



# TS616

## DUAL WIDE BAND OPERATIONAL AMPLIFIER WITH HIGH OUTPUT CURRENT

- **LOW NOISE** : 2.5nV/√Hz
- **HIGH OUTPUT CURRENT** : 420mA
- **VERY LOW HARMONIC AND INTERMODULATION DISTORTION**
- **HIGH SLEW RATE** : 420V/μs
- **-3dB BANDWIDTH** : 40MHz@gain=12dB on 25Ω load single ended.
- **20.7Vp-p DIFFERENTIAL OUTPUT SWING** on 50Ω load, 12V power supply
- **CURRENT FEEDBACK STRUCTURE**
- **5V to 12V POWER SUPPLY**
- **SPECIFIED FOR 20Ω and 50Ω DIFFERENTIAL LOAD**

### DESCRIPTION

The TS616 is a dual operational amplifier featuring a high output current of 410mA. The drivers can be configured differentially for driving signals in telecommunication systems using multiple carriers. The TS616 is ideally suited for xDSL (High Speed Asymmetrical Digital Subscriber Line) applications. This circuit is capable of driving a 10Ω or 25Ω load at ±2.5V, 5V, ±6V or +12V power supply. The TS616 is able to reach a -3dB bandwidth of 40MHz on 25Ω load with a 12dB gain. This device is designed for high slew rates supporting low harmonic distortion and intermodulation.

### APPLICATION

- Line driver for xDSL
- Multiple Video Line Driver

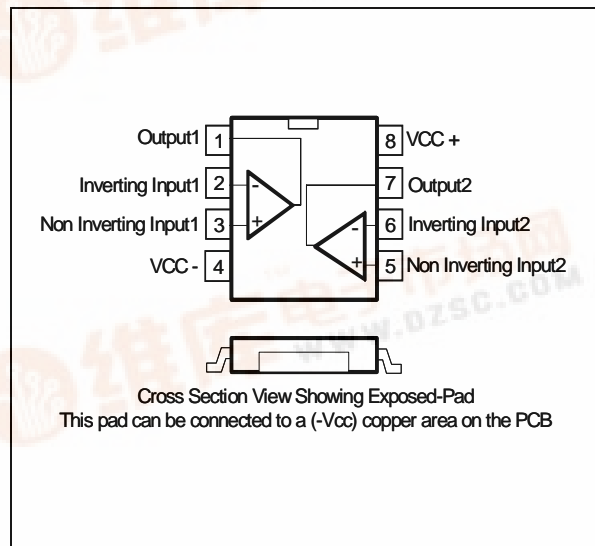


### ORDER CODE

Part Number	Temperature Range	Package
TS616IDW	-40, +85°C	DW
TS616IDWT	-40, +85°C	DW

DW = Small Outline Package with Exposed-Pad, T = Tape & Reel

### PIN CONNECTIONS (top view)



**ABSOLUTE MAXIMUM RATINGS**

Symbol	Parameter	Value	Unit
$V_{CC}$	Supply voltage <sup>1)</sup>	$\pm 7$	V
$V_{id}$	Differential Input Voltage <sup>2)</sup>	$\pm 2$	V
$V_{in}$	Input Voltage Range <sup>3)</sup>	$\pm 6$	V
$T_{oper}$	Operating Free Air Temperature Range	-40 to + 85	°C
$T_{std}$	Storage Temperature	-65 to +150	°C
$T_j$	Maximum Junction Temperature	150	°C
$R_{thjc}$	Thermal Resistance Junction to Case	16	°C/W
$R_{thja}$	Thermal Resistance Junction to Ambient Area	60	°C/W
$P_{max.}$	Maximum Power Dissipation (@ $T_a=25^\circ\text{C}$ ) for $T_j=150^\circ\text{C}$	2	W
ESD only pins 1, 4, 7, 8	CDM : Charged Device Model	1.5	kV
	HBM : Human Body Model	2	kV
	MM : Machine Model	200	V
ESD only pins 2, 3, 5, 6	CDM : Charged Device Model	1.5	kV
	HBM : Human Body Model	2	kV
	MM : Machine Model	100	V
	Output Short Circuit	4)	

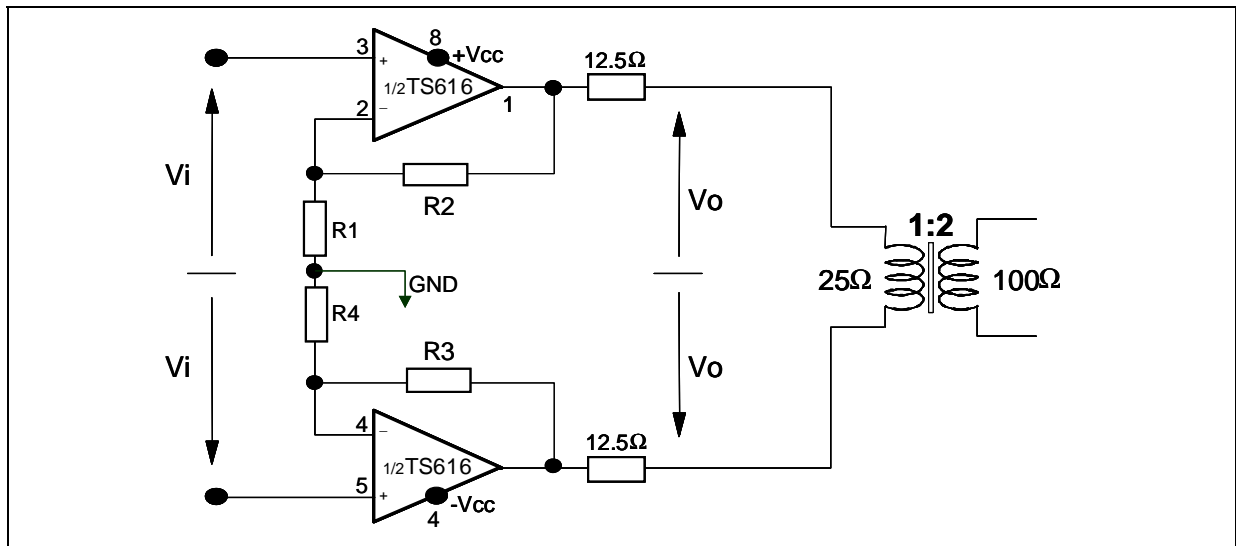
1. All voltage values, except differential voltage are with respect to network terminal.
2. Differential voltage are non-inverting input terminal with respect to the inverting input terminal.
3. The magnitude of input and output voltage must never exceed  $V_{CC} + 0.3V$ .
4. An output current limitation protects the circuit from transient currents. Short-circuits can cause excessive heating. Destructive dissipation can result from short circuit on amplifiers.

**OPERATING CONDITIONS**

Symbol	Parameter	Value	Unit
$V_{CC}$	Power Supply Voltage	$\pm 2.5$ to $\pm 6$	V
$V_{icm}$	Common Mode Input Voltage	$-V_{CC} + 1.5V$ to $+V_{CC} - 1.5V$	V

**TYPICAL APPLICATION:**

Differential Line Driver for xDSL Applications



**ELECTRICAL CHARACTERISTICS**
 $V_{CC} = \pm 6\text{Volts}$ ,  $R_{fb} = 910\Omega$ ,  $T_{amb} = 25^\circ\text{C}$  (unless otherwise specified)

**Note:** As described on page 24 (table 71), the TS616 requires a 620 $\Omega$  feedback resistor for an optimized bandwidth with a gain of 12B for a 12V power supply. Nevertheless, due to production test constraints, the TS616 is tested with the same feedback resistor for 12V and 5V power supplies (910 $\Omega$ ).

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
<b>DC PERFORMANCE</b>						
$V_{io}$	Input Offset Voltage	$T_{amb}$		1	3.5	mV
		$T_{min.} < T_{amb} < T_{max.}$		1.6		
$\Delta V_{io}$	Differential Input Offset Voltage	$T_{amb} = 25^\circ\text{C}$			2.5	mV
$I_{ib+}$	Positive Input Bias Current	$T_{amb}$		5	30	$\mu\text{A}$
		$T_{min.} < T_{amb} < T_{max.}$		7.2		
$I_{ib-}$	Negative Input Bias Current	$T_{amb}$		3	15	$\mu\text{A}$
		$T_{min.} < T_{amb} < T_{max.}$		3.1		
$Z_{IN+}$	Input(+) Impedance			82		k $\Omega$
$Z_{IN-}$	Input(-) Impedance			54		$\Omega$
$C_{IN+}$	Input(+) Capacitance			1		pF
CMR	Common Mode Rejection Ratio $20 \log (\Delta V_{ic}/\Delta V_{io})$	$\Delta V_{ic} = \pm 4.5\text{V}$	58	64		dB
		$T_{min.} < T_{amb} < T_{max.}$		62		
SVR	Supply Voltage Rejection Ratio $20 \log (\Delta V_{cc}/\Delta V_{io})$	$\Delta V_{cc} = \pm 2.5\text{V to } \pm 6\text{V}$	72	81		dB
		$T_{min.} < T_{amb} < T_{max.}$		80		
$I_{CC}$	Total Supply Current per Operator	No load		13.5	17	mA
<b>DYNAMIC PERFORMANCE and OUTPUT CHARACTERISTIC</b>						
$R_{OL}$	Open Loop Transimpedance	$V_{out} = 7\text{Vp-p}$ , $R_L = 25\Omega$	5	13.5		M $\Omega$
		$T_{min.} < T_{amb.} < T_{max.}$		5.7		
BW	-3dB Bandwidth	Small Signal $V_{out} < 20\text{mVp}$ $A_V = 12\text{dB}$ , $R_L = 25\Omega$	25	40		MHz
	Full Power Bandwidth	Large Signal $V_{out} = 3\text{Vp}$ $A_V = 12\text{dB}$ , $R_L = 25\Omega$		26		
	Gain Flatness @ 0.1dB	Small Signal $V_{out} < 20\text{mVp}$ $A_V = 12\text{dB}$ , $R_L = 25\Omega$		7		
$T_r$	Rise Time	$V_{out} = 6\text{Vp-p}$ , $A_V = 12\text{dB}$ , $R_L = 25\Omega$		10.6		ns
$T_f$	Fall Time	$V_{out} = 6\text{Vp-p}$ , $A_V = 12\text{dB}$ , $R_L = 25\Omega$		12.2		ns
$T_s$	Settling Time	$V_{out} = 6\text{Vp-p}$ , $A_V = 12\text{dB}$ , $R_L = 25\Omega$		50		ns
SR	Slew Rate	$V_{out} = 6\text{Vp-p}$ , $A_V = 12\text{dB}$ , $R_L = 25\Omega$	330	420		V/ $\mu\text{s}$
$V_{OH}$	High Level Output Voltage	$R_L = 25\Omega$ Connected to GND	4.8	5.05		V
$V_{OL}$	Low Level Output Voltage	$R_L = 25\Omega$ Connected to GND		-5.3	-5.1	V
$I_{out}$	Output Sink Current	$V_{out} = -4\text{Vp}$	-320	-490		mA
		$T_{min.} < T_{amb} < T_{max.}$		-395		
	Output Source Current	$V_{out} = +4\text{Vp}$	330	420		
		$T_{min.} < T_{amb} < T_{max.}$		370		

## TS616

**Note:** As described on page 24 (table 71), the TS616 requires a 620Ω feedback resistor for an optimized bandwidth with a gain of 12B for a 12V power supply. Nevertheless, due to production test constraints, the TS616 is tested with the same feedback resistor for 12V and 5V power supplies (910Ω).

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
<b>NOISE AND DISTORTION</b>						
eN	Equivalent Input Noise Voltage	F = 100kHz		2.5		nV/√Hz
iNp	Equivalent Input Noise Current (+)	F = 100kHz		15		pA/√Hz
iNn	Equivalent Input Noise Current (-)	F = 100kHz		21		pA/√Hz
HD2	2nd Harmonic Distortion (differential configuration)	V <sub>out</sub> = 14Vp-p, A <sub>v</sub> = 12dB F = 110kHz, R <sub>L</sub> = 50Ω diff.		-87		dBc
HD3	3rd Harmonic Distortion (differential configuration)	V <sub>out</sub> = 14Vp-p, A <sub>v</sub> = 12dB F = 110kHz, R <sub>L</sub> = 50Ω diff.		-83		dBc
IM2	2nd Order Intermodulation Product (differential configuration)	F1 = 100kHz, F2 = 110kHz V <sub>out</sub> = 16Vp-p, A <sub>v</sub> = 12dB R <sub>L</sub> = 50Ω diff.		-76		dBc
		F1 = 370kHz, F2 = 400kHz V <sub>out</sub> = 16Vp-p, A <sub>v</sub> = 12dB R <sub>L</sub> = 50Ω diff.		-75		
IM3	3rd Order Intermodulation Product (differential configuration)	F1 = 100kHz, F2 = 110kHz V <sub>out</sub> = 16Vp-p, A <sub>v</sub> = 12dB R <sub>L</sub> = 50Ω diff.		-88		dBc
		F1 = 370kHz, F2 = 400kHz V <sub>out</sub> = 16Vp-p, A <sub>v</sub> = 12dB R <sub>L</sub> = 50Ω diff.		-87		

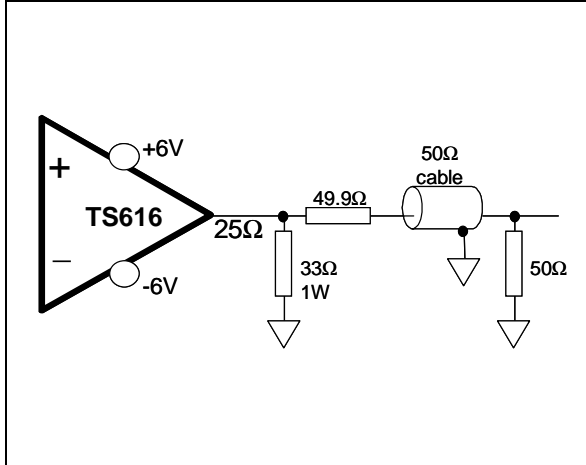
**ELECTRICAL CHARACTERISTICS**
 $V_{CC} = \pm 2.5\text{Volts}$ ,  $R_{ib} = 910\Omega$ ,  $T_{amb} = 25^\circ\text{C}$  (unless otherwise specified)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
<b>DC PERFORMANCE</b>						
$V_{io}$	Input Offset Voltage	$T_{amb}$		0.2	2.5	mV
		$T_{min.} < T_{amb} < T_{max.}$		1		
$\Delta V_{io}$	Differential Input Offset Voltage	$T_{amb} = 25^\circ\text{C}$			2.5	mV
$I_{ib+}$	Positive Input Bias Current	$T_{amb}$		4	30	$\mu\text{A}$
		$T_{min.} < T_{amb} < T_{max.}$		7		
$I_{ib-}$	Negative Input Bias Current	$T_{amb}$		1.1	11	$\mu\text{A}$
		$T_{min.} < T_{amb} < T_{max.}$		1.2		
$Z_{IN+}$	Input(+) Impedance			71		k $\Omega$
$Z_{IN-}$	Input(-) Impedance			62		$\Omega$
$C_{IN+}$	Input(+) Capacitance			1.5		pF
CMR	Common Mode Rejection Ratio $20 \log (\Delta V_{ic}/\Delta V_{io})$	$\Delta V_{ic} = \pm 1\text{V}$	55	61		dB
		$T_{min.} < T_{amb.} < T_{max.}$		60		
SVR	Supply Voltage Rejection Ratio $20 \log (\Delta V_{cc}/\Delta V_{io})$	$\Delta V_{cc} = \pm 2\text{V to } \pm 2.5\text{V}$	63	79		dB
		$T_{min.} < T_{amb.} < T_{max.}$		78		
$I_{CC}$	Total Supply Current per Operator	No load		11.5	15	mA
<b>DYNAMIC PERFORMANCE and OUTPUT CHARACTERISTICS</b>						
$R_{OL}$	Open Loop Transimpedance	$V_{out} = 2\text{Vp-p}$ , $R_L = 10\Omega$	2	4.2		M $\Omega$
		$T_{min.} < T_{amb.} < T_{max.}$		1.5		
BW	-3dB Bandwidth	Small Signal $V_{out} < 20\text{mVp}$ $A_V = 12\text{dB}$ , $R_L = 10\Omega$	20	28		MHz
	Full Power Bandwidth	Large Signal $V_{out} = 1.4\text{Vp}$ $A_V = 12\text{dB}$ , $R_L = 10\Omega$		20		
	Gain Flatness @ 0.1dB	Small Signal $V_{out} < 20\text{mVp}$ $A_V = 12\text{dB}$ , $R_L = 10\Omega$		5.7		
$T_r$	Rise Time	$V_{out} = 2.8\text{Vp-p}$ , $A_V = 12\text{dB}$ $R_L = 10\Omega$		11		ns
$T_f$	Fall Time	$V_{out} = 2.8\text{Vp-p}$ , $A_V = 12\text{dB}$ $R_L = 10\Omega$		11.5		ns
$T_s$	Settling Time	$V_{out} = 2.2\text{Vp-p}$ , $A_V = 12\text{dB}$ $R_L = 10\Omega$		39		ns
SR	Slew Rate	$V_{out} = 2.2\text{Vp-p}$ , $A_V = 12\text{dB}$ $R_L = 10\Omega$	100	130		V/ $\mu\text{s}$
$V_{OH}$	High Level Output Voltage	$R_L = 10\Omega$ Connected to GND	1.5	1.7		V
$V_{OL}$	Low Level Output Voltage	$R_L = 10\Omega$ Connected to GND		-1.9	-1.7	V
$I_{out}$	Output Sink Current	$V_{out} = -1.25\text{Vp}$	-300	-400		mA
		$T_{min.} < T_{amb} < T_{max.}$		-360		
	Output Source Current	$V_{out} = +1.25\text{Vp}$	200	270		
		$T_{min.} < T_{amb} < T_{max.}$		240		

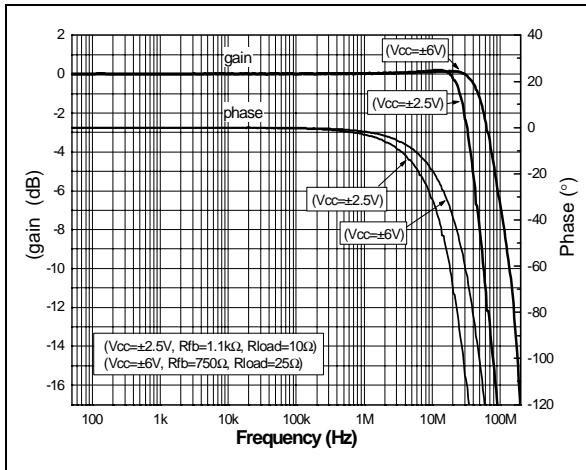
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Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
<b>NOISE AND DISTORTION</b>						
eN	Equivalent Input Noise Voltage	F = 100kHz		2.5		nV/ $\sqrt{\text{Hz}}$
iNp	Equivalent Input Noise Current (+)	F = 100kHz		15		pA/ $\sqrt{\text{Hz}}$
iNn	Equivalent Input Noise Current (-)	F = 100kHz		21		pA/ $\sqrt{\text{Hz}}$
HD2	2nd Harmonic Distortion (differential configuration)	V <sub>out</sub> = 6Vp-p, A <sub>V</sub> = 12dB F = 110kHz, R <sub>L</sub> = 20 $\Omega$ diff.		-97		dBc
HD3	3rd Harmonic Distortion (differential configuration)	V <sub>out</sub> = 6Vp-p, A <sub>V</sub> = 12dB F = 110kHz, R <sub>L</sub> = 20 $\Omega$ diff.		-98		dBc
IM2	2nd Order Intermodulation Product (differential configuration)	F1 = 100kHz, F2 = 110kHz V <sub>out</sub> = 6Vp-p, A <sub>V</sub> = 12dB R <sub>L</sub> = 20 $\Omega$ diff.		-86		dBc
		F1 = 370kHz, F2 = 400kHz V <sub>out</sub> = 6Vp-p, A <sub>V</sub> = 12dB R <sub>L</sub> = 20 $\Omega$ diff.		-88		
IM3	3rd Order Intermodulation Product (differential configuration)	F1 = 100kHz, F2 = 110kHz V <sub>out</sub> = 6Vp-p, A <sub>V</sub> = 12dB R <sub>L</sub> = 20 $\Omega$ diff.		-90		dBc
		F1 = 370kHz, F2 = 400kHz V <sub>out</sub> = 6Vp-p, A <sub>V</sub> = 12dB R <sub>L</sub> = 20 $\Omega$ diff.		-85		

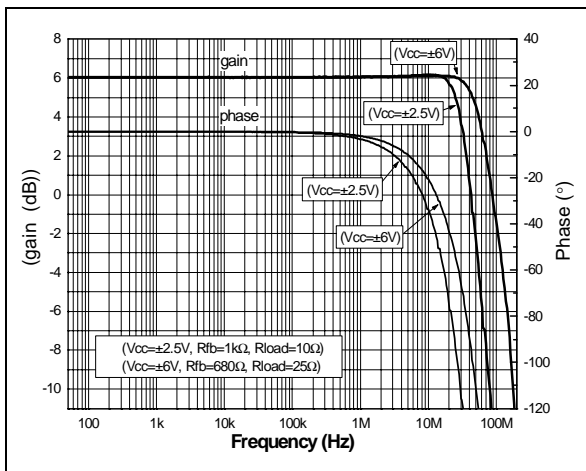
**Figure 1: Load Configuration**  
 Load:  $R_L=25\Omega$ ,  $V_{CC}=\pm 6V$



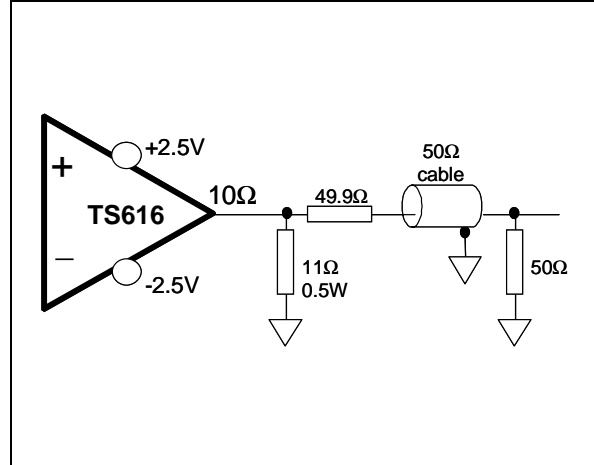
**Figure 2: Closed Loop Gain vs. Frequency**  
 $A_V=+1$



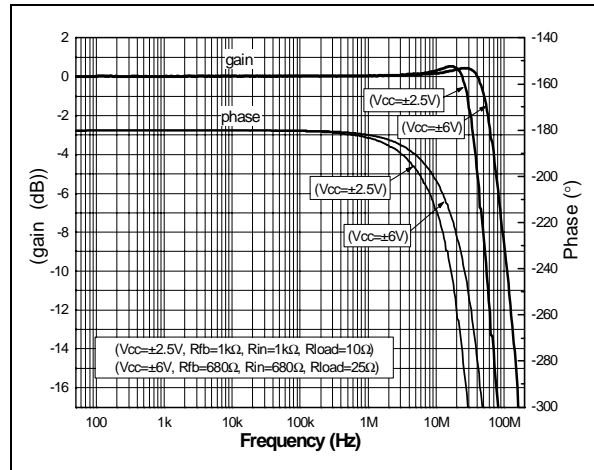
**Figure 3: Closed Loop Gain vs. Frequency**  
 $A_V=+2$



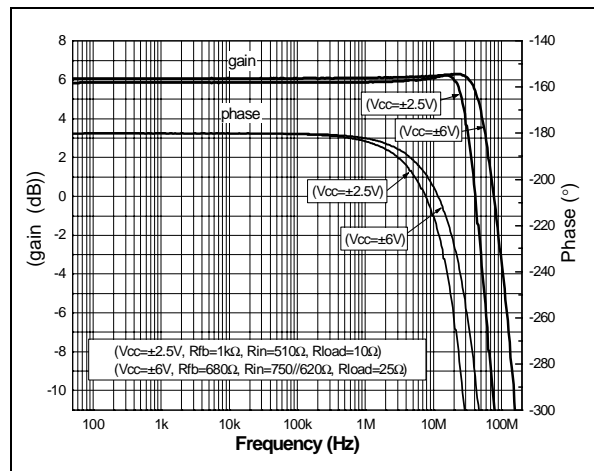
**Figure 4: Load Configuration**  
 Load:  $R_L=10\Omega$ ,  $V_{CC}=\pm 2.5V$



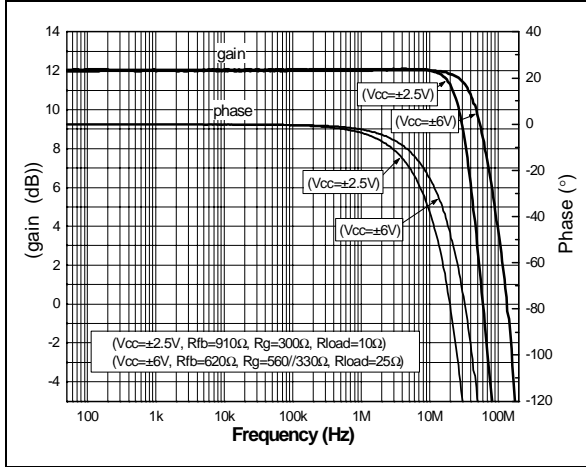
**Figure 5: Closed Loop Gain vs. Frequency**  
 $A_V=-1$



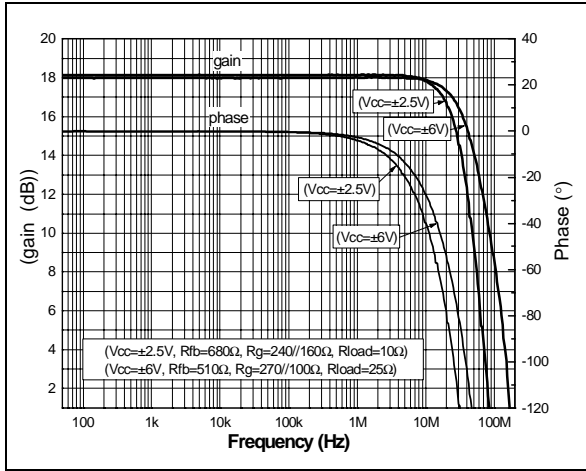
**Figure 6: Closed Loop Gain vs. Frequency**  
 $A_V=-2$



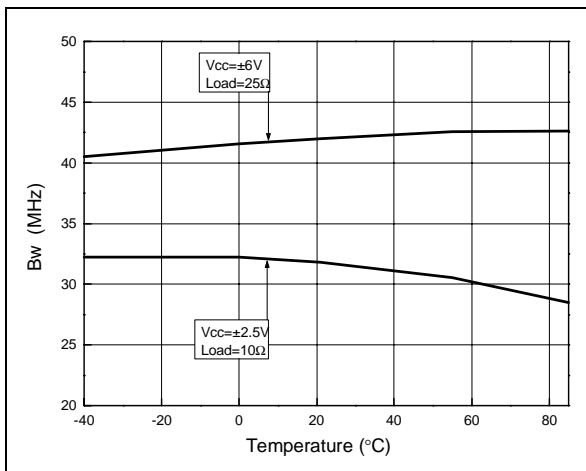
**Figure 7: Closed Loop Gain vs. Frequency**  
 $A_V=+4$



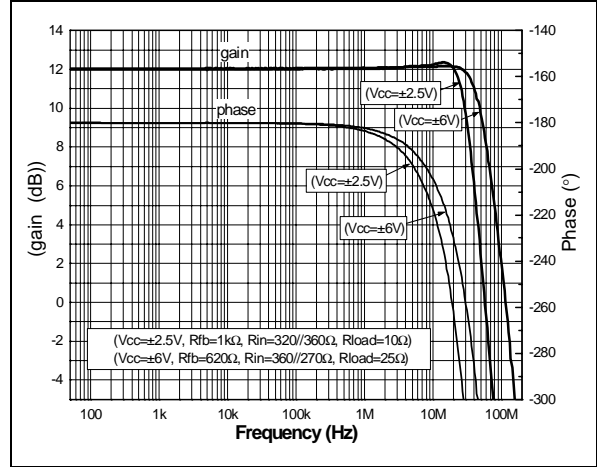
**Figure 8: Closed Loop Gain vs. Frequency**  
 $A_V=+8$



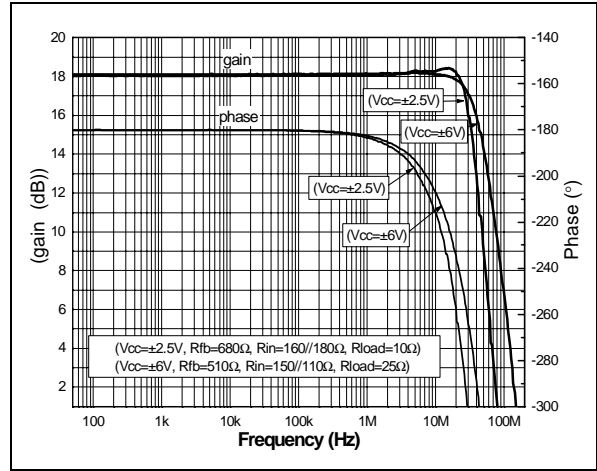
**Figure 9: Bandwidth vs. Temperature**  
 $A_V=+4, R_{fb}=910\Omega$



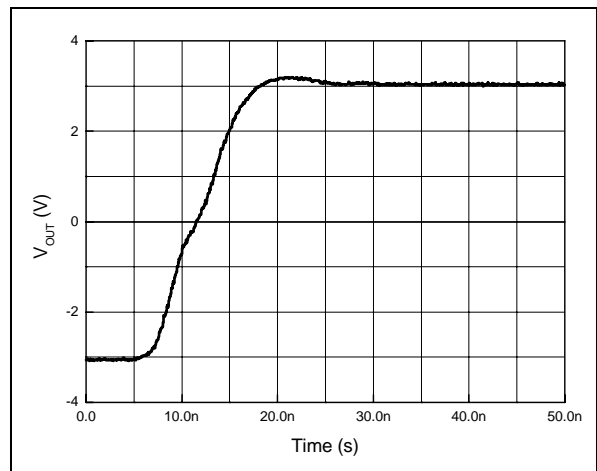
**Figure 10: Closed Loop Gain vs. Frequency**  
 $A_V=-4$



**Figure 11: Closed Loop Gain vs. Frequency**  
 $A_V=-8$

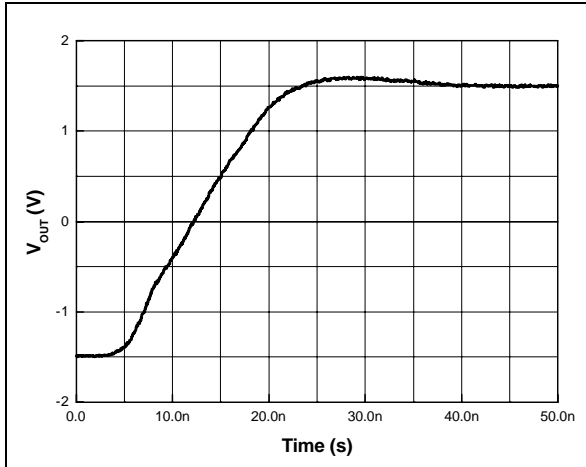


**Figure 12: Positive Slew Rate**  
 $A_V=+4, R_{fb}=620\Omega, V_{CC}=\pm 6V, R_L=25\Omega$

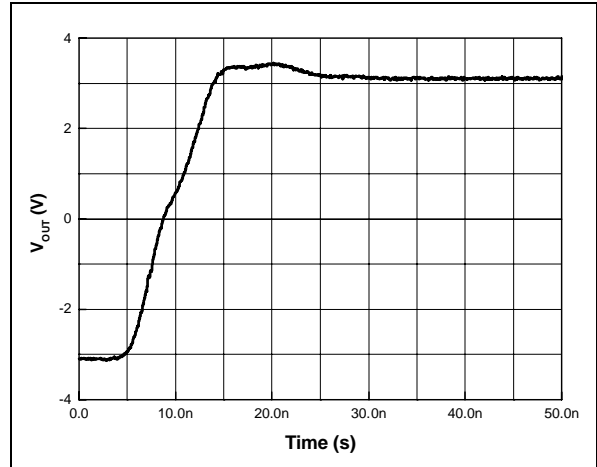




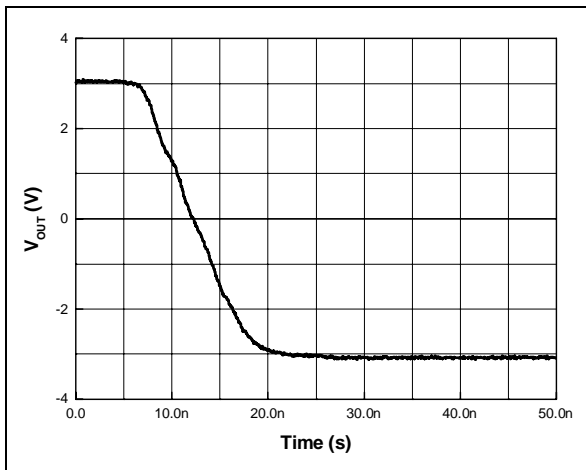
**Figure 13: Positive Slew Rate**  
 $A_V=+4$ ,  $R_{fb}=910\Omega$ ,  $V_{CC}=\pm 2.5V$ ,  $R_L=10\Omega$



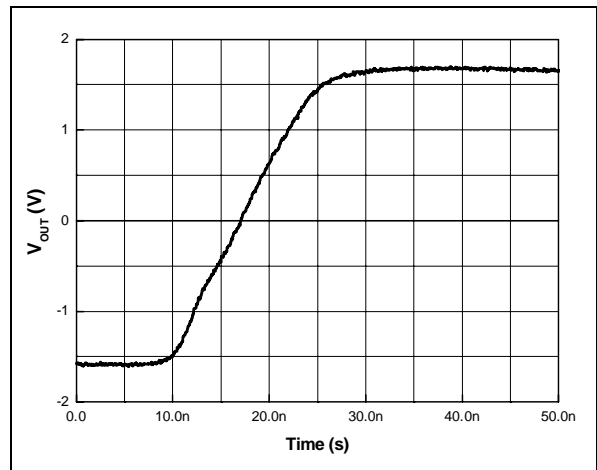
**Figure 16: Positive Slew Rate**  
 $A_V= - 4$ ,  $R_{fb}=620\Omega$ ,  $V_{CC}=\pm 6V$ ,  $R_L=25\Omega$



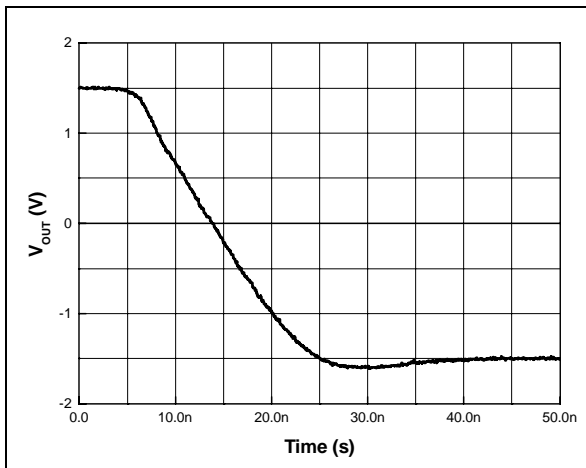
**Figure 14: Negative Slew Rate**  
 $A_V=+4$ ,  $R_{fb}=620\Omega$ ,  $V_{CC}=\pm 6V$ ,  $R_L=25\Omega$



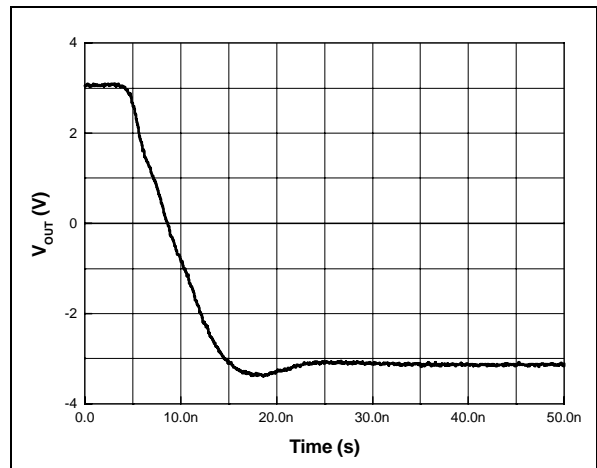
**Figure 17: Positive Slew Rate**  
 $A_V= - 4$ ,  $R_{fb}=910\Omega$ ,  $V_{CC}=\pm 2.5V$ ,  $R_L=10\Omega$



**Figure 15: Negative Slew Rate**  
 $A_V=+4$ ,  $R_{fb}=910\Omega$ ,  $V_{CC}=\pm 2.5V$ ,  $R_L=10\Omega$

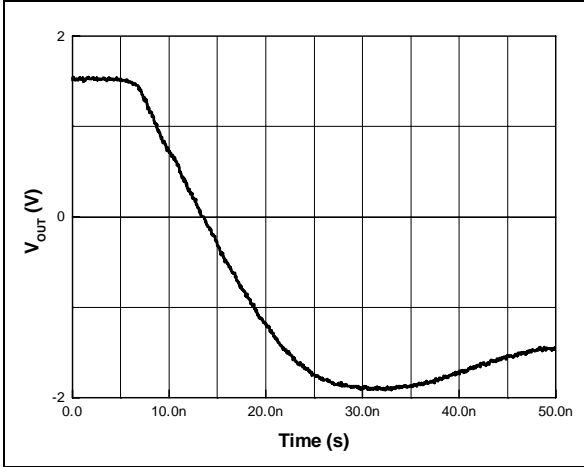


**Figure 18: Negative Slew Rate**  
 $A_V= - 4$ ,  $R_{fb}=620\Omega$ ,  $V_{CC}=\pm 6V$ ,  $R_L=25\Omega$



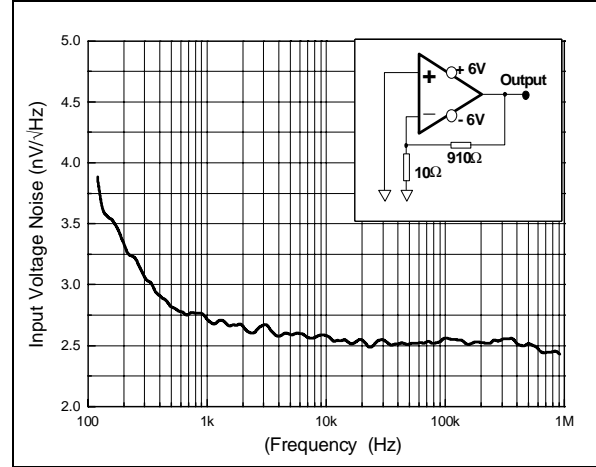
**Figure 19: Negative Slew Rate**

$A_V = -4$ ,  $R_{fb} = 910\Omega$ ,  $V_{CC} = \pm 2.5V$ ,  $R_L = 10\Omega$



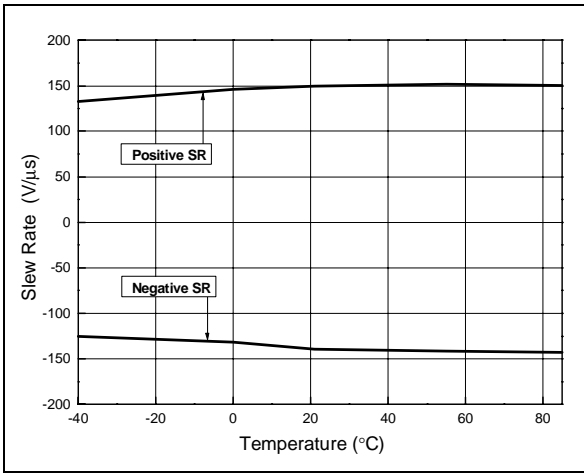
**Figure 22: Input Voltage Noise Level**

$A_V = +92$ ,  $R_{fb} = 910\Omega$ , Input+ connected to Gnd via  $10\Omega$



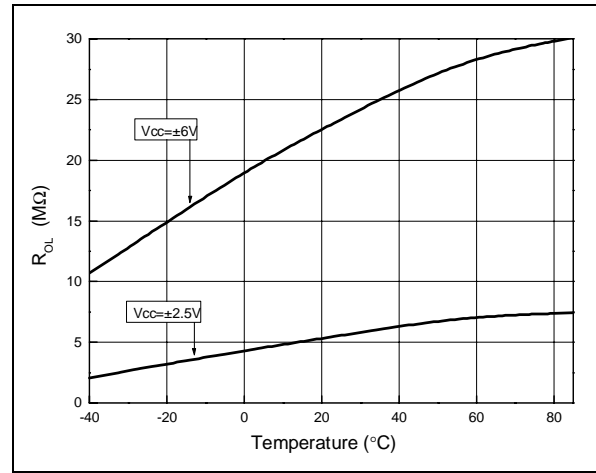
**Figure 20: Slew Rate vs. Temperature**

$A_V = +4$ ,  $R_{fb} = 910\Omega$ ,  $V_{CC} = \pm 2.5V$ ,  $R_L = 10\Omega$



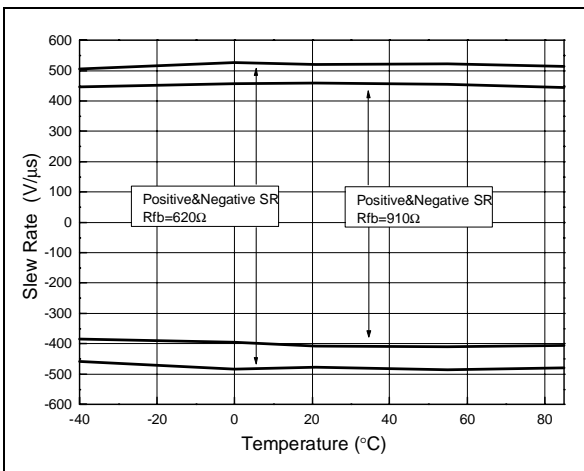
**Figure 23: Transimpedance vs. Temperature**

Open Loop



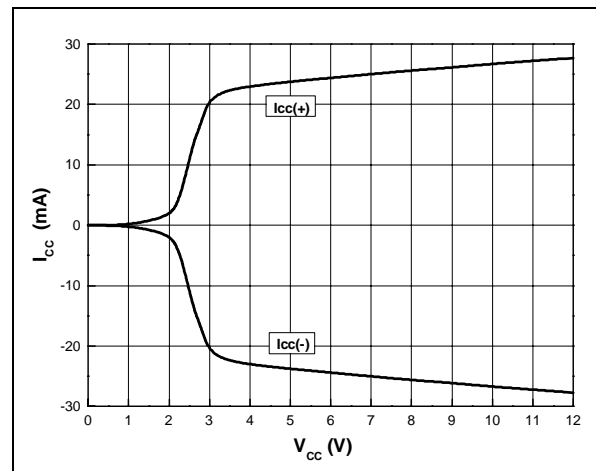
**Figure 21: Slew Rate vs. Temperature**

$A_V = +4$ ,  $R_{fb} = 910\Omega$ ,  $V_{CC} = \pm 6V$ ,  $R_L = 25\Omega$

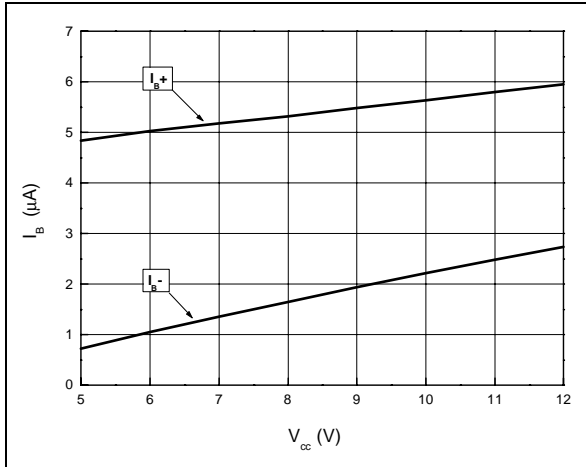


**Figure 24: I<sub>cc</sub> vs. Power Supply**

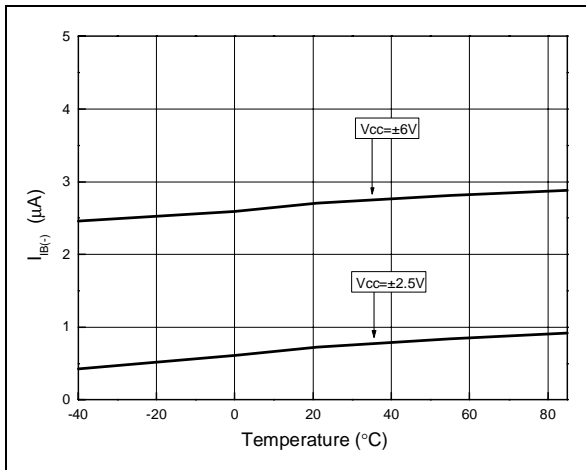
Open loop, no load



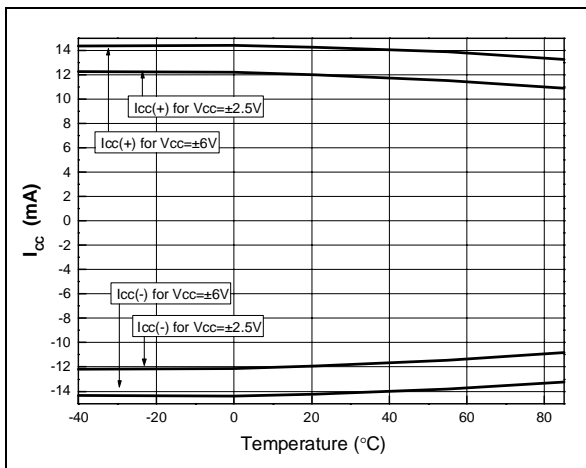
**Figure 25:**  $I_{B}$  vs. Power Supply  
Open loop, no load



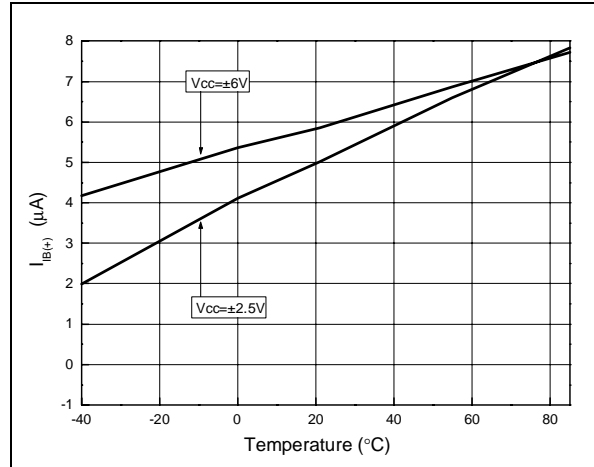
**Figure 26:**  $I_{B(-)}$  vs. Temperature  
Open loop, no load



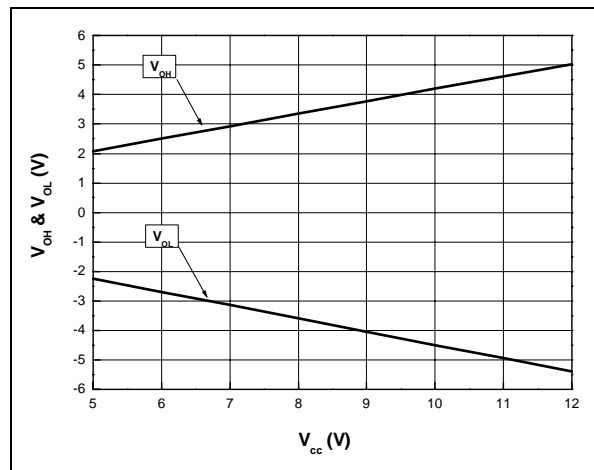
**Figure 27:**  $I_{CC}$  vs. Temperature  
Open loop, no load



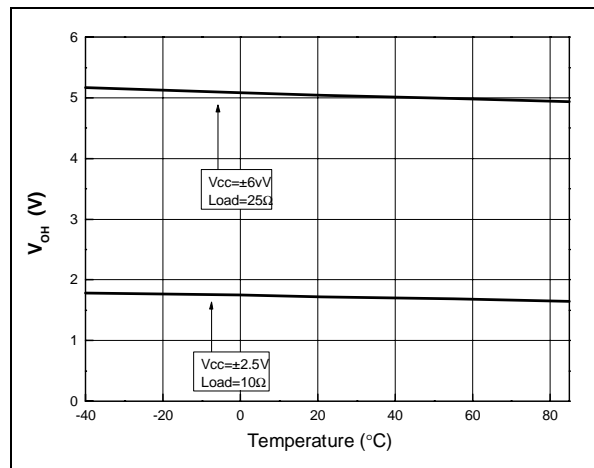
**Figure 28:**  $I_{B(+)}$  vs. Temperature  
Open loop, no load



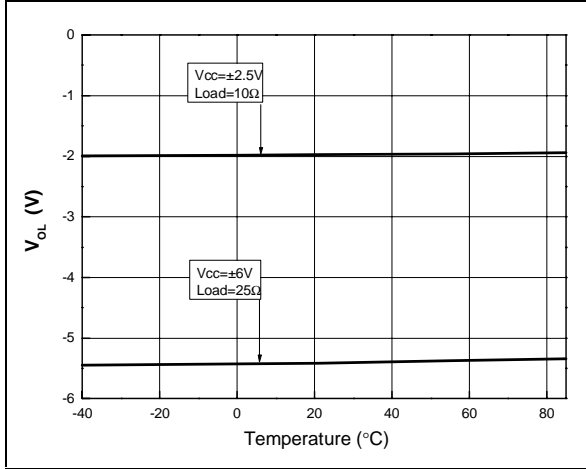
**Figure 29:**  $V_{OH}$  &  $V_{OL}$  vs. Power Supply  
Open loop,  $R_L = 25\Omega$



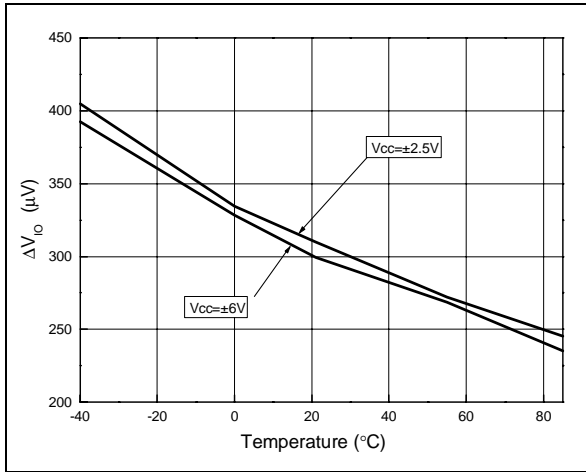
**Figure 30:**  $V_{OH}$  vs. Temperature  
Open loop



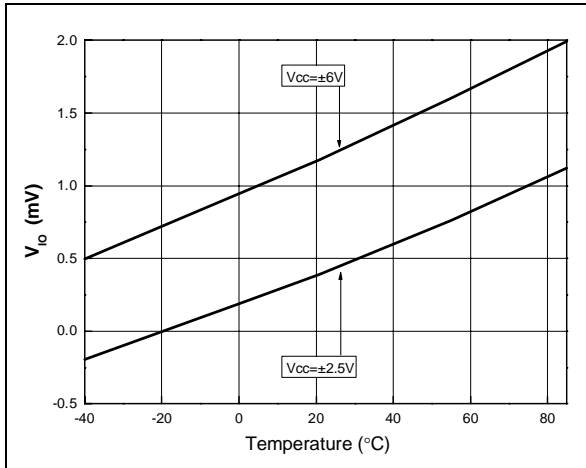
**Figure 31:  $V_{ol}$  vs. Temperature**  
Open loop



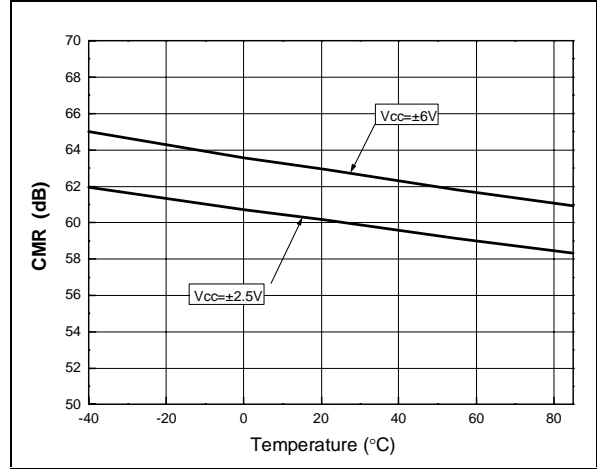
**Figure 32: Differential  $V_{io}$  vs. Temperature**  
Open loop, no load



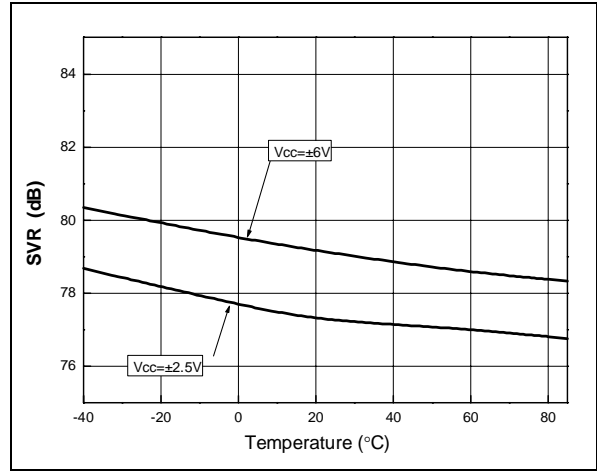
**Figure 33:  $V_{io}$  vs. Temperature**  
Open loop, no load



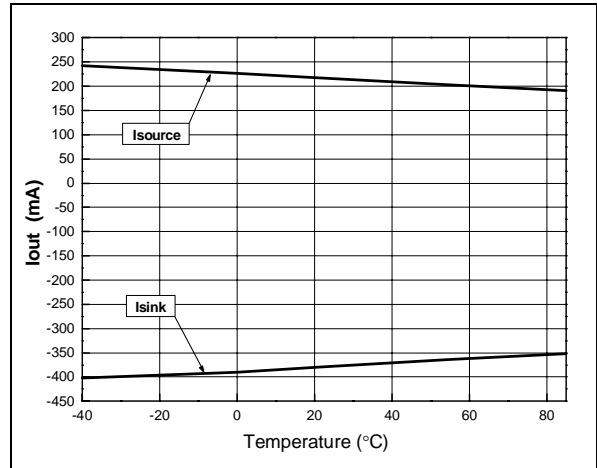
**Figure 34: CMR vs. Temperature**  
Open loop, no load



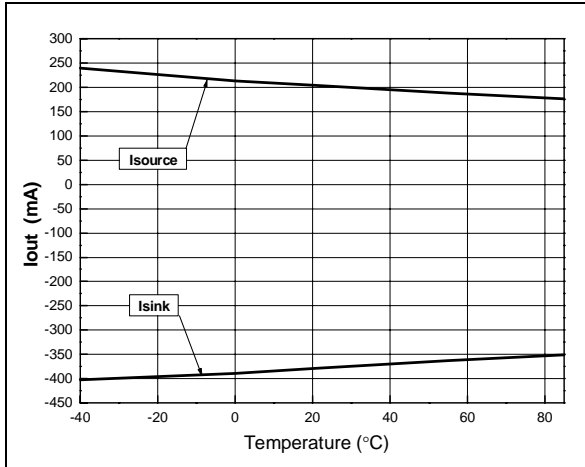
**Figure 35: SVR vs. Temperature**  
Open loop, no load



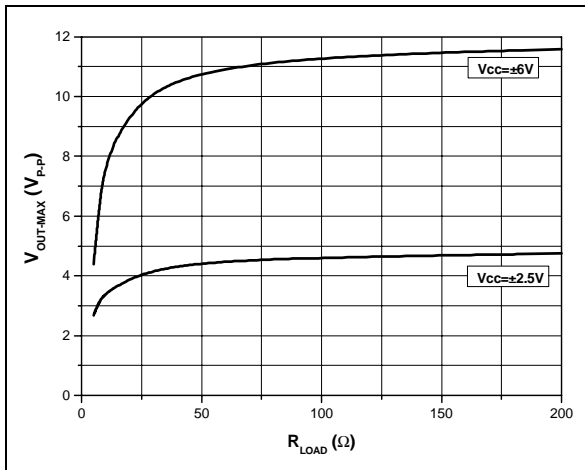
**Figure 36:  $I_{out}$  vs. Temperature**  
Open loop,  $V_{CC}=\pm 6V$ ,  $R_L=10\Omega$



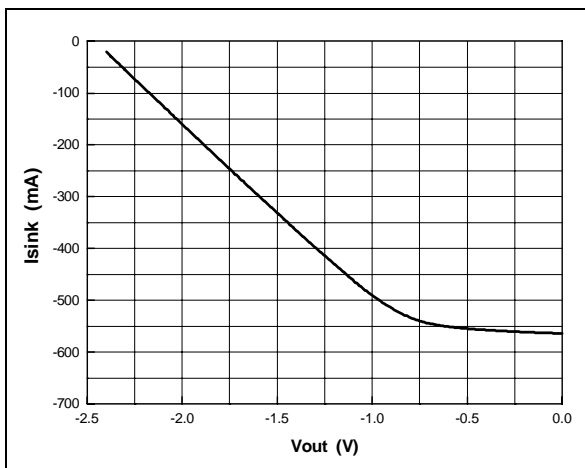
**Figure 37:**  $I_{out}$  vs. Temperature  
Open loop,  $V_{CC}=\pm 2.5V$ ,  $R_L=25\Omega$



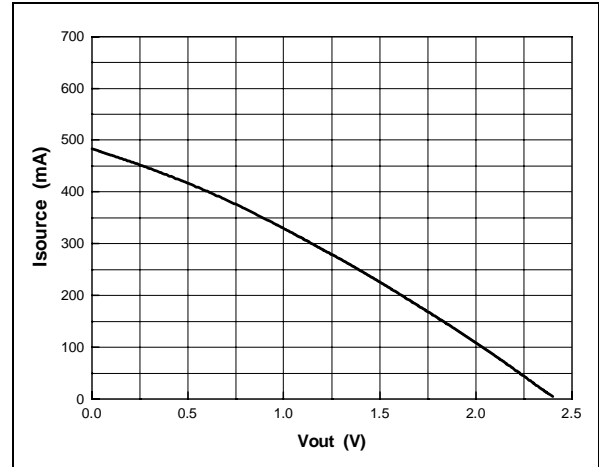
**Figure 38:** Maximum Output Amplitude vs. Load  
 $A_V=+4$ ,  $R_{fb}=620\Omega$ ,  $V_{CC}=\pm 6V$



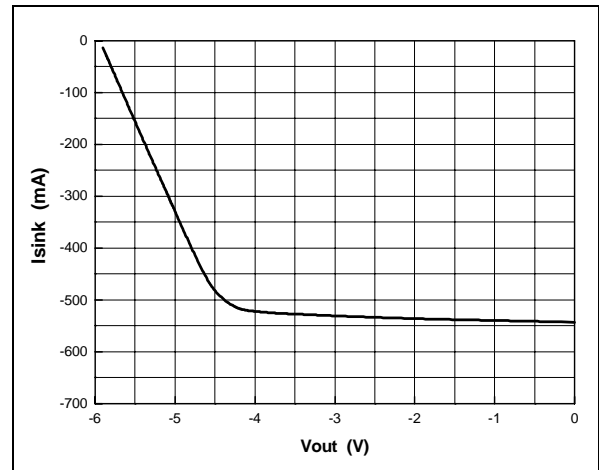
**Figure 39:**  $I_{sink}$  vs. Output Amplitude.  
 $V_{CC}=\pm 2.5V$ , Open Loop, no Load



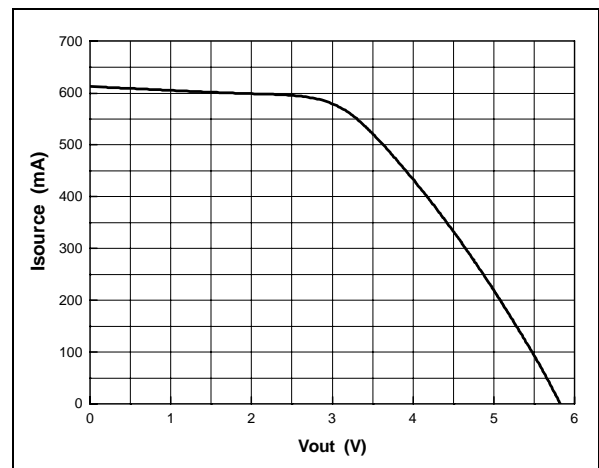
**Figure 40:**  $I_{source}$  vs. Output Amplitude.  
 $V_{CC}=\pm 2.5V$ , Open Loop, no Load



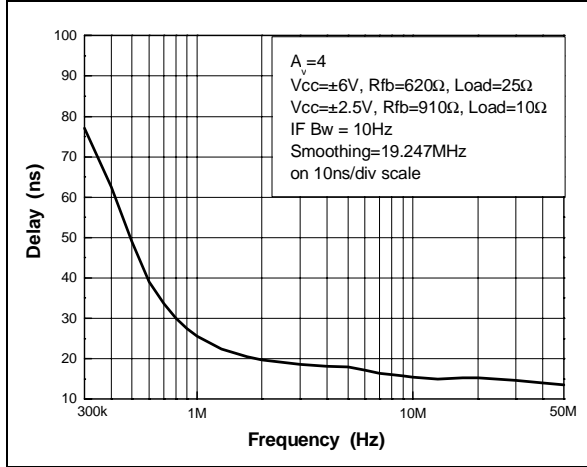
**Figure 41:**  $I_{sink}$  vs. Output Amplitude  
 $V_{CC}=\pm 6V$ , Open Loop, no Load



**Figure 42:**  $I_{source}$  vs. Output Amplitude  
 $V_{CC}=\pm 6V$ , Open Loop, no Load



**Figure 43: Group Delay**  
 $V_{CC}=\pm 6V$ ,  $V_{CC}=\pm 2.5V$



**SAFE OPERATING AREA**

**Figure 44: Safe Operating Area**

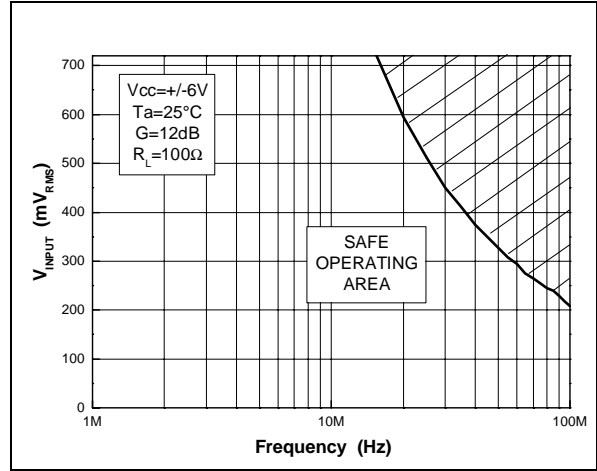


Figure 44 shows the safe operating condition. This curve shows the input level vs. the input frequency. It's necessary to consider this characteristic to guarantee the design. In the dash-lined zone, the consumption increases. Moreover, this increased consumption could do damage to the chip if the temperature increases.

**INTERMODULATION DISTORTION PRODUCT**

Non-ideal output of the amplifier can be described by the following series:

$$V_{out} = C_0 + C_1 V_{in} + C_2 V_{in}^2 + \dots + C_n V_{in}^n$$

due to non-linearity in the input-output amplitude transfer, where the input is  $V_{in} = A \sin \omega t$ ,  $C_0$  is the DC component,  $C_1(V_{in})$  is the fundamental and  $C_n$  is the amplitude of the harmonics of the output signal  $V_{out}$ .

A one-frequency (one-tone) input signal contributes to harmonic distortion. A two-tone input signal contributes to harmonic distortion and intermodulation product.

The study of the intermodulation/distortion for a two-tone input signal is the first step in characterizing the driving capability of multi-tone input signals.

In this case :

$$+ C_2 (A \sin \omega_1 t + B \sin \omega_2 t)^2$$

$$\dots + C_n (A \sin \omega_1 t + B \sin \omega_2 t)^n$$

$$V_{in} = A \sin \omega_1 t + B \sin \omega_2 t$$

$$V_{out} = C_0 + C_1 (A \sin \omega_1 t + B \sin \omega_2 t)$$

and :

$$+ C_1 (A \sin \omega_1 t + B \sin \omega_2 t)$$

$$- \frac{C_2}{2} (A^2 \cos 2\omega_1 t + B^2 \cos 2\omega_2 t)$$

$$+ 2C_2 AB (\cos(\omega_1 - \omega_2)t - \cos(\omega_1 + \omega_2)t)$$

$$+ \left( \frac{C_3}{4} \right)$$

$$+ (C_3 A^3 \sin 3\omega_1 t + B^3 \sin 3\omega_2 t)$$

$$+ \frac{3C_3 A^2 B}{2} \left( \sin(2\omega_1 - \omega_2)t - \frac{1}{2} \sin(2\omega_1 + \omega_2)t \right)$$

$$+ \frac{3C_3 A B^2}{2} \left( \sin(-\omega_1 + 2\omega_2)t - \frac{1}{2} \sin(\omega_1 + 2\omega_2)t \right)$$

$$\dots + C_n (V_{in})^n$$

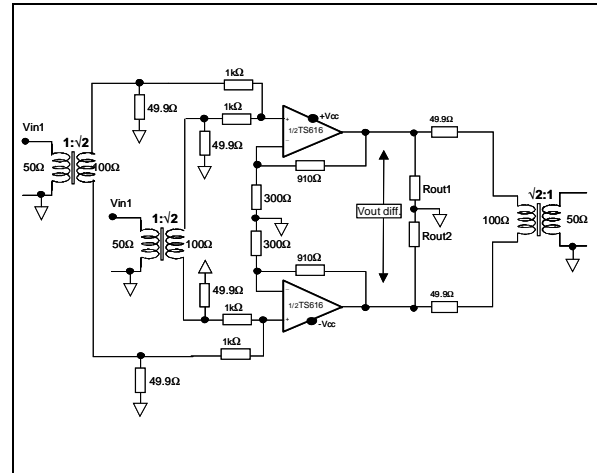
$$V_{out} = C_0 + C_2 \left( \frac{A^2 + B^2}{2} \right)$$

$$\left( A^3 \sin \omega_1 t + B^3 \sin \omega_2 t + 2A^2 B \sin \omega_1 t + 2AB^2 \sin \omega_2 t \right)$$

In this expression, we recognize the second order intermodulation IM2 by the frequencies  $(\omega_1 - \omega_2)$  and  $(\omega_1 + \omega_2)$  and the third order intermodulation IM3 by the frequencies  $(2\omega_1 - \omega_2)$ ,  $(2\omega_1 + \omega_2)$ ,  $(-\omega_1 + 2\omega_2)$  and  $(\omega_1 + 2\omega_2)$ .

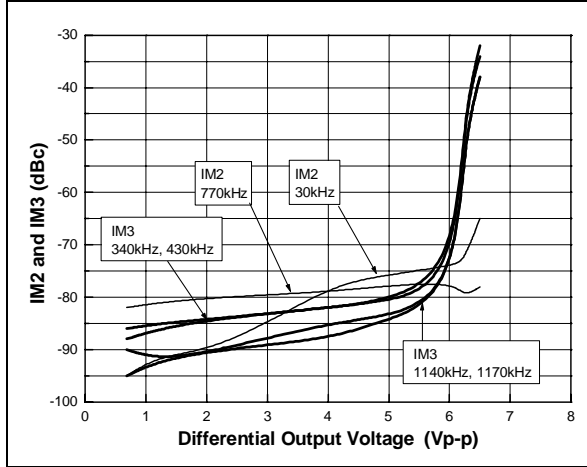
The measurement of the intermodulation product of the driver is achieved by using the driver as a mixer by a summing amplifier configuration. In this way, the non-linearity problem of an external mixing device is avoided.

**Figure 45:** Non-inverting Summing Amplifier for Intermodulation measurements

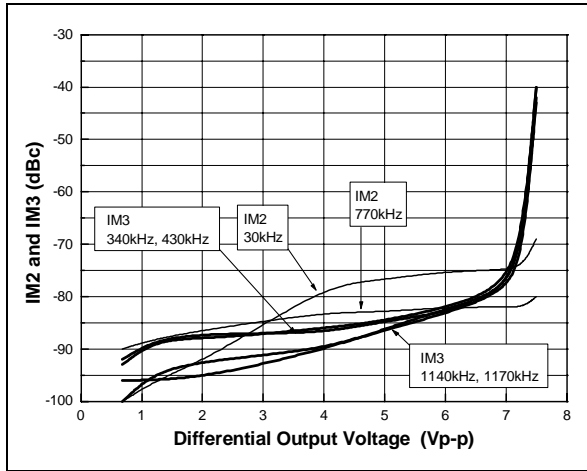


The following graphs show the IM2 and the IM3 of the amplifier in different configurations. The two-tone input signal was generated by the multi-source generator Marconi 2026. Each tone has the same amplitude. The measurement was performed using a HP3585A spectrum analyzer.

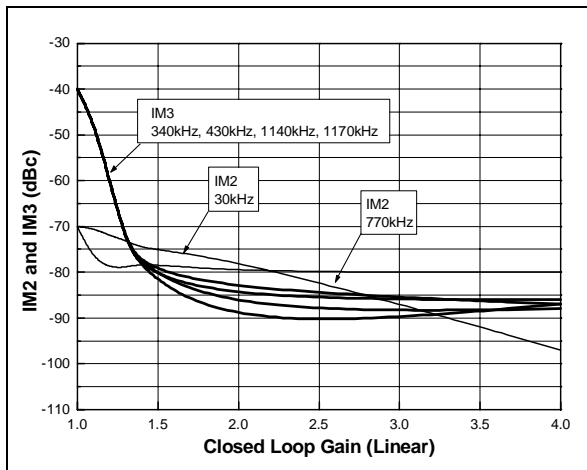
**Figure 46: Intermodulation vs. Output Amplitude**  
 370kHz & 400kHz,  $A_v=+1.5$ ,  $R_{fb}=1k\Omega$ ,  $R_L=14\Omega$  diff.,  $V_{CC}=\pm 2.5V$



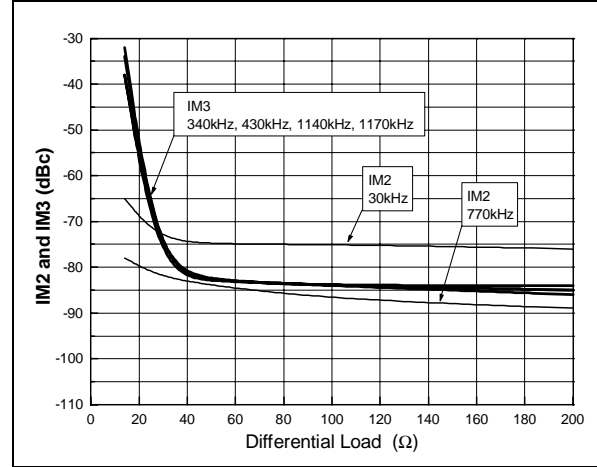
**Figure 47: Intermodulation vs. Output Amplitude**  
 370kHz & 400kHz,  $A_v=+1.5$ ,  $R_{fb}=1k\Omega$ ,  $R_L=28\Omega$  diff.,  $V_{CC}=\pm 2.5V$



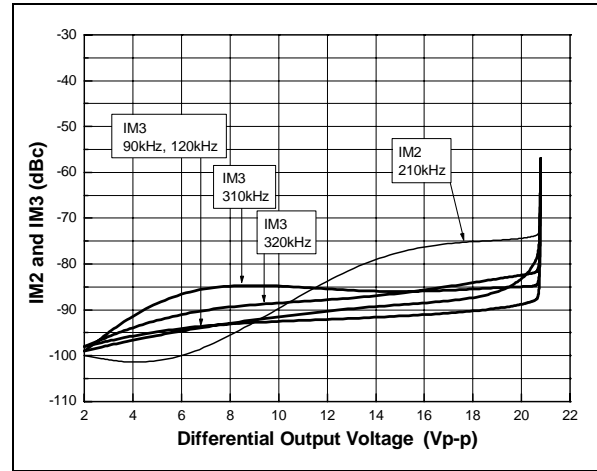
**Figure 48: Intermodulation vs. Gain**  
 370kHz & 400kHz,  $R_L=20\Omega$  diff.,  $V_{out}=6V_{pp}$ ,  $V_{CC}=\pm 2.5V$



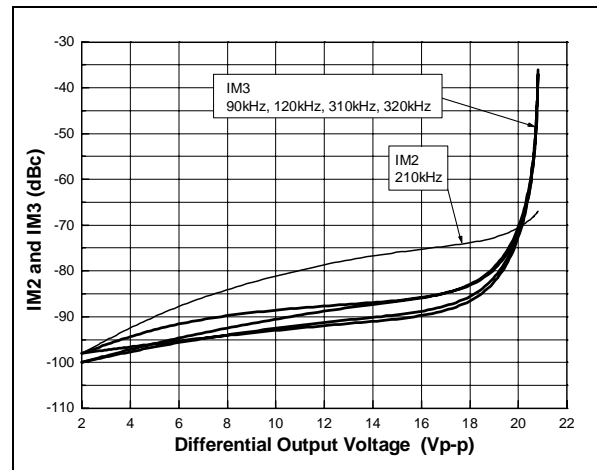
**Figure 49: Intermodulation vs. Load**  
 370kHz & 400kHz,  $A_v=+1.5$ ,  $R_{fb}=1k\Omega$ ,  $V_{out}=6.5V_{pp}$ ,  $V_{CC}=\pm 2.5V$



**Figure 50: Intermodulation vs. Output Amplitude**  
 100kHz & 110kHz,  $A_v=+4$ ,  $R_{fb}=620\Omega$ ,  $R_L=200\Omega$  diff.,  $V_{CC}=\pm 6V$



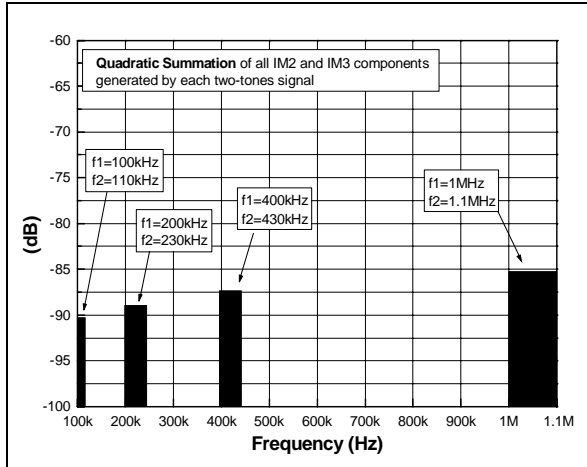
**Figure 51: Intermodulation vs. Output Amplitude**  
 100kHz & 110kHz,  $A_v=+4$ ,  $R_{fb}=620\Omega$ ,  $R_L=50\Omega$  diff.,  $V_{CC}=\pm 6V$





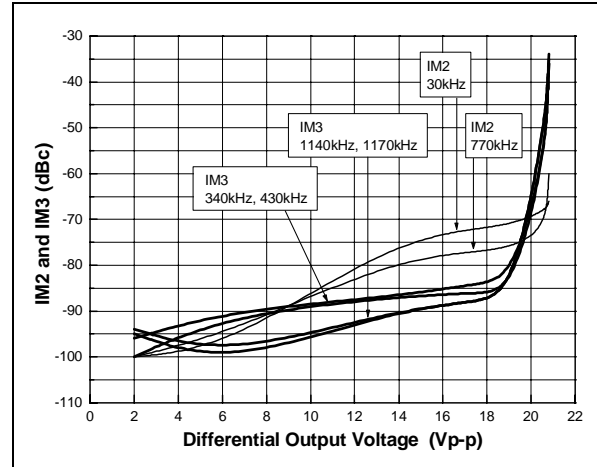
**Figure 52: Intermodulation vs. Frequency Range**

$A_V=+4$ ,  $R_{fb}=620\Omega$ ,  $R_L=50\Omega$  diff.,  $V_{out}=16V_{pp}$ ,  $V_{CC}=\pm 6V$



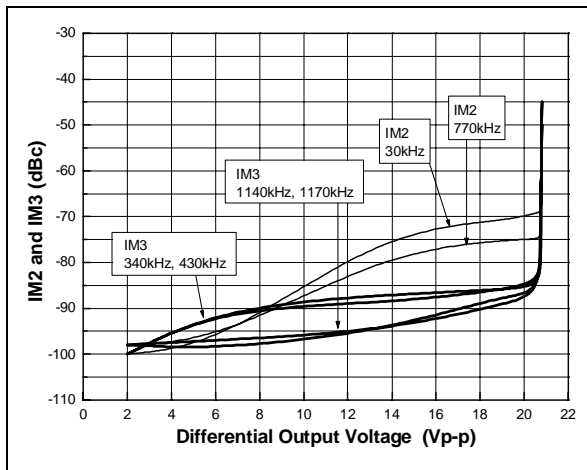
**Figure 54: Intermodulation vs. Output Amplitude**

370kHz & 400kHz,  $A_V=+4$ ,  $R_{fb}=620\Omega$ ,  $R_L=50\Omega$  diff.,  $V_{CC}=\pm 6V$



**Figure 53: Intermodulation vs. Output Amplitude**

370kHz & 400kHz,  $A_V=+4$ ,  $R_{fb}=620\Omega$ ,  $R_L=200\Omega$  diff.,  $V_{CC}=\pm 6V$



**PRINTED CIRCUIT BOARD LAYOUT CONSIDERATIONS**

In the ADSL frequency range, printed circuit board parasites can affect the closed-loop performance.

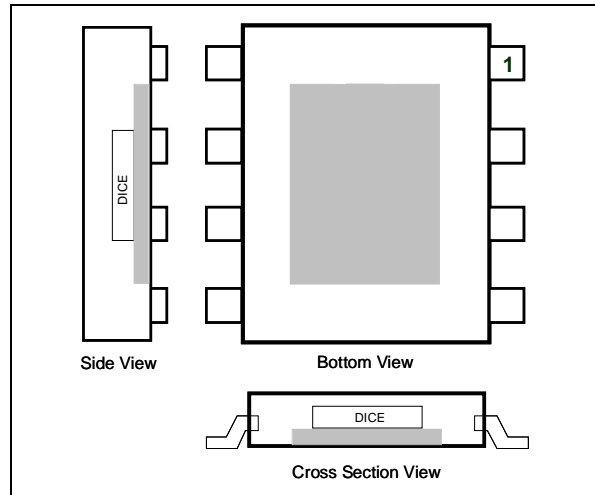
The implementation of a proper ground plane on both sides of the PCB is mandatory to provide low inductance and low resistance common return. The most important factors affecting gain flatness and bandwidth are stray capacitances at the output and inverting input. To minimize these capacitances, the space between signal lines and ground plane should be increased. Feedback components connections must be as short as possible in order to decrease the associated inductance which affects high frequency gain errors. It is very important to choose the smallest possible external components, for example, surface mounted devices (SMD) in order to minimize the size of all DC and AC connections.

**THERMAL INFORMATION**

The TS616 is housed in an Exposed-Pad plastic package. As depicted in figure 55, this package uses a lead frame upon which the die is mounted. This lead frame is exposed as a thermal pad on the underside of the package. The thermal contact is direct with the dice. This thermal path provides excellent colling.

The thermal pad is electrically isolated from all pins in the package. It should be soldered to a copper area of the PCB underneath the package. Through these thermal paths within this copper area, heat can be conducted away from the package. In this case, the copper area should be connected to (-V<sub>CC</sub>).

**Figure 55: Exposed-Pad Package**



**Figure 56: Evaluation Board**

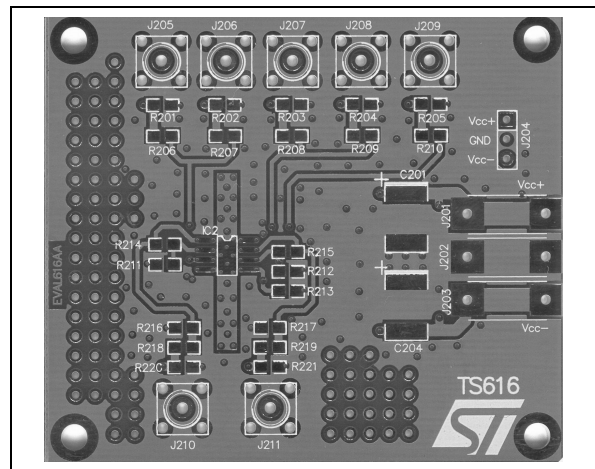


Figure 57: Schematic Diagram

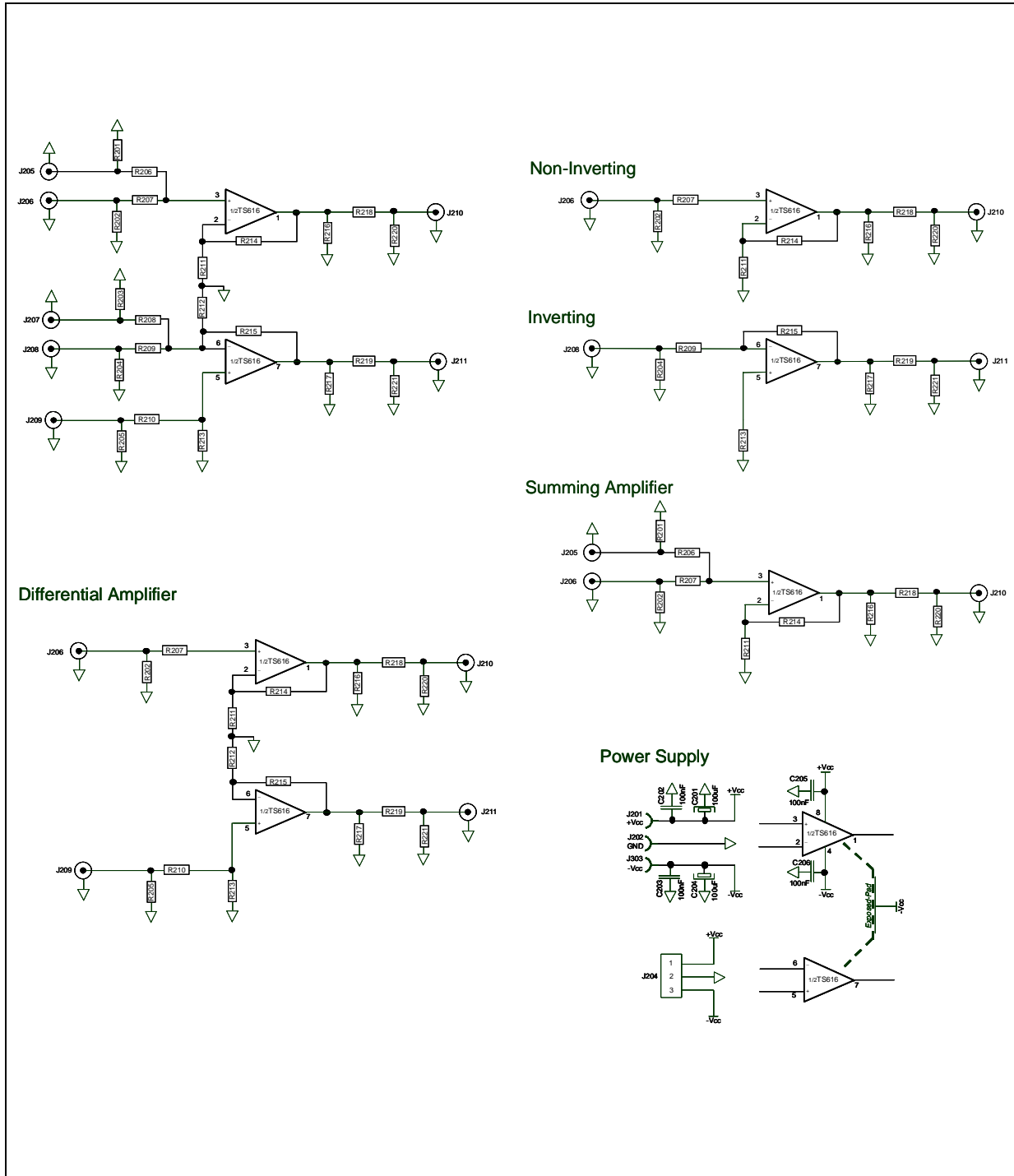


Figure 58: Component Locations - Top Side

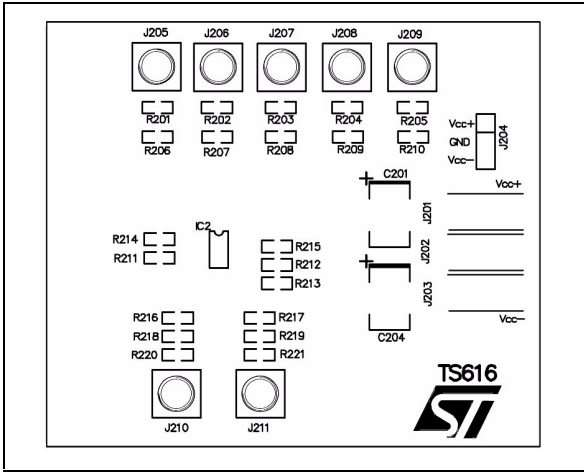


Figure 60: Top Side Board Layout

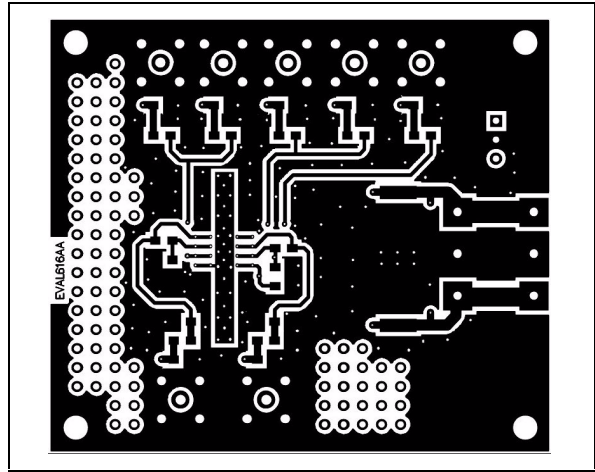


Figure 59: Component Locations - Bottom Side

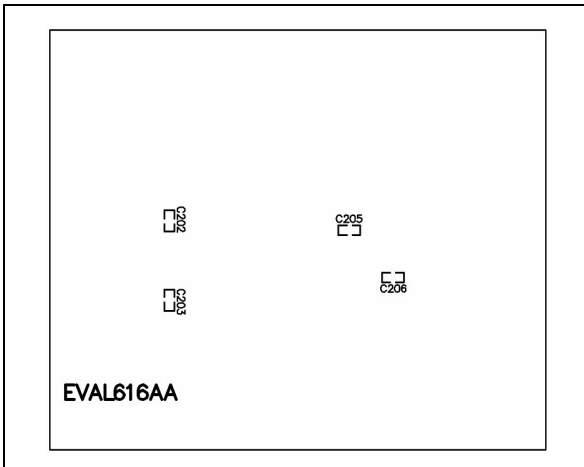
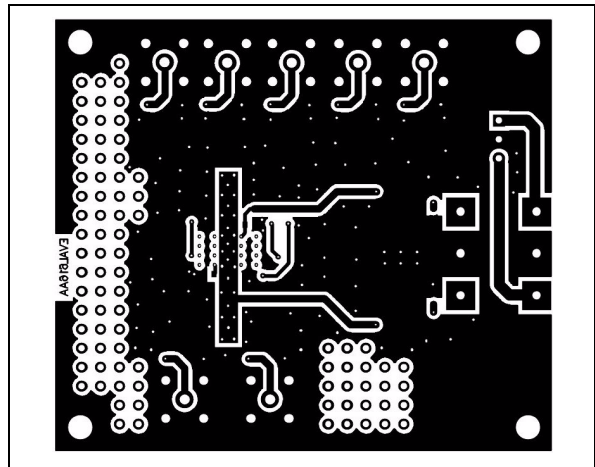
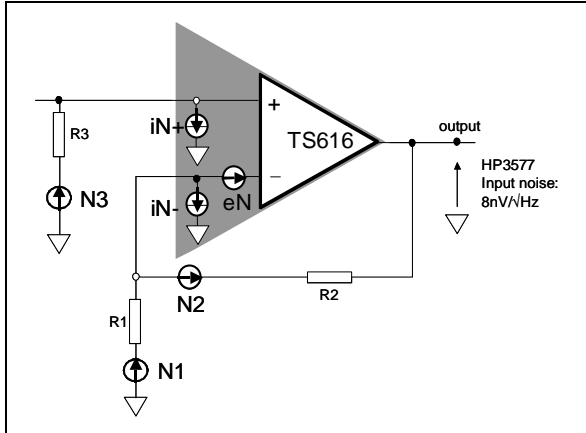


Figure 61: Bottom Side Board Layout



**NOISE MEASUREMENT**

**Figure 62:** Noise Model



eN : input voltage noise of the amplifier  
 iNn : negative input current noise of the amplifier  
 iNp : positive input current noise of the amplifier  
 The closed loop gain is :

$$A_V = g = 1 + \frac{R_{fb}}{R_g}$$

The six noise sources are :

$$V1 = eN \times \left(1 + \frac{R2}{R1}\right)$$

$$V2 = iNn \times R2$$

$$V3 = iNp \times R3 \times \left(1 + \frac{R2}{R1}\right)$$

$$V4 = \frac{R2}{R1} \times \sqrt{4kTR1}$$

$$V5 = \sqrt{4kTR2}$$

$$V6 = \left(1 + \frac{R2}{R1}\right) \sqrt{4kTR3}$$

We assume that the thermal noise of a resistance R is:

$$\sqrt{4kTR\Delta F}$$

wher ΔF is the specified bandwidth.

On 1Hz bandwidth the thermal noise is reduced to

$$\sqrt{4kTR}$$

k is the Boltzmann's constant, equal to 1,374.10<sup>-23</sup>J/°K. T is the temperature (°K).

The output noise eNo is calculated using the Superposition Theorem. However it is not the simple sum of all noise sources. The square root of the sum of the square of each noise source.

$$eNo = \sqrt{V1^2 + V2^2 + V3^2 + V4^2 + V5^2 + V6^2}, (eq1)$$

$$eNo^2 = eN^2 \times g^2 + iNn^2 \times R2^2 + iNp^2 \times R3^2 \times g^2 + \left(\frac{R2}{R1}\right)^2 \times 4kTR1 + 4kTR2 + \left(1 + \frac{R2}{R1}\right)^2 \times 4kTR3, (eq2)$$

The input noise of the instrumentation must be extracted from the measured noise value. The real output noise value of the driver is:

$$eNo = \sqrt{(\text{Measured})^2 - (\text{instrumentation})^2}, (eq3)$$

The input noise is called the Equivalent Input Noise as it is not directly measured but it is evaluated from the measurement of the output divided by the closed loop gain (eNo/g).

After simplification of the fourth and the fifth term of (eq2) we obtain:

$$eNo^2 = eN^2 \times g^2 + iNn^2 \times R2^2 + iNp^2 \times R3^2 \times g^2 + g \times 4kTR2 + \left(1 + \frac{R2}{R1}\right)^2 \times 4kTR3, (eq4)$$

**Measurement of eN:**

We assume a short-circuit on the non-inverting input (R3=0). (eq4) comes:

$$eNo = \sqrt{eN^2 \times g^2 + iNn^2 \times R2^2 + g \times 4kTR2}, (eq5)$$

In order to easily extract the value of eN, the resistance R2 will be chosen as low as possible. In the other hand, the gain must be large enough.

R1=10Ω, R2=910Ω, R3=0, Gain=92

Equivalent Input Noise: 2.57nV/√Hz

**Input Voltage Noise: eN=2.5nV/√Hz**

**Measurement of iNn:**

R3=0 and the output noise equation is still the (eq5). This time the gain must be decreased to decrease the thermal noise contribution.

R1=100Ω, R2=910Ω, R3=0, Gain=10.1

Equivalent Input Noise: 3.40nV/√Hz

**Negative Input Current Noise: iNn =21pA/√Hz**

**Measurement of iNp:**

To extract iNp from (eq3), a resistance R3 is connected to the non-inverting input. The value of R3 must be chosen in order to keep its thermal noise

## TS616

contribution as low as possible against the  $i_{Np}$  contribution.

$R1=100\Omega$ ,  $R2=910\Omega$ ,  $R3=100\Omega$ , Gain=10.1

Equivalent Input Noise:  $3.93nV/\sqrt{Hz}$

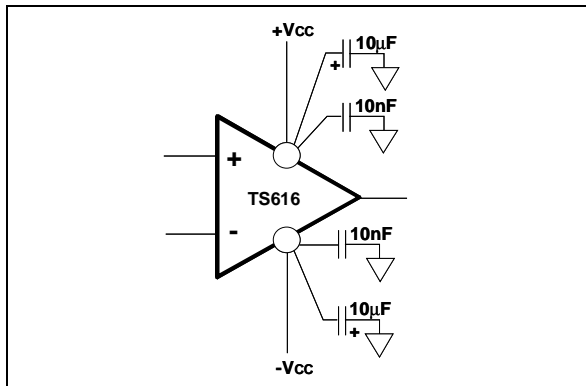
**Positive Input Current Noise:  $i_{Np}=15pA/\sqrt{Hz}$**

Conditions: frequency=100kHz,  $V_{CC}=\pm 2.5V$   
Instrumentation: Spectrum Analyzer HP3585A  
(input noise of the HP3585A:  $8nV/\sqrt{Hz}$ )

### POWER SUPPLY BYPASSING

Correct power supply bypassing is very important for optimizing the performance in high frequency ranges. Bypass capacitors should be placed as close as possible to the IC pins to improve high frequency bypassing. A capacitor greater than  $1\mu F$  is necessary to minimize the distortion. For a better quality bypassing a capacitor of  $10nF$  can be added using the same implementation conditions. Bypass capacitors must be incorporated for both the negative and the positive supply.

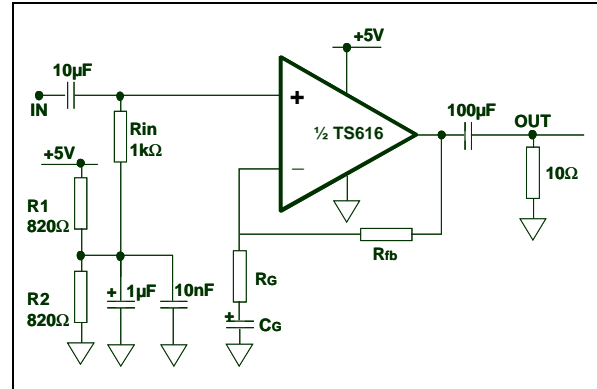
**Figure 63:** Circuit for Power Supply Bypassing



### SINGLE POWER SUPPLY

The following figure shows the case of a 5V single power supply configuration

**Figure 64:** Circuit for +5V single supply



The TS616 operates with power supplies from 12V down to 5V. This can be achieved by either a dual power supplies of  $\pm 6V$  or  $\pm 2.5V$  or a single power supply of 12V or 5V referenced to the ground. In the case of asymmetrical supply, a new biasing is necessary to assume a positive output dynamic range between 0V and  $+V_{CC}$  supply rails. Considering the values of  $V_{OH}$  and  $V_{OL}$ , the amplifier will provide an output dynamic from +0.5V to 10.6V on  $25\Omega$  load for a 12V supply and from 0.45V to 3.8V on  $10\Omega$  load for a 5V supply.

The amplifier must be biased with a mid-supply (nominally  $+V_{CC}/2$ ), in order to maintain the DC component of the signal at this value. Several options are possible to provide this bias supply, such as a virtual ground using an operational amplifier or a two-resistance divider (which is the cheapest solution). A high resistance value is required to limit the current consumption. On the other hand, the current must be high enough to bias the non-inverting input of the amplifier. If we consider

this bias current (30µA max.) as the 1% of the current through the resistance divider to keep a stable mid-supply, two resistances of 2.2kΩ can be used in the case of a 12V power supply and two resistances of 820Ω can be used in the case of a 5V power supply.

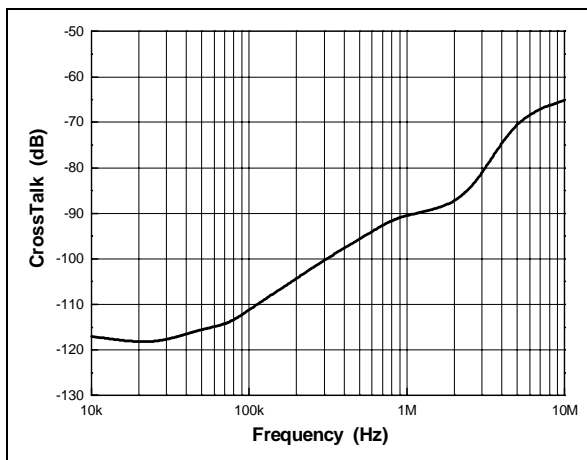
The input provides a high pass filter with a break frequency below 10Hz which is necessary to remove the original 0 volt DC component of the input signal, and to fix it at  $+V_{CC}/2$ .

**CHANNEL SEPARATION - CROSSTALK**

The following figure shows the crosstalk from an amplifier to a second amplifier. This phenomenon, accentuated at high frequencies, is unavoidable and intrinsic to the circuit.

Nevertheless, the PCB layout also has an effect on the crosstalk level. Capacitive coupling between signal wires, distance between critical signal nodes and power supply bypassing are the most significant factors.

**Figure 65:** Crosstalk vs. Frequency  
 $A_V=+4$ ,  $R_{fb}=620\Omega$ ,  $V_{CC}=\pm 6V$ ,  $V_{out}=2Vp$



**CHOICE OF THE FEEDBACK CIRCUIT**

**Table 1:** Closed-Loop Gain - Feedback Components

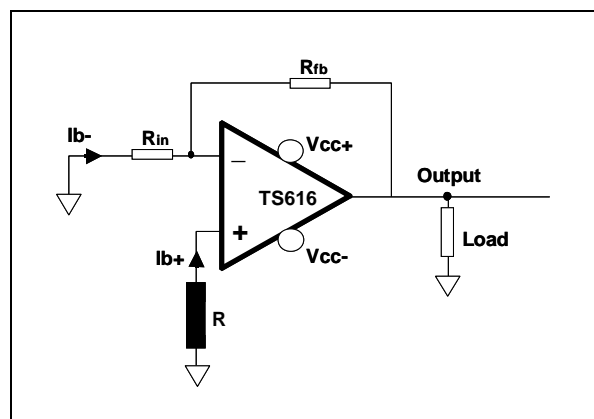
$V_{CC}$ (V)	Gain	$R_{fb}$ ( $\Omega$ )
$\pm 6$	+1	750
	+2	680
	+4	620
	+8	510
	-1	680
	-2	680
	-4	620
	-8	510
$\pm 2.5$	+1	1.1k
	+2	1k
	+4	910
	+8	680
	-1	1k
	-2	1k
	-4	910
	-8	680

**INVERTING AMPLIFIER BIASING**

In this case a resistance R is necessary to achieve good input biasing, see Figure 66.

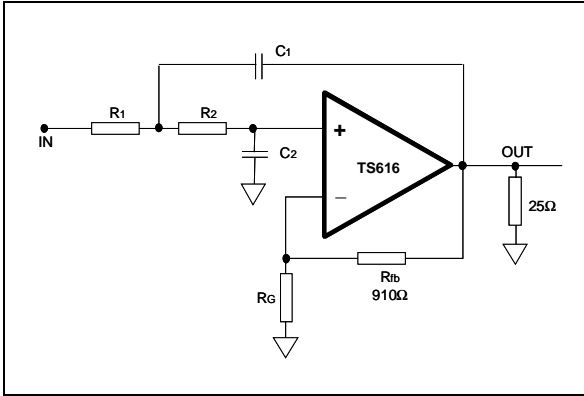
This resistance is calculated by assuming the negative and positive input bias current. The aim is to compensate for the offset bias current which could affect the input offset voltage and the output DC component. Assuming  $I_{b-}$ ,  $I_{b+}$ ,  $R_{in}$ ,  $R_{fb}$  and a zero volt output, the resistance R comes:  $R = R_{in} // R_{fb}$ .

**Figure 66:** Compensation of the Input Bias Current



ACTIVE FILTERING

Figure 67: Low-Pass Active Filtering. Sallen-Key



The resistors Rfb and Rg give the gain of the filter as a classical non-inverting amplification configuration :

$$A_V = g = 1 + \frac{R_{fb}}{R_g}$$

Assume the following expression is the response of the system:

$$T_{j\omega} = \frac{V_{out,j\omega}}{V_{in,j\omega}} = \frac{g}{1 + 2\zeta \frac{j\omega}{\omega_c} + \frac{(j\omega)^2}{\omega_c^2}}$$

the cut-off frequency is not gain-dependent and it becomes:

$$\omega_c = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

The damping factor becomes:

$$\zeta = \frac{1}{2} \omega_c (C_1 R_1 + C_1 R_2 + C_2 R_1 - C_1 R_1 g)$$

The higher the gain, the more sensitive the damping factor is. When the gain is higher than 1 it is

preferable to use very stable resistors and capacitances values.

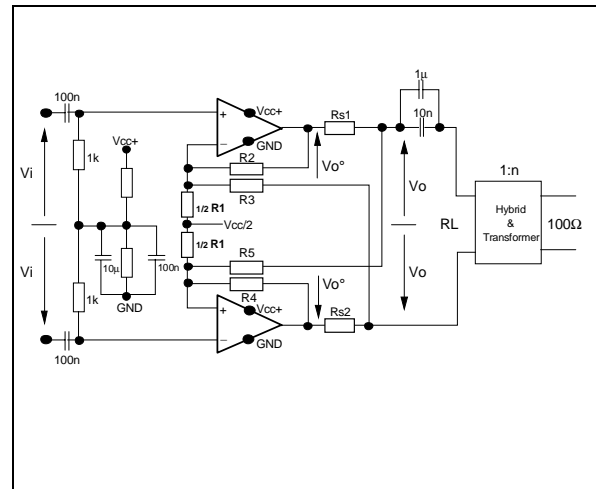
In the case of R1=R2:

$$\zeta = \frac{2C_2 - C_1 \frac{R_{fb}}{R_g}}{2\sqrt{C_1 C_2}}$$

INCREASING THE LINE LEVEL BY USING AN ACTIVE IMPEDANCE MATCHING

With passive matching, the output signal amplitude of the driver must be twice the amplitude on the load. To go beyond this limitation, active matching impedance can be used. With this technique, it is possible to keep good impedance matching with an amplitude on the load higher than half of the output driver amplitude. This concept is shown in Figure 68 for a differential line.

Figure 68: TS616 as a differential line driver with an active impedance matching

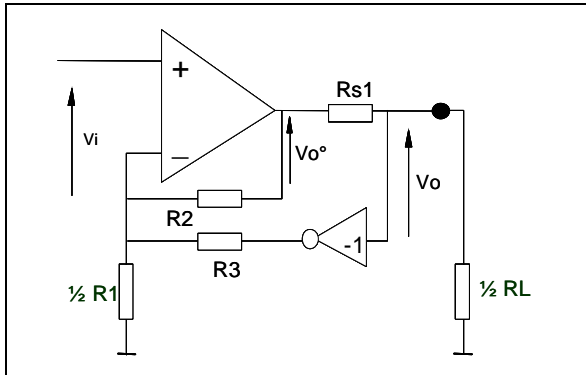




**Component Calculation**

Let us consider the equivalent circuit for a single-ended configuration as shown in Figure 69.

**Figure 69:** Single ended equivalent circuit



Let us consider the unloaded system. Assuming the currents through R1, R2 and R3 are respectively:

$$\frac{2Vi}{R1}, \frac{(Vi - Vo^\circ)}{R2} \text{ and } \frac{(Vi + Vo)}{R3}$$

as  $Vo^\circ$  equals  $Vo$  without load, the gain in this case becomes :

$$G = \frac{Vo(\text{no load})}{Vi} = \frac{1 + \frac{2R2}{R1} + \frac{R2}{R3}}{1 - \frac{R2}{R3}}$$

The gain, for the loaded system will be (eq1):

$$GL = \frac{Vo(\text{with load})}{Vi} = \frac{1}{2} \frac{1 + \frac{2R2}{R1} + \frac{R2}{R3}}{1 - \frac{R2}{R3}}, \text{(eq1)}$$

As shown in Figure70, this system is an ideal generator with a synthesized impedance as the internal impedance of the system. From this, the output voltage becomes:

$$Vo = (ViG) - (RoI_{out}), \text{(eq2)}$$

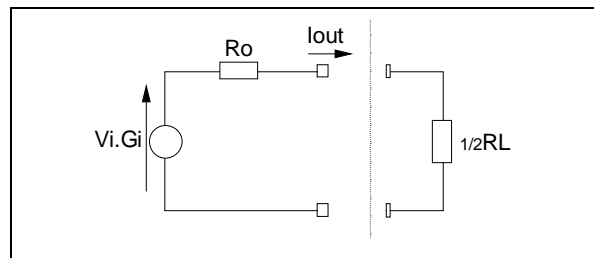
with  $Ro$  the synthesized impedance and  $I_{out}$  the output current. On the other hand  $Vo$  can be expressed as:

$$Vo = \frac{Vi \left( 1 + \frac{2R2}{R1} + \frac{R2}{R3} \right)}{1 - \frac{R2}{R3}} - \frac{Rs1 I_{out}}{1 - \frac{R2}{R3}}, \text{(eq3)}$$

By identification of both equations (eq2) and (eq3), the synthesized impedance is, with  $Rs1=Rs2=Rs$ :

$$Ro = \frac{Rs}{1 - \frac{R2}{R3}}, \text{(eq4)}$$

**Figure 70:** Equivalent schematic.  $Ro$  is the synthesized impedance.



Unlike the level  $Vo^\circ$  required for a passive impedance,  $Vo^\circ$  will be smaller than  $2Vo$  in our case. Let us write  $Vo^\circ = kVo$  with  $k$  the matching factor varying between 1 and 2. Assuming that the current through R3 is negligible, (eq4) becomes the following :

$$Ro = \frac{kVoRL}{RL + 2Rs1}$$

After choosing the  $k$  factor,  $Rs$  will equal to  $1/2RL(k-1)$ .

A good impedance matching assumes:

$$Ro = \frac{1}{2}RL, \text{(eq5)}$$

(eq4) and (eq5) give :

$$\frac{R2}{R3} = 1 - \frac{2Rs}{RL}, \text{(eq6)}$$

By fixing an arbitrary value of R2, (eq6) becomes :

$$R3 = \frac{R2}{1 - \frac{2Rs}{RL}}$$

Finally, the values of R2 and R3 allow us to extract R1 from (eq1), and it becomes:

$$R1 = \frac{2R2}{2\left(1 - \frac{R2}{R3}\right)GL - 1 - \frac{R2}{R3}}, \text{(eq7)}$$

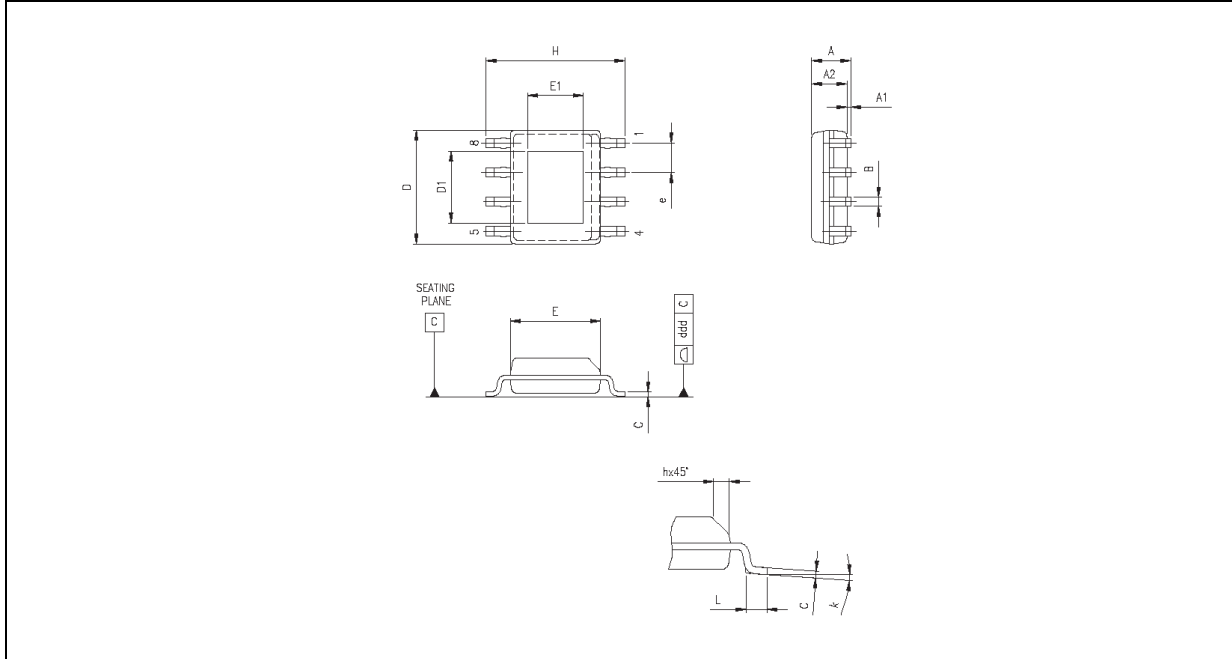
with GL the required gain.

**Table 2** : Components Calculation for Impedance Matching Implementation

GL (gain for the loaded system)	GL is fixed for the application requirements GL=Vo/Vi=0.5(1+2R2/R1+R2/R3)/(1-R2/R3)
R1	$2R2/[2(1-R2/R3)GL-1-R2/R3]$
R2 (=R4)	Arbitrary fixed
R3 (=R5)	$R2/(1-Rs/0.5RL)$
Rs	$0.5RL(k-1)$
Load viewed by each driver	$kRL/2$

**PACKAGE MECHANICAL DATA**

**8 PINS - PLASTIC MICROPACKAGE (SO Exposed-Pad)**



Dim.	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A	1.350		1.750	0.053		0.069
A1	0.000		0.250	0.001		0.010
A2	1.100		1.650	0.043		0.065
B	0.330		0.510	0.013		0.020
C	0.190		0.250	0.007		0.010
D	4.800		5.000	0.189		0.197
D1		3.10			0.122	
E	3.800		4.000	0.150		0.157
E1		2.41			0.095	
e	1.270			0.050		
H	5.800		6.200	0.228		0.244
h	0.250		0.500	0.010		0.020
L	0.400		1.270	0.016		0.050
k	0d		8d	0d		8d
ddd			0.100			0.004

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