Op Amp Aol vs Vout Swing Rules-of-Thumb

Tim Green, MGTS

9/29/2015

Precision Analog Linear Applications

Key TI Consultants:

Art Kay, MGTS

Marek Lis

Precision Analog Linear Applications

Slam Test vs AoI Test

Datasheet Specifications

OPA180 Specs for Discussion

- Output – Voltage Output Swing from Rail
- Aol – Open Loop Voltage Gain

Output Swing

ELECTRICAL CHARACTERISTICS: V_S = ±2 V to ±18 V (V_S = +4 V to +36 V) (continued)

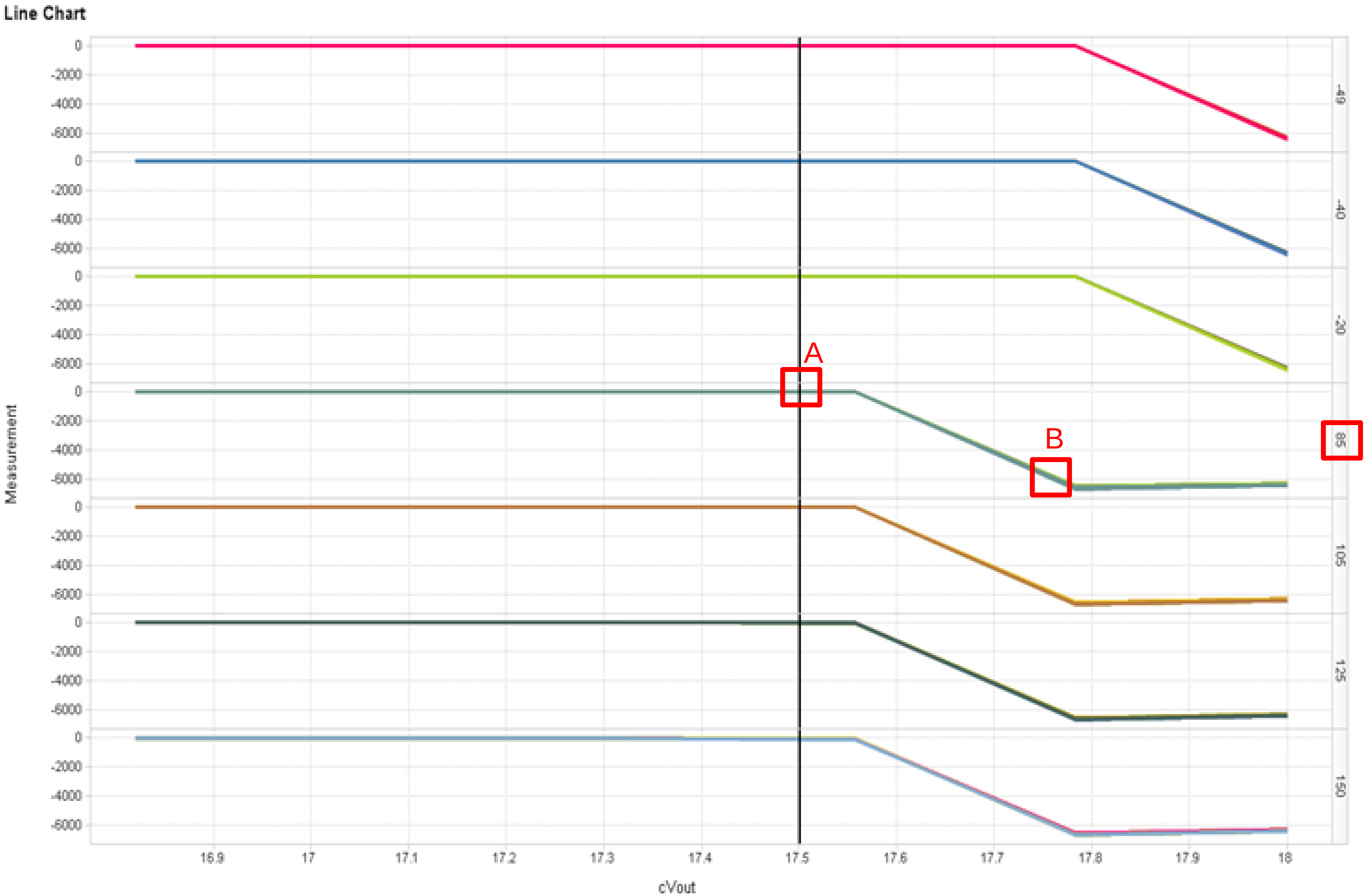
At T_A = +25°C, R_L = 10 kΩ connected to $V_S/2$, and V_{COM} = V_{OUT} = $V_S/2$, unless otherwise noted.

PARAMETER	CONDITIONS	OPA2180, OPA4180 MIN	TYP	MAX	UNIT
OUTPUT					
Voltage output swing from rail	No load		8	18	mV
	R_L = 10 kΩ		250	300	mV
	T_A = –40°C to +105°C, R_L = 10 kΩ		325	360	mV

This is "Slam Test" or "Saturation Test".
This is a ***NON-LINEAR*** test.
The output is driven hard into output stage saturation.

Aol is *NOT* guaranteed closer than 500mV to either rail

OPEN-LOOP GAIN					
A_{OL}	Open-loop voltage gain	(V–) + 500 mV < V_O < (V+) – 500 mV, R_L = 10 kΩ	110	120	dB
		T_A = –40°C to +105°C, (V–) + 500 mV < V_O < (V+) – 500 mV, R_L = 10 kΩ	104	114	dB



V+ = +18V
V- = -18V

Point A:
Vout = (V+) - 0.5V
Vos = 35uV
Aol = 114dB

Point B:
Vout = (V+) - 0.25V
Vos = 6000uV
Aol = 69.42dB
Aol = x2958

Point B
Closed Loop Gain:
Acl=Aol/(1+Aolβ)
Acl= 2958 / (1+2958*0.0065)
Acl=146
Acl should be x154 !!

Gets WORSE Closer to the rail the output swings!

Note: Beyond point “B” is Test Equipment Range Limitation

Datasheet Specifications

Check Op Amp Datasheet for Op Amp used in application circuit as *ALL* Op Amps have this limitation!

- Output – Voltage Output Swing from Rail
  - Output ***Saturation*** Specification
  - Slam Test
  - Claw Curve
- Aol – Open Loop Voltage Gain
  - Measured in ***Linear*** Operating Range
  - Note Vout Swing where Aol is Tested

CMOS RRO Op Amps
and
Linear Vout Region

OPA188 – How do we know it is CMOS output?

ELECTRICAL CHARACTERISTICS:
High-Voltage Operation, V_S = ±4 V to ±18 V (V_S = +8 V to +36 V) (continued)

At T_A = +25°C, R_L = 10 kΩ connected to V_S / 2[1], and V_{CM} = V_{OUT} = V_S / 2[1], unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT					
Voltage output swing from rail	No load		6	15	mV
	R_L = 10 kΩ		220	250	mV
	T_A = –40°C to +125°C		310	350	mV

Output Saturation or Slam Test shows < 300mV to the rail at light load (10kΩ) and <<100mV at no load.

OPA188 Aol Test

ELECTRICAL CHARACTERISTICS:
High-Voltage Operation, V_S = ±4 V to ±18 V (V_S = +8 V to +36 V)

At T_A = +25°C, R_L = 10 kΩ connected to V_S / 2[(1)], and V_{CM} = V_{OUT} = V_S / 2[(1)], unless otherwise noted.

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	(V–) + 0.5 V < V_O < (V+) – 0.5 V	130	136		dB
		(V–) + 0.5 V < V_O < (V+) – 0.5 V, T_A = –40°C to +125°C	120	126		dB

$$Vout = (V+) - 0.5V$$

$$Vout = 18V - 0.5V = 17.5V$$

$$RL = 10k\Omega$$

$$Iout = \frac{Vout}{RL}$$

$$Iout = \frac{17.5V}{10k\Omega} = 1.75mA$$

$$Rds\_on = \frac{(V+) - Vout}{Iout} = \frac{18V - 17.5V}{1.75mA} = 285.7\Omega$$

OPA188 Claw Curves (they look like a Lobster Claw!)

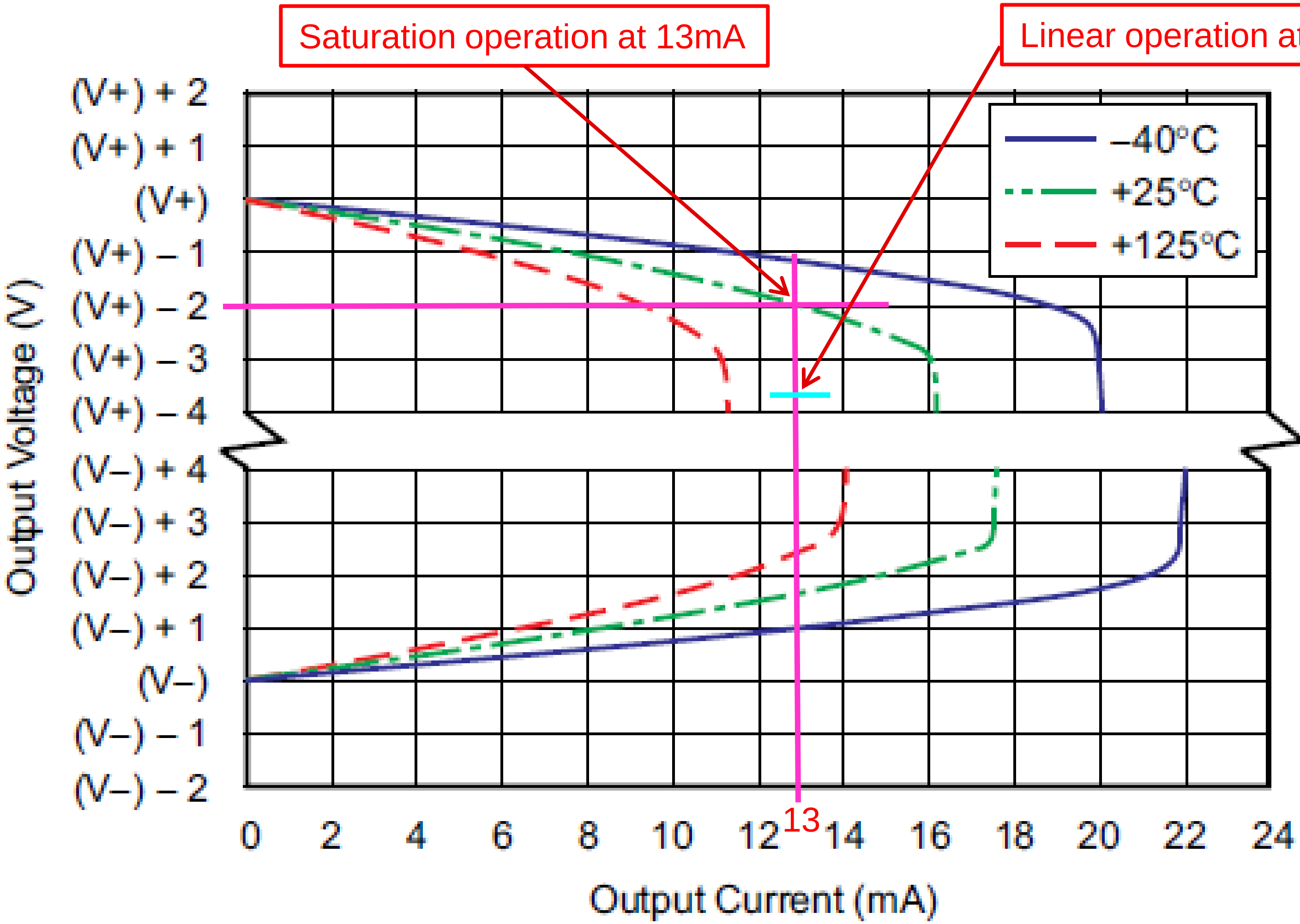


Figure 12. OUTPUT VOLTAGE SWING vs OUTPUT CURRENT (Maximum Supply)

OPA188 Claw Curve vs Linear Operation at 13mA

From Aol Test :

$$Rds\_on = 285.7\Omega$$

$$Iout = 13mA$$

$$Vdrop\_rds = Iout * Rds\_on$$

$$Vdrop\_rds = 13mA * 285.7\Omega = 3.7V$$

$$Vdrop\_claw = 2V @ 13mA$$

For Linear Operation at 13mA use Vdrop_rds = 3.7V

Bipolar Emitter Follower Output Stage and Linear Vout Region

OPA227 –
How do we know it is Bipolar Emitter Follower output?

OUTPUT						
Voltage Output	R_L = 10 kΩ	(V–)+2	(V+)–2	(V–)+2	(V+)–2	V
	R_L = 10 kΩ	(V–)+2	(V+)–2	(V–)+2	(V+)–2	V
	T_A = –40°C to 85°C					
	R_L = 600 Ω	(V–)+3.5	(V+)–3.5	(V–)+3.5	(V+)–3.5	V
	R_L = 600 Ω	(V–)+3.5	(V+)–3.5	(V–)+3.5	(V+)–3.5	V
	T_A = –40°C to 85°C					

Output Saturation or Slam Test shows >1.5V to the rail at light load (10kΩ)

OPA227 Aol Test

6.6 Electrical Characteristics: OPAx227 Series (V_S = ±5 V to ±15 V)

At T_A = 25°C, and R_L = 10 kΩ, unless otherwise noted.

PARAMETER		TEST CONDITIONS	OPA227P, U OPA2227P, U			OPA227PA, UA OPA2227PA, UA OPA4227PA, UA			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
OPEN-LOOP GAIN									
A_{OL}	Open-Loop Voltage Gain	V_O = (V–)+2 V to (V+)–2 V, R_L = 10 kΩ	132	160		132	160		dB
		T_A = –40°C to 85°C	132			132			dB
		V_O = (V–)+3.5V to (V+)–3.5 V, R_L = 600 Ω	132	160		132	160		dB
		T_A = –40°C to 85°C	132			132			dB

Aol Test (10kΩ) :

$$Vout = (V-) + 2V$$

$$Vout = -15V + 2V = -13V$$

$$RL = 10k\Omega$$

$$Iout = \frac{Vout}{RL}$$

$$Iout = \frac{-13V}{10k\Omega} = -1.3mA$$

Aol Test (600Ω) :

$$Vout = (V-) + 3.5V$$

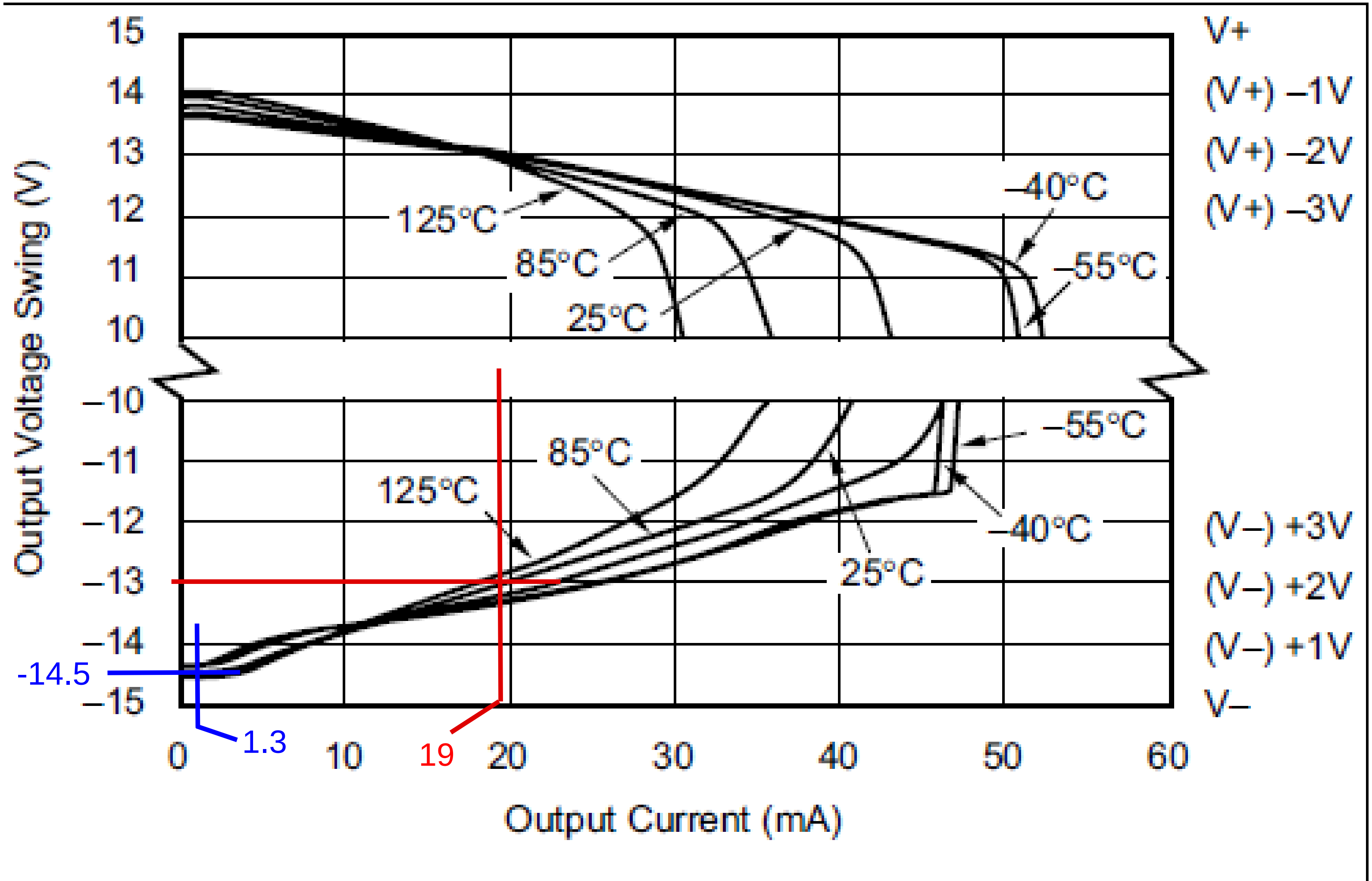
$$Vout = -15V + 3.5V = -11.5V$$

$$RL = 600\Omega$$

$$Iout = \frac{Vout}{RL}$$

$$Iout = \frac{-11.5V}{600\Omega} = -19.17mA$$

OPA227 Claw Curves (they look like a Lobster Claw!)



OPA227 Claw Curve vs Linear Operation

OPA227	Vdrop	Vdrop
Iout	**Aol**	**Claw**
1.3mA	2V	0.5V
19mA	3.5V	2V

Vdrop_Linear = Vdrop_Claw + 1.5V

Bipolar Collector Output Stage and Linear Vout Region

OPA211 –
How do we know it is Bipolar Emitter Follower output?

ELECTRICAL CHARACTERISTICS: V_S = ±2.25V to ±18V (continued)

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +125°C.
At T_A = +25°C, R_L = 10kΩ connected to midsupply, V_{CM} = V_{OUT} = midsupply, unless otherwise noted.

PARAMETER		CONDITIONS	Standard Grade OPA211AI, OPA2211AI			High Grade OPA211I[1]			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
OUTPUT									
Voltage Output	V_{OUT}	**R_L = 10kΩ, A_{OL} ≥ 114dB**	**(V–) + 0.2**		**(V+) – 0.2**	**(V–) + 0.2**		**(V+) – 0.2**	**V**
		R_L = 600Ω, A_{OL} ≥ 110dB	(V–) + 0.6		(V+) – 0.6	(V–) + 0.6		(V+) – 0.6	V
		I_O < 15mA, A_{OL} ≥ 110dB	**(V–) + 0.6**		**(V+) – 0.6**	**(V–) + 0.6**		**(V+) – 0.6**	**V**

Output Saturation or Slam Test shows <300mV to the rail at light load (10kΩ). Not as small as CMOS RRO unloaded (<100mV) but not as large as Bipolar emitter follower output (2V).

OPA211 –
How do we know it is Bipolar Collector output?

Also because of the simplified schematic in the datasheet !

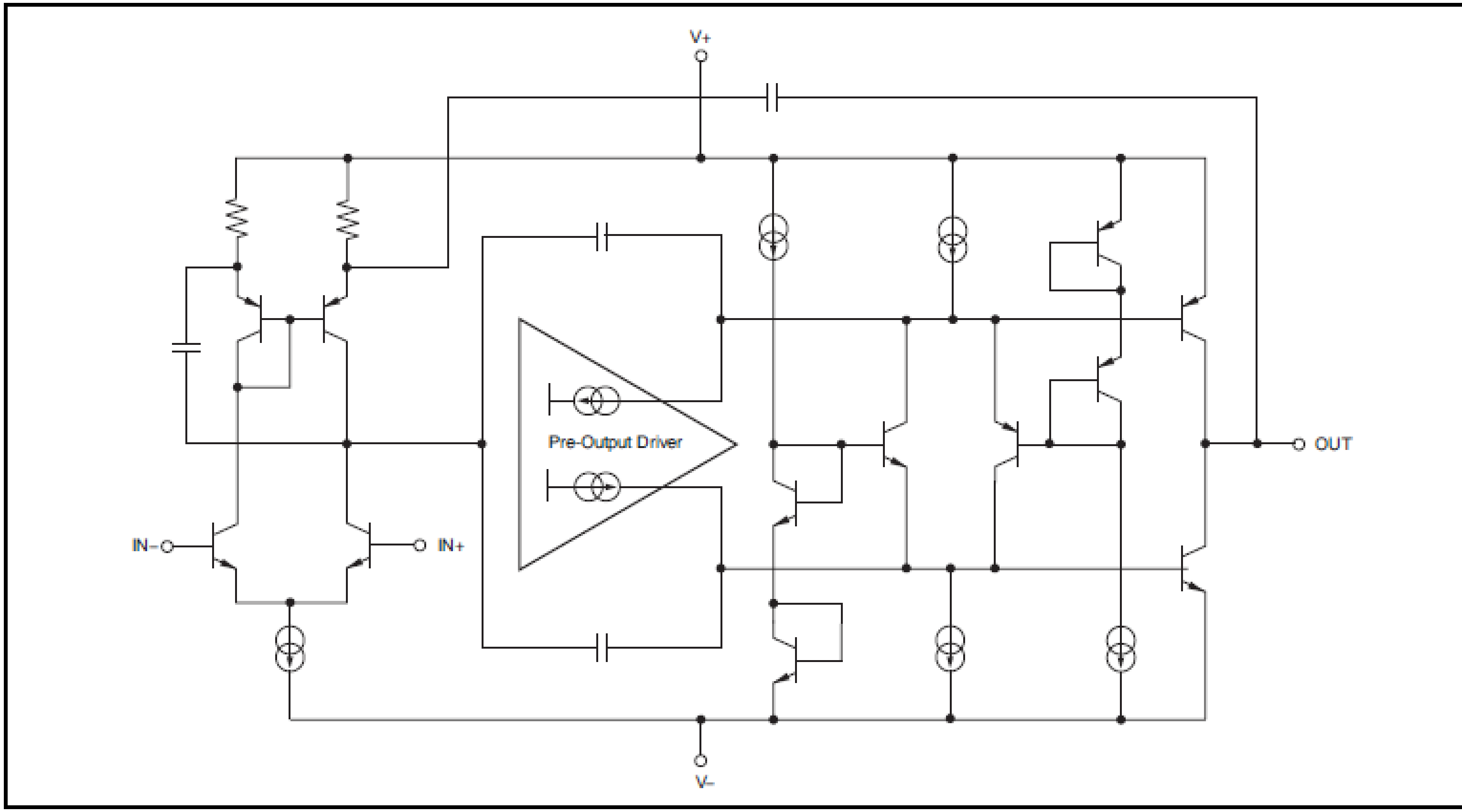


Figure 44. OPA211 Simplified Schematic

OPA211 Aol Test

ELECTRICAL CHARACTERISTICS: V_S = ±2.25V to ±18V

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +125°C.
At T_A = +25°C, R_L = 10kΩ connected to midsupply, V_{CM} = V_{OUT} = midsupply, unless otherwise noted.

OPEN-LOOP GAIN									
Open-Loop Voltage Gain	A_{OL}	(V–) + 0.2V ≤ V_O ≤ (V+) – 0.2V, R_L = 10kΩ	114	130		114	130		dB
	A_{OL}	(V–) + 0.6V ≤ V_O ≤ (V+) – 0.6V, R_L = 600Ω	110	114		110	114		dB
Over Temperature									
OPA211	A_{OL}	(V–) + 0.6V ≤ V_O ≤ (V+) – 0.6V, I_O ≤ 15mA	**110**			**110**			**dB**
OPA211	A_{OL}	(V–) + 0.6V ≤ V_O ≤ (V+) – 0.6V, 15mA ≤ I_O ≤ 30mA	**103**			**103**			**dB**
OPA2211 (per channel)	A_{OL}	(V–) + 0.6V ≤ V_O ≤ (V+)–0.6V, I_O ≤ 15mA	**100**						**dB**

Aol Test (10kΩ):

$$Vout = (V+) - 0.2V$$

$$Vout = 18V - 0.2V = 17.8V$$

$$RL = 10k\Omega$$

$$Iout = \frac{Vout}{RL}$$

$$Iout = \frac{17.8V}{10k\Omega} = 1.78mA$$

Aol Test (600Ω):

$$Vout = (V+) - 0.6V$$

$$Vout = 18V - 0.6V = 17.4V$$

$$RL = 600\Omega$$

$$Iout = \frac{Vout}{RL}$$

$$Iout = \frac{17.4V}{600\Omega} = 29mA$$

From OPA211 Aol Test

$$\text{Aol Test } (10k\Omega) \rightarrow \text{Vdrop\_10k} = 0.2V\ @\ 1.78mA$$

$$\text{Aol Test } (600\Omega) \rightarrow \text{Vdrop\_600} = 0.6V\ @\ 29mA$$

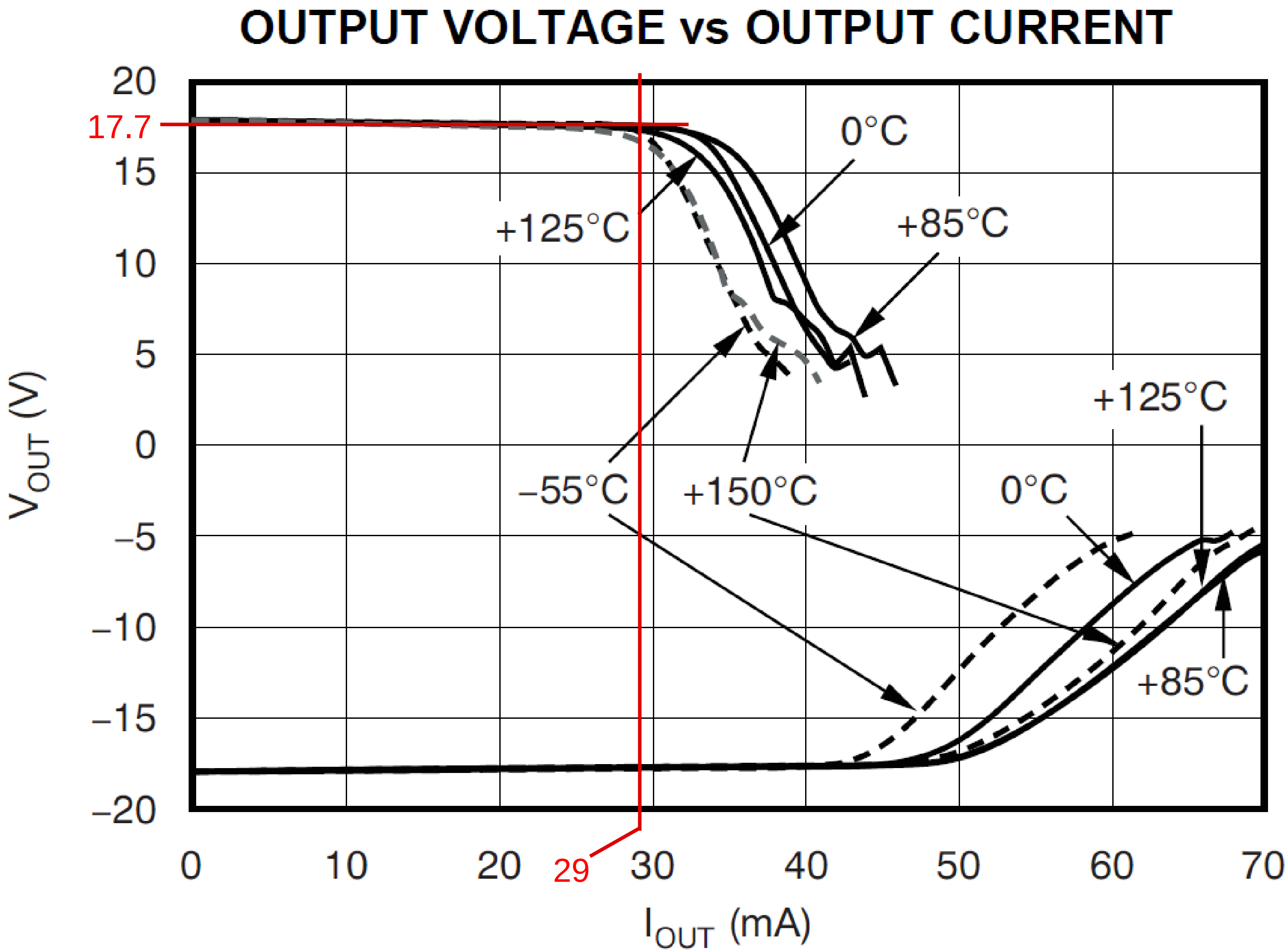
Rc (collector output resistance) :

$$Rc = \frac{\text{Vdrop\_600} - \text{Vdrop\_10k}}{\text{Iout\_600}}$$

$$Rc = \frac{0.6V - 0.2V}{29mA} = 13.8\Omega$$

$$\text{Vdrop\_Linear} = \text{Iout} * Rc + 0.2V$$

OPA211 Claw Curves (they look like a Lobster Claw!)



OPA211 Claw Curve vs Linear Operation

OPA211	Vdrop	Vdrop
Iout	**Aol**	**Claw**
29mA	0.6V	0.3V

Vdrop_Linear = (Iout * Rc) + 0.2V
Rc for OPA211 = 13.8Ω