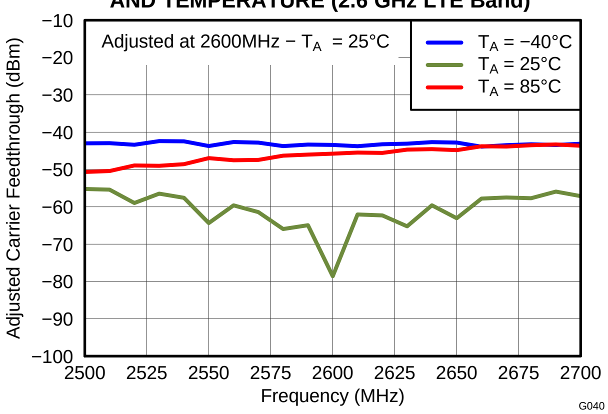


Figure 37.

ADJUSTED CARRIER FEEDTHROUGH vs LO FREQUENCY AND TEMPERATURE (WiMAX/LTE Band)

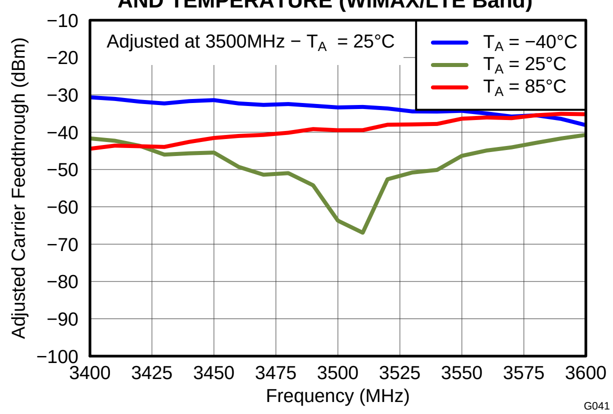


Figure 38.

TYPICAL CHARACTERISTICS: Two-Tone Baseband, Mid-Band Calibration (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted. Single point adjustment mid-band.

ADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY AND TEMPERATURE (750 LTE Band)

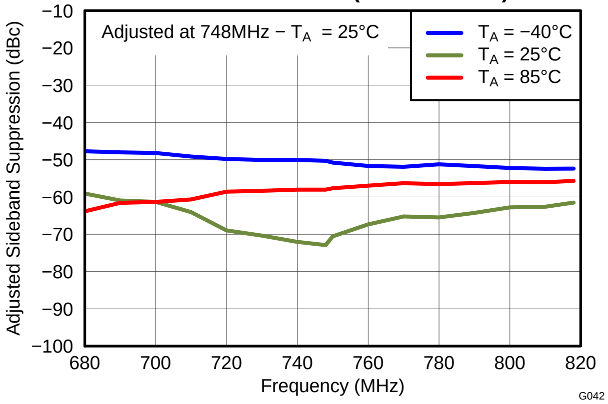


Figure 39.

ADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY AND TEMPERATURE (GSM900 Band)

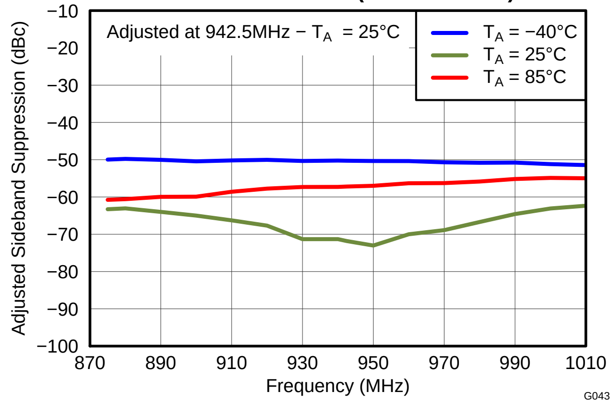


Figure 40.

ADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY AND TEMPERATURE (PCS Band)

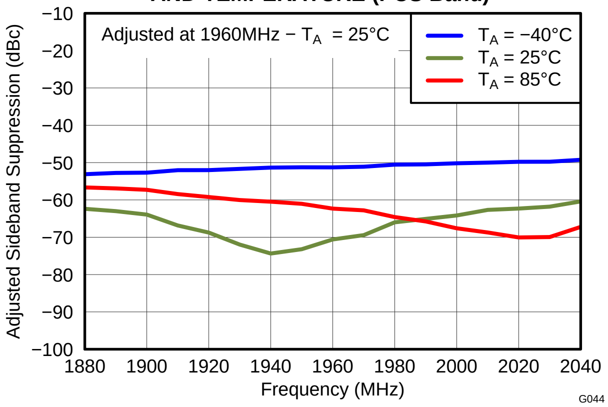


Figure 41.

ADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY AND TEMPERATURE (UMTS Band)

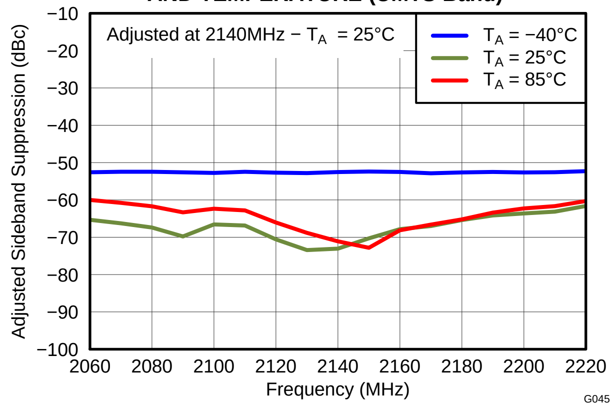


Figure 42.

ADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY AND TEMPERATURE (2.6 GHz LTE Band)

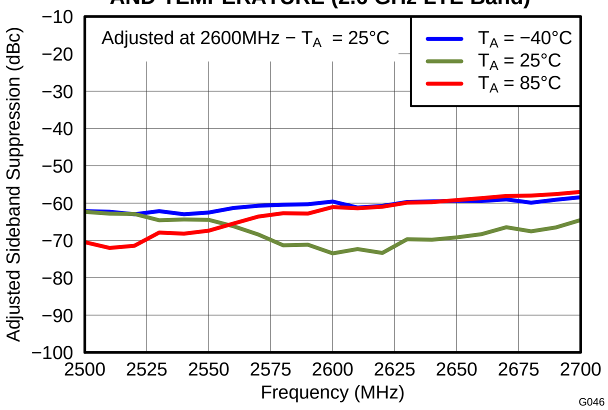


Figure 43.

ADJUSTED SIDEBAND SUPPRESSION vs LO FREQUENCY AND TEMPERATURE (WiMAX/LTE Band)

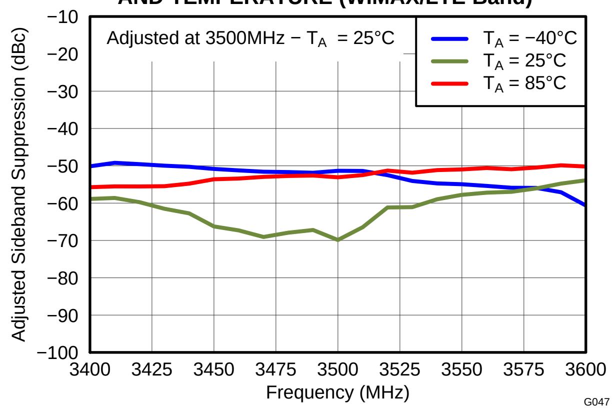


Figure 44.

TYPICAL CHARACTERISTICS: No Baseband

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); and input baseband ports terminated in 50 Ω, unless otherwise noted.

OUTPUT NOISE vs LO FREQUENCY (f_{LO}) AND TEMPERATURE

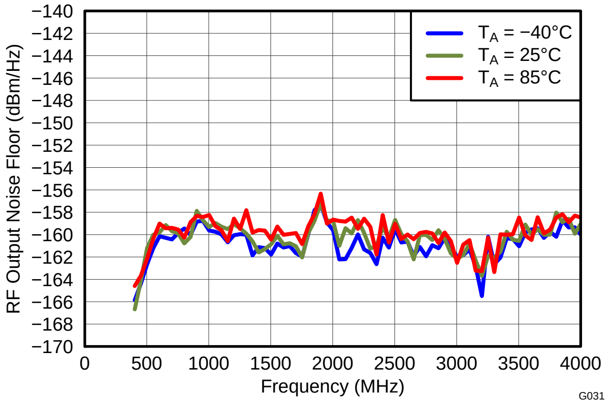


Figure 45.

OUTPUT NOISE vs LO FREQUENCY (f_{LO}) AND SUPPLY VOLTAGE

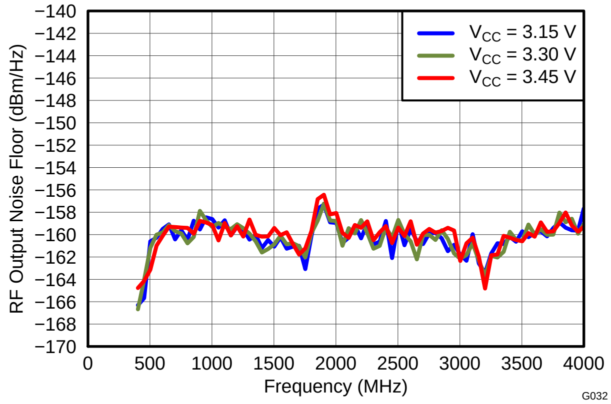


Figure 46.

OUTPUT NOISE vs LO FREQUENCY (f_{LO}) AND LO DRIVE LEVEL

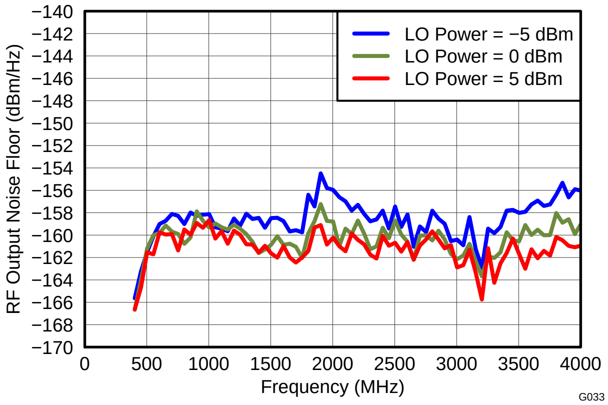


Figure 47.

OUTPUT NOISE vs LO FREQUENCY (f_{LO}) AND GAIN SELECT SETTING

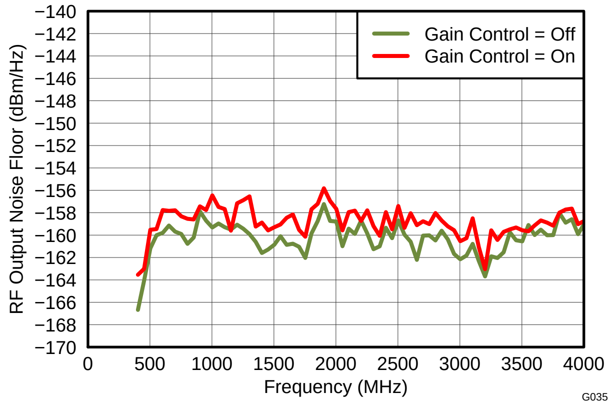


Figure 48.

OUTPUT NOISE vs OUTPUT POWER

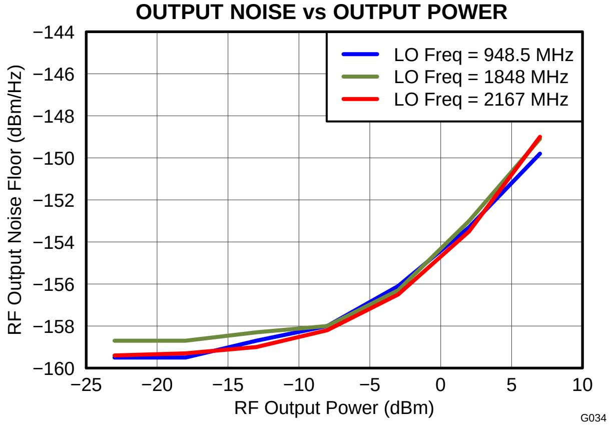


Figure 49.

TYPICAL CHARACTERISTICS: Two-Tone Baseband

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

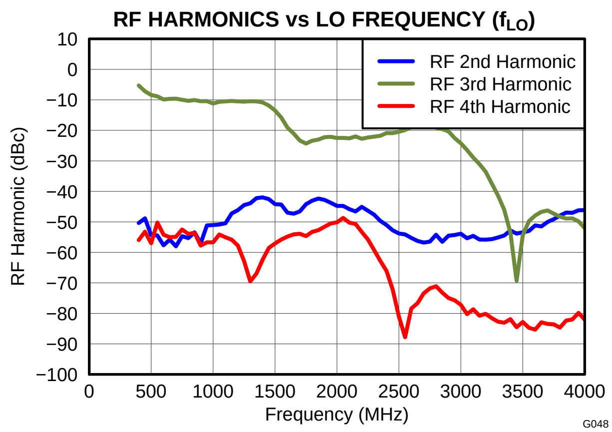


Figure 50.

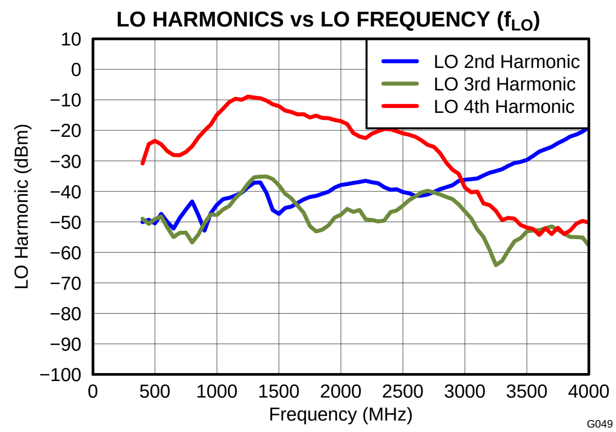


Figure 51.

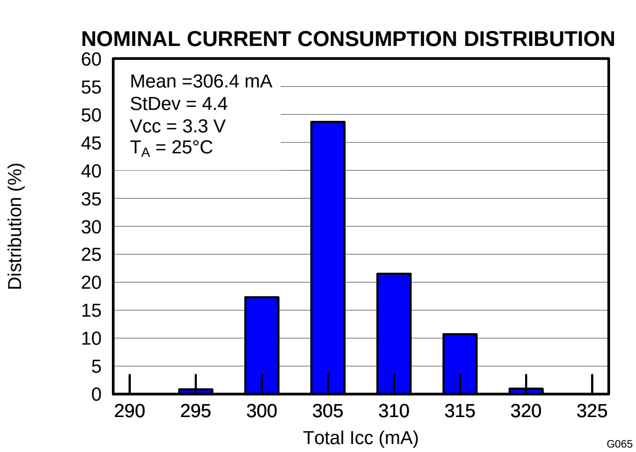


Figure 52.

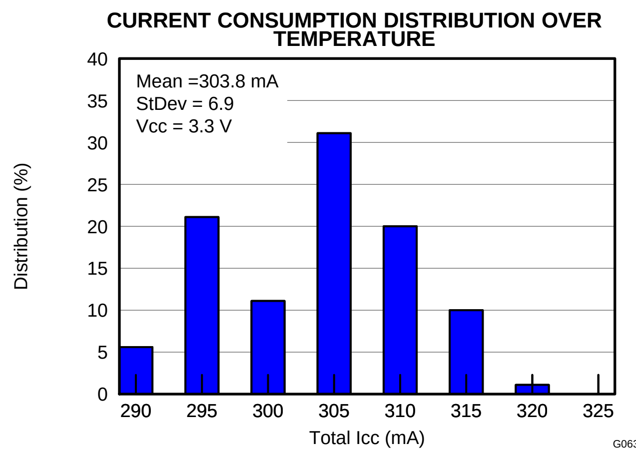


Figure 53.

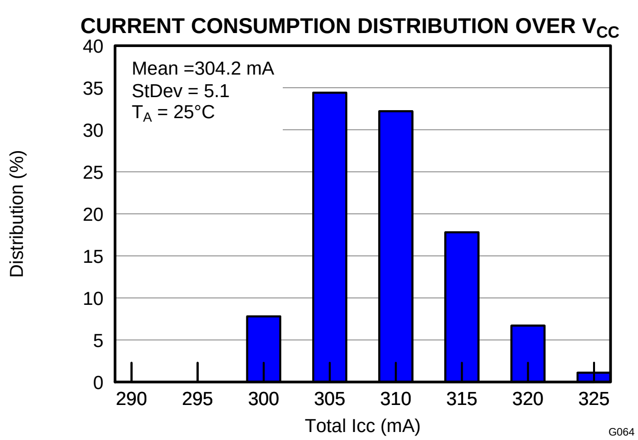


Figure 54.

TYPICAL CHARACTERISTICS: Two-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

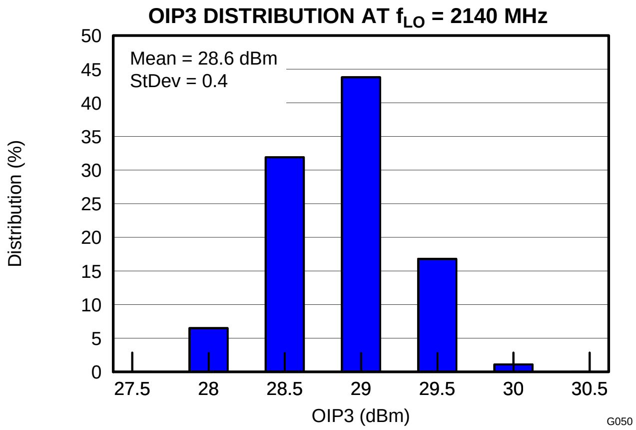


Figure 55.

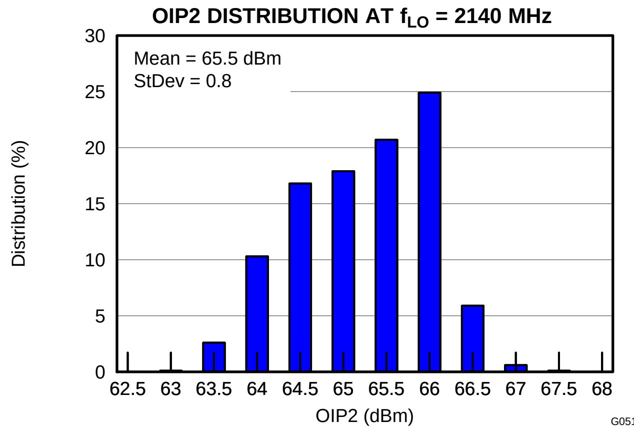


Figure 56.

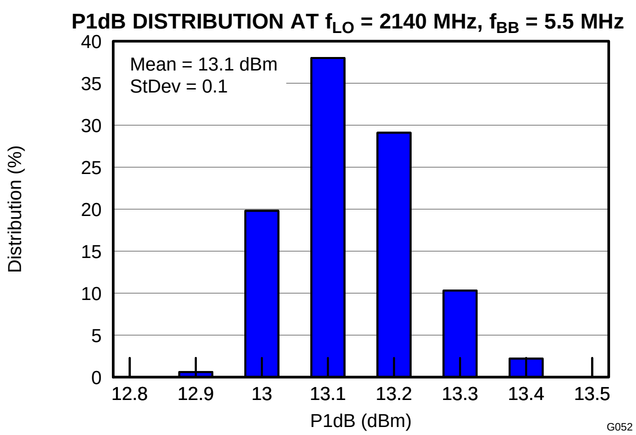


Figure 57.

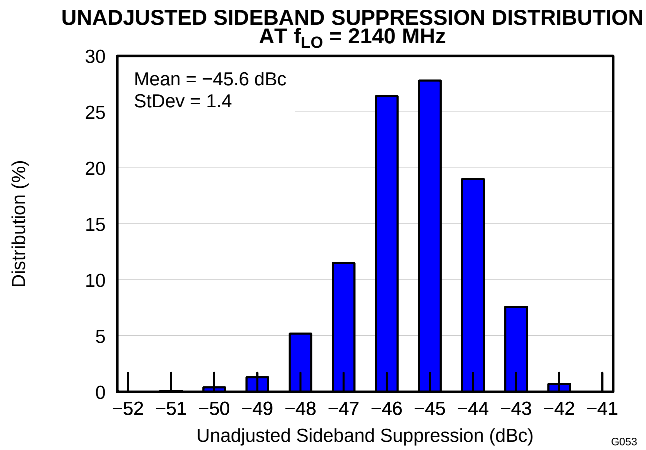


Figure 58.

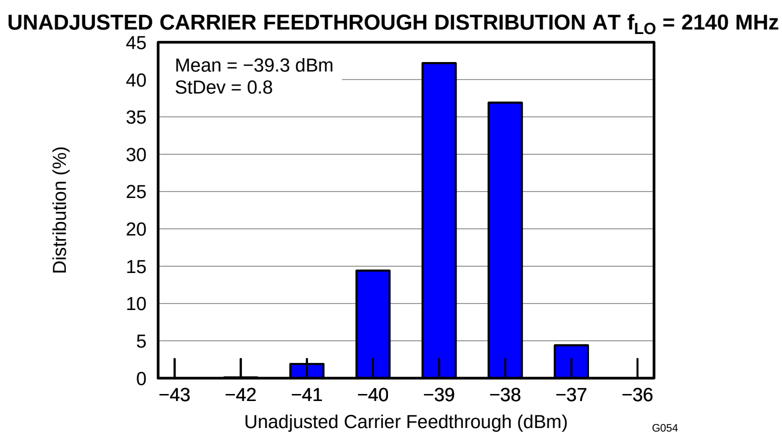


Figure 59.

TYPICAL CHARACTERISTICS: Two-Tone Baseband (continued)

V_{CC} = 3.3 V; T_A = +25°C; LO = 0 dBm, single-ended drive (LOP); I/Q frequency (f_{BB}) = 4.5 MHz, 5.5 MHz; baseband I/Q amplitude = 0.5-V_{PP}/tone differential sine waves in quadrature with V_{CM} = 0.25 V; and broadband output match, unless otherwise noted.

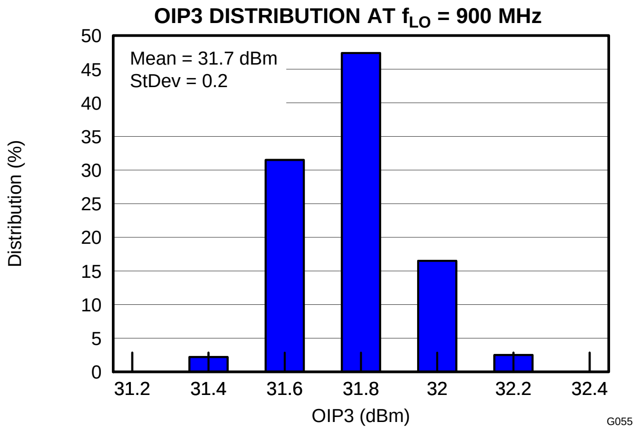


Figure 60.

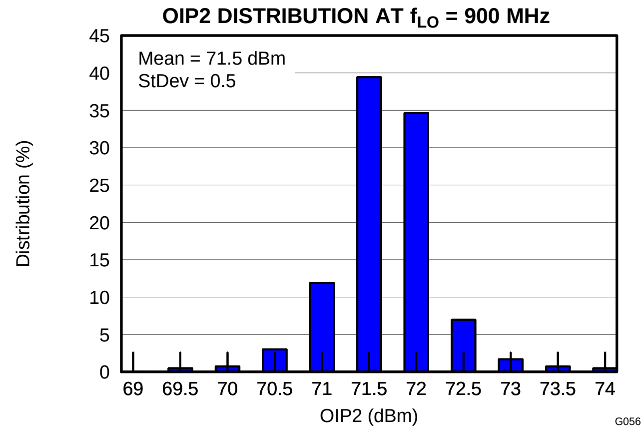


Figure 61.

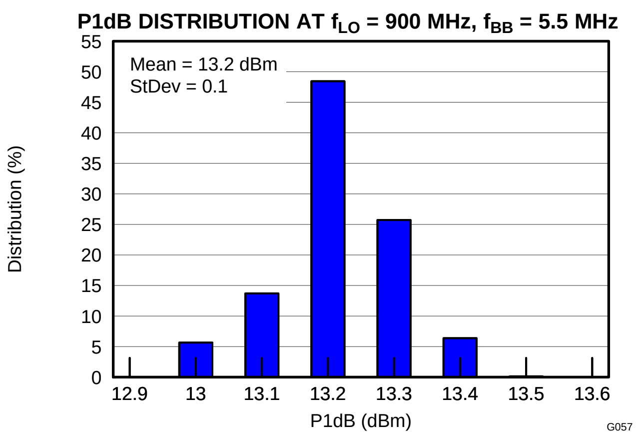


Figure 62.

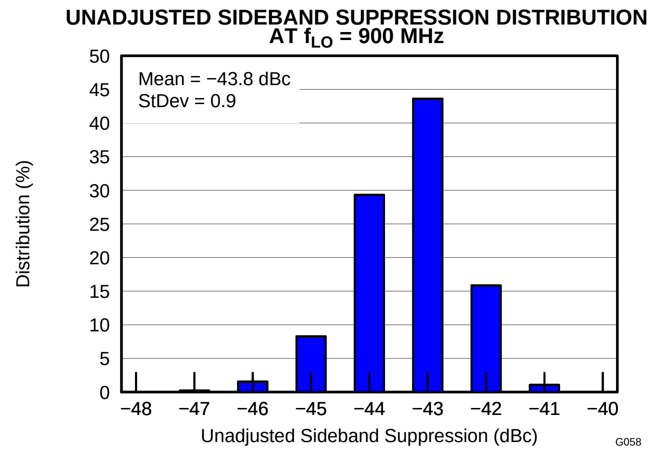


Figure 63.

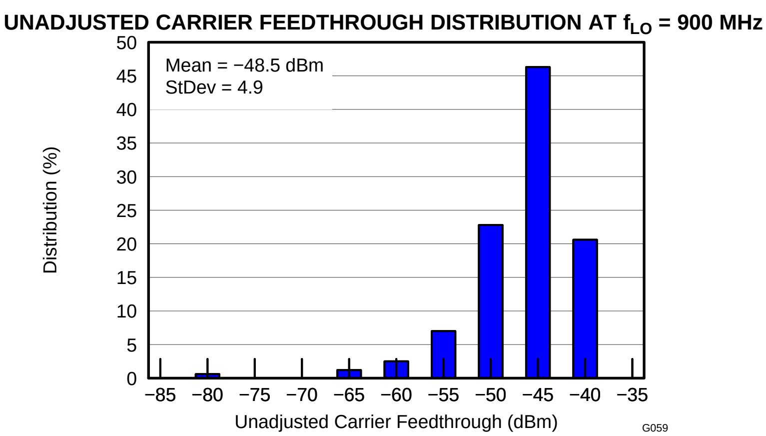
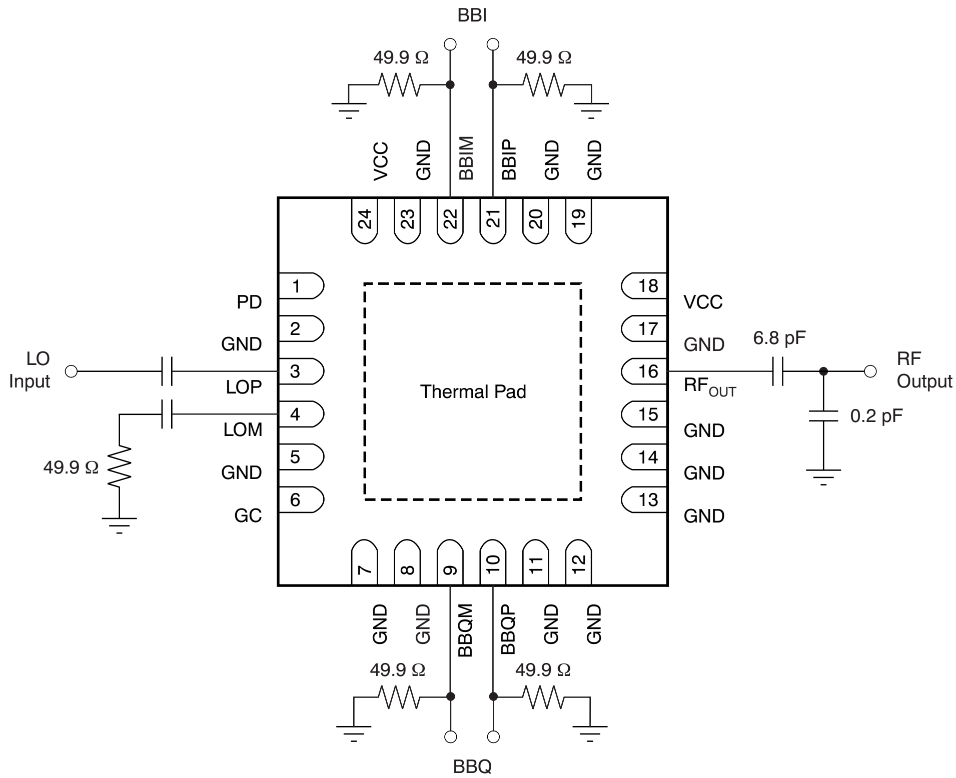


Figure 64.

APPLICATION INFORMATION

Application Schematic

Figure 65 shows a typical TRF37T05 application schematic.



(1) Pin 1 (PD) and Pin 6 (GC) are internally pulled down.

Figure 65. Typical Application Circuit

Power Supply and Grounding

The TRF37T05 is powered by supplying a nominal 3.3 V to pins 18 and 24. These supplies can be tied together and sourced from a single clean supply. Proper RF bypassing should be placed close to each power supply pin.

Ground pin connections should have at least one ground via close to each ground pin to minimize ground inductance. The PowerPAD™ must be tied to ground, preferably with the recommended ground via pattern to provide a good thermal conduction path to the alternate side of the board and to provide a good RF ground for the device. (Refer to *PCB Design Guidelines* for additional information.)

Baseband Inputs

The baseband inputs consist of the in-phase signal (I) and the Quadrature-phase signal (Q). The I and Q lines are differential lines that are driven in quadrature. The nominal drive level is 1-V_{PP} differential on each branch.

The baseband lines are nominally biased at 0.25-V common-mode voltage (V_{CM}); however, the device can operate with a V_{CM} in the range of 0 V to 0.5 V. The baseband input lines are normally terminated in 50 Ω, though it is possible to modify this value if necessary to match to an external filter load impedance requirement.

LO Input

The LO inputs can be driven either single-ended or differentially. There is no significant performance difference between either option with the exception of the sideband suppression. If driven single-ended, either input can be used, but LOP (pin 3) is recommended for best broadband performance of sideband suppression. When driving in single-ended configuration, simply ac-couple the unused port and terminate in 50 Ω. The comparison of the sideband suppression performance is shown in Figure 66 for driving the LO single-ended from either pin and for driving the LO input differentially.

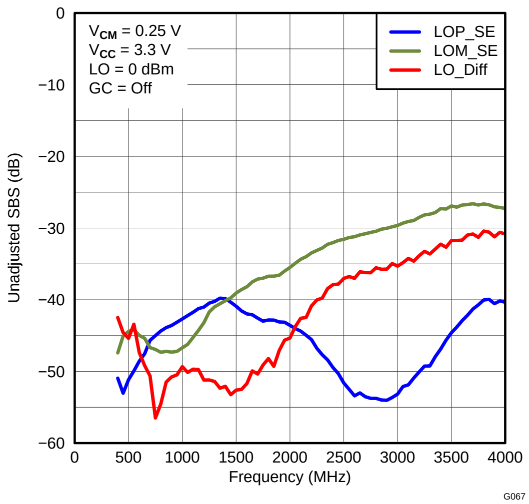


Figure 66. Unadjusted Sideband Suppression (SBS) vs LO Drive Options

RF Output

The RF output must be ac-coupled and can drive a 50-Ω load. The suggested output match provides the best broadband performance across the frequency range of the device. It is possible to modify the output match to optimize performance within a selected band if needed. The optimized matching circuits are to match the RF output impedances to 50 Ω.

Figure 67 shows a slightly better OIP3 performance at the frequency above 1850 MHz with an 0.2-pF matching capacitor.

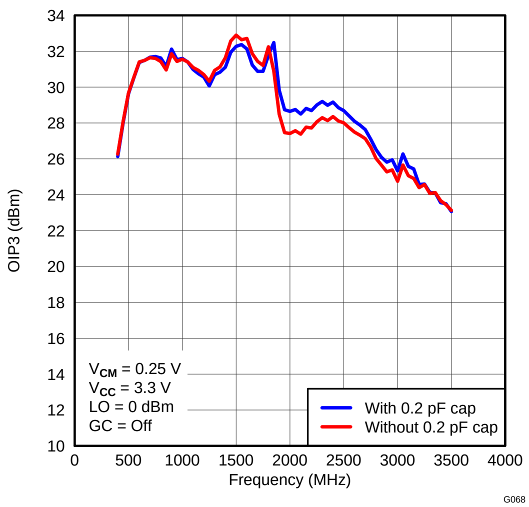


Figure 67. OIP3 with and without a Shunt 0.2-pF Matching Capacitor at the RF Port

350-MHz Operation

A different matching circuit, as shown in Figure 68, could also be applied to improve the performance for the frequency from 300 MHz to 400 MHz.

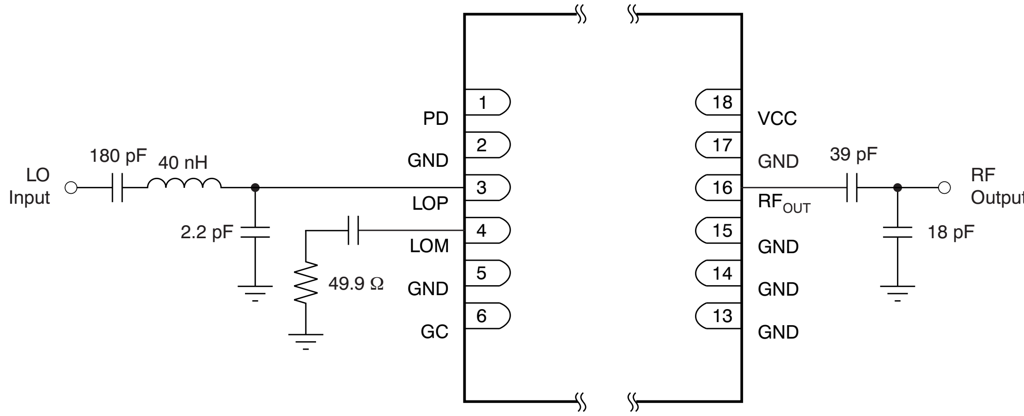


Figure 68. Matching Components for Operation Centered at 350 MHz

Figure 69 and Figure 70 show a slight improvement in OIP3 performance at 350 MHz with an 0.2-pF matching capacitor.

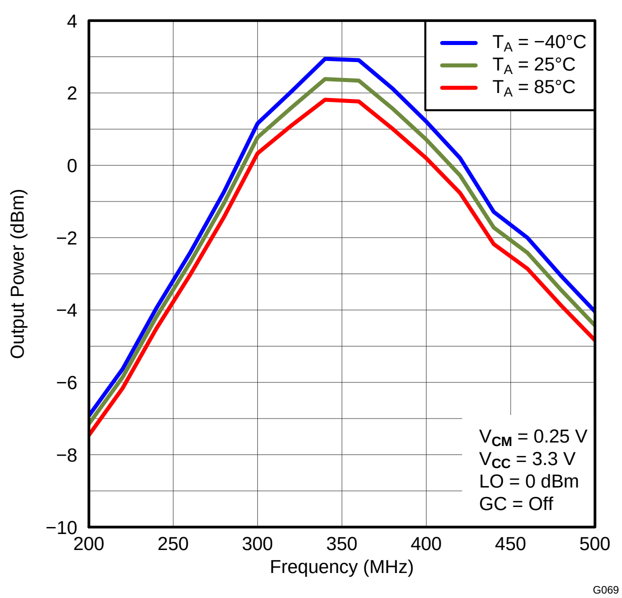


Figure 69. Output Power with 350-MHz Matching Circuit

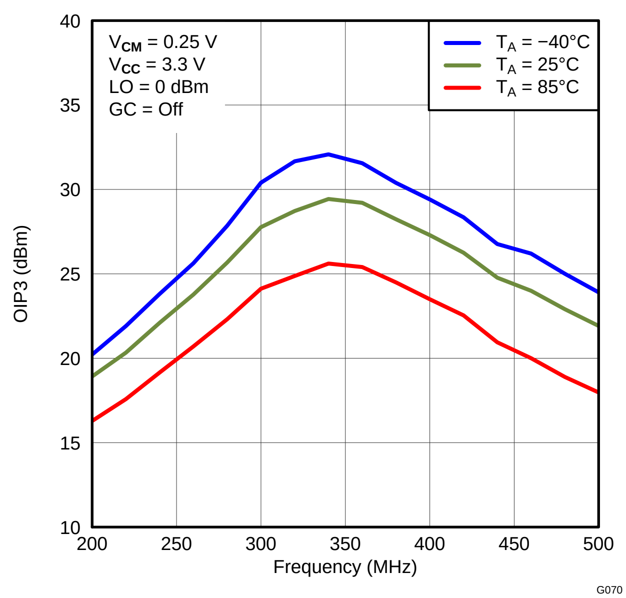


Figure 70. OIP3 with 350-MHz Matching Circuit

DAC to Modulator Interface Network

For optimum linearity and dynamic range, a digital-to-analog converter (DAC) can interface directly with the TRF37T05 modulator. It is imperative that the common-mode voltage of the DAC and the modulator baseband inputs be properly maintained. With the proper interface network, the common-mode voltage of the DAC can be translated to the proper common-mode voltage of the modulator. The TRF37T05 common-mode voltage is typically 0.25 V, and is ideally suited to interface with the DAC3482/3484 (DAC348x) family because the common-mode voltages of both devices are the same; there is no translation network required. The interface network is shown in Figure 71.

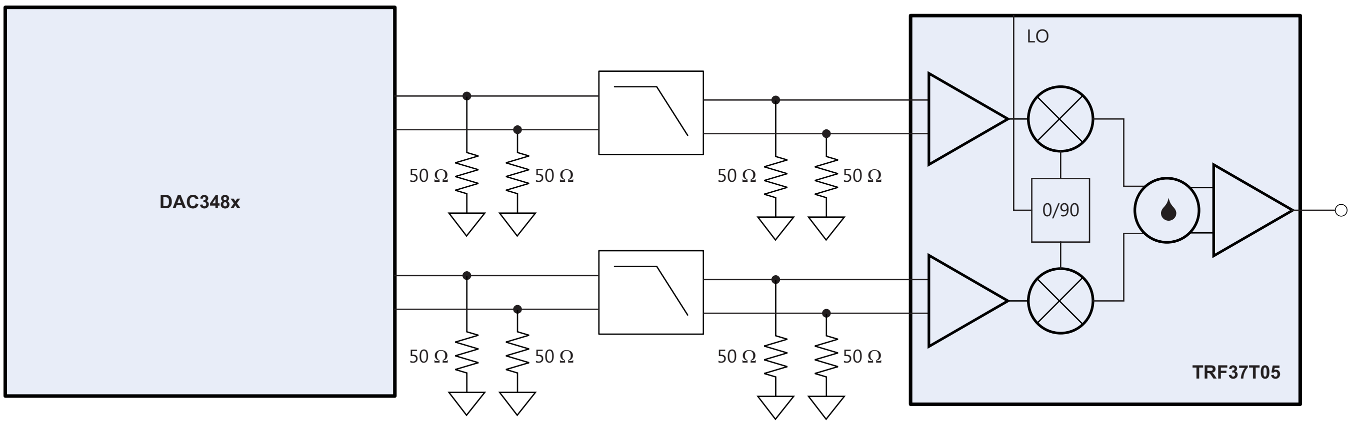


Figure 71. DAC348x Interface with the TRF37T05 Modulator

The DAC348x requires a load resistor of 25 Ω per branch to maintain its optimum voltage swing of 1-V_{PP} differential with a 20-mA max current setting. The load of the DAC is separated into two parallel 50-Ω resistors placed on the input and output side of the low-pass filter. This configuration provides the proper resistive load to the DAC while also providing a convenient 50-Ω source and load termination for the filter.

DAC348x with TRF37T05 Modulator Performance

The combination of the DAC348x driving the TRF37T05 modulator yields excellent system parameters suitable for high-performance applications. As an example, the following sections illustrate the typical modulated adjacent channel power ratio (ACPR) for common telecom standards and bands. These measurements were taken on the DAC348x evaluation board.

WCDMA

The adjacent channel power ratio (ACPR) performance using a single-carrier WCDMA signal in the UMTS band is shown in Figure 72.

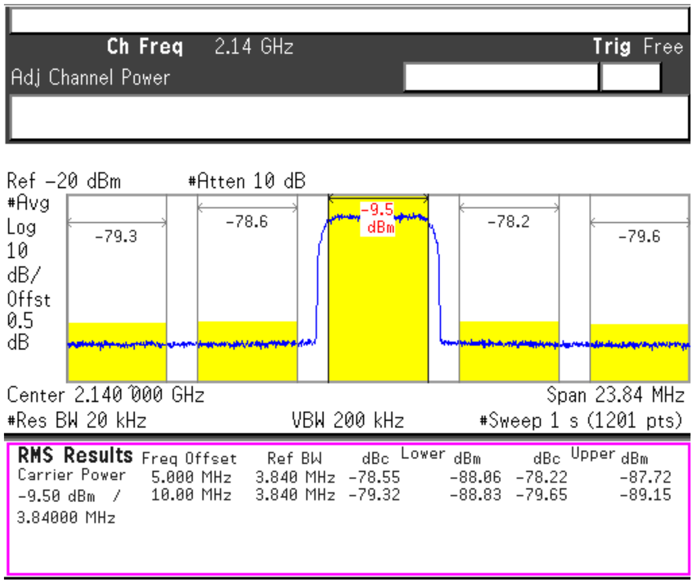


Figure 72. Single-Carrier WCDMA ACPR, IF = 30 MHz, LO Frequency = 2110 MHz

A marginal improvement in OIP3 and output noise performance can be observed by increasing the LO drive power, resulting in slightly improved ACPR performance. The ACPR performance versus LO drive level is plotted in Figure 73 across common frequencies to illustrate the amount of improvement that is possible.

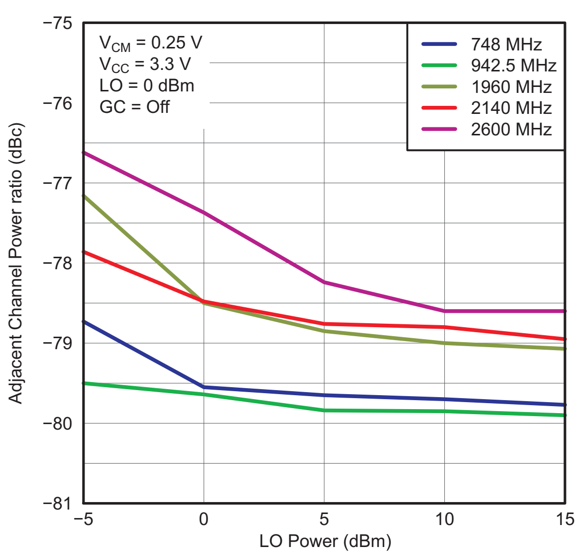


Figure 73. Single-Carrier WCDMA ACPR Performance vs LO Power

LTE

ACPR performance using a 10 MHz LTE signal in the 700-MHz band is shown in Figure 74.

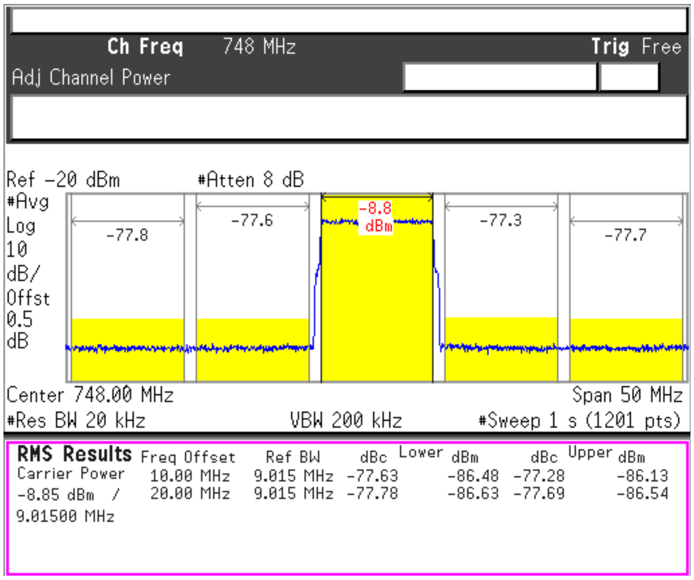


Figure 74. 10 MHz LTE ACPR, IF = 30 MHz, LO Frequency = 718 MHz

MC-GSM

ACPR performance using a four-carrier MC-GSM signal in the 1800-MHz band is shown in Figure 75.

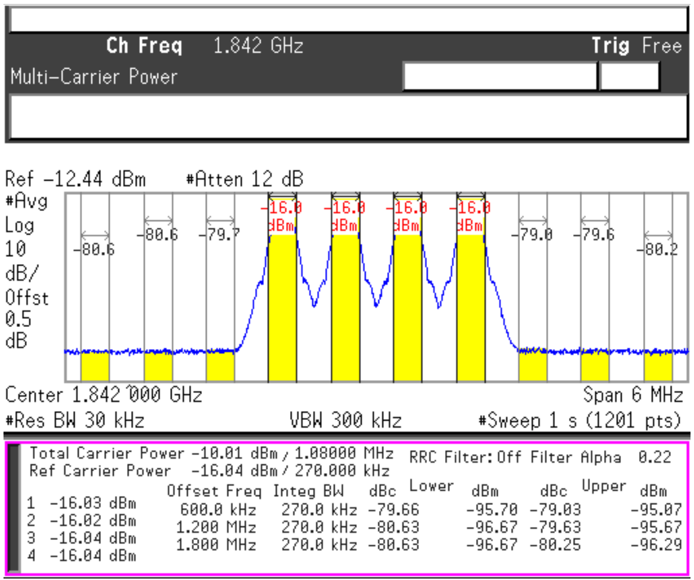


Figure 75. Four-Carrier MC-GSM, IF = 30 MHz ACPR, LO Frequency = 1812 MHz

DEFINITION OF SPECIFICATIONS

Carrier Feedthrough

This specification measures the power of the local oscillator component that is present at the output spectrum of the modulator. The performance depends on the dc offset balance within the baseband input lines. Ideally, if all of the baseband lines were perfectly matched, the carrier (that is, the LO) would be naturally suppressed; however, small dc offset imbalances within the device allow some of the LO component to feed through to the output. This parameter is expressed as an absolute power in dBm, and is independent of the RF output power and the injected LO input power.

It is possible to adjust the baseband dc offset balance to suppress the output carrier component. Devices such as the DAC348x DAC family have dc offset adjustment capabilities specifically for this function. The Adjusted Carrier Feedthrough graphs (see Figure 33 through Figure 38) optimize the performance at the center of the band at room temperature. Then, with the adjusted dc offset values held constant, the parameter is measured over the frequency band and across the temperature extremes. The typical performance plots provide an indication of how well the adjusted carrier suppression can be maintained over frequency and temperature with only one calibration point.

Sideband Suppression

This specification measures the suppression of the undesired sideband at the output of the modulator relative to the desired sideband. If the amplitude and phase within the I and Q branch of the modulator were perfectly matched, the undesired sideband (or image) would be naturally suppressed. Amplitude and phase imbalance in the I and Q branches result in the increase of the undesired sideband. This parameter is measured in dBc relative to the desired sideband.

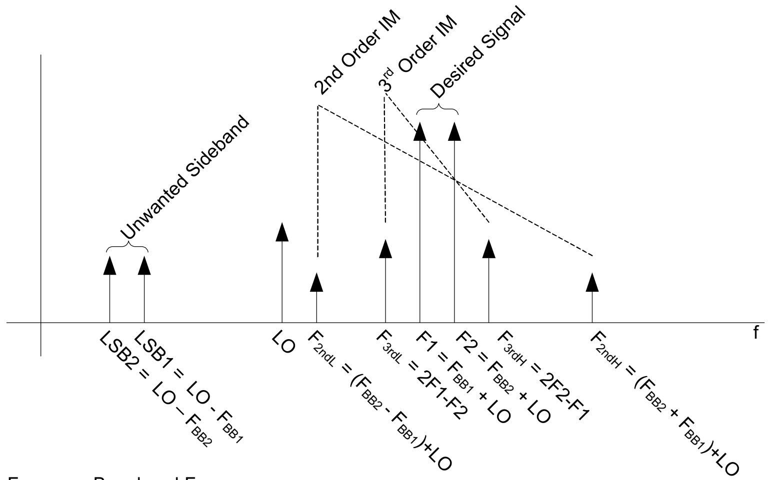
It is possible to adjust the relative amplitude and phase balance within the baseband lines to suppress the unwanted sideband. Devices such as the DAC348x DAC family have amplitude and phase adjustment control specifically for this function. The Adjusted Sideband Suppression graphs (refer to Figure 39 through Figure 44) optimize the performance at the center of the band at room temperature. Then, with the adjusted amplitude and phase values held constant, the parameter is measured over the frequency band and across the temperature extremes. The performance plots provide an indication of how well the adjusted sideband suppression can be maintained over frequency and temperature with only one calibration point.

Output Noise

The output noise specifies the absolute noise power density that is output from the RF_{OUT} pin (pin 16). This parameter is expressed in dBm/Hz. This parameter, in conjunction with the OIP3 specification, indicates the dynamic range of the device. In general, at high output signal levels the performance is limited by the linearity of the device; at low output levels, on the other hand, the performance is limited by noise. As a result of the higher gain and output power of the TRF37T05 compared to earlier devices, it is expected that the noise density is slightly higher as well. With its increased gain and high OIP3 performance, the overall dynamic range of the TRF37T05 is maintained at exceptional levels.

Definition of Terms

A simulated output spectrum with two tones is shown in Figure 76, with definitions of various terms used in this data sheet.



F_{BBn} = Baseband Frequency
Fn = RF Frequency
$F_{3rdH/L}$ = 3rd Order Intermodulation Product Frequency (High Side / Low Side)
$F_{2ndH/L}$ = 2nd Order Intermodulation Product Frequency (High Side / Low Side)
LO = Local Oscillator Frequency
LSBn = Lower Sideband Frequency

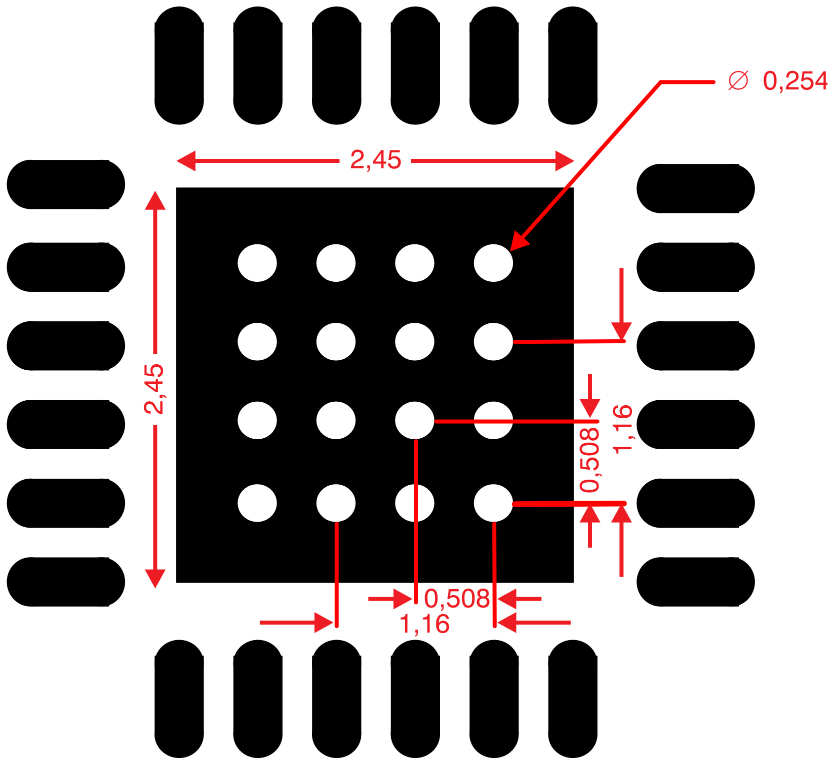
Figure 76. Graphical Illustration of Common Terms

EVALUATION BOARD

Populated RoHS-compliant evaluation boards are available for testing the TRF37T05 as a stand-alone device. Contact your local TI representative for information on ordering these evaluation modules, or see the TRF37T05 product folder on the TI website. In addition, the TRF37T05 can be evaluated with the DAC348x (quad/dual 16-bit, 1.25GSPS) EVM driving the baseband inputs through a seamless interface at 0.25V common-mode voltage.

PCB Design Guidelines

The TRF37T05 device is fitted with a ground slug on the back of the package that must be soldered to the printed circuit board (PCB) ground with adequate ground vias to ensure a good thermal and electrical connection. The recommended via pattern and ground pad dimensions are shown in Figure 77. The recommended via diameter is 10 mils (0.10 in or 0,25 mm). The ground pins of the device can be directly tied to the ground slug pad for a low-inductance path to ground. Additional ground vias may be added if space allows.



Note: Dimensions are in millimeters (mm).

Figure 77. PCB Ground Via Layout Guide

Decoupling capacitors at each of the supply pins are strongly recommended. The value of these capacitors should be chosen to provide a low-impedance RF path to ground at the frequency of operation. Typically, the value of these capacitors is approximately 10 pF or lower.

The device exhibits symmetry with respect to the quadrature input paths. It is recommended that the PCB layout maintain this symmetry in order to ensure that the quadrature balance of the device is not impaired. The I/Q input traces should be routed as differential pairs and the respective lengths all kept equal to each other. On the RF traces, maintain proper trace widths to keep the characteristic impedance of the RF traces at a nominal 50 Ω.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TRF37T05IRGER	ACTIVE	VQFN	RGE	24	3000	Green (RoHS & no Sb/Br)	CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 85	TR37T05 IRGE	Samples
TRF37T05IRGET	ACTIVE	VQFN	RGE	24	250	Green (RoHS & no Sb/Br)	CU NIPDAUAG	Level-2-260C-1 YEAR	-40 to 85	TR37T05 IRGE	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

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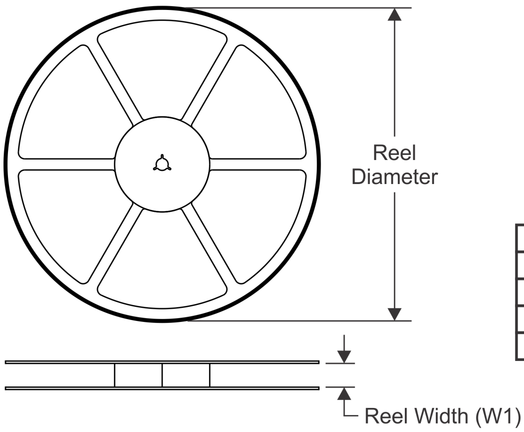
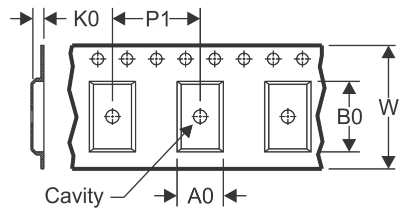
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

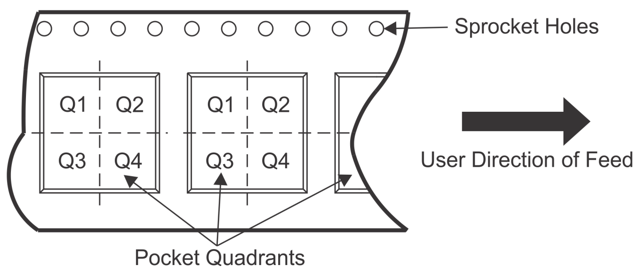
TAPE AND REEL INFORMATION





A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

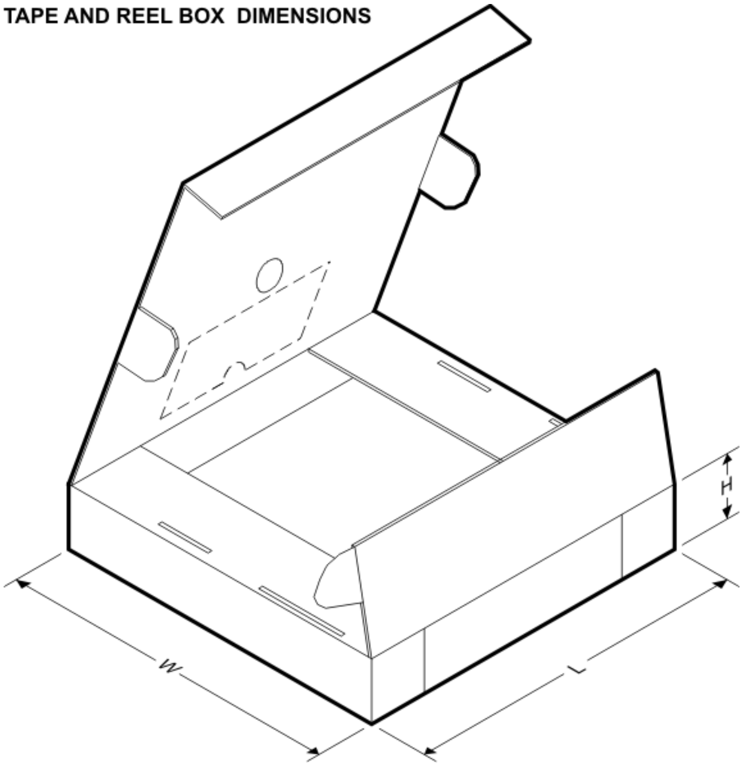
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TRF37T05IRGER	VQFN	RGE	24	3000	330.0	12.4	4.3	4.3	1.5	8.0	12.0	Q2
TRF37T05IRGET	VQFN	RGE	24	250	330.0	12.4	4.3	4.3	1.5	8.0	12.0	Q2

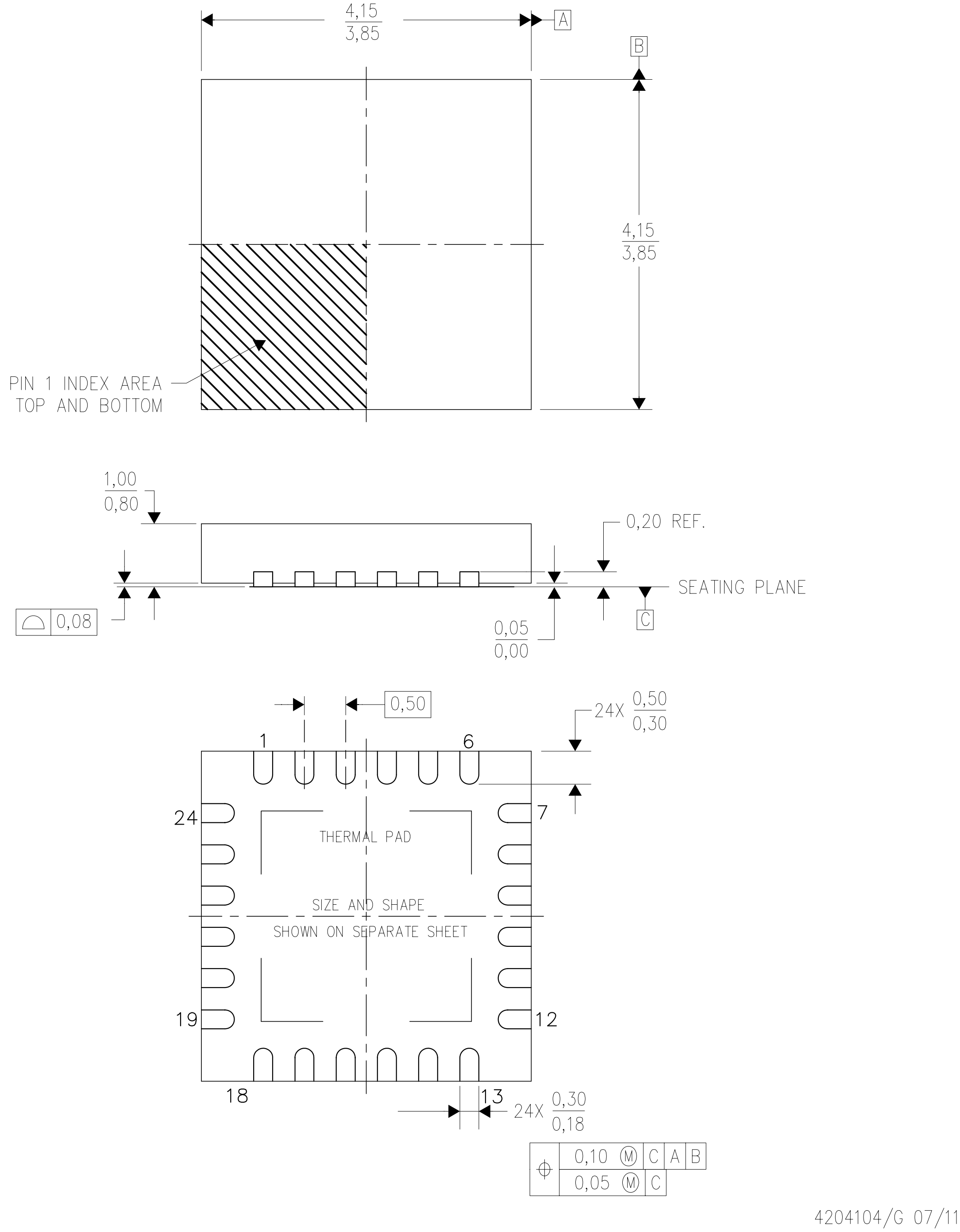
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TRF37T05IRGER	VQFN	RGE	24	3000	338.1	338.1	20.6
TRF37T05IRGET	VQFN	RGE	24	250	338.1	338.1	20.6

RGE (S-PVQFN-N24) PLASTIC QUAD FLATPACK NO-LEAD



NOTES:

A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
B. This drawing is subject to change without notice.
C. Quad Flatpack, No-Leads (QFN) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
F. Falls within JEDEC MO-220.

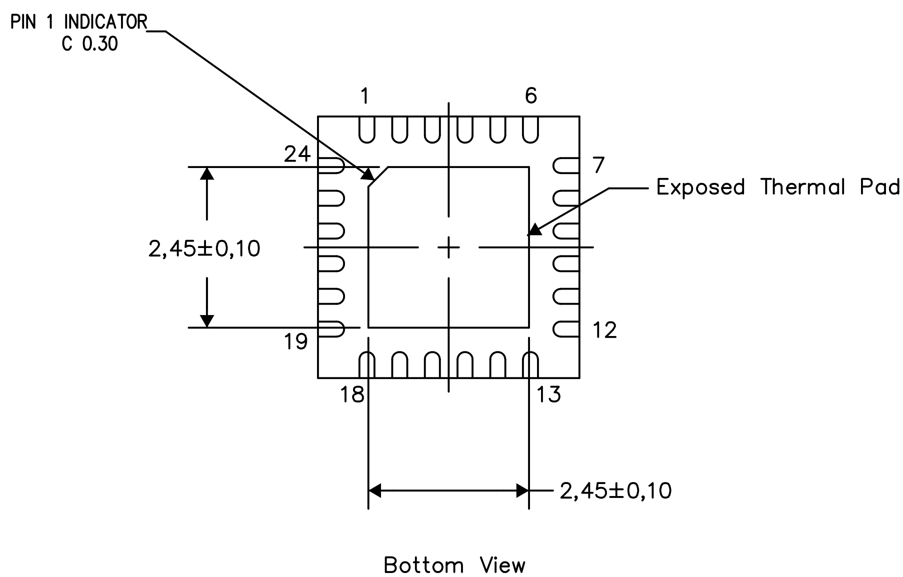
RGE (S-PVQFN-N24) PLASTIC QUAD FLATPACK NO-LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

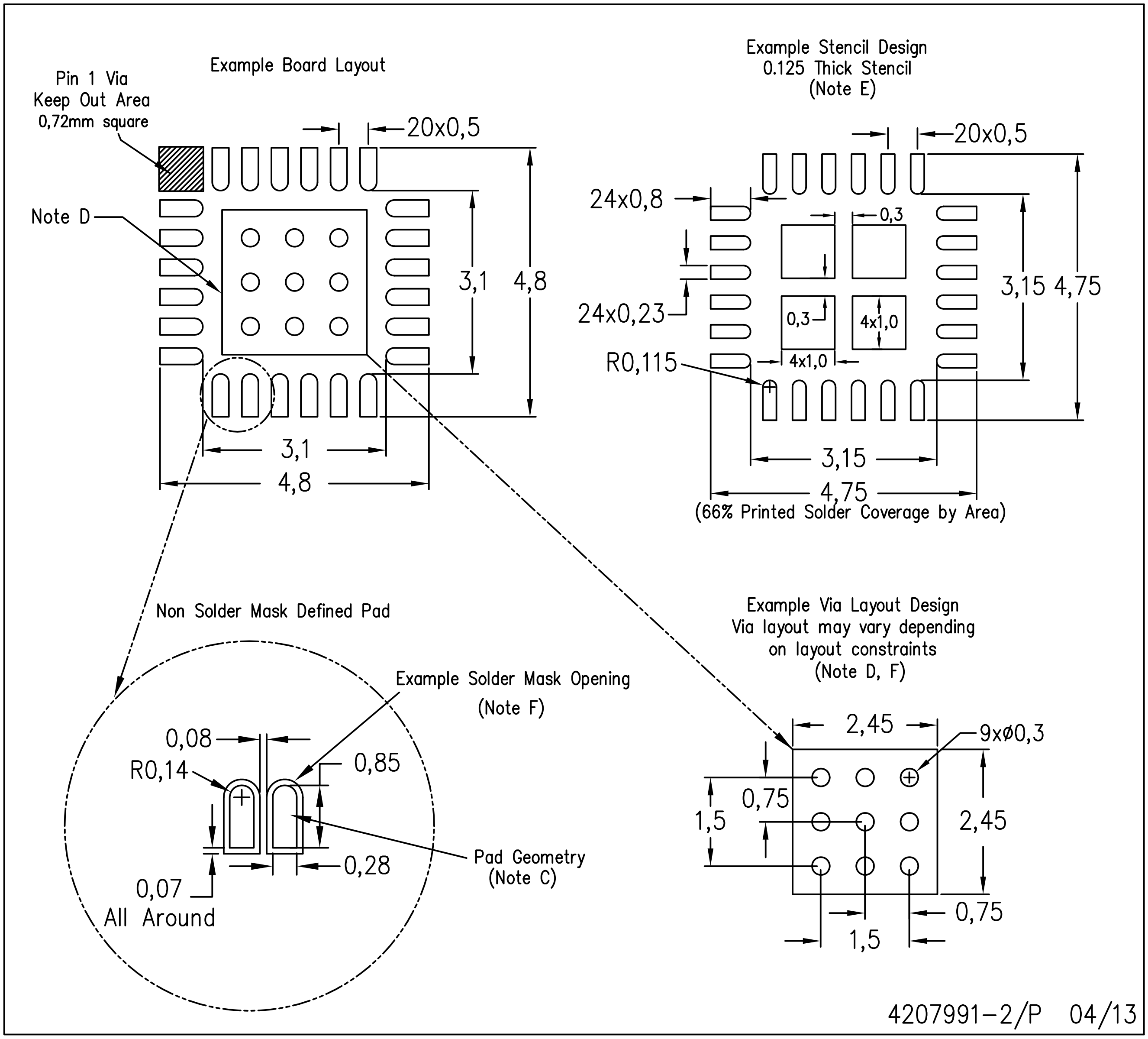


Exposed Thermal Pad Dimensions

4206344-3/AD 04/13

NOTES: A. All linear dimensions are in millimeters

RGE (S–PVQFN–N24) PLASTIC QUAD FLATPACK NO–LEAD



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC–7351 is recommended for alternate designs.
- D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http: //www.ti.com>.
- E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
- F. Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in the thermal pad.