

# TRF1305B1 Single-Channel, DC to > 6.5GHz, 3dB-Bandwidth, Fully Differential Amp

## 1 Features

- Three performance-optimized power gain variants:
  - 15dB (TRF1305A1)
  - 10dB (TRF1305B1)
  - 5dB (TRF1305C1)
- Fixed gain can be reduced with external resistors
- Wide large-signal RF bandwidth:
  - TRF1305B1: 7.2GHz (3dB), 6.4GHz (1dB)
- OP1dB (differential 100Ω load):
  - 15.7dBm (2GHz), 12.8dBm (4GHz)
- OIP3: 34dBm (2GHz), 25.5dBm (4GHz)
- Noise Figure: 10.4dB (2GHz), 13.4dB (4GHz)
- Slew rate: 25kV/μs
- Large input (±1V) and output (±0.5V) common-mode voltage ranges
- Flexible configurations and modes:
  - Single-ended input, differential output (S2D)
  - Differential input, differential output (D2D)
  - Single-ended output (limited performance)
  - AC- or DC-coupled input/output
  - Adjustable output common-mode voltage
  - Input common-mode range extension mode
- Supports 5V, flexible single or split supplies
- Active power dissipation: 500mW
- Power-down mode

## 2 Applications

- RF sampling or GSPS ADC driver
- [Test and measurement](#)
- [Wireless communications test](#)
- [RF digitizers](#)
- [Oscilloscopes \(DSOs\)](#)
- [High speed digitizer](#)
- [Spectrum analyzer](#)
- [Vector signal transceiver \(VST\)](#)
- Mass spectrometry systems
- Common-mode level shifting
- IQ mixer interface

## 3 Description

The TRF1305B1 is a very-high-performance, closed-loop, single-channel RF amplifier that has an operational bandwidth from true-dc to > 6.5GHz. The device has excellent performance to drive high-speed, high-performance ADCs, such as the [ADC12DJ5200RF](#) and [ADC32RF5x](#) with a dc- or ac-coupled interface. The amplifier is optimized for use in RF, zero and complex IF, and high-speed time-domain applications. The device is optimized for performance in the fixed gain configuration. If lower gain is desired, use external resistors.

The TRF1305B1 features a VOCM pin that allows setting different output common-mode and input common-mode voltages; for example, level-shifting or for most IQ down-converter ADC-interface applications that have differing dc common-mode voltages. The TRF1305B1 also features a floating 2-rail split or single-supply option, and a MODE pin that allows extending the input common-mode range closer to the supplies.

The TRF1305B1 has a power-down feature. The device is fabricated with TI's proprietary advanced BiCMOS process and is available in a space-saving, 2mm × 2mm, 12-pin, WQFN-FCRLF package.

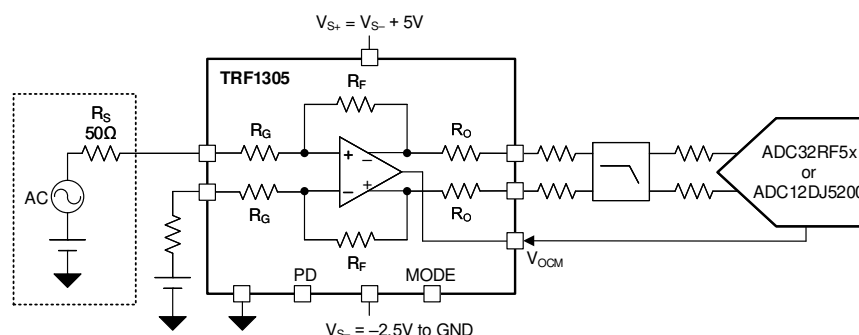
### Device Information

PART NUMBER <sup>(1)</sup>	D2D POWER GAIN	PACKAGE <sup>(2)</sup>
TRF1305A1 <sup>(3)</sup>	15dB	RPV (WQFN-FCRLF, 12)
TRF1305B1	10dB	
TRF1305C1 <sup>(3)</sup>	5dB	

(1) See [Section 4](#).

(2) For more information, see [Section 11](#).

(3) Preview information (not Advanced Information).



**TRF1305x1 in S2D Configuration Driving a High-Speed ADC**



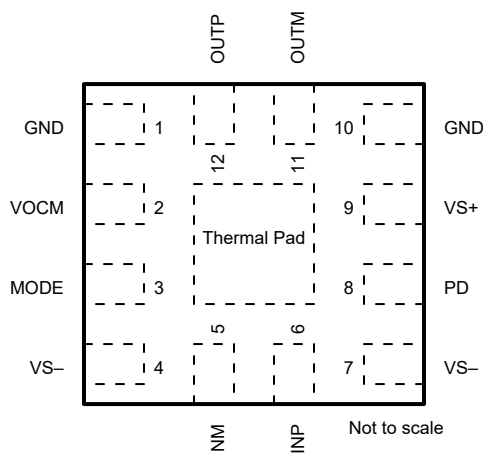
## Table of Contents

<b>1 Features</b> .....	<b>1</b>	7.4 Device Functional Modes.....	<b>16</b>
<b>2 Applications</b> .....	<b>1</b>	<b>8 Application and Implementation</b> .....	<b>17</b>
<b>3 Description</b> .....	<b>1</b>	8.1 Application Information.....	17
<b>4 Device Comparison Table</b> .....	<b>2</b>	8.2 Typical Application.....	20
<b>5 Pin Configuration and Functions</b> .....	<b>3</b>	8.3 Power Supply Recommendations.....	22
<b>6 Specifications</b> .....	<b>4</b>	8.4 Layout.....	22
6.1 Absolute Maximum Ratings.....	4	<b>9 Device and Documentation Support</b> .....	<b>24</b>
6.2 ESD Ratings.....	4	9.1 Documentation Support.....	24
6.3 Recommended Operating Conditions.....	4	9.2 Receiving Notification of Documentation Updates....	24
6.4 Thermal Information.....	4	9.3 Support Resources.....	24
6.5 Electrical Characteristics - TRF1305B1.....	5	9.4 Trademarks.....	24
6.6 Typical Characteristics - TRF1305B1.....	8	9.5 Electrostatic Discharge Caution.....	24
<b>7 Detailed Description</b> .....	<b>14</b>	9.6 Glossary.....	24
7.1 Overview.....	14	<b>10 Revision History</b> .....	<b>24</b>
7.2 Functional Block Diagram.....	14	<b>11 Mechanical, Packaging, and Orderable Information</b> .....	<b>24</b>
7.3 Feature Description.....	14		

## 4 Device Comparison Table

DEVICE	GAIN	CHANNEL COUNT
TRF1305A1 (preview)	15dB	1
<a href="#">TRF1305B1</a>	10dB	
TRF1305C1 (preview)	5dB	
TRF1305A2 (preview)	15dB	2
<a href="#">TRF1305B2</a> (active)	10dB	
TRF1305C2 (preview)	5dB	

## 5 Pin Configuration and Functions



**Figure 5-1. RPV Package, 12-Pin WQFN-FCRLF (Top View)**

**Table 5-1. Pin Functions**

PIN		TYPE	DESCRIPTION
NAME	NO.		
GND	1, 10	Ground	Ground. Reference for RF signals and PD control signal. Connect to ground plane on the board. Internally shorted to the thermal pad.
INM	5	Input	Negative side of differential input signal
INP	6	Input	Positive side of differential input signal
MODE	3	Input	Mode selection pin. See also <a href="#">MODE Pin section</a> .
OUTM	11	Output	Negative side of differential output signal
OUTP	12	Output	Positive side of differential output signal
PD	8	Input	Power-down signal, referenced to thermal pad. Supports both 1.8V and 3.3V logic. Logic 0 or open = device enabled. Logic 1 = device powered down.
VOCM	2	Input	Output common-mode voltage input pin. Floating the pin sets the output common-mode voltage to $V_{S-} + 2.5V$ .
VS-	4, 7	Power	Negative supply voltage
VS+	9	Power	Positive supply voltage
Thermal Pad	Pad	Ground	Reference for RF signals and PD control signal; also serves as a thermal pad. Connect to heat-dissipating ground or $V_{S-}$ plane on the board.

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

		MIN	MAX	UNIT
$V_{S-}$	Negative supply voltage, referenced to thermal pad	–3	3	V
$V_{S+}$	Positive supply voltage	–0.3	$V_{S-} + 5.5$	V
$V_S$	Total supply voltage, $V_S = V_{S+} - V_{S-}$	–0.3	5.5	V
$P_{IN}$	Input RF power		20	dBm
$V_{PD}$	PD pin voltage, referenced to thermal pad, $V_{S+} \geq 3.3V$	–0.3	3.6	V
	PD pin voltage, referenced to thermal pad, $V_{S+} < 3.3V$	–0.3	$V_{S+} + 0.3$	
$V_{OCM}$	VOCM pin voltage	$V_{S-} + 1$	$V_{S-} + 4$	V
$V_{MODE}$	MODE pin voltage	$V_{S-} - 0.3$	$V_{S-} + 3.3$	V
$T_J$	Junction temperature	–40	150	°C
$T_{stg}$	Storage temperature	–40	150	°C

- (1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. Absolute maximum ratings do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If briefly operating outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not sustain damage, but it may not be fully functional. Operating the device in this manner may affect device reliability, functionality, performance, and shorten the device lifetime.

### 6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup>	±1000	V
		Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002, all pins <sup>(2)</sup>	±500	

- (1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.

- (2) JEDEC document JEP157 states that 250V CDM allows safe manufacturing with a standard ESD control process.

### 6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
$V_{S+}$	Positive supply voltage	2.5		5	V
$V_{S-}$	Negative supply voltage	–2.5		0	V
$V_S$	Total supply voltage, $V_S = V_{S+} - V_{S-}$		5		V
$T_J$	Junction temperature	–40		125	°C

### 6.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		TRF1305x1	UNIT
		RPV (WQFN-FCRLF)	
		12 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	66.9	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	64.3	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	17.4	°C/W
$\Psi_{JT}$	Junction-to-top characterization parameter	1.7	°C/W
$\Psi_{JB}$	Junction-to-board characterization parameter	17.2	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	9.0	°C/W

- (1) For information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

## 6.5 Electrical Characteristics - TRF1305B1

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VOCM, PD, and MODE pins,  $V_{ICM} = \text{midsupply}$ , D2D ac-coupled input/output with differential source impedance ( $Z_S = 100\Omega$ ), differential output load ( $Z_L = 100\Omega$ ), external input resistor network (see [Figure 8-3](#)), and inputs de-embedded up to  $R_{IN\_SER}$  and outputs up to the device pins (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>AC PERFORMANCE</b>						
SSBW	Small-signal bandwidth (3dB)	$P_{IN} = -20\text{dBm}$ at each input		7.3		GHz
	Small-signal bandwidth (1dB)	$P_{IN} = -20\text{dBm}$ at each input		6.4		
LSBW	Large-signal bandwidth (3dB)	Differential $P_{IN} = -3\text{dBm}$		7.2		GHz
	Large-signal bandwidth (1dB)	Differential $P_{IN} = -3\text{dBm}$		6.4		
S21	Power gain	$f = 4\text{GHz}$		10		dB
	Gain variation over temperature	$f = 4\text{GHz}$ , $T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$		1		
S11	Input return loss	$f = 10\text{MHz}$ to $7.5\text{GHz}$		-11.3		dB
S12	Reverse isolation	$f < 10\text{GHz}$ (device enabled)		-20		dB
$G_{IMB}$	Differential gain imbalance	$f < 5\text{GHz}$ , S2D, $P_{IN} = -20\text{dBm}$ with $50\Omega Z_S$		$\pm 0.2$		dB
$PH_{IMB}$	Differential phase imbalance	$f < 5\text{GHz}$ , S2D, $P_{IN} = -20\text{dBm}$ with $50\Omega Z_S$		$\pm 2$		°
OP1dB	Output 1dB compression point	$f = 500\text{MHz}$		15.5		dBm
		$f = 1\text{GHz}$		16		
		$f = 2\text{GHz}$		15.7		
		$f = 3\text{GHz}$		15		
		$f = 4\text{GHz}$		12.8		
		$f = 5\text{GHz}$		11		
HD2	Second-order harmonic distortion	$f = 500\text{MHz}$ , $V_O = 2V_{PP}$		-84		dBc
		$f = 1\text{GHz}$ , $V_O = 2V_{PP}$		-72		
		$f = 2\text{GHz}$ , $V_O = 2V_{PP}$		-62		
		$f = 3\text{GHz}$ , $V_O = 2V_{PP}$		-56		
		$f = 4\text{GHz}$ , $V_O = 2V_{PP}$		-53		
HD3	Third-order harmonic distortion	$f = 500\text{MHz}$ , $V_O = 2V_{PP}$		-68		dBc
		$f = 1\text{GHz}$ , $V_O = 2V_{PP}$		-62		
		$f = 2\text{GHz}$ , $V_O = 2V_{PP}$		-61		
		$f = 3\text{GHz}$ , $V_O = 2V_{PP}$		-51		
		$f = 4\text{GHz}$ , $V_O = 2V_{PP}$		-47		
OIP2	Output second-order intercept point	$f = 500\text{MHz}$ , $P_O = 1\text{dBm}$ per tone, 2MHz spacing		85		dBm
		$f = 1\text{GHz}$ , $P_O = 1\text{dBm}$ per tone, 2MHz spacing		71.5		
		$f = 2\text{GHz}$ , $P_O = 1\text{dBm}$ per tone, 2MHz spacing		64		
		$f = 3\text{GHz}$ , $P_O = 1\text{dBm}$ per tone, 2MHz spacing		58		
		$f = 4\text{GHz}$ , $P_O = 1\text{dBm}$ per tone, 2MHz spacing		54.5		
		$f = 5\text{GHz}$ , $P_O = 1\text{dBm}$ per tone, 2MHz spacing		56.5		

## 6.5 Electrical Characteristics - TRF1305B1 (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VO<sub>CM</sub>, PD, and MODE pins,  $V_{ICM}$  = midsupply, D2D ac-coupled input/output with differential source impedance ( $Z_S$ ) = 100 $\Omega$ , differential output load ( $Z_L$ ) = 100 $\Omega$ , external input resistor network (see Figure 8-3), and inputs de-embedded up to  $R_{IN\_SER}$  and outputs up to the device pins (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OIP3	Output third-order intercept point	f = 500MHz, P <sub>O</sub> = 1dBm per tone, 2MHz spacing		43.5		dBm
		f = 1GHz, P <sub>O</sub> = 1dBm per tone, 2MHz spacing		40		
		f = 2GHz, P <sub>O</sub> = 1dBm per tone, 2MHz spacing		34		
		f = 3GHz, P <sub>O</sub> = 1dBm per tone, 2MHz spacing		32		
		f = 4GHz, P <sub>O</sub> = 1dBm per tone, 2MHz spacing		25.5		
		f = 5GHz, P <sub>O</sub> = 1dBm per tone, 2MHz spacing		19		
NF	Noise figure	f = 500MHz		8		dB
		f = 1GHz		8.8		
		f = 2GHz		10.4		
		f = 4GHz		13.4		
		f = 5GHz		13.3		
NSD	Output noise spectral density	f = 500MHz		−155.3		dBm/Hz
		f = 1GHz		−154.8		
		f = 2GHz		−153.8		
		f = 4GHz		−150.7		
		f = 5GHz		−150.7		
DC PERFORMANCE						
V <sub>OD-MAX</sub>	Max differential output voltage	f = 1GHz		4		V <sub>PP</sub>
	Slew rate	2V V <sub>O</sub> step, S2D configuration, V <sub>S+</sub> = 2.5V, V <sub>S−</sub> = −2.5V		25		kV/μs
	Output differential offset voltage			±3		mV
	Overdrive recovery time	From 2 × overdrive of each SE output to each output voltage settling to < ±50mV		6		ns
COMMON-MODE						
V <sub>ICM</sub>	Input common-mode voltage	Default range <sup>(1)</sup>	V <sub>S−</sub> + 1.5		V <sub>S−</sub> + 3.5	V
V <sub>OCM</sub>	Output common-mode voltage		V <sub>S−</sub> + 2		V <sub>S−</sub> + 3	V
	Output common-mode offset voltage from V <sub>OCM</sub> voltage			±10		mV
IMPEDANCE						
Z <sub>in-SE</sub>	Single-ended input impedance	At INP pin with appropriate termination on INM pin		47		Ω
Z <sub>O-DIFF</sub>	Differential output impedance	f = near dc		8		Ω

## 6.5 Electrical Characteristics - TRF1305B1 (continued)

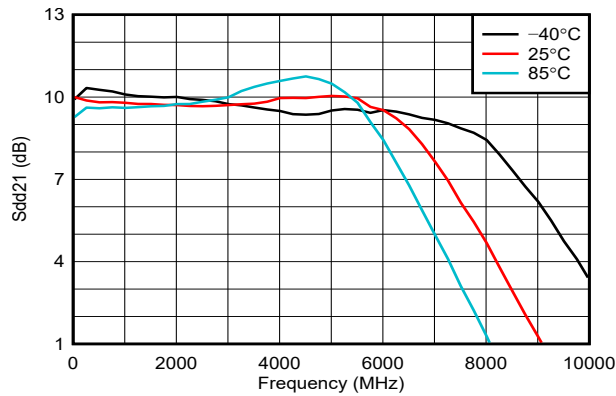
at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VO<sub>CM</sub>, PD, and MODE pins,  $V_{\text{ICM}}$  = midsupply, D2D ac-coupled input/output with differential source impedance ( $Z_S$ ) = 100Ω, differential output load ( $Z_L$ ) = 100Ω, external input resistor network (see [Figure 8-3](#)), and inputs de-embedded up to  $R_{\text{IN\_SER}}$  and outputs up to the device pins (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>POWER SUPPLY</b>						
$I_{\text{QA}}$	Active quiescent current			102		mA
$I_{\text{QPD}}$	Power-down quiescent current			25		mA
<b>POWER DOWN</b>						
$V_{\text{PD\_Hi}}$	PD pin logic high	Referenced to PAD, see <a href="#">Section 6.1</a>	1.35			V
$V_{\text{PD\_Lo}}$	PD pin logic low	Referenced to PAD, see <a href="#">Section 6.1</a>			0.3	V
$I_{\text{PD\_Bias}}$	PD bias current (current on PD pin)	PD = high (1.8V logic)		15		μA
		PD = high (3.3V logic)		30		
$t_{\text{ON}}$	Turn-on time	From 50% $V_{\text{PD}}$ transition to 90% RF out		25		ns
$t_{\text{OFF}}$	Turn-off time	From 50% $V_{\text{PD}}$ transition to 10% RF out		20		ns

(1)  $V_{\text{ICM}}$  range can be extended closer to  $V_{S+}$  or  $V_{S-}$  in D2D configuration. See also [Section 7.4.1](#).

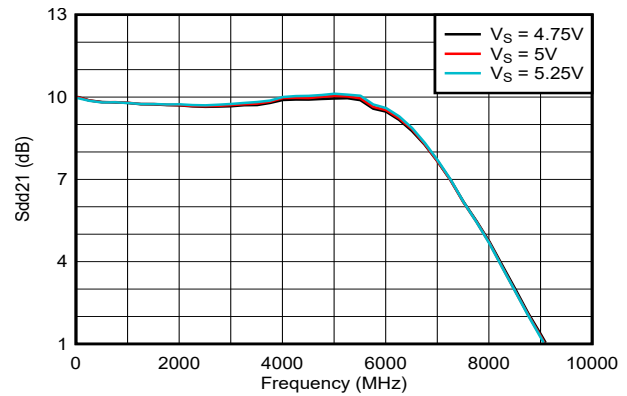
## 6.6 Typical Characteristics - TRF1305B1

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VOCM, PD, and MODE pins,  $V_{ICM} = \text{mid supply}$ , D2D ac-coupled input/output configuration with  $Z_S = 100\Omega$ ,  $Z_L = 100\Omega$ , external input resistor network (see Figure 8-3), inputs de-embedded up to  $R_{IN\_SER}$  and outputs up to the device pins, ambient temperatures shown, and resistor network included as part of DUT characteristic plots (unless otherwise noted)



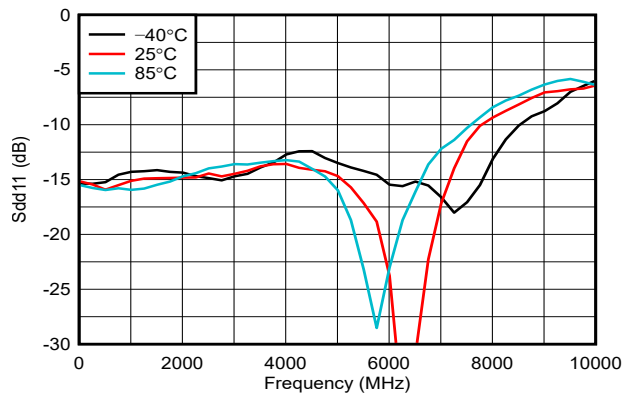
$P_{IN} = -20\text{dBm}$  at each input pin with  $50\Omega$  source

Figure 6-1. Power Gain (S21) Across Temperature



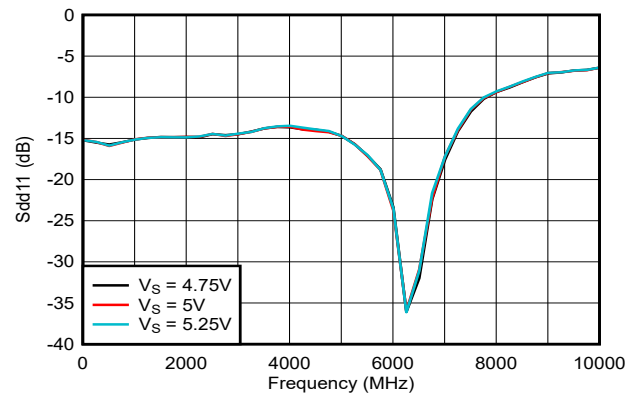
$P_{IN} = -20\text{dBm}$  at each input pin with  $50\Omega$  source

Figure 6-2. Power Gain (S21) Across Supply Voltage



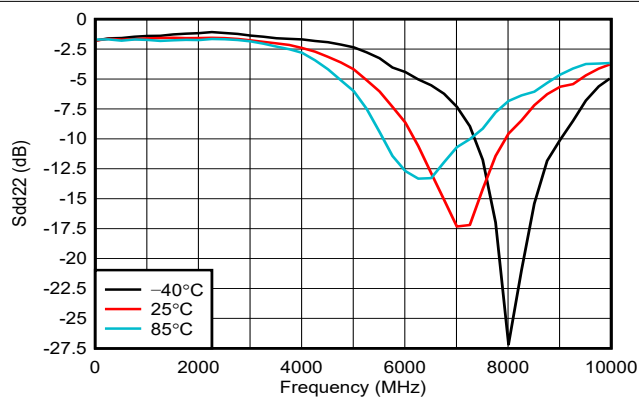
$P_{IN} = -20\text{dBm}$  at each input pin with  $50\Omega$  source

Figure 6-3. Input Return Loss (S11) Across Temperature



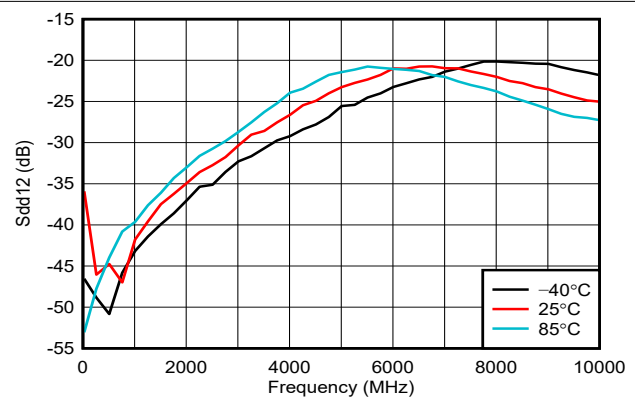
$P_{IN} = -20\text{dBm}$  at each input pin with  $50\Omega$  source

Figure 6-4. Input Return Loss (S11) Across Supply Voltage



$P_{IN} = -20\text{dBm}$  at each input pin with  $50\Omega$  source

Figure 6-5. Output Return Loss (S22) Across Temperature



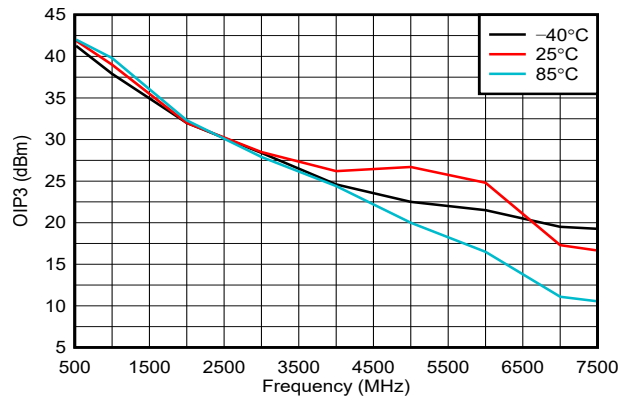
$P_{IN} = -20\text{dBm}$  at each input pin with  $50\Omega$  source

Figure 6-6. Reverse Isolation (S12) Across Temperature



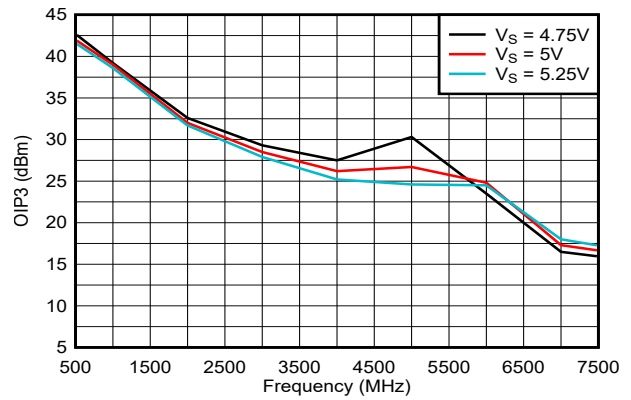
## 6.6 Typical Characteristics - TRF1305B1 (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VOCM, PD, and MODE pins,  $V_{ICM} = \text{mid supply}$ , D2D ac-coupled input/output configuration with  $Z_S = 100\Omega$ ,  $Z_L = 100\Omega$ , external input resistor network (see Figure 8-3), inputs de-embedded up to  $R_{IN\_SER}$  and outputs up to the device pins, ambient temperatures shown, and resistor network included as part of DUT characteristic plots (unless otherwise noted)



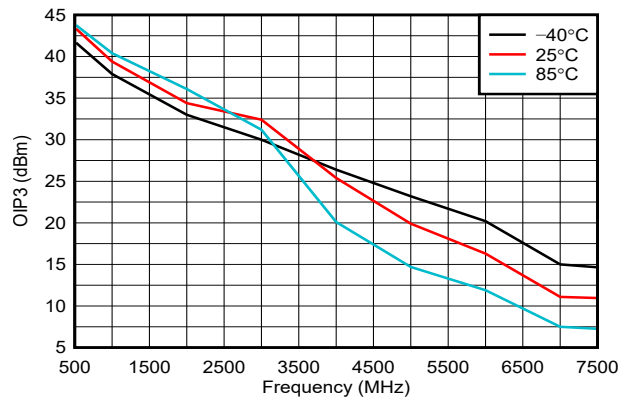
$P_O = -5\text{dBm/ tone}$ , 2MHz tone spacing

**Figure 6-7. OIP3 Across Temperature**



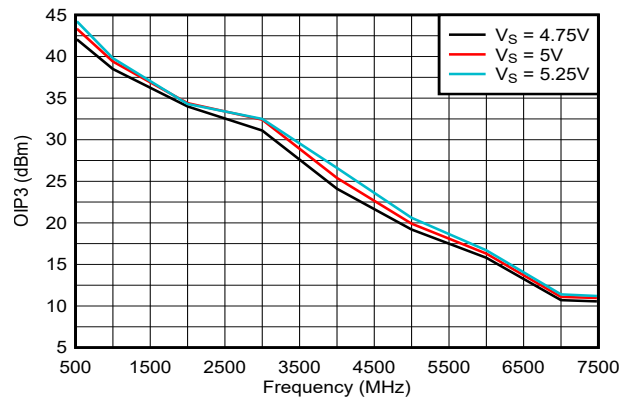
$P_O = -5\text{dBm/ tone}$ , 2MHz tone spacing

**Figure 6-8. OIP3 Across Supply Voltage**



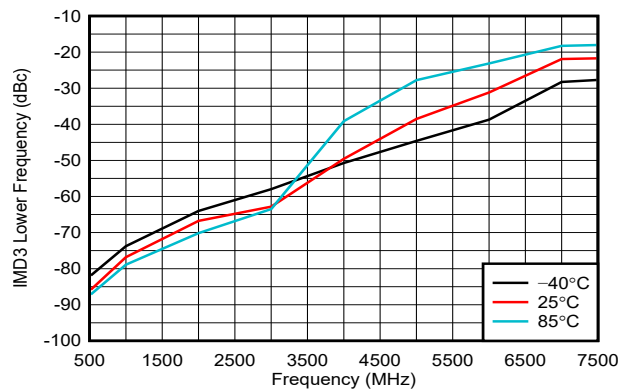
$P_O = 1\text{dBm/ tone}$ , 2MHz tone spacing

**Figure 6-9. OIP3 Across Temperature**



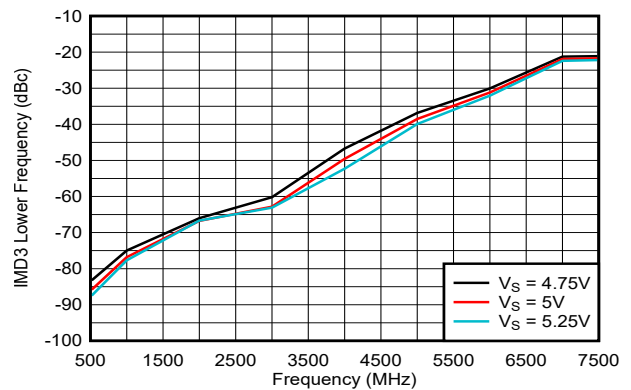
$P_O = 1\text{dBm/ tone}$ , 2MHz tone spacing

**Figure 6-10. OIP3 Across Supply Voltage**



At  $(2f_1 - f_2)$  frequency where  $f_1 < f_2$ ,  
 $P_O = 1\text{dBm/ tone}$ , 2MHz tone spacing

**Figure 6-11. IMD3 Lower Across Temperature**

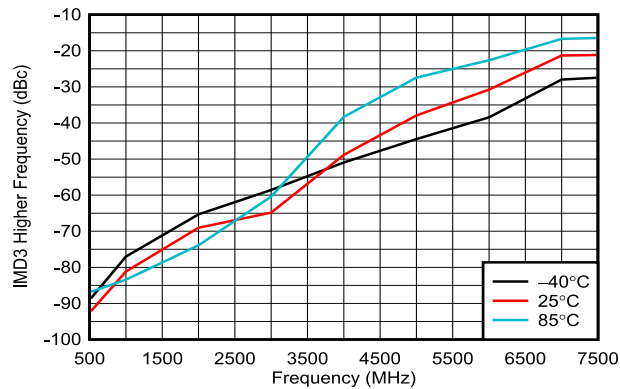


At  $(2f_1 - f_2)$  frequency where  $f_1 < f_2$ ,  
 $P_O = 1\text{dBm/ tone}$ , 2MHz tone spacing

**Figure 6-12. IMD3 Lower Across Supply Voltage**

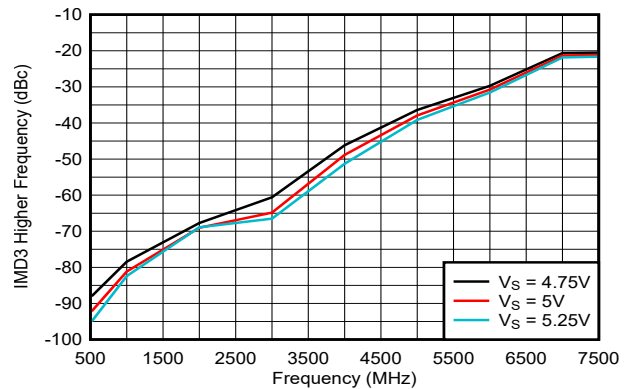
## 6.6 Typical Characteristics - TRF1305B1 (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VO<sub>CM</sub>, PD, and MODE pins,  $V_{\text{ICM}}$  = midsupply, D2D ac-coupled input/output configuration with  $Z_S = 100\Omega$ ,  $Z_L = 100\Omega$ , external input resistor network (see Figure 8-3), inputs de-embedded up to  $R_{\text{IN\_SER}}$  and outputs up to the device pins, ambient temperatures shown, and resistor network included as part of DUT characteristic plots (unless otherwise noted)



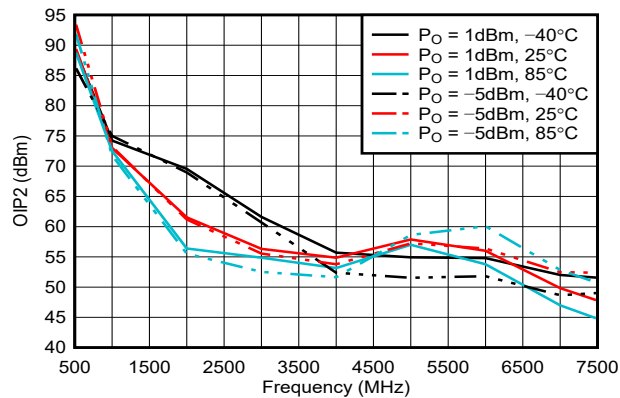
At  $(2f_2 - f_1)$  frequency where  $f_1 < f_2$ ,  
 $P_O = 1\text{dBm/tone}$ , 2MHz tone spacing

Figure 6-13. IMD3 Higher Across Temperature



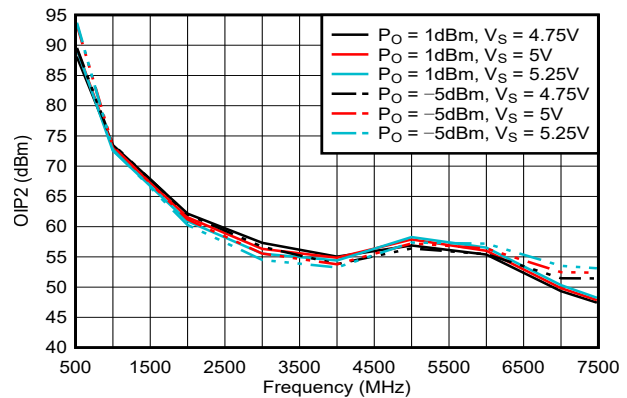
At  $(2f_2 - f_1)$  frequency where  $f_1 < f_2$ ,  
 $P_O = 1\text{dBm/tone}$ , 2MHz tone spacing

Figure 6-14. IMD3 Higher Across Supply Voltage



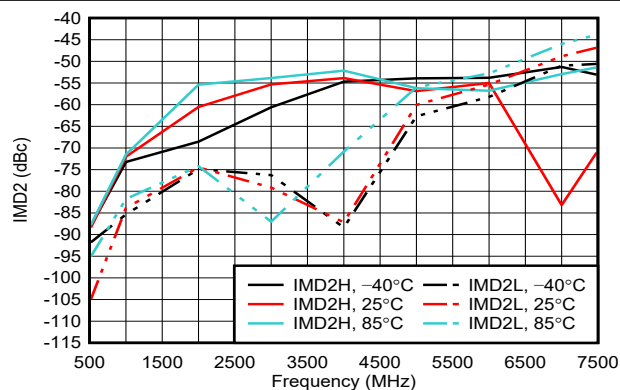
Per tone  $P_O$  as shown, 2MHz tone spacing

Figure 6-15. OIP2 Across Temperature



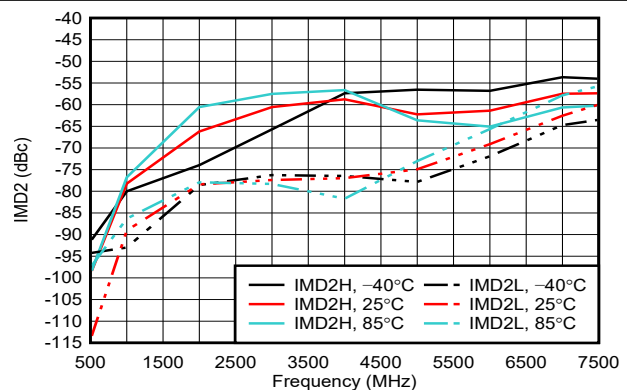
Per tone  $P_O$  as shown, 2MHz tone spacing

Figure 6-16. OIP2 Across Supply Voltage



$P_O = 1\text{dBm/tone}$ , 2MHz tone spacing

Figure 6-17. IMD2 Across Temperature



$P_O = -5\text{dBm/tone}$ , 2MHz tone spacing

Figure 6-18. IMD2 Across Temperature

## 6.6 Typical Characteristics - TRF1305B1 (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VO<sub>CM</sub>, PD, and MODE pins,  $V_{\text{ICM}}$  = midsupply, D2D ac-coupled input/output configuration with  $Z_S = 100\Omega$ ,  $Z_L = 100\Omega$ , external input resistor network (see Figure 8-3), inputs de-embedded up to  $R_{\text{IN\_SER}}$  and outputs up to the device pins, ambient temperatures shown, and resistor network included as part of DUT characteristic plots (unless otherwise noted)

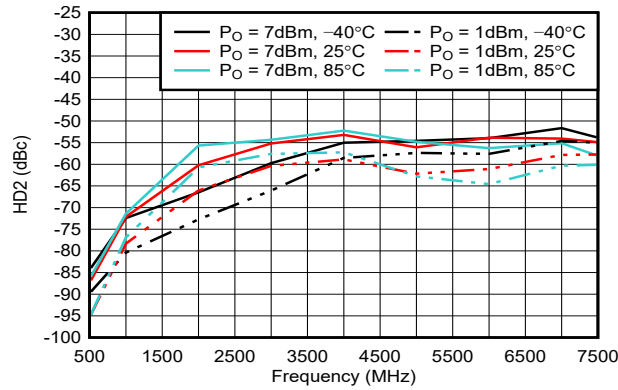


Figure 6-19. HD2 Across Output Power and Temperature

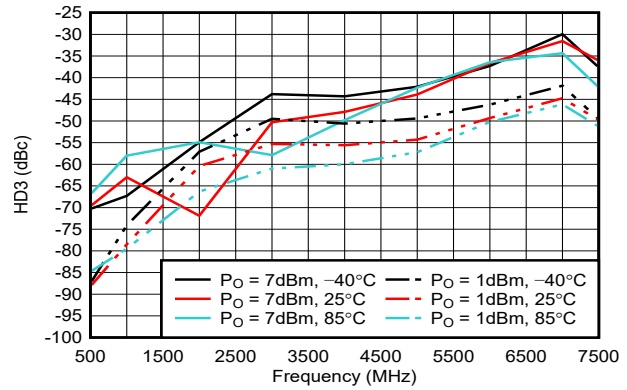


Figure 6-20. HD3 Across Output Power and Temperature

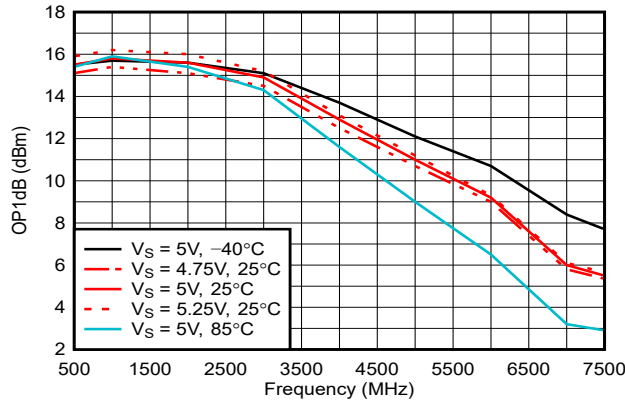


Figure 6-21. OP1dB Across Supply Voltage and Temperature

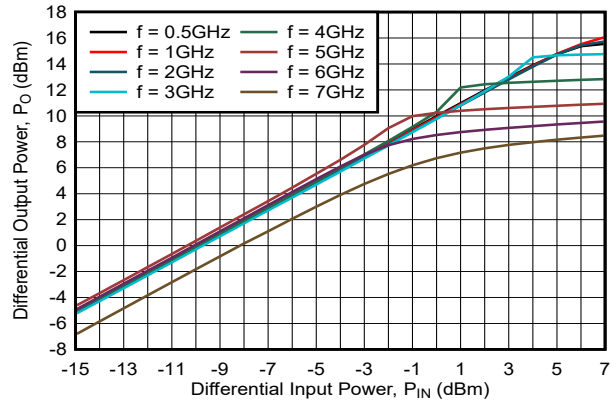


Figure 6-22. Differential Input vs Differential Output Power

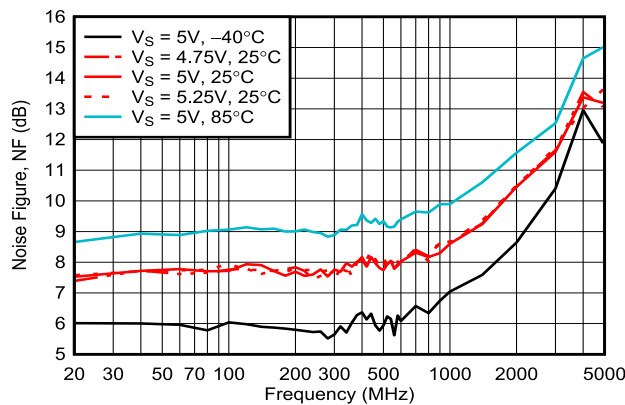


Figure 6-23. Noise Figure Across Temperature

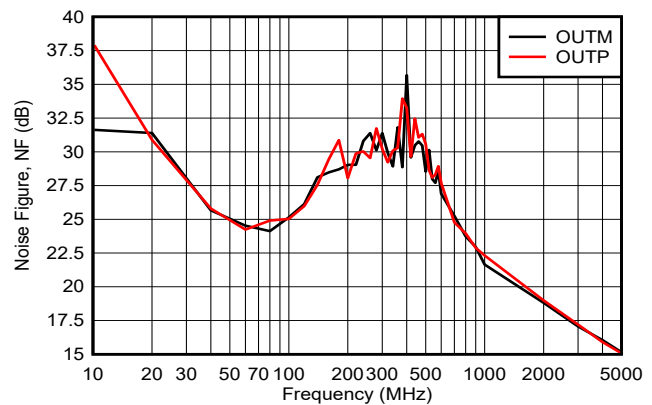
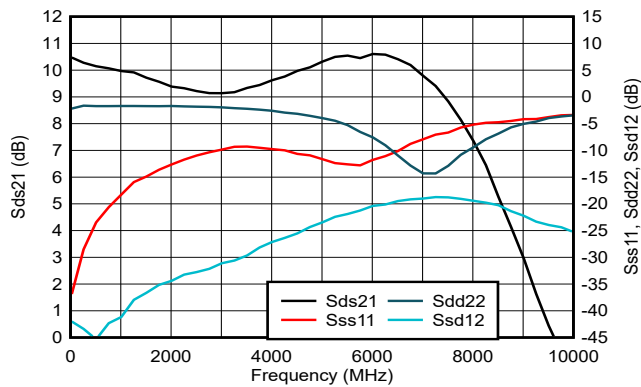


Figure 6-24. Noise Figure at Each Single-Ended Output

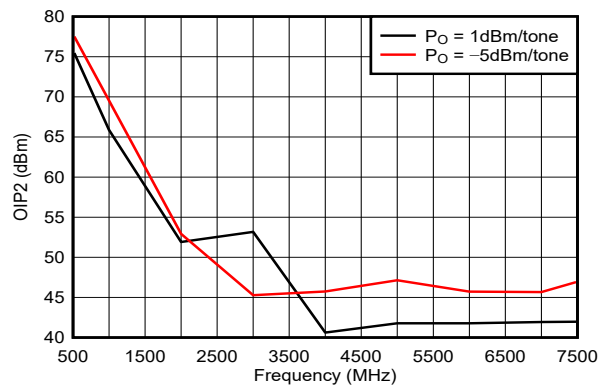
## 6.6 Typical Characteristics - TRF1305B1 (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VO<sub>CM</sub>, PD, and MODE pins,  $V_{\text{ICM}}$  = midsupply, D2D ac-coupled input/output configuration with  $Z_S = 100\Omega$ ,  $Z_L = 100\Omega$ , external input resistor network (see Figure 8-3), inputs de-embedded up to  $R_{\text{IN\_SER}}$  and outputs up to the device pins, ambient temperatures shown, and resistor network included as part of DUT characteristic plots (unless otherwise noted)



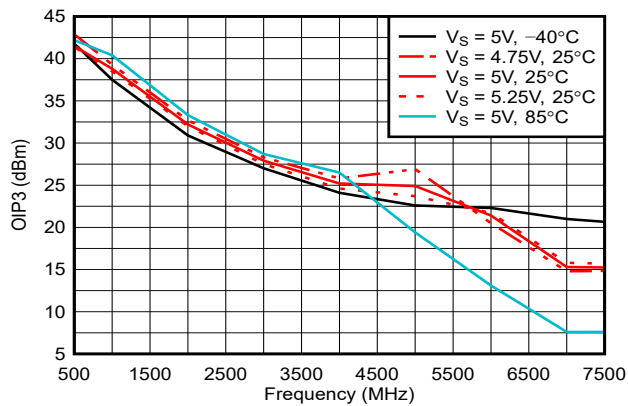
S2D,  $P_{\text{IN}} = -20\text{dBm}$  at each input pin with  $50\Omega$  source, de-embedded up to INP and OUTP/OUTM pins

Figure 6-25. S-Parameters in S2D Configuration



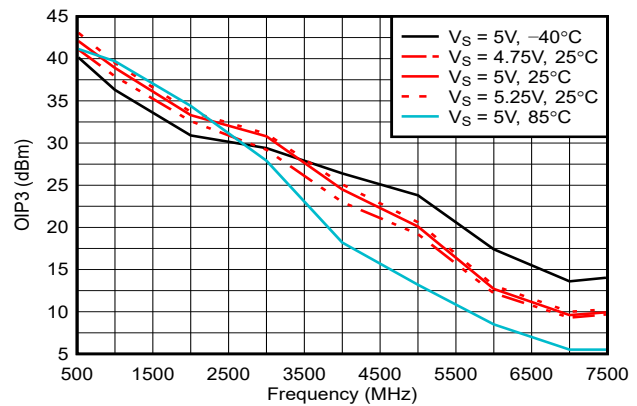
S2D, de-embedded up to INP and OUTP/OUTM pins

Figure 6-26. OIP2 Across Output Power



S2D,  $P_O = -5\text{dBm/ton}$ , 2MHz tone spacing, de-embedded up to INP and OUTP/OUTM pins

Figure 6-27. OIP3 Across Supply Voltage and Temperature



S2D,  $P_O = 1\text{dBm/ton}$ , 2MHz tone spacing, de-embedded up to INP and OUTP/OUTM pins

Figure 6-28. OIP3 Across Supply Voltage and Temperature

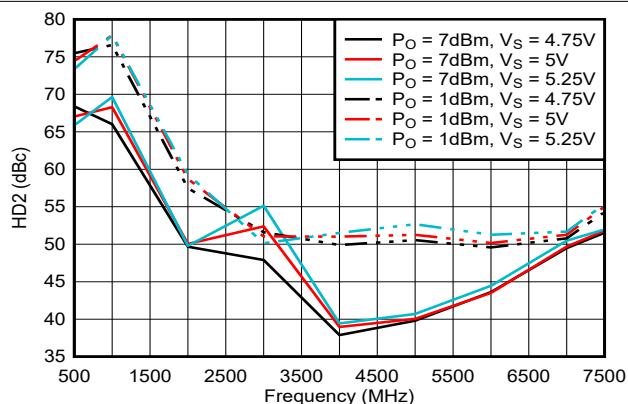


Figure 6-29. HD2 Across Supply Voltage and Output Power

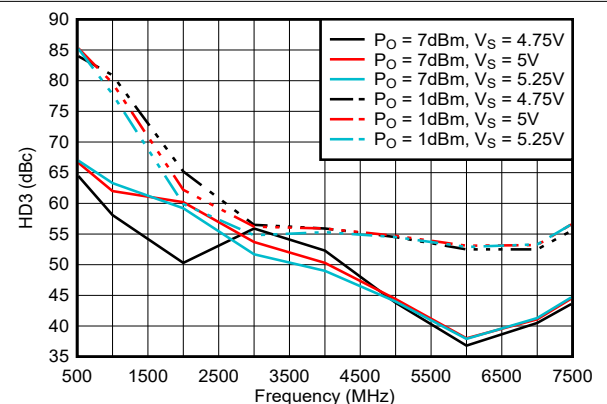


Figure 6-30. HD3 Across Supply Voltage and Output Power

## 6.6 Typical Characteristics - TRF1305B1 (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{S+} = 5\text{V}$ ,  $V_{S-} = 0\text{V}$ , floating VO<sub>CM</sub>, PD, and MODE pins,  $V_{\text{ICM}}$  = midsupply, D2D ac-coupled input/output configuration with  $Z_S = 100\Omega$ ,  $Z_L = 100\Omega$ , external input resistor network (see Figure 8-3), inputs de-embedded up to  $R_{\text{IN\_SER}}$  and outputs up to the device pins, ambient temperatures shown, and resistor network included as part of DUT characteristic plots (unless otherwise noted)

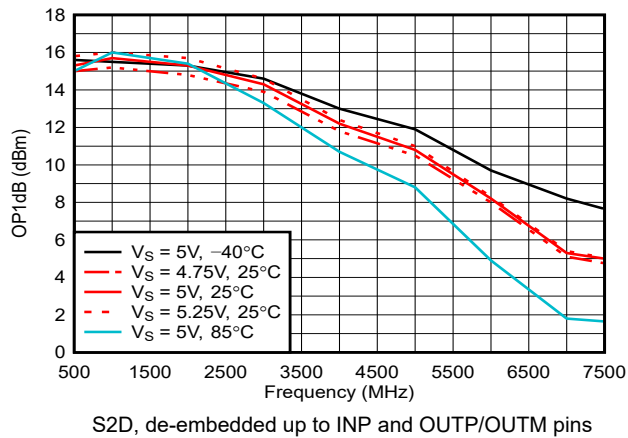


Figure 6-31. OP1dB Across Supply Voltage and Temperature

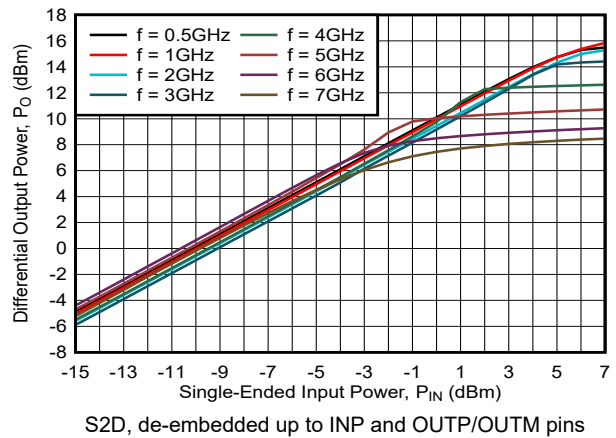


Figure 6-32. Single-Ended Input vs Differential Output Power

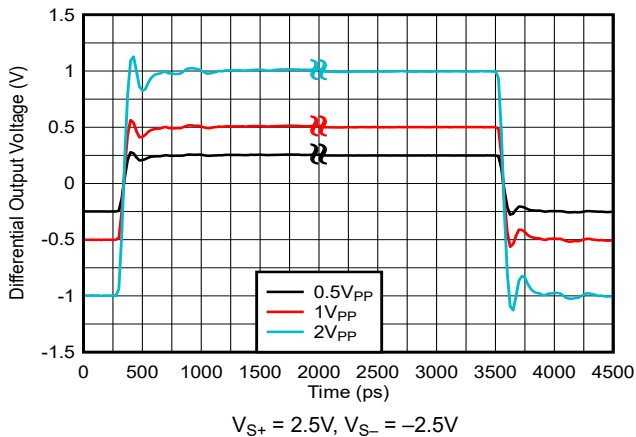


Figure 6-33. Step Response

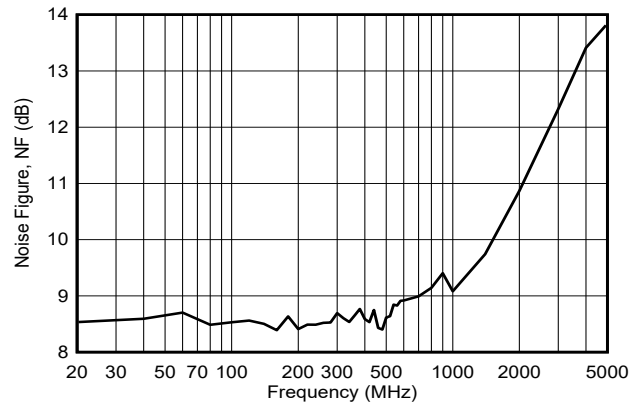


Figure 6-34. Noise Figure in S2D Configuration

## 7 Detailed Description

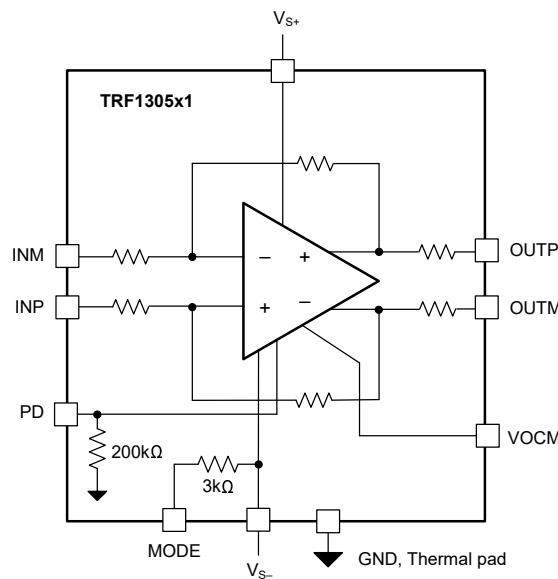
### 7.1 Overview

The TRF1305A1, TRF1305B1, and TRF1305C1 (TRF1305x1) devices are single-channel, high-performance fully differential RF amplifiers optimized for very wideband signals from dc to > 6.5GHz. This device family is primarily designed to interface with high-speed and RF data converters that often require differential input (ADCs) and output (DACs) signaling. The TRF1305x1 can be dc or ac coupled, and configured as single-ended input and differential output (S2D) or differential input and differential output (D2D). The devices feature an output common-mode pin (VOCM) that allows the flexibility to set a desired common-mode output voltage. The amplifier allows the data converters to interface with a dc-coupled IQ demodulator or modulator if used in a direct conversion system. The TRF1305x1 family comes in three fixed power gain variants (15dB, 10dB, and 5dB), and has a closed-loop feedback-amplifier architecture.

The devices are powered using two-rail supplies with a typical differential voltage of 5V between the positive and negative supplies, and usable in split- or single-supply configurations. A power-down feature is also available that allows the amplifier to be powered down.

The output of the amplifiers is low impedance. Use appropriate external series termination to match to an arbitrary impedance.

### 7.2 Functional Block Diagram



### 7.3 Feature Description

The TRF1305x1 includes the following key features:

- Two-rail floating supply with supply-independent thermal pad
  - Connect the thermal pad to GND or  $V_{S-}$
  - RF signals and PD pin are referenced to thermal pad
- Single-supply or split-supply operation
- Supports single-ended and differential input configurations
- Performance-optimized preset fixed-gain variants
- Output common-mode control
- Input common-mode range selection by pullup resistor
- MODE pin:  $V_{ICM}$  range extension closer to  $V_{S+}$  or  $V_{S-}$  modes
- Digital-logic-controllable power-down option

### 7.3.1 Fully Differential RF Amplifier

The TRF1305x1 is a voltage-feedback fully differential amplifier (FDA) with wide bandwidth. The amplifier is designed for a differential power gain of 15dB, 10dB, or 5dB depending on the device variant. This amplifier has excellent time-domain specifications with high slew rate, high input and output common-mode ranges, and fast transient settling time.

The output average voltage (common-mode) of the FDA device is controlled by a separate common-mode loop. The target output common-mode voltage is set by the VOCM input pin.

### 7.3.2 Output Common-Mode Control

Figure 7-1 shows a functional diagram of the output common-mode control. Internally, the VOCM pin potential is set by the LDO output voltage that is equal to  $V_{S-} + 2.5V$  connected through a 2.5kΩ resistor.

Floating the VOCM pin is allowed. The output common-mode voltage at the output pins, OUTP and OUTM, defaults to the LDO output voltage of  $V_{S-} + 2.5V$  when VOCM pin is floated. Floating the VOCM pin results in a  $V_{OCM}$  voltage equal to midsupply when  $V_S = 5V$ . If the VOCM pin is driven, then drive the pin from a low-impedance source. Limit the value of  $R_{OCM}$  to less than 25Ω for accurate reflection of the forced  $V_{OCM}$  voltage at the device outputs.

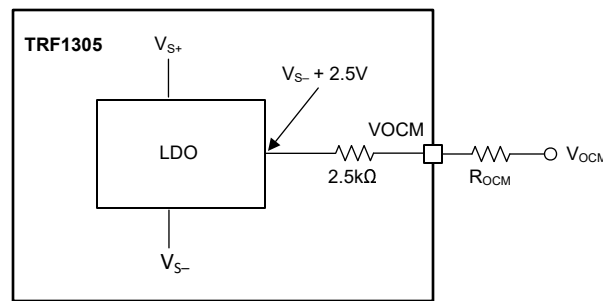


Figure 7-1. Output Common-Mode Control

### 7.3.3 Internal Resistor Configuration

Figure 7-2 shows the internal resistor configurations of TRF1305x1. Table 7-1 provides the values of these resistors for different gain variants.

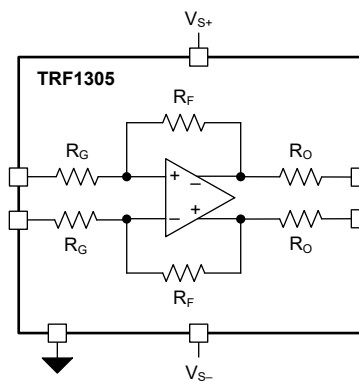


Figure 7-2. TRF1305x1 Internal Resistor Configuration

Table 7-1. Resistor Values

DEVICE NAME	GAIN (dB)	$R_G$ (Ω)	$R_F$ (Ω)	$R_O$ (Ω)
TRF1305A1	15	6.25	258	4
TRF1305B1	10	12.5	161	4
TRF1305C1	5	17	97	4



## 7.4 Device Functional Modes

### 7.4.1 MODE Pin

The TRF1305x1 have additional useful features that can be configured using the MODE pin. To select the device mode, either connect a  $\pm 2\%$  maximum tolerance pullup resistor between the MODE pin and  $V_{S+}$ , or force a voltage on the MODE pin. Internally, the MODE pin is referenced to  $V_{S-}$  through a 3k $\Omega$  resistor (see [Section 7.2](#)).

[Table 7-2](#) provides the value of the pullup resistor for each mode, the expected voltage,  $V_{MODE}$ , at the MODE pin when the pullup resistor is used or the necessary  $V_{MODE}$  voltage to set the device mode, and the mode configurations. The  $V_{MODE}$  voltage thresholds are approximately midway between the adjacent modes typical  $V_{MODE}$  voltage. If the mode functionality is used, use a decoupling capacitor on the MODE pin.

**Table 7-2. MODE Pin Configuration**

MODE NUMBER	PULLUP RESISTOR TO $V_{S+}$ ( $\pm 2\%$ MAXIMUM TOLERANCE)	MODE PIN VOLTAGE, $V_{MODE}$ (V)	$V_{ICM}$ RANGE EXTENSION <sup>(1)</sup>
0	OPEN	$V_{S-}$	Default $V_{ICM}$ range
1	25.6k $\Omega$	$V_{S-} + 0.5V$	Low side, extends $V_{ICM}$ range closer to $V_{S-}$
2	12.8k $\Omega$	$V_{S-} + 0.95V$	High side, extends $V_{ICM}$ range closer to $V_{S+}$
N/A	Do not use pullup resistor < 10k $\Omega$ or set $V_{MODE} > V_{S-} + 1.15V$		

(1) Only available in D2D configuration.

To switch the mode without turning the supplies off, use a switch or MUX connected between the pullup resistor options and  $V_{S+}$ , or force a mode-appropriate  $V_{MODE}$  voltage. However, powering down the device using the [power-down feature](#) between mode changes is preferred. The low-side and high-side  $V_{ICM}$  range extension modes source and sink currents, respectively (see also [Section 7.4.1.1](#)). Ensure that the external circuitry is ready to sink or source these currents before the device is put in the active mode from the powered-down state.

#### 7.4.1.1 Input Common-Mode Extension

The TRF1305x1 supports a  $V_{ICM}$  voltage closer to either  $V_{S+}$  or  $V_{S-}$  voltage than the default specified input common-mode range in the *Electrical Characteristics*, when configured in one of the  $V_{ICM}$  extension modes. The  $V_{ICM}$  extension mode can only be used in D2D configuration.

When configured in the low-side  $V_{ICM}$  extension mode, TRF1305B1 supports a 450mV lower input common-mode voltage than the default option. For example, the lower limit of  $V_{ICM}$  voltage range extends from a default value of  $V_{S-} + 1.5V$  to  $V_{S-} + 1.05V$  for the TRF1305B1 variant, and the higher limit also shifts lower from a default value of  $V_{S-} + 3.5V$  to  $V_{S-} + 3.05V$ . At the lowest  $V_{ICM}$  voltage, approximately 15mA current must be sunk by the external circuitry connected to the INP and INM pins.

When configured in the high-side  $V_{ICM}$  extension mode, TRF1305B1 supports a 450mV higher input common-mode voltage than the default option. For example, the higher limit of  $V_{ICM}$  voltage range extends from a default value of  $V_{S-} + 3.5V$  to  $V_{S-} + 3.95V$  for the TRF1305B1 variant, and the lower limit also shifts up from a default of  $V_{S-} + 1.5V$  to  $V_{S-} + 1.95V$ . At the highest  $V_{ICM}$  voltage, approximately 15mA current must be sourced by the external circuitry connected to the INP and INM pins.

Either resistors connected to supplies or external current sources can be used to sink or source the currents flowing out or into to the INP and INM pins during the low-side or high-side  $V_{ICM}$  extension modes, respectively.

### 7.4.2 Power-Down Mode

The TRF1305x1 have two bias modes, active and power-down, that are controlled by the voltage on the PD pin. The PD pin is referenced to the thermal pad through a 200k $\Omega$  resistor; see also [Section 7.2](#). If the  $V_{S+} \geq 3.3V$  configuration is used, ensure that the PD voltage does not exceed the *Absolute Maximum Ratings* in case the high PD voltage is derived from  $V_{S+}$ .

Both 1.8V and 3.3V digital logic is supported for power down control.



## 8 Application and Implementation

### Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

### 8.1 Application Information

#### 8.1.1 Input and Output Interface Considerations

##### 8.1.1.1 Single-Ended Input

In the single-ended input configuration, one of the amplifier input pins is driven from a source while the other input is terminated with an external resistor. Figure 8-1 shows an ac-coupled, single-ended input configuration driven from and matched to a 50Ω source. Figure 8-1 shows how the non-driven INM pin is terminated with a 50Ω external resistor to match to a source with the same 50Ω impedance at the INP pin. The configuration shown in Figure 8-1 works for all gain versions of TRF1305x1.

To configure the design in Figure 8-1 for single-ended, dc-coupled input, replace the ac-coupling capacitors with shorts, and externally bias both INP and INM pins to a voltage close to the mid-supply or within the common-mode limits of the amplifier.

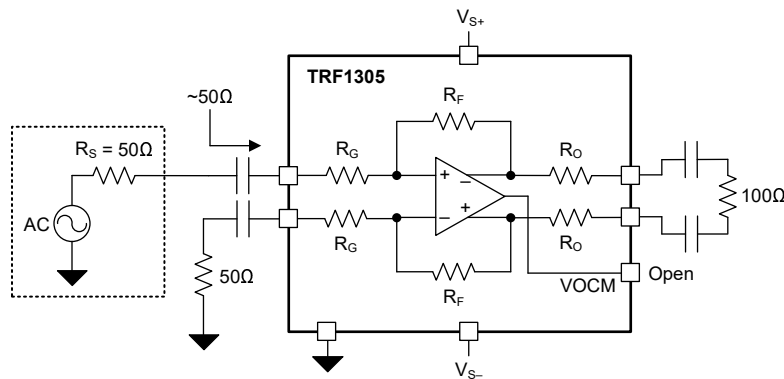
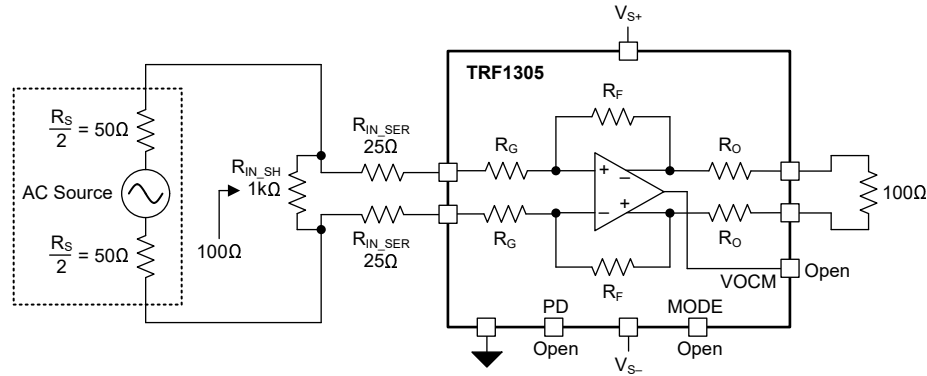


Figure 8-1. AC-Coupled, Single-Ended Input Matched to a 50Ω Source

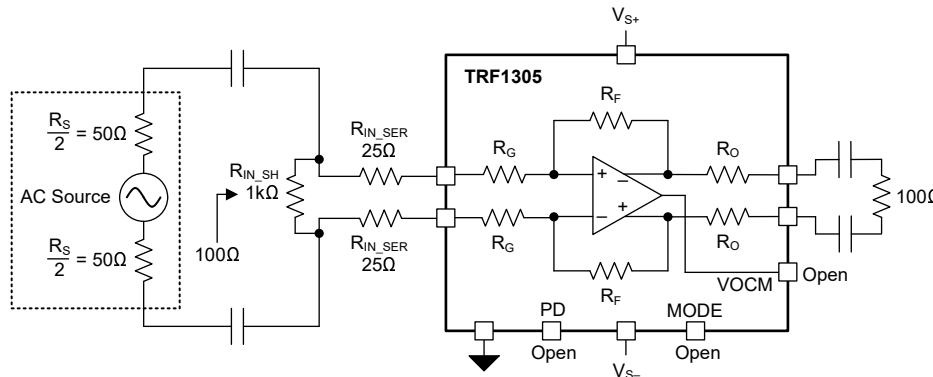
##### 8.1.1.2 Differential Input

Figure 8-2 shows how a simple network consisting of three resistors is used to match the differential input to a 100Ω differential source. Though the 1kΩ shunt resistor,  $R_{IN\_SH}$ , does not have any impact at dc to low frequencies, the resistor is necessary to get the full wideband performance from TRF1305x1. Figure 8-3 shows the configuration for ac-coupled differential input designs. The resistors values shown in Figure 8-2 and Figure 8-3 work for all gain versions of the TRF1305x1 for an 100Ω input match to a 100Ω differential source.

Use small foot-print resistors (0201 preferred), and RF quality for high frequency matching.



**Figure 8-2. DC-Coupled Differential Input Matched to a 100Ω Differential Source**

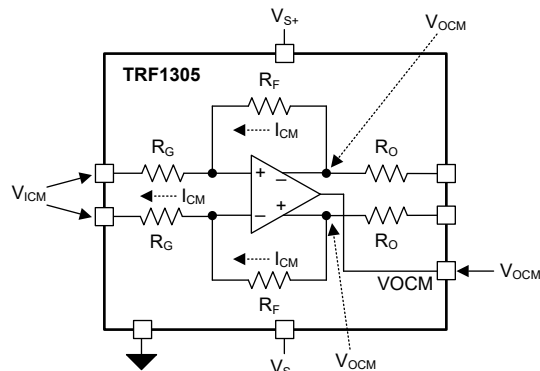


**Figure 8-3. AC-Coupled Differential Input Matched to a 100Ω Differential Source**

#### 8.1.1.3 DC Coupling Considerations

The TRF1305x1 accepts a wide range of input dc common-mode (CM) voltages. Take into consideration the dc current loading of the source when the TRF1305x1 is dc-coupled at the input. Figure 8-4 shows that when the input CM voltage,  $V_{ICM}$ , is different than the output CM voltage,  $V_{OCM}$ , a net dc current flow from or to the source occurs. Equation 1 shows the relationship that the source or sink current,  $I_{CM}$ , has with the input and output CM voltages:

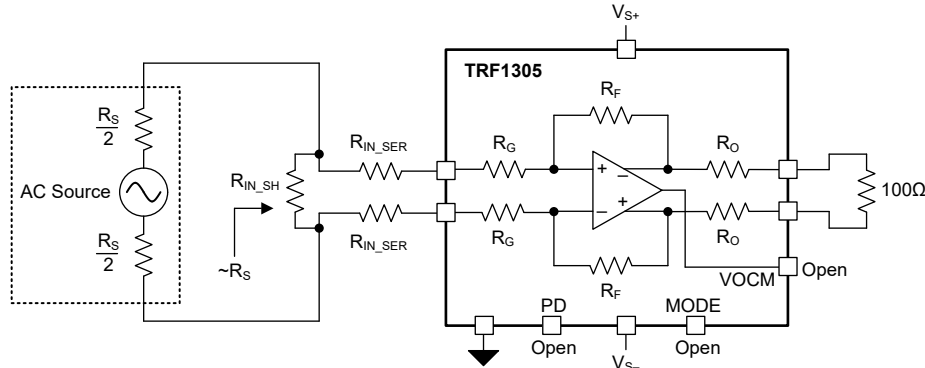
$$I_{CM} = \frac{(V_{OCM} - V_{ICM})}{(R_F + R_G)} \quad (1)$$



**Figure 8-4. Net DC Current Flow When Input and Output Common-Mode Voltages are not Equal**

### 8.1.2 Gain Adjustment With External Resistors in a Differential Input Configuration

The TRF1305x1 allow minor gain adjustments by configuring the input external resistive network that is part of the differential input configuration. Figure 8-5 shows the external input network that comprises of a shunt resistor,  $R_{IN\_SH}$ , and two series input resistors,  $R_{IN\_SER}$ , connected to the input pins of the amplifier.



**Figure 8-5. Gain Adjustment With External Resistor Network**

Table 8-1 provides resistor configurations for a 100Ω differential source impedance.

**Table 8-1. Resistor Table for  $R_S = 100\Omega$**

TRF1305B1		
POWER GAIN (dB)	$R_{IN\_SH} (\Omega)$	$R_{IN\_SER} (\Omega)$
10	1000	25
9	408	30
8	267	35
7	204	41
6	169	47
5	146	54

Use external resistive attenuation network only for small gain adjustments because there is a dB-to-dB noise figure degradation with the resistive attenuators. Use an amplifier version that requires minimal attenuation for achieving the overall gain.

For example, to realize 10dB overall gain with  $R_S = 100\Omega$  differential, the two options are:

1. TRF1305B1 with  $R_{IN\_SH} = 1000\Omega$  and  $R_{IN\_SER} = 25\Omega$  resistors
2. TRF1305A1 with  $R_{IN\_SH} = 125\Omega$  and  $R_{IN\_SER} = 49\Omega$  resistors

Option 1 is recommended because the NF is better by approximately 3dB compared to option 2.

## 8.2 Typical Application

### 8.2.1 TRF1305x1 as ADC Driver in a Zero-IF Receiver

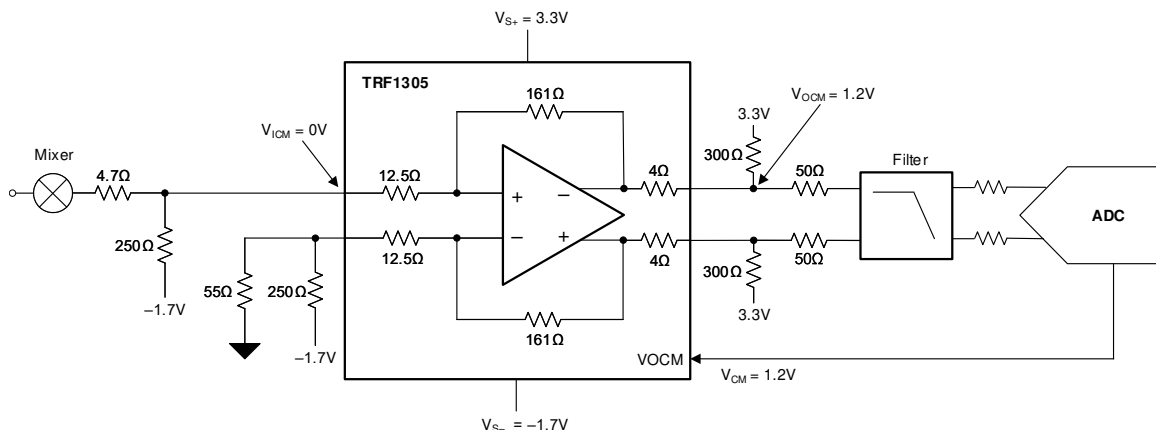


Figure 8-6. TRF1305x1 as ADC Driver in a Zero-IF Receiver

Consider a zero-IF (direct down conversion) application with an IQ demodulator interfaced to a pair of ADCs. In this case, the TRF1305x1 is used as an interface amplifier between the demodulator and the ADCs. The dc common-mode of the demodulator output and ADC input are different. The TRF1305x1 dc couples the demodulator to ADC without degrading the signal integrity of the signal chain.

#### 8.2.1.1 Design Requirements

The primary design requirement for an IQ demodulator application is to interface a pair of passive mixers with an RF ADC. The mixers have a 0-V common-mode voltage. The ADC requires an input common-mode voltage of 1.2V with full-scale swing of 1.35V<sub>PP</sub>. Choose the power supplies, and design the input/output network for the TRF1305x1 as the ADC driver amplifier, to perform the dc level shifting and amplification function.

#### 8.2.1.2 Detailed Design Procedure

The first step is to choose the TRF1305x1 supplies. Ensure that the midsupply voltage,  $V_{MIDSUPPLY}$ , is between the ADC common-mode (CM) voltage and the mixer CM voltage.  $V_{MIDSUPPLY}$  is typically positioned closer to the ADC CM because the output CM range of the amplifier is less than the input CM range. Ensure that the dc of the signal at the input and output of the amplifier are within the valid operating common-mode voltage range. Use the MODE pin for cases where an extended range of the input CM is required.

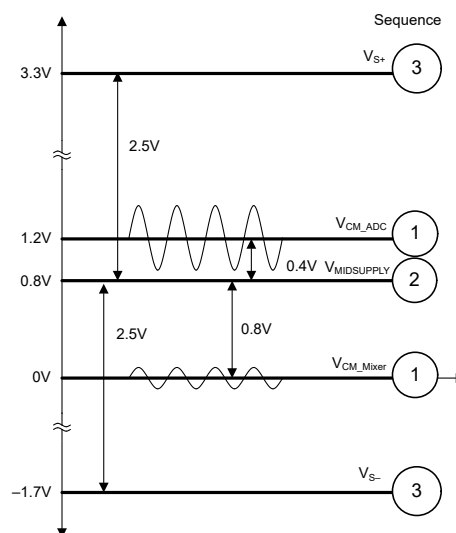


Figure 8-7. Choosing Supply Voltages With Given Common-Mode Voltages

Figure 8-7 shows how  $V_{MIDSUPPLY}$  is chosen to be 0.8V, so that the amplifier input has a CM offset from  $V_{MIDSUPPLY}$  of 0.8V and output has a CM offset from  $V_{MIDSUPPLY}$  of 0.4V ( $1.2V - 0.8V$ ). The CM offsets are within the valid common-mode range of the amplifier, so the supplies of the TRF1305B1 are chosen to be  $V_{S+} = 3.3V$  ( $0.8V + 2.5V$ ) and  $V_{S-} = -1.7V$  ( $0.8V - 2.5V$ ).

The output CM is greater than the input CM; therefore, a net 6.9-mA ( $(1.2V - 0V) / (161\Omega + 12.5\Omega)$ ) dc current flows from the output to input through the internal feedback resistors. Depending on the choice of the passive mixer, this current can required to be sunk outside the mixer so that the bias conditions of the mixer are not disturbed. A 250 $\Omega$  pulldown resistor connected to the INP pin to  $-1.7V$  supply is adequate. If the 6.9mA dc current is sourced entirely from the amplifier, then the output headroom can be affected. Therefore, source the current externally from the supply using a pair of pullup resistors connected to the amplifier outputs. 300 $\Omega$  pullup resistors from OUTP and OUTM to 3.3V are adequate.

The I-channel mixer output has a 50 $\Omega$  port and is connected to the amplifier INP pin through a small (4.7 $\Omega$ ) series resistor. The INM pin is terminated to ground through a 55 $\Omega$  resistor and to  $-1.7V$  through a 250 $\Omega$  resistor. This configuration allows the amplifier to have the same input impedance at each of the INP and INM input pins. The impedance of the mixer is close to 43 $\Omega$  and provides better than a  $-20$ -dB return loss (theoretically). Be aware that there is some drop in the gain due to these resistor networks. The values of the resistors chosen in Figure 8-6 are a good starting point; in practice, some adjustment is often needed to simultaneously meet the dc conditions and the RF performance.

At the amplifier output, 50 $\Omega$  series resistors are used to match to the antialiasing filter with 100 $\Omega$  differential input impedance. The filter output is connected to ADC with appropriate matching. Figure 8-6 only shows the I-channel; the Q-channel has an identical configuration.

## 8.3 Power Supply Recommendations

### 8.3.1 Supply Voltages

For the TRF1305x1, the typical differential supply between  $V_{S+}$  and  $V_{S-}$  is 5V. The  $V_{S+}$  and  $V_{S-}$  supply pins can be floated with respect to ground within the specified range listed in the *Absolute Maximum Ratings* and *Recommended Operating Conditions*.

### 8.3.2 Single-Supply Operation

The  $V_{S-}$  pin is connected to ground in the single-supply configuration. Single-supply operation is most convenient in ac-coupled configurations because the dc common-mode voltages of the source at the inputs and the driven circuit at the outputs are inherently decoupled.

### 8.3.3 Split-Supply Operation

In split-supply configuration, choose the  $V_{S+}$  and  $V_{S-}$  voltages to be within the ranges specified in the *Absolute Maximum Ratings* and *Recommended Operating Conditions*. The TRF1305x1 allows choosing negative voltages for the  $V_{S-}$  supply, thereby allowing the flexibility to choose input and output common-mode voltages according to the input network and output network requirements.

### 8.3.4 Supply Decoupling

The  $V_{S+}$  and  $V_{S-}$  supply pins are decoupled individually to ground using external capacitors. Place the decoupling capacitors close to the device supply pins.

## 8.4 Layout

### 8.4.1 Layout Guidelines

The TRF1305x1 devices are wideband closed-loop feedback amplifiers. When designing with wideband RF amplifiers that have high gain, take certain board layout precautions to maintain stability and optimized performance. Use a multilayer board to maintain signal integrity, power integrity, and thermal performance.

Route the RF input and output lines as grounded coplanar waveguide (GCPW) lines. Ground pins are the reference for the RF signals. Ensure that the second layer of the PCB has a continuous ground layer without any ground cutouts in the vicinity of the amplifier. To minimize phase imbalance, match the length of the output differential lines of both channels. Length matching the input traces is also important, especially if the input configuration is differential. Use small-footprint, passive components wherever possible.

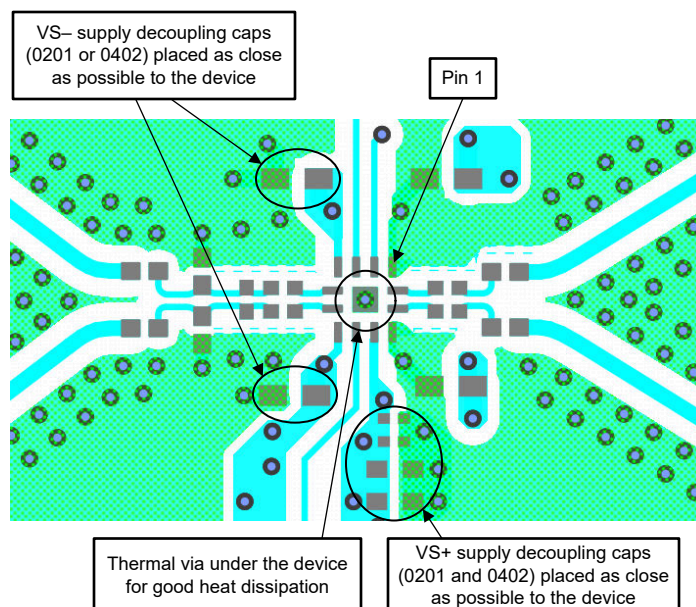
For good heat dissipation, connect the device thermal pad to the board ground planes using thermal vias under the device. For improved heat dissipation, connect the device thermal pad to the top layer ground plane of the board.

#### 8.4.1.1 Thermal Considerations

The TRF1305x1 are packaged in a WQFN-FCRLF package that has excellent thermal properties. Connect the thermal pads underneath the devices to the thermally dissipative ground plane on the board. For good thermal design, use thermal vias to connect the thermal pad plane on the top layer of the PCB to the ground planes in the inner layers.

### 8.4.2 Layout Example

Figure 8-8 shows an example layout for TRF1305x1 with a differential input configuration. Key areas are highlighted in the figure.



**Figure 8-8. Layout Example: TRF1305x1 With Differential Input**

The TRF1305x1 can be evaluated using EVM boards that can be ordered from the [TRF1305B1](#) product folder. For more information about the evaluation board construction and test setup, see the [TRF1305x1 EVM User's Guide](#).

## 9 Device and Documentation Support

### 9.1 Documentation Support

#### 9.1.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, [TRF1305x1-D2D EVM User's Guide](#)

### 9.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 9.3 Support Resources

TI E2E™ [support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

### 9.4 Trademarks

TI E2E™ is a trademark of Texas Instruments.

All trademarks are the property of their respective owners.

### 9.5 Electrostatic Discharge Caution



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.

### 9.6 Glossary

#### [TI Glossary](#)

This glossary lists and explains terms, acronyms, and definitions.

## 10 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

DATE	REVISION	NOTES
September 2024	*	Initial Release

## 11 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.



## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](#) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2024, Texas Instruments Incorporated