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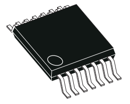
TS615

Dual Wide-Band Operational Amplifier with High Output Current

- **Low noise: 2.5 nV/√Hz**
- **High output current: 420 mA**
- **Very low harmonic and intermodulation distortion**
- **High slew rate: 410 V/µs**
- **-3 dB bandwidth: 40 MHz @ gain = 12 dB on 25 Ω single-ended load**
- **21.2 Vp-p differential output swing on 50 Ω load, 12 V power supply**
- **Current feedback structure**
- **5 V to 12 V power supply**
- **Specified for 20 Ω and 50 Ω differential load**
- **Power down function with short-circuited output to keep matching with the line in sleep mode**

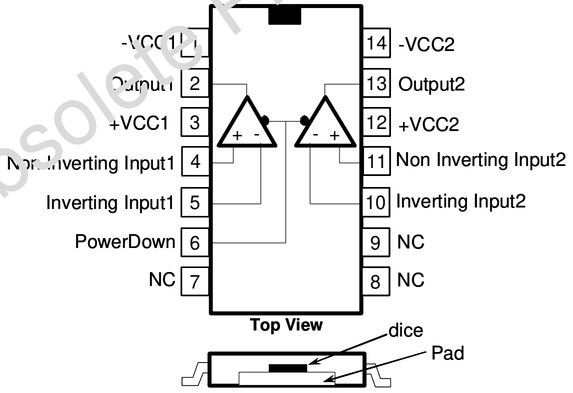


P
TSSOP14 Exposed-Pad
(Plastic Micropackage)

Description

The TS615 is a dual operational amplifier featuring a high output current of 410 mA. This driver can be configured differentially for driving signals in telecommunication systems using multiple carriers. The TS615 is ideally suited for xDSL (High Speed Asymmetrical Digital Subscriber Line) applications. This circuit is capable of driving a 10 Ω or 25 Ω load on a range of power supplies: ±2.5 V, 5 V, ±6 V or +12 V. The TS615 is capable of reaching a -3 dB bandwidth of 40 MHz on a 25 Ω load with a 12 dB gain. This device is designed for high slew rates and demonstrates low harmonic distortion and intermodulation. The TS615 offers a power-down function in order to decrease power consumption. During sleep mode, the device short circuits its output in order to keep the impedance matched to the line. The TS615 is housed in TSSOP14 exposed-pad plastic package for a very low thermal resistance.

Pin Connections (top view)



Cross Section View Showing Exposed-Pad.
This pad must be connected to a (-Vcc) copper area on the PCB.

Applications

- **Line driver for xDSL**
- **Multiple video line driver**

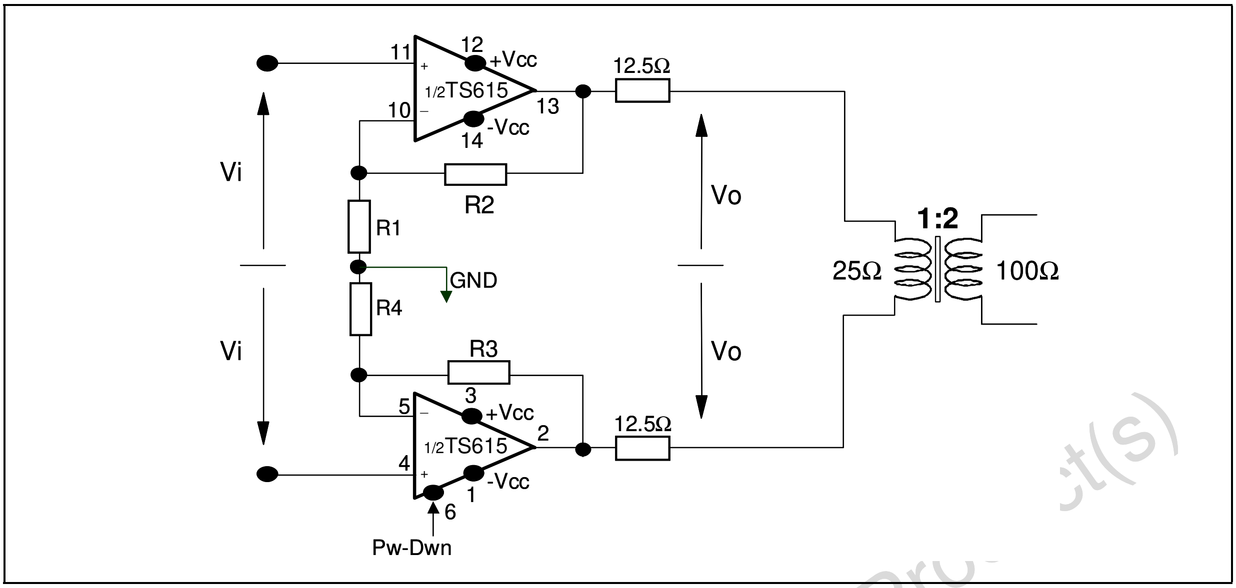
Order Codes

Part Number	Temperature Range	Package	Packaging	Marking
TS615IPWT	-40, +85°C	TSSOP (Thin Shrink Outline Package)	Tape & Reel	TS615

1 Typical Application

Figure 1 shows a schematic of a typical xDSL application using the TS615.

Figure 1. Differential line driver for xDSL applications



2 Absolute Maximum Ratings

Table 1. Key parameters and their absolute maximum ratings

Symbol	Parameter	Value	Unit
VCC	Supply voltage [1]	±7	V
Vid	Differential Input Voltage [2]	±2	V
V_{in}	Input Voltage Range [3]	±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	4	°C/W
R_{thja}	Thermal Resistance Junction to Ambient Area	40	°C/W
$P_{max.}$	Maximum Power Dissipation (@25°C)	3.1	W
ESD except pins 4, 5, 10, 11	CDM: Charged Device Model HBM: Human Body Model MM: Machine Model	1.5 2 200	kV kV V
ESD only pins 4, 5, 10, 11	CDM: Charged Device Model HBM: Human Body Model MM: Machine Model	1 1 100	kV kV 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.

Table 2. Operating conditions

Symbol	Parameter	Value	Unit
VCC	Power Supply Voltage	±2.5 to ±6	V
Vicm	Common Mode Input Voltage	-VCC+1.5V to +VCC-1.5V	V

3 Electrical Characteristics

Table 3. V_{CC} = ±6V, R_{fb}=910Ω,T_{amb} = 25°C (unless otherwise specified)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
DC performance						
V_{io}	Input Offset Voltage	T_{amb}		1.25	3.5	mV
		$T_{min.} < T_{amb} < T_{max.}$		2.1		
ΔV_{io}	Differential Input Offset Voltage	T_{amb} = 25°C			2.5	mV
I_{ib+}	Positive Input Bias Current	T_{amb}		6	30	µA
		$T_{min.} < T_{amb} < T_{max.}$		7.8		
I_{ib-}	Negative Input Bias Current	T_{amb}		3	15	µA
		$T_{min.} < T_{amb} < T_{max.}$		3.2		
Z_{IN+}	Input(+) Impedance			82		kΩ
Z_{IN-}	Input(-) Impedance			54		Ω
C_{IN+}	Input(+) Capacitance			1		pF
CMR	Common Mode Rejection Ratio 20 log ($\Delta V_{ic}/\Delta V_{io}$)	ΔV_{ic} = ±4.5V	58	63		dB
		$T_{min.} < T_{amb} < T_{max.}$		61		
SVR	Supply Voltage Rejection Ratio 20 log ($\Delta V_{cc}/\Delta V_{io}$)	ΔV_{cc}=±2.5V to ±6V	72	79		dB
		$T_{min.} < T_{amb} < T_{max.}$		78		
I_{CC}	Total Supply Current per Operator	No load		14	17	mA
Dynamic performance and output characteristics						
R_{OL}	Open Loop Transimpedance	V_{out} = 7Vp-p, R_L = 25Ω	5	21		MΩ
		$T_{min.} < T_{amb.} < T_{max.}$		8.9		
BW	-3dB Bandwidth	Small Signal V_{out}<20mVp A_V = 12dB, R_L = 25Ω	25	40		MHz
	Full Power Bandwidth	Large Signal V_{out}=3Vp A_V = 12dB, R_L = 25Ω		26		
	Gain Flatness @ 0.1dB	Small Signal V_{out}<20mVp A_V = 12dB, R_L = 25Ω		7		MHz
Tr	Rise Time	V_{out} = 6Vp-p, A_V = 12dB, R_L = 25Ω		10.6		ns
Tf	Fall Time	V_{out} = 6Vp-p, A_V = 12dB, R_L = 25Ω		12.2		ns
Ts	Settling Time	V_{out} = 6Vp-p, A_V = 12dB, R_L = 25Ω		50		ns
SR	Slew Rate	V_{out} = 6Vp-p, A_V = 12dB, R_L = 25Ω	330	410		V/µs
V_{OH}	High Level Output Voltage	R_L=25Ω Connected to GND	4.8	5.1		V
V_{OL}	Low Level Output Voltage	R_L=25Ω Connected to GND		-5.5	-5.2	V
I_{out}	Output Sink Current	V_{out} = -4Vp	-350	-530		mA
		$T_{min.} < T_{amb} < T_{max.}$		-440		
	Output Source Current	V_{out} = +4Vp	330	420		
		$T_{min.} < T_{amb} < T_{max.}$		365		

Table 3. V_{CC} = ±6V, R_{fb}=910Ω,T_{amb} = 25°C (unless otherwise specified)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
Noise and distortion						
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_{out} = 14Vp-p, A_V = 12dB F= 110kHz, R_L = 50Ω diff.		-87		dBc
HD3	3rd Harmonic distortion (differential configuration)	V_{out} = 14Vp-p, A_V = 12dB F= 110kHz, R_L = 50Ω diff.		-83		dBc
IM2	2nd Order Intermodulation Product (differential configuration)	F1= 100kHz, F2 = 110kHz V_{out} = 16Vp-p, A_V = 12dB R_L = 50Ω diff.		-76		dBc
		F1= 370kHz, F2 = 400kHz V_{out} = 16Vp-p, A_V = 12dB R_L = 50Ω diff.		-75		
IM3	3rd Order Intermodulation Product (differential configuration)	F1 = 100kHz, F2 = 110kHz V_{out} = 16Vp-p, A_V = 12dB R_L = 50Ω diff.		-88		dBc
		F1 = 370kHz, F2 = 400kHz V_{out} = 16Vp-p, A_V = 12dB R_L = 50Ω diff.		-87		

Table 4. V_{CC} = ±2.5V, R_{fb}=910Ω,T_{amb} = 25°C (unless otherwise specified)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
DC performance						
V_{io}	Input Offset Voltage	T_{amb}		0.5	2.5	mV
		$T_{min.} < T_{amb} < T_{max.}$		1.2		
ΔV_{io}	Differential Input Offset Voltage	T_{amb} = 25°C			2.5	mV
I_{ib+}	Positive Input Bias Current	T_{amb}		5	30	µA
		$T_{min.} < T_{amb} < T_{max.}$		8		
I_{ib-}	Negative Input Bias Current	T_{amb}		0.8	11	µA
		$T_{min.} < T_{amb} < T_{max.}$		1.24		
Z_{IN+}	Input(+) Impedance			71		kΩ
Z_{IN-}	Input(-) Impedance			62		Ω
C_{IN+}	Input(+) Capacitance			1.5		pF
CMR	Common Mode Rejection Ratio	$\Delta V_{ic} = \pm 1V$	55	60		dB
	20 log ($\Delta V_{ic}/\Delta V_{io}$)	$T_{min.} < T_{amb.} < T_{max.}$		58		
SVR	Supply Voltage Rejection Ratio	ΔV_{cc}=±2V to ±2.5V	63	77		dB
	20 log ($\Delta V_{cc}/\Delta V_{io}$)	$T_{min.} < T_{amb.} < T_{max.}$		76		
I_{CC}	Total Supply Current per Operator	No load		11.9	15	mA
Dynamic performance and output characteristics						
R_{OL}	Open Loop Transimpedance	V_{out} = 2Vp-p, R_L = 10Ω	2	5.4		MΩ
		$T_{min.} < T_{amb.} < T_{max.}$		2.1		
BW	-3dB Bandwidth	Small Signal V_{out}<20mVp A_V = 12dB, R_L = 10Ω	20	30		MHz
	Full Power Bandwidth	Large Signal V_{out} = 1.4Vp A_V = 12dB, R_L = 10Ω		20		
	Gain Flatness @ 0.1dB	Small Signal V_{out}<20mVp A_V = 12dB, R_L = 10Ω		5.7		MHz
Tr	Rise Time	V_{out} = 2.8Vp-p, A_V = 12dB R_L = 10Ω		11		ns
Tf	Fall Time	V_{out} = 2.8Vp-p, A_V = 12dB R_L = 10Ω		11.5		ns
Ts	Settling Time	V_{out} = 2.2Vp-p, A_V = 12dB R_L = 10Ω		39		ns
SR	Slew Rate	V_{out} = 2.2Vp-p, A_V = 12dB R_L = 10Ω	100	130		V/µs
V_{OH}	High Level Output Voltage	R_L=10Ω Connected to GND	1.5	1.75		V
V_{OL}	Low Level Output Voltage	R_L=10Ω Connected to GND		-2.05	-1.8	V
I_{out}	Output Sink Current	V_{out} = -1.25Vp	-350	-470		mA
		$T_{min.} < T_{amb} < T_{max.}$		-450		
	Output Source Current	V_{out} = +1.25Vp	200	270		
		$T_{min.} < T_{amb} < T_{max.}$		245		

Table 4. V_{CC} = ±2.5V, R_{fb}=910Ω,T_{amb} = 25°C (unless otherwise specified)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
Noise and distortion						
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_{out} = 6Vp-p, A_V = 12dB F= 110kHz, R_L = 20Ω diff.		-97		dBc
HD3	3rd Harmonic distortion (differential configuration)	V_{out} = 6Vp-p, A_V = 12dB F= 110kHz, R_L = 20Ω diff.		-98		dBc
IM2	2nd Order Intermodulation Product (differential configuration)	F1= 100kHz, F2 = 110kHz V_{out} = 6Vp-p, A_V = 12dB R_L = 20Ω diff.		-86		dBc
		F1= 370kHz, F2 = 400kHz V_{out} = 6Vp-p, A_V = 12dB R_L = 20Ω diff.		-88		
IM3	3rd Order Intermodulation Product (differential configuration)	F1 = 100kHz, F2 = 110kHz V_{out} = 6Vp-p, A_V = 12dB R_L = 20Ω diff.		-90		dBc
		F1 = 370kHz, F2 = 400kHz V_{out} = 6Vp-p, A_V = 12dB R_L = 20Ω diff.		-85		

Power-down mode features

The power-down command is a MOS input featuring a high input impedance.

Table 5. V_{CC} = ±2.5V, 5V, ±6V or 12V, T_{amb} = 25°C

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{pdw}	Pin (6) Threshold Voltage for Power Down Mode				V
	Low Level	$-V_{CC}$		$-V_{CC}+0.8$	
	High Level	$-V_{CC}+2$		$+V_{CC}$	
Icc_{pdw}	Power Down Mode Total Current Consumption@ V_{CC}=5V		69	80	µA
	Power Down Mode Total Current Consumption@ V_{CC}=12V		148	180	µA
R_{pdw}	Power Down Mode Output Impedance @ V_{CC}=5V		19	23	Ω
	Power Down Mode Output Impedance @ V_{CC}=12V		15.3	19	Ω
C_{pdw}	Power Down Mode Output Capacitance		63		pF

Power down control	Circuit status
V_{pdw}=Low Level	Active
V_{pdw}=High Level	Standby

Figure 2. Load configuration
Load: R_L=25Ω, V_{CC}=±6V

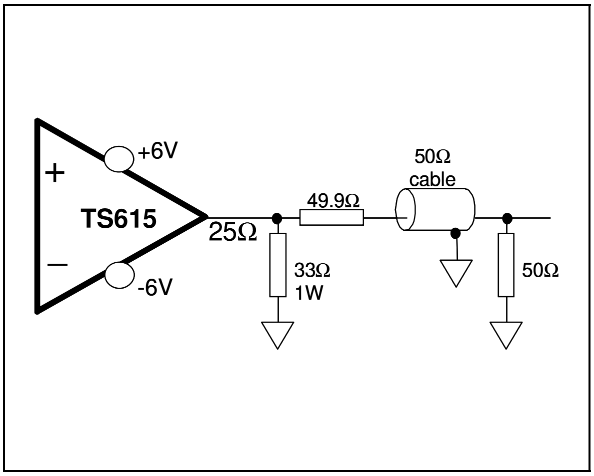


Figure 5. Load configuration
Load: R_L=10Ω, V_{CC}=±2.5V

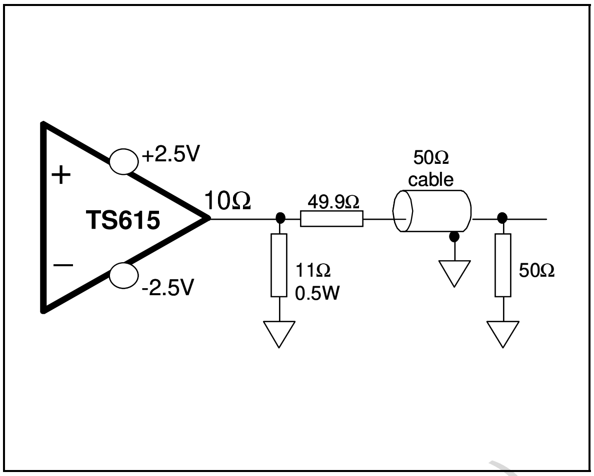


Figure 3. Closed loop gain vs. frequency
A_V=+1

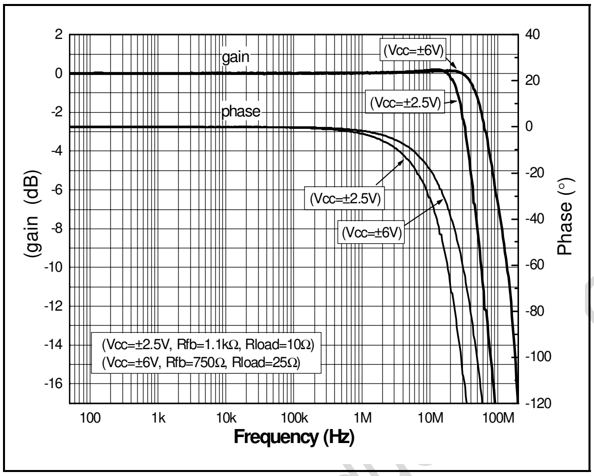


Figure 6. Closed loop gain vs. frequency
A_V=-1

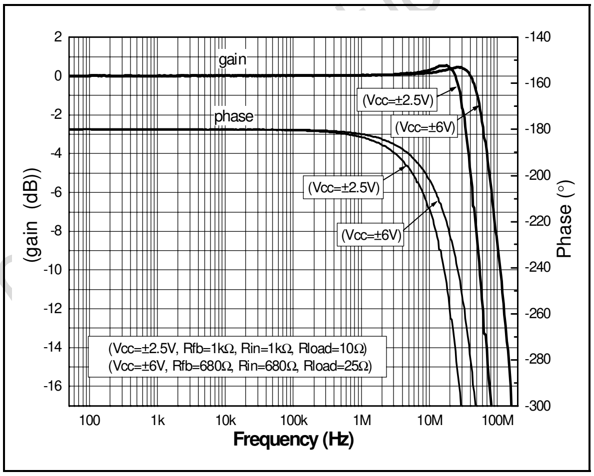


Figure 4. Closed loop gain vs. frequency
A_V=+2

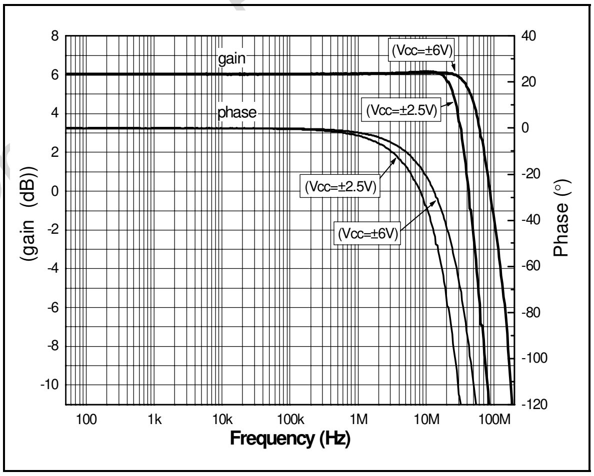


Figure 7. Closed loop gain vs. frequency
A_V=-2

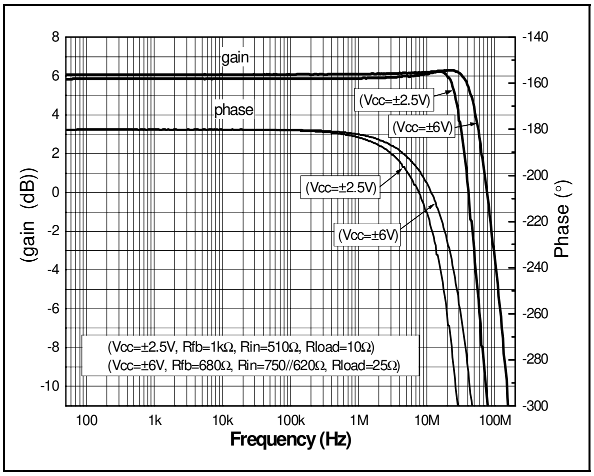


Figure 8. Closed loop gain vs. frequency A_V=+4

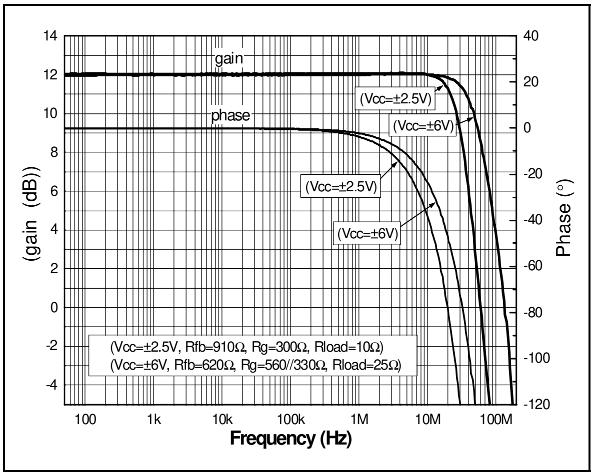


Figure 9. Closed loop gain vs. frequency A_V=+8

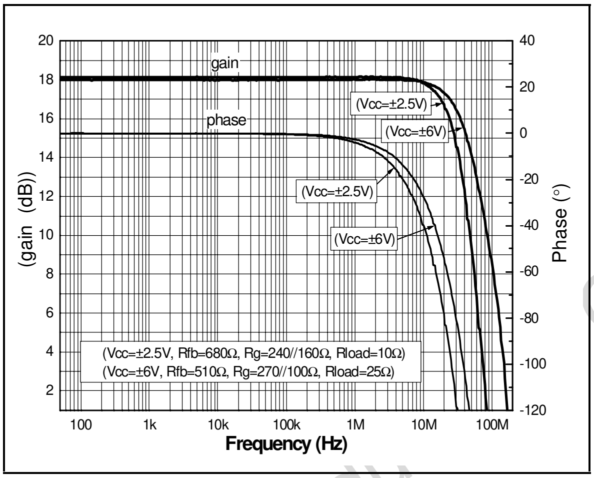


Figure 10. Bandwidth vs. temperature: A_V=+4, R_{fb}=910Ω

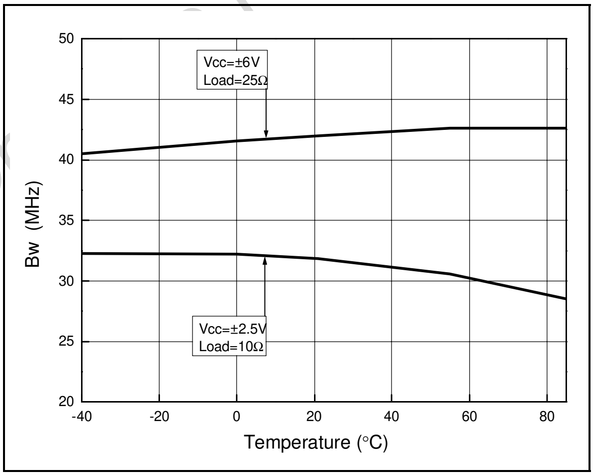


Figure 11. Closed loop gain vs. frequency A_V=-4

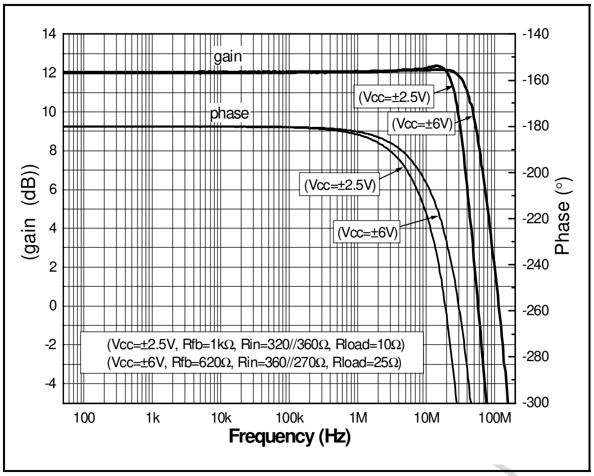


Figure 12. Closed loop gain vs. frequency A_V=-8

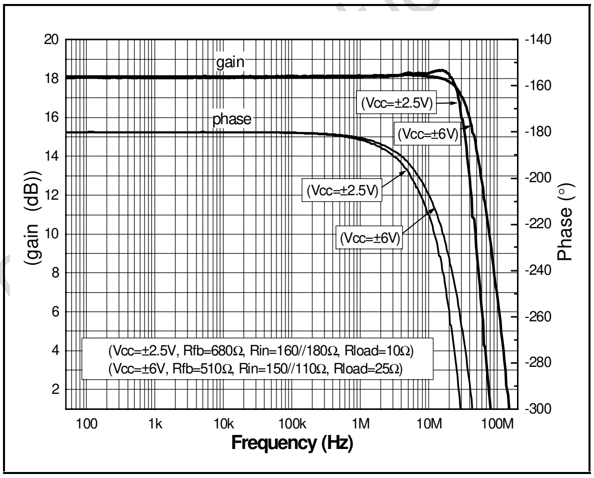


Figure 13. Positive slew rate: A_V=+4, R_{fb}=620Ω, V_{CC}=±6V, R_L=25Ω

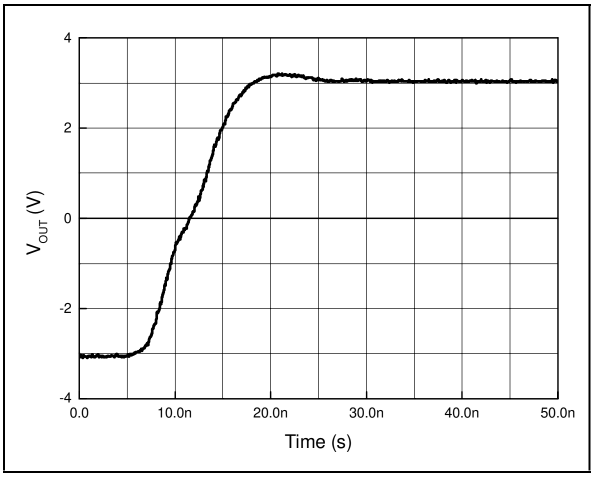


Figure 14. Positive slew rate: A_V=+4, R_{fb}=910Ω, V_{CC}=±2.5V, R_L=10Ω

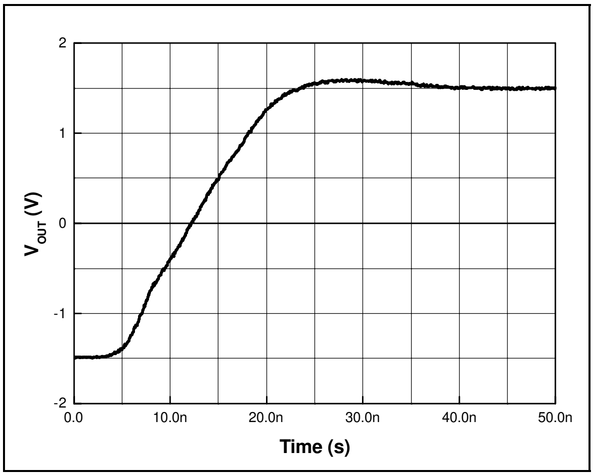


Figure 15. Negative slew rate: A_V=+4, R_{fb}=620Ω, V_{CC}=±6V, R_L=25Ω

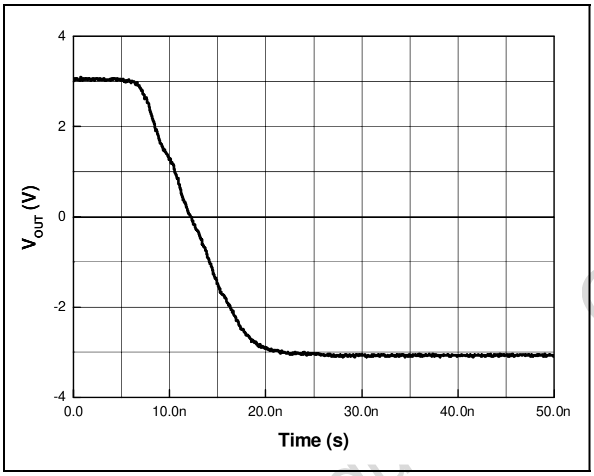


Figure 16. Negative slew rate: A_V=+4, R_{fb}=910Ω, V_{CC}=±2.5V, R_L=10Ω

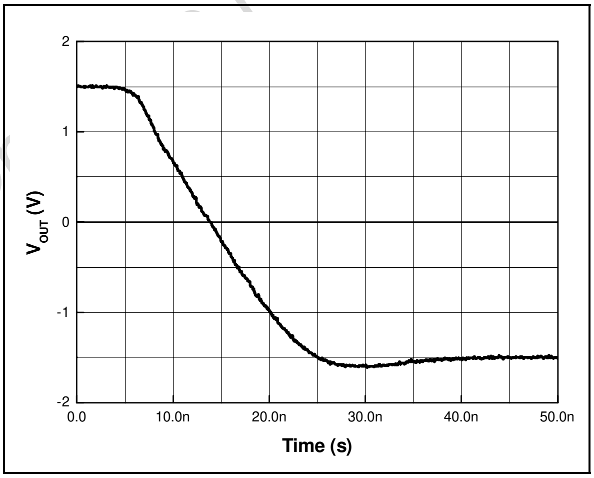


Figure 17. Positive slew rate: A_V= - 4, R_{fb}=620Ω, V_{CC}=±6V, R_L=25Ω

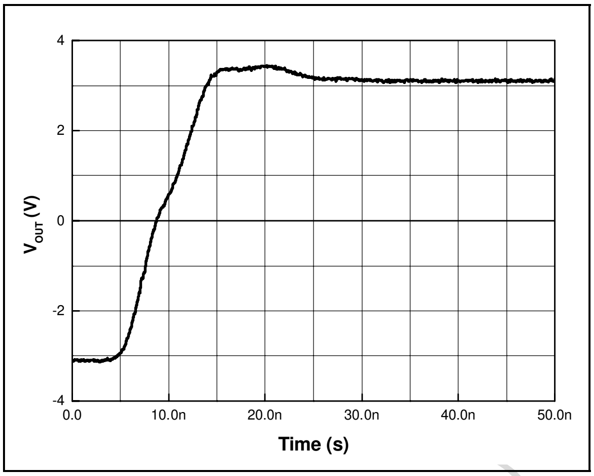


Figure 18. Positive slew rate: A_V= - 4, R_{fb}=910Ω, V_{CC}=±2.5V, R_L=10Ω

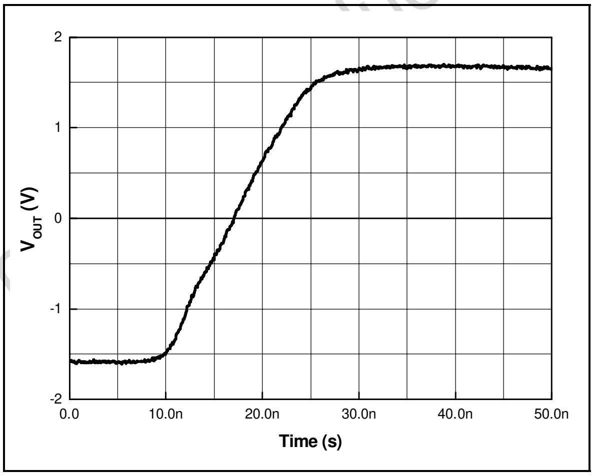


Figure 19. Negative slew rate: A_V= - 4, R_{fb}=620Ω, V_{CC}=±6V, R_L=25Ω

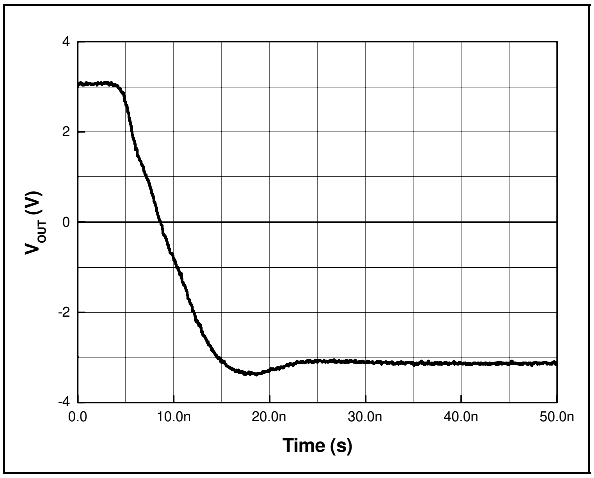


Figure 20. Negative slew rate: A_V= - 4, R_{fb}=910Ω, V_{CC}=±2.5V, R_L=10Ω

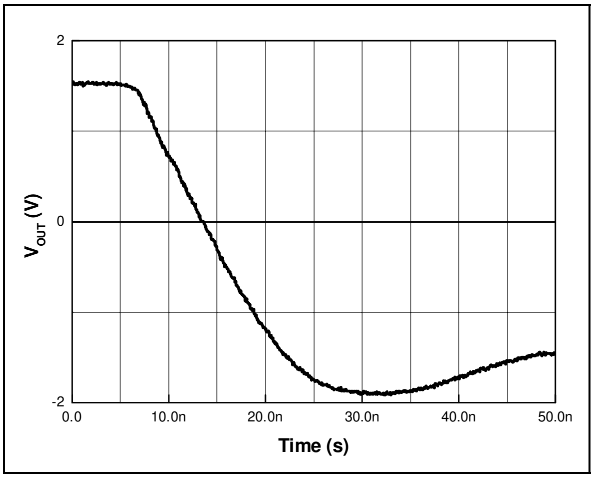


Figure 21. Slew rate vs. temperature: A_V=+4, R_{fb}=910Ω, V_{CC}=±2.5V, R_L=10Ω

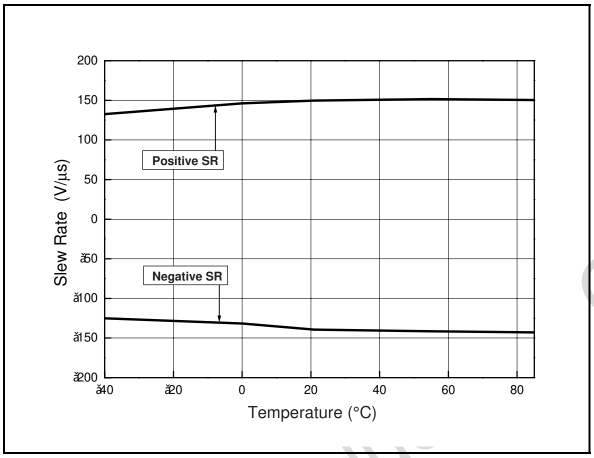


Figure 22. Slew rate vs. temperature: A_V=+4, R_{fb}=910Ω, V_{CC}=±6V, R_L=25Ω

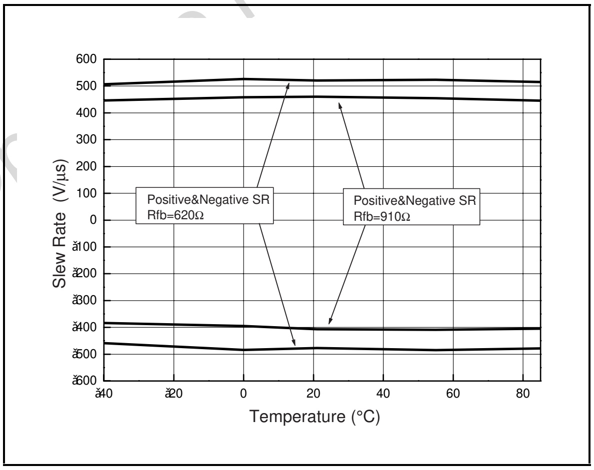


Figure 23. Input voltage noise level: A_V=+92, R_{fb}=910Ω, Input+ connected to Gnd via 10Ω

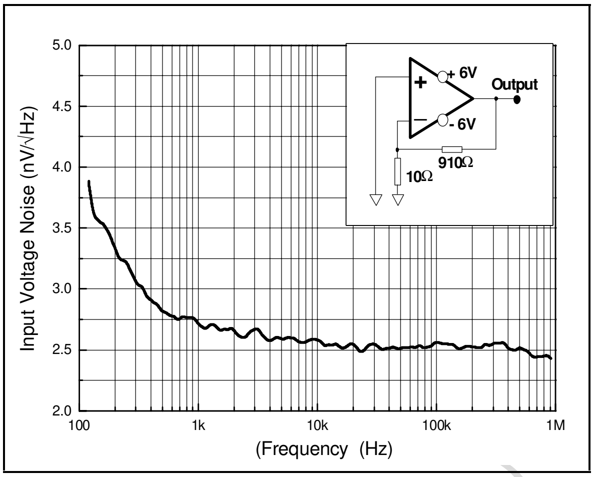


Figure 24. Transimpedance vs. temperature, open loop

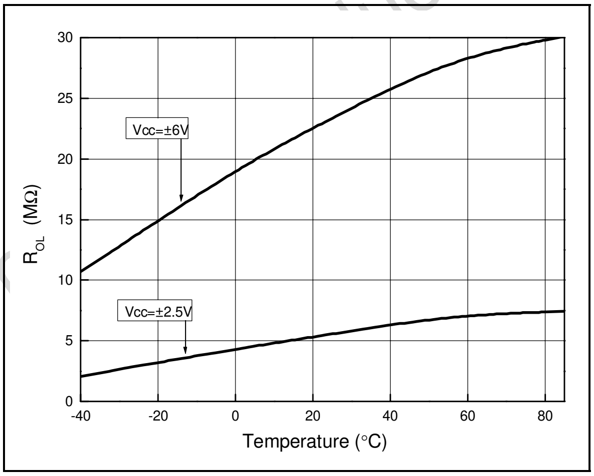


Figure 25. Icc vs. power supply Open loop, no load

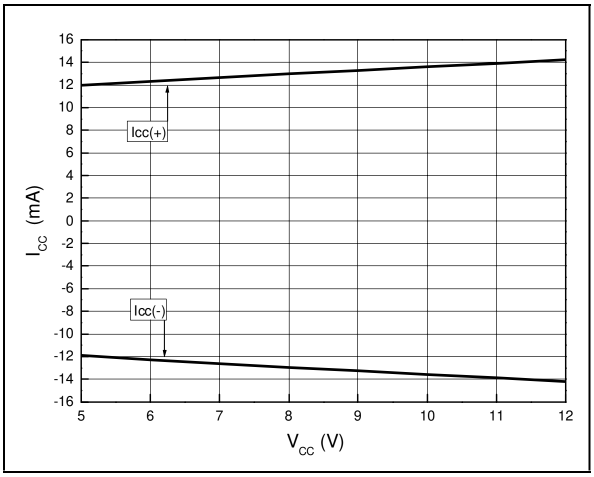


Figure 26. Iib vs. power supply Open loop, no load

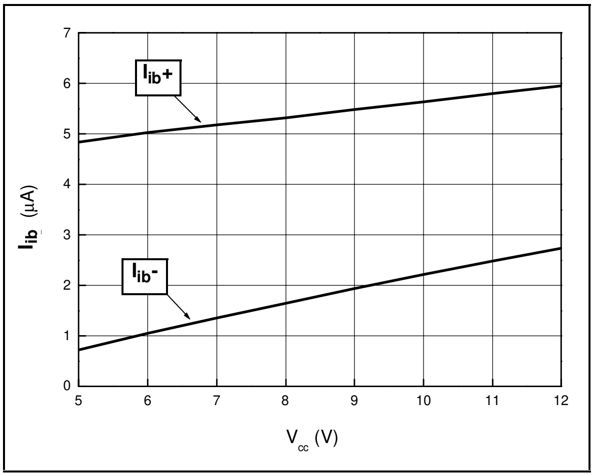


Figure 27. Iib(-) vs. temperature Open loop, no load

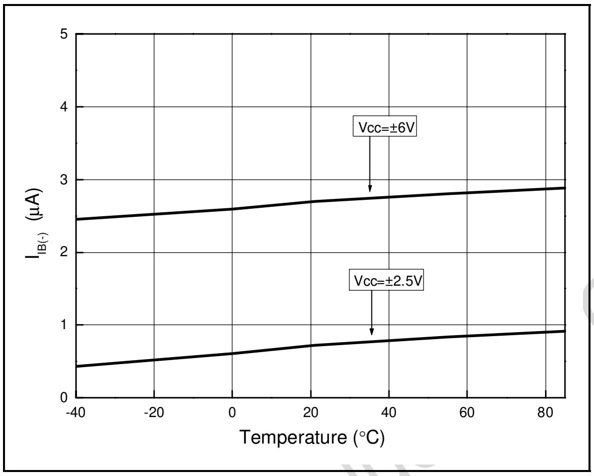


Figure 28. Icc vs. temperature Open loop, no load

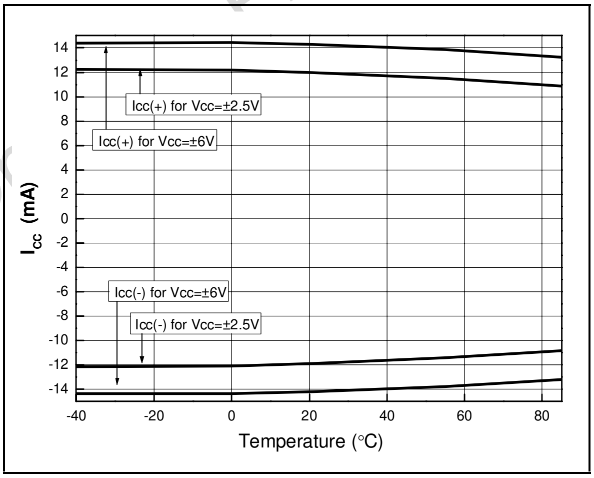


Figure 29. Iib(+) vs. temperature Open loop, no load

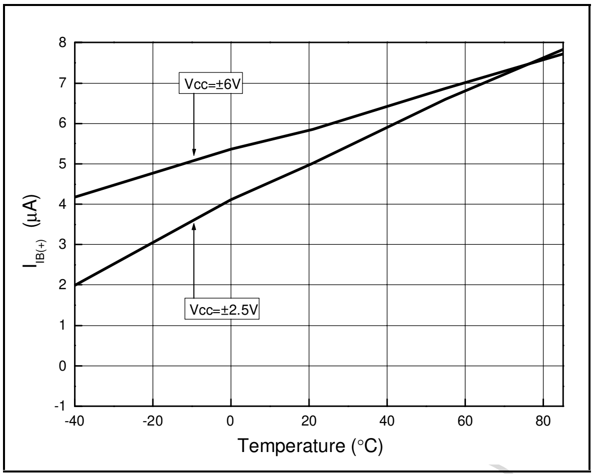


Figure 30. Voh & Vol vs. power supply Open loop, R_L=25Ω

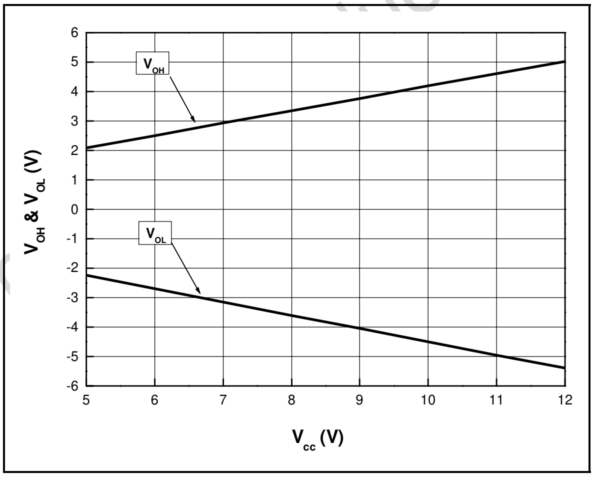


Figure 31. Voh vs. temperature Open loop

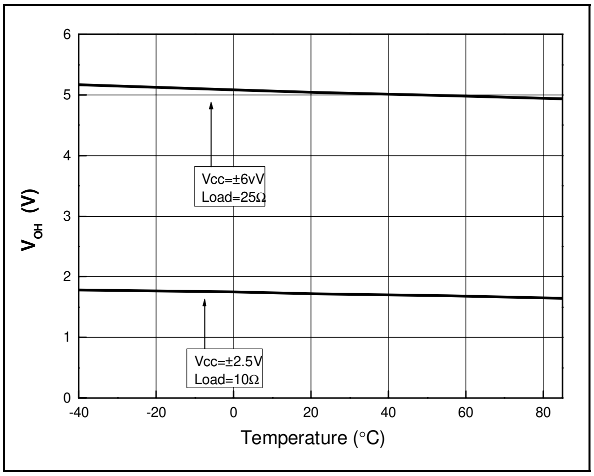


Figure 32. Vol vs. temperature Open loop

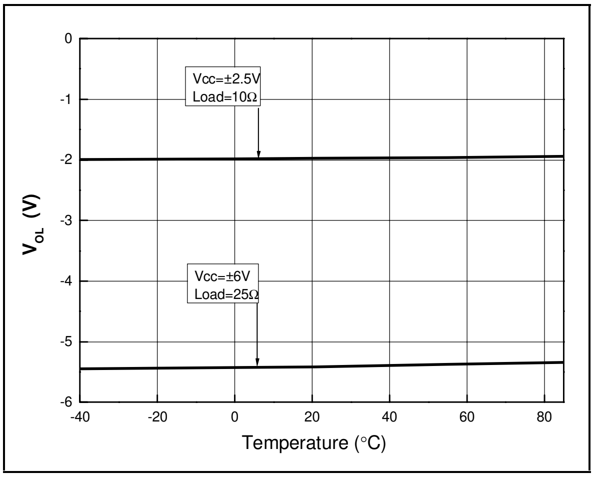


Figure 35. CMR vs. temperature Open loop, no load

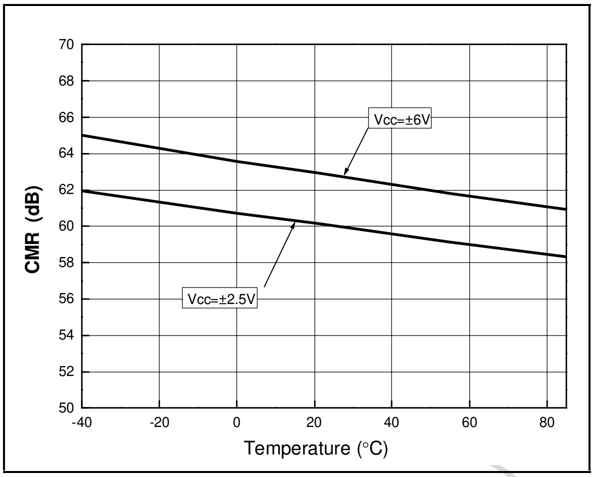


Figure 33. Differential Vio vs. temperature Open loop, no load

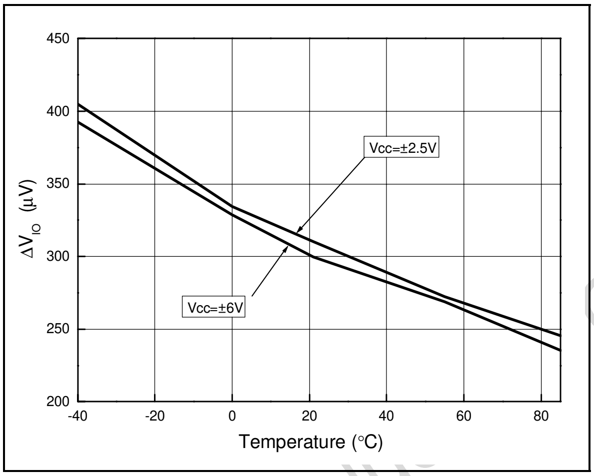


Figure 36. SVR vs. temperature Open loop, no load

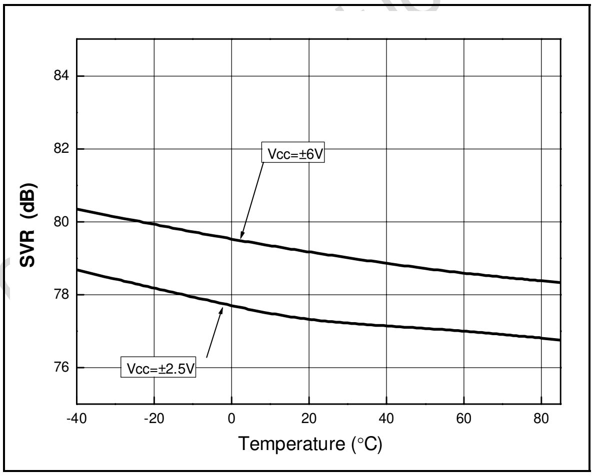


Figure 34. Vio vs. temperature Open loop, no load

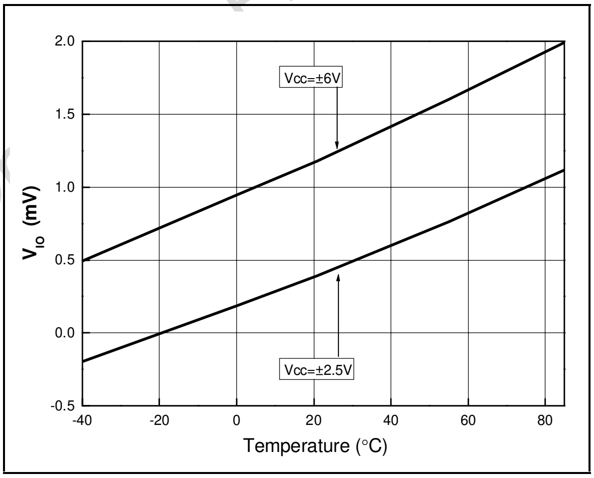


Figure 37. Iout vs. temperature Open loop, V_{CC}=±6V, R_L=10Ω

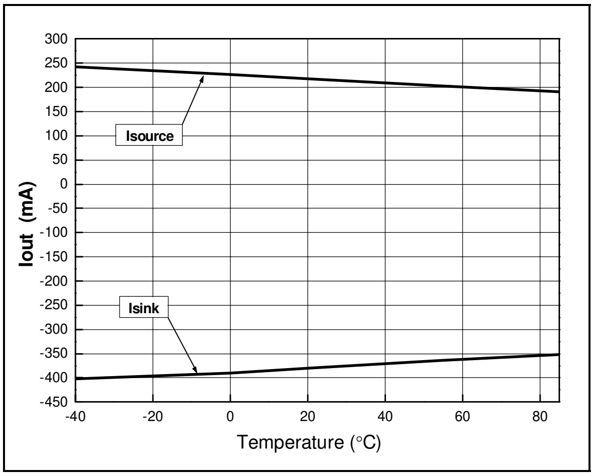


Figure 38. Iout vs. temperature Open loop, V_{CC}=±2.5V, R_L=25Ω

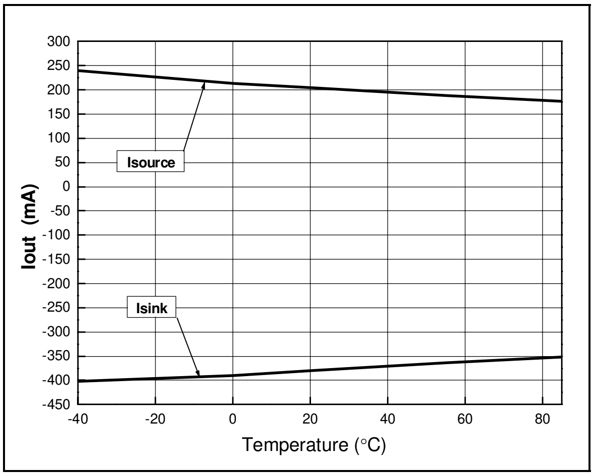


Figure 39. Maximum output amplitude vs. load: A_V=+4, R_{fb}=620Ω, V_{CC}=±6V

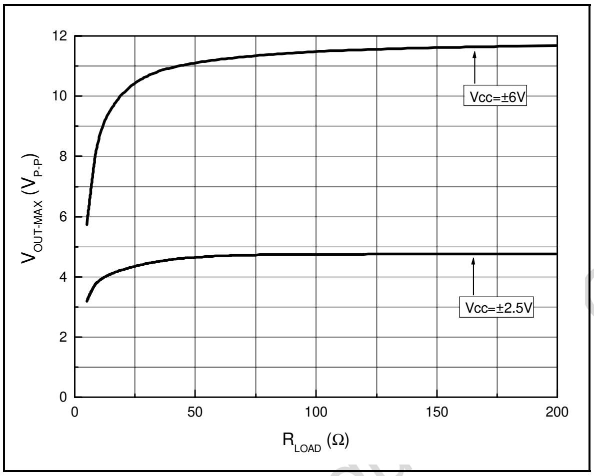


Figure 40. Isink vs. output amplitude V_{CC}=±2.5V, open loop, no load

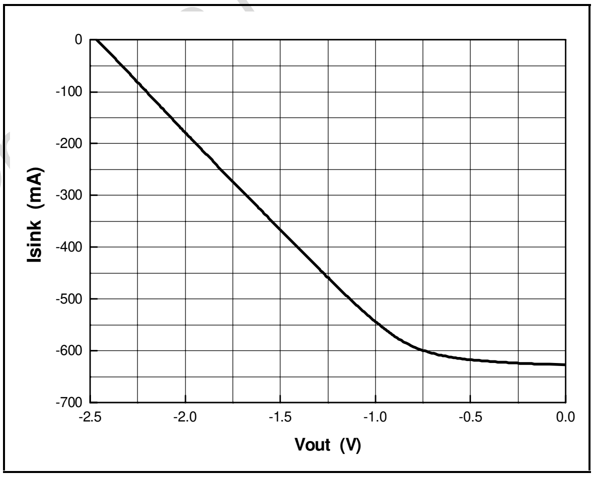


Figure 41. Isource vs. output amplitude V_{CC}=±2.5V, open loop, no load

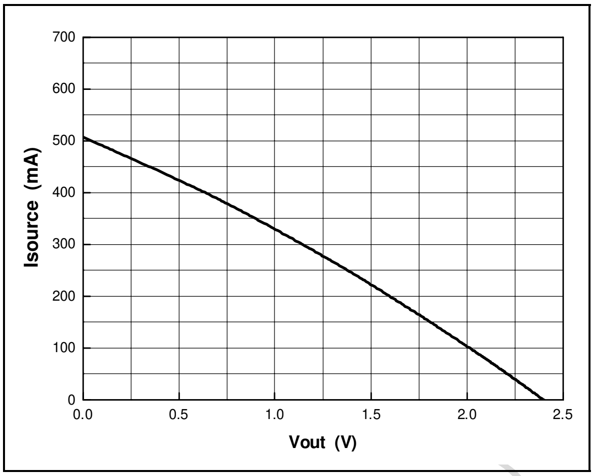


Figure 42. Isink vs. output amplitude V_{CC}=±6V, open loop, no load

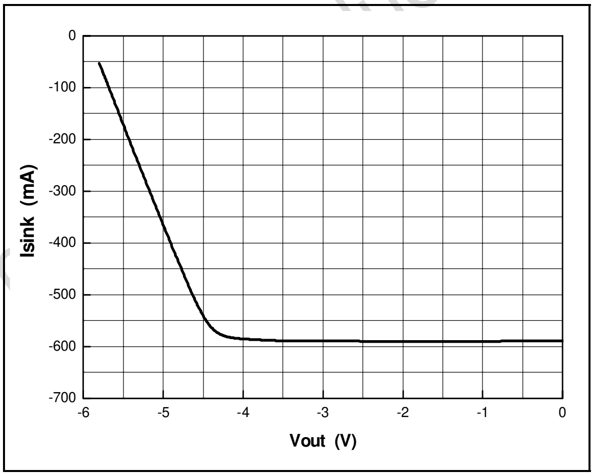


Figure 43. Isource vs. output amplitude V_{CC}=±6V, open loop, no load

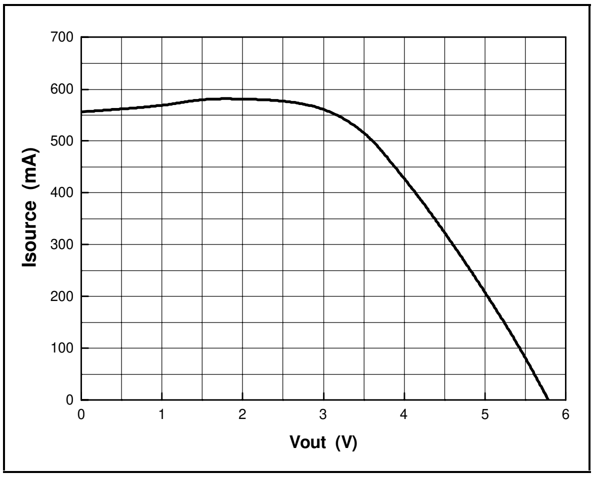
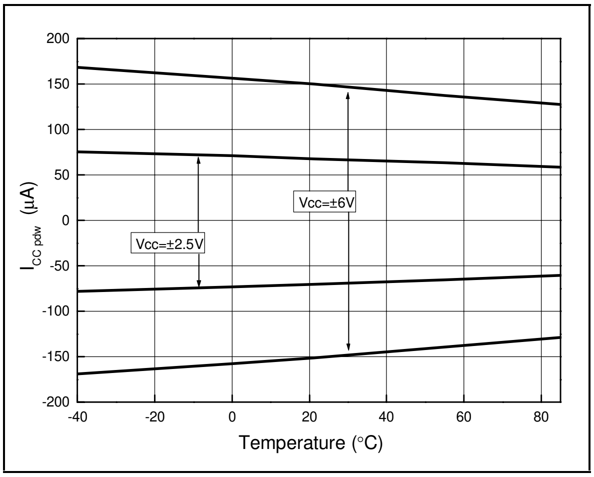


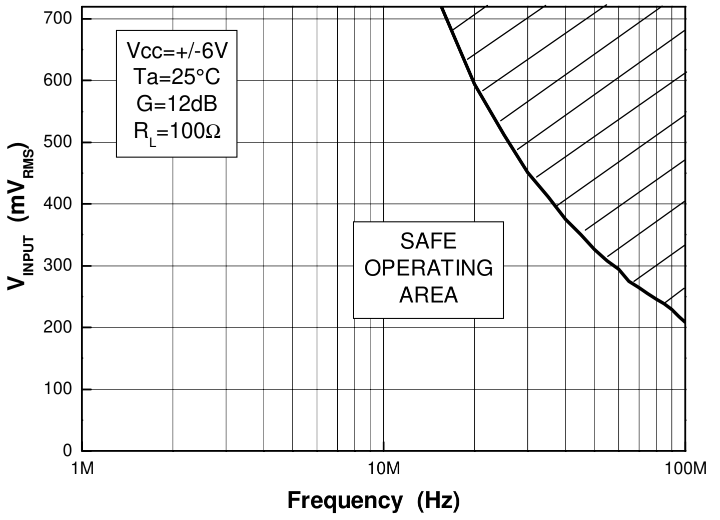
Figure 44. Icc (power down) vs. temperature no load, open loop



4 Safe Operating Area

Figure 45 shows the safe operating zone for the TS615. The curve shows the input level vs. the input frequency—a characteristic curve which must be considered in order to ensure a good application design. In the dash-lined zone, the consumption increases, and this increased consumption could do damage to the chip if the temperature increases

Figure 45. Safe operating area



5 Intermodulation Distortion Product

The non-ideal output of the amplifier can be described by the following series, due to a non-linearity in the input-output amplitude transfer:

$$V_{out} = C_o + C_1 V_{in} + C_2 V_{in}^{2} \ldots + C_n V_{in}^{n}$$

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

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

This intermodulation product, or rather, the study of the intermodulation distortion of a two-tone input signal is the first step in characterizing the amplifiers capability for driving multi-tone signals.

The two-tone input is equal to:

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

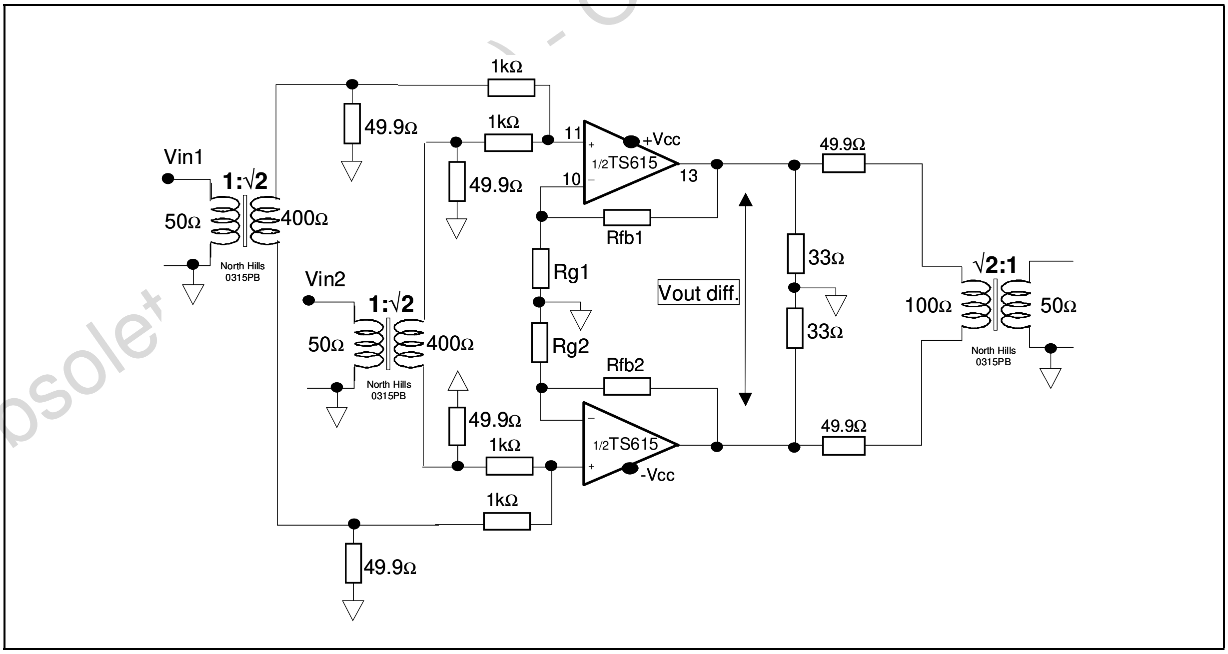
giving:

$$V_{out} = C_0 + C_1(A\sin\omega_1 t + B\sin\omega_2 t) + C_2(A\sin\omega_1 t + B\sin\omega_2 t)^2 \ldots + C_n(A\sin\omega_1 t + B\sin\omega_2 t)^n$$

In this expression, we can extract distortion terms and intermodulations terms from a single sine wave: second-order intermodulation terms IM2 by the frequencies $(\omega_1-\omega_2)$ and $(\omega_1+\omega_2)$ with an amplitude of $C2A^2$ and third-order intermodulation terms IM3 by the frequencies $(2\omega_1-\omega_2)$, $(2\omega_1+\omega_2)$, $(-\omega_1+2\omega_2)$ and $(\omega_1+2\omega_2)$ with an amplitude of $(3/4)C3A^3$.

We can measure the intermodulation product of the driver by using the driver as a mixer via a summing amplifier configuration. In doing this, the non-linearity problem of an external mixing device is avoided.

Figure 46. Non-inverting summing amplifier



The following graphs show the IM2 and the IM3 of the amplifier in different configurations. The two-tone input signal is created by a Marconi 2026 multisource generator. Each tone has the same amplitude. The measurement was carried out using an HP3585A spectrum analyzer.

Figure 47. Intermodulation vs. output amplitude: 370 kHz & 400 kHz, $A_V = +1.5$, $R_{fb} = 1\ k\Omega$, $R_L = 14\ \Omega$ diff., $V_{CC} = \pm 2.5\ V$

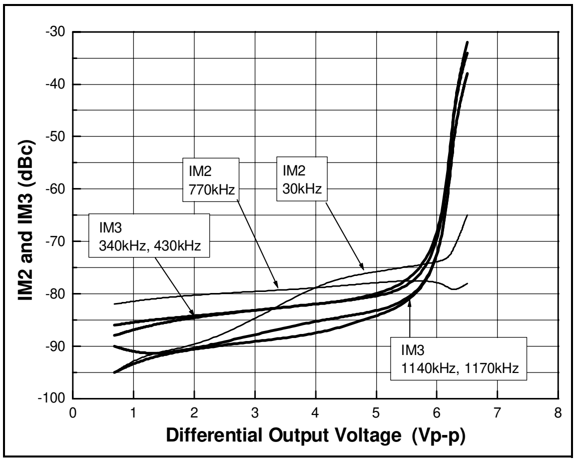


Figure 48. Intermodulation vs. output amplitude: 370 kHz & 400 kHz, $A_V = +1.5$, $R_{fb} = 1\ k\Omega$, $R_L = 28\ \Omega$ diff., $V_{CC} = \pm 2.5\ V$

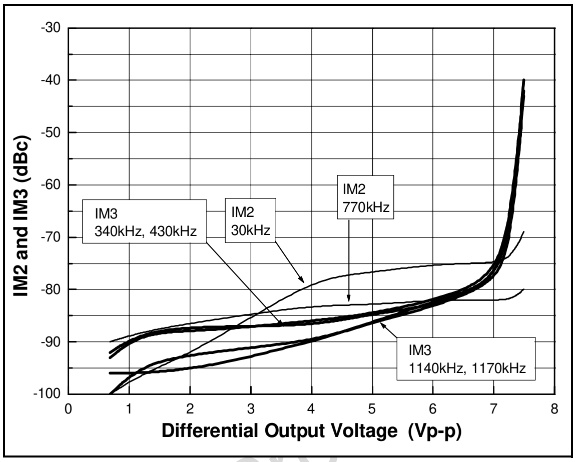


Figure 49. Intermodulation vs. gain: 370kHz & 400kHz, R_L=20Ω diff., Vout=6Vpp, V_{CC}=±2.5V

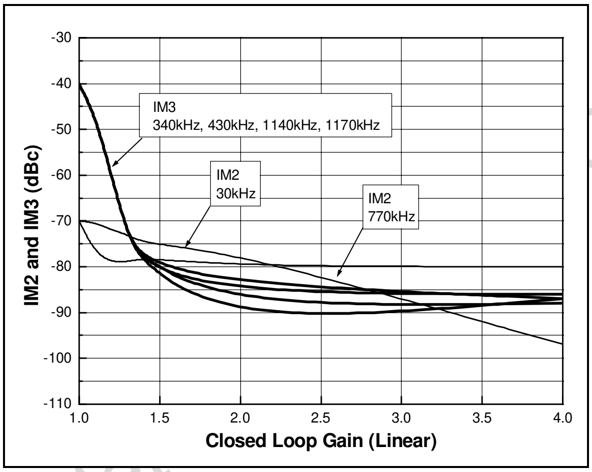


Figure 50. Intermodulation vs. Load: 370kHz & 400kHz, A_V=+1.5, R_{fb}=1kΩ, Vout=6.5Vpp, V_{CC}=±2.5V

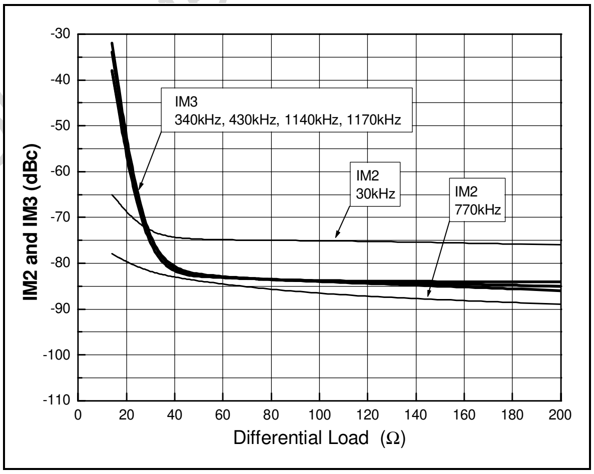


Figure 51. Intermodulation vs. Output Amplitude: 100kHz & 110kHz, A_V=+4, R_{fb}=620Ω, R_L=200Ω diff., V_{CC}=±6V

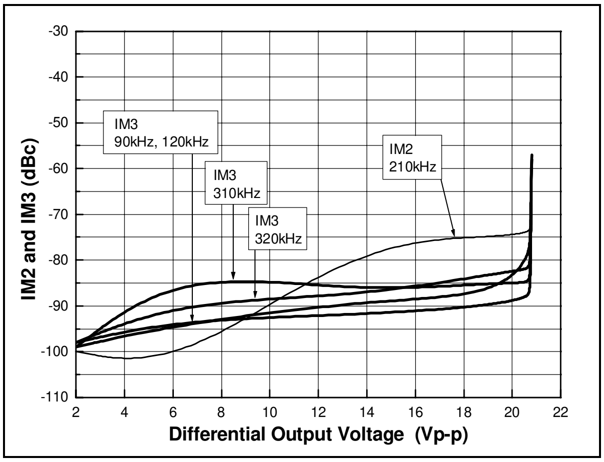


Figure 52. Intermodulation vs. Output Amplitude: 100kHz & 110kHz, A_V=+4, R_{fb}=620Ω, R_L=50Ω diff., V_{CC}=±6V

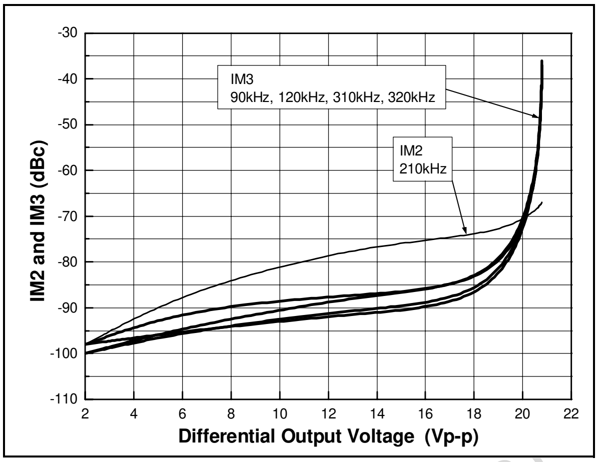


Figure 53. Intermodulation vs. Frequency Range: A_V=+4, R_{fb}=620Ω, R_L=50Ω diff., Vout=16Vpp, V_{CC}=±6V

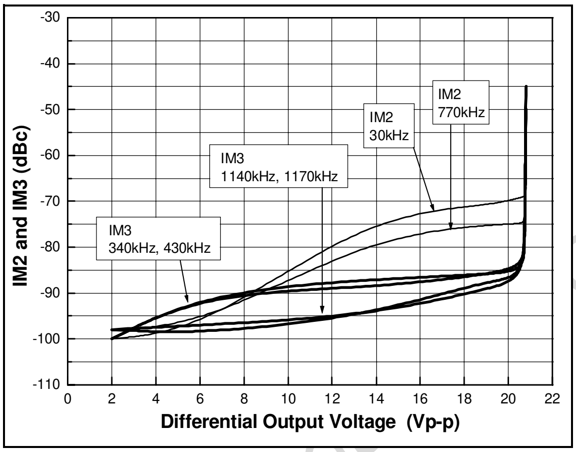
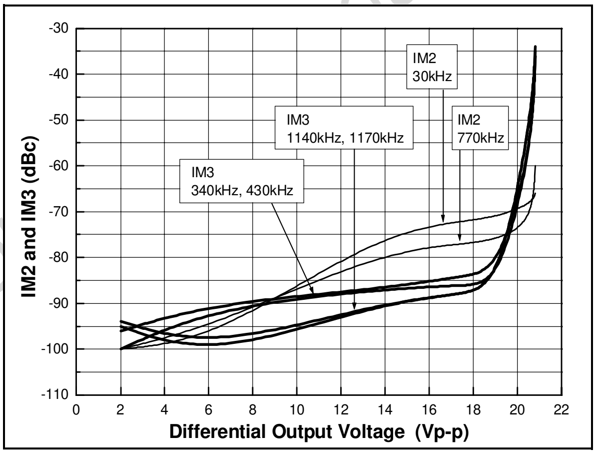


Figure 54. Intermodulation vs. Output Amplitude: 370kHz & 400kHz, A_V=+4, R_{fb}=620Ω, R_L=50Ω diff., V_{CC}=±6V



6 Printed Circuit Board Layout Considerations

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

The use of a proper ground plane on both sides of the PCB is necessary to provide low inductance and a low resistance common return. The most important factors affecting gain flatness and bandwidth are stray capacitance at the output and inverting input. To minimize capacitance, the space between signal lines and ground plane should be maximized. Feedback component 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.

6.1 Thermal information

The TS615 is housed in an exposed-pad plastic package. As described in *Figure 55*, this package has a lead frame upon which the dice 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 an excellent thermal performance.

The thermal pad is electrically isolated from all pins in the package. It must 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. The copper area **must** be connected to -V_{CC} available on pin 4.

Figure 55. Exposed-pad package

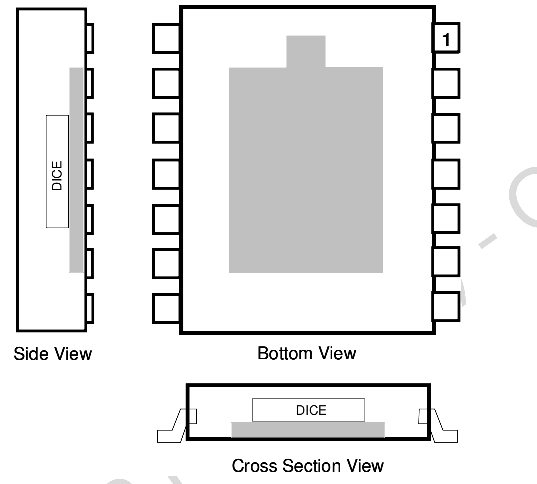


Figure 56. Evaluation board

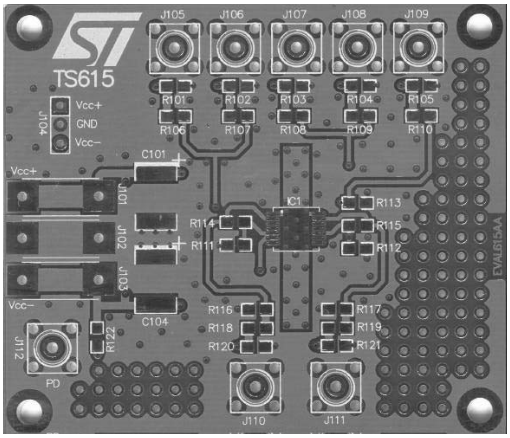


Figure 57. Schematic diagram

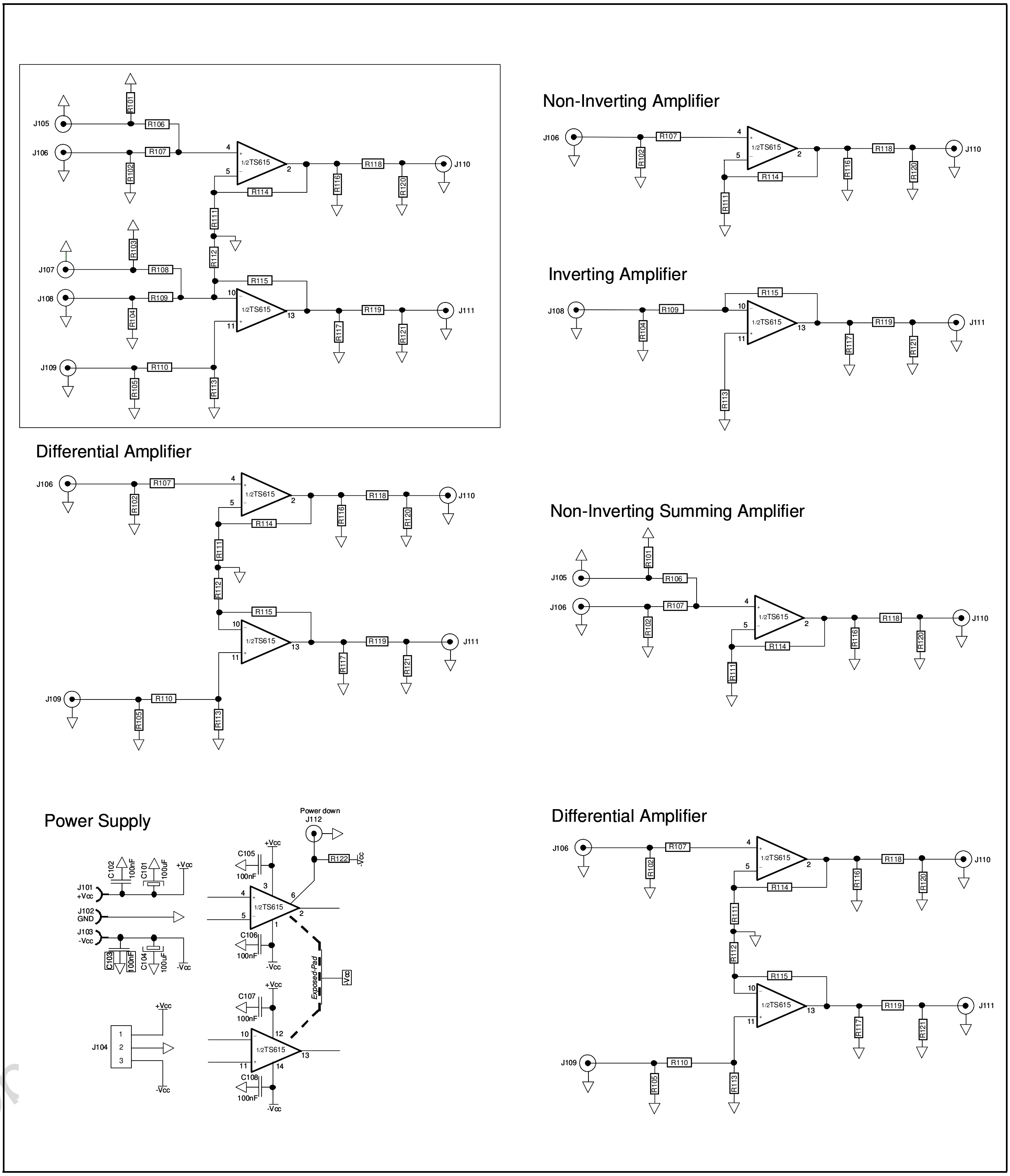


Figure 58. Component locations - top side

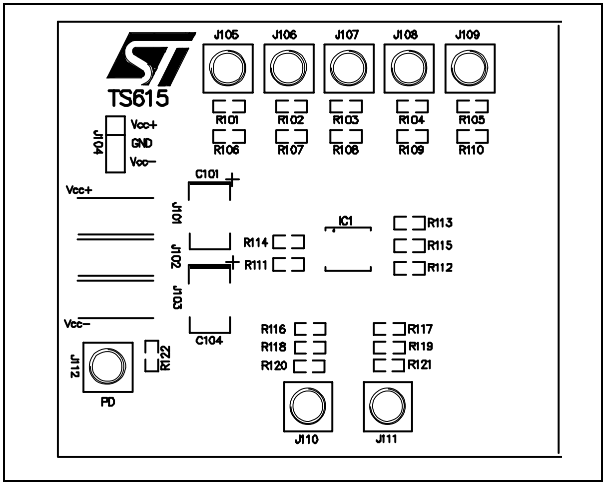


Figure 59. Component locations - bottom side

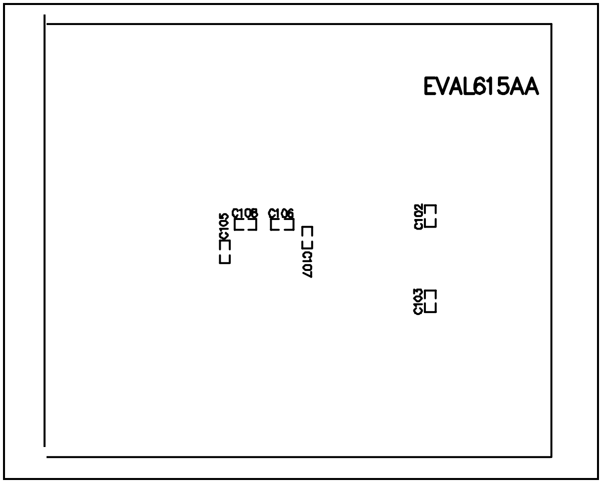


Figure 60. Top side board layout

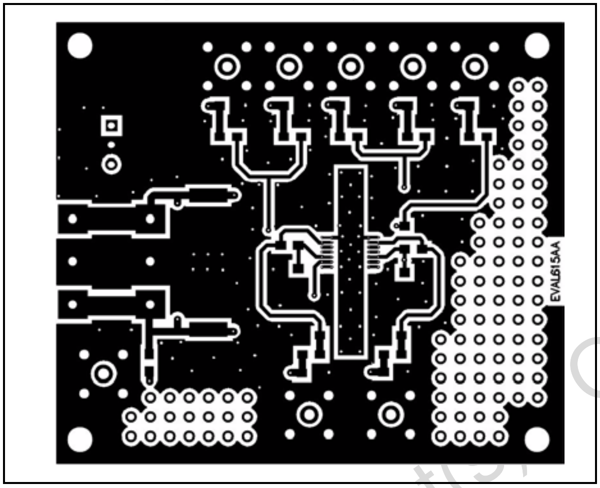
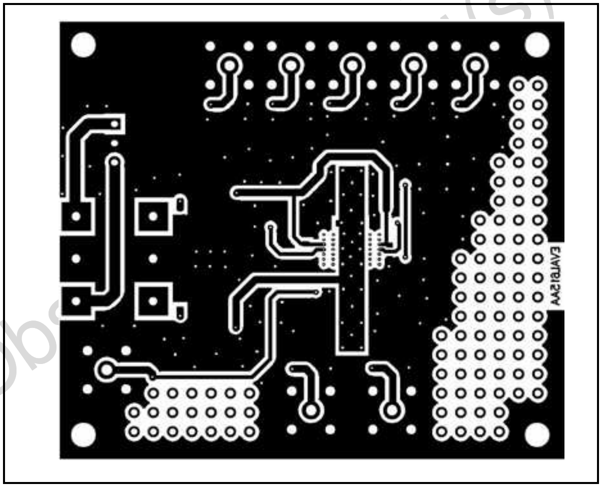


Figure 61. Bottom side board layout

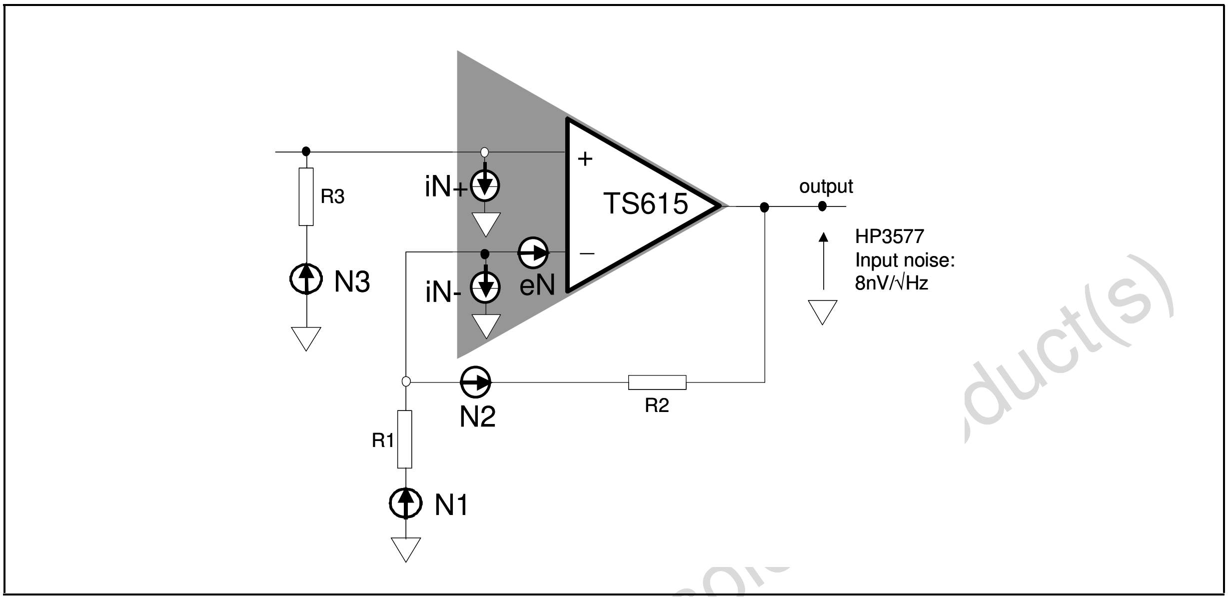


7 Noise Measurements

The noise model is shown in *Figure 62*, where:

- eN: input voltage noise of the amplifier
- iNn: negative input current noise of the amplifier
- iNp: positive input current noise of the amplifier

Figure 62. Noise model



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:

$$\sqrt{4kTRDF}$$

where ΔF is the specified bandwidth.

On a 1Hz bandwidth the thermal noise is reduced to

$$\sqrt{4kTR}$$

where k is Boltzmann's constant, equals to 1374 x 10^{-23}J/°K. T is the temperature (°K).

The output noise eNo is calculated using the Superposition Theorem. However eNo is not the sum of all noise sources, but rather the square root of the sum of the square of each noise source, as shown in *Equation 1*.

$$eNo = \sqrt{V1^2 + V2^2 + V3^2 + V4^2 + V5^2 + V6^2} \qquad \textit{Equation 1}$$

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

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

$$eNo = \sqrt{(\text{Measured})^2 - (\text{instrumentation})^2} \qquad \textit{Equation 3}$$

The input noise is called the Equivalent Input Noise as it is not directly measured but 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 *Equation 2* we obtain:

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

7.1 Measurement of *eN*

If we assume a short-circuit on the non-inverting input (R3=0), *Equation 4* becomes:

$$eNo = \sqrt{eN^2 \times g^2 + iNn^2 \times R2^2 + g \times 4kTR2} \qquad \textit{Equation 5}$$

In order to easily extract the value of eN, the resistance R2 will be chosen as low as possible. On 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

7.2 Measurement of *iNn*

To measure the negative input current noise iNn, we set R3=0 and use *Equation 5*. This time the gain must be lower in order 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

7.3 Measurement of *iNp*

To extract iNp from *Equation 3*, a resistance R3 is connected to the non-inverting input. The value of R3 must be chosen in order to keep its thermal noise contribution as low as possible against the iNp contribution.

- **R1=100Ω, R2=910Ω, R3=100Ω, Gain=10.1**
- **Equivalent input noise**: 3.93nV/√Hz
- **Positive input current noise**: iNp=15pA/√Hz
- **Conditions:** Frequency=100kHz, V_{CC}=±2.5V
- **Instrumentation**: HP3585A Spectrum Analyzer (the input noise of the HP3585A is 8nV/√Hz)