VTC Incorporated

VA2703

T-79-40

DUAL HIGH-SPEED OPERATIONAL TRANSCONDUCTANCE AMPLIFIER WITH LINEARIZING DIODES

FEATURES

- Dual Version of VA703
- Low Offset Voltage: 0.5mV
- Linearizing Diodes
- Wide Open-Loop Bandwidth: 75MHz
- Large Output Swing: ±4V with 5V supplies
- Large Output Current: ±5mA
- Adjustable/Gatable Current-Controlled Gain
- Available in Commercial Version

APPLICATIONS

- Multiplexers
- Sample/Hold Circuits
- Current-Controlled Filters
- Multiplier

DESCRIPTION

The VA2703 is a dual high-speed operational transconductance amplifier with the added features of current-controlled gain and input linearizing diodes. The complementary bipolar process employed with this device combines excellent DC and AC characteristics. Offset voltages are typically 0.5mV while the wideband transistor characteristics provide stable, well-behaved amplifier configurations to 50MHz. The linearizing diodes are used to minimize distortion for high input level applications. The VA2703 is extremely versatile for use in applications such as current-controlled amplifiers, multipliers, sample/hold circuits and VCOs.

ABSOLUTE MAXIMUM RATINGS

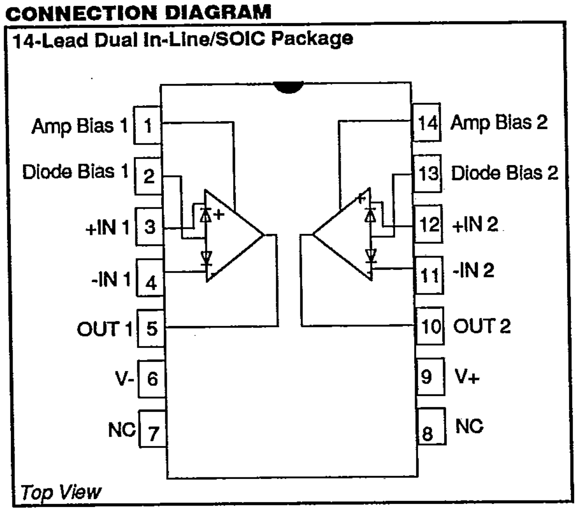
Supply Voltages	±6V
Differential Input Voltage	±4.5V
Common Mode Input Voltage	±V_S
Amp Bias Current	10mA
Diode Bias Current	10mA
Power Dissipation (T_A=70°C, Note 1)	550mW
Output Short Circuit Current Duration	Indefinite
Operating Temperature Range: VA2703J	0°C to 70°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering to 60 Sec.)	300°C

Note 1: Power derating above T_A = 70°C to be based on a maximum junction temperature of 150°C and the thermal resistance factors of θ_{JC} = 75°C/W and θ_{JA} = 145°C/W.

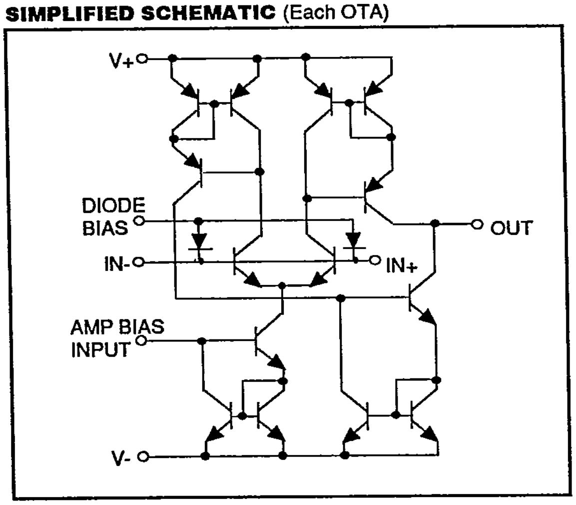
PACKAGE TYPES AVAILABLE

- 14-Pin Plastic DIP
- 14-Pin SOIC

CONNECTION DIAGRAM



SIMPLIFIED SCHEMATIC (Each OTA)



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ELECTRICAL CHARACTERISTICS (V_S=±5V, T_A=25°C, I_{ABC} = 500µA, unless otherwise specified) (Note 1)

PARAMETER	SYMBOL	CONDITION		VA2703J MIN	TYP	MAX	UNITS
Input Offset Voltage	V_{OS}	I_{ABC} =5µA to 5mA			1	5	mV
		T_A =0° to 70°C				8	mV
		T_A =-55° to +125°C					mV
Offset Voltage Change	ΔV_{OS}	I_{ABC} =5µA to 5mA			3	5	mV
Input Bias Current	I_B				2.5	5	µA
		T_A=0° to 70°C				8	µA
		T_A =-55° to +125°C					µA
Input Offset Current	I_{OS}				0.12	0.6	µA
Differential Input Current	I_{DIFF}	I_{ABC} =0, V_{DIFF} =±3V			10	200	nA
Common Mode Range	V_{CM}			±2.75	+4 -3.3		V
Leakage Current	I_{LEAK}	I_{ABC}=0, V_{TP} =0V I_{ABC}=0, V_{TP} =10V	(Figure 1)		5 2	100 100	nA nA
Differential Input Capacitance	C_{IND}				4		pF
Differential Input Resistance	R_{IND}	(Note 5)		10	26		KΩ
Common Mode Input Capacitance	C_{INC}				3		pF
Common Mode Input Resistance	R_{INC}	V_{CM} =±2.75V			1		MΩ
Forward Transconductance (Large Signal)	g_m	I_o =±120µA		7700	9900	15000	µmho
			T_A = Full	4000			µmho
Common Mode Rejection Ratio	CMRR	ΔV_{CM}= ±2.75V		80	110		dB
Open Loop Bandwidth	BW	(Figure 2 a,b)	f - 3dB		75		MHz
			Ø(45°)		35		MHz
Output Voltage Swing	V_{OUT}	I_{ABC} =5µA to 5mA, R_L=∞		±3.5	±4.25		V
Output Current	I_{OUT}	R_L =0		350	500	750	µA
		I_{ABC} =5µA, R_L =0		3	5	7	µA
		T_A = Full		300			µA
Output Capacitance	C_{OUT}				3		pF
Output Resistance	R_{OUT}	V_o =±3.5V			0.5		MΩ
Slew Rate	SR	Unity Gain (Figure 3, Note 2)			50		V/µs
Total Input Noise Voltage	e_N	BW = 10Hz to 100kHz (Figure 4)			3		µVrms
Positive Supply Current	I_{S+}	Both OTAs (Note 3)		1.6	2	3	mA
Power Supply Rejection Ratio	PSRR	ΔV_{ps} =±0.5V		70	86		dB
Amplifier Bias Voltage	V_{ABV}	Measured Pin 1(14) wrt Pin 6 (Note 4)			1.5		V
Diode Voltage	V_D	Pin 2 wrt Pin 3, 4 (Com), I_2= 2mA Pin 13 wrt Pin 11,12 (Com) I_{13} =2mA (Note 4)			0.75		V

Notes:
1. I_{ABC}= (Amplifier Bias Current) The current supplied to the amplifier bias terminal to establish its operating point.
2. Slew Rate = f(I_{ABC}) per $SR = \frac{\Delta V_O}{\Delta t} = \frac{I_O}{C_L} \approx \frac{I_{ABC}}{C_L}$ where C_L=Total Load Capacitance
3. Negative Supply Current (I_{S-}) = $I_{S+} + 2 \cdot I_{ABC}$
4. Dual in-line pins used for reference
5. Not tested, guaranteed by design.

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TEST CIRCUITS

Figure 1: Leakage Current

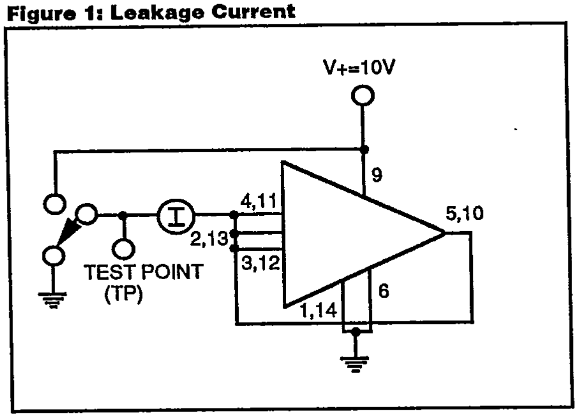


Figure 3: Slew Rate

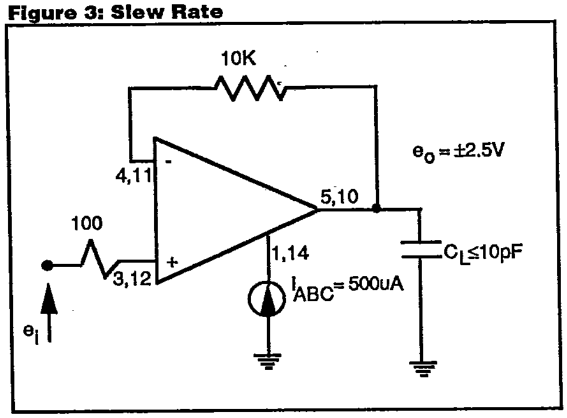


Figure 2: Open Loop Bandwidth

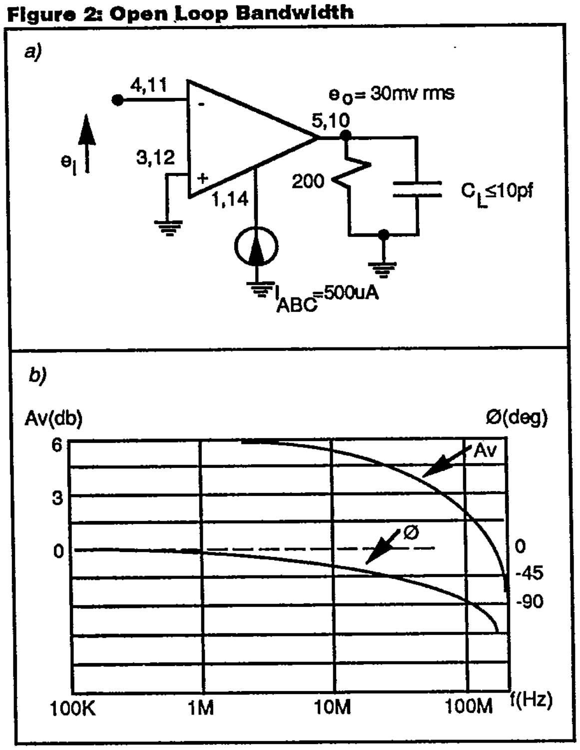
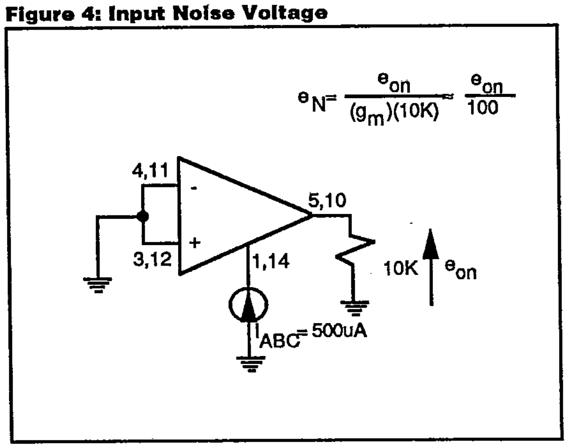


Figure 4: Input Noise Voltage



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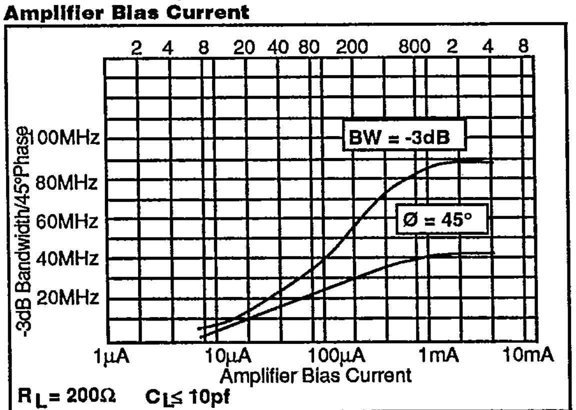
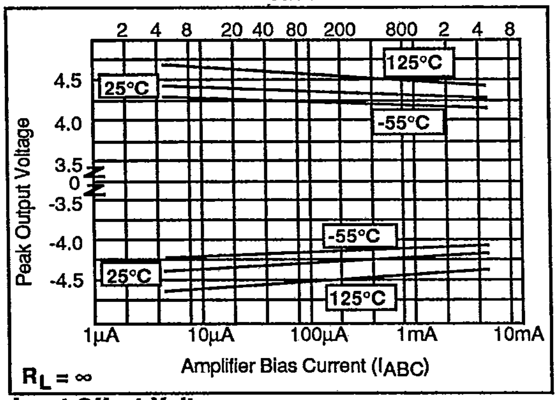
TYPICAL PERFORMANCE CHARACTERISTICS (V_S= ±5V, T_A = 25° C unless otherwise stated)

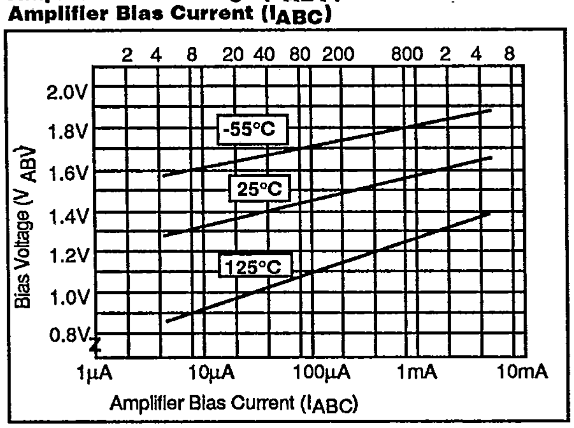
-3dB Bandwidth/45° Phase vs Amplifier Bias Current



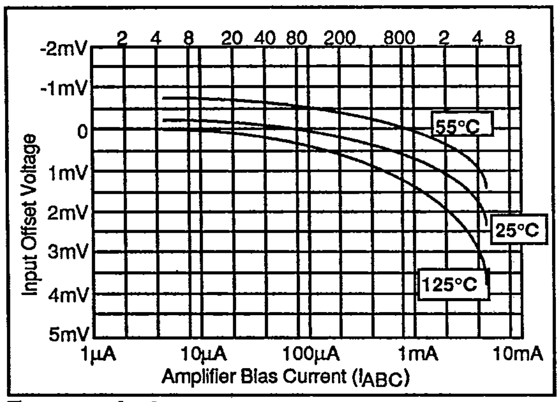
Peak Output Voltage vs Amplifier Bias Current (I_{ABC})



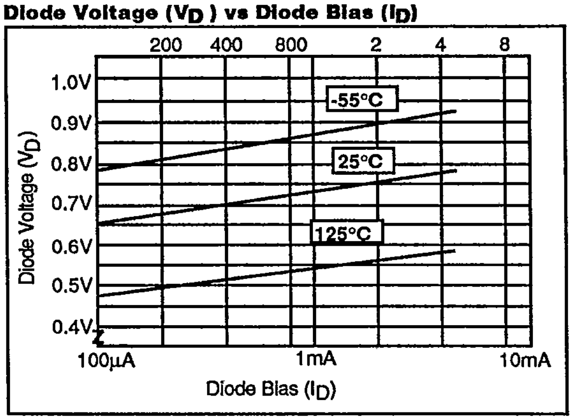
Amplifier Bias Voltage (V_{ABV}) vs Amplifier Bias Current (I_{ABC})



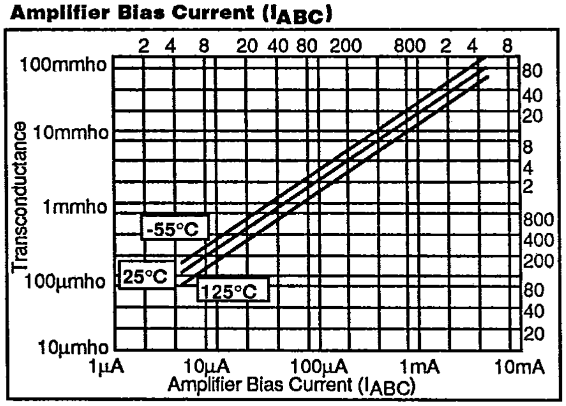
Input Offset Voltage vs Amplifier Bias Current (I_{ABC})



Diode Voltage (V_D) vs Diode Bias (I_D)



Transconductance vs Amplifier Bias Current (I_{ABC})



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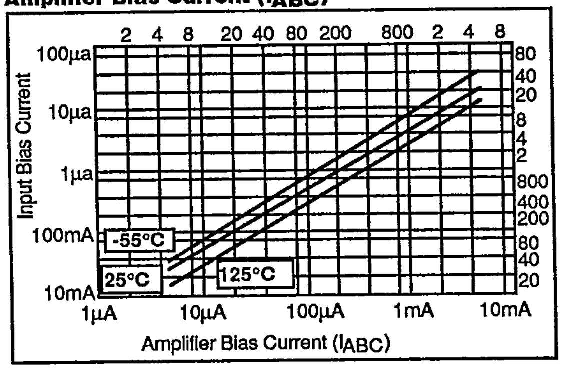
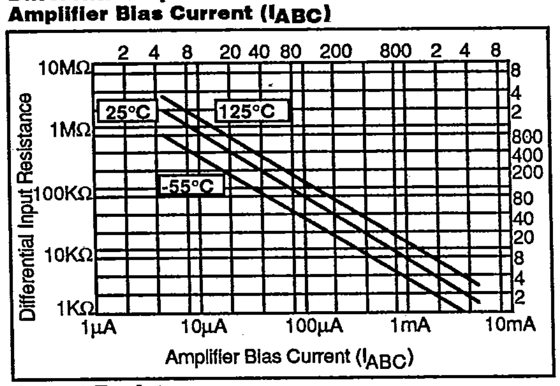
TYPICAL PERFORMANCE CHARACTERISTICS (V_S= ±5V, T_A = 25° C unless otherwise stated)

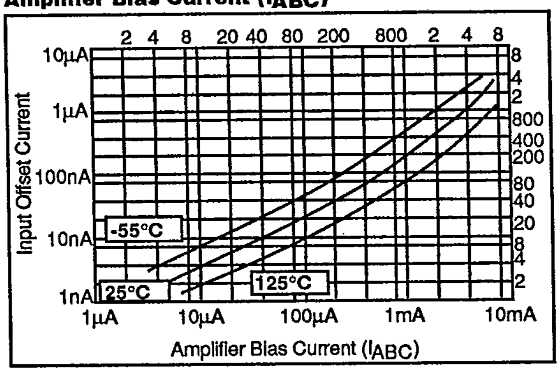
Input Bias Current vs Amplifier Bias Current (I_{ABC})



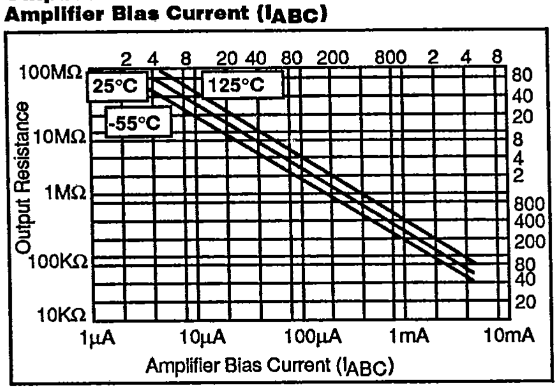
Differential Input Resistance vs Amplifier Bias Current (I_{ABC})



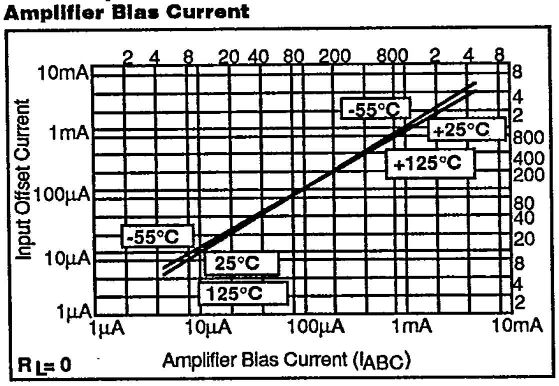
Input Offset Current vs Amplifier Bias Current (I_{ABC})



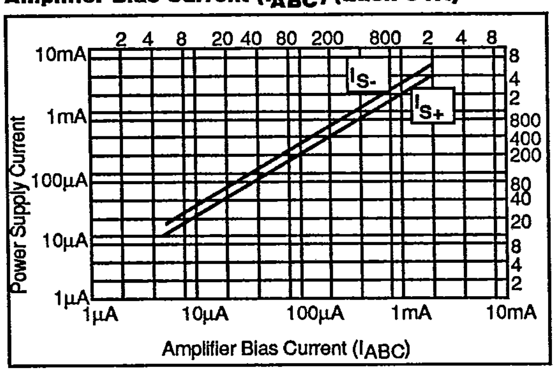
Output Resistance vs Amplifier Bias Current (I_{ABC})



Peak Output Current vs Amplifier Bias Current



Power Supply Current vs Amplifier Bias Current (I_{ABC}) (Each OTA)



APPLICATION INFORMATION

Design Equations

The operational transconductance amplifier (OTA) produces an output current proportional to the differential voltage (V_D) applied at the input according to:

$$I_o = g_m(V_{in+} - V_{in-}) = g_m V_D$$

In addition, the OTA gain (g_m) can be conveniently controlled with an external bias current I_{ABC} to yield:

$$I_o = \frac{I_{ABC}}{2V_T} \cdot V_D$$

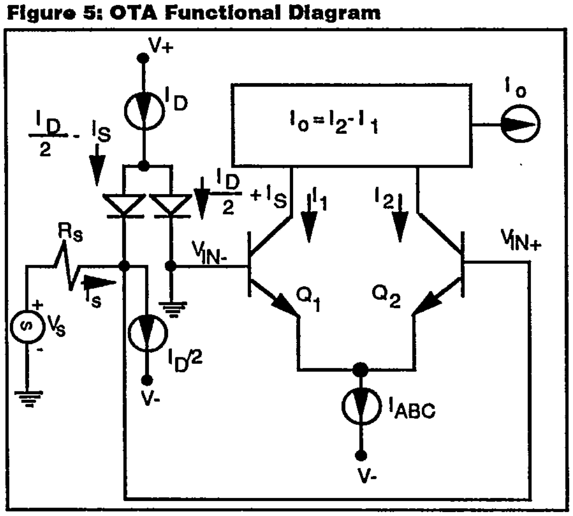
$$\text{where } g_m = \frac{I_{ABC}}{2V_T}$$

$$V_T = \text{Thermal Voltage} = \frac{KT}{q} \approx 26\text{mV at } 25°\text{C}$$

Thus, the OTA becomes a very versatile building block. At a constant I_{ABC}, all of the standard operational amplifier circuits can be configured while modulation of I_{ABC} provides for such functions as current controlled active filters, sample/hold amplifiers and multipliers.

The defining equation $I_o = g_m V_D$ becomes increasingly non-linear as the input differential voltage (V_D) becomes greater than a few millivolts. In many applications the linearizing diodes can be used to minimize this non-linearity and resulting signal distortion. To understand the use of the linearizing diodes, some basic equations need to be developed. Figure 5 represents the basic functional parts of the OTA. For convenience, the diodes are shown biased with ideal current sources while in practice resistor biasing can be used with very good results.

Figure 5: OTA Functional Diagram



Without the linearizing diodes (I_D=0), the input voltage V_s is seen at V_{IN+} based upon voltage divider action between the source impedance R_s and the differential input resistance of Q_1 and Q_2.

$$\text{where } R_{IND} \approx \beta(r_{e1} + r_{e2})$$

$$\text{and } r_e = \frac{2}{I_{ABC}} \cdot V_T,\ \beta = \text{current gain}$$

$$\text{since } V_T \approx 26\text{mV at } 25°\text{C}$$

$$R_{IND} = \frac{104\beta}{I_{ABC(mA)}}$$

ex: at $I_{ABC} = 1\text{mA}$
$\beta = 100$
$R_{IND} = 10 \cdot 4\text{K}$

The current distribution in Q_1 and Q_2 is governed by:

$$V_D = V_{IN+} - V_{IN-} = V_T \ln \frac{I_2}{I_1}$$

For small differential input voltages $I_1 \approx I_2$, and $\ln \frac{I_2}{I_1}$ can be represented in the Taylor series expansion as:

$$\ln \frac{I_2}{I_1} = \frac{I_2 - I_1}{I_1} = \frac{I_o}{I_1}$$

$$\text{and since } I_1 \approx I_2 \approx \frac{I_{ABC}}{2}$$

$$V_D = 2V_T \cdot \frac{I_o}{I_{ABC}}$$

$$I_o = \frac{I_{ABC}}{2} \cdot \frac{V_D}{V_T}$$

It is the $I_1 \approx I_2$ assumption that limits the accuracy of the $\frac{I_o}{V_D}$ equation to small values of input voltage (V_D). Even with an input voltage as small as $V_D = V_T = 26\text{mV}$, the I_2/I_1 ratio = 2.7.

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With a bias (I_D) applied to the linearizing diodes a low impedance shunt based upon the dynamic resistance of the diodes is placed across differential pair Q_1 and Q_2. This shunting action is what linearizes the output current as a function of input voltage (current) $V_S(I_S)$. Looking at the defining equations:

I_1 and I_2 can be expressed as:

$$I_2 = \frac{I_{ABC} + I_o}{2}, \quad I_1 = \frac{I_{ABC} - I_o}{2}$$

and since the diodes and Q_1, Q_2 are of the same geometry and see the same temperatures, the diode and transistor currents can be equated according to

$$V_T \ln \frac{I_D/2 + I_S}{I_D/2 - I_S} = V_T \ln \frac{I_{ABC} + I_o}{I_{ABC} - I_o}$$

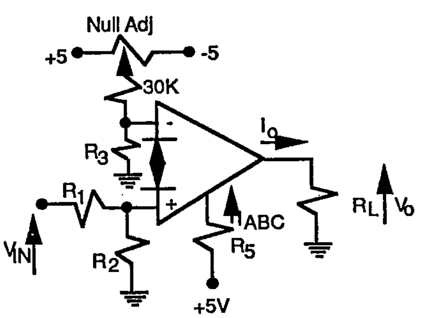
solving for I_o yields:

$$I_o = \frac{2 I_S I_{ABC}}{I_D}$$

An interesting result is that no assumptions have been made to affect linearity other than the diodes be biased (I_D) and modulated (I_S) with current sources and the diodes be kept in conduction $|I_D| < I_S/2$. The output current is also independent of temperature.

Figures 6 a, b and c illustrate the effects of using the linearizing diodes in an open loop amplifier configuration with a large signal voltage gain of approximately 1V/V. The transfer curve compares circuit operation with and without the diodes. Corresponding total harmonic distortion (THD) for a 3Vp-p 1KHz output sine wave is 5% for the non-diode case and 0.6% with linearizing diodes. For closed loop configurations, the linearizing diodes generally are not used since the degenerative feedback keeps the input differential voltage at small values.

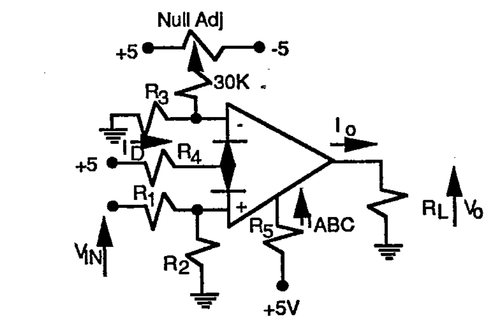
Figure 6a: Open Loop Amplifier Without Diodes



$$V_o / V_{IN} \approx \frac{R_2}{R_1 + R_2} \cdot \frac{R_L I_{ABC}}{2V_T}$$

$$I_{ABC} \approx \frac{8.5}{R_5}$$

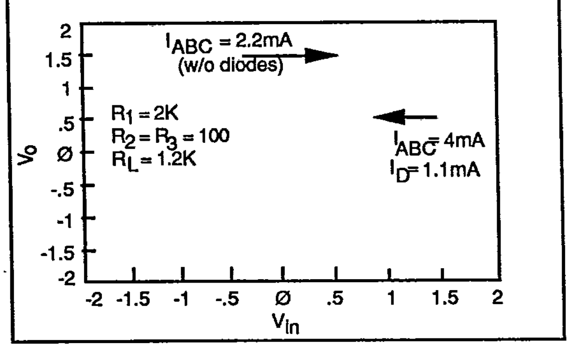
Figure 6b: Open Loop Amplifier With Diodes



$$V_o / V_{IN} \approx \frac{R_2}{(R_1 + R_2)} \cdot \frac{1}{(R_1 // R_2 + 2r_d + R_3)} \cdot \frac{2 R_L I_{ABC}}{I_D}$$

$$I_D \approx \frac{+5 - V_D}{R_4 + R_2/2}, \quad R_2 = R_3$$

Figure 6c: Linearity Profile With and Without Diodes



It is instructive to look more closely at the defining I_S equation when the linearizing diodes are used to see how well the current source assumption and attendant linearity are being met in practice.

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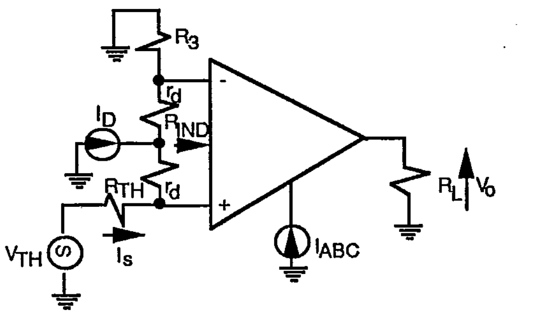
Referring to Figure 6b, the equivalent circuit can be reduced to Figure 7 below.

Figure 7: Equivalent Circuit (Figure 6b)



$$V_{TH} = \frac{V_{IN} R_2}{R_1 + R_2} \qquad R_{TH} = R_1 /\!/ R_2$$

r_d = dynamic resistance of diodes $= \dfrac{V_T}{\frac{I_D \pm I_S}{2}}$

$= \dfrac{26\Omega}{\frac{I_D \pm I_S}{2}}$ at 25°C, with I_D in mA

where $I_D \approx \dfrac{4.25}{R_4 + R_2/2}$ and $R_2 = R_3$

since $2r_d << R_{IND}$

$$I_S = \frac{V_{TH}}{R_{TH} + 2r_d + R_3} = \frac{V_{IN} R_2}{R_1 + R_2} \cdot \frac{1}{R_{TH} + 2r_d + R_3}$$

As the equations in Figure 7 indicate, to maximize linearity and minimize temperature effects, R_D should be kept small wrt $R_{TH} + R_3$ and I_S modulation current small wrt $I_D/2$.

In practice, I_D values from 1mA to 5mA are the best choice for most applications.

60MHz Unity Gain Follower

Figure 8a is a unity gain follower configuration which emphasizes the basic speed capability of the VA2703. As illustrated in Figures 8b and 8c, small signal rise time = fall time = 5ns (measured small signal bandwidth ≈ 60MHz) and large signal (±2.5V) slew rate plus small signal settling is less than 200ns. R2 is used for phase recovery by introducing a zero at approximately 40MHz while C1 ensures high frequency rolloff at frequencies above 100MHz.

Figure 8a: 60MHz Unity Gain Follower

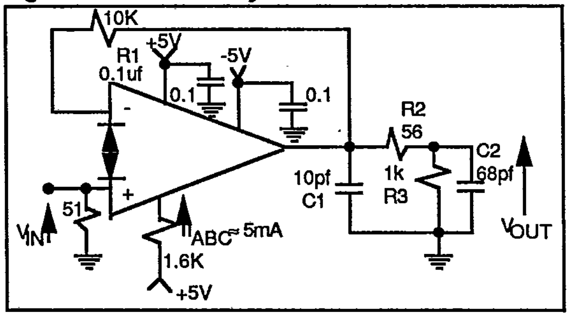


Figure 8b: Small Signal Step Response

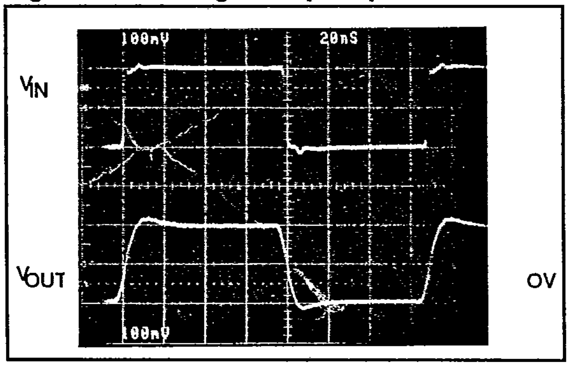
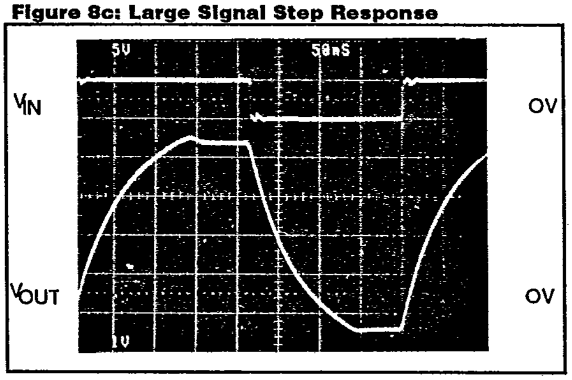


Figure 8c: Large Signal Step Response



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Amplitude Modulator

Figure 9a shows the transconductance amplifier operating as a 2 quadrant linearized multiplier to produce an amplitude modulated output waveform with defining equations:

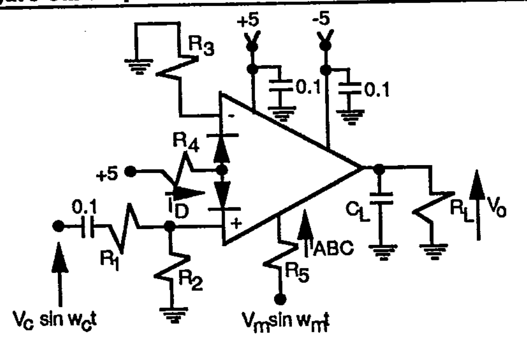
$$V_o = K_1 (V_c \sin w_c t \, V_m \sin w_m t + K_2 V_c \sin w_c t)$$

$$\text{where } K_1 = \frac{R_2}{R_1 + R_2} \cdot \frac{1}{R_1 // R_2 + 2rd + R_3} \cdot \frac{2R_L}{R_5} \cdot \frac{1}{I_D},$$

$$I_D \approx \frac{4.25}{R_4 + R_2/2} \text{ and } K_2 = 5 - V_{ABV} = 3.5,\ r_d \approx \frac{52}{I_{D(mA)}} \Omega$$

Figure 9b shows the input and output waveforms at a carrier frequency of $f_c = 1MHz$ and modulation frequency $f_m = 10kHz$. Since the basic OTA has a bandwidth in excess of 50MHz the circuit bandwidth is determined by the load time constant = $R_L (C_L + C_o)$. For the above example at $R_L = 2K$ and $C_L + C_o \approx 9pf$, the bandwidth = 4MHz. Attendant power bandwidth, (signal swing before distortion), being a function of C and I_{ABC} is actually larger than the small signal bandwidth. Power bandwidth = 5MHz at $V_o = 6Vp\text{-}p$.

Figure 9a: Amplitude Modulator



ex: With $R_1 = R_5 = 1K$, $R_2 = R_3 = 200$, $R_4 = R_L = 2K$

$K_1 = 0.8$ $K_2 = 3.5$

$V_o = 0.8 V_c \sin w_c t \, V_m \sin w_m t + 2.8 V_c \sin w_c t$

Layout Considerations

As with any high-speed circuitry, certain layout considerations are necessary if stable operation is to be ensured and performance is to be optimized. All connections to the OTA should be kept as short as possible including the power supplies which should be bypassed with 0.1µF capacitors, or better yet, a combination of 1µF - 10µF electrolytics/tantalums in parallel with a 0.01µF ceramic. It is suggested that a ground plane be considered as the best method of maximizing performance because it minimizes stray inductance and unwanted coupling in the ground signal paths. To minimize capacitive effects, resistor values should be kept as small as possible consistent with the application.

Figure 9b: Amplitude Modulator Waveforms