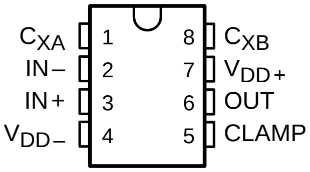
TLC2652M, TLC2652AM
Advanced LinCMOS™ PRECISION CHOPPER-STABILIZED OPERATIONAL AMPLIFIERS

SGLS048 – SEPTEMBER 1988 – REVISED OCTOBER 1991

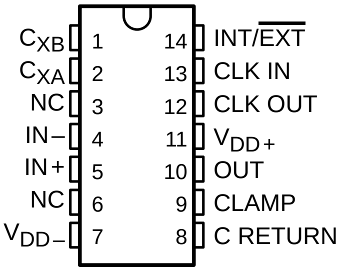
available features

- **Extremely Low Offset Voltage . . . 1 μV Max**
- **Extremely Low Change in Offset Voltage With Temperature . . . 0.003 μV/°C Typ**
- **Low Input Offset Current . . . 500 pA Max at T_A = – 55°C to 125°C**
- **A_{VD} . . . 135 dB Min**
- **CMRR and k_{SVR} . . . 120 dB Min**
- **Single-Supply Operation**
- **Common-Mode Input Voltage Range Includes the Negative Rail**
- **No Noise Degradation With External Capacitors Connected to V_{DD-}**

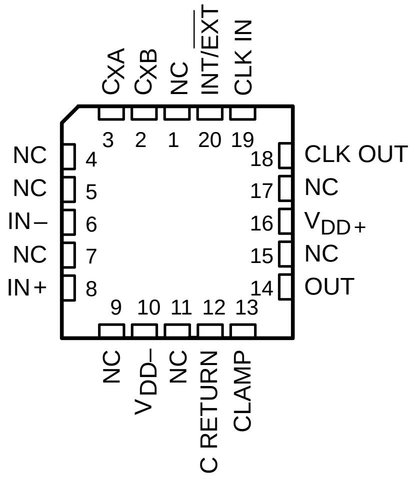
JG PACKAGE
(TOP VIEW)



J PACKAGE
(TOP VIEW)



FK PACKAGE
(TOP VIEW)



NC – No internal connection

description

The TLC2652M and TLC2652AM are high-precision chopper-stabilized operational amplifiers using Texas Instruments Advanced LinCMOS™ process. This process in conjunction with unique chopper-stabilization circuitry produces operational amplifiers whose performance matches or exceeds that of similar devices available today.

Chopper-stabilization techniques make possible extremely high dc precision by continuously nulling input offset voltage even during variation in temperature, time, common-mode voltage, and power supply voltage. In addition, low-frequency noise voltage is significantly reduced. This high precision, coupled with the extremely high input impedance of the CMOS input stage, makes the TLC2652M and TLC2652AM an ideal choice for low-level signal processing applications such as strain gauges, thermocouples, and other transducer amplifiers. (For applications that require extremely low noise and higher usable bandwidth, use the TLC2654M or TLC2654AM device, which has a chopping frequency of 10 kHz.)

The TLC2652M and TLC2652AM input common-mode range includes the negative rail, thereby providing superior performance in either single-supply or split-supply applications, even at power supply voltage levels as low as ±1.9 V.

AVAILABLE OPTIONS

T_A	V_{IO} max AT 25°C	PACKAGE		
		8-PIN	14-PIN	20-PIN
		CERAMIC DIP (JG)	CERAMIC DIP (JG)	CHIP CARRIER (FK)
55°C to 125°C	1 μV 3 μV	TLC2652MJG TLC2652AMJG	TLC2652MJ TLC2652AMJ	TLC2652MFK TLC2652AMFK

Advanced LinCMOS is a trademark of Texas Instruments Incorporated.

description (continued)

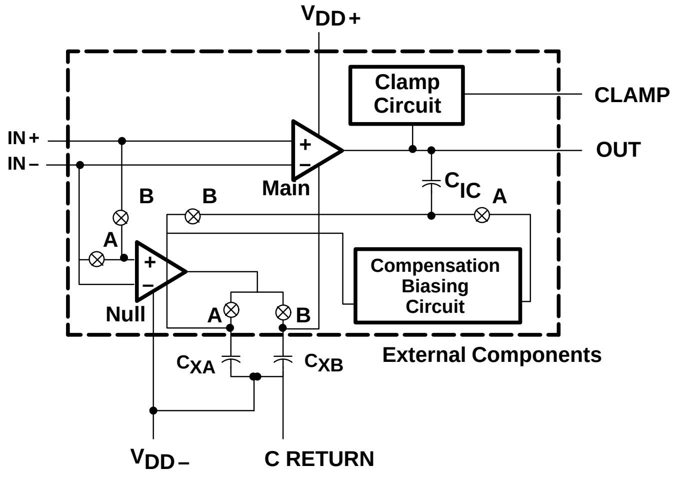
Two external capacitors are required for operation of the device; however, the on-chip chopper control circuitry is transparent to the user. On devices in the 14-pin and 20-pin packages, the control circuitry is made accessible to allow the user the option of controlling the clock frequency with an external frequency source. In addition, the clock threshold level of the TLC2652M and TLC2652AM require no level shifting when used in the single-supply configuration with a normal CMOS or TTL clock input.

Innovative circuit techniques are used on the TLC2652M and TLC2652AM to allow exceptionally fast overload recovery time. If desired, an output clamp pin is available to reduce the recovery time.

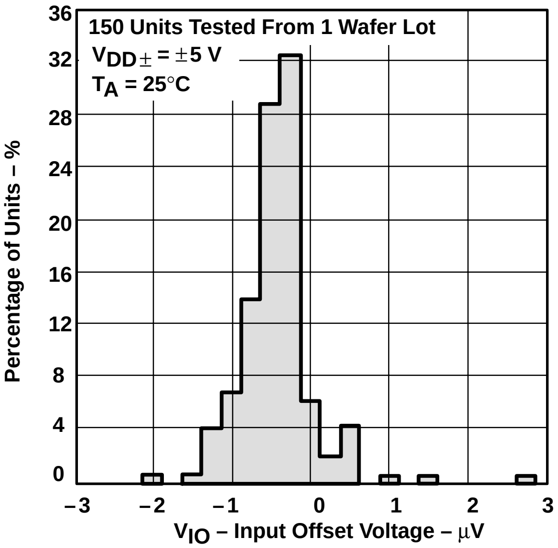
The device inputs and output are designed to withstand –100-mA surge currents without sustaining latch-up. Additionally the TLC2652M and TLC2652AM incorporate internal ESD-protection circuits that prevent functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2; however, care should be exercised in handling these devices as exposure to ESD may result in degradation of the device parametric performance.

The M-suffix devices are characterized for operation over full military temperature range of –55°C to 125°C.

functional block diagram



DISTRIBUTION OF TLC2652M INPUT OFFSET VOLTAGE



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

Supply voltage V_{DD+} (see Note 1)	8 V
Supply voltage V_{DD-} (see Note 1)	–8 V
Differential input voltage (see Note 2)	±16 V
Input voltage, V_I (any input, see Note 1)	±8 V
Voltage range on CLK IN and INT/$\overline{\text{EXT}}$	V_{DD-} to V_{DD-} + 5.2 V
Input current, I_I (each input)	±5 mA
Output current, I_O	±50 mA
Duration of short-circuit current at (or below) 25°C (see Note 3)	unlimited
Current into CLK IN and INT/$\overline{\text{EXT}}$	±5 mA
Continuous total dissipation	See Dissipation Rating Table
Operating free-air temperature, T_A	–55°C to 125°C
Storage temperature range	–65°C to 150°C
Case temperature for 60 seconds: FK package	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: J or JG package	300°C

NOTES:
1. All voltage values, except differential voltages, are with respect to the midpoint between V_{DD+} and V_{DD-}.
2. Differential voltages are at the noninverting input with respect to the inverting input.
3. The output may be shorted to either supply. Temperature and/or supply voltages must be limited to ensure that the maximum dissipation rating is not exceeded.

DISSIPATION RATING TABLE

PACKAGE	$T_A \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ POWER RATING
FK	1375 mV	11.0 mW/°C	880 mW	715 mW	275 mW
J	1375 mV	11.0 mW/°C	880 mW	715 mW	275 mW
JG	1050 mV	8.4 mW/°C	672 mW	546 mW	210 mW

recommended operating conditions

	MIN	MAX	UNIT
Supply voltage, $V_{DD\pm}$	± 1.9	±8	V
Common-mode input voltage, V_{IC}	V_{DD-}	$V_{DD+} - 1.9$	V
Clock input voltage	V_{DD-}	$V_{DD-} + 5$	V
Operating free-air temperature, T_A	–55	125	°C

electrical characteristics at specified free-air temperature, $V_{DD\pm}$ = ±5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A†	TLC2652M			TLC2652AM			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage (see Note 4)	V_{IC} = 0, R_S = 50 Ω	25°C		0.6	3.5		0.5	3	µV
			Full range			10			8	
α_{VIO}	Temperature coefficient of input offset voltage		Full range		0.003	0.03*		0.003	0.03*	µV/°C
	Input offset voltage long-term drift (see Note 5)		25°C		0.003	0.06		0.003	0.02	µV/mo
I_{IO}	Input offset current		25°C		2			2		pA
			Full range			500			500	
I_{IB}	Input bias current		25°C		4			4		pA
			Full range			500			500	
V_{ICR}	Common-mode input voltage range	R_S = 50 Ω	Full range	−5 to 3.1			−5 to 3.1			V
V_{OM+}	Maximum positive peak output voltage swing	R_L = 10 kΩ, See Note 6	25°C	4.7	4.8		4.7	4.8		V
			Full range	4.7			4.7			
V_{OM-}	Maximum negative peak output voltage swing	R_L = 10 kΩ, See Note 6	25°C	−4.7	−4.9		−4.7	−4.9		V
			Full range	−4.7			−4.7			
A_{VD}	Large-signal differential voltage amplification	V_O = ±4 V, R_L = 10 kΩ	25°C	120	150		135	150		dB
			Full range	120			130			
f_{ch}	Internal chopping frequency		25°C		450			450		Hz
	Clamp on-state current	R_L = 100 kΩ	25°C	25			25			µA
			Full range	25			25			
	Clamp off-state current	V_O = −5 V to 5 V	25°C			100			100	pA
			Full range			500			500	
CMRR	Common-mode rejection ratio	V_O = 0, $V_{IC} = V_{ICR}$ min, R_S = 50 Ω	25°C	120	140		120	140		dB
			Full range	120			120			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD\pm}/\Delta V_{IO}$)	$V_{DD\pm}$ = ±1.9 V to ±8 V, V_O = 0, R_S = 50 Ω	25°C	120	135		120	135		dB
			Full range	120			120			
I_{DD}	Supply current	V_O = 0, No load	25°C		1.5	2.4		1.5	2.4	mA
			Full range			2.5			2.5	

*This parameter is not production tested.

† Full range is −55° to 125°C.

NOTES: 4. This parameter is not production tested. Thermocouple effects preclude measurement of the actual V_{IO} of these devices in high speed automated testing. V_{IO} is measured to a limit determined by the test equipment capability at the temperature extremes. The test ensures that the stabilization circuitry is preforming properly.

5. Typical values are based on the input offset voltage shift observed through 168 hours of operating life test at T_A = 150°C extrapolated at T_A = 25°C using the Arrhenius equation and assuming an activation energy of 0.96 eV.

6. Output clamp is not connected.

operating characteristics specified free-air temperature, $V_{DD\pm} = \pm5$ V

PARAMETER		TEST CONDITIONS	T_A†	TLC2652AM			UNIT
				MIN	TYP	MAX	
SR+	Positive slew rate at unity gain	$V_O = \pm2.3$ V, $R_L = 10$ kΩ, $C_L = 100$ pF	25°C	2	2.8		V/µs
			Full range	1.3			
SR–	Negative slew rate at unity gain		25°C	2.3	3.1		V/µs
			Full range	1.6			
V_n	Equivalent input noise voltage	f = 10 Hz	25°C		94		nV/√Hz
		f = 1 kHz	25°C		23		
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	f = 0 to 1 Hz	25°C		0.8		µV
		f = 0 to 10 Hz	25°C		2.8		
I_n	Equivalent input noise current	f = 10 kHz	25°C		0.004		fA/√Hz
	Gain-bandwidth product	f = 10 kHz, $R_L = 10$ kΩ, $C_L = 100$ pF	25°C		1.9		MHz
ϕ_m	Phase margin at unity gain	$R_L = 10$ kΩ, $C_L = 100$ pF	25°C		48°		

† Full range is –55° to 125°C.

TYPICAL CHARACTERISTICS

Table of Graphs

			FIGURE
V_{IO}	Normalized input offset voltage	vs Chopping frequency	1
I_{IB}	Input bias current	vs Common-mode input voltage vs Chopping frequency vs Temperature	2 3 4
I_{IO}	Input offset current	vs Chopping frequency vs Temperature	5 6
	Clamp current	vs Output voltage	7
$V_{(OPP)}$	Maximum peak-to-peak output voltage swing	vs Frequency	8
V_{OM}	Maximum peak output voltage swing	vs Output current vs Temperature	9, 10 11, 12
A_{VD}	Differential voltage amplification	vs Frequency vs Temperature	13 14
f_{ch}	Chopping frequency	vs Supply voltage vs Temperature	15 16
I_{DD}	Supply current	vs Supply voltage vs Temperature	17 18
I_{OS}	Short-circuit output current	vs Supply voltage vs Temperature	19 20
SR	Slew rate	vs Supply voltage vs Temperature	21 22
	Pulse response	Small signal Large signal	23 24
$V_{N(PP)}$	Peak-to-peak equivalent input noise voltage	vs Chopping frequency	25, 26
V_n	Equivalent input noise voltage	vs Frequency	27
	Gain-bandwidth product	vs Supply voltage vs Temperature	28 29
ϕ_m	Phase margin	vs Supply voltage vs Temperature vs Load capacitance	30 31 32
	Phase shift	vs Frequency	13

TYPICAL CHARACTERISTICS

NORMALIZED INPUT OFFSET VOLTAGE vs CHOPPING FREQUENCY

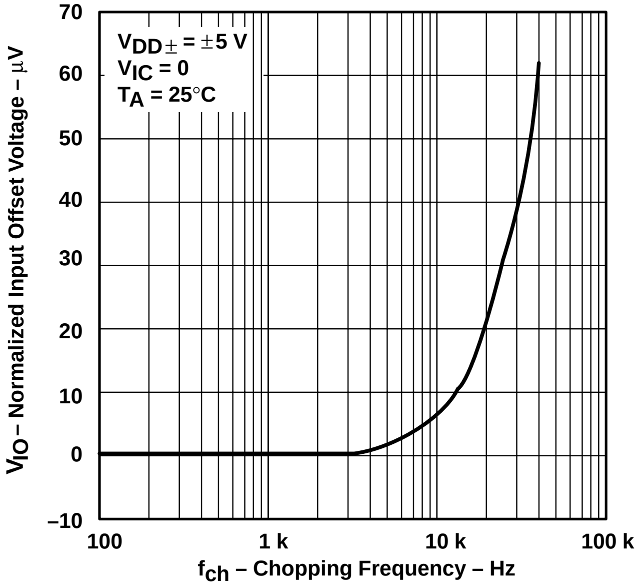


Figure 1

INPUT BIAS CURRENT vs COMMON-MODE INPUT VOLTAGE

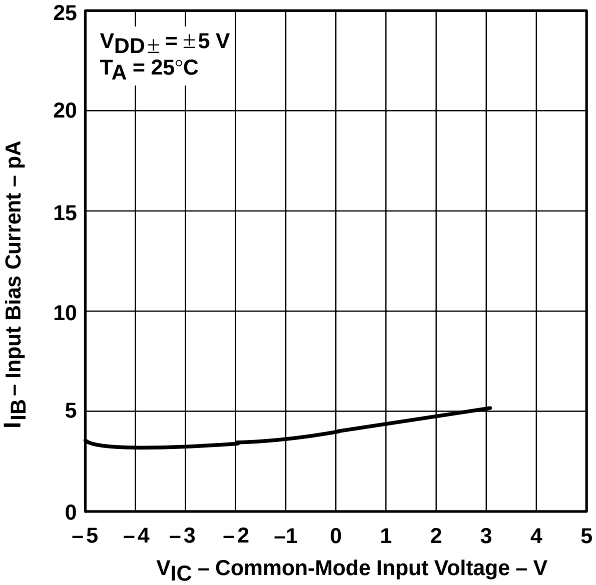


Figure 2

INPUT BIAS CURRENT vs CHOPPING FREQUENCY

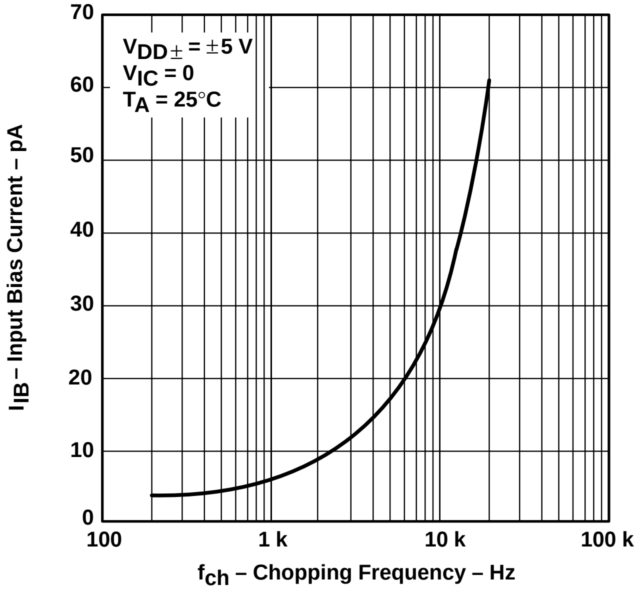


Figure 3

INPUT BIAS CURRENT vs FREE-AIR TEMPERATURE

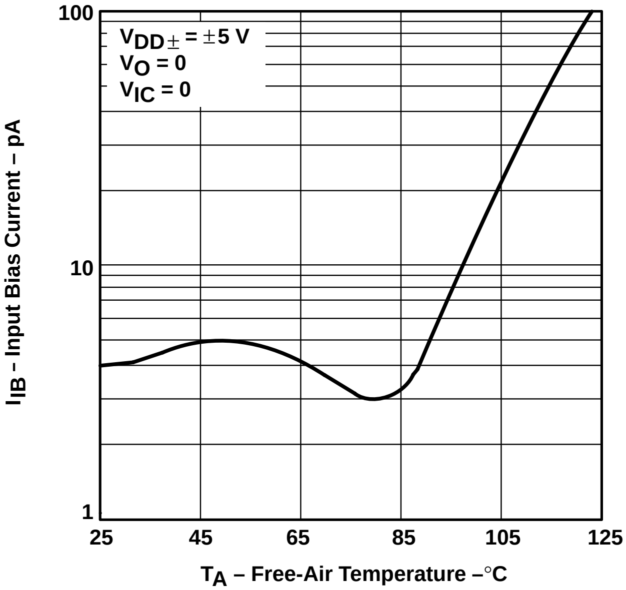


Figure 4

TYPICAL CHARACTERISTICS

INPUT OFFSET CURRENT
vs
CHOPPING FREQUENCY

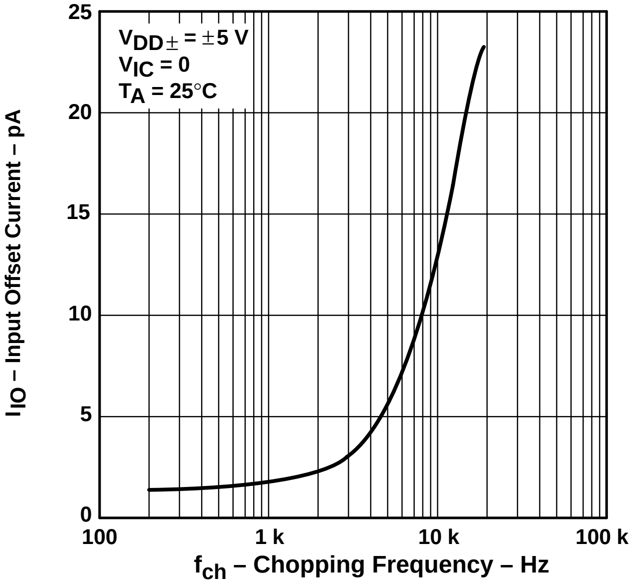


Figure 5

INPUT OFFSET CURRENT
vs
FREE-AIR TEMPERATURE

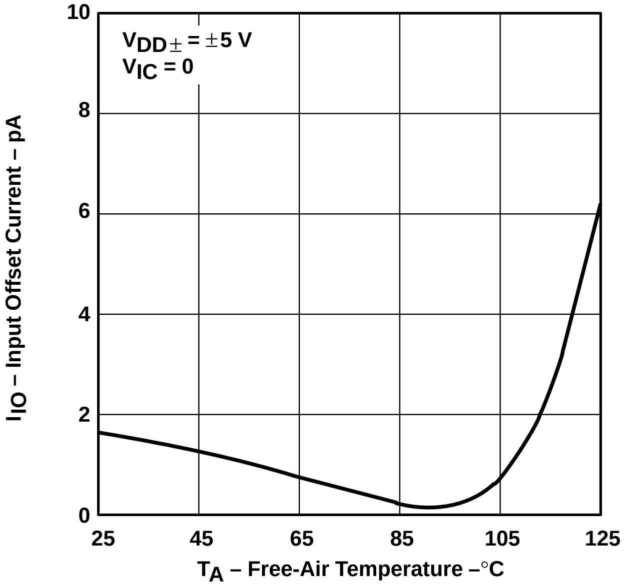


Figure 6

CLAMP CURRENT
vs
OUTPUT VOLTAGE

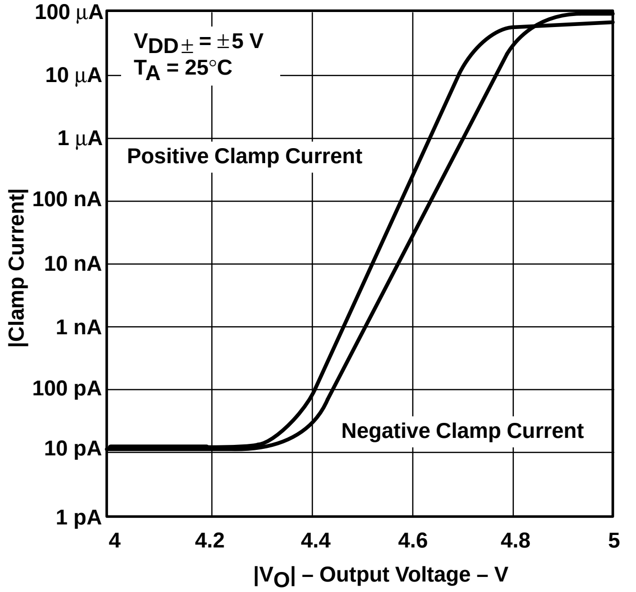


Figure 7

MAXIMUM PEAK-TO-PEAK OUTPUT
VOLTAGE
vs
FREQUENCY

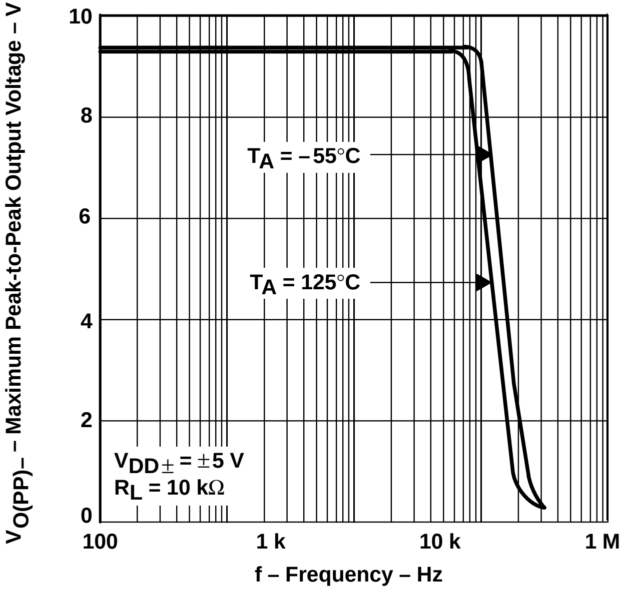


Figure 8

TYPICAL CHARACTERISTICS

MAXIMUM PEAK OUTPUT VOLTAGE vs OUTPUT CURRENT

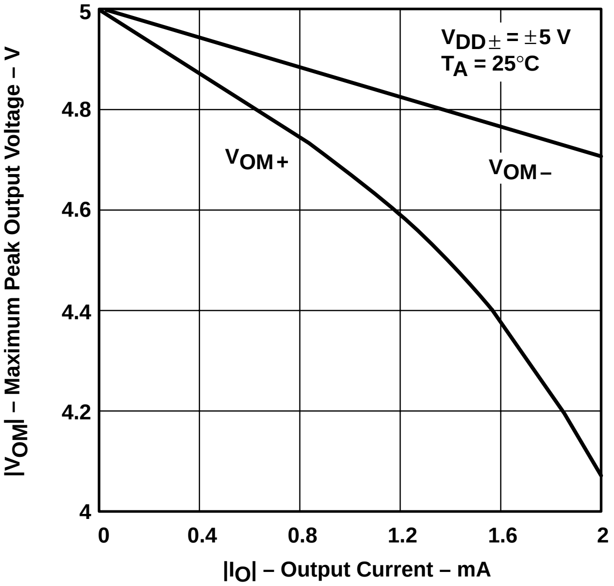


Figure 9

MAXIMUM PEAK OUTPUT VOLTAGE vs OUTPUT CURRENT

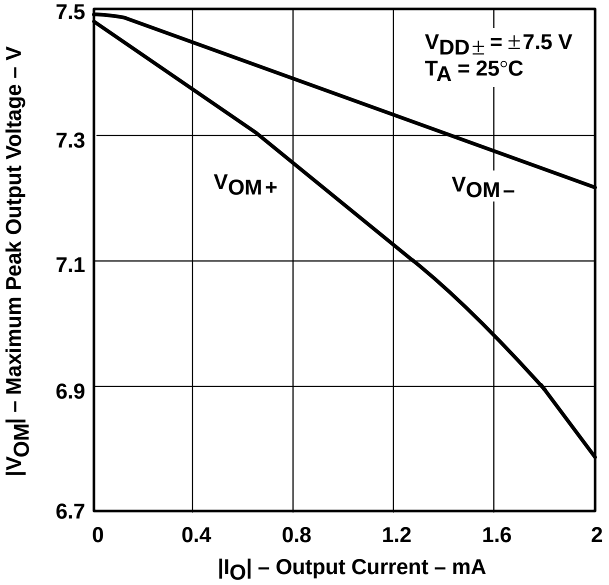


Figure 10

MAXIMUM PEAK OUTPUT VOLTAGE vs FREE-AIR TEMPERATURE

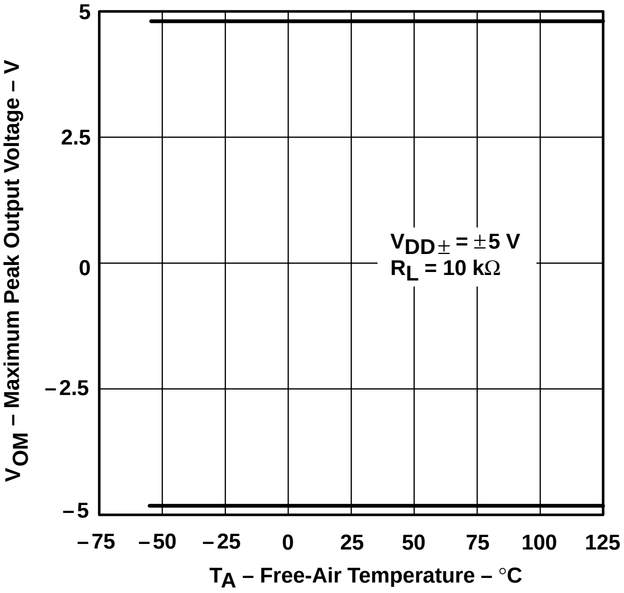


Figure 11

MAXIMUM PEAK OUTPUT VOLTAGE vs FREE-AIR TEMPERATURE

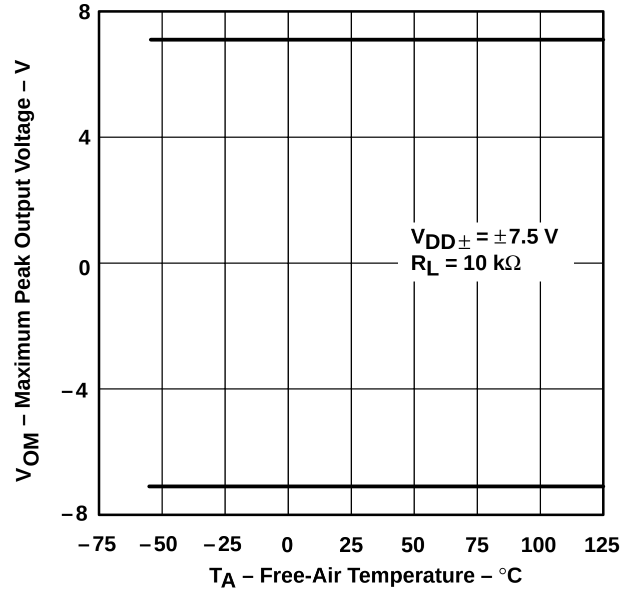


Figure 12

TYPICAL CHARACTERISTICS

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION AND PHASE SHIFT vs FREQUENCY

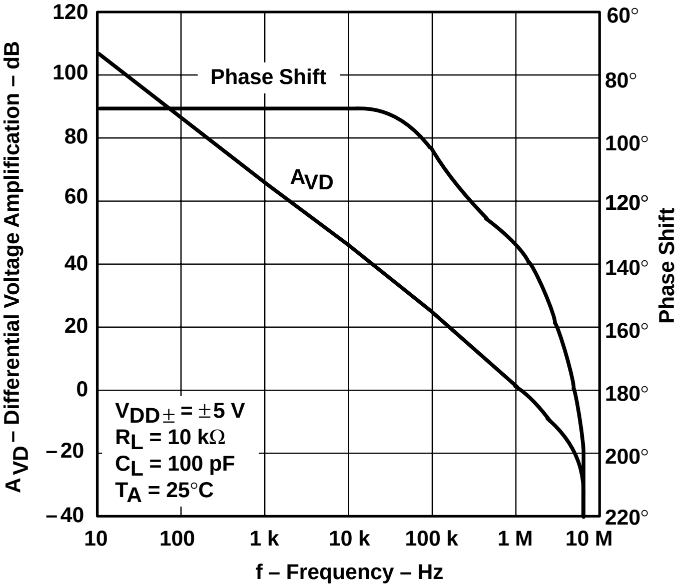


Figure 13

LARGE-SIGNAL VOLTAGE AMPLIFICATION vs FREE-AIR TEMPERATURE

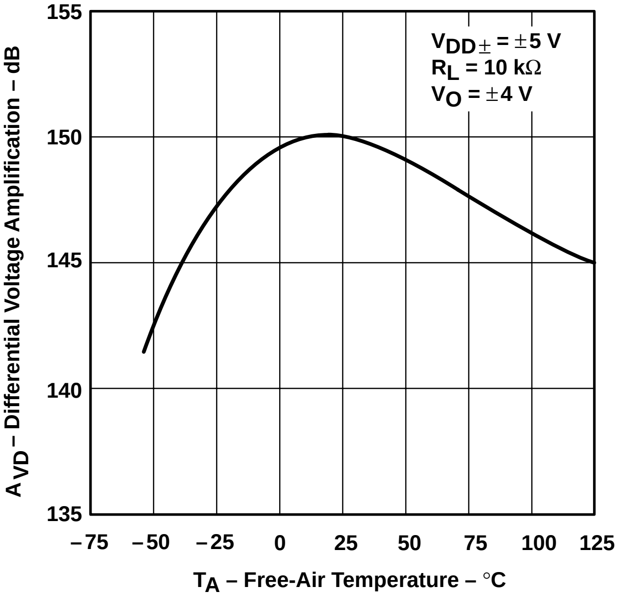


Figure 14

CHOPPING FREQUENCY vs SUPPLY VOLTAGE

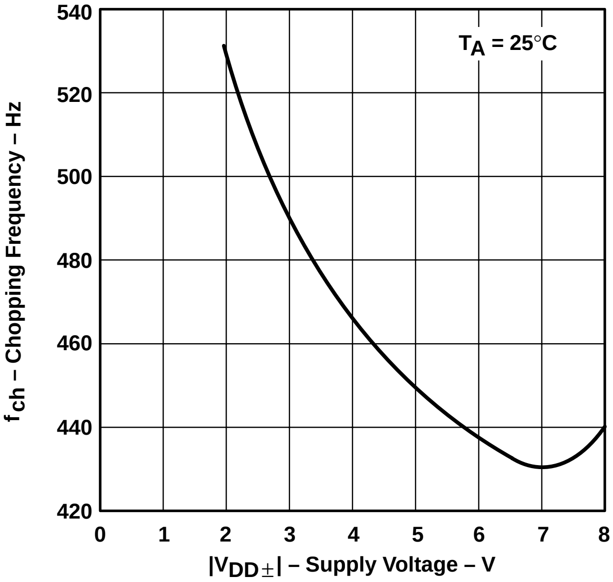


Figure 15

CHOPPING FREQUENCY vs FREE-AIR TEMPERATURE

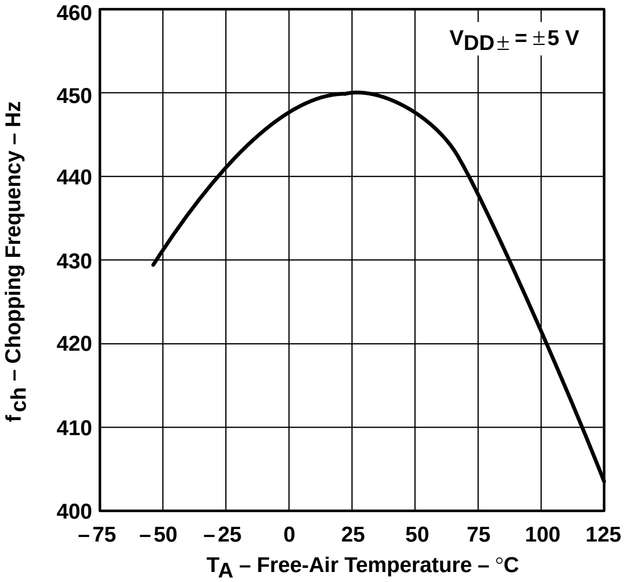


Figure 16

TYPICAL CHARACTERISTICS

SUPPLY CURRENT
vs
SUPPLY VOLTAGE

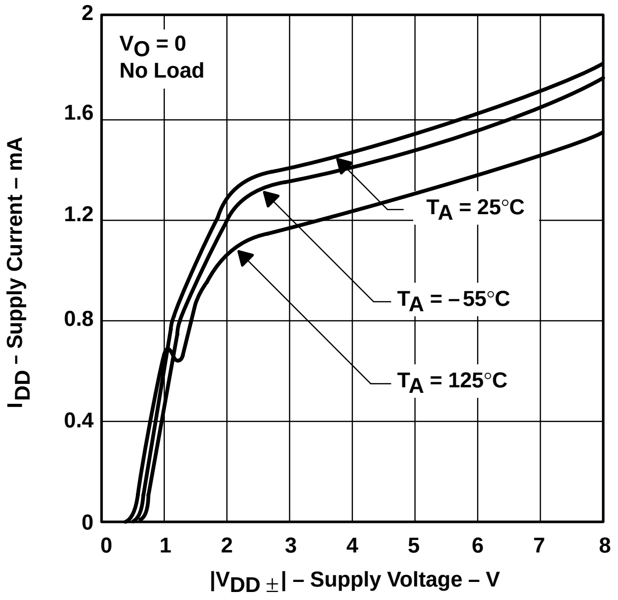


Figure 17

SUPPLY CURRENT
vs
FREE-AIR TEMPERATURE

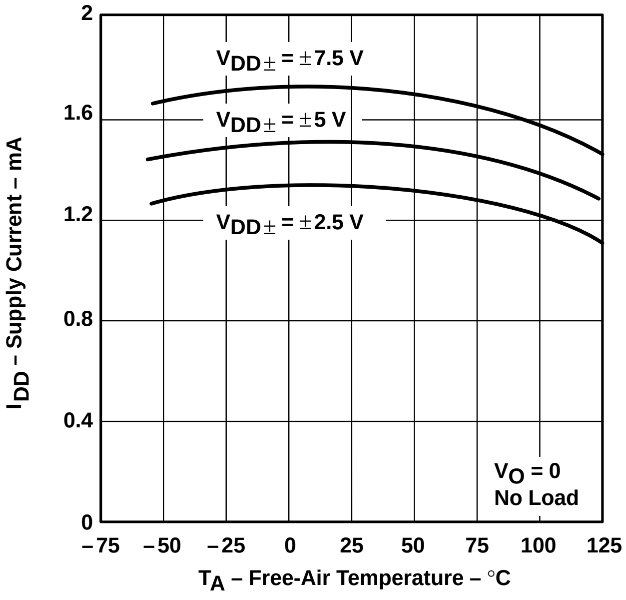


Figure 18

SHORT-CIRCUIT OUTPUT CURRENT
vs
SUPPLY VOLTAGE

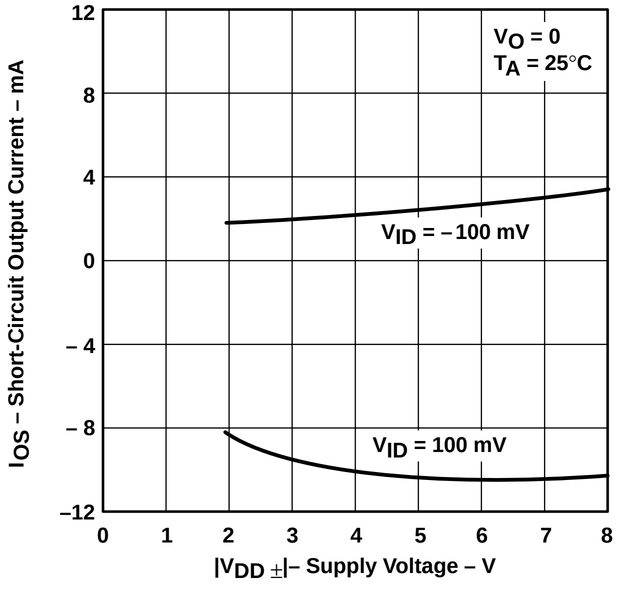


Figure 19

SHORT-CIRCUIT OUTPUT CURRENT
vs
FREE-AIR TEMPERATURE

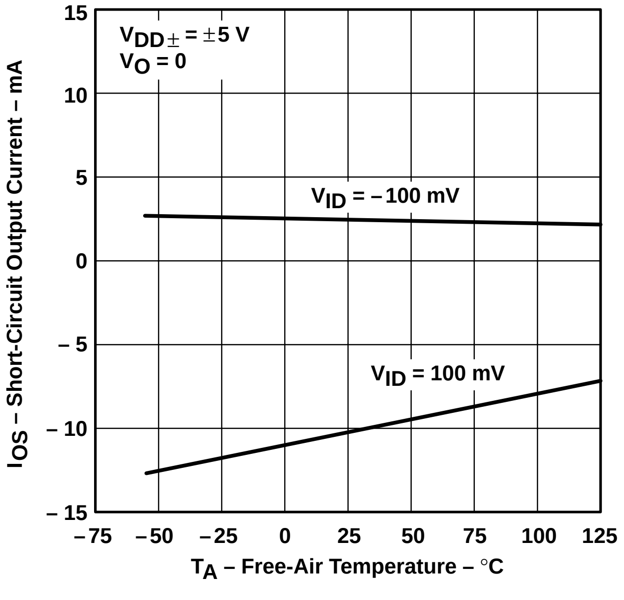


Figure 20

TYPICAL CHARACTERISTICS

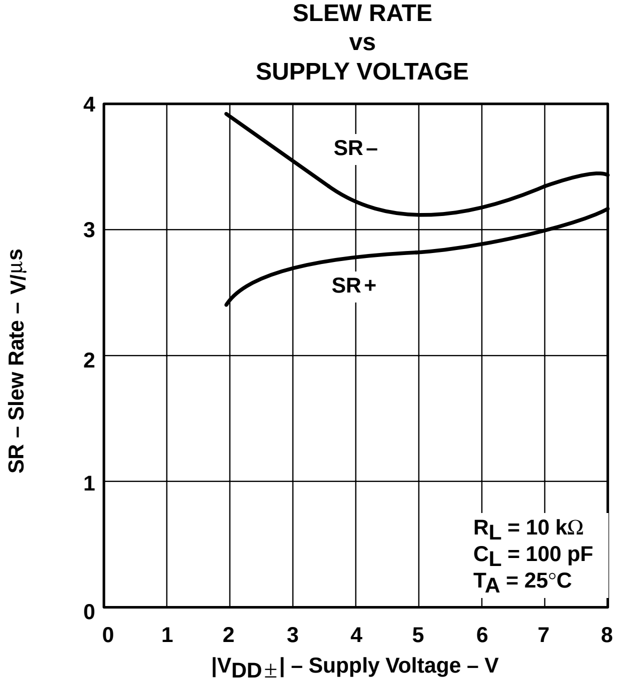


Figure 21

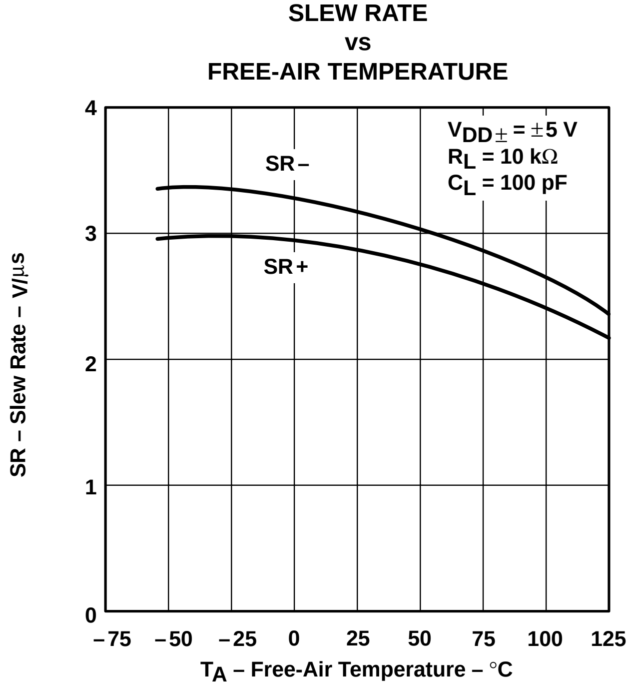


Figure 22

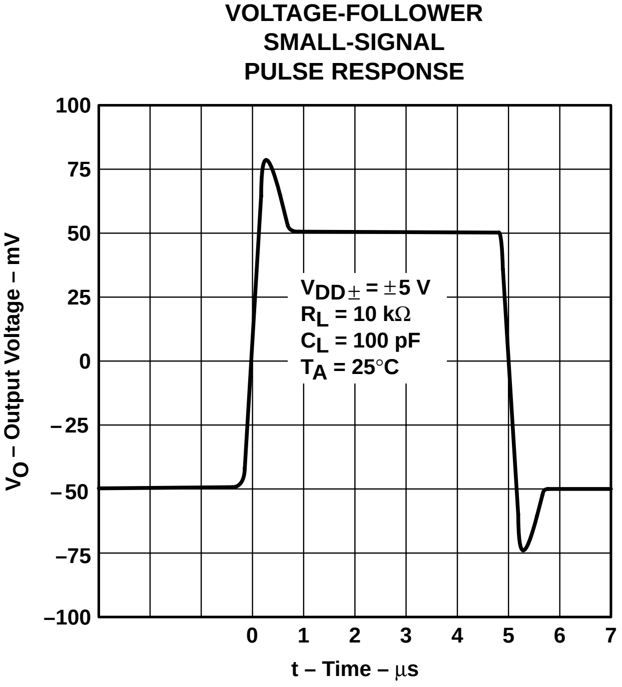


Figure 23

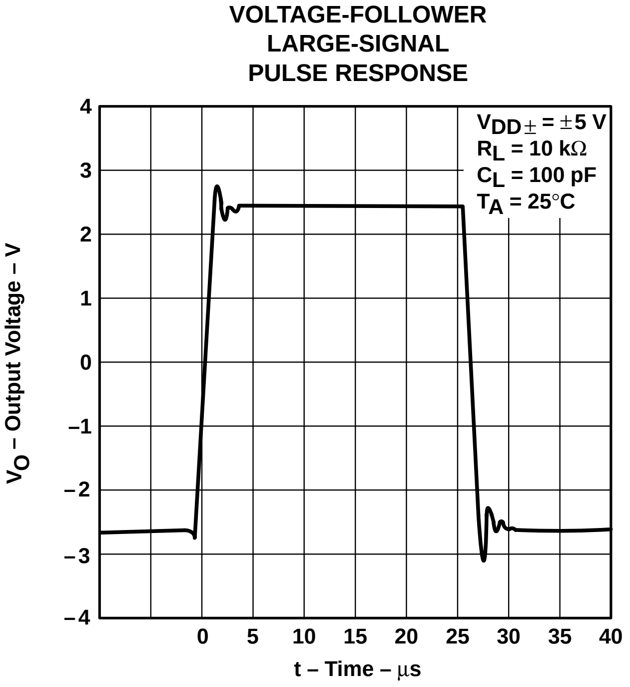


Figure 24

TYPICAL CHARACTERISTICS

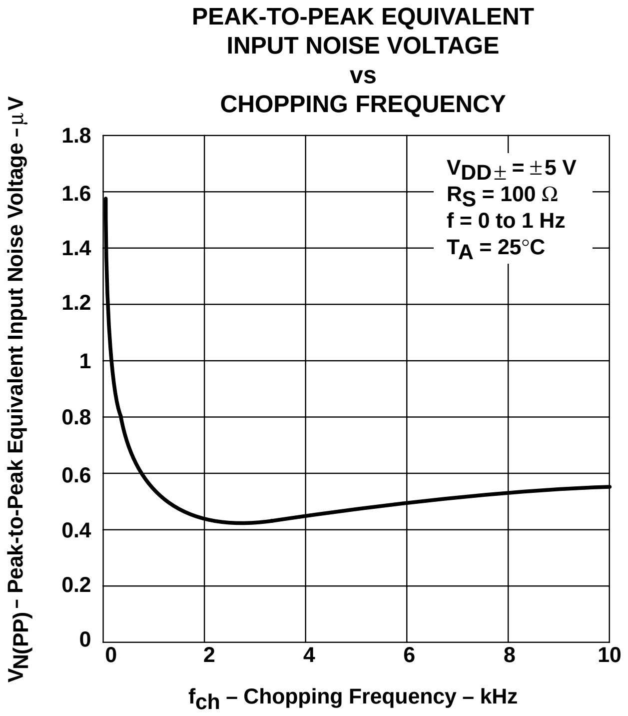


Figure 25

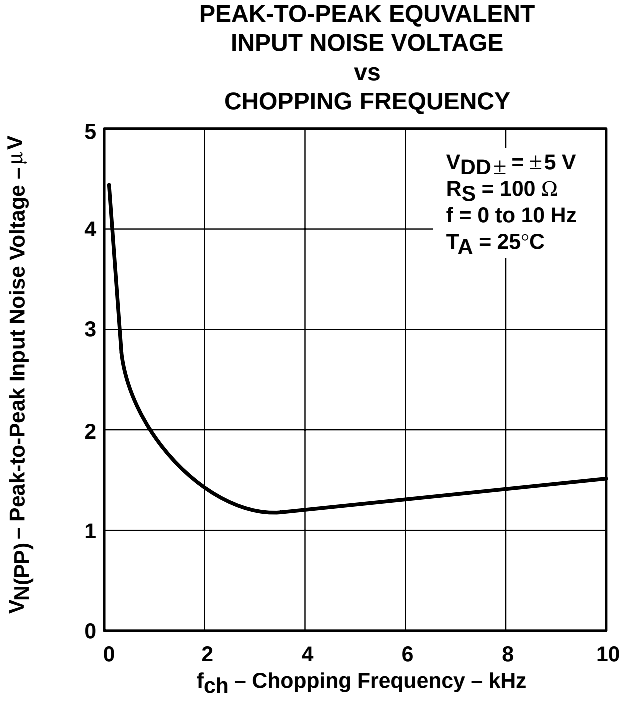


Figure 26

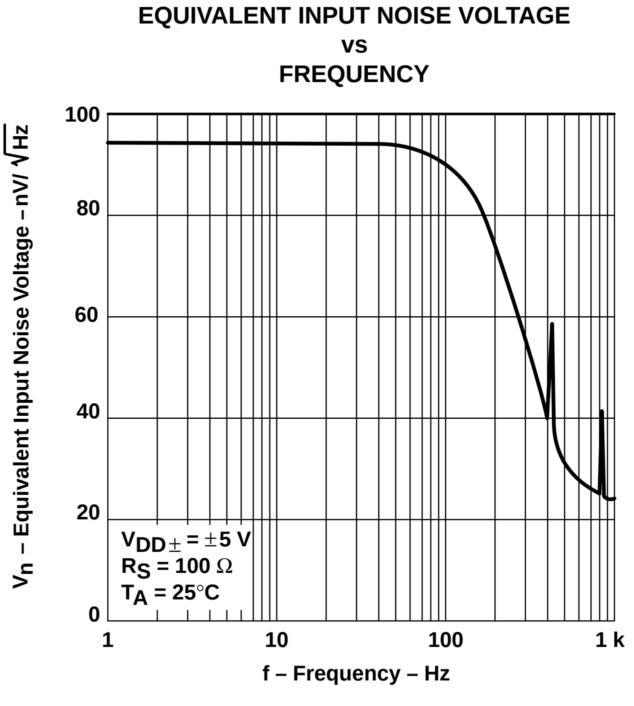


Figure 27

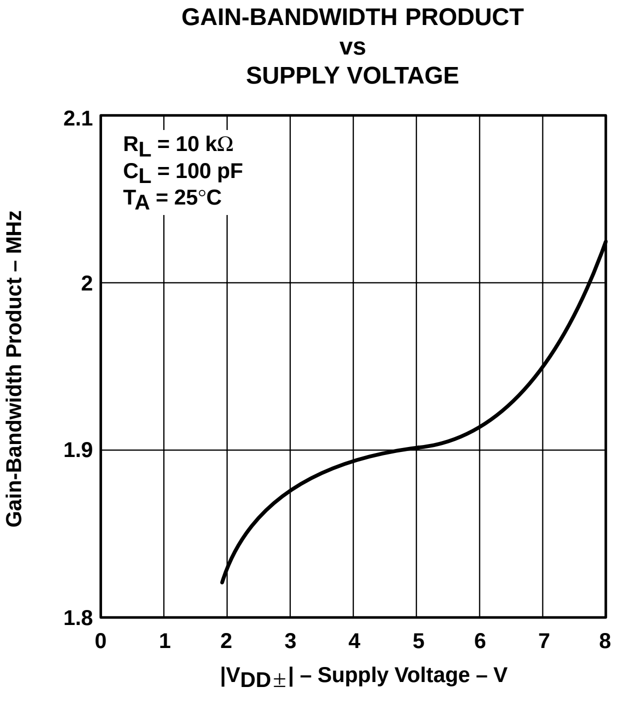


Figure 28

TYPICAL CHARACTERISTICS

GAIN-BANDWIDTH PRODUCT vs FREE-AIR TEMPERATURE

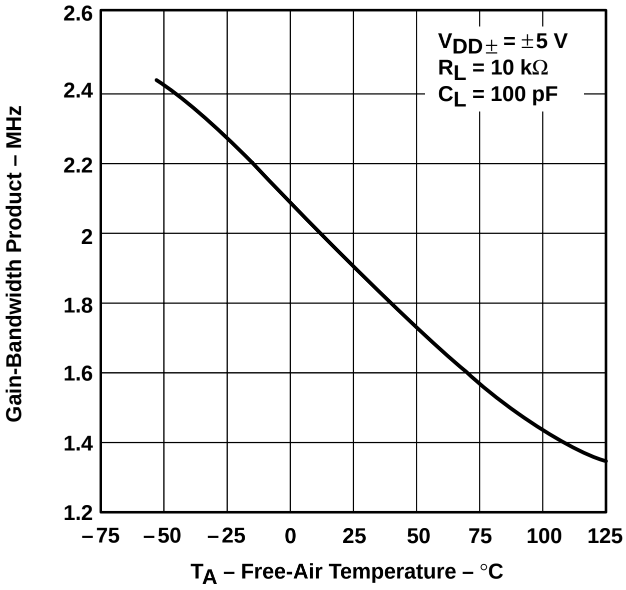


Figure 29

PHASE MARGIN vs SUPPLY VOLTAGE

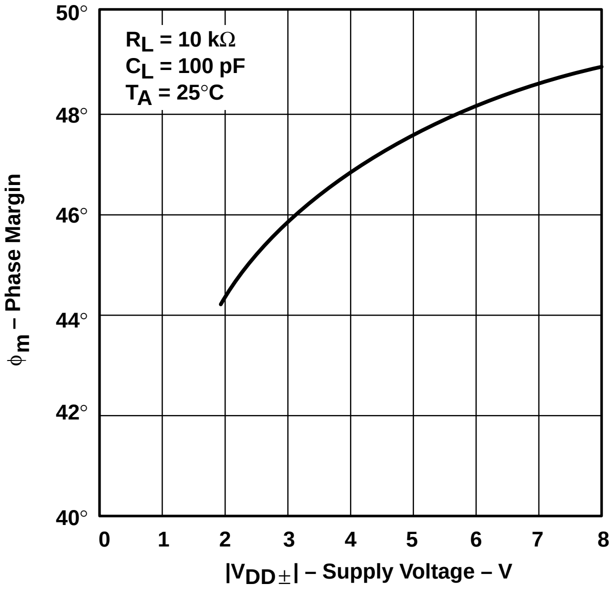


Figure 30

PHASE MARGIN vs FREE-AIR TEMPERATURE

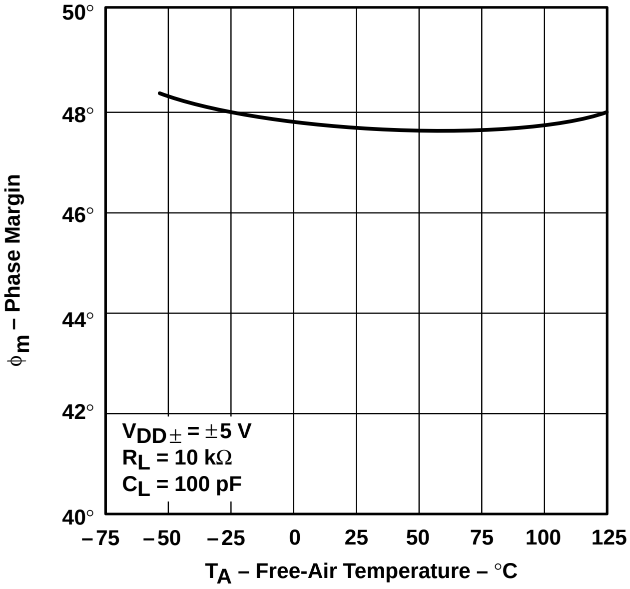


Figure 31

PHASE MARGIN vs LOAD CAPACITANCE

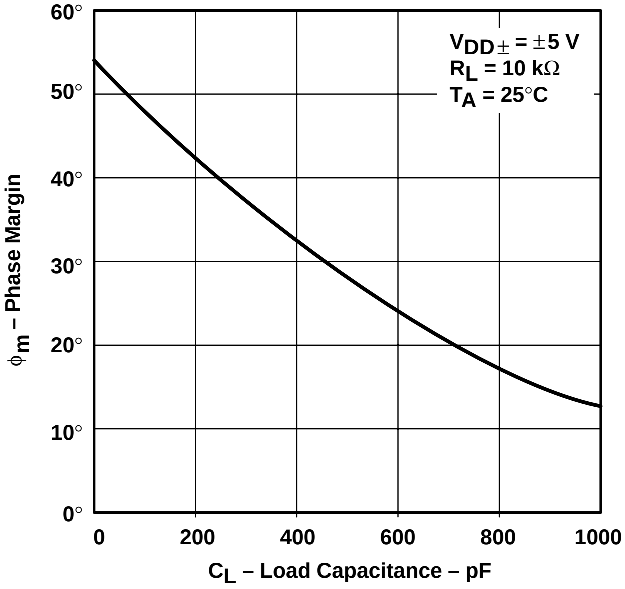


Figure 32

APPLICATION INFORMATION

capacitor selection and placement

The two important factors to consider when selecting external capacitors C_{XA} and C_{XB} are leakage and dielectric absorption. Both factors can cause system degradation, negating the performance advantages realized by using the TLC2652M.

Degradation from capacitor leakage becomes more apparent with the increasing temperatures. Low-leakage capacitors and standoffs are recommended for operation at T_A = 125°C. In addition, guardbands are recommended around the capacitor connections both sides of the printed circuit board to alleviate problems caused by surface leakage on circuit boards.

Capacitors with high dielectric absorption tend to take several seconds to settle upon application of power, which directly affects input offset voltage. In applications where fast settling of input offset voltage is needed, it is recommended that high-quality film capacitors, such as mylar, polystyrene, or polypropylene be used. In other applications, however, a ceramic or other low-grade capacitor may suffice.

Unlike many choppers available today, the TLC2652M is designed to function with values of C_{XA} and C_{XB} in the range of 0.1 µF to 1 µF without degradation to input offset voltage or input noise voltage. These capacitors should be located as close as possible to C_{XA} and C_{XB} and returned to either V_{DD-} or C RETURN. Note that on many choppers, connecting these capacitors to V_{DD-} causes degradation in noise performance, a problem that is eliminated on the TLC2652M.

internal/external clock

The TLC2652M has an internal clock that sets the chopping frequency to a nominal value of 450 Hz. On 8-pin packages, the chopping frequency can only be controlled by the internal clock; however, on all 14-pin packages and 20-pin FK package, the device chopping frequency may be set by the internal clock or controlled externally by use of INT/$\overline{\text{EXT}}$ and CLK IN. To use the internal 450-Hz clock, no connection is necessary. If external clocking is desired, connect INT/$\overline{\text{EXT}}$ to V_{DD-} and the external clock to CLK IN. The external clock trip point is 2.5 V above the negative rail; however, CLK IN may be driven from the negative rail to 5 V above the negative rail. If this level is exceeded, damage could occur to the device unless the current into CLK IN is limited to ±5 mA. When operating in the single-supply configuration, this feature allows the TLC2652 to be driven directly by 5-V TTL and CMOS logic. A divide-by-two frequency divider interfaces with CLK IN and sets the chopping frequency. The duty cycle of the external clock is not critical but should be kept between 30% and 60%.

overload recovery/output clamp

When large differential input voltage conditions are applied to the TLC2652M, the nulling loop will attempt to prevent the output from saturating by driving C_{XA} and C_{XB} to internally-clamped voltage levels. Once the overdrive condition is removed, a period of time is required to allow the built-up charge to dissipate. This time period is defined as overload recovery time (see Figure 33). Typical overload recovery time for the TLC2652M is significantly faster than competitive products; however, if required, this time can be reduced further by use of internal clamp circuitry accessible through CLAMP.

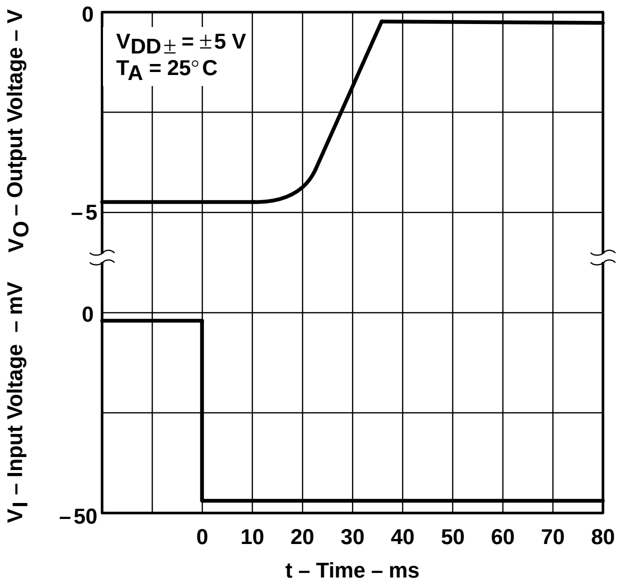


Figure 33. Overload Recovery

APPLICATION INFORMATION

overload recovery/output clamp (continued)

The clamp is simply a switch that is automatically activated when the output is approximately 1 V from either supply rail. When connected to the inverting input (in parallel with the closed-loop feedback resistor), the closed-loop gain is reduced and the TLC2652M output is prevented from going into saturation. Since the output must source or sink current through the switch (see Figure 7), the maximum output voltage swing is slightly reduced.

thermoelectric effects

To take advantage of the extremely low offset voltage drift of the TLC2652M, care must be taken to compensate for the thermoelectric effects present when two dissimilar metals are brought into contact with each other (such as device leads being soldered to a printed circuit board). Dissimilar metal junctions can produce thermoelectric voltages in the range of several microvolts per degree Celsius (orders of magnitude greater than the 0.01-μV/°C typical of the TLC2652M).

To help minimize thermoelectric effects, careful attention should be paid to component selection and circuit board layout. Avoid the use of nonsoldered connections (such as sockets, relays, switches, etc.) in the input signal path. Cancel thermoelectric effects by duplicating the number of components and junctions in each device input. The use of low-thermoelectric-coefficient components, such as wire-wound resistors, is also beneficial.

latch-up avoidance

Because CMOS devices are susceptible to latch-up due to their inherent parasitic thyristors, the TLC2652M inputs and output are designed to withstand –100-mA surge currents without sustaining latch-up; however, techniques to reduce the chance of latch-up should be used whenever possible. Internal protection diodes should not, by design, be forward biased. Applied input and output voltages should not exceed the supply voltage by more than 300 mV. Care should be exercised when using capacitive coupling on pulse generators. Supply transients should be shunted by using decoupling capacitors (0.1 μF typical) located across the supply rails as close to the device as possible.

The current path established if latch-up occurs is usually between the supply rails and is limited only by the impedance of the power supply and the forward resistance of the parasitic thyristor. The chance of latch-up occurring increases with increasing temperature and supply voltage.

electrostatic discharge protection

The TLC2652M incorporates internal ESD-protection circuits that prevent functional failures at voltages at or below 2000 V. Care should be exercised in handling these devices, as exposure to ESD may result in degradation of the device parametric performance.

theory of operation

Chopper-stabilized operational amplifiers offer the best dc performance of any monolithic operational amplifier. This superior performance is the result of using two operational amplifiers – a main amplifier and a nulling amplifier – plus oscillator-controlled logic and two external capacitors to create a system that behaves as a single amplifier. With this approach, the TLC2652M achieves submicrovolt input offset voltage, submicrovolt noise voltage, and offset voltage variations with temperature in the nV/°C range.

APPLICATION INFORMATION

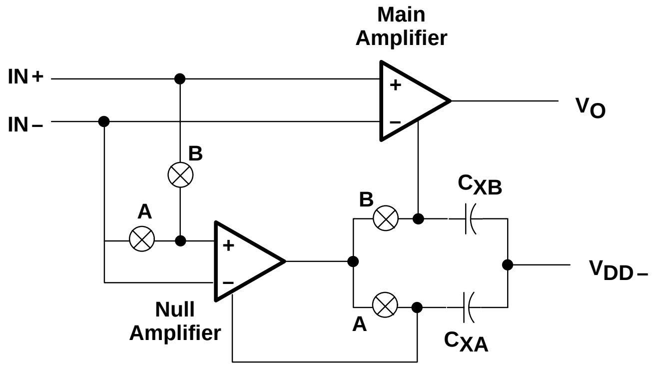


Figure 34. TLC2652M Simplified Block Diagram

theory of operation (continued)

The TLC2652M on-chip control logic produces two dominant clock phases - a nulling phase and an amplifying phase. The term chopper-stabilized derives from the process of switching between these two clock phases. Figure 34 shows a simplified block diagram of the TLC2652M. Switches A and B are make-before-break types. During the nulling phase, switch A is closed, shorting the nulling amplifier inputs together and allowing the nulling amplifier to reduce its own input offset voltage by feeding its output signal back to an inverting input node.

Simultaneously, external capacitor C_{XA} stores the nulling potential to allow the offset voltage of the amplifier to remain nulled during the amplifying phase.

During the amplifying phase, switch B is closed, connecting the output of the nulling amplifier to a noninverting input of the main amplifier. In this configuration, the input offset voltage of the main amplifier is nulled. Also, external capacitor C_{XB} stores the nulling potential to allow the offset voltage of the main amplifier to remain nulled during the next nulling phase.

This continuous chopping process allows offset voltage nulling during variations in time and temperature over the common-mode input voltage range and power supply range. In addition, because the low-frequency signal path is through both the null and main amplifiers, extremely high gain is achieved.

The low-frequency noise of a chopper amplifier depends on the magnitude of the component noise prior to chopping and the capability of the circuit to reduce this noise while chopping. The use of the Advanced LinCMOS process, with its low-noise analog MOS transistors and patent-pending input stage design, significantly reduces the input noise voltage.

The primary source of nonideal operation in chopper-stabilized amplifiers is error charge from the switches.

As charge imbalance accumulates on critical nodes, input offset voltage can increase, especially with increasing chopping frequency. This problem has been significantly reduced in the TLC2652M by use of a patent-pending compensation circuit and the Advanced LinCMOS process.

The TLC2652M incorporates a feed-forward design that ensures continuous frequency response. Essentially, the gain magnitude of the nulling amplifier and compensation network crosses unity at the break frequency of the main amplifier. As a result, the high-frequency response of the system is the same as the frequency response of the main amplifier. This approach also ensure that the slewing characteristics remain the same during both the nulling and amplifying phases.

IMPORTANT NOTICE

Texas Instruments (TI) reserves the right to make changes to its products or to discontinue any semiconductor product or service without notice, and advises its customers to obtain the latest version of relevant information to verify, before placing orders, that the information being relied on is current.

TI warrants performance of its semiconductor products and related software to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Certain applications using semiconductor products may involve potential risks of death, personal injury, or severe property or environmental damage ("Critical Applications").

TI SEMICONDUCTOR PRODUCTS ARE NOT DESIGNED, INTENDED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE-SUPPORT APPLICATIONS, DEVICES OR SYSTEMS OR OTHER CRITICAL APPLICATIONS.

Inclusion of TI products in such applications is understood to be fully at the risk of the customer. Use of TI products in such applications requires the written approval of an appropriate TI officer. Questions concerning potential risk applications should be directed to TI through a local SC sales office.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards should be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein. Nor does TI warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used.

Copyright © 1996, Texas Instruments Incorporated