Smart Sensors for IoT
Exercise 5 (16.11.2022)

Christian Enz

Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland

Problem 1 Input bias and offset currents

The circuit of Fig. 1 is to be used as an inverting amplifier with a gain of 10 V/V and is to employ the μA741 op amp (the datasheet is appended at the end of the exercises).

- Specify suitable component values to ensure a maximum output error of 10 mV.

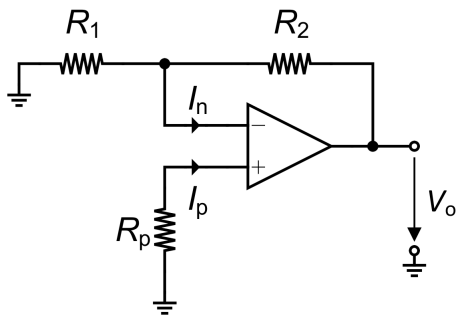


Figure 1: System to estimate the output error due to the input bias currents for the case of resistive feedback.

Problem 2 Common-Mode Rejection Ratio (CMRR)

The difference amplifier of Fig. 2 uses a μA741 op amp and a perfectly matched resistance set with $R_1 = R_3 = 10\,\text{k}\Omega$ and $R_2 = R_4 = 100\,\text{k}\Omega$. Suppose the inputs are tied together and driven with a common signal V_I . Estimate the typical change in V_O if:

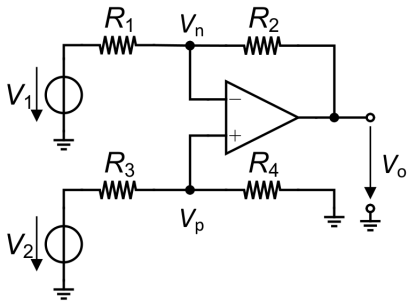


Figure 2: Difference amplifier.

- V_I is slowly changed from 0 to 10 V;
- V_I is a 10 kHz, 5 V 0-peak sine wave.

Hint: the output voltage can be rewritten as:

$$V_O = A_{dm}\left(V_{i+} - V_{i-} + \frac{A_{cm}}{A_{dm}}V_{ic}\right) \tag{1}$$

Problem 3 Power-Supply Rejection Ratio (PSRR)

A μA741 op amp is connected as in Fig. 1 with $R_1 = 100\,\Omega$ and $R_2 = 100\,\mathrm{k}\Omega$.

- Predict the typical as well as the maximum ripple at the output for a power-supply ripple ΔV_{DD} of 0.05 Vp at 120 Hz (assume ideal V_{SS}).

Hint: The μA741 datasheets do not show the PSRR rolloff with frequency, so let us use the ratings given at dc, keeping in mind that the results will be optimistic.

Problem 4 Single-Pole Open-Loop Gain

With respect to the non-ideal op-amp frequency response, we shall make the simplifying assumption that the open-loop gain $a(s)$ possesses just a single pole. Such a gain shall be expressed in the form:

$$a(s) = \frac{a_0}{1 + s/\omega_b} = \frac{a_0}{1 + jf/f_b}; \tag{2}$$

where s is the complex frequency, a_0 is the open-loop dc gain, and $-\omega_b$ is the s-plane pole location. Equivalently, in the second half of the equation, we express gain in terms of the frequency f, where j is the imaginary unit, and $f_b = \omega_b/(2\pi)$ is the open-loop −3-dB frequency, also called the open-loop bandwidth. We calculate gain magnitude and phase as:

$$|a(jf)| = \mathrm{mag}\, a(jf) = \frac{a_0}{\sqrt{1 + (f/f_b)^2}}; \tag{3}$$

$$\measuredangle a(jf) = \mathrm{ph}\, a(jf) = -\arctan(f/f_b). \tag{4}$$

Magnitude is plotted in Fig. 3. The gain is high and approximately constant only from dc up to f_b. Past f_b it rolls off at the rate of −20 dB/dec, until it drops to 0 dB (or 1 V/V) at $f = f_t$.

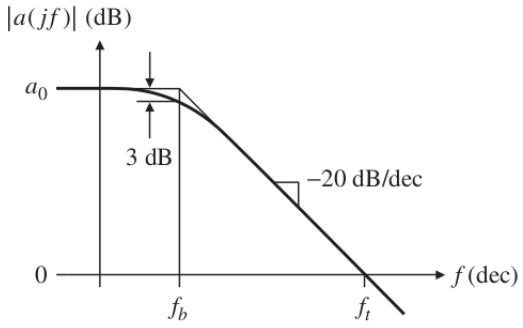


Figure 3: Single-pole open-loop gain.The frequency axis is on a logarithmic-base-10 scale.

- Calculate f_t by imposing $1 = a_0/\sqrt{1+(f_t/f_b)^2}$. *Hint: notice that* $f_t \gg f_b$
- According to the µA741 datasheet, what are the typical a_0 (called *large signal voltage gain*), f_b and f_t values?
- Calculate the module and phase of $a(s)$ when $f \ll f_b$, $f = f_b$ and $f \gg f_b$.
- Consider another amplifier than the µA741, which has a magnitude of 80 dB at $f = 10$ Hz and a phase angle of $-58°$ at $f = 320$ Hz. Estimate a_0, f_b, and f_t.

Problem 5 Slew rate

Suppose a µA741 op amp is configured as voltage follower (Fig. 4). We stress that SR is a nonlinear large-signal parameter, while t_R is a linear small-signal parameter. The critical output-step magnitude corresponding to the onset of slew-rate limiting is such that $V_{om(\text{crit})}/\tau = SR$. Since $\tau = 1/(2\pi f_t)$,

$$V_{om(\text{crit})} = \frac{SR}{2\pi f_t}. \tag{5}$$

- What are the SR, t_R, τ and $V_{om(\text{crit})}$ for the µA741 op amp?
- Investigate the response to an input step of 30 mV.
- Investigate the response to an input step of 0.8 V.

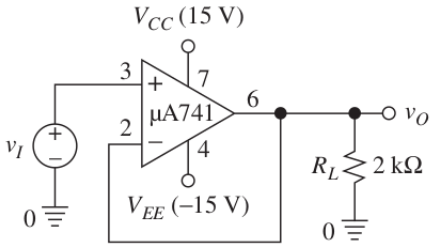


Figure 4: Voltage follower.

μA741

FREQUENCY-COMPENSATED OPERATIONAL AMPLIFIER

FAIRCHILD LINEAR INTEGRATED CIRCUIT

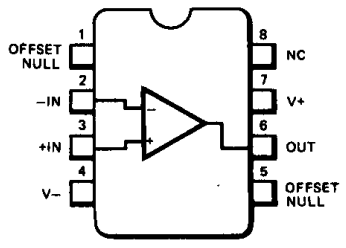
GENERAL DESCRIPTION — The μA741 is a high performance monolithic Operational Amplifier constructed using the Fairchild Planar* epitaxial process. It is intended for a wide range of analog applications. High common mode voltage range and absence of latch-up tendencies make the μA741 ideal for use as a voltage follower. The high gain and wide range of operating voltage provides superior performance in integrator, summing amplifier, and general feedback applications. Electrical characteristics of the μA741A and E are identical to MIL-M-38510/10101.

- **NO FREQUENCY COMPENSATION REQUIRED**
- **SHORT CIRCUIT PROTECTION**
- **OFFSET VOLTAGE NULL CAPABILITY**
- **LARGE COMMON MODE AND DIFFERENTIAL VOLTAGE RANGES**
- **LOW POWER CONSUMPTION**
- **NO LATCH-UP**

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	
μA741A, μA741, μA741E	±22 V
μA741C	±18 V
Internal Power Dissipation (Note 1)	
Metal Can	500 mW
Molded and Hermetic DIP	670 mW
Mini DIP	310 mW
Flatpak	570 mW
Differential Input Voltage	±30 V
Input Voltage (Note 2)	±15 V
Storage Temperature Range	
Metal Can, Hermetic DIP, and Flatpak	−65°C to +150°C
Mini DIP, Molded DIP	−55°C to +125°C
Operating Temperature Range	
Military (μA741A, μA741)	−55°C to +125°C
Commercial (μA741E, μA741C)	0°C to +70°C
Lead Temperature (Soldering)	
Metal Can, Hermetic DIPs, and Flatpak (60 s)	300°C
Molded DIPs (10 s)	260°C
Output Short Circuit Duration (Note 3)	Indefinite

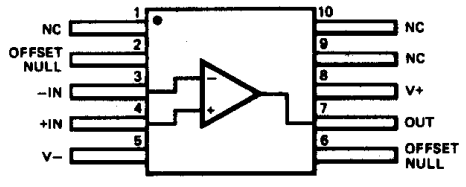
8-LEAD MINIDIP
(TOP VIEW)
PACKAGE OUTLINES 6T 9T
PACKAGE CODES T R



ORDER INFORMATION

TYPE	PART NO.
μA741C	μA741TC
μA741C	μA741RC

10-LEAD FLATPAK
(TOP VIEW)
PACKAGE OUTLINE 3F

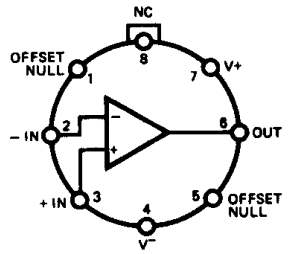


ORDER INFORMATION

TYPE	PART NO.
μA741A	μA741AFM
μA741	μA741FM

CONNECTION DIAGRAMS

8-LEAD METAL CAN
(TOP VIEW)
PACKAGE OUTLINE 5B

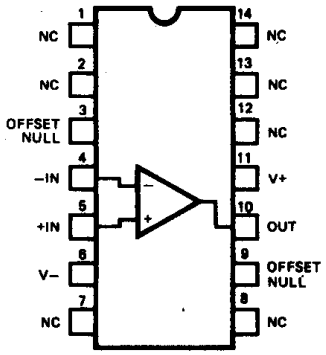


Note: Pin 4 connected to case

ORDER INFORMATION

TYPE	PART NO.
μA741A	μA741AHM
μA741	μA741HM
μA741E	μA741EHC
μA741C	μA741HC

14-LEAD DIP
(TOP VIEW)
PACKAGE OUTLINE 6A, 9A



ORDER INFORMATION

TYPE	PART NO.
μA741A	μA741ADM
μA741	μA741DM
μA741E	μA741EDC
μA741C	μA741DC
μA741C	μA741PC

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Notes on following pages.

*Planar is a patented Fairchild process.

μA741

ELECTRICAL CHARACTERISTICS (V_S = ±15 V, T_A = 25°C unless otherwise specified)

PARAMETERS (see definitions)		CONDITIONS	MIN	TYP	MAX	UNITS
Input Offset Voltage		$R_S \leq 10\ k\Omega$		1.0	5.0	mV
Input Offset Current				20	200	nA
Input Bias Current				80	500	nA
Input Resistance			0.3	2.0		MΩ
Input Capacitance				1.4		pF
Offset Voltage Adjustment Range				±15		mV
Large Signal Voltage Gain		$R_L \geq 2\ k\Omega$, V_{OUT} = ±10 V	50,000	200,000		
Output Resistance				75		Ω
Output Short Circuit Current				25		mA
Supply Current				1.7	2.8	mA
Power Consumption				50	85	mW
Transient Response (Unity Gain)	Rise time	V_{IN} = 20 mV, R_L = 2 kΩ, $C_L \leq 100$ pF		0.3		μs
	Overshoot			5.0		%
Slew Rate		$R_L \geq 2\ k\Omega$		0.5		V/μs

The following specifications apply for $-55°C \leq T_A \leq +125°C$:

Input Offset Voltage	$R_S \leq 10\ k\Omega$		1.0	6.0	mV
Input Offset Current	T_A = +125°C		7.0	200	nA
	T_A = −55°C		85	500	nA
Input Bias Current	T_A = +125°C		0.03	0.5	μA
	T_A = −55°C		0.3	1.5	μA
Input Voltage Range		±12	±13		V
Common Mode Rejection Ratio	$R_S \leq 10\ k\Omega$	70	90		dB
Supply Voltage Rejection Ratio	$R_S \leq 10\ k\Omega$		30	150	μV/V
Large Signal Voltage Gain	$R_L \geq 2\ k\Omega$, V_{OUT} = ±10 V	25,000			
Output Voltage Swing	$R_L \geq 10\ k\Omega$	±12	±14		V
	$R_L \geq 2\ k\Omega$	±10	±13		V
Supply Current	T_A = +125°C		1.5	2.5	mA
	T_A = −55°C		2.0	3.3	mA
Power Consumption	T_A = +125°C		45	75	mW
	T_A = −55°C		60	100	mW

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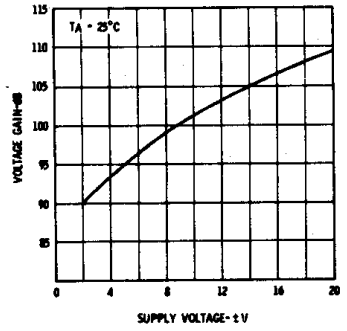
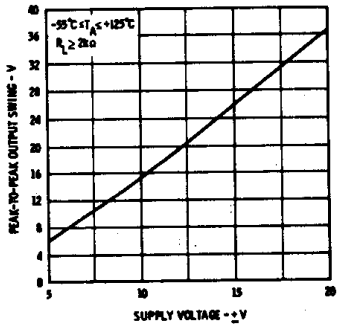
TYPICAL PERFORMANCE CURVES FOR μA741A AND μA741

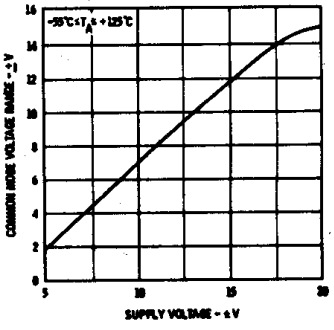
OPEN LOOP VOLTAGE GAIN AS A FUNCTION OF SUPPLY VOLTAGE



OUTPUT VOLTAGE SWING AS A FUNCTION OF SUPPLY VOLTAGE

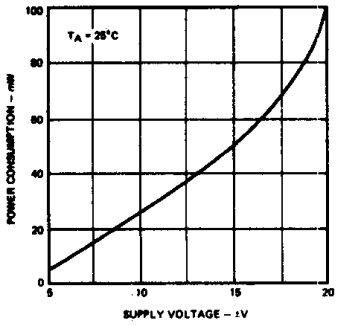


INPUT COMMON MODE VOLTAGE RANGE AS A FUNCTION OF SUPPLY VOLTAGE

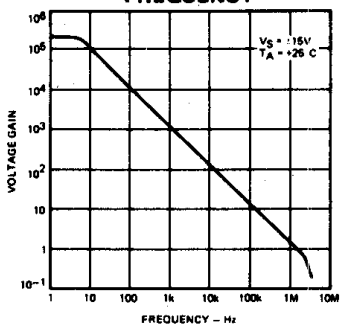


TYPICAL PERFORMANCE CURVES FOR μA741A, μA741, μA741E AND μA741C

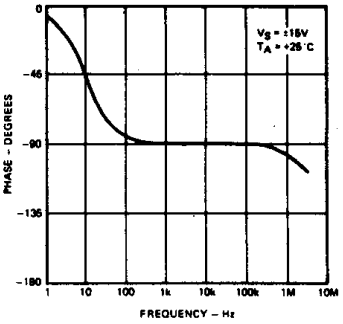
POWER CONSUMPTION AS A FUNCTION OF SUPPLY VOLTAGE



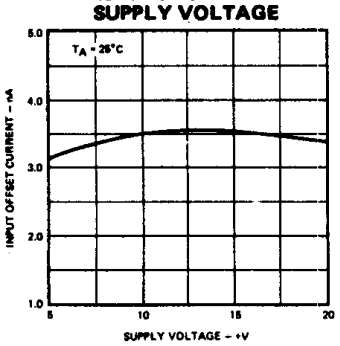
OPEN LOOP VOLTAGE GAIN AS A FUNCTION OF FREQUENCY



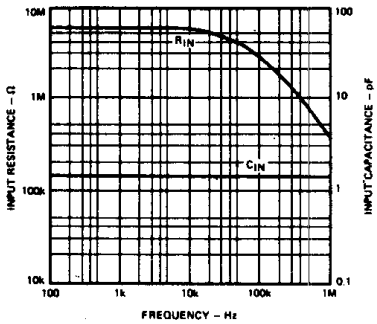
OPEN LOOP PHASE RESPONSE AS A FUNCTION OF FREQUENCY



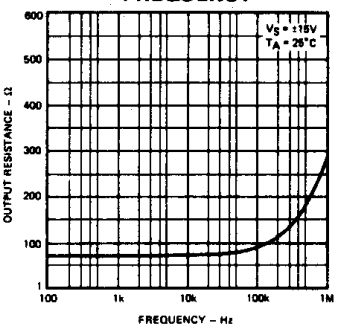
INPUT OFFSET CURRENT AS A FUNCTION OF SUPPLY VOLTAGE



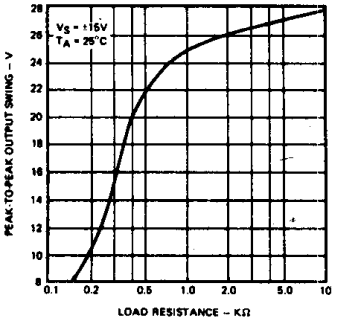
INPUT RESISTANCE AND INPUT CAPACITANCE AS A FUNCTION OF FREQUENCY



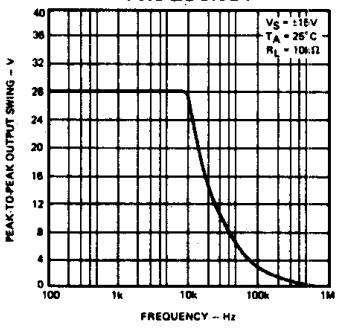
OUTPUT RESISTANCE AS A FUNCTION OF FREQUENCY



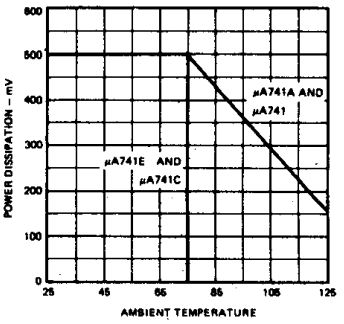
OUTPUT VOLTAGE SWING AS A FUNCTION OF LOAD RESISTANCE



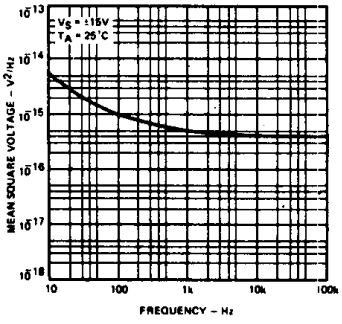
OUTPUT VOLTAGE SWING AS A FUNCTION OF FREQUENCY



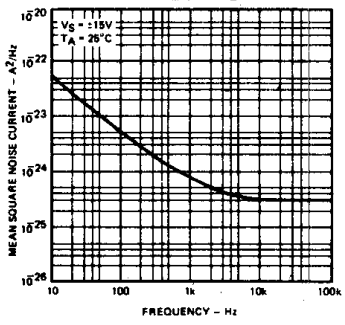
ABSOLUTE MAXIMUM POWER DISSIPATION AS A FUNCTION OF AMBIENT TEMPERATURE



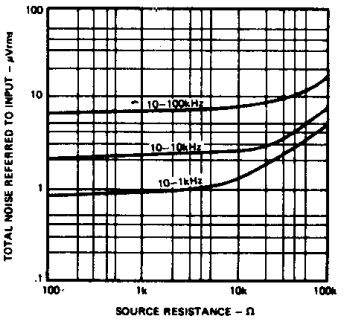
INPUT NOISE VOLTAGE AS A FUNCTION OF FREQUENCY



INPUT NOISE CURRENT AS A FUNCTION OF FREQUENCY

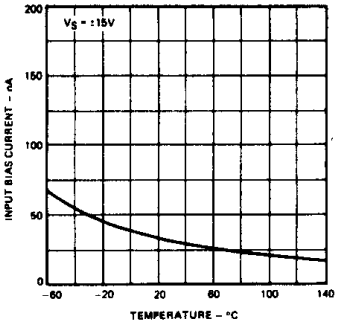


BROADBAND NOISE FOR VARIOUS BANDWIDTHS

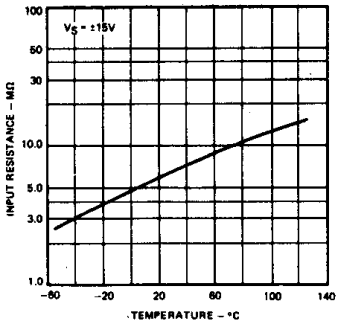


TYPICAL PERFORMANCE CURVES FOR μA741A AND μA741

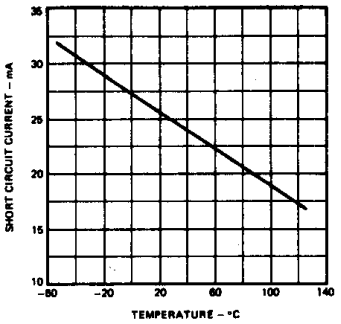
INPUT BIAS CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



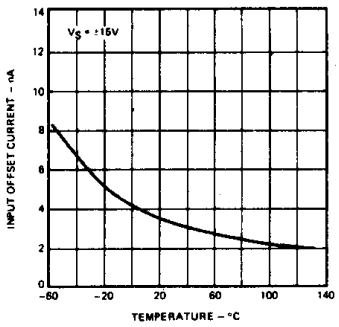
INPUT RESISTANCE AS A FUNCTION OF AMBIENT TEMPERATURE



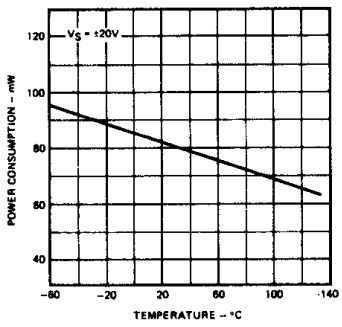
OUTPUT SHORT-CIRCUIT CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



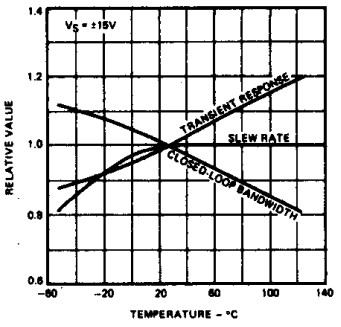
INPUT OFFSET CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



POWER CONSUMPTION AS A FUNCTION OF AMBIENT TEMPERATURE

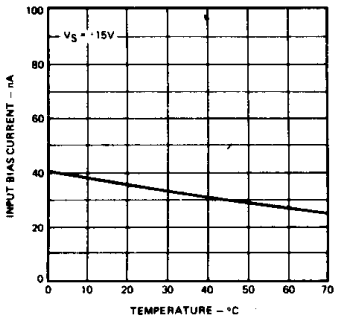


FREQUENCY CHARACTERISTICS AS A FUNCTION OF AMBIENT TEMPERATURE

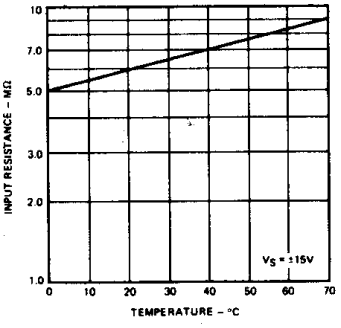


TYPICAL PERFORMANCE CURVES FOR μA741E AND μA741C

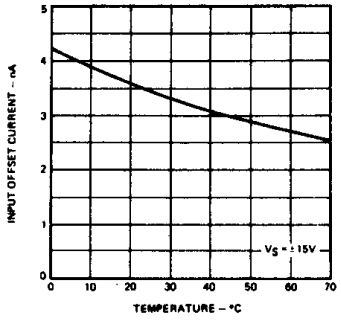
INPUT BIAS CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



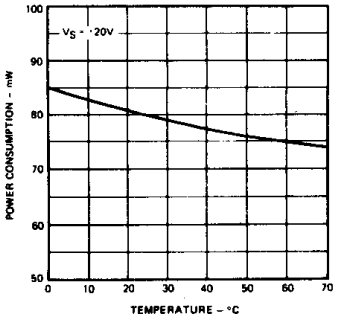
INPUT RESISTANCE AS A FUNCTION OF AMBIENT TEMPERATURE



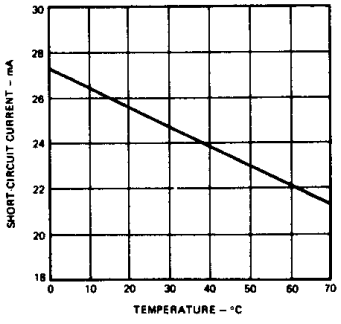
INPUT OFFSET CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



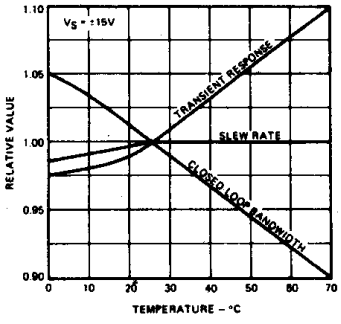
POWER CONSUMPTION AS A FUNCTION OF AMBIENT TEMPERATURE



OUTPUT SHORT CIRCUIT CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



FREQUENCY CHARACTERISTICS AS A FUNCTION OF AMBIENT TEMPERATURE



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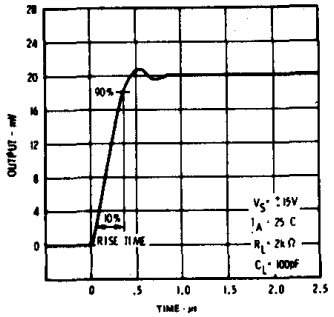
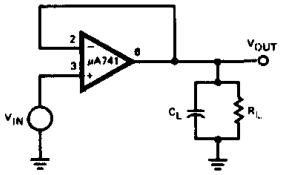
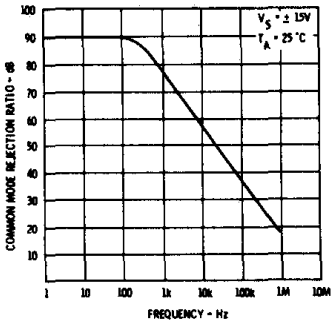
TRANSIENT RESPONSE



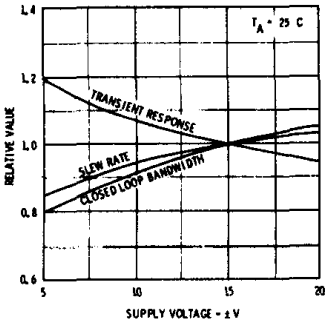
TRANSIENT RESPONSE TEST CIRCUIT



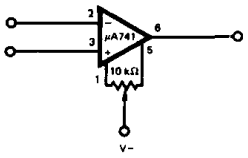
COMMON MODE REJECTION RATIO AS A FUNCTION OF FREQUENCY



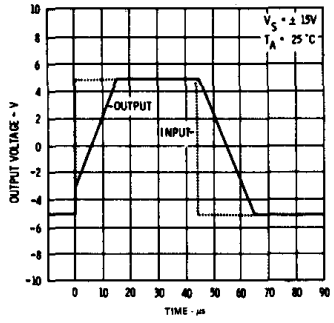
FREQUENCY CHARACTERISTICS AS A FUNCTION OF SUPPLY VOLTAGE



VOLTAGE OFFSET NULL CIRCUIT

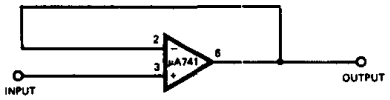


VOLTAGE FOLLOWER LARGE SIGNAL PULSE RESPONSE



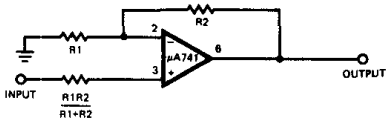
TYPICAL APPLICATIONS

UNITY-GAIN VOLTAGE FOLLOWER



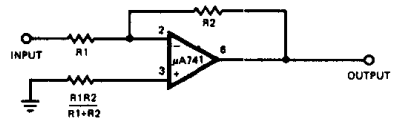
R_{IN} = 400 MΩ
C_{IN} = 1 pF
R_{OUT} << 1 Ω
B.W. = 1 MHz

NON-INVERTING AMPLIFIER



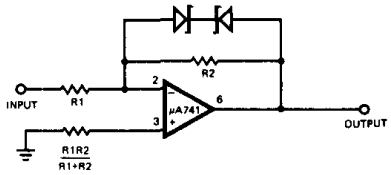
GAIN	R1	R2	B W	R_{IN}
10	1 kΩ	9 kΩ	100 kHz	400 MΩ
100	100 Ω	9.9 kΩ	10 kHz	280 MΩ
1000	100 Ω	99.9 kΩ	1 kHz	80 MΩ

INVERTING AMPLIFIER



GAIN	R1	R2	B W	R_{IN}
1	10 kΩ	10 kΩ	1 MHz	10 kΩ
10	1 kΩ	10 kΩ	100 kHz	1 kΩ
100	1 kΩ	100 kΩ	10 kHz	1 kΩ
1000	100 Ω	100 kΩ	1 kHz	100 Ω

CLIPPING AMPLIFIER



$$\frac{E_{OUT}}{E_{IN}} = \frac{R2}{R1} \text{ if } |E_{OUT}| \leq V_Z + 0.7\ V$$

where V_Z = Zener breakdown voltage