LT6230/LT6230-10/ LT6231/LT6232

215MHz, Rail-to-Rail Output, 1.1nV/√Hz, 3.5mA Op Amp Family

FEATURES

- **Low Noise Voltage: 1.1nV/√Hz**
- **Low Supply Current: 3.5mA/Amp Max**
- **Low Offset Voltage: 350μV Max**
- Gain Bandwidth Product:
  LT6230: 215MHz; $A_V \geq 1$
  LT6230-10: 1450MHz; $A_V \geq 10$
- Wide Supply Range: 3V to 12.6V
- Output Swings Rail-to-Rail
- Common Mode Rejection Ratio 115dB Typ
- Output Current: 30mA
- Operating Temperature Range –40°C to 85°C
- LT6230 Shutdown to 10μA Maximum
- LT6230/LT6230-10 in SOT-23 Package
- Dual LT6231 in 8-Pin SO and Tiny DFN Packages
- LT6232 in 16-Pin SSOP Package

APPLICATIONS

- Ultrasound Amplifiers
- Low Noise, Low Power Signal Processing
- Active Filters
- Driving A/D Converters
- Rail-to-Rail Buffer Amplifiers

DESCRIPTION

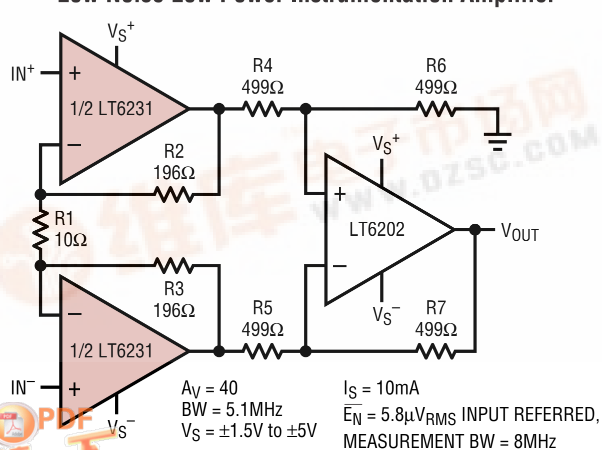
The LT®6230/LT6231/LT6232 are single/dual/quad low noise, rail-to-rail output unity gain stable op amps that feature 1.1nV/√Hz noise voltage and draw only 3.5mA of supply current per amplifier. These amplifiers combine very low noise and supply current with a 215MHz gain bandwidth product, a 70V/μs slew rate and are optimized for low supply voltage signal conditioning systems. The LT6230-10 is a single amplifier optimized for higher gain applications resulting in higher gain bandwidth and slew rate. The LT6230 and LT6230-10 include an enable pin that can be used to reduce the supply current to less than 10μA.

The amplifier family has an output that swings within 50mV of either supply rail to maximize the signal dynamic range in low supply applications and is specified on 3.3V, 5V and ±5V supplies. The $e_n \bullet \sqrt{I_{SUPPLY}}$ product of 1.9 per amplifier is among the most noise efficient of any op amp.

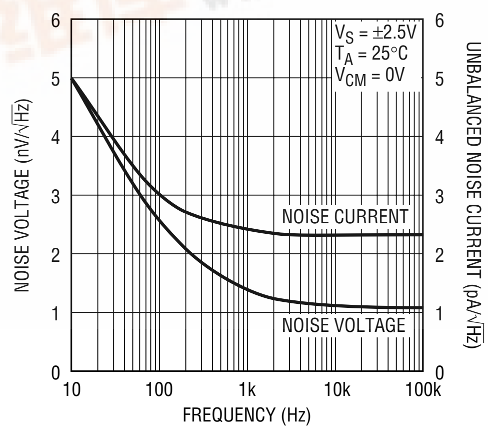
The LT6230/LT6230-10 is available in the 6-lead SOT-23 package and the LT6231 dual is available in the 8-pin SO package with standard pinouts. For compact layouts, the dual is also available in a tiny dual fine pitch leadless package (DFN). The LT6232 is available in the 16-pin SSOP package.

TYPICAL APPLICATION

Low Noise Low Power Instrumentation Amplifier



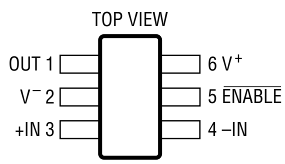
Noise Voltage and Unbalanced Noise Current vs Frequency



ABSOLUTE MAXIMUM RATINGS (Note 1)

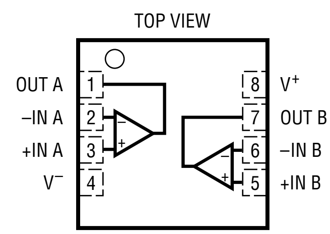
Total Supply Voltage (V^+ to V^-) 12.6V
Input Current (Note 2) .... ±40mA
Output Short-Circuit Duration (Note 3) .... Indefinite
Operating Temperature Range (Note 4) ...–40°C to 85°C
Specified Temperature Range (Note 5) ....–40°C to 85°C
Junction Temperature .... 150°C
Junction Temperature (DD Package) .... 125°C
Storage Temperature Range ....–65°C to 150°C
Storage Temperature Range
(DD Package) .... –65°C to 125°C
Lead Temperature (Soldering, 10 sec) .... 300°C

PACKAGE/ORDER INFORMATION



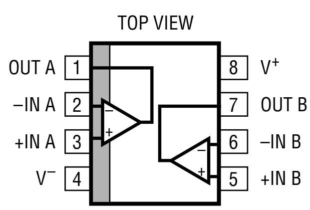
S6 PACKAGE
6-LEAD PLASTIC TSOT-23
T_{JMAX} = 150°C, θ_{JA} = 250°C/W

ORDER PART NUMBER	S6 PART MARKING*
LT6230CS6	LTAFJ
LT6230IS6	LTAFK
LT6230CS6-10	
LT6230IS6-10	



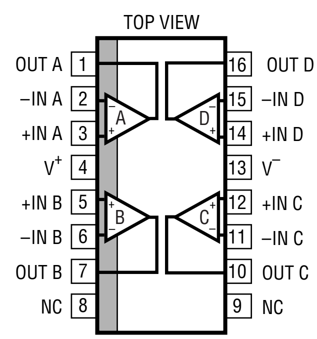
DD PACKAGE
8-LEAD (3mm × 3mm) PLASTIC DFN
T_{JMAX} = 125°C, θ_{JA} = 160°C/W
UNDERSIDE METAL CONNECTED TO V^-
(PCB CONNECTION OPTIONAL)

ORDER PART NUMBER	DD PART MARKING*
LT6231CDD	LAEU
LT6231IDD	



S8 PACKAGE
8-LEAD PLASTIC SO
T_{JMAX} = 150°C, θ_{JA} = 200°C/W

ORDER PART NUMBER	S8 PART MARKING
LT6231CS8	6231
LT6231IS8	6231I



GN PACKAGE
16-LEAD NARROW PLASTIC SSOP
T_{JMAX} = 150°C, θ_{JA} = 135°C/W

ORDER PART NUMBER	GN PART MARKING
LT6232CGN	6232
LT6232IGN	6232I

*The temperature grade is identified by a label on the shipping container. Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

$T_A = 25°C$, $V_S = 5V$, 0V; $V_S = 3.3V$, 0V; $V_{CM} = V_{OUT}$ = half supply, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6230S6, LT6230S6-10 LT6231S8, LT6232GN LT6231DD		100 50 75	500 350 450	µV µV µV
	Input Offset Voltage Match (Channel-to-Channel) (Note 6)			100	600	µV
I_B	Input Bias Current			5	10	µA
	I_B Match (Channel-to-Channel) (Note 6)			0.1	0.9	µA
I_{OS}	Input Offset Current			0.1	0.6	µA
	Input Noise Voltage	0.1Hz to 10Hz		180		nV_{P-P}
e_n	Input Noise Voltage Density	f = 10kHz, V_S = 5V		1.1	1.7	$nV/\sqrt{Hz}$
i_n	Input Noise Current Density, Balanced Source Unbalanced Source	f = 10kHz, V_S = 5V, R_S = 10k f = 10kHz, V_S = 5V, R_S = 10k		1 2.4		$pA/\sqrt{Hz}$ $pA/\sqrt{Hz}$
	Input Resistance	Common Mode Differential Mode		6.5 7.5		MΩ kΩ
C_{IN}	Input Capacitance	Common Mode Differential Mode		2.9 7.7		pF pF
A_{VOL}	Large-Signal Gain	V_S = 5V, V_O = 0.5V to 4.5V, R_L = 10k to V_S/2 R_L = 1k to V_S/2 V_O = 1V to 4V, R_L = 100Ω to V_S/2	105 21 5.4	200 40 9		V/mV V/mV V/mV
		V_S = 3.3V, V_O = 0.65V to 2.65V, R_L = 10k to V_S/2 R_L = 1k to V_S/2	90 16.5	175 32		V/mV V/mV
V_{CM}	Input Voltage Range	Guaranteed by CMRR, V_S = 5V, 0V V_S = 3.3V, 0V	1.5 1.15		4 2.65	V V
CMRR	Common Mode Rejection Ratio	V_S = 5V, V_{CM} = 1.5V to 4V V_S = 3.3V, V_{CM} = 1.15V to 2.65V	90 90	115 115		dB dB
	CMRR Match (Channel-to-Channel) (Note 6)	V_S = 5V, V_{CM} = 1.5V to 4V	84	120		dB
PSRR	Power Supply Rejection Ratio	V_S = 3V to 10V	90	115		dB
	PSRR Match (Channel-to-Channel) (Note 6)	V_S = 3V to 10V	84	115		dB
	Minimum Supply Voltage (Note 7)		3			V
V_{OL}	Output Voltage Swing LOW (Note 8)	No Load I_{SINK} = 5mA V_S = 5V, I_{SINK} = 20mA V_S = 3.3V, I_{SINK} = 15mA		4 85 240 185	40 190 460 350	mV mV mV mV
V_{OH}	Output Voltage Swing HIGH (Note 8)	No Load I_{SOURCE} = 5mA V_S = 5V, I_{SOURCE} = 20mA V_S = 3.3V, I_{SOURCE} = 15mA		5 90 325 250	50 200 600 400	mV mV mV mV
I_{SC}	Short-Circuit Current	V_S = 5V V_S = 3.3V	±30 ±25	±45 ±40		mA mA
I_S	Supply Current per Amplifier Disabled Supply Current per Amplifier	 $\overline{ENABLE}$ = V^+ – 0.35V		3.15 0.2	3.5 10	mA µA

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_S = 5V, 0V; V_S = 3.3V, 0V; V_{CM} = V_{OUT} = half supply, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
$I_{\overline{ENABLE}}$	$\overline{ENABLE}$ Pin Current	$\overline{ENABLE}$ = 0.3V		–25	–75	µA
V_L	$\overline{ENABLE}$ Pin Input Voltage LOW				0.3	V
V_H	$\overline{ENABLE}$ Pin Input Voltage HIGH		V^+ – 0.35V			V
	Output Leakage Current	$\overline{ENABLE}$ = V^+ – 0.35V, V_O = 1.5V to 3.5V		0.2	10	µA
t_{ON}	Turn-On Time	$\overline{ENABLE}$ = 5V to 0V, R_L = 1k, V_S = 5V		300		ns
t_{OFF}	Turn-Off Time	$\overline{ENABLE}$ = 0V to 5V, R_L = 1k, V_S = 5V		41		µs
GBW	Gain Bandwidth Product	Frequency = 1MHz, V_S = 5V LT6230-10		200 1300		MHz MHz
SR	Slew Rate	V_S = 5V, A_V = –1, R_L = 1k, V_O = 1.5V to 3.5V	42	60		V/µs
		LT6230-10, V_S = 5V, A_V = –10, R_L = 1k, V_O = 1.5V to 3.5V		250		V/µs
FPBW	Full Power Bandwidth	V_S = 5V, V_{OUT} = $3V_{P-P}$ (Note 9)	4.8	6.3		MHz
		LT6230-10, HD_2 = HD_3 = ≤ 1%		11		MHz
t_S	Settling Time (LT6230, LT6231, LT6232)	0.1%, V_S = 5V, V_{STEP} = 2V, A_V = –1, R_L = 1k		55		ns

The ● denotes the specifications which apply over 0°C < T_A < 70°C temperature range. V_S = 5V, 0V; V_S = 3.3V, 0V; V_{CM} = V_{OUT} = half supply, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6230S6, LT6230S6-10 LT6231S8, LT6232GN LT6231DD	● ● ●			600 450 550	µV µV µV
	Input Offset Voltage Match (Channel-to-Channel) (Note 6)		●			800	µV
V_{OS} TC	Input Offset Voltage Drift (Note 10)	V_{CM} = Half Supply	●		0.5	3	µV/°C
I_B	Input Bias Current		●			11	µA
	I_B Match (Channel-to-Channel) (Note 6)		●			1	µA
I_{OS}	Input Offset Current		●			0.7	µA
A_{VOL}	Large-Signal Gain	V_S = 5V, V_O = 0.5V to 4.5V, R_L = 10k to V_S/2 R_L = 1k to V_S/2 V_O = 1V to 4V, R_L = 100Ω to V_S/2	● ● ●	78 17 4.1			V/mV V/mV V/mV
		V_S = 3.3V, V_O = 0.65V to 2.65V, R_L = 10k to V_S/2 R_L = 1k to V_S/2	● ●	66 13			V/mV V/mV
V_{CM}	Input Voltage Range	Guaranteed by CMRR, V_S = 5V, 0V V_S = 3.3V, 0V	● ●	1.5 1.15		4 2.65	V V
CMRR	Common Mode Rejection Ratio	V_S = 5V, V_{CM} = 1.5V to 4V V_S = 3.3V, V_{CM} = 1.15V to 2.65V	● ●	90 85			dB dB
	CMRR Match (Channel-to-Channel) (Note 6)	V_S = 5V, V_{CM} = 1.5V to 4V	●	84			dB
PSRR	Power Supply Rejection Ratio	V_S = 3V to 10V	●	85			dB
	PSRR Match (Channel-to-Channel) (Note 6)	V_S = 3V to 10V	●	79			dB
	Minimum Supply Voltage (Note 7)		●	3			V
V_{OL}	Output Voltage Swing LOW (Note 8)	No Load I_{SINK} = 5mA V_S = 5V, I_{SINK} = 20mA V_S = 3.3V, I_{SINK} = 15mA	● ● ● ●			50 200 500 380	mV mV mV mV

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over 0°C < T_A < 70°C temperature range. V_S = 5V, 0V; V_S = 3.3V, 0V; V_{CM} = V_{OUT} = half supply, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OH}	Output Voltage Swing HIGH (Note 8)	No Load I_{SOURCE} = 5mA V_S = 5V, I_{SOURCE} = 20mA V_S = 3.3V, I_{SOURCE} = 15mA	● ● ● ●			60 215 650 430	mV mV mV mV
I_{SC}	Short-Circuit Current	V_S = 5V V_S = 3.3V	● ●	±25 ±20			mA mA
I_S	Supply Current per Amplifier Disabled Supply Current per Amplifier	 $\overline{ENABLE}$ = V^+ – 0.25V	● ●		 1	4.2	mA µA
$I_{\overline{ENABLE}}$	$\overline{ENABLE}$ Pin Current	$\overline{ENABLE}$ = 0.3V	●			–85	µA
V_L	$\overline{ENABLE}$ Pin Input Voltage LOW		●			0.3	V
V_H	$\overline{ENABLE}$ Pin Input Voltage HIGH		●	V^+ – 0.25V			V
	Output Leakage Current	$\overline{ENABLE}$ = V^+ – 0.25V, V_O = 1.5V to 3.5V	●		1		µA
t_{ON}	Turn-On Time	$\overline{ENABLE}$ = 5V to 0V, R_L = 1k, V_S = 5V	●		300		ns
t_{OFF}	Turn-Off Time	$\overline{ENABLE}$ = 0V to 5V, R_L = 1k, V_S = 5V	●		65		µs
SR	Slew Rate	V_S = 5V, A_V = –1, R_L = 1k, V_O = 1.5V to 3.5V	●	35			V/µs
		LT6230-10, A_V = –10, R_L = 1k, V_O = 1.5V to 3.5V	●		225		V/µs
FPBW	Full Power Bandwidth (Note 9)	V_S = 5V, V_{OUT} = $3V_{P-P}$ LT6230, LT6231, LT6232	●	3.7			MHz

The ● denotes the specifications which apply over –40°C < T_A < 85°C temperature range. V_S = 5V, 0V; V_S = 3.3V, 0V; V_{CM} = V_{OUT} = half supply, $\overline{ENABLE}$ = 0V, unless otherwise noted. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6230S6, LT6230S6-10 LT6231S8, LT6232GN LT6231DD	● ● ●			700 550 650	µV µV µV
	Input Offset Voltage Match (Channel-to-Channel) (Note 6)		●			1000	µV
V_{OS} TC	Input Offset Voltage Drift (Note 10)	V_{CM} = Half Supply	●		0.5	3	µV/°C
I_B	Input Bias Current		●			12	µA
	I_B Match (Channel-to-Channel) (Note 6)		●			1.1	µA
I_{OS}	Input Offset Current		●			0.8	µA
A_{VOL}	Large-Signal Gain	V_S = 5V, V_O = 0.5V to 4.5V, R_L = 10k to V_S/2 R_L = 1k to V_S/2 V_O = 1V to 4V, R_L = 100Ω to V_S/2	● ● ●	72 16 3.6			V/mV V/mV V/mV
		V_S = 3.3V, V_O = 0.65V to 2.65V, R_L = 10k to V_S/2 R_L = 1k to V_S/2	● ●	60 12			V/mV V/mV
V_{CM}	Input Voltage Range	Guaranteed by CMRR, V_S = 5V, 0V V_S = 3.3V, 0V	● ●	1.5 1.15		4 2.65	V V
CMRR	Common Mode Rejection Ratio	V_S = 5V, V_{CM} = 1.5V to 4V V_S = 3.3V, V_{CM} = 1.15V to 2.65V	● ●	90 85			dB dB
	CMRR Match (Channel-to-Channel) (Note 6)	V_S = 5V, V_{CM} = 1.5V to 4V	●	84			dB
PSRR	Power Supply Rejection Ratio	V_S = 3V to 10V	●	85			dB

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over –40°C < T_A < 85°C temperature range. V_S = 5V, 0V; V_S = 3.3V, 0V; V_{CM} = V_{OUT} = half supply, $\overline{ENABLE}$ = 0V, unless otherwise noted. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
	PSRR Match (Channel-to-Channel) (Note 6)	V_S = 3V to 10V	●	79			dB
	Minimum Supply Voltage (Note 7)		●	3			V
V_{OL}	Output Voltage Swing LOW (Note 8)	No Load I_{SINK} = 5mA V_S = 5V, I_{SINK} = 15mA V_S = 3.3V, I_{SINK} = 15mA	● ● ● ●			60 210 510 390	mV mV mV mV
V_{OH}	Output Voltage Swing HIGH (Note 6)	No Load I_{SOURCE} = 5mA V_S = 5V, I_{SOURCE} = 20mA V_S = 3.3V, I_{SOURCE} = 15mA	● ● ● ●			70 220 675 440	mV mV mV mV
I_{SC}	Short-Circuit Current	V_S = 5V V_S = 3.3V	● ●	±15 ±15			mA mA
I_S	Supply Current per Amplifier Disabled Supply Current per Amplifier	 $\overline{ENABLE}$ = V^+ – 0.2V	● ●		 1	4.4 	mA µA
$I_{\overline{ENABLE}}$	$\overline{ENABLE}$ Pin Current	$\overline{ENABLE}$ = 0.3V	●			–100	µA
V_L	$\overline{ENABLE}$ Pin Input Voltage LOW		●			0.3	V
V_H	$\overline{ENABLE}$ Pin Input Voltage HIGH		●	V^+ – 0.2V			V
	Output Leakage Current	$\overline{ENABLE}$ = V^+ – 0.2V, V_O = 1.5V to 3.5V	●		1		µA
t_{ON}	Turn-On Time	$\overline{ENABLE}$ = 5V to 0V, R_L = 1k, V_S = 5V	●		300		ns
t_{OFF}	Turn-Off Time	$\overline{ENABLE}$ = 0V to 5V, R_L = 1k, V_S = 5V	●		72		µs
SR	Slew Rate	V_S = 5V, A_V = –1, R_L = 1k, V_O = 1.5V to 3.5V	●	31			V/µs
		LT6230-10, A_V = –10, R_L = 1k, V_O = 1.5V to 3.5V	●		185		V/µs
FPBW	Full Power Bandwidth (Note 9)	V_S = 5V, V_{OUT} = $3V_{P-P}$ LT6230, LT6231, LT6232	●	3.3			MHz

T_A = 25°C, V_S = ±5V, V_{CM} = V_{OUT} = 0V, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6230, LT6230-10 LT6231S8, LT6232GN LT6231DD		100 50 75	500 350 450	µV µV µV
	Input Offset Voltage Match (Channel-to-Channel) (Note 6)			100	600	µV
I_B	Input Bias Current			5	10	µA
	I_B Match (Channel-to-Channel) (Note 6)			0.1	0.9	µA
I_{OS}	Input Offset Current			0.1	0.6	µA
	Input Noise Voltage	0.1Hz to 10Hz		180		nV_{P-P}
e_n	Input Noise Voltage Density	f = 10kHz		1.1	1.7	nV/√Hz
i_n	Input Noise Current Density, Balanced Source Unbalanced Source	f = 10kHz, R_S = 10k f = 10kHz, R_S = 10k		1 2.4		pA/√Hz pA/√Hz

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_S = ±5V, V_{CM} = V_{OUT} = 0V, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
	Input Resistance	Common Mode Differential Mode		6.5 7.5		MΩ kΩ
C_{IN}	Input Capacitance	Common Mode Differential Mode		2.4 6.5		pF pF
A_{VOL}	Large-Signal Gain	V_O = ±4.5V, R_L = 10k R_L = 1k V_O = ±2V, R_L = 100Ω	140 35 8.5	260 65 16		V/mV V/mV V/mV
V_{CM}	Input Voltage Range	Guaranteed by CMRR	–3		4	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –3V to 4V	95	120		dB
	CMRR Match (Channel-to-Channel) (Note 6)	V_{CM} = –3V to 4V	89	125		dB
PSRR	Power Supply Rejection Ratio	V_S = ±1.5V to ±5V	90	115		dB
	PSRR Match (Channel-to-Channel) (Note 6)	V_S = ±1.5V to ±5V	84	115		dB
V_{OL}	Output Voltage Swing LOW (Note 8)	No Load I_{SINK} = 5mA I_{SINK} = 20mA		4 85 240	40 190 460	mV mV mV
V_{OH}	Output Voltage Swing HIGH (Note 8)	No Load I_{SOURCE} = 5mA I_{SOURCE} = 20mA		5 90 325	50 200 600	mV mV mV
I_{SC}	Short-Circuit Current		±30			mA
I_S	Supply Current per Amplifier Disabled Supply Current per Amplifier	 $\overline{ENABLE}$ = 4.65V		3.3 0.2	3.9	mA µA
$I_{\overline{ENABLE}}$	$\overline{ENABLE}$ Pin Current	$\overline{ENABLE}$ = 0.3V		–35	–85	µA
V_L	$\overline{ENABLE}$ Pin Input Voltage LOW				0.3	V
V_H	$\overline{ENABLE}$ Pin Input Voltage HIGH		4.65			V
	Output Leakage Current	$\overline{ENABLE}$ = V^+ – 4.65V, V_O = ±1V		0.2	10	µA
t_{ON}	Turn-On Time	$\overline{ENABLE}$ = 5V to 0V, R_L = 1k		300		ns
t_{OFF}	Turn-Off Time	$\overline{ENABLE}$ = 0V to 5V, R_L = 1k		62		µs
GBW	Gain Bandwidth Product	Frequency = 1MHz LT6230-10	150 1000	215 1450		MHz MHz
SR	Slew Rate	A_V = –1, R_L = 1k, V_O = –2V to 2V	50	70		V/µs
		LT6230-10, A_V = –10, R_L = 1k, V_O = –2V to 2V		320		V/µs
FPBW	Full Power Bandwidth	V_{OUT} = $3V_{P-P}$ (Note 9)	5.3	7.4		MHz
		LT6230-10, HD2 = HD3 ≤ 1%		11		MHz
t_S	Settling Time (LT6230, LT6231, LT6232)	0.1%, V_{STEP} = 2V, A_V = –1, R_L = 1k		50		ns

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over 0°C < T_A < 70°C temperature range. V_S = ±5V, V_{CM} = V_{OUT} = 0V, $\overline{ENABLE}$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6230S6, LT6230S6-10 LT6231S8, LT6232GN LT6231DD	● ● ●			600 450 550	µV µV µV
	Input Offset Voltage Match (Channel-to-Channel) (Note 6)		●			800	µV
V_{OS} TC	Input Offset Voltage Drift (Note 10)		●		0.5	3	µV/°C
I_B	Input Bias Current		●			11	µA
	I_B Match (Channel-to-Channel) (Note 6)		●			1	µA
I_{OS}	Input Offset Current		●			0.7	µA
A_{VOL}	Large-Signal Gain	V_O = ±4.5V, R_L = 10k R_L = 1k V_O = ±2V, R_L = 100Ω	● ● ●	100 27 6			V/mV V/mV V/mV
V_{CM}	Input Voltage Range	Guaranteed by CMRR	●	–3		4	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –3V to 4V	●	95			dB
	CMRR Match (Channel-to-Channel) (Note 6)	V_{CM} = –3V to 4V	●	89			dB
PSRR	Power Supply Rejection Ratio	V_S = ±1.5V to ±5V	●	85			dB
	PSRR Match (Channel-to-Channel) (Note 6)	V_S = ±1.5V to ±5V	●	79			dB
V_{OL}	Output Voltage Swing LOW (Note 8)	No Load I_{SINK} = 5mA I_{SINK} = 20mA	● ● ●			50 200 500	mV mV mV
V_{OH}	Output Voltage Swing HIGH (Note 8)	No Load I_{SOURCE} = 5mA I_{SOURCE} = 20mA	● ● ●			60 215 650	mV mV mV
I_{SC}	Short-Circuit Current		●	±25			mA
I_S	Supply Current per Amplifier Disabled Supply Current per Amplifier	 $\overline{ENABLE}$ = 4.75V	● ●		 1	4.6 	mA µA
$I_{\overline{ENABLE}}$	$\overline{ENABLE}$ Pin Current	$\overline{ENABLE}$ = 0.3V	●			–95	µA
V_L	$\overline{ENABLE}$ Pin Input Voltage LOW		●			0.3	V
V_H	$\overline{ENABLE}$ Pin Input Voltage HIGH		●	4.75			V
	Output Leakage Current	$\overline{ENABLE}$ = 4.75V, V_O = ±1V	●		1		µA
t_{ON}	Turn-On Time	$\overline{ENABLE}$ = 5V to 0V, R_L = 1k	●		300		ns
t_{OFF}	Turn-Off Time	$\overline{ENABLE}$ = 0V to 5V, R_L = 1k	●		85		µs
SR	Slew Rate	A_V = –1, R_L = 1k, V_O = –2V to 2V	●	44			V/µs
		LT6230-10, A_V = –10, R_L = 1k, V_O = –2V to 2V	●		315		V/µs
FPBW	Full Power Bandwidth	V_{OUT} = $3V_{P-P}$ (Note 9) LT6230, LT6231, LT6232	●	4.66			MHz

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over –40°C < T_A < 85°C temperature range. V_S = ±5V, V_{CM} = V_{OUT} = 0V, $\overline{ENABLE}$ = 0V, unless otherwise noted. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6230, LT6230-10 LT6231S8, LT6232GN LT6231DD	● ● ●			700 550 650	µV µV µV
	Input Offset Voltage Match (Channel-to-Channel) (Note 6)		●			1000	µV
V_{OS} TC	Input Offset Voltage Drift (Note 10)		●		0.5	3	µV/°C
I_B	Input Bias Current		●			12	µA
	I_B Match (Channel-to-Channel) (Note 6)		●			1.1	µA
I_{OS}	Input Offset Current		●			0.8	µA
A_{VOL}	Large-Signal Gain	V_O = ±4.5V, R_L = 10k R_L = 1k V_O = ±1.5V, R_L = 100Ω	● ● ●	93 25 4.8			V/mV V/mV V/mV
V_{CM}	Input Voltage Range	Guaranteed by CMRR	●	–3		4	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –3V to 4V	●	95			dB
	CMRR Match (Channel-to-Channel) (Note 6)	V_{CM} = –3V to 4V	●	89			dB
PSRR	Power Supply Rejection Ratio	V_S = ±1.5V to ±5V	●	85			dB
	PSRR Match (Channel-to-Channel) (Note 6)	V_S = ±1.5V to ±5V	●	79			dB
V_{OL}	Output Voltage Swing LOW (Note 8)	No Load I_{SINK} = 5mA I_{SINK} = 15mA	● ● ●			60 210 510	mV mV mV
V_{OH}	Output Voltage Swing HIGH (Note 8)	No Load I_{SOURCE} = 5mA I_{SOURCE} = 20mA	● ● ●			70 220 675	mV mV mV
I_{SC}	Short-Circuit Current		●	±15			mA
I_S	Supply Current per Amplifier Disabled Supply Current per Amplifier	 $\overline{ENABLE}$ = 4.8V	● ●		 1	4.85	mA µA
$I_{\overline{ENABLE}}$	$\overline{ENABLE}$ Pin Current	$\overline{ENABLE}$ = 0.3V	●			–110	µA
V_L	$\overline{ENABLE}$ Pin Input Voltage LOW		●			0.3	V
V_H	$\overline{ENABLE}$ Pin Input Voltage HIGH		●	4.8			V
	Output Leakage Current	$\overline{ENABLE}$ = 4.8V, V_O = ±1V	●		1		µA
t_{ON}	Turn-On Time	$\overline{ENABLE}$ = 5V to 0V, R_L = 1k	●		300		ns
t_{OFF}	Turn-Off Time	$\overline{ENABLE}$ = 0V to 5V, R_L = 1k	●		72		µs
SR	Slew Rate	A_V = –1, R_L = 1k, V_O = –2V to 2V	●	37			V/µs
		LT6230-10, A_V = –10, R_L = 1k, V_O = –2V to 2V	●		260		V/µs
FPBW	Full Power Bandwidth (Note 9)	V_{OUT} = $3V_{P-P}$ LT6230, LT6231, LT6232	●	3.9			MHz

ELECTRICAL CHARACTERISTICS

Note 1: Absolute maximum ratings are those values beyond which the life of the device may be impaired.

Note 2: Inputs are protected by back-to-back diodes. If the differential input voltage exceeds 0.7V, the input current must be limited to less than 40mA.

Note 3: A heat sink may be required to keep the junction temperature below the absolute maximum rating when the output is shorted indefinitely.

Note 4: The LT6230C/LT6230I the LT6231C/LT6231I, and LT6232C/LT6232I are guaranteed functional over the temperature range of –40°C and 85°C.

Note 5: The LT6230C/LT6231C/LT6232C are guaranteed to meet specified performance from 0°C to 70°C. The LT6230C/LT6231C/LT6232C are designed, characterized and expected to meet specified performance from –40°C to 85°C, but are not tested or QA sampled at these temperatures. The LT6230I/LT6231I/LT6232I are guaranteed to meet specified performance from –40°C to 85°C.

Note 6: Matching parameters are the difference between the two amplifiers A and D and between B and C of the LT6232; between the two amplifiers of the LT6231. CMRR and PSRR match are defined as follows: CMRR and PSRR are measured in µV/V on the matched amplifiers. The difference is calculated between the matching sides in µV/V. The result is converted to dB.

Note 7: Minimum supply voltage is guaranteed by power supply rejection ratio test.

Note 8: Output voltage swings are measured between the output and power supply rails.

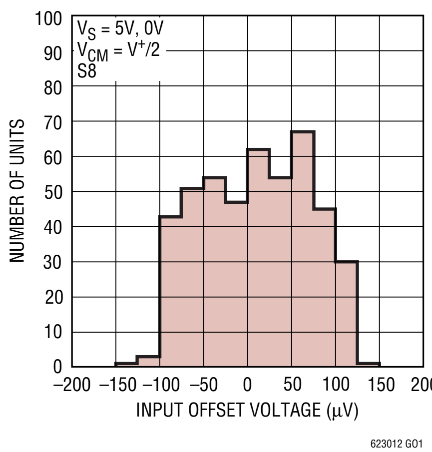
Note 9: Full-power bandwidth is calculated from the slew rate:
$FPBW = SR/2\pi V_P$

Note 10: This parameter is not 100% tested.

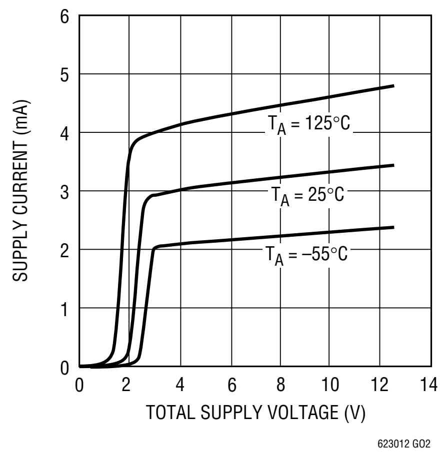
TYPICAL PERFORMANCE CHARACTERISTICS

(LT6230/LT6231/LT6232)

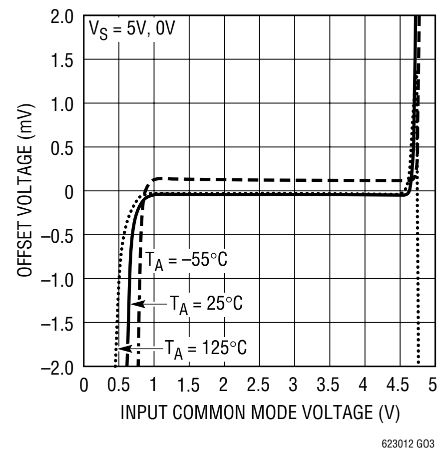
V_{OS} Distribution



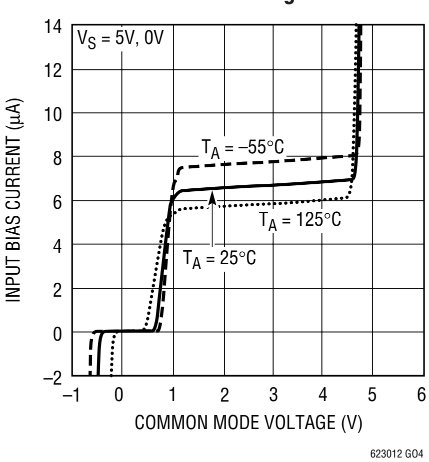
Supply Current vs Supply Voltage (Per Amplifier)



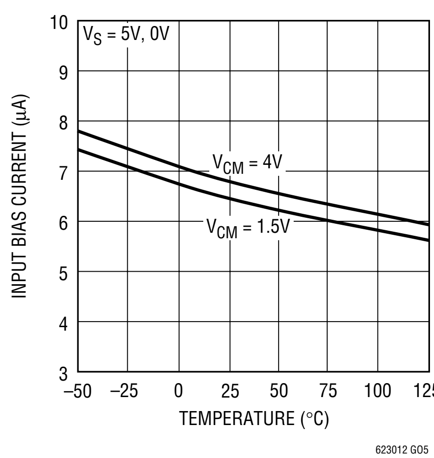
Offset Voltage vs Input Common Mode Voltage



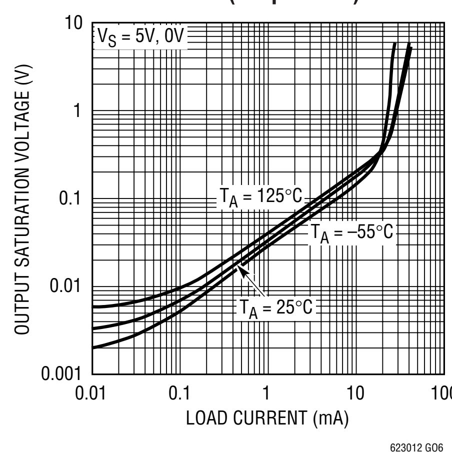
Input Bias Current vs Common Mode Voltage



Input Bias Current vs Temperature



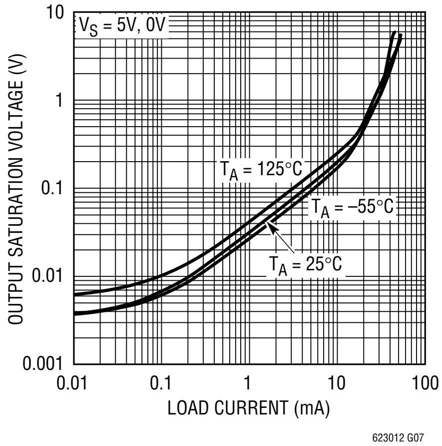
Output Saturation Voltage vs Load Current (Output Low)



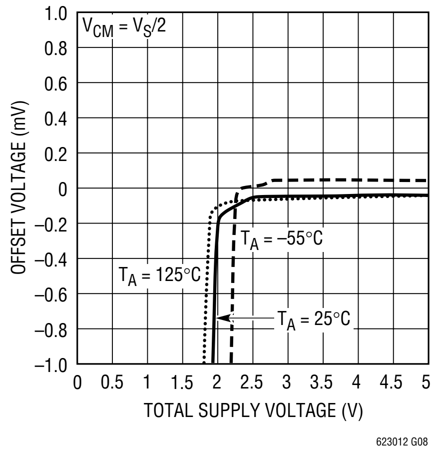
TYPICAL PERFORMANCE CHARACTERISTICS

(LT6230/LT6231/LT6232)

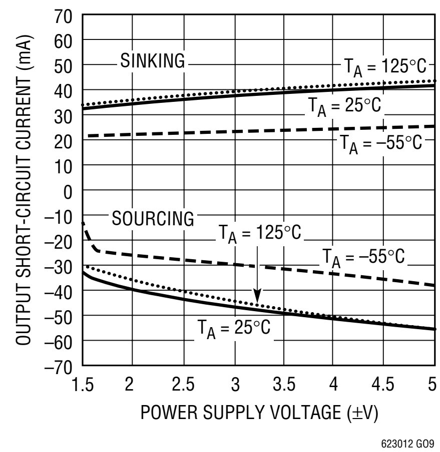
Output Saturation Voltage vs Load Current (Output High)



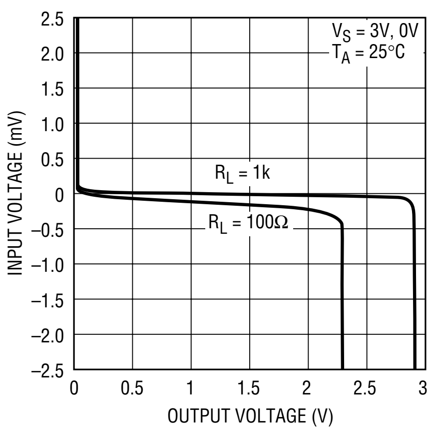
Minimum Supply Voltage



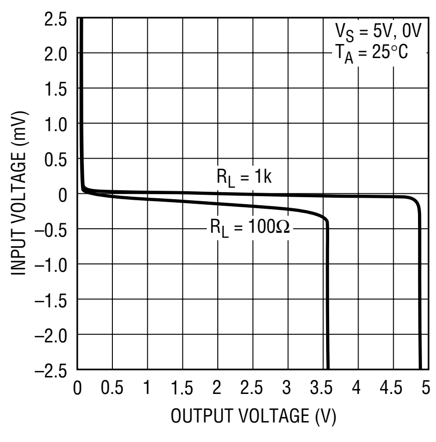
Output Short Circuit Current vs Power Supply Voltage



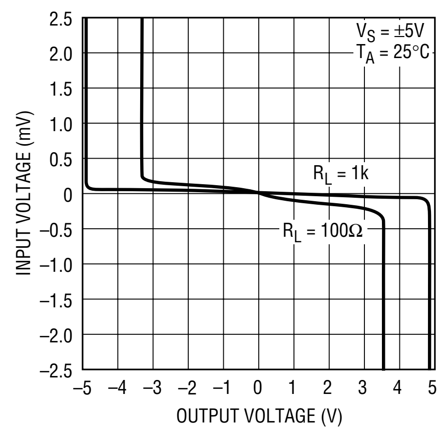
Open Loop Gain



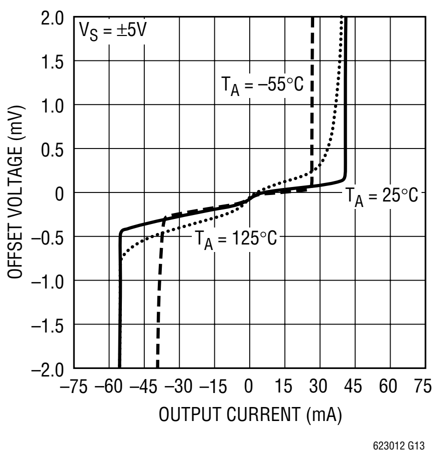
Open Loop Gain



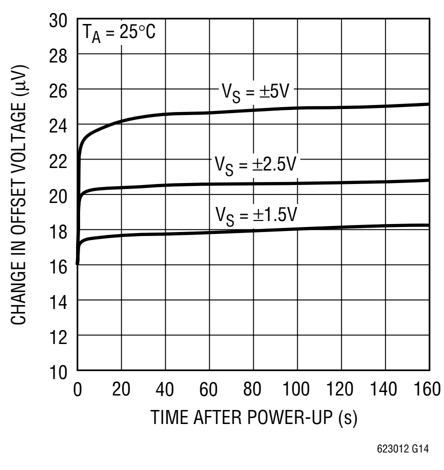
Open Loop Gain



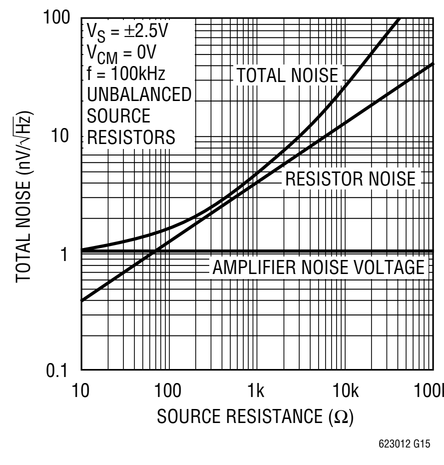
Offset Voltage vs Output Current



Warm-Up Drift vs Time



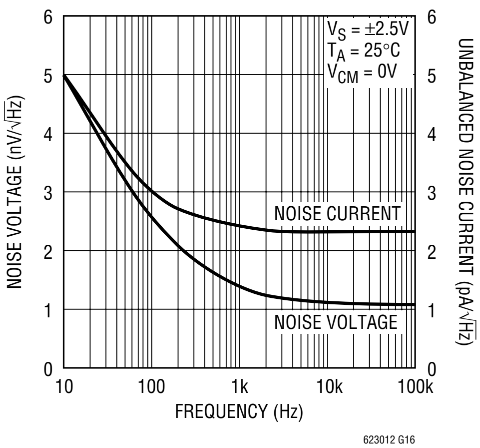
Total Noise vs Total Source Resistance



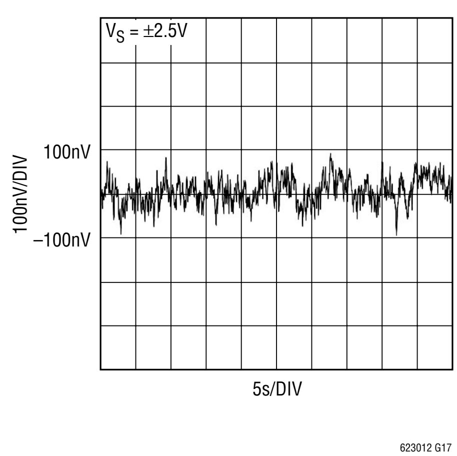
TYPICAL PERFORMANCE CHARACTERISTICS

(LT6230/LT6231/LT6232)

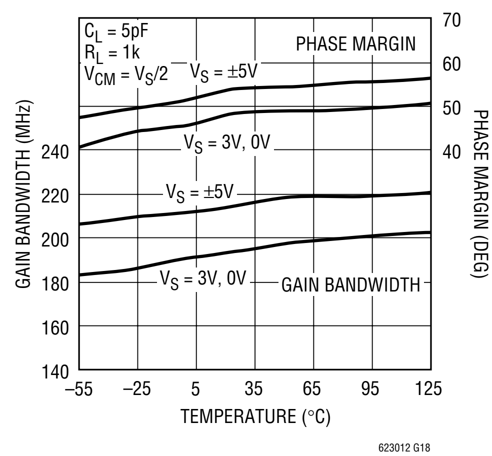
Noise Voltage and Unbalanced Noise Current vs Frequency



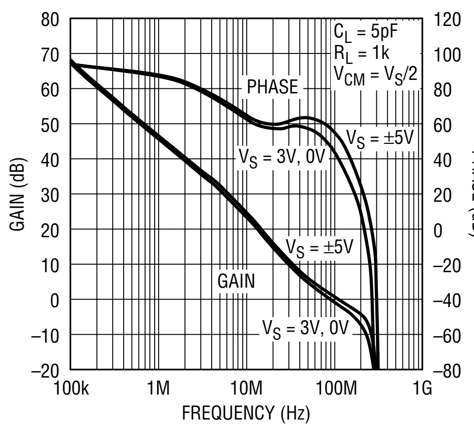
0.1Hz to 10Hz Output Voltage Noise



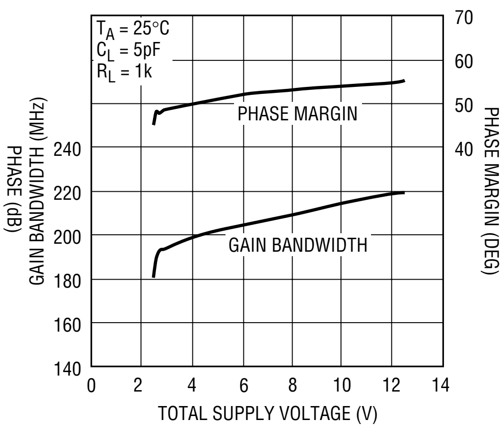
Gain Bandwidth and Phase Margin vs Temperature



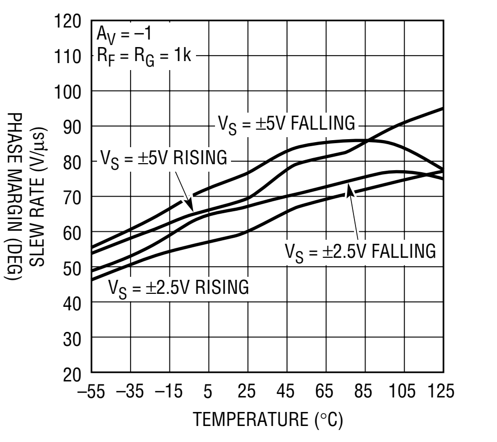
Open Loop Gain vs Frequency



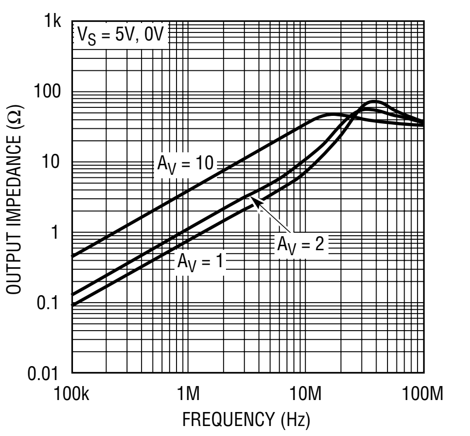
Gain Bandwidth and Phase Margin vs Supply Voltage



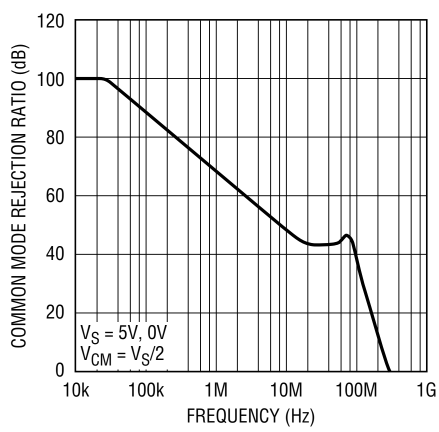
Slew Rate vs Temperature



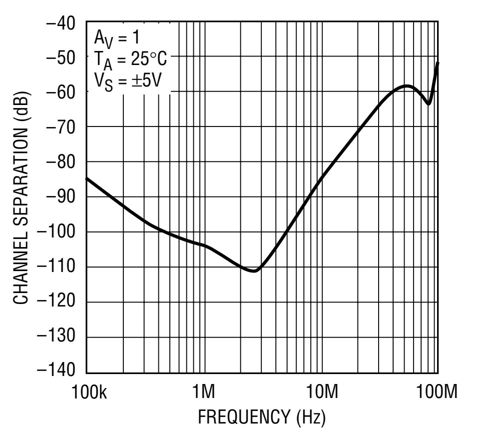
Output Impedance vs Frequency



Common Mode Rejection Ratio vs Frequency



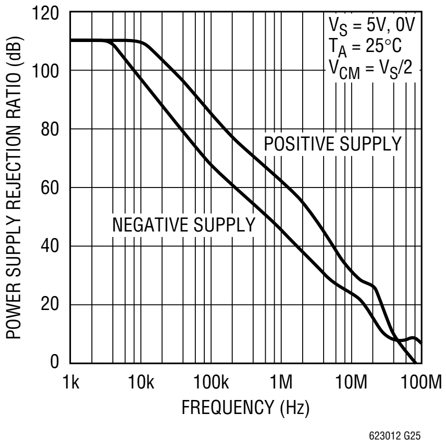
Channel Separation vs Frequency



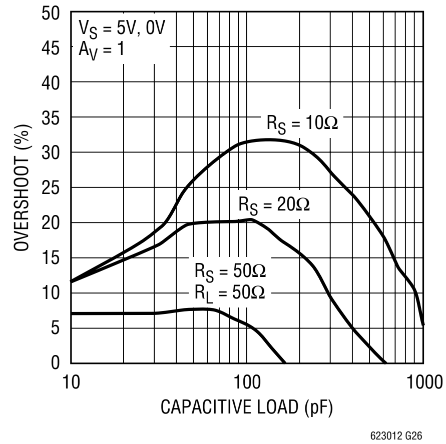
TYPICAL PERFORMANCE CHARACTERISTICS

(LT6230/LT6231/LT6232)

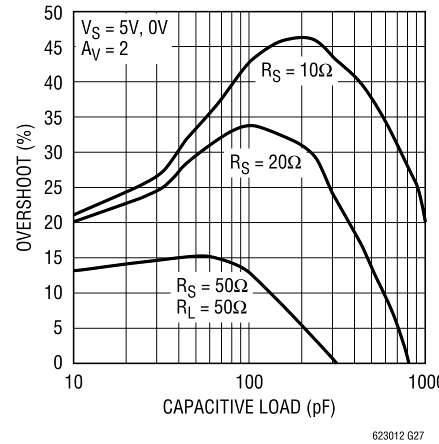
Power Supply Rejection Ratio vs Frequency



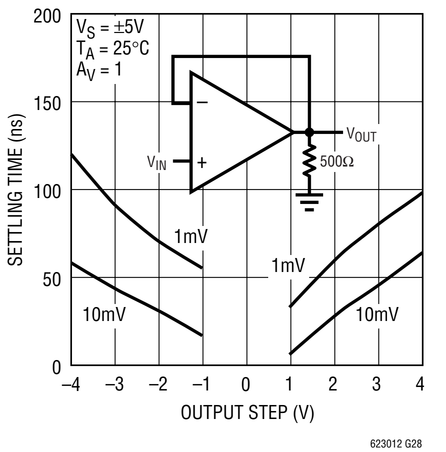
Series Output Resistance and Overshoot vs Capacitive Load



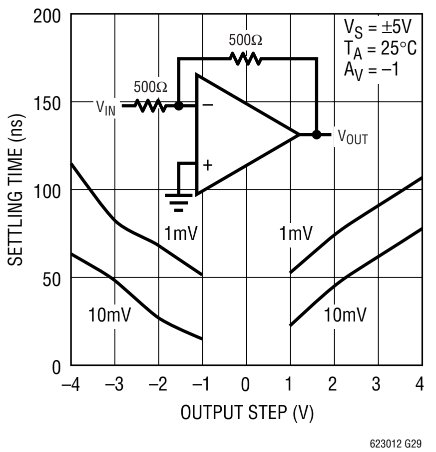
Series Output Resistance and Overshoot vs Capacitive Load



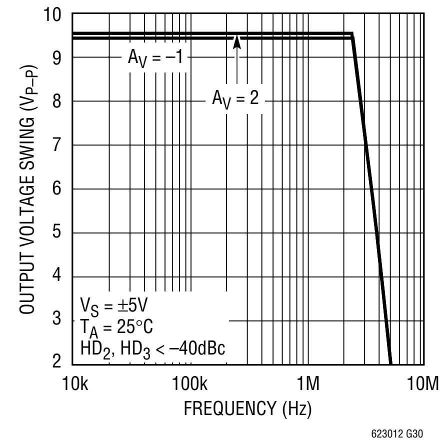
Settling Time vs Output Step (Non-Inverting)



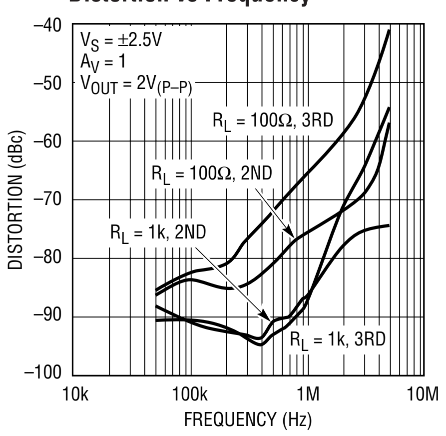
Settling Time vs Output Step (Inverting)



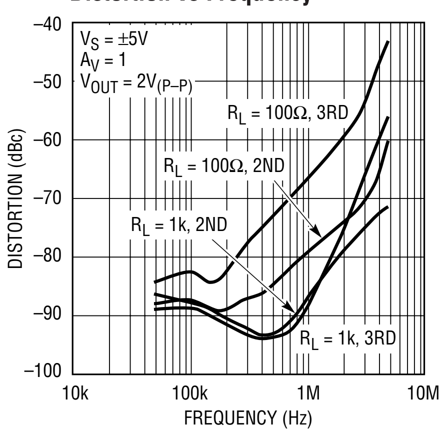
Maximum Undistorted Output Signal vs Frequency



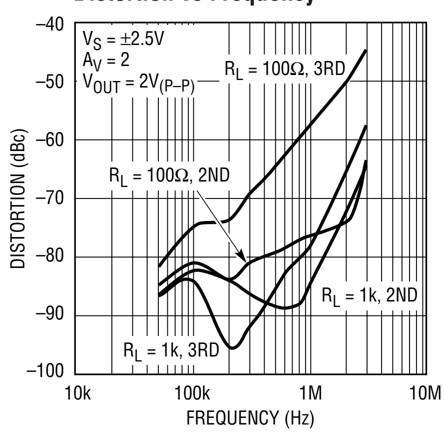
Distortion vs Frequency



Distortion vs Frequency



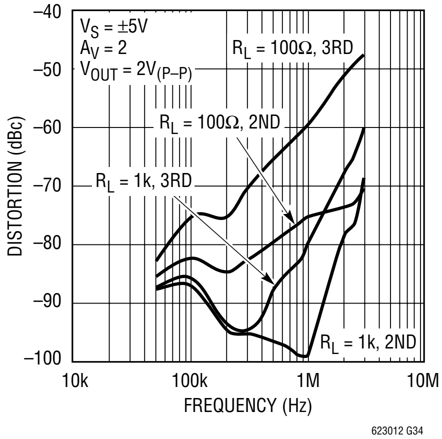
Distortion vs Frequency



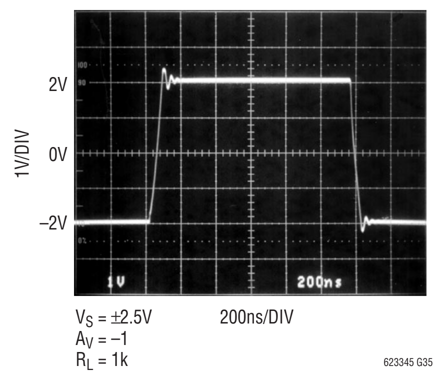
TYPICAL PERFORMANCE CHARACTERISTICS

(LT6230/LT6231/LT6232)

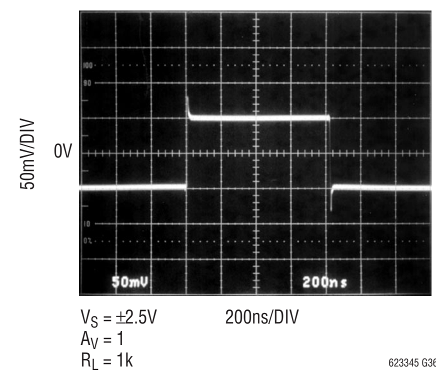
Distortion vs Frequency



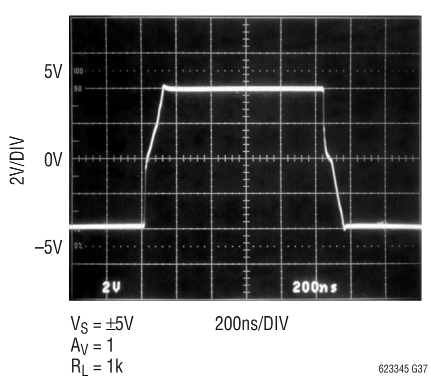
Large Signal Response



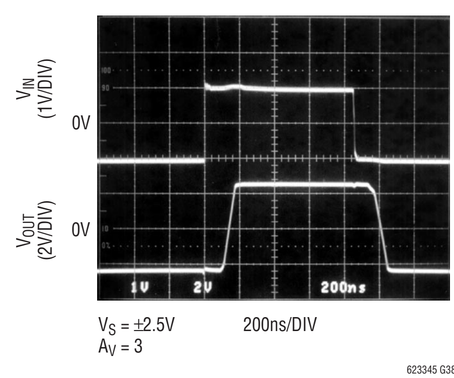
Small Signal Response



Large Signal Response

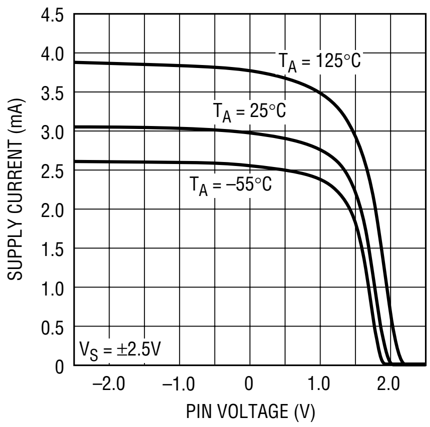


Output Overdrive Recovery

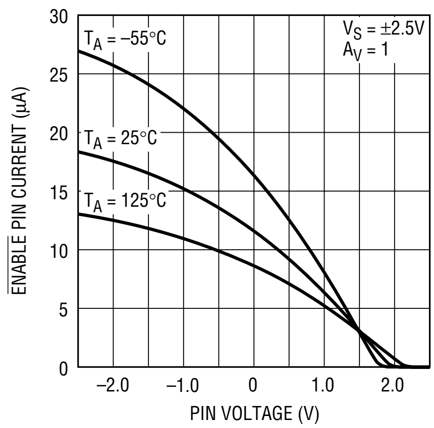


(LT6230) $\overline{\text{ENABLE}}$ Characteristics

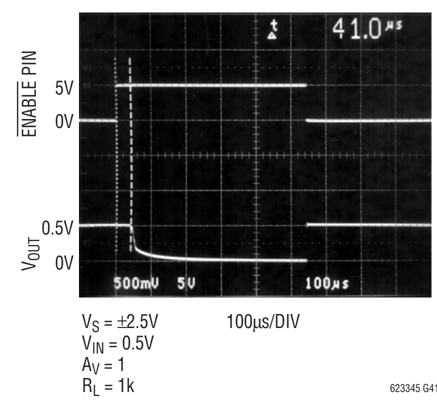
Supply Current vs $\overline{\text{ENABLE}}$ Pin Voltage



$\overline{\text{ENABLE}}$ Pin Current vs $\overline{\text{ENABLE}}$ Pin Voltage



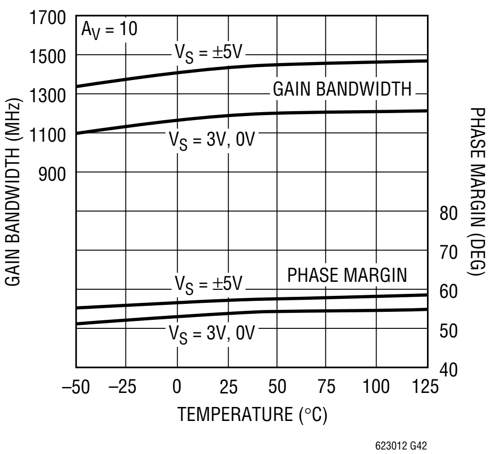
$\overline{\text{ENABLE}}$ Pin Response Time



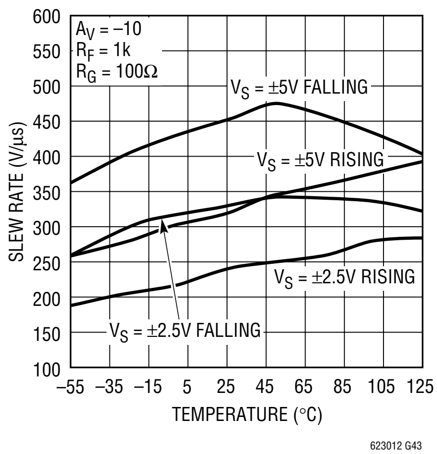
TYPICAL PERFORMANCE CHARACTERISTICS

(LT6230-10)

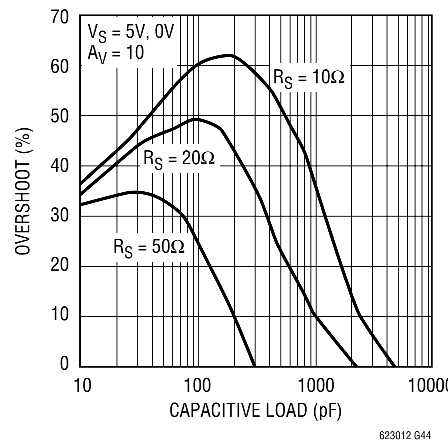
Gain Bandwidth and Phase Margin vs Temperature



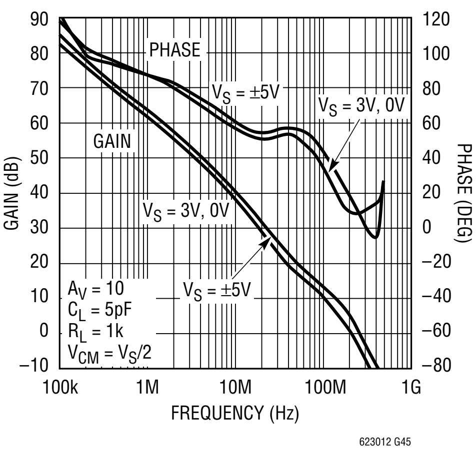
Slew Rate vs Temperature



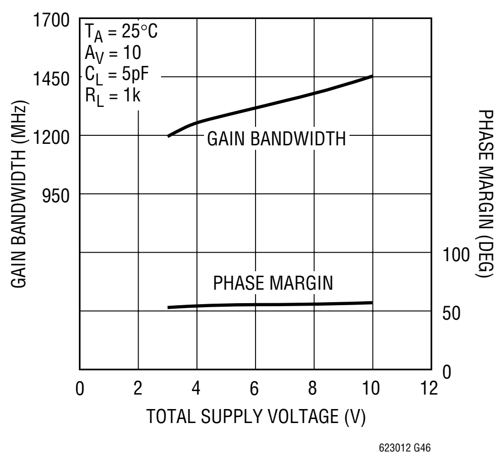
Series Output Resistor and Overshoot vs Capacitive Load



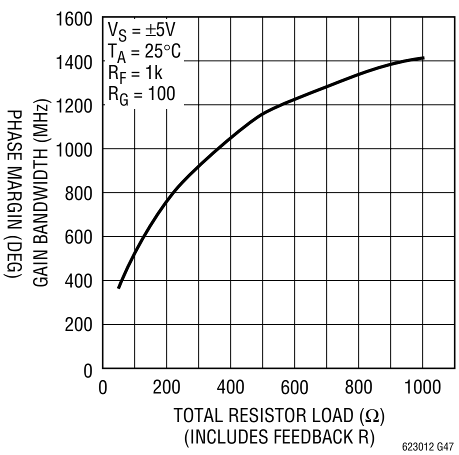
Open Loop Gain and Phase vs Frequency



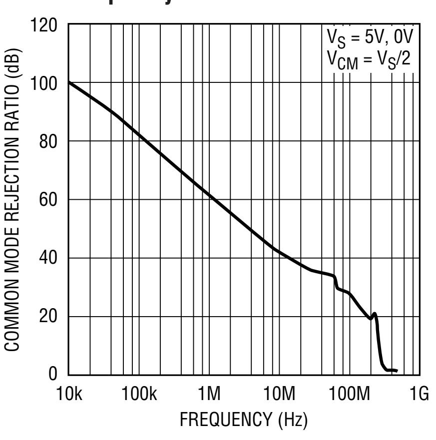
Gain Bandwidth and Phase Margin vs Supply Voltage



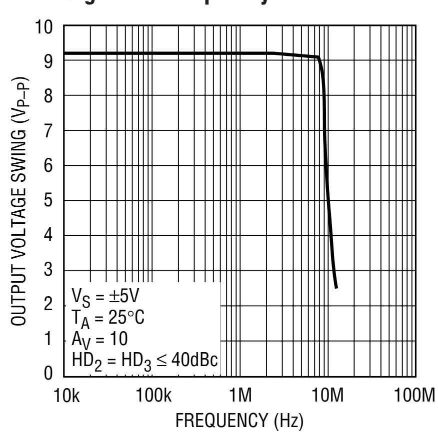
Gain Bandwidth vs Resistor Load



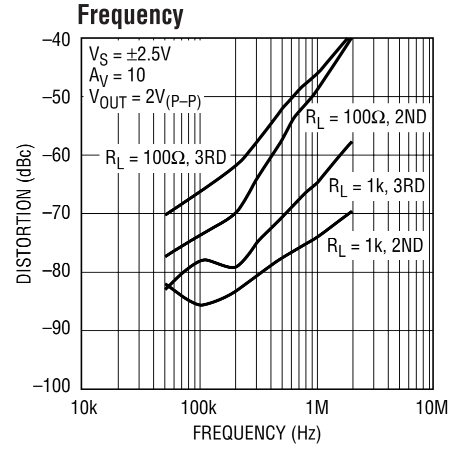
Common Mode Rejection Ratio vs Frequency



Maximum Undistorted Output Signal vs Frequency



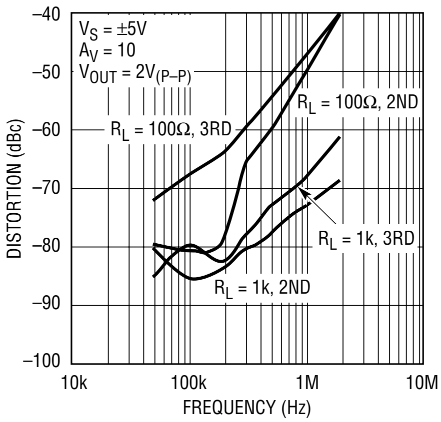
2nd and 3rd Harmonic Distortion vs Frequency



TYPICAL PERFORMANCE CHARACTERISTICS

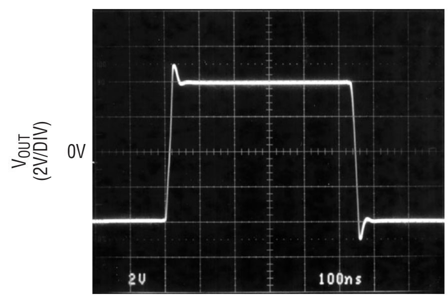
(LT6230-10)

2^{nd} and 3^{rd} Harmonic Distortion vs Frequency



623012 G51

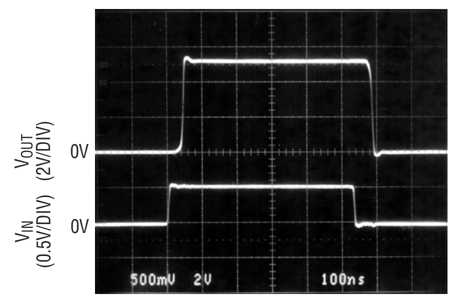
Large Signal Response



V_S = ±5V 100ns/DIV
A_V = 10
R_F = 900Ω, R_G = 100Ω

623345 G52

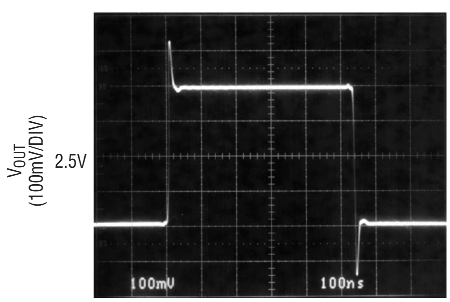
Output-Overload Recovery



V_S = 5V, 0V 100ns/DIV
A_V = 10
R_F = 900Ω, R_G = 100Ω

623345 G53

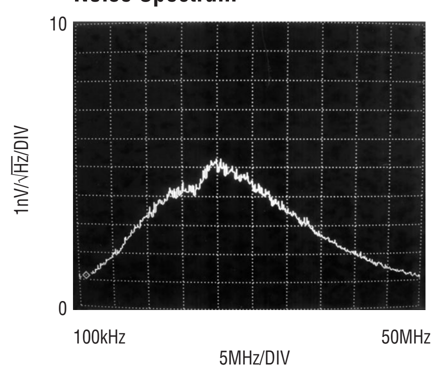
Small Signal Response



V_S = 5V, 0V 100ns/DIV
A_V = 10
R_F = 900Ω, R_G = 100Ω

623345 G54

Input Referred High Frequency Noise Spectrum



623345 G55

APPLICATIONS INFORMATION

Amplifier Characteristics

Figure 1 is a simplified schematic of the LT6230/LT6231/LT6232, which has a pair of low noise input transistors Q1 and Q2. A simple current mirror Q3/Q4 converts the differential signal to a single-ended output, and these transistors are degenerated to reduce their contribution to the overall noise.

Capacitor C1 reduces the unity cross frequency and improves the frequency stability without degrading the gain bandwidth of the amplifier. Capacitor C_M sets the overall amplifier gain bandwidth. The differential drive generator supplies current to transistors Q5 and Q6 that swing the output from rail-to-rail.

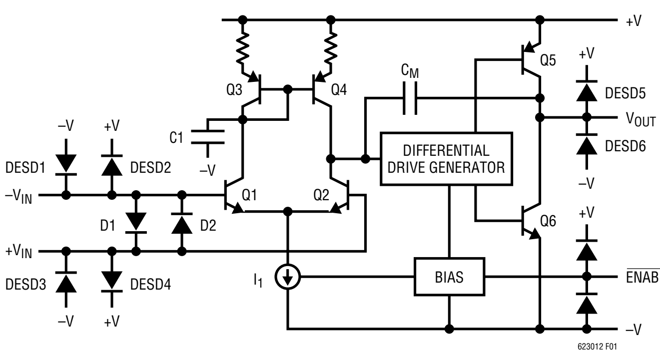


Figure 1. Simplified Schematic

Input Protection

There are back-to-back diodes, D1 and D2 across the + and – inputs of these amplifiers to limit the differential input voltage to ±0.7V. The inputs of the LT6230/LT6231/LT6232 do not have internal resistors in series with the input transistors. This technique is often used to protect the input devices from over voltage that causes excessive current to flow. The addition of these resistors would significantly degrade the low noise voltage of these amplifiers. For instance, a 100Ω resistor in series with each input would generate 1.8nV/$\sqrt{Hz}$ of noise, and the total amplifier noise voltage would rise from 1.1nV/$\sqrt{Hz}$ to 2.1nV/$\sqrt{Hz}$. Once the input differential voltage exceeds ±0.7V, steady state current conducted through the protection diodes should be limited to ±40mA. This implies 25Ω of protection resistance is necessary per volt of overdrive beyond ±0.7V. These input diodes are rugged enough to handle transient currents due to amplifier slew rate overdrive and clipping without protection resistors.

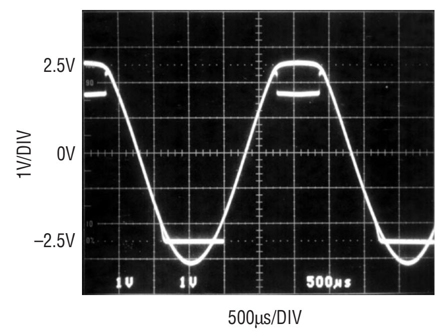


Figure 2. $V_S = \pm 2.5V$, $A_V = 1$ with Large Overdrive

The photo of Figure 2 shows the output response to an input overdrive with the amplifier connected as a voltage follower. With the input signal low, current source I_1 saturates and the differential drive generator drives Q6 into saturation so the output voltage swings all the way to $V^–$. The input can swing positive until transistor Q2 saturates into current mirror Q3/Q4. When saturation occurs, the output tries to phase invert, but diode D2 conducts current from the signal source to the output through the feedback connection. The output is clamped a diode drop below the input. In this photo, the input signal generator is limiting at about 20mA.

With the amplifier connected in a gain of $A_V \geq 2$, the output can invert with very heavy overdrive. To avoid this inversion, limit the input overdrive to 0.5V beyond the power supply rails.

ESD

The LT6230/LT6231/LT6232 have reverse-biased ESD protection diodes on all inputs and outputs as shown in Figure 1. If these pins are forced beyond either supply, unlimited current will flow through these diodes. If the current is transient and limited to one hundred milliamps or less, no damage to the device will occur.

Noise

The noise voltage of the LT6230/LT6231/LT6232 is equivalent to that of a 75Ω resistor, and for the lowest possible noise it is desirable to keep the source and feedback resistance at or below this value, i.e. $R_S + R_G||R_{FB} \leq 75\Omega$.

APPLICATIONS INFORMATION

With $R_S + R_G||R_{FB} = 75\Omega$ the total noise of the amplifier is:

$$e_N=\sqrt{(1.1nV)^2+(1.1nV)^2} = 1.55nV/\sqrt{Hz}$$

Below this resistance value, the amplifier dominates the noise, but in the region between 75Ω and about 3k, the noise is dominated by the resistor thermal noise. As the total resistance is further increased beyond 3k, the amplifier noise current multiplied by the total resistance eventually dominates the noise.

The product of $e_N \bullet \sqrt{I_{SUPPLY}}$ is an interesting way to gauge low noise amplifiers. Most low noise amplifiers with low e_N have high I_{SUPPLY} current. In applications that require low noise voltage with the lowest possible supply current, this product can prove to be enlightening. The LT6230/LT6231/LT6232 have an $e_N \bullet \sqrt{I_{SUPPLY}}$ product of only 1.9 per amplifier, yet it is common to see amplifiers with similar noise specifications to have $e_N \bullet \sqrt{I_{SUPPLY}}$ as high as 13.5.

For a complete discussion of amplifier noise, see the LT1028 data sheet.

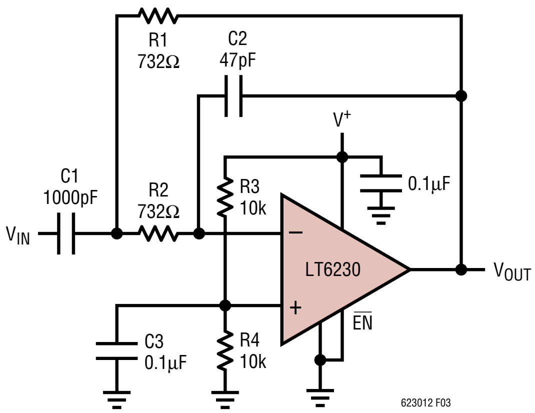
Enable Pin

The LT6230 includes an $\overline{ENABLE}$ pin that shuts down the amplifier to 10μA maximum supply current. The $\overline{ENABLE}$ pin must be driven high to within 0.35V of V^+ to shut down the supply current. This can be accomplished with simple gate logic; however care must be taken if the logic and the LT6230 operate from different supplies. If this is the case, then open drain logic can be used with a pull-up resistor to ensure that the amplifier remains off. See Typical Characteristic Curves.

The output leakage current when disabled is very low; however, current can flow into the input protection diodes D1 and D2 if the output voltage exceeds the input voltage by a diode drop.

APPLICATIONS INFORMATION

Single Supply, Low Noise, Low Power, Bandpass Filter with Gain = 10



$f_0 = \frac{1}{2\pi RC} = 1MHz$

$C = \sqrt{C_1C_2}$, R = R1 = R2

$f_0 = \left(\frac{732\Omega}{R}\right)MHz$, MAXIMUM f_0 = 1MHz

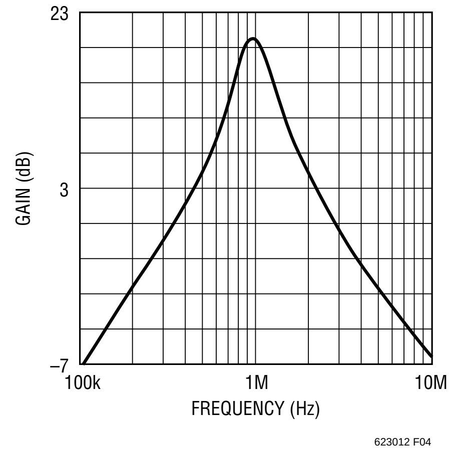
$f_{-3dB} = \frac{f_0}{2.5}$

A_V = 20dB at f_0

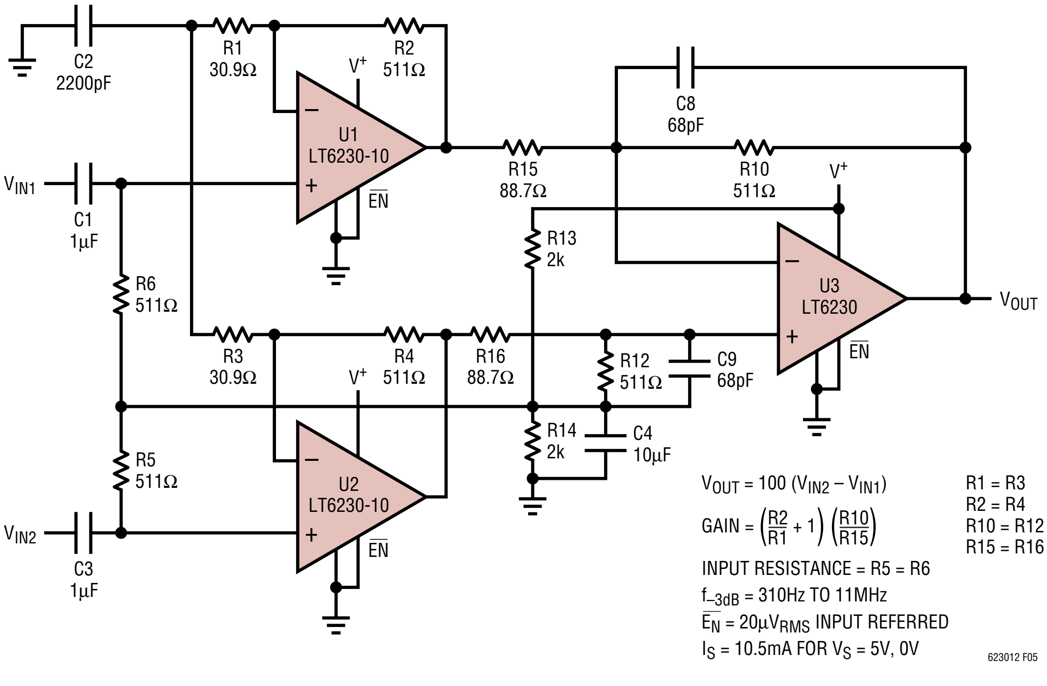
$\overline{E_N}$ = 4μV_{RMS} INPUT REFERRED

I_S = 3.7mA FOR V^+ = 5V

Frequency Response Plot of Bandpass Filter



Low Noise, Low Power, Single Supply, Instrumentation Amplifier with Gain = 100



$V_{OUT} = 100\ (V_{IN2} - V_{IN1})$

$GAIN = \left(\frac{R2}{R1} + 1\right)\left(\frac{R10}{R15}\right)$

INPUT RESISTANCE = R5 = R6

f_{-3dB} = 310Hz TO 11MHz

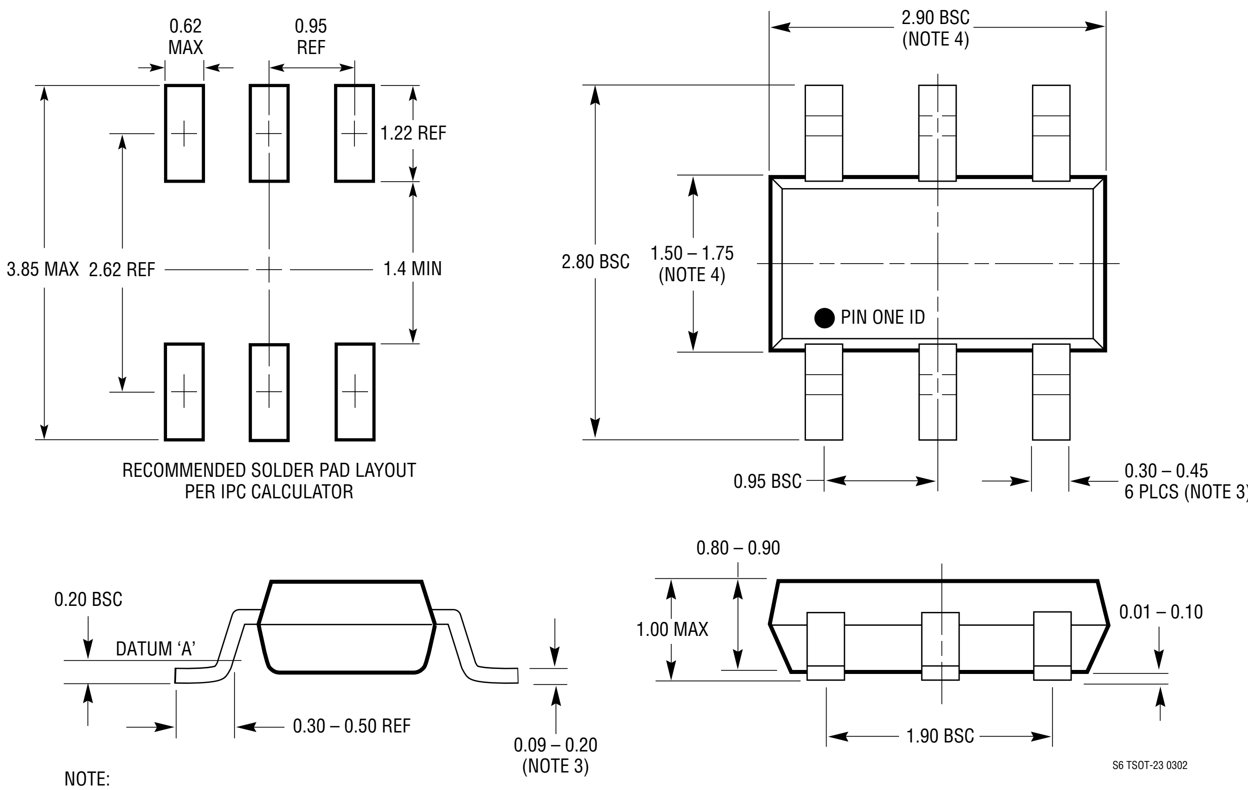
$\overline{E_N}$ = 20μV_{RMS} INPUT REFERRED

I_S = 10.5mA FOR V_S = 5V, 0V

R1 = R3
R2 = R4
R10 = R12
R15 = R16

PACKAGE DESCRIPTION

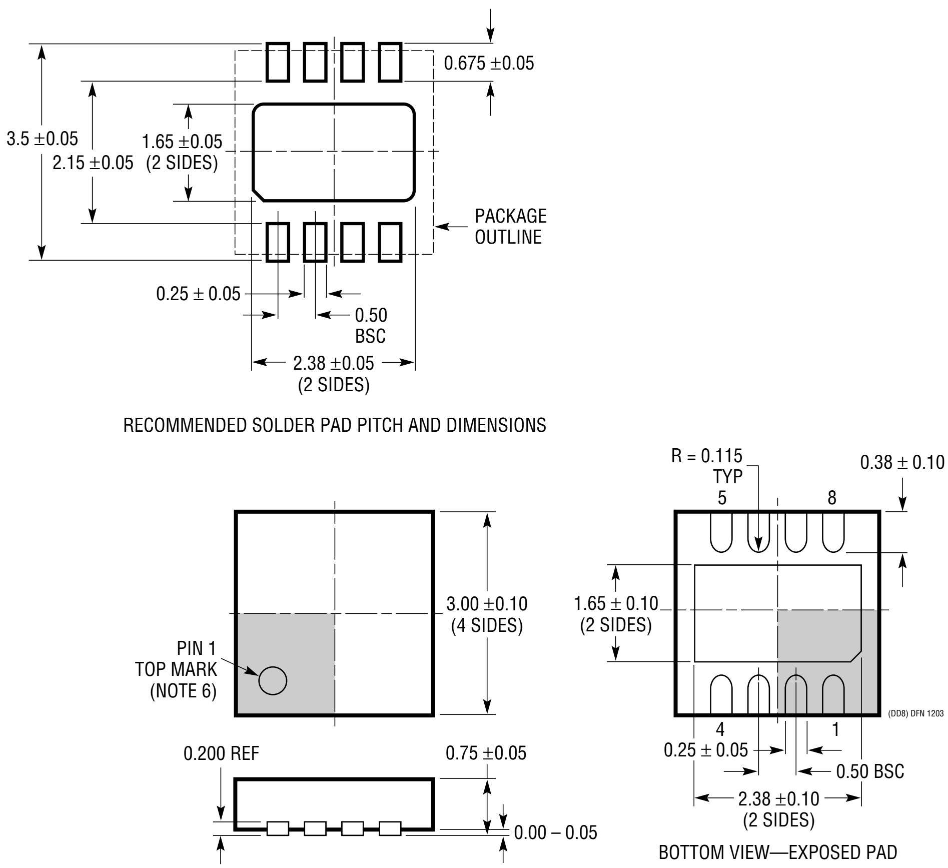
S6 Package
6-Lead Plastic TSOT-23
(Reference LTC DWG # 05-08-1636)



NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. JEDEC PACKAGE REFERENCE IS MO-193

PACKAGE DESCRIPTION

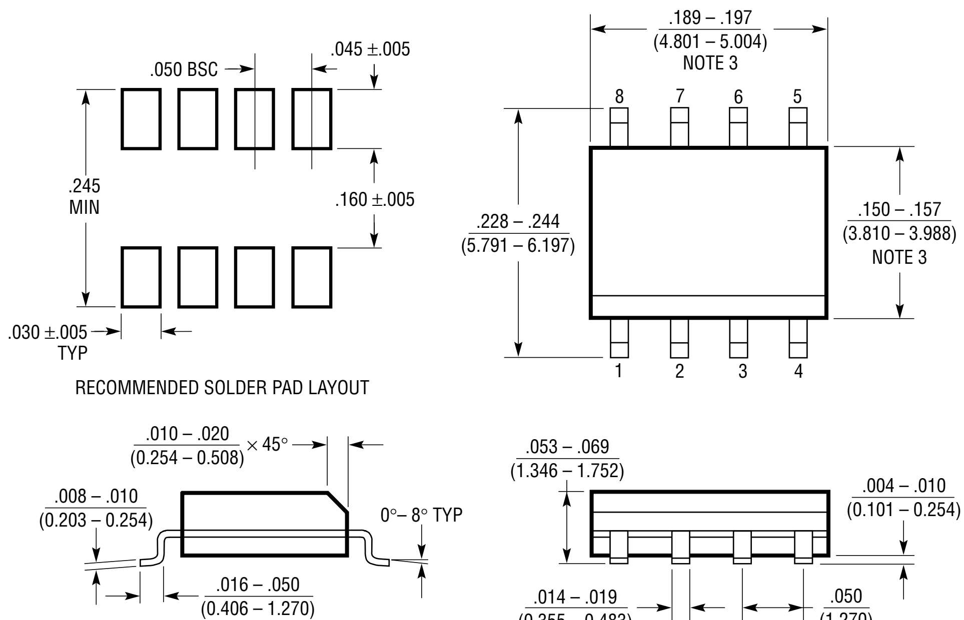
DD Package
8-Lead Plastic DFN (3mm × 3mm)
(Reference LTC DWG # 05-08-1698)



NOTE:
1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (WEED-1)
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON TOP AND BOTTOM OF PACKAGE

PACKAGE DESCRIPTION

S8 Package
8-Lead Plastic Small Outline (Narrow .150 Inch)
(Reference LTC DWG # 05-08-1610)

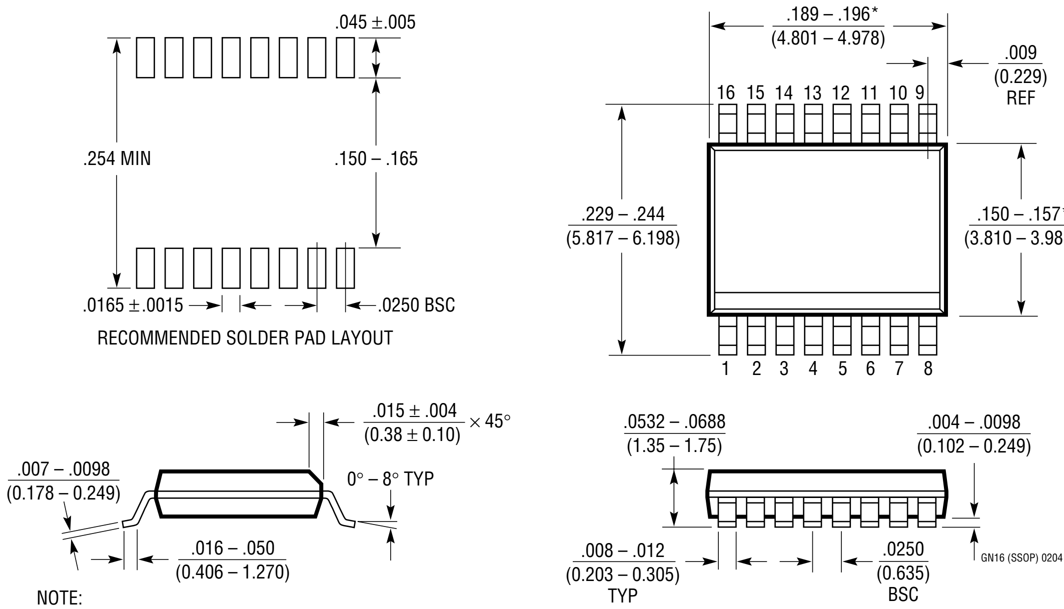


NOTE:
1. DIMENSIONS IN $\frac{\text{INCHES}}{\text{(MILLIMETERS)}}$
2. DRAWING NOT TO SCALE
3. THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .006" (0.15mm)

SO8 0303

PACKAGE DESCRIPTION

GN Package
16-Lead Plastic SSOP (Narrow .150 Inch)
(Reference LTC DWG # 05-08-1641)



NOTE:
1. CONTROLLING DIMENSION: INCHES
2. DIMENSIONS ARE IN $\frac{\text{INCHES}}{\text{(MILLIMETERS)}}$
3. DRAWING NOT TO SCALE

*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

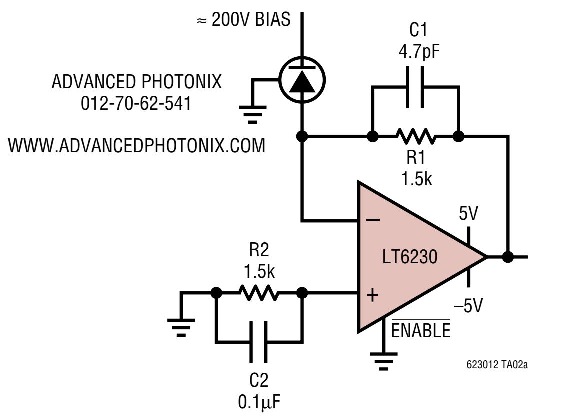
**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

TYPICAL APPLICATIONS

The LT6230 is applied as a transimpedance amplifier with an I-to-V conversion gain of 1.5kΩ set by R1. The LT6230 is ideally suited to this application because of its low input offset voltage and current, and its low noise. This is because the 1.5k resistor has an inherent thermal noise of $5nV/\sqrt{Hz}$ or $3.4pA/\sqrt{Hz}$ at room temperature, while the LT6230 contributes only 1.1nV and $2.4pA/\sqrt{Hz}$. So, with respect to both voltage and current noises, the LT6230 is actually quieter than the gain resistor.

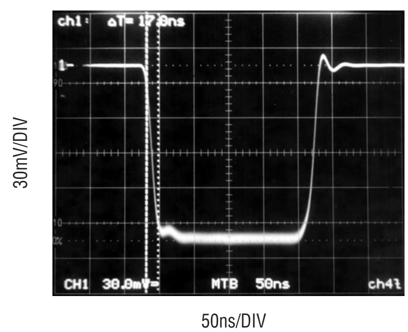
The circuit uses an avalanche photodiode with the cathode biased to approximately 200V. When light is incident on the photodiode, it induces a current I_{PD} which flows into the amplifier circuit. The amplifier output falls negative to maintain balance at its inputs. The transfer function is therefore $V_{OUT} = -I_{PD} \bullet 1.5k$. C1 ensures stability and good settling characteristics. Output offset was measured at 280µV, so low in part because R2 serves to cancel the DC effects of bias current. Output noise was measured at $1.1mV_{P-P}$ on a 100MHz measurement bandwidth, with C2 shunting R2's thermal noise. As shown in the scope photo, the rise time is 17ns, indicating a signal bandwidth of 20MHz.

Low Power Avalanche Photodiode Transimpedance Amplifier
I_S = 3.3mA



OUTPUT OFFSET = 500µV TYPICAL
BANDWIDTH = 20MHz
OUTPUT NOISE = $1.1mV_{P-P}$ (100MHz MEASUREMENT BW)

Photodiode Amplifier Time Domain Response



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1028	Single, Ultra Low Noise 50MHz Op Amp	$0.85nV/\sqrt{Hz}$
LT1677	Single, Low Noise Rail-to-Rail Amplifier	3V Operation, 2.5mA, $4.5nV/\sqrt{Hz}$, 60µV Max V_{OS}
LT1806/LT1807	Single/Dual, Low Noise 325MHz Rail-to-Rail Amplifier	2.5V Operation, 550µV Max V_{OS}, $3.5nV/\sqrt{Hz}$
LT6200/LT6201	Single/Dual, Low Noise 165MHz	$0.95nV\sqrt{Hz}$, Rail-to-Rail Input and Output
LT6202/LT6203/LT6204	Single/Dual/Quad, Low Noise, Rail-to-Rail Amplifier	$1.9nV/\sqrt{Hz}$, 3mA Max, 100MHz Gain Bandwidth

Linear Technology Corporation
LT/TP 0304 1K REV A • PRINTED IN USA