

## FEATURES

**Output frequency range:** 30 MHz to 2200 MHz  
**1 dB output compression:** 11 dBm at 350 MHz  
**Noise floor:** -159 dBm/Hz at 350 MHz  
**Sideband suppression:** -50 dBc at 350 MHz  
**Carrier feedthrough:** -46 dBm at 350 MHz  
**Single supply:** 4.75 V to 5.5 V  
**24-lead, RoHS-compliant, LFCSP with exposed pad**

## APPLICATIONS

**Radio-link infrastructure**  
**Cable modem termination systems**  
**UHF/VHF radio**  
**Wireless infrastructure systems**  
**Wireless local loop**  
**WiMAX/broadband wireless access systems**

## GENERAL DESCRIPTION

The **ADL5385** is a silicon, monolithic, quadrature modulator designed for use from 30 MHz to 2200 MHz. Its excellent phase accuracy and amplitude balance enable both high performance intermediate frequency (IF) and direct radio frequency (RF) modulation for communication systems.

The **ADL5385** takes the signals from two differential baseband inputs and modulates them onto two carriers in quadrature with each other. The two internal carriers are derived from a single-ended, external local oscillator input signal at twice the frequency as the desired carrier output. The two modulated signals are summed together in a differential-to-single-ended amplifier designed to drive 50  $\Omega$  loads.

## FUNCTIONAL BLOCK DIAGRAM

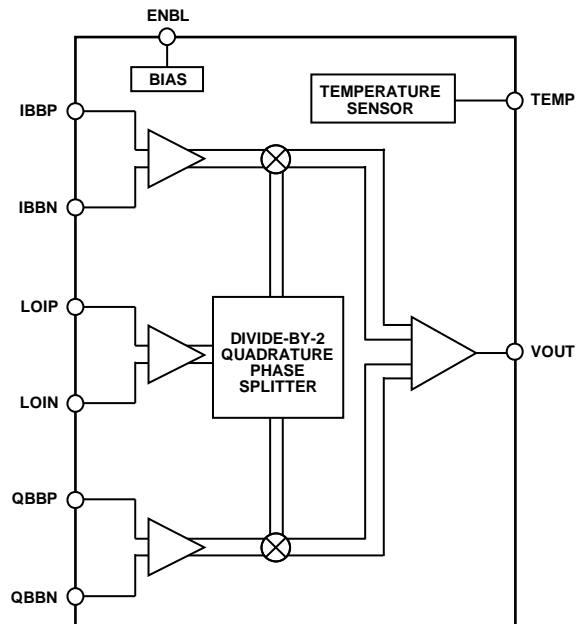


Figure 1.

The **ADL5385** can be used as either an IF or a direct-to-RF modulator in digital communication systems. The wide baseband input bandwidth allows for either baseband drive or drive from a complex IF. Typical applications are in radio-link transmitters, cable modem termination systems, and broadband wireless access systems.

The **ADL5385** is fabricated using the Analog Devices, Inc., advanced silicon germanium bipolar process and is packaged in a 24-lead, RoHS-compliant LFCSP with exposed pad. Performance is specified over -40°C to +85°C. A RoHS-compliant evaluation board is also available.

# ADL5385\* Product Page Quick Links

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### **Application Notes**

- AN-924: Digital Quadrature Modulator Gain

### **Data Sheet**

- ADL5385: 30 MHz to 2200 MHz Quadrature Modulator Data Sheet

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## REVISION HISTORY

### 12/2016—Rev. C to Rev. D

Changes to Evaluation Board Section.....	21
Deleted Figure 46 and Table 9; Renumbered Sequentially .....	23
Deleted Figure 47.....	24
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### 3/2016—Rev. B to Rev. C

Changes to Figure 2.....	8
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### 12/2014—Rev. A to Rev. B

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Added Figure 45; Renumbered Sequentially .....	22
Added Figure 46 and Table 9.....	23

Added Figure 47 .....	24
Changes to Ordering Guide .....	26

### 10/2012—Rev. 0 to Rev. A

Added 30 MHz Output Frequency .....	Throughout
Changes to Applications Section.....	1
Changes to Table 1.....	3
Added EPAD Notation to Figure 2 and Table 3 .....	8
Added Figure 8; Renumbered Sequentially .....	9
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Updated Outline Dimensions.....	24
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### 10/2006—Revision 0: Initial Version

## SPECIFICATIONS

Unless otherwise noted,  $V_S = 5\text{ V}$ ;  $T_A = 25^\circ\text{C}$ ; LO =  $-7\text{ dBm}$ ; I/Q inputs =  $1.4\text{ V}$  p-p differential sine waves in quadrature on a  $500\text{ mV}$  dc bias; baseband frequency =  $1\text{ MHz}$ ; LO source and RF output load impedances are  $50\ \Omega$ .

Table 1.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
OUTPUT FREQUENCY RANGE		30		2200	MHz
EXTERNAL LO FREQUENCY RANGE	External LO frequency $2\times$ output frequency	60		4400	MHz
OUTPUT FREQUENCY = 30 MHz (LO = 0 dBm)					
Output Power	Single (lower) sideband output		4.7		dBm
Output P1dB			11		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-57		dBm
	+85°C after optimization at +25°C		-68		dBm
	-40°C after optimization at +25°C		-65		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-51		dBc
	+85°C after optimization at +25°C		-59		dBc
	-40°C after optimization at +25°C		-60		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 5\text{ dBm}$		-88		dBc
Third Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 5\text{ dBm}$		-57		dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3\text{ dBm}$ per tone		76		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3\text{ dBm}$ per tone		24		dBm
Quadrature Phase Error			0.43		Degrees
I/Q Amplitude Balance			0.015		dB
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-155		dBm/Hz
	20 MHz offset from LO, output power = $-5\text{ dBm}$		-150		dBm/Hz
Output Return Loss			-20		dB
OUTPUT FREQUENCY = 50 MHz					
Output Power	Single (lower) sideband output	4	5.6	8	dBm
Output P1 dB			11		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-57		dBm
	+85°C after optimization at +25°C		-67		dBm
	-40°C after optimization at +25°C		-67		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-57		dBc
	@ +85°C after optimization at +25°C		-64		dBc
	@ -40°C after optimization at +25°C		-68		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 5\text{ dBm}$		-83		dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 5\text{ dBm}$		-58		dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3\text{ dBm}$ per tone		69		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3\text{ dBm}$ per tone		26		dBm
Quadrature Phase Error			-0.17		Degrees
I/Q Amplitude Balance			-0.03		dB
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-155		dBm/Hz
	20 MHz offset from LO, output power = $-5\text{ dBm}$		-150		dBm/Hz
Output Return Loss			-19		dB

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
OUTPUT FREQUENCY = 140 MHz					
Output Power	Single (lower) sideband output		5.7		dBm
Output P1 dB			11		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-52		dBm
	+85°C after optimization at +25°C		-66		dBm
	-40°C after optimization at +25°C		-67		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-53		dBc
	+85°C after optimization at +25°C		-63		dBc
	-40°C after optimization at +25°C		-68		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 5$ dBm		-83		dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 5$ dBm		-57		dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		70		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		26		dBm
Quadrature Phase Error			-0.33		Degrees
I/Q Amplitude Balance			-0.03		dB
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-160		dBm/Hz
Output Return Loss			-20		dB
OUTPUT FREQUENCY = 350 MHz					
Output Power	Single (lower) sideband output	3	5.6	7	dBm
Output P1 dB			11		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-46		dBm
	+85°C after optimization at +25°C		-65		dBm
	-40°C after optimization at +25°C		-66		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-50		dBc
	+85°C after optimization at +25°C		-63		dBc
	-40°C after optimization at +25°C		-61		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 5$ dBm		-80		dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 5$ dBm		-53		dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		71		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		26		dBm
Quadrature Phase Error			0.39		Degrees
I/Q Amplitude Balance			-0.03		dB
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-159		dBm/Hz
	20 MHz offset from LO, output power = -5 dBm		-157		dBm/Hz
Output Return Loss			-21		dB
OUTPUT FREQUENCY = 860 MHz					
Output Power	Single (lower) sideband output	2.5	5.3	6.5	dBm
Output P1 dB			11		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-41	-35	dBm
	+85°C after optimization at +25°C		-63		dBm
	-40°C after optimization at +25°C		-65		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-41	-35	dBc
	+85°C after optimization at +25°C		-58		dBc
	-40°C after optimization at +25°C		-59		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 5$ dBm		-73	-57	dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 5$ dBm		-50	-45	dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		70		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		25		dBm
Quadrature Phase Error			0.67		Degrees
I/Q Amplitude Balance			-0.03		dB

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-159		dBm/Hz
Output Return Loss	20 MHz offset from LO, output power = -5 dBm		-157		dBm/Hz
			-19		dB
OUTPUT FREQUENCY = 1450 MHz					
Output Power	Single (lower) sideband output		4.4		dBm
Output P1 dB			10		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-36		dBm
	+85°C after optimization at +25°C		-50		dBm
	-40°C after optimization at +25°C		-50		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-44		dBc
	+85°C after optimization at +25°C		-61		dBc
	-40°C after optimization at +25°C		-51		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 4$ dBm		-64		dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 4$ dBm		-52		dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		63		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		24		dBm
Quadrature Phase Error			0.42		Degrees
I/Q Amplitude Balance			-0.02		dB
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-160		dBm/Hz
Output Return Loss			-33		dB
OUTPUT FREQUENCY = 1900 MHz					
Output Power	Single (lower) sideband output		3.4		dBm
Output P1 dB			9		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-35		dBm
	+85°C after optimization at +25°C		-51		dBm
	-40°C after optimization at +25°C		-51		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-33		dBc
	+85°C after optimization at +25°C		-43		dBc
	-40°C after optimization at +25°C		-47		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 3$ dBm		-58		dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 3$ dBm		-47		dBc
Output IP2	F1 = +3.5 MHz, F2 = +4.5 MHz, $P_{OUT} = -3$ dBm per tone		57		dBm
Output IP3	F1 = +3.5 MHz, F2 = +4.5 MHz, $P_{OUT} = -3$ dBm per tone		22		dBm
Quadrature Phase Error			2.6		Degrees
I/Q Amplitude Balance			0.003		dB
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-160		dBm/Hz
	20 MHz offset from LO, output power = -5 dBm		-156		dBm/Hz
Output Return Loss			-20		dB
OUTPUT FREQUENCY = 2150 MHz					
Output Power	Single (lower) sideband output		2.6		dBm
Output P1 dB			8		dBm
Carrier Feedthrough	Unadjusted (nominal drive level)		-36		dBm
	+85°C after optimization at +25°C		-47		dBm
	-40°C after optimization at +25°C		-48		dBm
Sideband Suppression	Unadjusted (nominal drive level)		-37		dBc
Second Baseband Harmonic	$(f_{LO} - (2 \times f_{BB}))$ , $P_{OUT} = 2.6$ dBm		-56		dBc
Third Baseband Harmonic	$(f_{LO} + (3 \times f_{BB}))$ , $P_{OUT} = 2.6$ dBm		-45		dBc
Output IP2	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		54		dBm
Output IP3	F1 = 3.5 MHz, F2 = 4.5 MHz, $P_{OUT} = -3$ dBm per tone		21		dBm
Quadrature Phase Error			1.5		Degrees
I/Q Amplitude Balance			<0.05		dB

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
Noise Floor	20 MHz offset from LO, all BB inputs at a bias of 500 mV		-160		dBm/Hz
Output Return Loss	20 MHz offset from LO, output power = -5 dBm		-156		dBm/Hz
			-15		dB
LO INPUTS	Pin LOIP and Pin LOIN				
LO Drive Level	Characterization performed at typical level $f_{OUT} < 50$ MHz	-10	-7	+5	dBm
Input Impedance		0	0	5	dBm
Input Return Loss	350 MHz, LOIN ac-coupled to ground		50		$\Omega$
			-20		dB
BASEBAND INPUTS	Pin IBBP, Pin IBBN, Pin QBBP, Pin QBBN				
I and Q Input Bias Level			500		mV
Input Bias Current			-70		$\mu$ A
Bandwidth (0.1 dB)	RF = 500 MHz, output power = 0 dBm		80		MHz
Bandwidth (3 dB)	RF = 500 MHz, output power = 0 dBm		>500		MHz
ENABLE INPUT	ENBL				
Turn-On Settling Time	ENBL = high (for output to within 0.5 dB of final value)		1.0		$\mu$ s
Turn-Off Settling Time	ENBL = low (at supply current falling below 20 mA)		1.4		$\mu$ s
ENBL High Level (Logic 1)		1.5			V
ENBL Low Level (Logic 0)				0.4	V
TEMPERATURE OUTPUT	TEMP				
Output Voltage	$T_A = 27.15^\circ\text{C}$ , 300.3 K, $R_L = 1$ M $\Omega$ (after full warm up)		1.56		V
Temperature Slope	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ , $R_L = 1$ M $\Omega$		4.6		mV/ $^\circ\text{C}$
Output Impedance			1.0		k $\Omega$
POWER SUPPLIES	Pin VPS1 and Pin VPS2				
Voltage		4.75		5.5	V
Supply Current	ENBL = high		215	240	mA
	ENBL = low		80		$\mu$ A

## ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Supply Voltage VPOS	5.5 V
IBBP, IBBN, QBBP, QBBN Range	0 V to 2.0 V
LOIP and LOIN	13 dBm
Internal Power Dissipation	1.375 W
$\theta_{JA}$ (Exposed Pad Soldered Down)	58°C/W
Maximum Junction Temperature	164°C
Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

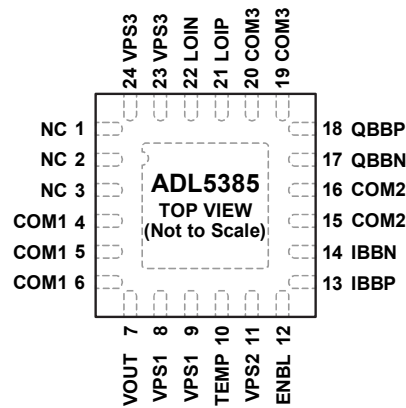
### ESD CAUTION



**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.



## PIN CONFIGURATION AND FUNCTION DESCRIPTIONS



## NOTES

1. NC = NO CONNECT. DO NOT CONNECT TO THIS PIN.
2. EXPOSED PAD. SOLDER THE EXPOSED PAD TO A LOW IMPEDANCE GROUND PLANE.

06118-002

Figure 2. Pin Configuration

Table 3. Pin Function Descriptions

Pin No.	Mnemonic	Description
1, 2, 3	NC	No Connect. Leave these pins open or tie them to ground.
4, 5, 6, 15, 16, 19, 20	COM1, COM2, COM3	Power Supply Common Pins. Connect COM1, COM2, and COM3 to a ground plane via a low impedance path.
7	VOUT	Device Output. Single-ended, 50 $\Omega$ internally biased RF/IF output; pin must be ac-coupled to the load.
8, 9, 11, 23, 24	VPS1, VPS2, VPS3	Power Supply Pins. Decouple each pin with a 0.1 $\mu$ F capacitor; Pin 8 and Pin 9 can share a single capacitor, as can Pin 23 and Pin 24. Connect all pins to the same supply.
10	TEMP	Temperature Sensor Output. Provides dc voltage proportional to die temperature. Slope is 4.6 mV/ $^{\circ}$ C
12	ENBL	Device Enable. Shuts device down when grounded and enables device when pulled to supply voltage.
13, 14, 17, 18	IBBP, IBBN, QBBN, QBBP	Differential In-Phase and Quadrature Baseband Inputs. These high impedance inputs must be externally dc-biased to 500 mV dc and driven from a low impedance source. Nominal characterized ac signal swing is 700 mV p-p on each pin (150 mV to 850 mV). This results in a differential drive of 1.4 V p-p with a 500 mV dc bias.
21	LOIP	Single-Ended Two-Times Local Oscillator Input. This input is internally biased and must be ac-coupled to the LO source.
22	LOIN EPAD	Common for LO Input. Must be ac-coupled to ground through a low impedance path. Exposed Pad. Solder the exposed pad to a low impedance ground plane.

### TYPICAL PERFORMANCE CHARACTERISTICS

Unless otherwise noted,  $V_S = 5\text{ V}$ ;  $T_A = 25^\circ\text{C}$ ;  $LO = -7\text{ dBm}$ ; I/Q inputs = 1.4 V p-p differential sine waves in quadrature on a 500 mV dc bias; baseband frequency = 1 MHz; LO source and RF output load impedances are 50  $\Omega$ .

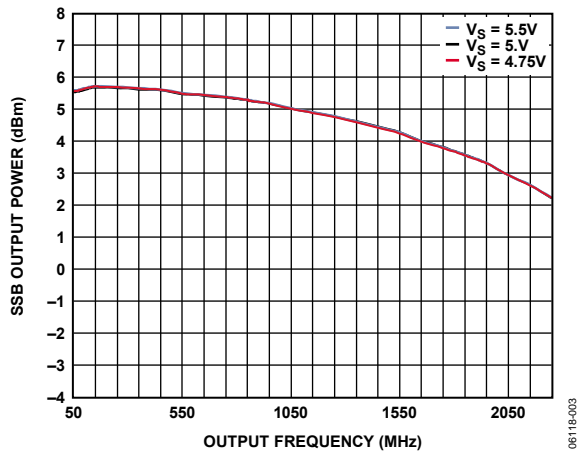


Figure 3. Single Sideband (SSB) Output Power ( $P_{out}$ ) vs. Output Frequency and Power Supply

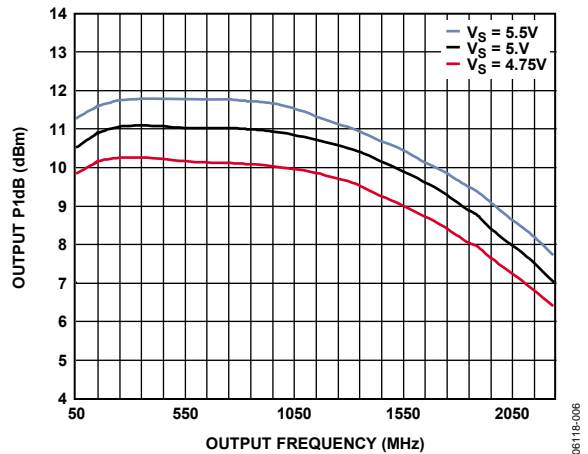


Figure 6. Output 1 dB Compression Point ( $OP_{1dB}$ ) vs. Output Frequency and Power Supply

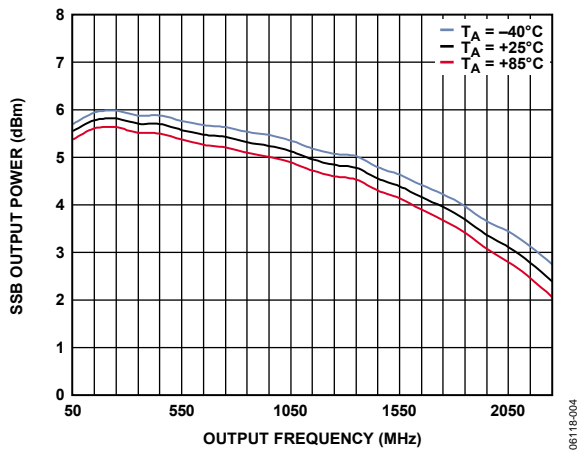


Figure 4. Single Sideband (SSB) Output Power ( $P_{out}$ ) vs. Output Frequency and Temperature

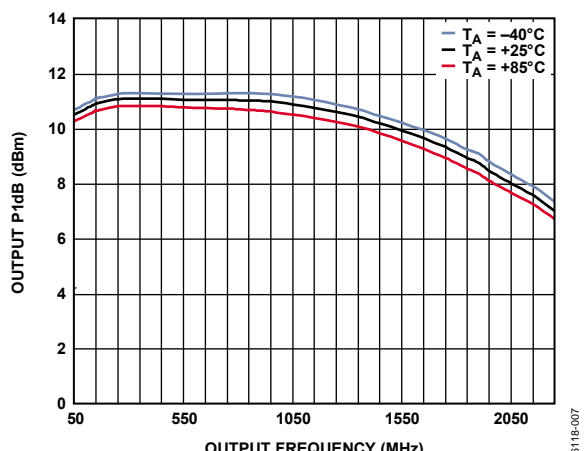


Figure 7. Output 1 dB Compression Point ( $OP_{1dB}$ ) vs. Output Frequency and Temperature

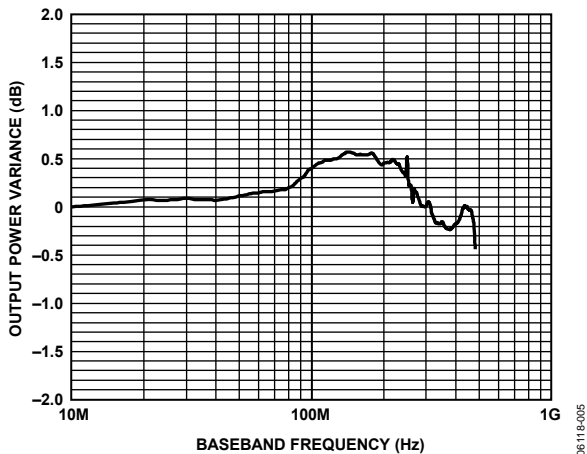


Figure 5. Baseband Frequency Response Normalized to Response for 1 MHz BB Signal; Carrier Frequency = 500 MHz

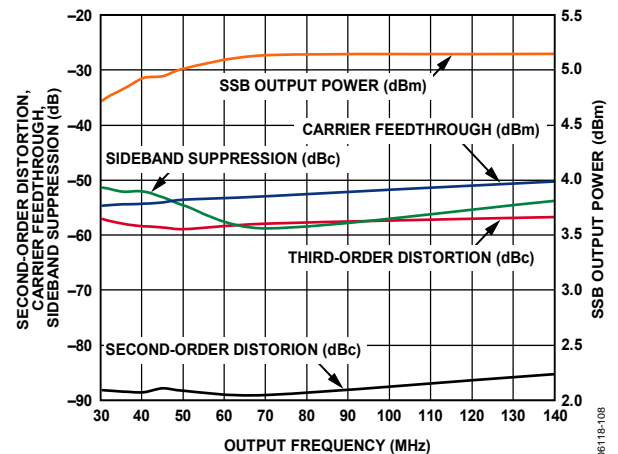


Figure 8. SSB Output Power, Second- and Third-Order Distortion, Carrier Feedthrough, and Sideband Suppression vs. Output Frequency; LO Amplitude = 0 dBm

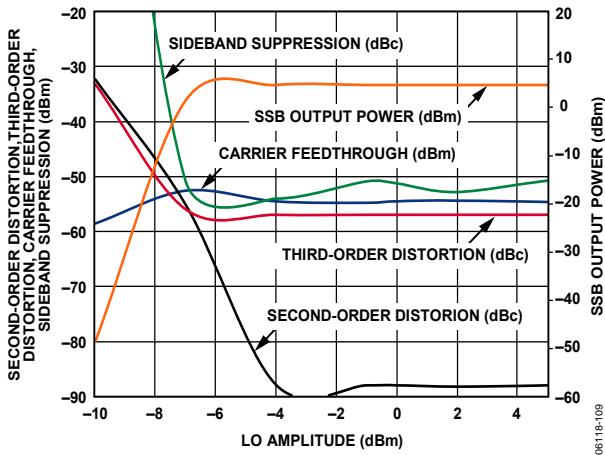


Figure 9. SSB Output Power, Second- and Third-Order Distortion, Carrier Feedthrough, and Sideband Suppression vs. LO Amplitude; Output Frequency = 30 MHz

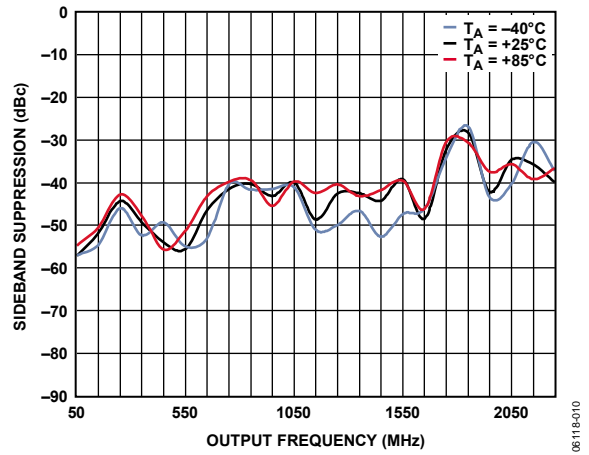


Figure 12. Sideband Suppression vs. Output Frequency and Temperature

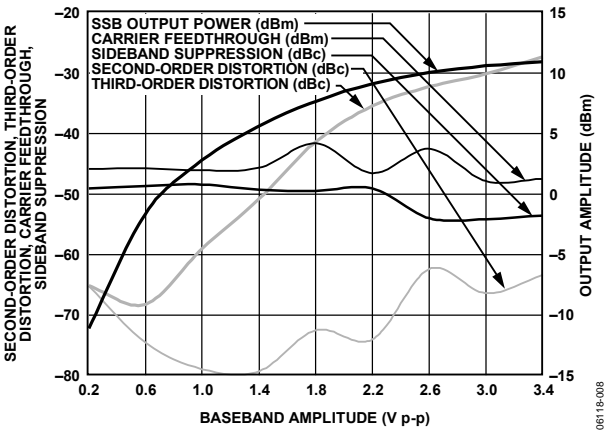


Figure 10. SSB Output Power, Second- and Third-Order Distortion, Carrier Feedthrough and Sideband Suppression vs. Differential Baseband Input Level; Output Frequency = 350 MHz

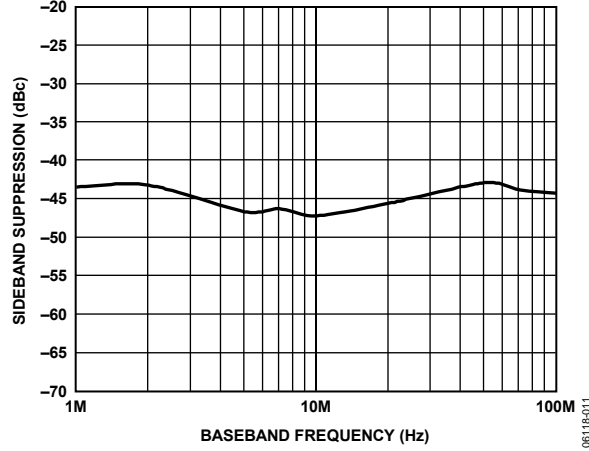


Figure 13. Sideband Suppression vs. Baseband Frequency; Output Frequency = 350 MHz

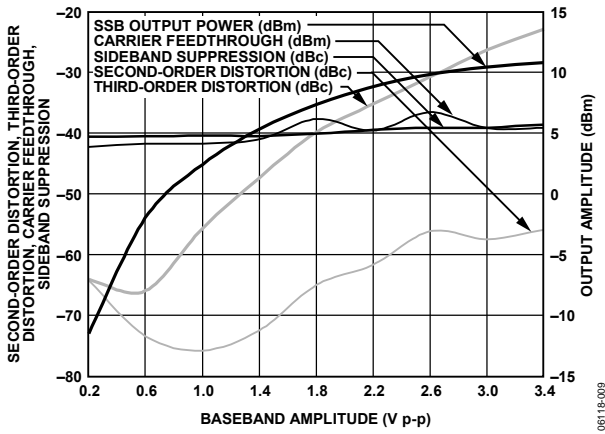


Figure 11. SSB Output Power, Second- and Third-Order Distortion, Carrier Feedthrough and Sideband Suppression vs. Baseband Single-Ended Input Level; Output Frequency = 860 MHz

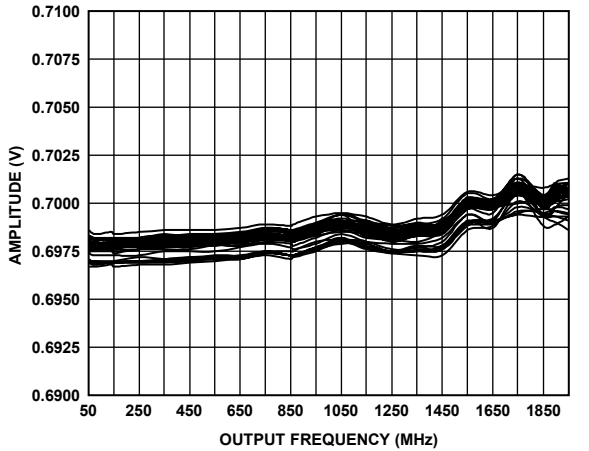


Figure 14. Distribution of Peak Q Amplitude to Null Undesired Sideband (Peak I Amplitude Held Constant at 0.7 V)

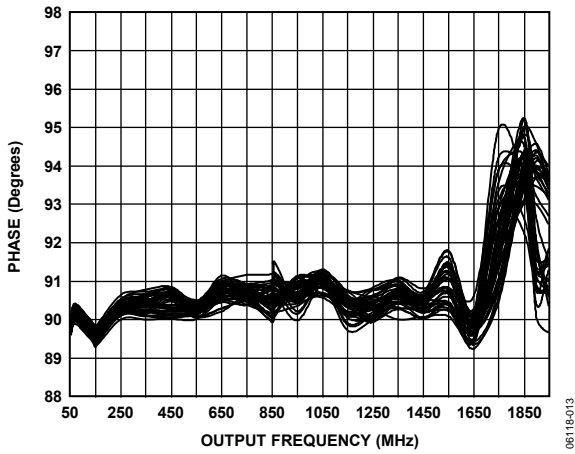


Figure 15. Distribution of IQ Phase to Null Undesired Sideband

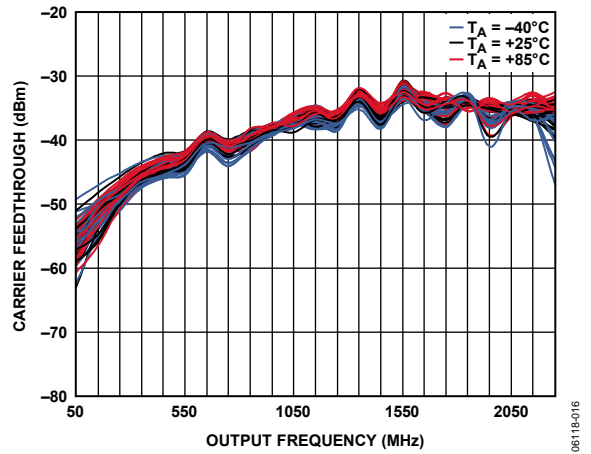


Figure 18. Distribution Carrier Feedthrough vs. Output Frequency and Temperature

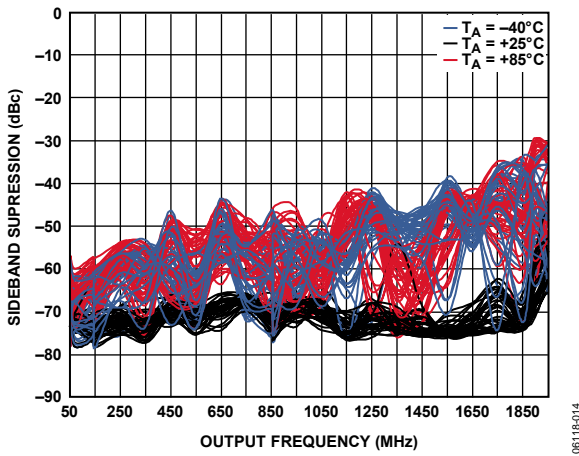


Figure 16. Sideband Suppression Distribution at Temperature Extremes, After Sideband Suppression Nulled to < -50 dBc at TA = +25°C

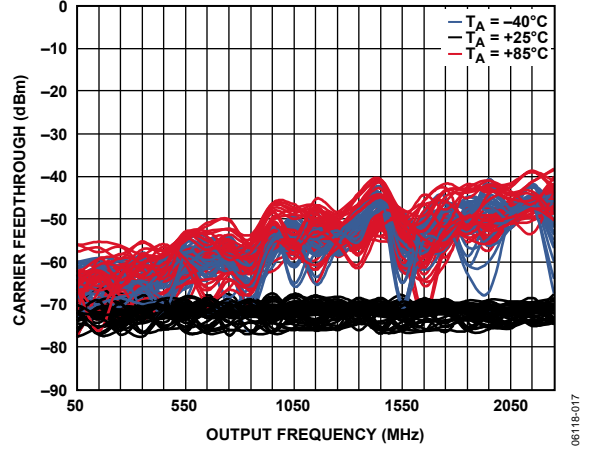


Figure 19. Carrier Feedthrough Distribution at Temperature Extremes, After Nulling to < -65 dBm at TA = +25°C

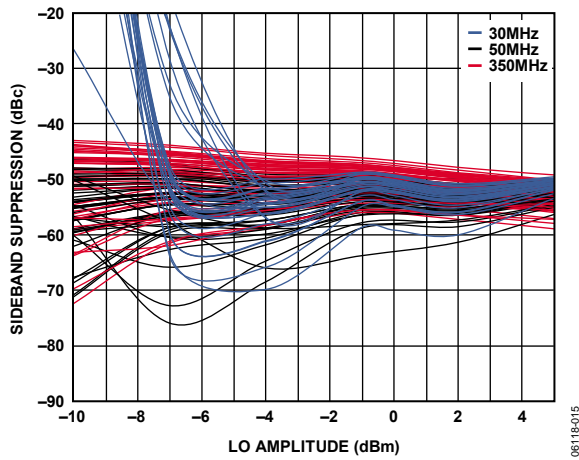


Figure 17. Distribution of Sideband Suppression vs. LO Input Power at 30 MHz, 50 MHz, and 350 MHz Output Frequencies

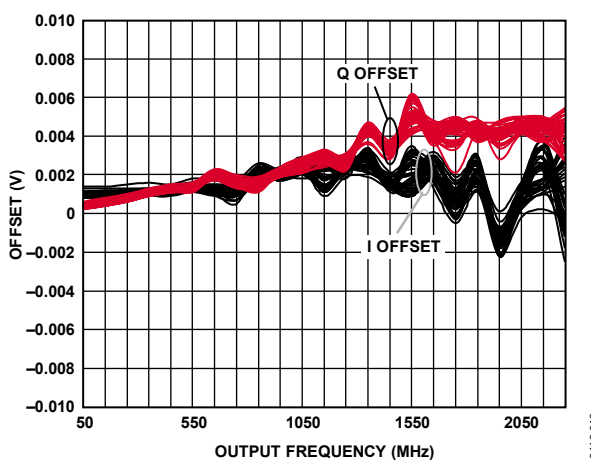


Figure 20. Distribution of I and Q Offset Required to Null Carrier Feedthrough

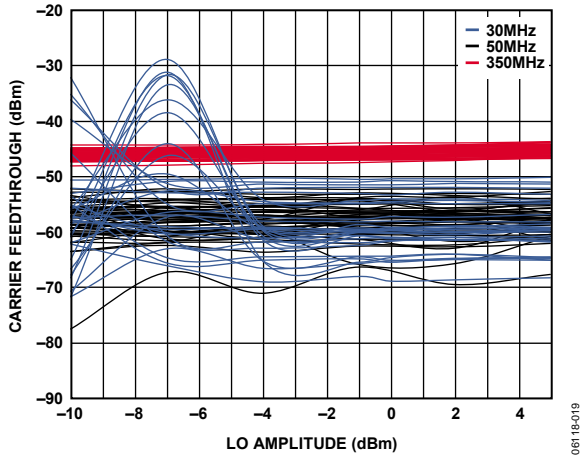


Figure 21. Distribution Carrier Feedthrough vs. LO Input Power at 30 MHz, 50 MHz, and 350 MHz Output Frequencies

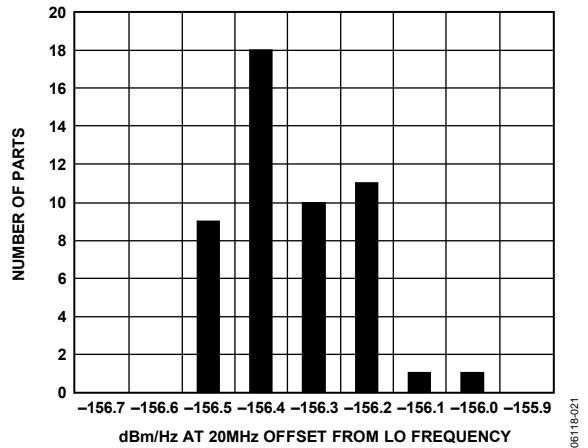


Figure 23. 20 MHz Offset Noise Floor Distribution, Output Frequency = 350 MHz,  $P_{OUT} = -5$  dBm, QPSK Carrier, Symbol Rate = 3.84 MSPS

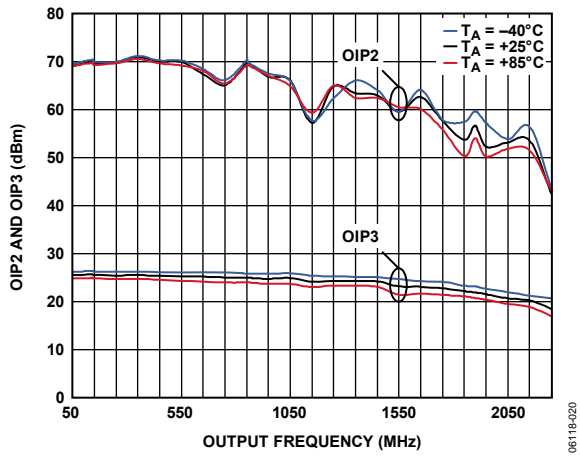


Figure 22. OIP3 and OIP2 vs. Output Frequency and Temperature

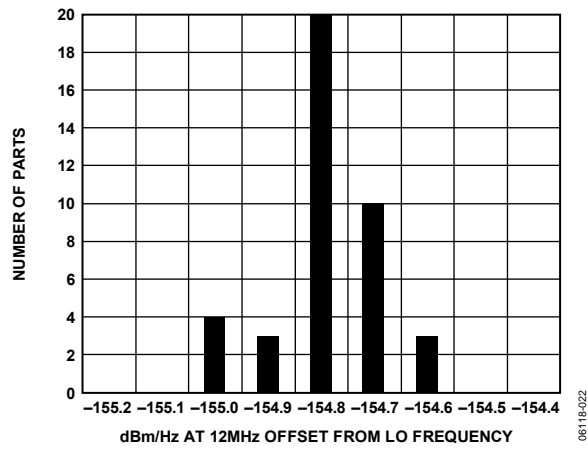


Figure 24. 12 MHz Offset Noise Floor Distribution, Output Frequency = 860 MHz,  $P_{OUT} = -5$  dBm, 64 QAM Carrier, Symbol Rate = 5 MSPS

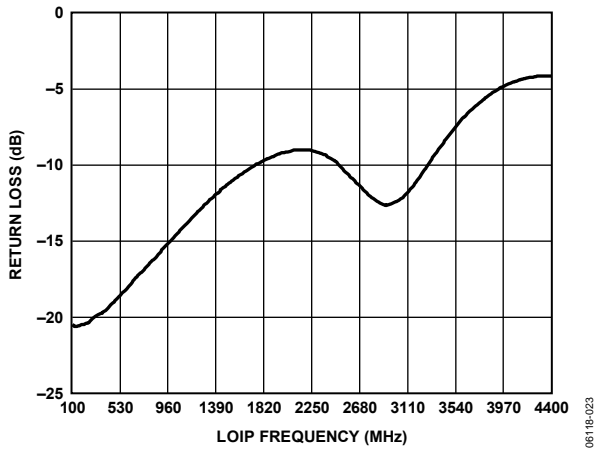


Figure 25. LO Port Input Return Loss vs. Frequency

06118-023

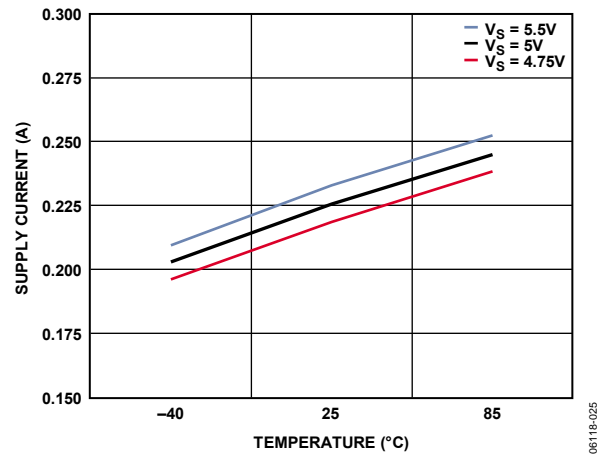


Figure 27. Power Supply Current vs. Temperature and Supply Voltage

06118-025

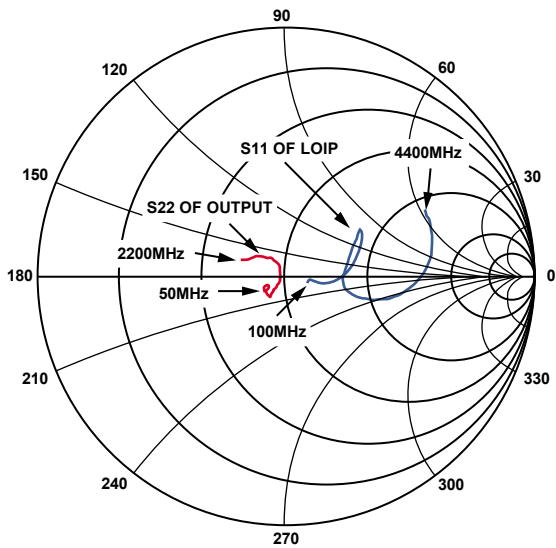


Figure 26. Output Impedance and LO Input Impedance vs. Frequency

06118-024

## CIRCUIT DESCRIPTION

### OVERVIEW

The ADL5385 can be divided into five sections: the local oscillator (LO) interface, the baseband voltage-to-current (V-to-I) converter, the mixers, the differential-to-single-ended (D-to-S) amplifier, and the bias circuit. A detailed block diagram of the device is shown in Figure 28.

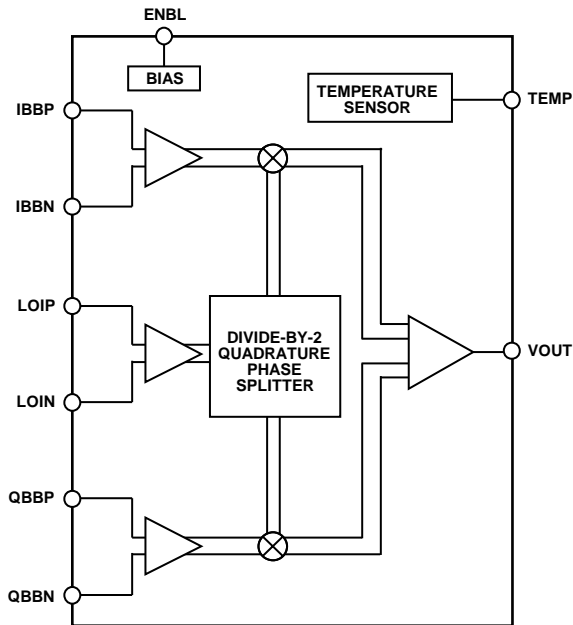


Figure 28. ADL5385 Block Diagram

The LO interface generates two LO signals at 90° of phase difference to drive two mixers in quadrature. Baseband signals are converted into currents by the V-to-I converters that feed into the two mixers. The outputs of the mixers are combined in the differential-to-single-ended amplifier, which provides a 50 Ω output interface. Reference currents to each section are generated by the bias circuit. A detailed description of each section follows.

### LO INTERFACE

The LO interface consists of a buffer amplifier followed by a pair of frequency dividers that generate two carriers at half the input frequency and in quadrature with each other. Each carrier is then amplified and amplitude-limited to drive the double-balanced mixers.

### V-TO-I CONVERTER

The differential baseband input voltages that are applied to the baseband input pins are fed to a pair of common-emitter, voltage-to-current converters. The output currents then modulate the two half-frequency LO carriers in the mixer stage.

### MIXERS

The ADL5385 has two double-balanced mixers: one for the in-phase channel (I channel) and one for the quadrature channel (Q channel). These mixers are based on the Gilbert cell design of four cross-connected transistors. The output currents from the two mixers are summed together in the resistor-inductor (RL) loads in the D-to-S amplifier.

### D-TO-S AMPLIFIER

The output D-to-S amplifier consists of two emitter followers driving a totem-pole output stage that converts the differential signal to a single-ended signal. Output impedance is established by the emitter resistors in the output transistors. The output of this stage connects to the output (VOUT) pin.

### BIAS CIRCUIT

A band gap reference circuit generates the proportional-to-absolute-temperature (PTAT) as well as temperature-independent reference currents used by different sections. The band-gap circuit is turned on by a logic high at the ENBL pin, which in turn powers up the whole device. A PTAT voltage output is available at the TEMP pin, which can be used for temperature monitoring as well as for temperature compensation purposes.

## BASIC CONNECTIONS

Figure 29 shows the basic connections for the ADL5385.

### POWER SUPPLY AND GROUNDING

All the VPS pins must be connected to the same 5 V source. Adjacent pins of the same name can be tied together and decoupled with a 0.1  $\mu\text{F}$  capacitor. Locate these capacitors as close as possible to the device. The power supply can range from 4.75 V to 5.5 V.

The COM1 pin, COM2 pin, and COM3 pin are tied to the same ground plane through low impedance paths. The exposed pad on the underside of the package is also soldered to a low thermal and electrical impedance ground plane. If the ground plane spans multiple layers on the circuit board, stitch the layers together with nine vias under the exposed pad. The Analog Devices AN-722 Application Note discusses the thermal and electrical grounding of the LFCSP in greater detail.

### BASEBAND INPUTS

The baseband inputs QBBP, QBBN, IBBP, and IBBN must be driven from a differential source. The nominal drive level of 1.4 V p-p differential (700 mV p-p on each pin) is biased to a common-mode level of 500 mV dc.

The dc common-mode bias level for the baseband inputs can range from 400 mV to 600 mV. This results in a reduction in the usable input ac swing range. The nominal dc bias of 500 mV allows for the largest ac swing, limited on the bottom end by the ADL5385 input range and on the top end by the output compliance range on most Analog Devices DACs.

### LO INPUT

A single-ended LO signal is applied to the LOIP pin through an ac coupling capacitor. The LO return pin, LOIN, must be ac-coupled to ground through a low impedance path.

The LO input can be driven differentially, in which case the user ac couples both sides of the differential LO source through a pair of series capacitors to the LOIP and LOIN pins. The nominal LO drive of  $-7$  dBm, which is recommended, can be increased to up to 5 dBm. For operation below 50 MHz, it is recommended to use a minimum LO drive level of 0 dBm. The effect of LO power on sideband suppression and carrier feedthrough is shown in Figure 17 and Figure 21. The performance vs. LO power at 30 MHz output frequency is shown at Figure 9.

### RF OUTPUT

The RF output is available at the VOUT pin (Pin 7). This pin must also be ac-coupled. Below 150 MHz, output power decreases due to internal ac-coupling. This is shown in Figure 8. The VOUT pin has a nominal broadband impedance of 50  $\Omega$  and does not need further external matching.

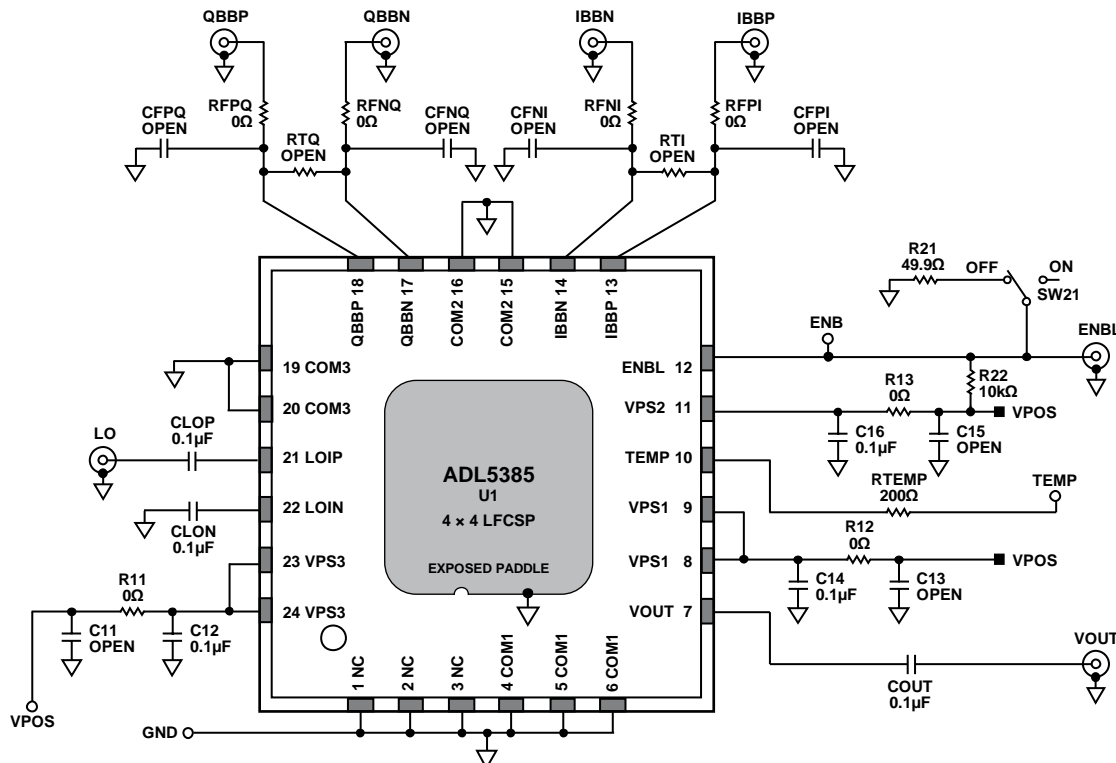


Figure 29. Basic Connections for the ADL5385



**OPTIMIZATION**

The carrier feedthrough and sideband suppression performance of the ADL5385 can be improved through the use of optimization techniques.

**Carrier Feedthrough Nulling**

Carrier feedthrough results from minute dc offsets that occur between each of the differential baseband inputs. In an ideal modulator, the quantities  $(V_{IOPP} - V_{IOPN})$  and  $(V_{QOPP} - V_{QOPN})$  are equal to zero, and this results in no carrier feedthrough. In a real modulator, those two quantities are nonzero and, when mixed with the LO, result in a finite amount of carrier feedthrough. The ADL5385 is designed to provide a minimal amount of carrier feedthrough. If even lower carrier feedthrough levels are required, minor adjustments can be made to the  $(V_{IOPP} - V_{IOPN})$  and  $(V_{QOPP} - V_{QOPN})$  offsets. The I-channel offset is held constant while the Q-channel offset is varied until a minimum carrier feedthrough level is obtained. The Q-channel offset required to achieve this minimum is held constant while the offset on the I-channel is adjusted, until a better minimum is reached. Through two iterations of this process, the carrier feedthrough can be reduced to as low as the output noise. The ability to null is sometimes limited by the resolution of the offset adjustment. Figure 30 shows the relationship of carrier feedthrough vs. dc offset.

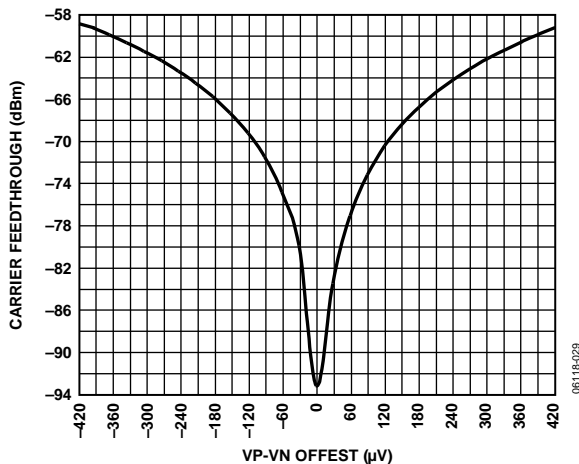


Figure 30. Carrier Feedthrough vs. DC Offset Voltage at 450 MHz

Note that throughout the nulling process, the dc bias for the baseband inputs remains at 500 mV. When no offset is applied,

$$V_{IOPP} = V_{IOPN} = 500 \text{ mV, or}$$

$$V_{IOPP} - V_{IOPN} = V_{IOS} = 0 \text{ V}$$

When an offset of  $+V_{IOS}$  is applied to the I-channel inputs,

$$V_{IOPP} = 500 \text{ mV} + V_{IOS}/2, \text{ while}$$

$$V_{IOPN} = 500 \text{ mV} - V_{IOS}/2, \text{ such that}$$

$$V_{IOPP} - V_{IOPN} = V_{IOS}$$

The same applies to the Q channel.

It is often desirable to perform a one-time carrier null calibration. This is usually performed at a single frequency. Figure 31 shows how carrier feedthrough varies with LO frequency over a range of  $\pm 50$  MHz on either side of a null at 350 MHz.

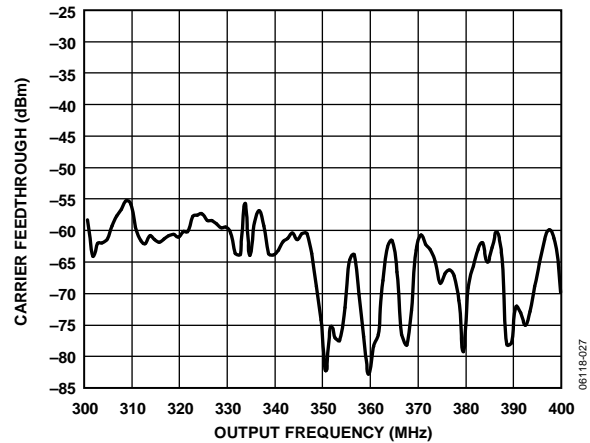


Figure 31. Carrier Feedthrough vs. Frequency After Nulling at 350 MHz

**Sideband Suppression Optimization**

Sideband suppression results from relative gain and relative phase offsets between the I and Q channels and can be suppressed through adjustments to those two parameters. Figure 32 illustrates how sideband suppression is affected by the gain and phase imbalances.

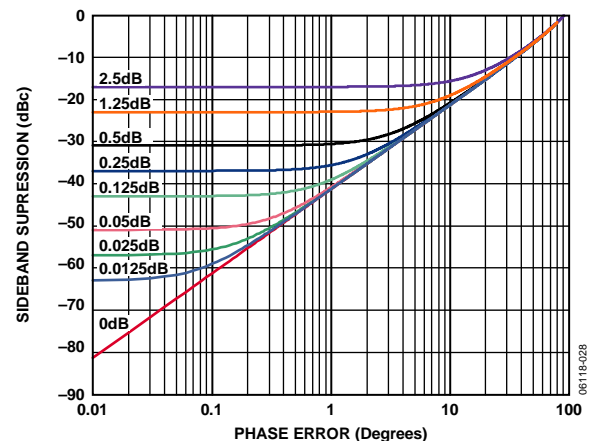


Figure 32. Sideband Suppression vs. Quadrature Phase Error for Various Quadrature Amplitude Offsets

Figure 32 underscores the fact that adjusting one parameter improves the sideband suppression only to a point; the other parameter must also be adjusted. For example, if the amplitude offset is 0.25 dB, improving the phase imbalance better than  $1^\circ$  does not yield any improvement in the sideband suppression. For optimum sideband suppression, an iterative adjustment between phase and amplitude is required.

The sideband suppression nulling can be performed either through adjusting the gain for each channel or through the modification of the phase and gain of the digital data coming from the digital signal processor.

## APPLICATIONS INFORMATION

### DAC MODULATOR INTERFACING

The ADL5385 is designed to interface with minimal components to members of the Analog Devices family of digital-to-analog converters (DAC). These DACs feature an output current swing from 0 mA to 20 mA, and the interface described in this section can be used with any DAC that has a similar output.

#### Driving the ADL5385 with an Analog Devices TxDAC®

An example of the interface using the AD9777 TxDAC is shown in Figure 33. The baseband inputs of the ADL5385 require a dc bias of 500 mV. The average output current on each of the outputs of the AD9777 is 10 mA. Therefore, a single 50 Ω resistor to ground from each of the DAC outputs results in an average current of 10 mA flowing through each of the resistors, thus producing the desired 500 mV dc bias for the inputs to the ADL5385.

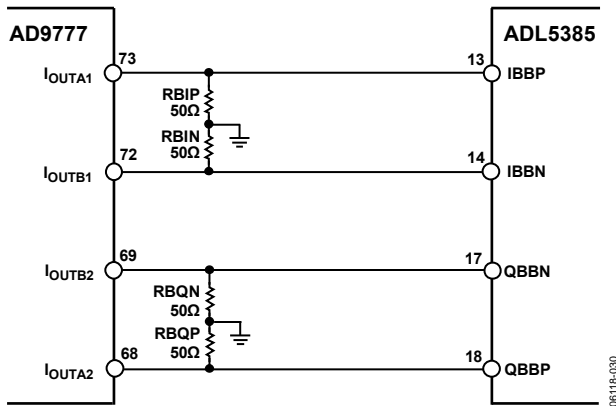


Figure 33. Interface Between AD9777 and ADL5385 with 50 Ω Resistors to Ground to Establish the 500 mV DC Bias for the ADL5385 Baseband Inputs

The AD9777 output currents have a swing that ranges from 0 mA to 20 mA. With the 50 Ω resistors in place, the ac voltage swing going into the ADL5385 baseband inputs ranges from 0 V to 1 V. A full-scale sine wave out of the AD9777 can be described as a 1 V p-p single-ended (or 2 V p-p differential) sine wave with a 500 mV dc bias.

#### Limiting the AC Swing

There are situations in which it is desirable to reduce the ac voltage swing for a given DAC output current. This can be achieved through the addition of another resistor to the interface. This resistor is placed in shunt between each side of the differential pair, as illustrated in Figure 34. It has the effect of reducing the ac swing without changing the dc bias already established by the 50 Ω resistors.

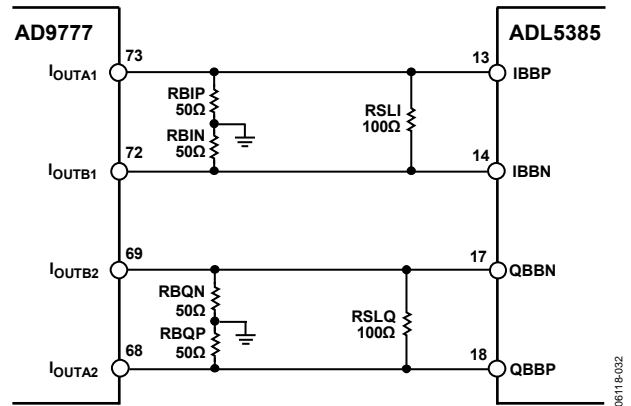


Figure 34. AC Voltage Swing Reduction Through Introduction of Shunt Resistor Between Differential Pair

The value of this ac voltage swing limiting resistor is chosen based on the desired ac voltage swing. Figure 35 shows the relationship between the swing-limiting resistor and the peak-to-peak ac swing that it produces when 50 Ω bias setting resistors are used.

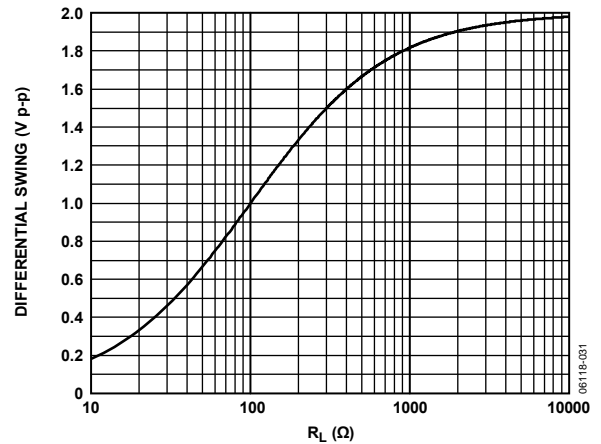


Figure 35. Relationship Between AC Swing Limiting Resistor and Peak-to-Peak Voltage Swing with 50 Ω Bias Setting Resistors

#### Filtering

When driving a modulator from a DAC, it is necessary to introduce a low-pass filter between the DAC and the modulator to reduce the DAC images. The interface for setting up the biasing and ac swing lends itself well to the introduction of such a filter. The filter can be inserted in between the dc bias setting resistors and the ac swing-limiting resistor, thus establishing the input and output impedances for the filter.

Examples of filters are discussed in the 155 Mbps (STM-1) 128 QAM Transmitter section and the CMTS Transmitter Application section.

**Using AD9777 Auxiliary DAC for Carrier Feedthrough Nulling**

The AD9777 features an auxiliary DAC that can be used to inject small currents into the differential outputs for each channel. The auxiliary DAC can produce the small offset currents necessary to implement the nulling described in the Carrier Feedthrough Nulling section.

**155 Mbps (STM-1) 128 QAM TRANSMITTER**

Figure 39 shows how the ADL5385 can be interfaced to the AD9777 DAC (or any Analog Devices dual DAC with an output bias level of 0.5 V) to generate a 155 Mbps 128 QAM carrier at 355 MHz. Because the TxDAC output and the IQ modulator inputs operate at the same bias levels of 0.5 V, a simple dc-coupled connection can be implemented without any active or passive level shifting. The bias level and modulator drive level is set by the 50 Ω ground-referenced resistors and the 100 Ω shunt resistors, respectively (see the DAC Modulator Interfacing section). A baseband filter is placed between the bias and signal swing resistors. This 5-pole Chebychev filter with in-band ripple of 0.1 dB has a corner frequency of 39 MHz.

Figure 36 shows a spectral plot of the 128 QAM spectrum at a carrier power of -6.3 dBm. Figure 37 shows how EVM (measured with the analyzer’s internal equalizer both on and off) and SNR, measured at 55 MHz carrier offset (2.5 times the carrier bandwidth) varies with output power.

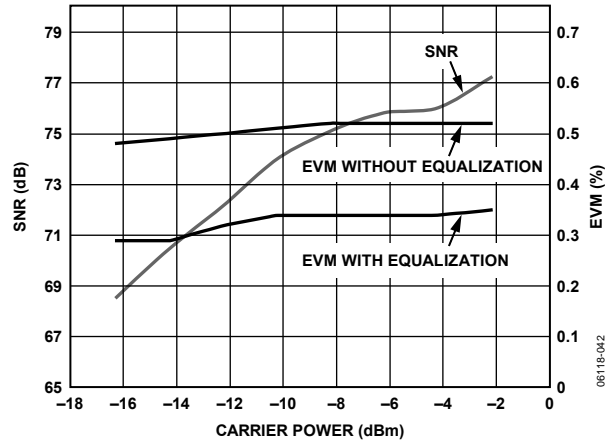


Figure 37. EVM and SNR vs. Output Power for 128 QAM Transmitter Application

**CMTS TRANSMITTER APPLICATION**

Because of its broadband operating range from 30 MHz to 2200 MHz, the ADL5385 can be used in direct-launch cable modem termination systems (CMTS) applications in the 50 MHz to 860 MHz cable band.

The same DAC and DAC-to-modulator interface and filtering circuit shown in Figure 39 was used in this application. Figure 38 shows a plot of a 4-carrier 256 QAM spectrum at an output frequency of 485 MHz.

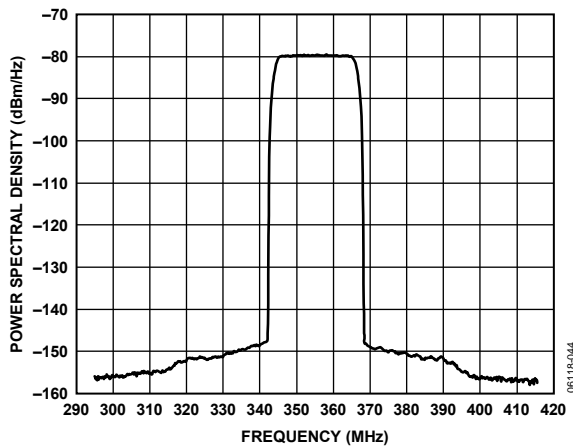


Figure 36. Spectral Plot of 128 QAM Transmitter at -6.3 dBm Output Power

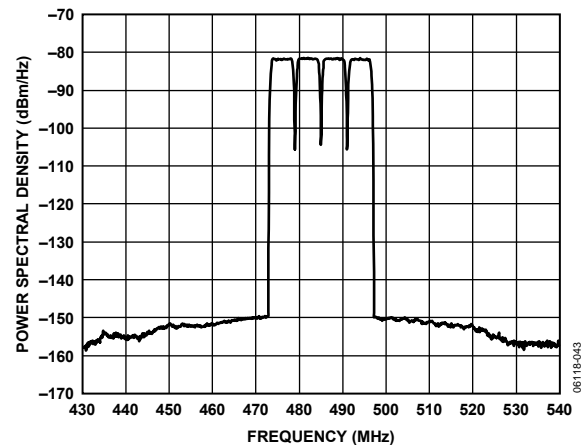


Figure 38. Spectrum of 4-Carrier 256 QAM CMTS Signal at 485 MHz

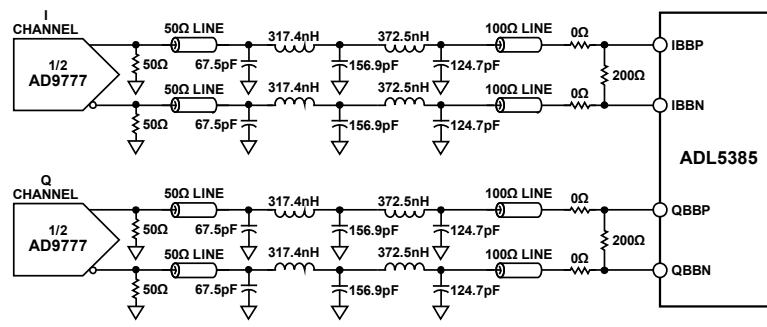


Figure 39. Recommended DAC-Modulator Interconnect for 128 QAM Transmitter

Figure 40 shows how adjacent channel power (measured at 750 kHz, 5.25 MHz, and 12 MHz offset from the last carrier) and modulation error ratio (MER) vary with carrier power.

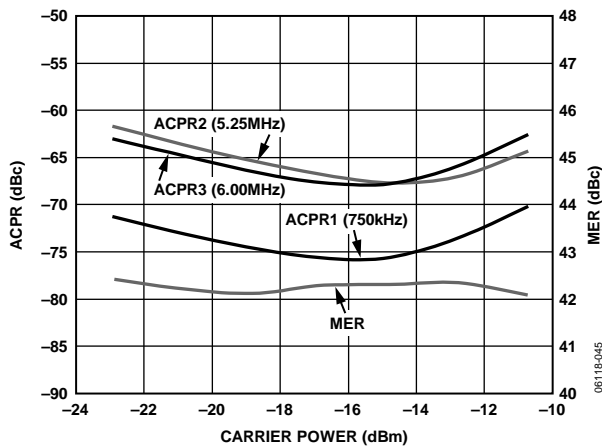


Figure 40. ACPR1, ACPR2, ACPR3, and Modulation Error Ratio (MER) vs. Output Power for 256 QAM Transmitter

**SPECTRAL PRODUCTS FROM HARMONIC MIXING**

For broadband applications such as cable TV head-end modulators, special attention must be paid to harmonics of the LO. Figure 41 shows the level of these harmonics (out to 3 GHz) as a function of the output frequency from 50 MHz to 1000 MHz, in a single-sideband (SSB) test configuration, with a baseband signal of 1 MHz and a SSB level of approximately -5 dBm. To read this plot correctly, first pick the output frequency of interest on the trace called P<sub>OUT</sub>. The associated harmonics can be read off the harmonic traces at multiples of this frequency. For example, at an output frequency of 500 MHz, the fundamental power is -5 dBm. The power of the second (P<sub>2LO - BB</sub>) and third (P<sub>3LO + BB</sub>) harmonics is -63 dBm (at 1000 MHz) and -16 dBm (at 1500 MHz), respectively. Of particular importance are the products from odd-harmonics of the LO, generated from the switching operation in the mixers.

For cable TV operation at frequencies above approximately 500 MHz, these harmonics fall out of the band and can be filtered by a fixed filter. However, as the frequency drops below 500 MHz, these harmonics start to fall close to or inside the cable band. This calls for either limitation of the frequency range to above 500 MHz or the use of a switchable filter bank to block in-band harmonics at low frequencies.

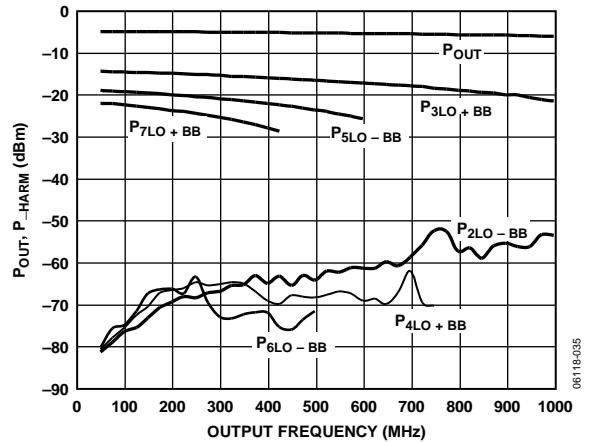


Figure 41. Spectral Components for Output Frequencies from 50 MHz to 1000 MHz

**RF SECOND-ORDER PRODUCTS**

A two-tone RF output signal produces second-order spectral components at sum and difference frequencies. In broadband systems, these intermodulation products fall inside the carrier or in the adjacent channels. Output second-order RF intermodulation intercept is defined as

$$OIP2_{RF} = P_{OUT} + (P_{OUT} - P_{IM(RF)})$$

where P<sub>IM(RF)</sub> is the level of the intermodulation product at f<sub>OUT1</sub> + f<sub>OUT2</sub>. OIP2<sub>RF</sub> levels from a two-tone test are plotted as a function of carrier frequency in Figure 42, where the baseband tones are 3.5 MHz and 4.5 MHz at -5 dBm each.

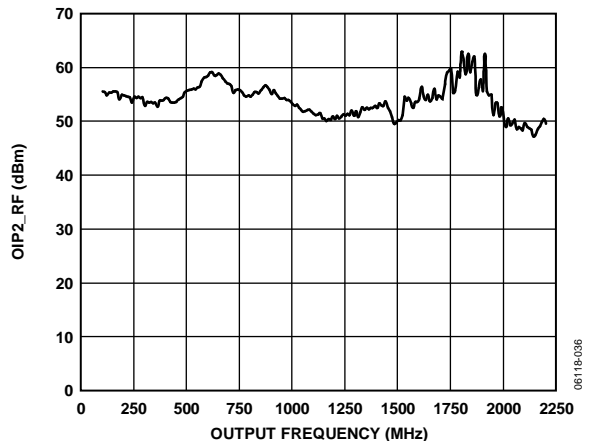


Figure 42. Output Second-Order Intermodulation vs. Carrier Frequency

## LO GENERATION USING PLLs

Analog Devices has a line of phase-locked loops (PLLs) that can be used for generating the LO signal. Table 4 lists the PLLs together with their maximum frequency and phase noise performance.

**Table 4. PLL Selection Table**

Device	Frequency $f_{IN}$ (MHz)	At 1 kHz Phase Noise dBc/Hz, 200 kHz PFD
ADF4110	550	-91 at 540 MHz
ADF4111	1200	-87 at 900 MHz
ADF4112	3000	-90 at 900 MHz
ADF4113	4000	-91 at 900 MHz
ADF4116	550	-89 at 540 MHz
ADF4117	1200	-87 at 900 MHz
ADF4118	3000	-90 at 900 MHz

The ADF4360-0 through the ADF4360-8 (see Table 5 for the full list of devices included in this range) come as a family of chips, with nine operating frequency ranges. One device can be chosen depending on the local oscillator frequency required. While the use of the integrated synthesizer might come at the expense of slightly degraded noise performance from the ADL5385, it can be a cheaper alternative to a separate PLL and VCO solution. Alternatively, the ADF4351 can be used, which covers a frequency range of 35 MHz to 4400 MHz. Table 5 shows the options available.

**Table 5. PLL/VCO Family Operating Frequencies**

Device	Output Frequency Range (MHz)
ADF4351	35 to 4400
ADF4360-0	2400 to 2725
ADF4360-1	2050 to 2450
ADF4360-2	1850 to 2150
ADF4360-3	1600 to 1950
ADF4360-4	1450 to 1750
ADF4360-5	1200 to 1400
ADF4360-6	1050 to 1250
ADF4360-7	350 to 1800
ADF4360-8	65 to 400

## TRANSMIT DAC OPTIONS

The AD9777 recommended in the previous sections is by no means the only DAC that can be used to drive the ADL5385. There are other appropriate DACs depending on the level of performance required. Table 6 lists the dual TxDACs that Analog Devices offers.

**Table 6. Dual TxDAC Selection Table**

Device	Resolution (Bits)	Update Rate (MSPS Minimum)
AD9709	8	125
AD9761	10	40
AD9763	10	125
AD9765	12	125
AD9767	14	125
AD9773	12	160
AD9775	14	160
AD9777	16	160
AD9776	12	1000
AD9778	14	1000
AD9779	16	1000
AD9122	16	1200

All DACs listed have nominal bias levels of 0.5 V and use the same DAC-modulator interface shown in Figure 33.

## MODULATOR/DEMULATOR OPTIONS

Table 7 lists other Analog Devices discrete modulators and demodulators.

**Table 7. Modulator/Demodulator Options**

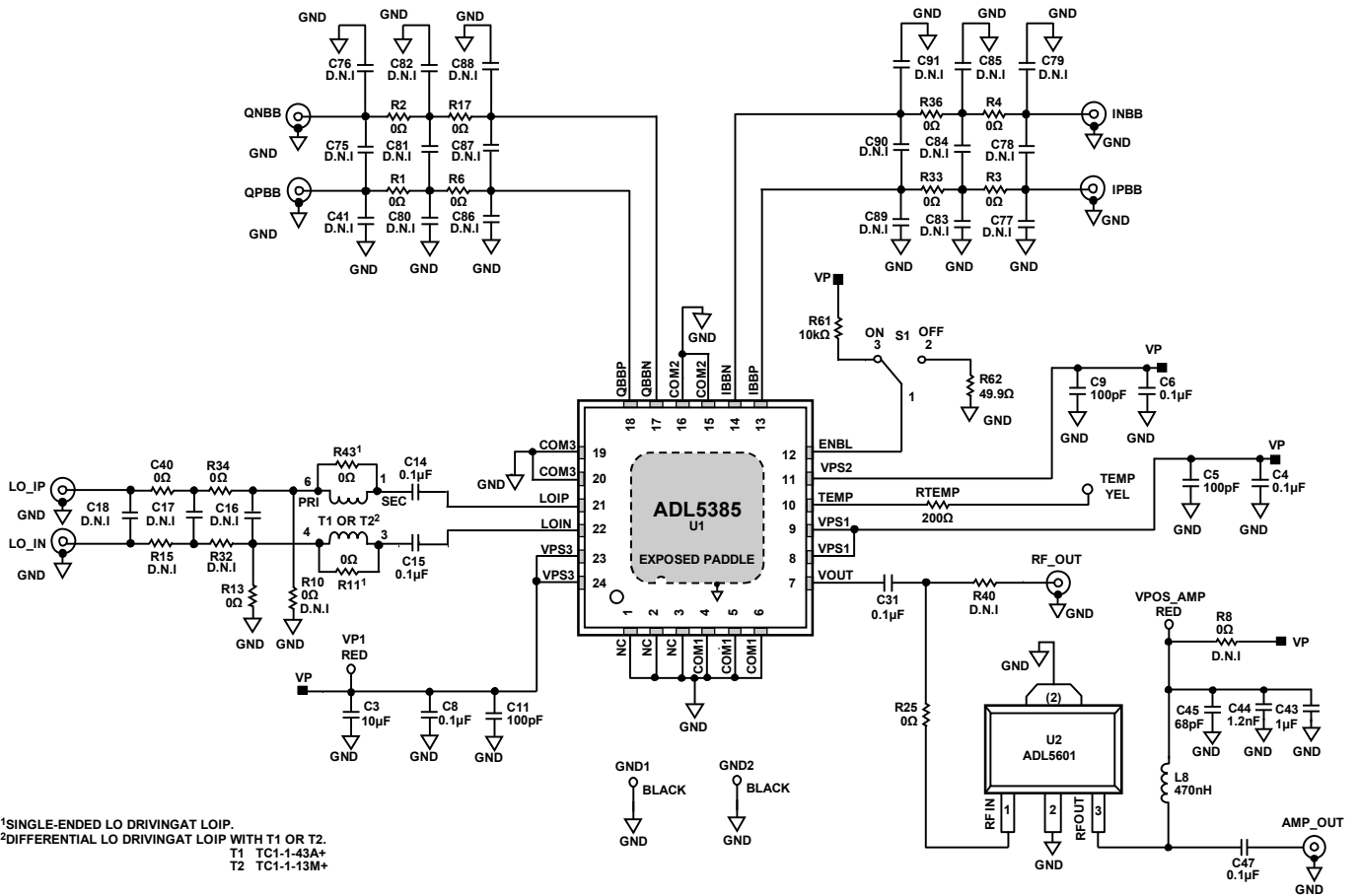
Device	Mod/Demod	Frequency Range (MHz)	Comments
AD8345	Mod	140 to 1000	External quadrature
AD8346	Mod	800 to 2500	
AD8349	Mod	700 to 2700	
ADL5390	Mod	20 to 2400	
ADL5370	Mod	300 to 1000	
ADL5371	Mod	500 to 1500	
ADL5372	Mod	1500 to 2500	
ADL5373	Mod	2300 to 3000	
ADL5375	Mod	400 to 6000	
ADL5386	Mod	50 to 2200	
AD8347	Demod	800 to 2700	Includes VVA and AGC
AD8348	Demod	50 to 1000	
ADL5380	Demod	400 to 6000	
ADL5382	Demod	700 to 2700	
ADL5387	Demod	30 to 2000	
AD8340	Vector mod	700 to 1000	
AD8341	Vector mod	1500 to 2400	

### EVALUATION BOARD

One populated, RoHS-compliant [ADL5385](#) evaluation board is available, the [ADL5385-DIFFLO-EBZ](#). The [ADL5385-DIFFLO-EBZ](#) can be configured to allow a differential LO drive through a balun or direct interfacing to a PLL evaluation board. It also includes component pads in its LO path to accommodate a harmonic filter. The four baseband inputs are located on one edge of the board to allow direct connection to a high speed DAC evaluation board. The [ADL5385-DIFFLO-EBZ](#) also includes an RF/IF amplifier.

The modulator output can be measured directly at the RF\_OUT SMA connector. Alternatively, by removing R40, and installing a 0 Ω resistor in the R25 pad, the modulator output can be fed to the RF amplifier.

The [ADL5385-DIFFLO-EBZ](#) ships installed with an [ADL5601](#) amplifier (50 MHz to 4000 MHz RF/IF amplifier). The [ADL5602](#) can be used if more gain is needed. Figure 43, Table 8, Figure 44, and Figure 45 show the schematic, configuration options, and layouts for the [ADL5385-DIFFLO-EBZ](#), respectively.



<sup>1</sup>SINGLE-ENDED LO DRIVING AT LOIP.  
<sup>2</sup>DIFFERENTIAL LO DRIVING AT LOIP WITH T1 OR T2.  
 T1 TC1-1-43A+  
 T2 TC1-1-13M+

Figure 43. ADL5385-DIFFLO-EBZ Schematic

Table 8. ADL5385-DIFFLO-EBZ Configuration Options

Component	Description	Default Value
VP1, VPOS_AMP, GND1, GND2	Power supply clip leads, and ground clip leads.	Red (VP1) = 5 V, red (VPOS_AMP) = GND, GND1 and GND2 = black
GND		Not applicable
S1, R61, R62	Device enable select. Set S1 to VP to enable the device. Set S1 to GND to power down the device.	S1 = on, R61 = 10 kΩ, R62 = 49.9 Ω
R1, R2, R3, R4, R6, R17, R33, R36, C41, C75 to C91	Baseband input filters. These components can be used to implement a low-pass filter for the baseband signals.	R1, R2, R3, R4, R6, R17, R33, R36 = 0 Ω, C41, C75 to C91 = open
C14, C15	LO driving capacitor.	C14, C15 = 0.1 µF
R15, R32, R34, C16 to C18, C40	LO input filters. These components can be used to implement a filter for the LO input signals.	R15, R32 = open, R34, C40 = 0 Ω, C16 to C18 = open

Component	Description	Default Value
LO_IP SMA, R10, R11, R13, R15, R32, R34, R43, C40, T1, T2	Single-ended LO input at LOIP.	R11, R13, R34, R43, C40 = 0 Ω, R10, R15, R32 = open, T1, T2 = open
LO_IN SMA, R10, R11, R13, R15, R32, R34, R43, C40, T1, T2	Optional single-ended LO input at LOIN.	R10, R11, R15, R32, R43 = 0 Ω, R13, R34, C40 = open, T1, T2 = open
LO_IP SMA, LO_IN SMA, R10, R11, R13, R15, R32, R34, R43, C40, T1, T2	Optional differential LO input.	R11, R15, R32, R34, R43, C40 = 0 Ω, R10, R13 = open, T1, T2 = open
LO_IP SMA, R10, R11, R13, R15, R32, R34, R43, C40, T1, T2	Optional differential LO driving with balun (T1 or T2) at LOIP.	R13, R34, C40 = 0 Ω, R10, R11, R15, R32, R43 = open, T1 = TC1-1-43A+, T2 = TC1-1-13M+
C31	AC-coupling capacitor connects ADL5385 VOUT to RF_OUT RF connector or to ADL5601 RF input.	C31 = 0.1 μF
C47	AC-coupling capacitor connects ADL5601 RFOUT to AMP_OUT connector.	C47 = 0.1 μF
R40	Resistor connects ADL5385 VOUT to RF_OUT SMA. To check ADL5385 performance itself, insert a 0 Ω at R40 and open R25. To check ADL5601 performance itself, insert a 0 Ω at R40 and be inserted 0.1 μF on R25, open C31.	R40 = open
R25	Resistor connects ADL5385 VOUT to ADL5601 RFIN.	R25 = 0 Ω
RTEMP	Resistor connects ADL5385 TEMP to TEMP test clip lead.	RTEMP = 200 Ω
L8	DC bias inductor.	L8 = 470 nH
C3, C4, C5, C6, C8, C9, C11, C43, C44, C45	Power supply bypassing capacitors.	C3 = 10 μF, C4, C6, C8 = 0.1 μF, C5, C9, C11 = 100 pF, C43 = 1 μF, C44 = 1.2 nF, C45 = 68 pF
R8	Resistor to share power supply between the ADL5385 and the ADL5601. To turn on the ADL5601 with the power supply on VP1, install a 0 Ω resistor in this location.	R8 = open
U1	ADL5385 quadrature modulator.	ADL5385
U2	SOT-89 RF/IF gain block.	ADL5601

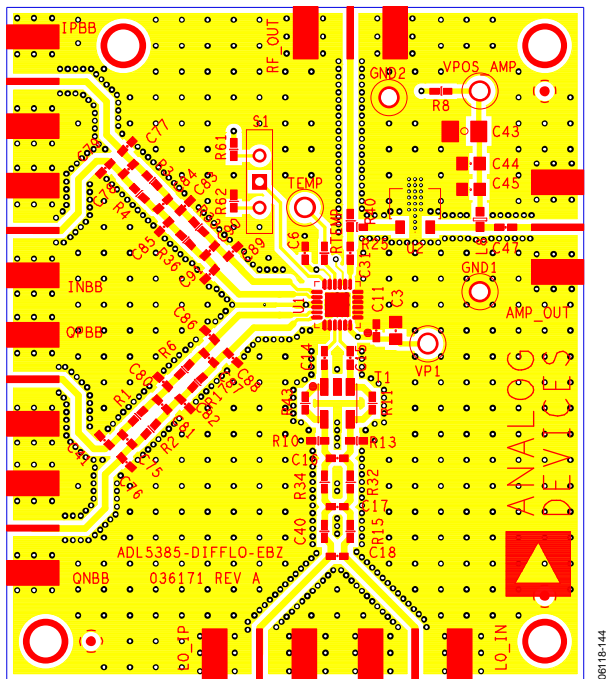


Figure 44. Layout of ADL5385-DIFFLO-EBZ, Top View

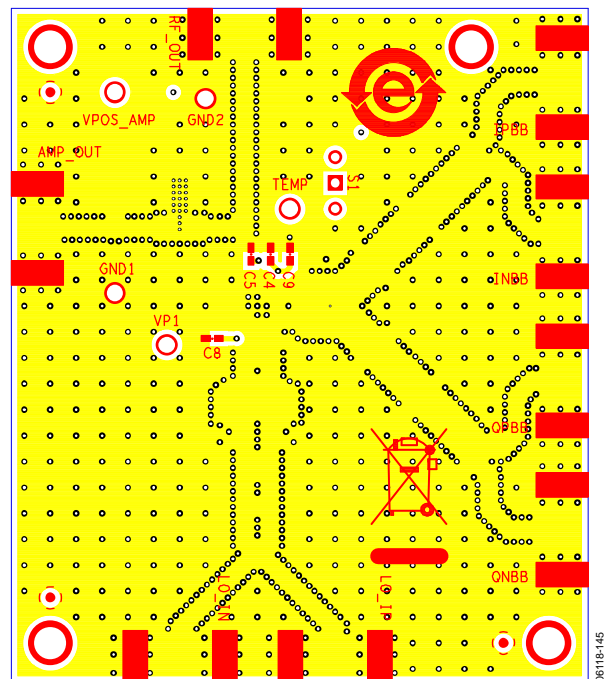


Figure 45. Layout of ADL5385-DIFFLO-EBZ, Bottom View

# CHARACTERIZATION SETUP

## SSB SETUP

Figure 46 is a diagram of the characterization test stand setup for the [ADL5385](#), which is intended to test the product as a single-sideband modulator. The Aeroflex IFR3416 signal generator provides the I and Q inputs as well as the LO input.

Output signals are measured directly using the spectrum analyzer, and currents and voltages are measured using the Agilent 34401A multimeter.

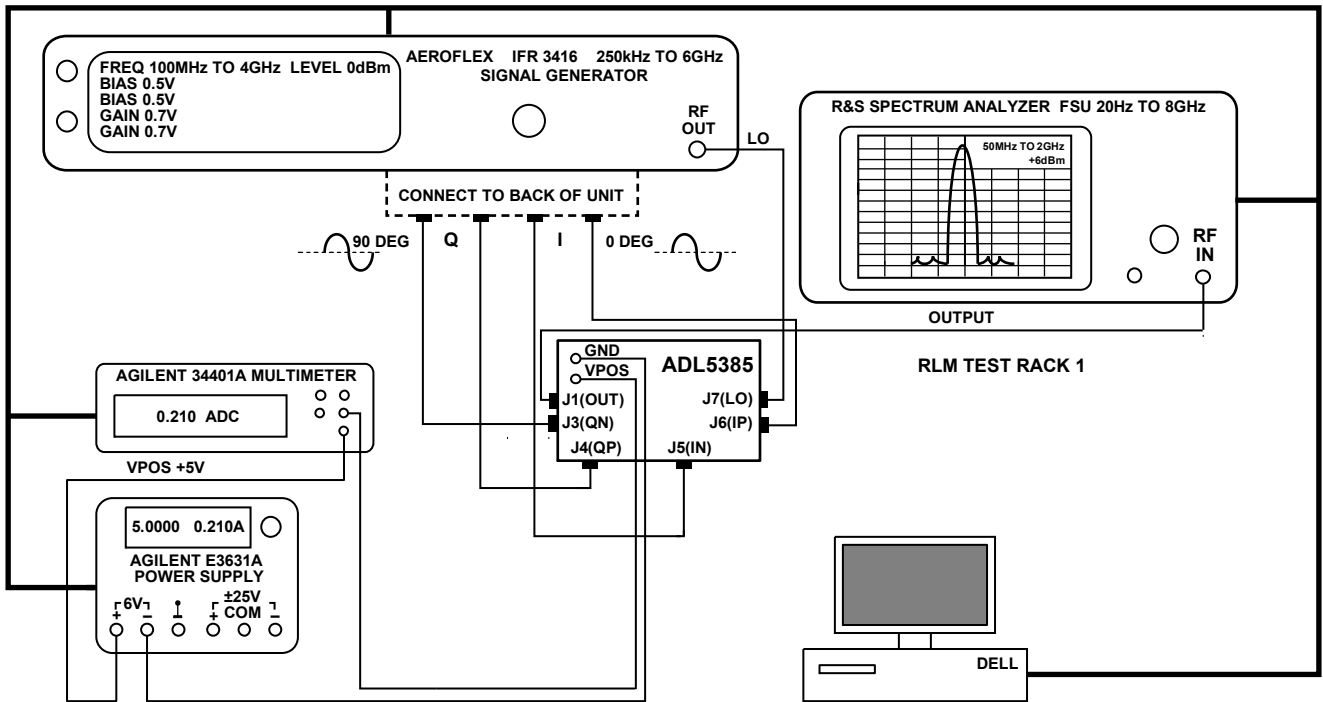
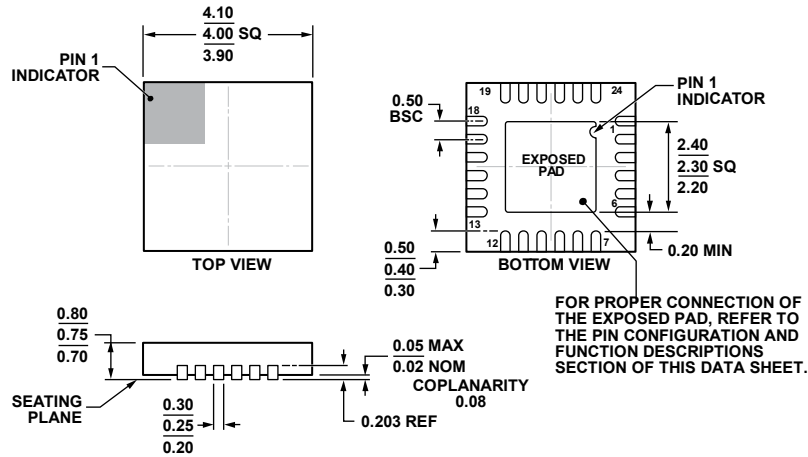


Figure 46. [ADL5385](#) Characterization Board SSB Test Setup

06119-0-00



OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-220-WGGD-8.

Figure 47. 24-Lead Lead Frame Chip Scale Package [LFCSP]  
4 mm × 4 mm Body and 0.75 mm Package Height  
(CP-24-14)

Dimensions shown in millimeters

01-18-2012-A

ORDERING GUIDE

Model <sup>1</sup>	Temperature Range	Package Description	Package Option	Ordering Quantity
ADL5385ACPZ-WP	-40°C to +85°C	24-Lead LFCSP, Waffle Pack	CP-24-14	64
ADL5385ACPZ-R7	-40°C to +85°C	24-Lead LFCSP, 7" Tape and Reel	CP-24-14	1500
ADL5385-DIFFLO-EBZ		Evaluation Board with Differential LO Input		1

<sup>1</sup> Z = RoHS Compliant Part.